THE LUBRICATION OF NORMAL HUMAN ANKLE JOINTS

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by

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ABSTRACT

The geometry, friction and lubrication of normal human ankle joints have been investigated. The joints exhibited convergingdiverging surfaces in the direction of motion. The cylindrical form of the measured surface contours indicated that a reduced radius of about 0.35 m gave a good representation of the ankle joint geometry.

Human ankle joint specimens were tested in a joint simulator. Although considerable difficulties were encountered in the measurement of the very small coefficient of friction between the cartilage surfaces, an upper limit of about 0.01 was identified for this important tribological feature of synovial joints.

An equivalent bearing to represent the ankle joint was proposed which consisted of a rigid cylinder covered with a compliant layer sliding on a rigid plane. The dimensions for this geometry were based on the measurements of the present study. Theoretical models were developed to estimate the cyclic variation in elastohydrodynamic film thickness and coefficient of friction for the ankle during walking.

Theoretical minimum film thicknesses of about 1 µm were estimated along with coefficients of friction up to 0.001. The theoretical predictions of the cyclic variation of film thickness remained small compared with the magnitude of the film thickness itself. Furthermore, the theoretical film thicknesses were smaller than the measured Ra roughnesses for cartilage which appear in the literature. When a very considerable increase in the bulk viscosity of the lubricant was introduced into the calculations film thicknesses of about 18 µm and coefficients of friction up to 0.01 were estimated. This value for film thickness was sufficient to separate the surface asperities of healthy articular cartilage.

Unless thin film mechanisms, such as an increased lubricant viscosity or micro-elastohydrodynamic lubrication act, the present study indicated that full fluid film lubrication cannot be sustained. However, the predicted film thicknesses were not much smaller than the surface roughness of cartilage and the ability to generate and preserve fluid films was found to be greatly enhanced by the entraining and squeeze film action. Thus, the modes of lubrication for normal human ankle joints must include a significant contribution from elastohydrodynamic lubrication.

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NOMENCLATURE

The following notation was used throughout the thesis. Special notation, or notation which was confined to a particular section only, has been defined in the text.

- a Half length of dry contact area when surface tractions are neglected.
- b Half length of equivalent bearing (Figure 5.2.1).
- β Twist angle (Figure B.1).
- d Effective elastic layer thickness (Figure 5.2.1).
- δ Surface deformation (Figure 7.2.1).
- E Elastic modulus.
- E' Reduced modulus.
- n Dynamic viscosity.
- F Load.
- F' Load per unit width.
- F_A ' Time averaged load per unit width for one cycle.
- f(x) Profile for the steady state solution from Section 7.6 at a particular time.
- h Film thickness.
- h Central film thickness excluding surface deformation in Sections 7.2 and 7.6.
- h Central film thickness at a particular time in Section 7.7.
- h Minimum film thickness at a particular time.
- θ Twist angle (Figure B.1).
- L Length for plane inclined surface bearing model (Figure 6.3.1).
- M Slope for plane inclined surface bearing model (Figure 6.3.1).

μ	Coefficient of friction.
р	Film pressure.
P _D	Dry contact stress for the contrained column model.
R	Reduced radius.
R ₁	Talus radius.
^R 2	Tibia radius.
Ra	Centre line overage deviation of surface.
r c	True cylinder radius.
r m	Measured profile radius for ankle.
r _s -	Joint component radius for equation 4.4.1.
σ	Composite surface roughness.
T	Torque in Chapter 4.
т _D	Dynamic torque.
т _s	Static torque.
т _f	Frictional torque.
t	Time.
t p	Period of cycle.
U ₁	Lower surface velocity (Figure 5.2.1).
^U 2	Upper surface velocity (Figure 5.2.1).
u	Entrainment velocity, $\frac{\sigma_1 + \sigma_2}{2}$
^u A	Time averaged entrainment velocity.
ν	Poisson's ratio.
V	Relative surface velocity.
×e	Exit boundary point (Figure 7.6.1).

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Dimensionless Groups

B Starvation factor, $\frac{b}{R}$ Layer thickness, $\frac{d}{R}$ D Film thickness, $\frac{h}{R}$ Н Minimum film thickness, $\frac{h_o}{R}$ Но Pressure, $\frac{p}{E'}$ Ρ Squeeze factor, $\frac{E't}{n}$ S Time, $rac{t}{t_p}$ Т U Speed, $\frac{\eta u_A}{E'R}$ W Load, $\frac{F_A'}{E'R}$ Co-ordinate in direction of surface motion, $\frac{x}{R}$ X

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CHAPTER 1

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INTRODUCTION

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The human ankle joint is a bearing system of considerable sophistication. Widely varying dynamic loads and velocities are imposed which can result in the severe situation of the highest loads occurring when the entraining velocities are zero. The synovial fluid which acts as a lubricant has non-Newtonian characteristics and it also contains boundary lubricating additives. The bearing material consists of a thin layer of cartilage, which is a viscoelastic material having a high porosity and low permeability. It is attached to relatively rigid bone of a trabecular structure. The bearing surfaces are capable of self repair when damaged, but only at a slow rate compared to most other body tissues. Yet the human ankle joint usually has a trouble free service life of about seventy years throughout which it functions with friction forces of about one percent of the normal loading.

However, synovial joints do not always remain healthy and the pain and degeneration associated with various types of arthritis may be considered as a bearing failure. Such failures in engineering bearings are often caused by impaired lubrication. However, this cannot be stated with certainty in relation to synovial joints. There is evidence to suggest that in rheumatoid arthritis the joint failure is related to direct biochemical attack, but in osteoarthrosis mechanical factors such as wear, fatigue of the subchondral bone (Radin, 1974) or the articular cartilage (Weightman et al, 1978) are involved. Recently, evidence has been presented which indicates that osteoarthrosis is a mildly inflammatory disease involving hydroxyapatite and pyrophosphate crystals (Huskinson et al, 1979).

Although lubrication failure has not yet been directly linked to the initiation of arthritic disorders, it is clear that inadequate lubrication must play some role in the subsequent degeneration of the joint. The human ankle joint has a low incidence of primary osteoarthrosis compared with the hip and the knee (Stauffer et al, 1977). However, loads (Seireg and Arvikar, 1975; Stauffer et al, 1977) and normal stresses on the surfaces (Greenwald, 1976) appear to be similar to those acting at the hip and the knee. It therefore seems possible that the human ankle may experience better lubrication protection than other highly stressed synovial joints which exhibit a higher incidence of degeneration.

When synovial joint surfaces are severely damaged due to trauma or arthritic disease, a total joint replacement is often inserted. Prosthetic joints, although inferior to natural ones, are themselves remarkable bearings. They have a service life of about two decades with coefficients of friction somewhat higher than those experienced by healthy, natural joints (Unsworth et al, 1975) and some progressive damage to the surfaces (Dowling et al, 1978). The materials used in prosthetic joints are less compliant than the natural tissues. However, some attempts have been made to introduce elastomeric materials having a compliance similar to cartilage (Medley et al, 1980; Unsworth et al, 1980).

The lubrication of human ankle joints has been considered in both experimental and theoretical investigations reported in this thesis. The purpose of these studies is to provide background information for the diagnosis, treatment and possibly the prevention of arthritic disease. Certain aspects are relevant to the development of current and proposed joint replacements. In the general field of Tribology similar analytical and experimental studies arise in such diverse areas as elastomeric seals (Swales et al, 1972; Ruskell, 1980), vehicle tyres (Moore, 1980) and stylus-record contact (Jamison et al, 1978). The normal human ankle joint exhibits a geometry which is more amenable to theoretical analysis than that of other synovial joints. The experiments reported in the present thesis involved dissected human specimens and the parameters for the theoretical studies were chosen with reference to the ankle joint. However, the generality of the investigation must be emphasized.

CHAPTER 2

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THE MECHANICS OF NORMAL SYNOVIAL JOINTS

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2.1 INTRODUCTION

The study of the lubrication of normal human ankle joints may be considered as part of the more general investigation into the mechanics of normal synovial joints. The literature on this topic is extensive. An over-view is presented in this chapter and used subsequently in both the development and the interpretation of the present research effort. Certain review articles on various aspects of synovial joint mechanics provide background for this chapter (Swanson and Freeman, 1970; Radin and Paul, 1972; Wright et al, 1973; Torzilli, 1976; Higginson, 1978; McCutchen, 1978; Swanson, 1979; Weightman and Kempson, 1979; Dowson, 1980; Wright and Medley, in the press).

Synovial joints permit relative sliding of surfaces with low friction and negligible wear while transmitting loads without damaging any of the structural components. A general model for synovial joints is shown in Figure 2.1.1. Most of the research work reported to date on the mechanics of synovial joints has been focussed on the subchondral bone, articular cartilage, meniscus and the synovial fluid. This may be attributed to the fact that severe dysfunction of a synovial joint occurs when these tissues are damaged either by trauma or a disease process. Thus, as shown in Figure 2.2.1, the present discussion considers only these tissue components. Also, most of the investigations of synovial joint mechanics have dealt with the hip, knee and ankle. Therefore. the present discussion concentrates on these joints, although it is expected that similar mechanisms act in other human synovial joints. Before the overall mechanical functions of synovial



Figure 2.1.1. : A general mechanical model for synovial joints.

joints, such as sliding and load transmission, are considered, a detailed examination of the intrinsic mechanical properties of each tissue component is presented.

2.2 SYNOVIAL JOINT COMPONENTS

Subchondral Bone:

The bone found directly underneath the articular cartilage has a trabecular structure with a thin covering plate as shown in Figure 2.2.1. The internal cavities contain red and yellow marrow and interconnect through the structure. The thickness of the subchondral bone plate, the width of the individual trabeculae and the cavity dimensions are all of the order of 1 mm (Swanson and Freeman, 1966).



Figure 2.2.1 : Subchondral bone structure.

Bulk subchondral bone behaves elastically under ordinary in vivo conditions (Swanson and Freeman, 1966; Pugh et al, 1973a, 1973b). Small specimens of bulk subchondral bone have compressive elastic moduli approximately one order of magnitude lower than that of cortical bone (Radin et al, 1970b). Tests on individual trabeculae (Townsend et al, 1975) indicate that the trabeculae have an elastic modulus of approximately the same value as that of cortical bone. Thus the web-like structure of trabecular bone accounts for its low bulk elastic modulus by allowing more deflection compared to a solid bone mass as shown in Figure 2.2.2.



(a) A single trabecular specimen

(b) An equivalent sized cortical bone specimen

Figure 2.2.2 : Deformation of a single trabecula compared to cortical bone of equivalent size for the same applied load.

It follows that the compressive strength increases with the bulk density (Behrens et al, 1974; Ducheyne et al, 1977). However, plugs of bone with the same bulk density may have different compressive strengths due to their internal trabecular architecture (Behrens et al, 1974; Pugh et al, 1973b). The marrow apparently does not play a significant role in the response to ordinary in vivo loads (Swanson and Freeman, 1966). However, in rapid plastic deformation involving large scale fracture of the trabeculae the marrow does resist a significant portion of the imposed load (Hayes and Carter, 1976). Occasionally individual trabeculae are fractured in vivo (Radin et al, 1973b) but this does not significantly affect the overall mechanical properties of bulk subchondral bone (Ducheyne et al, 1977).

Articular Cartilage:

A detailed description of articular cartilage has been published recently (Freeman, 1979). A layer of articular cartilage, about 2.5 mm thick, covers the subchondral bone, as shown in Figure 2.2.3. It is composed of 60 - 80% by weight water apparently divided approximately equally between the cells, proteoglycan gel and the free interstitial fluid (Linn and Sokoloff, 1965). The remaining tissue is approximately 40% by weight chondrocytes, 35% by weight collagen and 25% by weight



Figure 2.2.3 : Articular cartilage structure.

The surfaces of articular cartilage appear smooth to the naked eye but light and electron microscope studies have shown surface depressions 20 - 40 μ m in diameter and 0.3 - 15 μ m deep (Clarke, 1973). Using profile measuring devices Ra surface roughnesses in the range of 2 - 6 μ m have been measured

(Walker et al, 1968; Clarke, 1973; Sayles et al, 1979, Thomas et al, 1980).

The interstitial fluid in articular cartilage is composed of water and positively charged solutes. It is able to move within and across the surface of cartilage as shown in Figure 2.2.3. The proteoglycan gel is composed of a protein core which has glycosaminoglycan branches containing fixed negatively charged groups. The interstitial fluid, containing positively charged solutes, is bound by weak electrostatic forces to these fixed negatively charged groups. The chondrocytes or cartilage cells synthesize the protein for the proteoglycans and the collagen. The collagen fibres are in the order of 1 µm diameter and form a fine mesh network with specific orientations at various locations within the cartilage.

The collagen fibre network apparently entangles and immobilizes the proteoglycan gels. Thus cartilage stiffness is a result of the proteoglycan gels pushing against the collagen fibre network. When cartilage deforms under load the permeability of the proteoglycan gel allows the weakly bound interstitial fluid to be mechanically squeezed out to join the free interstitial fluid. The free interstitial fluid can move within the cartilage, away from the loaded regions, and across the cartilage surface into the synovial fluid. This fluid motion is impeded, and thus deformation resisted, by the small size of the pores within the proteoglycan gel and between the collagen fibres.

Further resistance to deformation and flow results from the osmotic pressure within the proteoglycans. The osmotic pressure is caused by the outflow of the interstitial fluid with its

positively charged solutes. This leaves the fixed negative charged groups in close proximity, resulting in forces of electrostatic repulsion (Edwards, 1967). Also the collagen fibre network begins to stretch and possibly re-orientate (McCall, 1969) to resist the imposed forces, causing tensile stress in the fibres. This complicated response to loading is shown in Figure 2.2.4. Osmotic pressure may also be considered to act on a larger scale across the cartilage surface as interstitial fluid is expressed into the synovial fluid and proteoglycan gels of net negative charge repel each other.



Figure 2.2.4 : Internal mechanisms resisting cartilage deformation.

Upon removal of the load, collagen fibres relax and osmotic pressure pulls fluid into the cartilage and ultimately into the proteoglycan gels. This behavior makes cartilage a viscoelastic material, since its behaviour is time dependent and recoverable as shown in Figure 2.2.5. It is interesting to note that interstitial fluid can be pulled in from the synovial fluid but differs from it by the absence of certain molecules in synovial fluid which are apparently too large to enter the cartilage pores.



Figure 2.2.5 : Time dependent cartilage deformation.

A number of recent studies have sought to determine the complex microscopic interaction of collagen fibre tension, osmotic pressure and resistance to interstitial fluid flow when cartilage deforms under various load patterns. These studies have used or developed theory for small specimens of articular cartilage from humans and animals.

A generalized viscoelastic model for the deformation of cartilage with an indentor has been developed recently (Parsons

and Black, 1977). This formulation extended and combined previous models for cartilage viscoelasticity (Hayes and Mockros, 1971) and indentation testing (Hayes et al, 1972; Hori and Mockros, 1976). It was used to show that, in a normal ionic environment, collagen fibres in the surface regions of cartilage are not pre-stressed under no load conditions (Parsons and Black. 1979).

Recent studies have also attempted to model both interstitial fluid flow and matrix deformation separately (Higginson et al, 1976; Mansour and Mow, 1977; Mow et al, 1980). Such models are sensitive to the decrease in permeability which occurs as cartilage is compressed (Maroudas et al, 1968; Mansour and Mow, Thus, it is very difficult to separate the various 1976). internal mechanisms of cartilage deformation. However, flow independent viscoelastic properties of cartilage with its surface layer removed have been measured for small shear strains (Hayes and Bodine, 1978). This study showed that, for a given load, collagenase digestion or proteoglycan depletion each gave characteristic increases in deformation while increasing the cross-linking of the collagen fibres decreased deformation

Further complications in the detailed study of cartilage mechanics result from the changes in collagen fibre orientation and proteoglycan distribution from the surface to the bone interface. This tissue variation has been studied mechanically by a number of groups (Kempson et al, 1968, 1973; Maroudas and Bullough, 1968; Cameron et al, 1975; Woo et al, 1976, 1979). The significant differences in mechanical properties reported by each of these groups indicate that models which

assume a homogeneous isotropic cartilage layer must be applied with caution.

The investigations of the intrinsic mechanical properties of cartilage begin to show potential in detecting pathogenic physico-Unfortunately, their use in characterising chemical changes. the overall response of cartilage to in vivo loading patterns has not be realized as yet. However, some studies have examined the behaviour of small cartilage specimens subject to cyclic compressive stress patterns similar to those believed to act in vivo (Johnson et al, 1977; Higginson and Snaith, 1979). After the first few cycles the cartilage response was essentially elastic with a very small amount of non-recoverable creep occurring during each cycle. Eventually a final cyclic steady state was reached as shown in Figure 2.2.6. A model was introduced which considered the non-recoverable creep accumulated during previous cycles to be part of the specimen's history. Instantaneous elastic moduli were evaluated at various creep strains. Then. with the measured rate of creep, cartilage response was characterized. As expected, the instantaneous elastic modulus was found to increase with increasing creep strain.

Menisci:

The menisci are present in the knee but not the hip or ankle joints. The two menisci in the knee are half-moon shaped fibrocartilage structures having approximately triangular crosssections as shown in Figure 2.2.7. The thickness at the joint periphery is in the order of 5 mm, which is approximately equal to the combined thickness of the articular cartilage layers.



Time

Figure 2.2.6 : The steady state response of cartilage to cyclic loading.



The menisci are approximately 70% by weight water with collagen comprising about 75% by weight of the remaining tissue (Peters and Smillie, 1972). With its high collagen content the meniscus is similar to a ligament in composition rather than articular cartilage. The collagen fibres exhibit significant circumferential orientation with some radial links between them (Cameron and Macnab, 1972) as shown in Figure 2.2.7.

The tensile strength (Bullough et al, 1970) and tensile elastic modulus (Uezaki et al, 1979) of the menisci are in the same range as those of articular cartilage, with fairly wide variations depending on collagen fibre orientation. The response to tensile forces is mainly elastic, as opposed to viscoelastic, and probably results from changes in collagen fibre orientation (Uezaki et al, 1979).

Synovial Fluid:

Synovial fluid is a light yellowish liquid contained within synovial joints in the region bounded by the synovial membrane and the articular cartilage surfaces as shown in Figure 2.2.8. It is essentially a dialysate of blood plasma with the addition of approximately 3 mg/ml hyaluronate macromolecules. These macromolecules are believed to be added to the plasma component by the synovial membrane and may combine directly with protein elements in the fluid or interact only mildly when in solution (Wright et al, 1973). By including water within their domain, hyaluronate macromolecules are believed to assume an approximately spherical shape in synovial fluid with a radius of about 1 µm. Synovial

fluid also contains a smaller glycoprotein molecule which may be involved in lubrication of the cartilage surfaces (Swann, 1978).



Figure 2.2.8 : Synovial fluid structure.

Synovial fluid, like many polymer solutions, recovers to some extent after being deformed or, in other words, it exhibits some elasticity. If synovial fluid is sheared, but not compressed, between two surfaces in relative motion, it imposes resisting shear and normal forces on the surfaces as shown in Figure 2.2.9 (Ogston and Stanier, 1953). The normal forces are very small compared to the physiological loads estimated to act through synovial joints. Thus synovial fluid is not believed to resist deformation significantly in vivo due to its elasticity (Ogston and Stanier, 1953; Caygill and West, 1969).



Figure 2.2.9 : Forces on the surfaces caused by tangential motion but not compression of the interposed synovial fluid.

In contrast to its elasticity, the resistance to shear resulting from the fluid viscosity is an important factor, when combined with lubrication mechanics, in the deformation or flow Extensive measurements of the of synovial fluid in vivo. viscosity of synovial fluid for humans and animals have been recorded (Ogston and Stanier, 1953; Davies, 1967; Palfrey and White, 1968; Davies and Palfrey, 1969; Cooke et al, 1978). These studies show reasonable agreement (Swanson, 1979). Viscosity decreases as shear rate increases and eventually approaches a constant value that is somewhat larger than that of water as shown in Figure 2.2.10. This behaviour is believed to be caused by tangling of the macromolecules at low shear rates and eventual separation at higher shear rates (Ogston and Stanier, 1953). For a given shear rate, the viscosity of synovial fluid has also been found to increase with increasing hyaluronate concentration (Ogston and Stanier, 1953; Negami, 1964), or decreasing temperature. (Ogston and Stanier, 1953; Evangelista et al, 1978).



Shear Rate

Figure 2.2.10 : The viscosity variation of synovial fluid with shear rate.

The viscosity combined with the elastic behaviour of synovial fluid has led to elaborate viscoelastic models to characterize the deformation and flow of the lubricant (Lai et al, 1977, 1978). However, one difficulty in comprehensive modelling of synovial fluid flow in vivo results from the possibility that the apparent viscosity may not be a property of the fluid alone. Theoretical investigations have been reported of fluid flow through passageways with dimensions similar to those of particles within the fluid. The apparent viscosity of synovial fluid depends on many features, including the extent to which the passageway surfaces inhibit particle spin (Allen and Kline, 1971).

The apparent viscosities of thin layers of synovial fluid sheared between cartilage and glass surfaces have been measured and shown to be two orders of magnitude higher than that of bulk synovial fluid (Walker et al, 1970). In this study, structured layers about 10 µm thick were observed on cartilage surfaces. These layers were believed to be rich in hyaluronate and protein elements of synovial fluid and a theory was developed to explain the formation and the viscosities of these layers (Dowson et al, 1970). Thus, macromolecular interaction with the cartilage surfaces may cause significant changes in the apparent viscosity during thin film flow of synovial fluid.

Concluding Remarks on Synovial Joint Components:

In general, the deformation of synovial tissues subject to external loading depends on local composition and structure as well as the complex behaviour of the various internal elements. However, the deformation can be approximated as elastic in order to gain some insight into the comparative behaviour of the tissues in vivo. Thus, the elastic moduli of various synovial joint tissues are given in Table 2.2.1. along with some common orthopaedic implant materials. Synovial fluid is not included in Table 2.2.1. since its elastic modulus is negligible compared with the more solid tissues. It is noted that the viscosity of bulk synovial fluid at high shear rates is a few times greater than that of water.

Having considered some simplified material constants to describe the load-deformation response of synovial joint tissues, it is important to remember that the exact behaviour and internal mechanisms responsible for this behaviour cannot be ignored. They are essential to many of the larger scale mechanisms of load transmission and lubrication which are discussed subsequently.

Material	Approximate Elastic Modulus (MPa)
Vitallium	10 ⁵
Cortical bone	10 ⁴
Individual subchondral trabeculae	104
Bone cement (PMMA)	10 ³
UHMW polyethylene	10 ³
Bulk subchondral bone	$10^2 - 10^3$
Articular cartilage	$10 - 10^2$
Meniscus	10

Table 2.2.1 : The elastic moduli of synovial joint components and some materials used in joint replacement.

2.3 LOAD TRANSMISSION

Both normal (perpendicular) and tangential forces are transmitted in vivo from one cartilage surface to the other during common activities like walking. The normal forces result from the static and dynamic effects of the body mass plus muscle and ligament tensions. During walking they vary from close to zero up to as much as eight times body weight (Paul, 1967, 1976; Seireg and Arvikar, 1975). The tangential forces result from friction during sliding motions. Since these friction forces are only about 1% of the normal forces they will be ignored in this discussion of load transmission. However, the subject of friction will be considered in a later section on lubrication. As shown in Table 2.2.1, cartilage and menisci have elastic moduli much lower than bulk subchondral bone, which itself has a much lower modulus than cortical bone. The purpose of this soft structure is apparently to "spread" the transmitted forces and thus reduce peak normal stresses at the cartilage surfaces. This serves to enhance lubrication. However, the joint tissues must be able to withstand the transmitted forces without sustaining progressive damage. This ability is as important to overall joint function as the lubrication of the surfaces.

To examine the way in which loads are transmitted through the joint tissues, it is convenient to consider the transmission of peak loads first and then consider the additional dynamic effects present during the in vivo transmission of these peak loads. This division allows a complete description of the spectrum of mechanisms which act to reduce high local forces in load transmission.

Peak Load Transmission:

The reduction of high local transmitted forces (or stress concentrations) within the joint tissues occurs by what will be termed internal and external mechanisms. High forces transmitted through specific tissue may result from local geometry, such as the bone asperities at the cartilage-subchondral bone interface, or from large scale geometry.

Internal mechanisms may exist within cartilage to reduce transmitted forces (Weightman and Kempson, 1979). Support for the existence of these internal mechanisms results from the observed increase in subchondral bone damage which occurs when
the same stresses are imposed on arthritic as on healthy joint surfaces (Freeman et al, 1975). The possible mechanisms of reducing stresses within cartilage include the development of tensile stresses in the collagen fibre network and local flow of interstitial fluid. These mechanisms are shown in Figure 2.3.1.



Figure 2.3.1 : Possible internal mechanisms of articular cartilage force spreading.

There is some conflict in the literature concerning the amount by which internal mechanisms in cartilage are capable of reducing transmitted forces. Recent mathematical modelling of cartilage (Askew and Mow, 1978) and subchondral bone (Hayes et al, 1978) suggests that cartilage layers are too thin to accomplish significant internal force spreading.

Internally subchondral bone can spread high normal forces by virtue of its trabecular structure and thickness. Hayes et al, 1978). This is done by inducing tensile stresses in laterally remote trabeculae as shown in Figure 2.3.2.



Figure 2.3.2 : Possible internal mechanisms of subchondral bone force spreading.

On a larger scale, certain factors create external force spreading mechanisms. The internal architecture of subchondral bone varies both normally and tangentially to the joint surfaces (Raux et al, 1975; Behrens et al, 1979). These variations may serve to spread transmitted forces evenly from the cortical bone through the subchondral bone (Hayes et al, 1978). Also, it has been suggested that high tensile stresses in the subchondral bone plate may act to reduce compressive stresses in the trabecular subchondral bone (Jacob et al, 1976).

Cartilage itself has property variations across the joint surfaces (Kempson et al, 1971; Cameron et al, 1975), although it has been estimated that such variations do not significantly alter the transmitted forces (Weightman and Kempson, 1979). However, it is generally agreed that cartilage, being much more deformable than subchondral bone, plays a more significant role in increasing the size of contact areas. This reduces normal stresses in both the cartilage and the subchondral bone (Day et al, 1975; Freeman et al, 1975; Weightman and Kempson, 1979). Cartilage viscoelasticity serves to further increase the contact areas and thus enhances this mechanism of load sharing. The ability of cartilage to increase contact areas is shown in Figure 2.3.3. The menisci in the knee also play a significant role in increasing contact areas and spreading transmitted forces (Seedhom et al, 1974; Shrive, 1974; Walker and Erkman, 1975; Maquet et al, 1975; Seedhom, 1979; Seedhom and Hargreaves, 1979).



Figure 2.3.3 : The ability of a soft surface to deform which increases contact areas and thus reduces peak contact stress for a given imposed load.

Some synovial joints also appear to reduce peak contact stresses by having a slightly smaller radius of curvature for the concave than for the convex surface (Greenwald et al, 1971, 1976). This mechanism is shown in Figure 2.3.4 and essentially serves to distribute the contact stress more evenly over the joint surface. The knee joint achieves a similar effect through the presence of the menisci (Seedhom and Hargreaves, 1979). In addition to geometry, this mechanism depends on the deformation of cartilage and menisci to create a conforming joint under peak loading conditions.



(a) Larger radius of curvature for concave than for convex surface

contact Stress contact stress low loading high loading

(b) Smaller radius of curvature for concave than for convex surface

Figure 2.3.4 : A method of achieving a more even distribution of contact stress magnitudes.

Dynamic Effects in Peak Loading Transmission:

The magnitude of the transmitted forces, which a particular region of tissue experiences, is reduced by the internal and external mechanisms mentioned previously. Under dynamic loading conditions, additional mechanisms act to reduce transmitted forces.

The creep of the cartilage, due to its viscoelastic properties, may create large contact areas during a period of static loading. The larger contact areas may then help to reduce contact stresses during the rapid application of peak loads.

Subchondral bone plays an important role as a shock absorber. Although cartilage, synovial fluid and the menisci all have intrinsic shock absorbing properties, they are present in layers too thin to achieve significant attenuation of transmitted forces (Radin and Paul, 1969, 1970a). However, subchondral bone, which is not so intrinsically energy-absorbing, is present in much thicker layers. It apparently provides enough deflection to reduce the accelerations of the body mass and thus significantly reduce the dynamic transmitted forces (Radin et al, 1970b; Radin and Paul, 1971a, 1971b, 1973). This mechanism is shown in Figure 2.3.5. Also subchondral bone may prevent the splitting of cartilage under peak dynamic loads by providing constraint at the bone-cartilage interface (Findlay and Repo, 1978).

There is one more mechanism which arises during dynamic load transmission. During dynamic in vivo activities in which both loads and velocities vary, it has been observed that cartilage increases in thickness (Ingelmark and Ekholm, 1948; Ekholm and Ingelmark, 1952). This may enhance the previously mentioned internal mechanisms by which cartilage spreads transmitted forces,

since more interstitial fluid would be present. Also the differences in radii of curvature between concave and convex surface curvatures may change such that the contact stress is more evenly distributed (Oberlander, 1978). Finally, having an increased cartilage thickness would allow more cartilage deformation, if required, as load and velocity patterns changed.



Figure 2.3.5 : Dynamic load attenuation by subchondral bone.

Concluding Remarks on Load Transmission:

In overall load transmission an important function of cartilage and menisci appears to be the ability to deform and create larger contact areas. An important function of subchondral bone appears to be its role as a shock absorber. In all these joint tissues internal force spreading mechanisms and local tissue variations may also influence load transmission. It is difficult to select any one mechanism as being the most important, since changes in any of them may increase stresses to abnormal levels in some region of the synovial joint.

2.4 LUBRICATION MECHANICS

The low friction forces arising during the relative sliding of articular cartilage surfaces may be attributed to effective lubrication. When synovial fluid is removed from a fresh cadaveric joint, oscillation under load produces higher friction and significant damage to the cartilage surfaces in a few hours (Clarke et al, 1975). Thus in vivo joint lubrication appears to depend on synovial fluid or one of its components. The exact way in which this occurs is not yet known. A number of different mechanisms have been suggested in the literature and are discussed separately in this section. However, during routine in vivo activities like walking it is likely that a number of different modes of lubrication act on a given surface region at various times (Dowson, 1967). Little research has been done on the lubrication of intact joints during the specific load and velocity patterns which occur in vivo.

Fluid Film Mechanism:

When a fluid lubricant is present in a bearing, films can be generated by the motion of converging-diverging surfaces. The viscosity of the lubricant causes its layers adjacent to the moving surfaces to "stick" together when shear is imposed by the surface motion. As a result, lubricant is pulled into the "contact" region by an 'entraining' action of the moving surface. If enough lubricant is entrained the surfaces are separated by a thin

fluid film. This means that the integral of the pressures in the lubricant film balances the applied load. This mechanism is shown in Figure 2.4.1 for the simplified case when only one surface is in motion.

load lubricant <u>velocity</u> elocity

Figure 2.4.1 : An example of fluid film lubrication.

It is common engineering practice to calculate a theoretical lubricant film thickness by assuming that the surfaces are perfectly smooth. If this film is thick enough to separate the real surface asperities it can be predicted that full fluid film lubrication occurs. In engineering applications, experimental techniques may be used to verify these predictions. Effective fluid films can be established which are only a few microns thick.

If the bearing surfaces remain rigid, the process by which fluid films are entrained is known as hydrodynamic lubrication. The lubrication of human finger joints by a hydrodynamic mechanism has been considered (Pagowski et al, 1976). However, when the film pressures are large enough to deform the surfaces the region of contact (close surface proximity) is increased. This reduces the film pressures required to balance the applied load. As a result lubricant can be drawn between the surfaces at higher loads or lower velocities than in hydrodynamic lubrication. This mechanism is called elastohydrodynamic lubrication and is depicted in Figure 2.4.2. The possibility of elastohydrodynamic lubrication of this type occurring in synovial joints has also been examined (Dintenfass, 1963; Tanner, 1966; Higginson, 1978; Dowson, 1967, 1980).



Figure 2.4.2 : A comparison between hydrodynamic and elastohydrodynamic lubrication.

During in vivo activities such as walking, the relative surface velocities are zero for the instants at which the directions of surface motion are reversed. When low or zero velocities occur the fluid film which may have been built up during the higher velocity periods is squezed out from between the surfaces as shown in Figure 2.4.3. A high lubricant viscosity extends this process so that films may remain until the surface velocity increases again and more lubricant is entrained between the surfaces. The surface deformation plays an additional role in trapping fluid within the contact region by being less deformed at the periphery as shown in Figure 2.4.3. Squeeze film behaviour has been studied in some detail for synovial joint models (Fein, 1967; Higginson and Norman, 1974a, 1974b; Gaman et al, 1974; Rhode et al, 1976, 1979; Rybicki et al, 1978, 1979).



Figure 2.4.3 : Elastohydrodynamic squeze film behaviour.

Complete analytical or experimental proof of the existence of adequate fluid films in synovial joints during common in vivo activities has not been achieved. However, current analytical estimates suggest that elastohydrodynamic films are not quite thick enough to prevent surface asperity interactions (Dowson, 1980; Marnell and White, 1980). Experimental work with cadaveric hip joints under in vivo load and velocity patterns have suggested that fluid films exist (0'Kelly et al, 1978) but mechanisms other than elastohydrodynamic may have helped to produce them. In another recent study, statically-loaded cadaveric joints were frozen and sectioned to reveal fluid films much thicker than those predicted by current elastohydrodynamic theory (Terayama et al, 1980). A number of features of synovial joints have obvious beneficial effects on their potential to develop elastohydrodynamic films. The deformation of cartilage and menisci by definition enhances film formation. The joint geometry is important in creating the required converging-diverging surfaces and in helping to reduce the required film pressures by encouraging large contact areas.

The previously mentioned possibility of slightly smaller radius of curvature for the concave compared with the convex surface may play an important role in enhancing fluid entrapment during squeezing actions. High synovial fluid viscosity would enhance elastohydrodynamic lubrication during both sliding and squeezing. The higher viscosity of synovial fluid at low shear rates may play an enhancing role during squeezing actions (Piotrowski, 1975). On the other hand, gross surface roughness would break up fluid film formation and allow intimate level surface contact. A number of more subtle effects may also contribute to the development of elastohydrodynamic lubrication in synovial joints. Some of these are discussed in the next section as separate mechanisms.

Special Thin Film Lubrication Mechanisms:

Two enhancing mechanisms, which depend to some extent on cartilage porosity, may occur in very thin film lubrication of synovial joints. The first, weeping lubrication, proposes that, once some of the opposing cartilage surface asperities begin to touch, interstitial fluid is expressed from the cartilage into the gap between the cartilage surfaces as shown in Figure 2.4.4 (Lewis and McCutchen, 1959; McCutchen, 1962, 1967, 1969, 1978). Thus more fluid is available for lubrication purposes. This

theory further postulates that the contacting asperity tips are protected by boundary lubrication and this concept is discussed in a later section. Weeping lubrication has been criticised on the grounds that the amount of fluid expressed may not be significant (Higginson and Norman, 1974).



Figure 2.4.4 : Weeping lubrication of synovial joints.

Boosted lubrication, the second mechanism, proposes an alternative behaviour in which fluid passes into the cartilage and laterally between the contacting asperities. The process involves a filtering of synovial fluid films in which the water and small solute components may be forced into the cartilage or laterally out of the contact zone leaving an increased concentration of hyaluronate macromolecules as shown in Figure 2.4.5. (Dowson et al, 1968, 1970; Walker et al, 1968, 1969, 1970; Longfield et al, 1969), The concentrated fluid in the contact zone is postulated to have a much higher viscosity and this enhances fluid film lubrication. This theory also includes the possibility that the filtering occurs through absorbed surface layers of hyaluronate macromolecules (Unsworth, 1972).



Figure 2.4.5 : Boosted lubrication of synovial joints.

Boosted lubrication has been criticised on the grounds that the calculated film thicknesses are too large for lateral filtering through the surface asperities or for filtering through cartilage to occur (Maroudas, 1979). However, when small cartilage specimens were used in friction experiments and quickly frozen at a time when boosted lubrication theory predicted thick films, such films were observed subsequently using scanning electron microscopy (Walker et al, 1970; Walker and Gold, 1973).

Recent analytical work has suggested that fluid may flow into cartilage at some locations and out of cartilage at other locations within a joint (Ling, 1974; Mansour and Mow, 1977). If so, both boosted and weeping lubrication may occur simultaneously. However, the fluid flow into or out of cartilage is slow compared to physiological loading times and thus may not be a particularly effective mechanism for the lubrication of synovial joints (Higginson, 1978).

A very recent theory, which has not been investigated experimentally, proposes a mechanism by which fluid viscosities higher than those of the bulk lubricant may exist in thin films. Micropolar lubrication models (Allen and Kline, 1971) have been applied to synovial joints (Tandon and Jaggi, 1979). Essentially the theory suggests that the hyaluronate macromolecules tend to spin in a synovial fluid film and this spin is inhibited by the close proximity of the cartilage surfaces. The result is that the effective viscosity is increased in these thin films and this leads to enhanced fluid film lubrication. This concept is illustrated in Figure 2.4.6 along with a possible extension of the theory which predicts that when the cartilage surfaces are moving, the macromolecules may migrate towards them. Such motion of particles to the high velocity regions has been observed in blood flow (Goldsmith, 1971). If this particular mechanism does occur it might contribute to the build up of hyaluronate surface layers which would further increase thin film viscosities.



Figure 2.4.6 : Micropolar lubrication of synovial joints.

Boundary Mechanisms:

Boundary lubrication involves the sliding and shearing of adsorbed layers on the surfaces. The adsorbed layers thus protect the underlying surfaces and maintain low friction. This mechanism is illustrated in Figure 2.4.7.



Figure 2.4.7 : Boundary lubrication of synovial joints.

The protein elements in synovial fluid appear to be directly involved in boundary lubrication by attaching themselves to the cartilage surfaces (Linn and Radin, 1968; Wilkins, 1968; Radin et al, 1970c, Swann, 1978; Davies et al, 1979, 1979). Hyaluronate macromolecules (Maroudas, 1967, 1969, 1979) and water molecules (Davies et al, 1979) may also contribute to the surface layers. These layers appear to have internal repulsive electrostatic forces (Roberts, 1971) which create osmotic pressure (McCutchen, 1966; Davies et al, 1979) capable of resisting compression. It has also been suggested that fat within the cartilage may act as a boundary lubricant (Little et al, 1969).

Concluding Remarks on Lubrication Mechanics:

Studies of friction in cadaveric hip joints using cyclic time varying loads and velocities suggests that fluid film lubrication predominates (0'Kelly et al, 1978). Other plausible, though sometimes conflicting, lubrication mechanisms have been suggested. It would appear that the lubrication of synovial joints is a complex process involving a number of mechanisms. Furthermore, it is unlikely that one particular mechanism or combination of mechanisms will operate universally as the loading and sliding conditions are changing continuously in synovial joints. Thus synovial joint lubrication remains an enigma in spite of considerable research effort.

2.5 CONCLUDING REMARKS ON THE MECHANICS OF NORMAL SYNOVIAL JOINTS:

Each mechanism proposed for the various aspects of synovial joint function has been discussed in physical and anatomical terms. Further insight can be gained by considering the major anatomical features of synovial joints and mentioning, for each feature, a number of associated mechanisms.

The size and trabecular structure of the subchondral bone mass aids in spreading transmitted forces. In addition, the large deflections which result from in vivo loading have suggested that subchondral bone is the major shock absorbing tissue in synovial joints.

The articular cartilage layers have low elastic moduli, which allow enough deformation to create large contact areas. In load transmission these contact areas ensure that the contact stresses are maintained at reduced levels. Also, fluid film lubrication is enhanced by large contact areas. The fluid flow within and across the surface of cartilage produces viscoelastic behaviour which may further increase contact areas when high loads are imposed for long periods of time. Fluid flux across cartilage surfaces may contribute to lubrication by boosted or weeping mechanisms. Also, the internal fluid flow, along with the reinforcing collagen fibre network, may act to reduce stress concentrations within cartilage.

Synovial fluid contains protein molecules which are adsorbed onto the cartilage surface and apparently act as a boundary lubricant. The bulk viscosity of synovial fluid is proportional to its concentration of large hyaluronate macromolecules. In thin film flow the concentration of hyaluronate macromolecules may

increase resulting in high apparent viscosities. If this occurs fluid film lubrication becomes plausible for a wider range of activities in vivo.

The opposing articular surfaces of synovial joints have slightly different curvatures. In the hip joint, the concave surface apparently has a smaller radius of curvature than the convex surface. This geometry may help to reduce the maximum contact stresses during high loading and to extend the duration of elastohydrodynamic squeeze films which act in synovial joints. The surface incongruity also ensures that regions of converging-diverging geometry exist which provides favourable conditions for fluid film lubrication during sliding.

The experimental verification of the various load transmission and lubrication mechanisms presents immense difficulties. In a living synovial joint there is likely to be a certain tolerance of abnormal motion and loading. Ultimately, studies of the gradual failure processes in synovial joint tissues may determine the clinical relevance of the numerous mechanisms described.

CHAPTER 3

SURFACE GEOMETRY OF THE ANKLE JOINT

3.1 INTRODUCTION

The components of synovial joints and the mechanics of their interactions are described in some detail in the previous chapter. While recognizing that all synovial joints have similar features, the study of the human ankle joint in particular must include some knowledge of the local anatomy.

The bones in the vicinity of the ankle joint are shown in Figures 3.1.1 and 3.1.2. The ankle joint, sometimes referred to as the talocrural joint, permits rotation of the foot in a posterior-anterior plane of vertical orientation. In other words, the simultaneous raising of the toes and lowering of the heel involves flexion of the ankle joint. The side-to-side motion of the foot, or rotation in a medial-lateral plane of horizontal orientation involves the subtalar joint between the talus, navicular and calcaneus bones. The combined motion of the ankle joint and the subtalar joint is analogous to the action of a universal joint. Many activities, including walking, involve this combined motion (Hicks, 1953; Morris, 1977).

Not only do the ankle and subtalar joints move simultaneously, they also have a common ligamentous structure as illustrated in Figures 3.1.3 and 3.1.4. Some of the ligament bands connect tibia and fibula to the talus, while others bypass the talus and connect with the calcaneus and navicular bones.

The ankle joint itself is composed of three pairs of articulating surfaces between:

- i) medial malleolus and talus
- ii) tibia and talus
- iii) lateral malleolus and talus.



Figure 3.1.1 : Sagittal section of the foot showing bone structure.



Figure 3.1.2 : Frontal section through the ankle showing bone structure.



Figure 3.1.3 : Medial ligament of the ankle.



Figure 3.1.4 : Lateral view of the ligaments of the ankle.

The lateral malleolus, formed by the distal end of the fibula, is held in place against the tibia by an interosseus ligament as shown in Figure 3.1.5. This ligament provides some compliance to the lateral constraint imposed by the lateral malleolus on the talus. The articulation between the lateral malleolus and the talus transmits a portion of the normal load on the ankle joint. However, most of the load is transmitted through the tibia-talus articulation (Lambert, 1971).



Figure 3.1.5 : Anterior view showing the ankle joint capsule and the interosseus ligament connecting the fibula to the tibia.

A normal ankle joint with the various connecting tissues dissected away is shown in Figure 3.1.6. The articulation between tibia and talus appears at first glance to be simply a contact between two congruent cylindrical surfaces of finite width. However, the talus surface has been described qualitatively by Barnett and Napier (1952) as having three radii of curvature as shown in Figure 3.1.7. This suggests that a changing centre of rotation may occur during ankle joint flexion.



Posterior view

Anterior view

Figure 3.1.6 : A dissected human ankle joint. (Joint number I of Table 3.2.1).

Lateral profile



POSTERIOR ANTERIOR

Medial profile

Figure 3.1.7 : Talus surface curvatures according to Barnett and Napier (1952).





Figure 3.2.3 : Sketch of surface dimensions of ankle joint number II (top view, approximately to scale).

Instantaneous centres of rotation have been measured for normal ankles under weight bearing conditions by a number of research groups (Sammarco et al, 1973; Ambrosia et al, 1976; Partasca et al, 1979; Rastegar et al, 1980). In all these investigations the location of the instantaneous centres moved by about 10 mm during ankle flexion. The apparent congruity of the tibia-talus articulation has been challenged by Greenwald et al (1976). They found that under low loads, up to 25 percent of the peak load during walking, separate medial and lateral contact areas exist. As the load was increased these areas merged to give contact over most of the tibial surface.

A number of prosthetic joints have been designed for the human ankle (Kempson et al, 1975; Stauffer, 1976; Pappas et al, 1976). Each of these designs replace the natural geometry with congruent cylindrical surfaces. This gives a single axis of rotation for the prosthetic ankle yet does not appear to affect the gait of the patient.

The functional success of the prosthetic ankle has some important implications. It is apparent that the ligament structure, which is retained in the joint replacement procedure, does not impose motion much different from a fixed axis rotation during walking. Thus, the changing instantaneous centres of rotation for the natural ankle are likely to be caused by the surface contours rather than imposed ligament constraints. Furthermore, these changing centres do not appear essential for normal walking.

The determination of detailed three dimensional characteristics of synovial joint surfaces is a complex procedure. Recently Scherrer and Hillberry (1979) applied a surface fitting procedure using a network of "patches" to a joint surface. They intended to combine this procedure with mathematics involving spatial linkages to study the relative positions of the joint surfaces during motion.

The purpose of the present study is to evaluate geometrical parameters for both the theoretical and experimental investigation of ankle joint lubrication. Current models of synovial joint lubrication for complete joints under typical in vivo conditions involve many approximations (Dowson, 1980). Thus, it is felt that the following simplifying assumptions can be made without losing the essential geometrical characteristics of ankle joint lubrication:

- i) Only the tibia-talus articulation is considered.
- ii) The motion is considered to be rotation in a single posterior-anterior plane of approximately vertical orientation.
- iii) The central regions of the contact areas have circular profiles when considered in planes parallel to the direction of motion.

The present study uses dissected human specimens. It includes the results from measuring surface curvature and sectioning to examine cartilage thickness.

3.2 Dissection of the Joint Specimens:

Eight ankle joint specimens were dissected in the present study. These specimens were obtained from amputations for severe vascular disease. The operations were performed at Leeds General

Infirmary. As such, the group of patients involved may not have been as active as the general population, especially in the latter stages of the vascular disease. The specimens were collected immediately following amputation and frozen intact until required for dissection. More specific details are given in Table 3.2.1, including the labelling of each joint by number.

Joint	Age (years)	Sex	Body Weight (N)	Comments
I				normal
11				normal
111	•			pathological
١v	66	Male	510	pathological
v	59	Male	687	pathological
1	48	Male	711	normal
2	52	Male		normal
3	67	Female	696	normal

Table 3.2.1 : Details of the ankle joint specimens.

The dissection procedure involved a systematic removal of the soft tissues surrounding the ankle joint. This was performed using a standard scalpel (with frequent blade changes), tweezers and self-gripping clamps. In some cases surgical scissors were used to remove tissue from the edges of the cartilage layers. A bone saw or chisel was used to remove bone in the final stages of the dissection. Surgical gloves were worn at all times to avoid the possibility of contacting disease from the specimens. Physiological saline solution (0.9% NaCl) was available for soaking the joint surfaces to prevent dehydration. The equipment used for dissection is shown in Figure 3.2.1.

The procedure itself began with an incision through the soft tissues surrounding the subtalar joint as shown in Figure 3.2.2. The lower portion of the foot was detached from the talus by cutting all the ligaments attached to the navicular and calcaneus Next the soft tissues surrounding the tibia and fibula bones. were removed. At this point, the talus was still held in place by the posterior talo-fibular ligament and some bands of the The talus was then separated from the tibia medial ligament. Upon separation the joint surfaces were covered with and fibula. tissue paper soaked in saline solution. The interosseus ligament, connecting fibula to tibia, was then severed and the fibula discarded.

The final stage of the dissection involved removing as much tissue as possible from the talus and tibia, excluding the cartilage itself. A test tube clamp attached to a retort stand was often used to hold the joint segments. This stripping of tissue promoted firm fixation when the bones were eventually mounted in tubular holders using plaster of Paris as a fixing agent. For the mounting, it was necessary to trim some part of both the tibia and the talus which were not involved in the ankle articulation.. This was accomplished using a bone saw or chisel.

Throughout the latter part of the dissection procedure, it was considered particularly important to keep the joint surfaces covered with tissue paper soaked in physiological saline solution at all times. This avoided the possibility of structural damage to the cartilage caused by dehydration. Figure 3.2.1 : The equipment used for the joint

dissection.

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Figure 3.2.2 : The initial incision through the soft tissues for the joint dissection.

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Joint numbers I and II were used for preliminary trials to develop the technique. Figure 3.1.6 of the previous section shows ankle joint number I with fibula still attached to the tibia. The surface dimensions and features of joint number II were recorded in an approximate fashion as shown in Figure 3.2.3.(sec PG.48)

Joint numbers III, IV and V all showed visual evidence of various amounts of pathological surface damage as illustrated by Figures 3.2.4, 3.2.5 and 3.2.6, respectively. The extensive white deposits on the surface of joint number IV completely destroyed the slippery nature of the cartilage surface. This condition apparently did not affect the subtalar joint since it retained a normal surface appearance.

These damaged joints were excluded from the present study of normal ankle joint geometry. They are shown in Figures 3.2.4, 3.2.5 and 3.2.6 for general interest. One observation of some relevance to the present study concerns the parallel scars torn in the surfaces of the joints shown in Figures 3.2.4, 3.2.5 and 3.2.6. These scars appear to be caused by abrasive action during motion. The orientation of some of the scars formed reasonably straight parallel lines when examined in plan view. This suggests that little rotation of the talus about the long axis of the tibia occurred in vivo.

In the present study, joints numbered 1, 2 and 3 were used in a detailed measurement procedure. The cartilage surface of these joints had a smooth shiny appearance similar to that revealed previously by Figure 3.1.6. It was assumed that these joints were normal and healthy enough to provide typical geometrical parameters.



Figure 3.2.4 : Surface appearance of joint number III



Figure 3.2.5 : Surface appearance of joint number IV



Figure 3.2.6 : Surface appearance of joint number V
3.3 Alignment of the Joint Components

Before the surface features of joints numbered 1, 2 and 3 were measured, the talar and tibial components of each were aligned. The orientation of the co-ordinate axes shown in Figure 3.3.1 was chosen for these joints, all of which were left ankles. The alignment technique involved mounting both talus and tibia in tubular holds as shown in Figure 3.3.2 The talus was penetrated by a self-tapping screw attached to a solid metal cylinder. The metal cylinder was gripped by three screws which acted through tapped holes in the wall of the tubular holder. Only two of these screws are revealed by the longitudinal section of Figure 3.3.2. The tibial component was held in a tubular holder of shorter length than the holder for the talus. The internal surface was slightly tapered and once again three screws acted through tapped holes in the However, in this case, the shaft of the tibia was tube wall. gripped directly by the screws. For joint number 2 a screw was inserted into the medullary canal of the tibia. The head of the screw was attached to a disc of larger diameter than the tabular holder. This device helped to hold the tibia in a fixed position.

With both joint components in place, small adjustments were made in their relative positions until the following conditions, illustrated in Figure 3.3.2, were achieved:

- i) virtually all of the tibial surface was in nominal contact with the talus;
- ii) the talus holder was aligned parallel to the z-axis;
- iii) the maximum z co-ordinate for the talus surface was at the centre of its own and the tibial articulating surface with respect to the anterior-posterior length.



Figure 3.3.1 : The co-ordinate system for ankle joint numbers 1, 2 and 3.



Figure 3.3.2 : Longitudinal section of the joint components in their holders.

iv) rotation of the joint yielded motion principallyin the x - z plane.

This positional arrangement was accomplished by using only a set square and visual estimates. The determination of the plane of rotation was aided by the length of the talus holder (175 mm) which was moved while keeping the tibia stationary. Usually the achievement of the specified position for alignment corresponded to a vertical position for most of the talar region which articulated with the lateral malleolus.

Once the joint components were aligned both talus and tibia, including screws and fixtures, were encased in plaster of Paris. In previous trials with joint numbers I, II and III, acrylic bone cement was also employed. However, the moisture at the scraps of tissue still adhering to the bone surface caused the cement to shrink away from the interface. The resulting fixation was somewhat less than optimal. To avoid migration of stray particles onto the cartilage surfaces, a layer of self-curing silicone rubber was placed over the surface of the plaster-of-Paris.

The fixation during alignment was altered for joint number 3. Instead of using three screws to hold the tibial shaft, some thickened plaster of Paris was applied directly. The appropriate adjustments in the positions of both tibia and talus were made before the plaster of Paris could harden. Then with the tibia in the correct position, the plaster of Paris was given time to set before more was added to completely encase the tibial shaft. This procedure required more skill and familiarity with the ankle joint than the one used on joint numbers 1 and 2.

3.4 Measurement of Surface Features:

Considering the co-ordinate system defined in Figure 3.3.1, the joint components were aligned to provide rotation about a line parallel to the y-axis such that motion was in the x - z plane, predominantly in the x-direction. The true shapes of the articulating regions were somewhat irregular as shown in Figure 3.2.3. However, measurements of surface dimensions were recorded in the x - y plane as shown in Figures 3.4.1, 3.4.2 and 3.4.3. The dimensions of equivalent rectangular bearing surfaces are shown in Table 3.4.1.

Joint Number	Width in the y-direction (mm)	Length of Tibia (mm)	Length of Talus (mm)	
1	27	31	38	
2	26	27	34	
3	26	27	34	
Average	26	28	35	

Table 3.4.1 : Characteristic surface dimensions.

The surface curvatures were measured along the numbered lines of Figures 3.4.1 to 3.4.3 which were oriented in the direction of motion. The lines with the same numbers on tibia and talus for a specific joint touched during articulation. This feature was achieved by carefully marking a touching point on both talus and tibia at the periphery of the contact zone. This common reference





Figure 3.4.1 : Surface dimensions for joint number 1 including the lines (1, 2, 3 and 4) along which the surface profiles were measured. All dimensions are in mm.





Figure 3.4.2 : Surface dimensions for joint number 2 including the lines (1, 2, 3, 4 and 5) along which surface profiles were measured. All dimensions are in mm.



Figure 3.4.3 : Surface dimensions for joint number 3 including the lines (1, 2, 3 and 4) along which the surface profiles were measured. All dimensions are in mm.

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point on each surface was extended in the direction of motion to produce two touching lines. During the surface profile measurements, the positions of the other lines were established at 4 mm spacings from the original line using a micrometer controlled specimen table.

A Talycontor instrument made by Rank Taylor Hobson was used to measure the surface profiles. This instrument uses a surface Essentially, contacting pin attached to a counter-weighted stylus arm. it is similar in principle to the more familiar Talysurf instrument, except that large rather than small scale surface features are measured. The standard pin used to contact the surface has a sharp conical point. This reduces pin tip radius effects on the measured profiles. However, a sharp pointed pin could both tear and sink into the soft cartilage surfaces thus producing inaccurate results. This danger was avoided by constructing a special pin with a precision ball glued into a spherical seating to form the tip as shown in Figure 3.4.4. With this pin, the tip radius influenced the measurements and the effect was included in the curve fitting procedure described in the next section.

The cartilage thickness was measured for joints numbered 2 and 3 at certain points along the lines used for the surface profile measurements. The technique involved marking some of these lines on the cartilage surface using a felt tipped pen. A fine-toothed hack saw was then used to cut the joint surfaces along the marked lines. Cartilage thickness was measured with a Profile Projector made by Nikon. This instrument produced an image in colour on a large circular screen, 400 mm in diameter. A photograph of the



Figure 3.4.4 : The special pin made for the Talycontor. All dimensions are in mm.

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screen image is shown in Figure 3.4.5. Reference lines were superimposed on the image and could be moved independently by precision micrometers. These traversing micrometers were connected to a digital display unit. Cartilage thicknesses were measured for each cross-section in a radial direction.



Figure 3.4.5 : The screen image of the Profile Projector showing a posterior-anterior cross-section of an ankle joint.

For the purposes of this study, thickness measurements were performed in the posterior, middle and anterior regions of each cross-section. The resulting values for thickness are listed in Table 3.4.2.

Joint	Component	Line		Thickness	ckness	
number			Posterior (mm)	Middle (mm)	Anterior (mm)	
2	Talus	1 3 5	1.5 1.3 1.4	1.7 1.4 1.3	1.4 1.2 0.9	
	Tibia	1 3 5	1.3 0.9 1.0	1.7 1.7 1.6	1.5 1.1 1.3	
3	Talus	1 2 4	1.1 1.2 1.3	1.3 1.3 1.1	0.8 1.0 0.9	
	Tibia	1 2 4	1.0 1.0 1.0	1.1 1.0 1.2	1.1 1.1 1.1	

Table 3.4.2 : Cartilage thickness measurements.

3.5 Calculation of Surface Radii of Curvature

The Talycontor instrument was used to measure surface profiles of joint numbers 1, 2 and 3. The graphical output from the Talycontor was converted to discrete digital data by hand and entered into computer data files. A curve fitting procedure in which the surface profile was represented by the arc of a circle was developed specifically for ankle joints. However, the curve fitting procedure included provisions for determining the parts of the profile which did not conform to this chosen form. To accomplish this, an estimate of the precision of an individual profile was required. A profile was taken twice consecutively and differences were within 0.25 percent. The details of the curve fitting procedure are listed as follows:

- A least squares method was used to obtain a best fit circle based on all the profile data. The mathematical development and the computer programme for this task are included in Appendix A.
- ii) Points were excluded from one of the ends of the profile so that an equal number remained on either side of the midpoint of the fitted arc.
- iii) Another curve fit was performed using the computer program listed in Appendix A.
 - iv) If the radius calculated using any single point involved in the circle fit was not within 0.25% of the radius of the fitted circle, then a point from each end of the arc was excluded from the next circle fit.
 - v) Step numbers ii), iii) and iv) were repeated until all
 the points involved in the fitted circle had radii within
 0.25% of the radius of the fitted circle and were equal
 in number on either side of the midpoint of the fitted arc.

The curve fitting procedure was applied to the data from the 26 individual profiles shown in Figures 3.4.1, 3.4.2 and 3.4.3. The results showing all the data collected are presented in Figures 3.5.1 to 3.5.6 using symbols defined in Table 3.5.1. It can be seen from these Figures that an arc of a circle provided a good representation of the profile geometry.

Symbol	Description
1, 2,	Profile line numbers shown in Figures 3.4.1, 3.4.2 and 3.4.3
Μ	Medial
L	Lateral
Α	Anterior
Р	Posterior
D	Points included in least squares fit
×	Points not included in least squares fit
+	Centre of fitted circle
LJ	10 mm
	arc of fitted circle
	Extension of arc of fitted circle

Table 3.5.1 Symbols for Figures 3.5.1 to 3.5.6

The calculated radii of curvature for each profile are given in Table 3.5.2. In lubrication theory, the reduced radius of curvature is a useful parameter. The radii are deemed to be positive for convex and negative for concave surfaces, and hence, for the profiles recorded, the following equation was adopted for the reduced radius of curvature. The resulting values are included in Table 3.5.2.

$$R = \frac{R_1(-R_2)}{R_1 + (-R_2)}$$
(3.5.1)

where $R_1 = talus radius$ $R_2 = tibia radius$ R = reduced radius



+

+

+



Figure 3.5.1 : The surface profiles for the talus of ankle joint number 1. (See Table 3.5.1 for definitions of the symbols used above).



L



10 mm

Figure 3.5.2; The surface profiles for the tibia of ankle joint number 1. (See Table 3.5.1 for definitions of the symbols used above).



10 mm

Figure 3.5.3 : The surface profiles for the talus of ankle joint number 2. (See Table 3.5.1 for definitions of the symbols used above).

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Figure 3.5.4 : The surface profiles for the tibia of the ankle joint number 2. (See Table 3.5.1 for definitions of the symbols used above).

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Figure 3.5.5 : The surface profiles for the talus of ankle joint number 3. (See Table 3.5.1 for definitions of the symbols used above). 74



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| 10 mm

Figure 3.5.6 : The surface profiles for the tibia of ankle joint number 3. (See Table 3.5.1 for definitions of the symbols used above).

				the second s
Joint Number	Line	Radius for	Radius for	Reduced Radius
		(mm)	(mm)	(m)
1	1 2 3	22.5 22.0 22.3	26.0 23.6 22.4	0.17 0.32 2.46
	4 Average	$\frac{22.3}{22.3}$	$\frac{22.1}{23.5}$	0.44
2	1 2 3 4 5	17.8 18.6 19.3 20.3 20.9	18.5 19.2 19.6 20.2 21.2	0.47 0.60 1.26 ¥ 1.48
	Average	19.4	19.7	1.27
3	1 2 3 4 Average	19.7 20.0 21.2 <u>21.8</u> 20.7	24.0 23.1 22.3 23.3 23.2	0.11 0.15 0.43 <u>0.34</u> 0.19
1		1		

Table 3.5.2 : Surface curvature values for ankle joint numbers 1, 2 and 3.

reduced radius undefined.

3.6 Accuracy of the Computed Radii of Curvature

In Section 3.1 the assumption was made that the central regions of the measured profiles were circular. This appeared to be the case as shown in Figures 3.5.1 to 3.5.6 and for each joint small changes occurred in the extent of this central region and the evaluated radius. The radii of curvature have been used to calculate reduced radii of curvature as listed in Table 3.5.2. A small error in a radius curvature could cause a large error in the reduced radius. Thus, a careful examination of the accuracy of the

calculation was necessary before the values recorded in Table 3.5.2 could be incorporated into an assessment of the overall geometry of the ankle joint.

The first error to be considered involved the special pin shown in Figure 3.4.4. The spherical tip of the pin had a The influence of pin tip radius radius tolerance of ± 0.003 mm. on the radius of curvature was given by equations (A.20) and (A.21) Cartilage dehydration was minimized throughout all of Appendix C. the experimental procedures by keeping the surfaces soaked in physiological saline solution. However, in the 40 seconds required for a traversal of the Talycontor stylus, dehydration could occur. This may have caused inaccuracy in the determination of the radius of surface curvature by reducing the cartilage This inaccuracy was estimated as \pm 0.02 mm based upon thickness. two successive traversals without wetting the surface. The Talycontor mechanism itself had a tolerance which can be estimated from the manufacturers specifications as ± 0.08 mm.

The possibility of the pin tip sinking into the soft cartilage was evaluated by using the following Hertzian formula from Timoshenko and Goodier (1951):

$$\frac{d}{R_{p}} = \left[\frac{3(1 - v^{2})F}{4E R_{p}^{2}}\right]$$

The calculated indentation of the pin tip was d = 0.004 mm and from this value a tolerance of ± 0.004 mm was chosen.

The average radius of curvature for all the surfaces was calculated from Table 3.5.2 as 21 mm. The percentage errors associated with various aspects of a profile measurement could thus be estimated using this average radius and the specified error ranges as listed in Table 3.6.2

Possible sources of error	Estimated percentage error
Pin tip radius	0.01
Cartilage dehydration	0.10
Talycontor mechanism	0.38
Pin indentation	0.02
Į – – – – – – – – – – – – – – – – – – –	1

Table 3.6.1 : Some error estimates associated with profile measurements.

In Section 3.3 the alignment procedure adopted in the present study was described. Since much of the alignment was accomplished "by eye", significant inaccuracies may exist in the values listed in Table 3.5.2

In Appendix B two types of misalignment which may arise in the measurement of a cylindrical surface using the Talycontor instrument are described. The measured joint surfaces were approximately cylindrical as indicated in Table 3.5.2. Thus, the equations developed in Appendix B could be used to estimate the errors. An aligned cylinder would have its horizontal (y) axis perpendicular to both the direction of stylus motion (x) and the z-axis. In Appendix B inclination in the vertical (y - z) plane is described by a tilt angle (θ) while rotation in the horizontal (x - y) plane is described by a twist angle (α).

It was convenient to define the peak point for a profile as the point with maximum z co-ordinate. The co-ordinate system for the ankle is defined in Figure 3.3.1. During the Talycontor measurements, peak point co-ordinates were recorded with respect to arbitrary locations of the origins for each joint component as listed in Table 3.6.2.

The points obtained for each component do not provide a precise representation of the medial-lateral profile. However, if the joint surfaces were cylindrical and aligned perfectly, lines joining the peak points would have zero slope in the \dot{y} - z and x - y planes. The slopes were calculated using the computer program listed in Appendix C for a linear regression based on a least squares criterion. The evaluated slopes in the y - z and the x - y planes can be used to estimate tilt and twist angles respectively. The peak points, least squares slopes and estimated tilt and twist angles are shown in Figure 3.6.1 for the tibia of joint number 3 and the estimated tilt and twist angles for each joint component are listed in Table 3.6.3

Equation (B.3) is developed in Appendix B to estimate the effects of tilt and twist on the measured radius of a cylinder. Equation (B.3) implies

$$r_{c} = \frac{2 r_{m}}{\cos\theta + \frac{1}{\cos\alpha}}$$
(3.6.1)

Joint Number	Component	Line	Peak Point Co-ordinates		
			x (mm)	y (mm)	z (mm)
1	Talus	1 2 3 4	17.6 16.6 16.2 16.1	0 4.0 8.0 12.0	6.3 5.6 5.7 6.1
	Tibia	1 2 3 4	13.4 13.4 13.0 13.0	0 4.0 8.0 12.0	4.2 3.6 3.9 4.2
2	Talus	1 2 3 4 5	- 14.7 15.0 15.0 15.1	- 4.0 8.0 12.0 16.0	- 6.9 6.2 6.2 7.3
	Tibia	1 2 3 4 5	- 12.1 12.7 12.9 13.1	4.0 8.0 12.0 16.0	- 5.3 4.8 5.5 4.9
3	Talus	1 2 3 4	15.7 15.7 15.3 15.6	0 4.0 8.0 12.0	6.3 5.6 5.1 5.1
	Tibia	1 2 3 4	11.1 11.4 11.7 12.7	0 4.0 8.0 12.0	3.2 2.7 2.5 2.5

Table 3.6.2 : Peak point co-ordinates with respect to arbitrary origins for each component.







Figure 3.6.1 : Peak points, least squares slope and estimated tilt and twist angles for the tibia of joint number 3. (Dimensions are expanded in the x and z directions.)

Joint Number	Component	Average measured radius (mm)	Estimated tilt angle θ (degrees)	Estimated twist angle α (degrees)
1	Talus	22.3	0.9	7.0
	Tibia	23.5	0.4	2.3
2	Talus	19.4	1.8	1.7
	Tibia	19.7	0.8	4.6
3	Talus	20.7	6.1	1.0
	Tibia	23.2	3.1	7.3

Table 3.6.3 : Estimated tilt and twist angles.

where r_m is the measured radius, θ is the tilt angle, α is the twist angle and r_c is the true cylinder radius.

The inaccuracy caused by tilt and twist was estimated by applying equation (3.6.1) to the values of average radius, tilt angles and twist angles listed in Table 3.6.3. The differences between the radius values calculated using equation (3.6.1) and the average measured radii are listed as estimated percentage errors in Table 3.6.4.

Joint Number	Component	Average measured radius (mm)	Estimated percentage error
1	Talus	22.3	0.37
	Tibia	23.5	0.04
2	Talus	19.4	0.003
	Tibia	19.7	0.16
3	Talus	20.7	0.28
	Tibia	23.2	0.34

Table 3.6.4 : Estimated percentage error in the average radius of curvature values caused by misalignment.

The percentage errors from Tables 3.6.1 and 3.6.4 were summed to yield a total error for the average measured radii of each joint component. These errors could themselves be used to estimate the errors in the reduced radii of curvature for each joint. The error in reduced radius of curvature was expressed by applying the following equation

$$R\% = \left(\frac{\partial R}{\partial R_1} R_1\%\right)^2 + \left(\frac{\partial R}{\partial R_2} R_2\%\right)^2$$
(3.6.2)

where R%, $R_1^{\ \%}$ and $R_2^{\ \%}$ were estimated percentage errors in the reduced radius of curvature, average measured radius of the talus and the average measured radius of the tibia respectively. Equation (3.6.2) follows from the methods outlined by Kline and McClintock (1953). Equations (3.5.1) and (3.6.2) implied that

$$R\% = R \sqrt{\left(\frac{R_1\%}{R_1}\right)^2 + \left(\frac{R_2\%}{R_2}\right)^2}$$
(3.6.3)

The total errors in the average measured radii and the reduced radii of curvature are listed in Table 3.6.5.

Joint Number	Component	Average measured radius		Reduced	Radius
		Value (mm)	Percent error	Value (क़)	Percent error
1	Talus Tibia both	22.3 23.5	0.88 0.55	0.44	20
2	Talus Tibia both	19.4 19.7	0.51 0.67	1.27	55
3	Talus Tibia both	20.7 23.2	0.79 0.85	0.19	10

Table 3.6.5 : Total errors in the radii of curvature.

3.7 <u>Selection of a Simple Geometry for Hydrodynamic Lubrication</u> Analysis of the Ankle Joint

The simple geometry of a partial journal bearing with a layered surface was chosen to represent the ankle joint. Values from Tables 3.4.1, 3.4.2 and 3.5.2 were used to specify average dimensions for this simple geometry as shown in Figure 3.7.1. In the theoretical analysis of joint lubrication presented in this thesis, the reduced radius was a parameter of major importance. For the average dimensions shown in Figure 3.7.1 the reduced radius was 0.35 m.

Some of the average dimensions could be compared to those chosen by Kempson et al (1975) for their standard sized prosthetic ankle joints. The rather close correspondence shown in Table 3.7.1 indicated that these dimensions from the present study can be classified as typical.

The specification of a simple geometry for synovial joint lubrication studies is quite common in the literature. A recent review by Dowson (1980) described the hip as a ball-insocket with a reduced radius of 0.10 - 1.00 m. In a similar manner ranges for the ankle joint dimensions can be chosen based on the present measurements as listed in Table 3.7.2. The reduced radius of curvature based on average values is 0.35 m with a range of 0.19 to 1.27 m. The range is similar to the range estimated by Dowson (1980) for the hip.

Dimension	Average value from present study	Standard sized ankle joint prosthesis designed by Kempson et al (1975)	
Width (mm)	26	25	
Tibia length (mm)	28	25	
Talus length (mm)	35	34	
Tibia radius (mm)	22.1	21	
Talus radius (mm)	20.8	21	

Table 3.7.1 : Comparison between average dimensions of the present study and those for the ankle joint prosthesis designed by Kempson et al (1975).



Figure 3.7.1 : The simple ankle joint geometry for lubrication modelling. All dimensions are in mm.

Dimensions	Average value	Range	
Tibia cartilage thickness	(mm)	1.2	0.8 - 1.7
Talus cartilage thickness	(mm)	1.2	0.9 - 1.7
Width	(mm)	26	22 - 31
Tibia length	(mm)	28	27 - 31
Talus length	(mm)	35	34 - 38
Tibia radius	(mm)	22.1	18.5 - 26.0
Talus radius	(mm)	20.8	17.8 - 22.5
Reduced radius	(m)	0.35	0.19- 1.27

Table 3.7.2 : The average values and ranges for the important dimensions representing the geometry of the ankle joint.

3.8 Concluding Remarks

Some general features of the ankle joint surface have been measured in order to specify a simple geometry for subsequent hydrodynamic lubrication analysis. The simple geometry can be discussed in a qualitative manner based on the measurements given in the present study.

In Section 3.1 assumptions were made which reduced the number of features measured. Only the tibia-talus articulation of the ankle was investigated since it transmits most of the joint load (Lambert, 1971). The selection of a single plane of motion was supported by the successful prosthetic replacement for the ankle which had this characteristic (Kempson et al, 1975).

The ankle joint specimens were obtained from a specialized group of patients. Normal healthy joints were selected by visual examination. The chances of this selection procedure failing to detect mildly diseased joints were lessened somewhat by the low incidence of primary osteoarthrosis in the ankle (Stautter et al, 1977).

The joint surfaces were measured with the cartilage in a However, cartilage creep may occur during in vivo relaxed state. activities which would change the reduced radius of curvature Ekholm and Ingelmark (1952) measured increases (Higginson, 1978). of 5 - 10% in the separation between the femur and tibial plateau as a result of exercise. They claimed that the knee joint cartilages increased in thickness. It is therefore possible that the calculated reduced radii of curvature could have been affected by in vivo activities. However, the measurements of Ekholm and Ingelmark may have included swelling of the menisci. In any case, increases in cartilage thickness can have various effects on surface curvature depending on the region in which it occurs. Thus, it was hoped that the calculated reduced radius of curvature for relaxed cartilage surfaces would provide a satisfactory approximation to that occurring in vivo.

The surface profiles measured in the posterior and anterior regions of the talus deviated by about 0.5 mm from a circular profile. A similar small deviation from circularity was found by Barnett and Napier (1952) and is probably responsible for the changing axis of rotation reported by Sammarco et al (1970) and others. The measured radii of both talus and tibia vary from medial to lateral regions by about five percent, as shown by Table 3.5.2. The overall effect was a considerable variation in reduced radius of curvature for both the medial-lateral direction and as joint flexion occurs. This variation exceeded

the maximum error estimated in Table 3.6.5 for the reduced radius of curvature due to errors in measurements.

In spite of the uncertainty in specifying reduced radii of curvature for the ankle joint, there remains strong evidence from the present study to suggest that converging-diverging surfaces are a typical feature of the joint. It is suggested that the simple geometry adopted and the average dimensions deduced adequately represent the ankle joint for subsequent hydrodynamic lubrication analysis.

CHAPTER 4

ANKLE JOINT FRICTION EXPERIMENTS

4.1 INTRODUCTION

A number of experimental approaches have been employed previously in the study of synovial joint lubrication. Some investigators such as McCutchen (1962) and Walker et al (1968) examined the friction between small sections of synovial joint surfaces and glass. Other investigators have used rubber, glass and metal surfaces in various combinations as analogues for particular aspects of synovial joint lubrication (McCutchen, 1966; Higginson and Norman, 1974). Research involving artificial surfaces has assisted the development of understanding the various lubrication mechanisms described in Chapter 2. However, the behaviour of these model experiments may not adequately represent synovial joints in vivo. Thus, it is also necessary to study whole joints under conditions similar to those occurring in vivo.

In general, the friction force at the cartilage surface were measured in the various studies of whole joints. It was hoped that the type of lubrication could be ascertained from these friction measurements. Initially attempts were made to use intact finger joints in friction measuring devices (Jones, 1936; Barnett and Cobbold, 1962). However, the surrounding muscles, ligaments and joint capsule contributed to the measured friction (Wright and Johns, 1960; Barnett and Cobbold, 1962). Thus, most of the measurements of friction directed towards an improved understanding of joint lubrication were usually carried out with dissected synovial joints.

The present study used the dissected human ankle joints described in Chapter 3 in a joint simulator apparatus. Attempts were made to measure the friction between the cartilage surfaces in order to gain insight into the lubrication of ankle joints in vivo.

4.2 Literature Review of Whole Joint Friction Experiments:

The magnitude of the friction between the cartilage surfaces of whole joints was first estimated by Jones (1934). He measured a static coefficient of friction for a dissected knee joint from Later Charnley (1960) performed a similar experiment on a horse. a human knee joint and obtained a range for the static coefficient of friction at various normal loads. This range of friction coefficients included the result obtained by Jones. The details of these early measurements of static friction are listed in Table 4.2.1. Jones did not detect a difference in friction when saline solution was applied to the joint surfaces instead of However, if the surfaces were allowed to dry, synovial fluid. the static coefficient of friction increased dramatically as shown in Table 4.2.1

Free Swinging Pendulums:

Synovial joints are subject to large motions in vivo. Thus, although static friction provides an estimate of whole joint friction behaviour, most subsequent investigations concentrated on measuring the friction forces between moving cartilage surfaces. Various types of apparatus have been used to measure dynamic friction. Possibly the simplest was a pendulum with a synovial joint at the fulcrum. The intention was to determine the coefficient of friction from the rate of decay in pendulum amplitude (Barnett and Cobbold, 1962; Clarke et al, 1975). It was originally thought that the
Investigator	Year Published	Joint	Lubricant	Load (N)	Static Coefficient of Friction
Jones	1934	horse knee	synovial saline	125 125	0.02 0.02
			dry	125	0.27
Charnley	1960	human knee	synovial	27-2675	0.005-0.023

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Table 4.2.1Measurements of static coefficients of friction for synovial joints

presence of a lubricant film between the surfaces could also be detected by the rate of decay of the pendulum amplitude (Jones, 1936; Charnley, 1960; Little et al, 1969). However, Barnett and Cobbold (1962) showed experimentally that this was not true in all cases. Furthermore, Unsworth et al (1975) produced analytical estimates which suggested that the presence of fluid film lubrication in synovial joints would be very difficult to detect from the rate of decay in pendulum amplitude. Thus, both Unsworth et al (1975) and O'Kelly et al (1978) measured friction directly without using the rate of decay of the pendulum amplitude.

In spite of these problems, pendulum devices have been widely Some details of the investigations using pendulums are used. listed in Table 4.2.2. The investigations of Clarke et al (1975) and Unsworth et al (1975) showed that the removal of the synovial fluid caused an increase in the coefficient of friction. When Ringer's or buffer solution was used instead of synovial fluid, the coefficient of friction increased in the studies of Little et al (1969) and Clarke et al (1975). In most of the studies included in Table 4.2.2. the coefficient of friction decreased with the increasing load. However, some of the individual experiments of Unsworth et al (1975) showed regions where the coefficient of friction increased with increasing load. Also. Swanson and Freeman (1970) stated that the experiments of Little et al (1969) showed increasing friction with increasing load. At low loads, both Unsworth et al (1975) and O'Kelly et al (1978) obtained some results showing a decrease of friction coefficient with decreasing pendulum velocity.

Investigator	Year Published	Joint	Lubricant	Load (N)	Initial Angular Displacement (degrees)	Coefficient of Friction
Charnley	1960	human ankle	synovial	134	5	0.014-0.024
Barnett & Cobbold	1962	dog ankle	synovial synovial	4 11	7.5 7.5	0.028 0.018
Little et al	1969	human hip	synovial ringers	890 890	-	0.005-0.012 0.009-0.018
Unsworth et al	1975	human hip	synovial synovial dry dry	134 1480 134 1250	5 5 5. 5	0.04-0.01 0.022-0.015 0.125-0.075 0.055-0.018
Clarke et al	1975	human hip	synovial synovial buffer buffer dry dry	450 1700 450 2000 450 1800	10 10 10 10 10 10	0.032 0.015 0.038 0.026 0.1 0.039
O'Kelly et al	1978	human hip	bovine synovial	100 1500	5-10 5-10	0.05-0.08 0.018-0.05

Table 4	.2.2	Studies	using	a synovial	joint at	the	fulcrum	of a	a free	swinging	pendulum
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This velocity behaviour, together with the observed decrease of the coefficient of friction with increasing load indicated that some fluid film action was taking place. However, at higher loads and lower velocities these trends were not so pronounced. Thus, all the investigators listed in Table 4.2.2. suggested that a mixture of fluid film and boundary lubrication occurred in their experiments, except Charnley (1960) and Little et al (1969) who proposed boundary lubrication. The increase in friction coefficient when Ringer's or buffer solution was used in place of synovial fluid also supported the view that boundary lubrication The Ringer's and buffer solutions had lower viscosity prevailed. than synovial fluid. Thus, if full fluid film lubrication occurred, a lower coefficient of friction would have been expected for the lower viscosity fluids. In certain experiments O'Kelly et al (1978) found evidence that fluids of lower viscosity than synovial fluid exhibited lower coefficients of friction.

It became increasingly clear that the loads and velocities encountered in the synovial joints tested in free swinging pendulum experiments affected the type of lubrication developed.

Driven Pendulums:

At the same time as work on free swinging pendulums was in progress, some investigators were starting to use driven pendulums. The surface velocities and amplitudes of rotation were much closer to those occurring in common activities in vivo than in the case of free swinging pendulums. However, these devices applied a constant load throughout the cyclic oscillation. Thus, the low loads and high surface velocities which occurred during the swing

phase on weight bearing joints were not adequately simulated.

Details of some of the driven pendulum experiments are listed in Table 4.2.3. These investigations showed an increase in the coefficient of friction when saline or buffer solution was used in place of synovial fluid. Contrary to the findings from the free swinging pendulum experiments of Unsworth et al (1975) and O'Kelly et al (1978), the coefficients of friction decreased with increasing velocity in all the investigations, except those of Faber et al (1967). In this study, an increase in the "fluid" component of friction was reported with increasing velocity.

However, they tested intact rabbit's knee joints at high velocities and predicted extremely low film thickness values based upon friction measurements.

Finally, Radin et al (1970) and Radin and Paul (1971) showed an increase in the coefficient of friction with increasing load, while Linn (1968) showed the opposite effect.

Simulators:

An experimental apparatus which applied cyclic time varying loads and velocities was first used on an animal joint by Linn (1967). This joint simulator was a modification of the driven pendulum apparatus used by Linn to generate the results listed in Table 4.2.3. To allow subtraction of torques generated by misalignment of the load axis, the same load pattern was applied for clockwise and counter-clockwise rotation. As a result, the low load, high surface velocity part of the swing phase was not represented. However, low load regions did occur with moderate surface velocities.

Investigator	Year Published	Joint	Lubricant	Load (N)	Amplitude of Rotation (degrees)	Frequency (cpm)	Coefficient of Friction
Faber et al	1967	rabbit knee	synovial	40-120	<u>+</u> 10	240-600	0.04-0.08
Linn	1967	dog ankle	bovine synovial saline saline	180 180 180 180	+ 18 + 18 + 18 + 18 + 18	5 200 5 200	0.01 0.004 0.02 0.01
Linn	1968	dog ankle	bovine synoviał	90 360 90 360	<u>+</u> 18 <u>+</u> 18	5 200	0.01 0.009 0.004 0.0035
Radin et al	1970	bovine ankle	synovial synovial buffer buffer	980 4900 980 4900	- - -	40 40 40 40	0.006 0.01 0.011 0.01
Radin & Paul	1971	bovine ankle	synovial synovial buffer buffer	890 4448 890 4448	- - -	40 40 40 40	0.0062 0.0112 0.0117 0.0115

Linn (1967) did not follow up his prelimnary work on the simulator apparatus. However, ten years later O'Kelly (1977) published an extensive study using a hip joint simulator. Once again similar load patterns were applied during clockwise and counter-clockwise rotation.

The results of Linn (1967), O'Kelly (1977) and O'Kelly et al (1978) are summarized in Table 4.2.4. A term composed of surface velocity divided by load was used by O'Kelly to correlate with the friction coefficient. If the friction coefficient increased as this term increased then fluid film lubrication predominated. Such behaviour was also demonstrated by Cudworth and Higginson (1976) for a rigid cylinder sliding over a compliant layer under constant load and velocity conditions in the presence of a Newtonian lubricant.

Whether it was correct to assume that the simple correlation reported by Cudworth and Higginson applied to the dynamic conditions imposed by the simulators used by Linn and O'Kelly remained uncertain. However, assuming the correlation was valid, Table 4.2.4 shows that Linn's results indicated boundary or mixed lubrication, while O'Kelly's results supported fluid film lubrication.

Viscosity Effects:

It is not clear from the various studies summarized in Tables 4.2.2, 4.2.3 and 4.2.4 whether fluid film or boundary lubrication predominates in synovial joints during activities such as walking. In an attempt to clarify this situation both Linn (1968) and O'Kelly (1977) conducted experiments with fluids of much greater viscosity than synovial fluid. Representative results are

Details of Investigation	V (velocity) (<u>mm</u>)	F (load) (N)	V F (mm s.N)	μ (coefficient of friction)
Linn (1967) - dog ankle - talus radius ≈ 8.2 mm - lubricated with saline - motion <u>+</u> 18.1° at 40 cpm	1.8 10.85	54 165	0.033 0.066	0.021-0.034 0.012
O'Kelly (1977) - human hip -femoral head radius ≃ 26mm - lubricated with saline - motion <u>+</u> 8° at 37-68 cpm	4-25 13-18 20-26	1271-2383 530 530	0.021-0.01 0.024-0.034 0.039-0.049	0.012-0.031 0.029-0.039 0.039-0.054
O'Kelly et al (1978) - human hip -femoral head radius ≃ 26mm - lubricated with bovine synovial fluid - motion <u>+</u> 8 ^o at 37-68 cpm	4-25 13-18 20-26	1271-2383 530 530	0.0021-0.01 0.024-0.034 0.039-0.049	0.01-0.05 0.025-0.061 0.035-0.085

summarized in Table 4.2.5. Linn (1968) recorded a decrease in friction with increasing viscosity and O'Kelly measured similar behaviour at low velocities. However, at higher velocities and lower loads O'Kelly measured an increasing friction coefficient with increasing viscosity. Thus, it appeared that fluid film lubrication could be encouraged by introducing high viscosities and velocities along with low loads. The drop in coefficient of friction under higher load and lower velocity conditions may be interpreted as evidence of mixed lubrication. Again a problem exists in determining the appropriate conditions for synovial joints and thus applying these observations to activities in vivo.

Lubricant Constituents:

Another approach to gaining insight into the relative contribution of boundary and fluid film effects in synovial joint lubrication was developed by Radin et al (1970). They tested a bovine ankle in a driven pendulum with a load of 1115 N and a frequency of oscillation of 40 cpm. Constituents of bovine synovial fluid were destroyed biochemically and the resulting friction measurements are summarized in Table 4.2.6. The low friction appeared to depend on the presence of protein. The absence of hyaluronate, which would reduce the synovial viscosity, did not seem to affect the friction. Thus Radin et al concluded that the lubrication of synovial joints was boundary in nature and required the protein constituents in synovial fluid. This result was supported by the more detailed work of Swann et al (1974).

Details of the Investigation	Joint	Lubricant	Viscosity (CP)	Load (N)	Average Velocity (mm/s)	Average Friction Coefficient
Linn (1968)	dog ankle	buffered saline	0.96	178	7	0.0076
driven pendulum	5	bovine synovial +	1.2	178	7	0.0037
		hyalurondaise bovine synovial	5.2	178	7	0.0037
	dog ankle	buffered saline bovine	0.96	178	7	0.0156
		synovial + hyalurondaise	2	178	7	0.0068
		bovine synovial bovine	6.4	178	7	0.0075
		synovial concentrated	10.7	178	7	0.0059
0'Kelly (1977	human hip	ringers	1	1964	6	0.018
simulator	,	ringers + hyaluronic acid	29	1964	6	0.012
		ringers + hyaluronic acid	58	1964	6	0.013
		ringers	1	530	20	0.022
		ringers + hyaluronic acid	29	530	20	0.035
		ringers + hyaluronic acid	58	530	20	0.043

Lubricant	Average Coefficient of Friction
bovine synovial fluid	0.0025
bovine synovial fluid without hyaluronate	0.0026
bovine synovial fluid without protein	0.0051
buffer solution	0.0052

Table 4.2.6 : Experiments on constituents of synovial fluid by Radin et al (1970).

However, the results obtained by O'Kelly et al (1978) did not support this view of the importance of boundary lubrication, since the destruction of the protein element in synovial fluid did not significantly alter friction in their experiments. The destruction of the hyaluronate had only a marginal effect and tended to increase friction.

Concluding Remarks on Previous Whole Joint Friction Experiments:

In whole joint friction experiments a vast number of contradictory findings have been reported. It is of some interest to simply list these findings as shown in Table 4.2.7.

Various joints with different geometries were subject to rather arbitrary ranges of load and velocity. Obviously, this makes it difficult to compare results. Also, since different testing equipment was used and friction forces were small, various types of errors probably distorted the results listed in Table 4.2.7.

Observation	Supporting	Opposing	Both
Replacing synovial fluid with saline solution increases friction	Linn (1967 Linn (1968 Little et al (1969) Radin et al (1970) Radin & Paul (1971) Clarke et al (1975		0'Kelly et al (1978)
Increasing load reduces friction coefficient	Barnett & Cobbold (1962) Clarke et al (1975) O'Kelly et al (1978)	Swanson & Freeman (1970) Radin et al (1970) Radin & Paul (1971)	Unsworth et al (1975)
Increasing velocity decreases friction	Linn (1967) Linn (1968)	Faber et al (1967) O'Kelly et al (1978)	Unsworth et al (1975)
Increasing velocity divided by load in simulator expt. decreases friction coefficient	Linn (1967)	0'Kelly (1977) O'Kelly et al (1978)	
Increasing viscosity decreases friction	Linn (1967)		0'Kelly (1977)
Removing protein increases friction	Radin et al (1970) Swann et al (1974)		0'Kelly et al (1978)

4.3 General Description of the Ankle Joint Simulator:

The simulator used in the present study was a modified version of the hip joint simulator described by 0'Kelly (1977). The hip joint simulator has also been described in two recent publications (0'Kelly et al, 1977, 1978). A sketch of the simulator as used in the present study is shown in Figures 4.3.1 and 4.3.2. The two rolling element bearing and the two hydrostatic bearings shown in Figure 4.3.1 had their centres aligned with the approximate centre of curvature of the talus surface. The upper loading assembly oscillated about this fixed centre in a vertical plane. The lower loading assembly was constrained by eight linear bearings, two for each of four fixed guide pillars, so that only vertical motion could occur. Only two of these eight linear bearings appear in Figure 4.3.1.

The power required to apply the cyclic load and oscillating motion to the joint was supplied by a belt driven from an electric motor with a Kopp variable speed control (Kapak Induction Motor, G.E.C. Machines). The belt drive rotated a steel cam which supplied input to the hydraulic circuit used to load the ankle specimens. The same shaft which drove the cam was also connected to a scotch yoke which converted rotary motion to sinusoidal linear reciprocating motion. This linear motion was applied to a rack and pinion which oscillated the upper loading assembly. A simplified representation of this gearing system is shown in Figure 4.3.1.

The torque assembly shown in Figure 4.3.2 floats on hydrostatic bearings, as shown in Figure 4.3.1, so that any torque about the talus centre was constrained by the Kistler force transducer.



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Figure 4.3.1 : Sketch of a medial-lateral section of the ankle joint simulator apparatus.



Figure 4.3.2 : Sketch of a posterior-anterior section of the ankle joint simulator apparatus.

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The oil used for the hydrostatic bearings (Shell HVI-650) had a viscosity of approximately 2 Pa.s and was supplied by a 0.746 kw Pratts hydraulic pump.

The following modifications were made for the present investiqation to the joint simulator used by O'Kelly (1977).

- A new cam was designed and fabricated to create a load pattern which approximated that encountered in the swing phase of the ankle during walking.
- ii) A hydraulic line was replaced with one of larger diameter, fewer bends and shorter length to help the cam follower to stay in contact with the cam.
- iii) A limit switch was attached to the simulator to signal the load and friction recording instrumentation at a known angular displacement of the upper loading assembly.
- iv) The Kistler force transducer was moved from under the torque assembly to the position shown in Figure 4.3.2.
- v) The oil in the hydraulic pump which supplied the hydrostatic bearings was changed to one which was thirty times more viscous.
- vi) Styro-foam pads, rubber spacers and flexible tubing were used to help isolate the vibrations of the hydraulic pump from the Kistler force transducer.
- vii) Fixtures were made for mounting the ankle specimens that allowed small scale adjustments to be made to the positions of the joint components. Alignment pins were also fabricated.

These modifications will be discussed in detail in subsequent sections of this chapter.

4.4 Load, Displacement and Velocity Imposed by the Simulator:

Considerable data on the displacement of the ankle joint in vivo was presented by Murray et al (1964). Values for the loads on the ankle during walking were estimated analytically by Seireg and Arviker (1975), while Stauffer et al (1977) used both analytical and experimental methods to give displacement and loading of the ankle joint during walking.

In the present study a hardened steel cam was designed to actuate the loading system as described in Appendix D. The heat treatment used to harden the cam was necessary because the stress imposed by the cam follower was sufficient to deform a mild steel In the previous investigations of O'Kelly (1977) difficulty cam. occurred in keeping the cam follower in contact with the cam throughout the loading cycle. As a result the imposed load increased in a series of sharp peaks. This problem did not occur to the same extent in the present study. During a cycle only one rather than two load peaks were imposed. This reduced the maximum rate of change of the cam radius. The shape of the cam was controlled by the theory developed in Appendix D. Also, the hydraulic line from balancing cylinder I to the master cylinder, shown in Figure D.1, was shorter, larger in diameter and had fewer bends than the line used by O'Kelly (1977). This promoted rapid flow of oil from the master cylinder and helped the follower to stay in contact with the cam as the radius descreased. In the operation of the simulator for the present study the cam follower

briefly lost contact with the cam at the toe-off position shown in Figure D.2.

The loads imposed by the joint simulator were measured by a force transducer made by applying strain gauges to the walls of a flanged tube which occupied the position normally used for the ankle specimens. This special force transducer, described in detail by 0'Kelly (1977), was connected to a bridge amplifier (Tinsley Telcon Ltd.). A low pass filter with a stabilized power supply (Farnell E30/2) was employed to reduce noise in the signal. The voltage output from the bridge amplifer was then recorded during a load cycle with a Tektronix storage oscilloscope. The oscilloscope was triggered by a signal from a limit switch mounted on the simulator and activated when the upper loading assembly reached a known angular displacement.

The voltage output from the oscilloscope was converted to load using the calibration curve shown in Figure 4.4.1. The calibration curve was obtained by placing the force transducer in a Howden testing machine, recording the load required to produce specific voltages and applying the least squares computer program listed in Appendix C. The loads were measured with the pinion gear detached since the special force transducer would not allow oscillatory motion of the upper loading assembly.

The load pattern obtained for the cam used in the present study is shown in Figure 4.4.2 along with the predicted load of Seireg and Arvikar (1975) and Stauffer et al (1977) for a person weighing 440 N. In general, joint loading has been estimated as directly proportional to body weight during walking. It has been shown that both measured and predicted loads for the hip vary,

F (Load in N)



depending on the stride length and walking speed as well as the body weight (Paul, 1976). Such variation must also occur in the ankle joint forces. Thus, the load pattern experienced by a particular ankle specimen during walking can only be approximated.

The load pattern applied by the simulator had a form similar to that predicted by previous investigators for a body weight of 440 N as shown in Figure 4.4.2. Since the loading pattern could not be altered easily (see Appendix D), the same load was applied to each specimen in the present experiments. The value for body weight of 440 N was exceeded by the subjects listed in Table 3.2.1. Thus, peak loads in excess of those predicted during walking were generally avoided. However, the swing phase loads were somewhat larger than those predicted by Seireg and Arvikar (1975) as shown in Figure 4.4.2. This was necessary since low loads could not be imposed or recorded with enough precision by the present apparatus.

The accuracy of the loading system depended on a number of factors. As stated previously, the centres of the roller bearings of the loading assembly had to be aligned with the centres of the hydrostatic bearings of the torque assembly. If the roller bearing centres were lower than the hydrostatic centres, the load at all points in the cycle decreased, since the minimum driving circuit pressure decreased. This occurred to some extent with the mounting of the ankle specimens. A test was conducted with the loading assembly 2.6 mm below the aligned position. The special force transducer recorded a peak load some twenty five percent below the normal level, while the swing phase loads decreased by about fifty percent. The compliance of the specimens also affected the F (load in kN)



Figure 4.4.2 : The cyclic load pattern imposed on the ankle specimens by the joint simulator and some predicted loads on the ankle during walking for a person weighing 440 N.

imposed load. Tests were conducted with a rubber disc (3.5 mm thick, elastic modulus of about 25 MPa) between various parts of the special force transducer. Variations of about five percent occurred in the peak load while variations of about twenty percent occurred in the swing phase load compared to the loads recorded with the rigid force transducer. In addition to these possible inaccuracies, the calibration curve shown in Figure 4.4.1 produced uncertainties in the imposed forces of about one percent for the peak load and about ten percent for the swing phase loads.

In the present experiments, cycle times of 0.8s and 1.2s were used along with the period of 1.0s recorded in Figure 4.4.2. The changes in loading pattern were small compared with the other inaccuracies involved in the loading system and were thus neglected.

The displacement of the ankle specimens in the simulator was adjusted by changing the radius of the connection point on the scotch yoke mechanism. Sinusoidal displacements were imposed by the scotch yoke and an amplitude of 9° was set for the experiments. O'Kelly (1977) chose an amplitude of 8° for her experiments with hip joints.

The displacement of the ankle during walking has been measured by Murray et al (1964) and Stauffer et al (1977) and their results are shown in Figure 4.4.3, along with the displacements imposed by the simulator. Obviously, the range of motion in the simulator was less than that encountered in vivo, but it was hoped that the lower amplitude of imposed displacement would limit the effects of the changing axis of rotation of the ankle when it was forced to oscillate about a fixed centre by the simulator.



Figure 4.4.3 : The cyclic displacement imposed on the ankle specimens by the joint simulator and some measured displacements on the ankle during walking.

The relative surface velocity of the ankle during walking was estimated from the displacement curves of Murray et al (1964) and Stauffer et al (1977) using an average radius of curvature of 21 mm for the ankle components. These velocity patterns are shown in Figure 4.4.4 with the simulator velocity calculated using the same average radius. It was apparent that higher velocities existed in normal walking than those imposed by the simulator. However, the precision of the calculation of surface velocities during walking depend on estimating slopes of the displacement curves and this was very poor. As a result, values for relative surface velocity during walking were not known with precision for the ankle joint.

The following equation related relative surface velocity in mm/s to the period of oscillation for a component radius of r_s in mm.

$$V = \frac{0.987 r_{s}}{t_{p}} \cos \left(2\pi \frac{t}{t_{p}}\right) \left(\frac{mm}{s}\right)$$
(4.4.1)

where t_p is the period of oscillation in seconds and t is the time in seconds. The period of oscillation was set to 0.8, 1.0 and 1.2 s in the course of the present experiments.

4.5 Friction Measurement:

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The Kistler force transducer shown in Figure 4.3.2 was connected to a charge amplifier also made by Kistler. The output from the charge amplifier was passed to an ultra-violet recording device made by SouthernInstruments. The same limit switch mentioned in Section 4.1 was used to trigger a vertical line on the recording paper at a known angular displacement of the torque



Figure 4.4.4 : The cyclic relative surface velocity imposed on the ankle specimens by the joint simulator and some velocity estimates for the ankle during walking, all for a joint component radius of 21 mm.

assembly. This system measured the torque imposed on the tibia of the ankle specimen during operation of the simulator. The oil supplied to the hydrostatic bearings shown in Figure 4.3.1 was the same as that used by Unsworth et al (1975) in their pendulum apparatus. In the present study and that of Unsworth et al (1975) it was assumed that the resisting torque imposed by the hydrostatic bearings was negligible.

The Kistler force transducer, charge amplifier and the ultraviolet recorder were used previously by both Unsworth et al (1975) and O'Kelly (1977). However, in the hip joint simulator used by O'Kelly the transducer was placed underneath the torque assembly shown in Figure 4.3.2. When increasing torques were applied to the torque assembly with zero normal load imposed, the resulting deflection of the ultra-violet recording instrument increased in a linear fashion. But when the peak normal load was applied statically to the torque assembly, the deflection of the ultraviolet recorder did not achieve a unique value for a specific applied torque. In other words, when a specific torque was applied the recorder gave a specific deflection. However, if the torque was increased and then allowed to return to its previous value, the deflection remained at a higher value than previously. The same "hysteresis" effect ocurred when the specific applied torque was momentarily decreased. One explanation for this behaviour is illustrated in Figure 4.5.1. Bending of the screw which was inserted into the Kistler force transducer may have interfered with the force applied to the transducer. Loosening or tightening the locking nut shown in Figure 4.5.1 did not solve the hysteresis problem. However, the normal load



Figure 4.5.1: A possible explanation for the hysteresis observed when calibrating the transducer in the configuration used by O'Kelly (1977).

became significantly coupled with the measured force at the Kistler transducer if the locking nut was not tightened to a specific and critical tension. As a result of these difficulties, the Kistler force transducer was moved from under the torque assembly to the position shown in Figure 4.3.2. The transducer was placed 0.210 m from the centre of rotation. In this position, most of the normal load was carried by the hydrostatic bearings.

A second major problem was encountered with pump vibration. The oil used in the hydraulic pump and supplied to the hydrostatic bearings had a viscosity of about 0.07 Pa.s. At the pressures and flow rates required to support the torque assembly, vibrations from the pump produced significant noise in the Kistler force transducer measurements. The vibrations were reduced by placing the pump on a styro-foam pad, interposing rubber pads where the hydraulic lines touched the simulator frame and replacing a section of the hydraulic line with a reinforced flexible tube. In addition, an oil with a viscosity of 2 Pa.s was used in the pump. The new oil was particularly effective in reducing the vibrations.

The Kistler force transducer was calibrated by applying known torques in both the clockwise and counter-clockwise direction when both swing phase and peak loading was statically imposed. All the results were included as input to the least square computer program listed in Appendix C. The resulting calibration curve is shown in Figure 4.5.2. The scatter in the data used for calibration was mainly a consequence of a rapid drift in the output from the charge amplifier.

In the experiments of O'Kelly (1977) the simulator was used on hip joints. Since the hip was believed to articulate with a



T (Torque in N m)

fixed centre of rotation for the applied displacements, the torques measured by the Kistler force transducer were divided by the joint radius to yield the friction force between the cartilage surfaces. However, the ankle has been described by many investigators (Sammarco et al, 1973; Ambrosia et al, 1976: Parlasca et al, 1979; Rastegar et al, 1980) as having a changing axis of rotation. Unfortunately, the simulator oscillates about a fixed centre. The range of motion in the present experiments was thus reduced to about half that measured for the natural ankle during walking. However, it was felt that the assumption of a fixed centre of rotation could not be made.

An analysis of the forces acting on the torque assembly was carried out to determine the influence that a changing centre of rotation would have on the measured torques. If surface deformation is neglected the contact between the talus and tibia can be considered to occur along a single line which is represented as a point C_A in Figure 4.5.3. The motion of the simulator occurred about a fixed centre (C), with a particular angular velocity (ω) at a given instant in time. A radius of curvature (r_1) of the anterior portion of the talus, with a specified centre (C_1) was used to represent the talus surface as shown in Figure 4.5.3. However, the radius of curvature, r_1 , changed to r_3 for the posterior surface of the talus as described qualitatively in Chapter 3. In this analysis the radius of curvature of the tibia surface (r_2) remained fixed with centre (C_2) which differed from the fixed centre of oscillation of the simulator.

The action of the load (F) and friction force (F_f) acting on the tibia at C_A is shown in Figure 4.5.4.



Figure 4.5.3 : The surface interaction of talus and tibia.



(a) Action of the load (F).



(b) Action of friction force (F_f) .

Figure 4.5.4 : The contact forces on the tibia.

Assuming the coefficient of friction between the cartilage surfaces was low, the load acted along the line connecting C_1 , C_2 and C_A . This gave rise to the specification of an angle, α , and distance, d_N , in the analysis of the load action. The friction force was assumed to act on the tibia in the direction of motion. Thus, since C_1 , C_2 and C were designated as distinct points, a second angle, β , was associated with the action of the friction force.

The torque assembly with associated forces, angles and distances is shown in Figure 4.5.5. The Kistler force transducer was represented as a simple pinned support and the hydrostatic bearings were represented as simple rollers. It was assumed that the forces imposed in the x-direction were resisted by the Kistler force transducer connection (F_{TX}) and that the pressure in the hydrostatic bearings may be represented by a single vertical force (F_{BZ}) acting through the centre (C). The Kistler force transducer measured the force, F_{TT} , shown in Figure 4.5.5.

Summing the forces on the torque transducer shown in Figures 4.5.4 and 4.5.5 yielded:

$$F \tan \alpha + F_{f} \cos \beta + F_{TX} = 0 \qquad (4.5.1)$$

and $-F + F_f \sin\beta + F_{BZ} + F_{TZ} = 0$ (4.5.2) in the X and Z directions respectively. Summing the moments about point C yielded:

$$-\frac{Fd_{N}}{\cos \alpha} + F_{f}r_{M} + F_{TZ}d_{T} = 0$$
 (4.5.3)

Since the torque assembly was constrained by the hydrostatic bearings and the Kistler force transducer, dynamic effects were deemed negligible.



Figure 4.5.5 : The forces on the torque assembly.

It was considered likely that F_f sin β and F_{TZ} would be small compared to F and this allowed equation (4.5.2) to become,

 $F_{BZ} \cong F$ However, the terms in equation (4.5.1) and (4.5.3) were of similar magnitude and further reduction was difficult. The values of d_T , F, r_M and F_{TZ} were known in the present experimental design but α , β , F_f , F_{TX} and d_N remained unknown with only equations (4.5.1) and (4.5.3) linking them together. The system was statically indeterminate and thus required further measured values to provide an evaluation of the friction force acting at the cartilage surfaces.

To accomplish this a static loading procedure was included in the experimental design. It was decided to move the upper loading assembly by hand to an equally spaced number of positions in its displacement cycle and to apply the load corresponding to that position. The loads were applied statically, the upper loading assembly being held in position by the pinion gear whilst the lower loading assembly was constrained to have only vertical motion by the eight linear bearings. Thus, it was assumed that equation (4.5.3) applied to this situation with $F_f = 0$. In other words, the following equation described the static loading situation:

$$\frac{Fd_{N}}{\cos \alpha} = T_{s}$$
(4.5.5)

where $T_s = F_{TZ}d_T$ for the static loading conditions. The values of the static torque (T_s) were measured at a number of points in the cycle and since the corresponding dynamic torque ($T_D = F_{TZ} d_T$) was known at each particular point, equation (4.5.3) could be used to yield:

 $T_{f} = T_{S} - T_{D}$ where $T_{f} = F_{f} r_{M}$ (4.5.6)

The static loading procedure was accomplished by turning the cam shaft to the appropriate position using a spanner. The positions were identified by markings on the belt drive wheel which had been made with reference to a known position in the simulator cycle. The load which the cam applied statically through the hydraulic circuit was different from the dynamic load as described in Appendix D. However, a calibration procedure was performed using the special force transducer described in Section 4.4. The driving circuit pressure was altered using the hand pump shown in Figure D.1, until the oscilloscope voltage attained the value which corresponded to the dynamic load for that position in the cycle. The least squares computer program in Appendix C was used to yield the calibration curve shown in Figure 4.5.6.

When an ankle joint specimen was used in the simulator, the dynamic torques were recorded with the Kistler force transducer. The static loading procedure was then performed. Once the appropriate pressure existed in the driving circuit, the upper loading assembly was raised manually with a lever and allowed to sink back into contact with the torque assembly. This was intended to introduce a squeeze film between the surfaces so that excessive static friction did not occur between the cartilage surfaces as the loading assembly settled into position. The tendency of the loading assembly to shift laterally was prevented by the pinion gear and the eight linear bearings. Thus, static friction forces which would require the possibility of lateral
Figure 4.5.6 : Calibration curve for the static loading procedure.



motion were not considered likely to exist and the raising and lowering of the loading assembly was probably not necessary.

In the derivation of equations (4.5.1), (4.5.2) and (4.5.3)it was stated that dynamic effects were negligible since the torque assembly was held in place by the hydrostatic bearings and the connection to the Kistler force transducer. However, during the loading cycle a slight deflection of the hydrostatic bearings occurred in the z-direction. It was considered possible that small shock loads might be recorded by the Kistler force trans-If so, friction forces which did not exist would be ducer. predicted by equation (4.5.6.) To test this hypothesis, spacers were inserted in place of a joint specimen and the pinion gear was detached so that no oscillation occurred. Care was taken to ensure that the load line passed through the line connecting both the hydrostatic and the rolling element bearing centres. One of the spacers was made of rubber (3.5 mm thick having an elastic modulus of about 25 MPa) to approximate the compliance of the ankle joint specimens. With this test configuration, the Kistler force transducer was loaded as if a partially aligned ankle was oscillating in the simulator with zero friction between the cartilage surfaces. Both static and dynamic measurements of torque were performed as shown in Figure 4.5.7. The small recorded torque indicated that deflection of the hydrostatic bearing had occurred. The differences between static and dynamic torques shown in Figure 4.5.7 indicated that some shock loading might have occurred. However, these differences were well within the precision of the measuring procedures. For the torque values, errors up to 0.1 Nm were possible as indicated by the standard



Figure 4.5.7 : Torque imposed on the torque assembly by the Kistler force transducer during static and dynamic application of load with spacers replacing the ankle specimen and without oscillation of the upper loading assembly. (The axes scales were chosen for easy comparison with subsequent plots).

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error quoted in Figure 4.5.2. In addition, inaccuracy in specifying the imposed loads occurred in both static and dynamic procedures.

Larger differences of about 0.4 Nm were recorded between the static and dynamic torques when the rubber spacer was replaced by a steel one. Therefore, the stiffness of the specimen appeared to increase the shock loading on the Kistler force transducer. However, the ankle specimens were probably closer in compliance to the configuration which included the rubber spacer.

4.6 Mounting of the Joints

A total of five joints were mounted in the ankle simulator. These joints have been described in Chapter 3 and they were included in the measurements of surface radii of curvature. The tubular sleeves used to hold the joint components (shown in Figure 3.3.2) were themselves used in mounting fixtures to place the specimens in the simulator.

Joints numbers II and III were mounted and used to develop the experimental technique. The complete mounting procedure was applied to joints number 1, 2 and 3. The joint components were initially fixed in plaster of Paris using the procedure described in Section 3.3. The surface profiles had been measured and the radius of curvature of the closest profiles to both medial and lateral sides of the talus had been calculated as described in Section 3.5. Dividers were used to enable the approximate centres of the arcs representing the surfaces to be marked on the tubular sleeve containing the talus for both the medial and lateral sides. The sleeves containing the talus was then inserted into the mounting fixture shown schematically in Figure 4.6.1.



Figure 4.6.1 : Schematic of the talus fixture.

The mounting fixture could displace and rotate the sleeve which held the talus since its various connecting screws were located in slots.

The tibia and talus with some of their mounting fixtures are shown in Figure 4.6.2.

The mounting of the tube containing the tibia involved the three levelling screws shown in Figure 4.6.2 and two clamps which held the rim of the tube onto the torque assembly. A schematic representation of this mounting fixture is shown in Figure 4.6.3. The talus mounting fixture was simply attached with four screws to the top of the upper loading assembly. A mounted ankle specimen is shown in Figure 4.6.4. Aligning pins were attached to the inside of the torque assembly as shown in Figure 4.6.4.

Gauge blocks were placed under the base of the loading assembly so that the centres of the rolling element bearings and the hydrostatic bearings were aligned. The joint components and mounting fixtures were placed into the simulator. The talus mounting fixture was fastened to the upper loading assembly but the tubular sleeve which held the talus remained loose. The sleeve was then positioned by hand until the aligning pins touched the marked centres mentioned previously. The six screws in the talus fixture which held the talus sleeve were carefully tightened. Since these screws were position on two horizontal planes, the sleeve could be tilted from the vertical, if required. The tubular sleeve containing the tibia was then raised using the levelling screws until it made nominal contact with the talus. Once again the tibia could be tilted slightly by setting each levelling screw at a different height. Once in position the tibia sleeve was clamped to the torque assembly.

Figure 4.6.2 : The tibia and talus with some of their mounting fixtures.

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Figure 4.6.4 : A mounted ankle specimen.

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Having completed a trial mounting of the ankle specimen, the various screws were tightened and a low load applied. With the pinion gear detached, it was possible to oscillate the upper loading assembly by hand. In general, the joint seized up at some point in the oscillation. If this occurred various small adjustments were made to the position until the torque imposed during the oscillation by hand was small. Trials under full load were then conducted with the pinion gear in place. Again adjustments were made until the measured torque was minimized. It was also important to keep the tibia located in the centre of the talus with respect to the anterior-posterior dimensions of the contact region. The mounting procedure could take from half an hour to four hours depending on the conformity of the particular joint specimen.

The complexity of the mounting procedure meant that a minimum of two days was required to test a particular ankle joint. On the first day the specimen which had been thawed out overnight, was dissected, fixed in the tubular sleeves and measured using the Talycontor instrument as described in Chapter 3. The joint components were then stored overnight in a refrigerator while keeping the surfaces soaked in saline. The mounting and friction experiments were performed on the second day.

4.7 General Experimental Procedure :

Certain general procedures adopted in the operation of the simulator must be considered in addition to the detailed factors described earlier.

The minimum driving pressure (p_M) had to be set prior to each test session. This involved inserting the special force transducer,

disconnecting the pinion gear and running the simulator for about ten minutes. The minimum driving pressure was then adjusted until the peak load specified for the friction experiments was attained. If the simulator was used continuously, the load pattern remained stable. However, if the simulator was left for about twenty minutes, the load had to be re-checked. Also, if the static loading procedure was introduced the minimum driving pressure had to be set again.

In general, the torque changed little when the simulator was running with an ankle joint in place. However, the torque values recorded in the present study were all obtained after about three minutes of running at the specified conditions. This helped to avoid the possibility of friction transients (Linn, 1967) which would have influenced the measured torque.

Two lubricants were used in all the experiments. Initially, saline solution (0.9% NaCl) was used with a cycle period of 1.0 s. Next, bovine synovial fluid replaced all the saline and was allowed to soak the surfaces for a minimum of about twenty minutes.

The ankle joint simulator and associated instrumentation are shown in Figure 4.7.1. Some of the equipment mentioned in previous sections is also visible.

4.8 Results of a Preliminary Study with Ankle Joint I:

When the cam had been fabricated and the limit switch installed, joint number I was tested in the simulator. The joint fixtures had been fabricated but only three screws existed in the talus fixture for gripping the talus holder and the alignment pins had not been constructed. The friction experiment with joint number I had a torque measuring system similar to that used by



Figure 4.7.1 : The ankle joint simulator and associated instrumentation





in the transducer

O'Kelly (1977) and it is possible that hysteresis might have affected the measured torque at high loads. Also, for this experiment, the oil flow rate to the hydrostatic bearings was reduced because of vibration from the pump which seriously distorted the measured torques. As a result, contact may have occurred in the hydrostatic bearings leading to the recording of reduced torques. In addition, the static loading procedure described in Section 4.6 was not applied in this experiment.

Despite the many limitations, the results of the friction experiment on joint number I have been included in this thesis. However, since it was considered a preliminary study its main purpose was to guide the development of the more elaborate procedures for testing further joints such as those numbered 2 and 3.

The dynamic torque was measured as shown in Figure 4.8.1. Small changes appeared in the torque curve when saline was used as a lubricant instead of bovine synovial fluid and when the period of the cycle (t_p) was altered. Also, the position of the joint was adjusted in an attempt to improve the alignment. This caused a change in the shape of the torque curve as well as increases in the magnitude of the torque shown in Figure 4.8.1.

It was not possible to locate the point of zero torque in Figure 4.8.1 since the Kistler force transducer output drifted significantly in about 60 seconds. This problem was solved in the investigations of O'Kelly (1977) and Linn (1967) by applying the same load pattern for clockwise and counter-clockwise rotation. The zero point was then located by a "folding" method. However, in the present experiment, in which an attempt was made to simulate swing phase loading, this technique could not be applied.



After the dynamic torques had been measured, a constant load was applied and the static torques measured at various positions in the cycle. This was an earlier version of the static loading procedures described in Section 4.6. Since the load was not constant, the static torques could not be compared directly with the correponding dynamic values. However, significant static torque values were recorded and it became clear that the dynamic torque values alone could not be used directly to determine friction in the ankle joint.

4.9 Results for Ankle Joints 2 and 3:

The full experimental procedure was employed in testing ankle joints 2 and 3. The dynamic torque was measured as outlined in Figure 4.9.1 and 4.9.2. The torque curves for different cycle periods and lubricants were identical. However, the range of torques recorded for joint 2 was much smaller than that for joint 3.

The dynamic torque curves are also shown in Figures 4.9.3 and 4.9.4 along with the static torque values. The zero positions for the dynamic torque curves were established by using the static torque values which had accurate zero values. Considering Figure 4.5.5 and equation (4.5.6), it was noted that for the frictional torque (T_f) to oppose the motion, the static torque (T_S) must have exceeded the dynamic torque (T_D) for 0.25 < t/t_p < 0.75. For all other portions in the cycle T_D > T_S . Thus, during the swing phase the dynamic torque T_D had a magnitude which was less than T_S until $t/t_p = 0.75$ and then greater than T_S for the remainder of the cycle. The dynamic torque curve was relocated until it satisfied this



Figure 4.9.1 : Measured torque (T) versus dimensionless time (t/t_p) for joint number 2.

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Figure 4.9.4 : Torque imposed on the torque assembly by the Kistler force transducer during static and dynamic application of load for joint number 3. If a frictional torque (T_f) existed, the $T_f = T_S - T_D$. To oppose the sliding motion i) $T_f < 0$ for $0 < \frac{t}{t_p} < 0.25$ and $0.75 < \frac{t}{t_p} < 1.0$. ii) $T_f > 0$ for $0.25 < \frac{t}{t_p} < 0.75$.

criterion as closely as possible and by this means the commom zero for dynamic and static torque curves were established. This procedure produced good agreement between static and dynamic torque throughout the cycle as shown in Figure 4.9.3 and 4.9.4. This clearly suggested that frictional torques were small compared with the torques arising from the alignment of the joint specimen.

4.10 Discussion of the Results:

The present study was intended to follow and extend the work of O'Kelly (1977). The magnitude of load and velocity applied in the present study to human ankle joint specimens were similar to those applied by O'Kelly and the resulting measured torques were also about the same. However, the present study did not yield the variation of friction between the cartilage surfaces throughout the applied cycle observed by O'Kelly.

The measured dynamic torque curves shown in Figures 4.8.1, 4.9.1 and 4.92 all exhibited a striking similarity to the loading curves. The effect of load on the Kistler force transducer measurements was small when the load axis was aligned as shown in Figure 4.5.7. Thus, it appeared that misalignment of the joint components had occurred in the cycle. The mounting procedure could not eliminate this misalignment. This suggested that the centre of rotation moved during the oscillation. This view was supported by the higher torque values measured for joint 3 compared with joint number 2. In Chapter 3, much poorer conformity of the surfaces of joint 3 (R = 0.19 m) were recorded. On the other hand joint 2 had excellent conformity (R = 1.00 m).

The measured torques changed when the position of the joint components was altered by a small amount as illustrated in Figure 4.8.1. Thus, the torque measurements from the present study were not unique for a particular ankle joint specimen.

When the accuracy of the measuring system was considered, it was clear that no significant differences existed between the static and dynamic torque measurements recorded in Figures 4.9.3 and 4.9.4. The rather large apparent difference between peak static and dynamic torque shown in Figure 4.9.4 was believed to result from setting the centre of rotation of the upper loading assembly lower than its position during the setting of the minimum driving pressure. This would have caused lower applied loads as discussed in Section 4.4 and thus lower dynamic torques.

By carefully considering Figures 4.9.3 and 4.9.4 it was possible to select maximum possible friction coefficients which applied to both the peak and the swing phase load regions. Friction coefficients of up to 0.01 would have remained undetected due to the difficulties in measurement associated with the present experiments. Friction coefficient of this magnitude have been recorded for the cartilage surfaces of synovial joints in many previous investigations as discussed in Section 4.2.

4.11 Concluding Remarks:

The experimental procedures outlined earlier were not capable of detecting and recording the low coefficients of friction for cartilage surfaces from human ankle joint specimens. It can, however, be stated that friction coefficients lower than about 0.01 must have occurred. The present study did show the difficulties involved in testing a joint with a changing centre of rotation in a simulator of the present form. Obviously, a much more sophisticated machine is required to overcome this limitation.

The load, velocity and angular displacement of the ankle joint have been described in this chapter. These conditions will be applied in subsequent theoretical studies. Both the present experimental situation and conditions similar to those occurring in the ankle during walking will be modelled.

CHAPTER 5

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THEORETICAL MODEL FOR ANKLE JOINT LUBRICATION

5.1 INTRODUCTION

A number of different approaches have been employed in theoretical studies of synovial joint lubrication. Each of these approaches makes an initial assumption concerning the lubrication of synovial joints in vivo. In some investigations boundary lubrication was assumed to occur (Radin and Paul, 1972). ln. others it was assumed that the surface asperities of cartilage were in close proximity, and this formed the basis of both the weeping (McCutchen, 1978) and boosted (Dowson et al, 1970) lubrication theories as discussed in Section 2.4. The concepts of boosted and weeping lubrication were extended in elaborate studies of the flow of the interstitial fluid within and across the surface of cartilage (Torzilli, 1976). However, if full fluid film lubrication exists in synovial joints in vivo, the models involving close proximity of the cartilage asperities may not apply.

Human synovial joints have compliant surface layers (cartilage) on a relatively rigid backing (subchondral bone). The convergingdiverging surface geometry and oscillating motion are capable of entraining the surrounding lubricant (synovial fluid). lt is known that bearings with these characteristics can generate self-acting fluid films (Tanner, 1966; Dowson, 1967; Bennett and Higginson, 1970). In assessing the mode of lubrication in a bearing it is customary to assume that fluid film lubrication occurs and then to compare the predicted film thickness generated between smooth surfaces with the composite surface roughness of the bearing surfaces. If the calculated film thickness is large enough to separate the surface asperities, full fluid film lubrication can be anticipated. Elastohydrodynamic lubrication occurs when

the film pressures are sufficient to deform the compliant surfaces, as described in Section 2.4.

A considerable simplification of the analysis occurs if it is assumed that the cartilage can be treated as a simple elastic material. Studies of the properties of cartilage have shown that it behaves essentially like an elastic solid when subject to cyclic loading patterns (Johnson et al, 1977; Higginson and Snaith, 1978). Investigation of squeeze film lubrication for a bearing which modelled the synovial joint and included porous elastic surfaces, indicated that the porosity had a small effect on full fluid film lubrication (Higginson and Norman, 1974a).

Thus the theoretical model developed in this thesis considers the cartilage to be an elastic surface layer exhibiting convergingdiverging surfaces. The entraining action of such a bearing lubricated by a fluid lubricant was then considered and the details of the model were based on the human ankle. A representative geometry was obtained as outlined in Chapter 3, along with load and velocity conditions for walking similar to those described in Chapter 4. The cartilage surfaces were assumed to be perfectly smooth and to be held apart by synovial fluid. A similar approach was used by Higginson (1978), Rybicki et al (1979) and Dowson (1980).

The predicted fluid film thicknesses will be compared with the surface roughnesses for cartilage quoted by Clarke (1979) and Sayles et al (1979). If the estimated film thicknesses are much smaller than the heights of the surface asperities, other lubrication mechanisms must also act. In this case, the present theoretical model would identify imposed conditions contributing

to the breakdown of full fluid film lubrication. However, if the predicted fluid film thicknesses exceed the heights of the surface asperities, the present theroretical model may provide a detailed description of the lubrication mechanics of the human ankle during walking.

5.2 An Equivalent Bearing for the Ankle

In Figure 3.7.1 a partial journal bearing with compliant surface layers was used to represent the geometry of the ankle joint. The theoretical modelling required a further geometrical transformation to an equivalent bearing. This facilitated the application of a standard form of the Reynolds equation and allowed comparison with the theory developed by other investigators. The equivalent bearing is shown in Figure 5.2.1 and the following standard, reduced form of the Reynolds equation was adopted.



Figure 5.2.1 : An equivalent bearing for the ankle.

$$\frac{\partial}{\partial x} \left(h^3 \frac{\partial p}{\partial x} \right) = 12\eta \left(u \frac{\partial h}{\partial x} + \frac{\partial h}{\partial t} \right)$$
(5.2.1)

The entrainment velocity $u = \frac{U_1 + U_2}{2}$ where U_1 and U_2 are the surface velocities of the bearing, and in the present case $u = \frac{U_1}{2}$. The derivation of the Reynolds equation in this form required the following assumptions:

- i) The fluid was Newtonian.
- The flow was laminar and inertial forces could be neglected.
- iii) Body forces (e.g. gravity) were negligible.
 - iv) The film thickness (h) was small compared to the radii of curvature of the surfaces and the contact dimensions.
 - v) The lubricant was incompressible.
 - vi) There was negligible variation in pressure (p) and viscosity (n) through the thickness of the film.
- vii) There was no slip at the surface-fluid interface.
- viii) The lubricant flow occurred in the x-direction only (i.e. the equivalent bearing was infinitely wide).
 - ix) The surfaces were impermeable and thus only the entrainment velocity (u) could draw lubricant into the contact.

x) The surfaces did not stretch in the x-direction.

The assumption of a Newtonian lubricant can often be relaxed in lubrication theory while still using equation (5.2.1). However, in the present analysis the lubricant was assumed Newtonian in spite of contrary finding at low shear rates by investigators such as Cooke et al (1974).

The results of Cooke et al indicated that the assumption was reasonably accurate for shear rates greater than 10^3 1/s.

The assumption that lubricant flow took place only in the x-direction was particularly important in the theoretical analysis, since it simplified the entire solution. It was supported by the possible sealing effects of the contact in the medial and lateral malleoli regions of the ankle joint. Greenwald et al (1976) reported that contact initiated in these regions as static loading was increased from zero. However, if the length of the contact was long compared to the width and the side regions were not sealed, the possibility of significant side leakage and thus two dimensional flow existed (Dowson and Whomes, 1967; Roberts and Swales, 1969). In any case, it was anticipated that the assumption of one dimensional flow would yield film thickness predictions which would give a good indication of the potential of fluid-film lubrication in the ankle joint. If the present analysis does not yield encouraging values of film thickness from the point of view of fluid-film lubrication, consideration of side-leakage will lead to less optimistic predictions.

The assumption of impermeable surfaces was discussed in Section 5.1, and the assumption of the lack of surface stretching has been supported by Linn (1967), He estimated that shearing of the cartilage surfaces in canine ankles was too small to stretch the surfaces enough to enhance fluid film lubrication.

5.3 Values of the Governing Parameters:

Two sets of values of the governing parameters were considered for the equivalent bearing shown in Figure 5.2.1. The first set, designated case A, was chosen to represent the ankle during the friction experiments. The second set, designated case B, was chosen to represent the ankle in vivo during walking. The sensitivity of calculated film thickness and coefficient of friction to variations in the chosen parameters will be considered in Chapter 8. Cases A and B will be used as basic reference conditions throughout the remainder of this thesis.

A reduced radius of curvature (R) of 0.35 m was chosen and calculated using the average values for talus and tibia radii of curvature listed in Table 3.7.2. This value was used in both cases A and B. The calculation of a reduced radius of curvature for the equivalent cylindrical geometry was described by Dowson and Higginson (1966). It was noted that errors in geometric equivalence occurred when the contact length approached the individual component radii. This condition was possible for the ankle geometry if contact existed over the entire tibia as shown in However, it should be noted that the selected Figure 3.7.1. component radii for the ankle were themselves approximations. Furthermore, it has been suggested by Dowson and Higginson (1966) that the effect on estimated film thickness of errors caused by the reduced radius approximation is often guite small. Thus, the value for reduced radius of curvature of 0.35 m was used throughout the analysis, although alternative values can readily be introduced.

The x-axis for the equivalent bearing shown in Figure 5.2.1 was a geometric transformation of the curved surface of the tibia. Thus, the bearing length (2b) must follow the arc of the tibia profile. A value for b of 15.2 mm was calculated using the average length of the tibia listed in Table 3.7.2. This value was used in both cases A and B.

The thicknesses (d) of the elastic layer for the equivalent bearing was chosen as 2.4 mm by summing the average cartilage thicknesses listed in Table 3.7.2. The validity of simply adding the two cartilage layers will be discussed further in Chapter 7. This value was also used in both cases A and B.

The entrainment velocity, \mathbf{u} , for case A was chosen for a period, t_p , of 1 s. Since only the tibia moved in the friction experiments the entrainment velocity was half the surface velocity. Using the average talus radius listed in Table 3.7.2 and equation (4.4.1) the following expression was derived for entrainment velocity;

 $u = 10.3 |\cos 6.28 t| (mm/s)$ (5.3.1)The entrainment velocity was always positive because the direction from which fluid was entrained did not matter to the theoretical For case B, a somewhat higher entrainment velocity formulation. was derived for the ankle joint during walking. Both Stauffer et al (1977) and Murray et al (1964) recorded relative angular displacemnt when both surfaces of the ankle were moving. From these measurements relative surface velocities were estimated as shown in Figure 4.4.4. Unfortunately, the entrainment velocity could not be determined from relative velocity unless one surface was stationary. Thus, without a better alternative, it seemed logical to assume that for case B one surface remained stationary while the other had a velocity with the same functional form as that used in the friction experiment. The entrainment velocity for case B was again half the velocity of the moving surface. Returning to Figure 4.4.4 the chosen entrainment velocity was;

 $u = 30.0 | \cos 6.28 t | (mm/s)$ (5.3.2) which acted over a period of 1s.

The loading cycle applied in the friction experiments is shown in Figure 4.4.2. The load pattern only approximated that predicted during walking as discussed in Section 4.4. However, the proportion of the load which would be transmitted by the talus-fibula contact was not known with certainty. Thus, for both cases A and B the load per unit width (F') was calculated by dividing the load applied by the simulator by the average ankle width of 25 mm shown in Table 3.7.2. The values for the chosen load per unit width are listed in Table 5.3.1 for a cycle period (t_p) of ls.

The lubricant viscosity chosen for case A was $5 \times 10^{-3} \text{ Ns/m}^2$ which corresponded to that found by Cooke et al (1978) for bovine synovial fluid. The shear rate for this value of viscosity was 10^3 1/s. However, the shear thinning found by Cooke et al had a decreasing rate and thus the chosen constant value should be a reasonable approximation when higher shear rates exist. For case B, a viscosity of $1 \times 10^{-2} \text{ Ns/m}^2$ was chosen which corresponded to that found by Cooke et al (1978) for human synovial fluid at a shear rate of 10^3 1/s.

The selection of higher viscosity values for synovial fluid will be discussed in the subsequent chapters of this thesis.

The selection of the elastic modulus (E) for the equivalent bearing shown in Figure 5.2.1 required careful consideration. The characterization of cartilage as a linear elastic material at a given creep strain was accomplished by Johnson et al (1977) and Higginson and Snaith (1979). Thus, if the creep of a synovial joint during walking was known and remained reasonably constant, it would be possible to specify the effective elastic modulus.

t _p (s)	Load (kN)	F' (load per unit width kN/m)
0	0.392	15.08
0.05	0.561	21.58
0.1	0.798	30.69
0.15	1.061	40.81
0.2	1.203	46.27
0.25	1.541	59.27
0.3	1.939	74.58
0.35	2.277	87.58
0.4	2.155	82.88
0.45	1.628	62.62
0.5	1.169	44.96
0.55	0.777	29.88
0.6	0.325	12.50
0.65	0.25 0	9.62
0.7	0.19 0	7.31
0.75	0.19 0	7.31
0.8	0.244	9.38
0.85	0.190	7.31
0.9	0.291	11.19
0.95	0.325	12.50
1.0	0.392	15.08

Table 5.3.1 : The loads and loads per unit width (F') for both cases A and B.

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However, Johnson et al tested small cartilage specimens in unconfined compression with a non-porous platen pushing on the cartilage surface. They recorded elastic moduli for cartilage in the range 10 - 20 MN/m² for creep strains up to 0.3. On the other hand, Higginson and Snaith tested small cartilage specimens in confined compression with a porous platen pushing on the cartilage surface. They recorded much higher elastic moduli in the range 50 - 150 MN/m² for creep strains up to 0.3.

It was necessary to decide which values to use in the present analysis for a whole joint surface. Freeman et al (1975) applied cyclic loading (46 - 2237 N at 0.33 Hz) to entire hip joint specimens After 2000 cycles creep strains were about 0.16 and values of the average stress divided by the strain occurring in one cycle gave an elastic modulus of about 10 MN/m^2 . Thus, a representative elastic modulus of 16 MN/m^2 was chosen for both cases A and B.

Finally it was necessary to select a value of Poisson's ratio, (v), for the equivalent bearing. Estimates of Poisson's ratio in compression have been made by a number of investigators as shown in Table 5.3.2. It was convenient for modelling purposes to select a value of 0.5 for both cases A and B. However, theoretical calculations will also be performed for a Poisson's ratio of 0.4 in Chapter 7 to enable an estimate to be made of the significance of this parameter.

Investigator	Year	<u>v (Poisson's ratio)</u>
Hayes and Mockros	1971	0.37 - 0.42
Hori and Mockros	1976	0.44 - 0.49
Johnson et al	1977	0.50

Table 5.3.2 : Estimates for Poisson's ratio in compression.

5.4 The Selection of Dimensionless Groups:

The following dimensionless groups were selected for the theoretical analysis:

 $H = \frac{h}{R}$, μ , $H_0 = \frac{h_0}{R}$, $P = \frac{P}{E^T}$ $T = \frac{t}{t_D}$, $X = \frac{x}{r}$ $U = \frac{\pi u_A}{F^{\dagger}R} \quad W = \frac{F_A}{F^{\dagger}R} \quad S = \frac{E^{\dagger}t}{\pi}$ $D = \frac{d}{R}$ $B = \frac{b}{R}$ vh = film thickness where R = reduced radius of curvature μ = coefficient of friction h_o = minimum film thickness at a particular instant in time t = time t_{p} = period for cyclic loads and velocities x = spacial co-ordinate η = dynamic viscosity u_{Δ} = time averaged entrainment velocity for one cycle $E' = \frac{2E}{1 - v^2}$ reduced modulus where E is the elastic modulus and v is Poisson's ratio, both for the layer. F_{Δ}^{I} = time averaged load per unit width for one cycle d = thickness of effective layer of elastic bearing material b = half bearing length in direction of motion v = Poisson's ratioIt was convenient to identify each dimensionless group by name and

to state whether it was a variable or a fixed parameter as shown in Table 5.4.1.

Dimensionless group	Designation		
н	Film thickness (variable)		
μ	Coefficient of friction (variable)		
н _о	Minimum film thickness (variable)		
Ρ	Pressure (variable)		
т	Time (variable)		
X	Co-ordinate in direction of surface motion (variable)		
U	Speed (fixed parameter)		
W	Load (fixed parameter)		
S	Squeeze factor (fixed parameter)		
D	Layer thickness (fixed parameter)		
В	Starvation factor (fixed parameter)		
ν	Poisson's ratio (fixed parameter)		

Table 5.4.1 : Identification of the dimensionless groups.

5.5 Concluding Remarks:

The various assumptions involved in the theoretical analysis presented in this thesis have been outlined. This included the introduction of an appropriate form of the Reynolds equation and the designation of an equivalent bearing for the ankle joint. Two main sets of conditions have been considered in this analysis of the ankle joint. They were designated as case A, representing the ankle joint in the friction experiments, and case B, representing the ankle joint in vivo during walking. The representative parameters defining conditions in each of these cases are listed in Table 5.5.1, along with the values for the dimensionless groups which had fixed values in the two cases.

Parameter	Dimension	Case A (representing the friction experiments)	Case B (representing the ankle joint in vivo during walking)
R	m	0.35	0.35
Ь	mm	15.1	15.2
d	mm	2.4	2.4
t p	S	1.0	1.0
^u A	mm/s	6.5572	19.099
F'A	kN/m	33.726	33.726
ŋ	Ns/m ²	0.005	0.01
E'	MN/m ²	42.667	42.667
U	-	2.195×10 ⁻¹²	1.279×10 ⁻¹¹
W	-	2.258×10 ⁻³	2.258×10 ⁻³
S	-	8.533×10 ⁹	4.267×10 ⁹
D	-	6.857×10 ⁻³	6.857×10 ⁻³
В	-	4.343×10^{-2}	4.343×10 ⁻²
ν	-	0.5	0.5

Table 5.5.1 : Parameter values for the two basic cases (A and B) considered in subsequent analysis.

CHAPTER 6

THE PLANE INCLINED SURFACE BEARING MODEL

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6.1 INTRODUCTION

The full analysis of the lubrication of ankle joints taking account of the compliant layers of bearing material and the cyclic nature of the loads and speed is a formidable task. In the study of piston ring lubrication, equation (5.2.1) has been solved for rigid parabolic surfaces using an implicit numerical procedure (Dowson et The lubrication of the equivalent bearing shown in al. 1979). Figure 5.2.1 for conditions of constant load and velocity has been considered in a number of recent studies (Hooke and O'Donoghue, 1972; Cudworth and Higginson, 1976; Gupta, 1976; Varnum and Hooke, 1977; Cudworth, 1978). Reasonable agreement between theory and experimental results has been obtained in these studies. However, it appears that no analysis has been undertaken for the lubrication of bearings consisting of layers of compliant material on a hard backing subjected to time varying loads and velocities.

It was therefore decided to approach the problem in two ways. In the first case deformation in the cartilage was modelled by representing the bearing by a simple, rigid plane inclined surface bearing subjected to cyclic, time dependent loads and velocities. In a subsequent analysis account was taken directly of surface deformation in the compliant layer. In this chapter the first approach is considered in some detail. The different approximation of surface deformation will be adopted in Chapter 7.

6.2 Simplifying Assumptions For Surface Deformation:

A full solution procedure would have to consider the generation of thicker or thinner films of lubricant within the contact as imposed conditions changed with time. This situation has been described by Gibson et al (1972) in the study of start up friction of O-ring seals. However, their analysis was not extended to cyclic time varying conditions.

In the present analysis, the assumed plane profile was permitted to adjust itself immediately throughout the cycle to accommodate changes in load and velocity. Thus, the procedure required some estimation of the surface profiles which occurred for various conditions of steady state sliding. When the entrainment velocity was zero a condition of pure squeeze film lubrication existed. Once again a profile for pure squeeze film lubrication was required.

In the theoretical analysis of the lubrication of compliant solids under conditions of steady state sliding and pure squeezing, the surface profile has often been approximated by a plane configuration. Baglin and Archard (1972) examined a cylinder sliding under steady state conditions over a half space of low elastic They assumed a plane inclined surface profile for the modulus. Hertzian region of the contact and obtained excellent agreement with the full numerical solution of Swales et al (1972). For pure squeeze film lubrication of a cylinder approaching a compliant layer, Cudworth and Mykura (1980) also assumed a plane surface profile. The theroretical predictions for a Hertzian contact were similar to those obtained in the theoretical analysis of Herrebrugh (1970). However, the experimental results of Cudworth and Mykura showed much thicker films than predicted for both Hertzian and layered contacts.

As mentioned previously, a plane surface configuration was assumed to approximate the profiles for steady state sliding and pure squeezing. This simplifying assumption allowed the lubrication of the equivalent bearing shown in Figure 5.2.1 to be approximated by the cyclic time varying lubrication of a plane inclined surface. The length and inclination of this surface was allowed to vary throughout the cycle. This type of problem has also been solved by Ruddy et al (1979) for a piston ring with a profile which changed with time as a result of ring twist effects.

When pure squeezing motion occurred, the plane surface was assumed to extend over the dry contact zone which was calculated without including surface traction effects. The same approximation for the dimensions of the plane surface was assumed by Cudworth and Mykura (1980). The required dry contact length was obtained from the data presented by Gupta and Walowit (1974).

When a non-zero entrainment velocity occurred, a method of estimating both the length and inclination of the equivalent plane inclined surface bearing was required. This was accomplished by considering the published solutions for the steady state sliding of a cylinder on a compliant surface layer. The following formulae were developed from the results of Varnum and Hooke (1977) and of Hooke and 0'Donoghue (1972) for minimum film thickness under steady state conditions:

$$\frac{h_{o}}{R} = 1.159 \left(\frac{d}{a}\right)^{0.4875} K$$
(6.2.1)
for $\frac{a}{d} \ge 2$

$$\frac{h_{o}}{R} = 1.335 e^{-0.2396 \left(\frac{a}{d}\right)} \cdot K \qquad (6.2.2)$$
for $\frac{a}{d} < 2$

$$K = \frac{\left(\frac{2\eta u}{ER}\right)^{0.6}}{\left(\frac{F^{1}}{ER}\right)^{0.2}}$$

The half length of the dry contact (a) was again obtained from the data presented by Gupta and Walowit (1974). Equations (6.2.1) and (6.2.2) required that the pressures in the lubricant film were close to the dry contact stresses.

where

The length of the plane inclined surface was initially chosen to be equal to the length of the dry contact zone. An iterative procedure was used to select a slope which gave a steady state film thickness for the plane inclined surface bearing equal to that predicted by equation (6.2.1) or (6.2.2). The following equation was used for the steady state film thickness of the plane inclined surface:

$$\frac{F'M^2}{12\eta u} = \ln \left(1 + \frac{ML}{h_0}\right) - \frac{2ML}{2h_0 + ML}$$
(6.2.3)

where M is the slope of the plane surface and L is the length in the direction of motion. In general, such a solution could not be obtained. Thus, the plane inclined surface was extended in length until the gradient of the film pressure distribution became zero at a distance of half the dry contact length from the point of minimum film thickness. The result was a plane inclined surface bearing with a pressure distribution similar to the dry contact stress and a steady state film thickness equal to that predicted for a cylinder sliding on a compliant layer. The features of the assumed plane inclined surface are illustrated in Figure 6.2.1.

The network of simplifying assumptions which were adopted in the present study effectively reduced the procedure for allowing for the effects of surface deformation to an easily implemented iterative procedure. It was then necessary to incorporate this procedure into a solution for the cyclic time varying film thickness.



Wedging and squeezing action

Pure squeezing



6.3 Lubrication Analysis:

For the analytical formulation it was convenient to describe the geometry of the equivalent plane inclined surface bearing as shown in Figure 6.3.1.



Figure 6.3.1 : The geometry of the plane inclined surface adopted for Section 6.3 only.

For this geometry equation (5.2.1) became:

$$\frac{\partial}{\partial x} \left(h^3 \frac{\partial p}{\partial x} \right) = 12 \eta \left(\frac{\partial h}{\partial t} - u \frac{\partial h}{\partial x} \right)$$
(6.3.1)

where the entraining velocity $u = U_1/2$ in this case. The film thickness (h) for the assumed geometry of a plane inclined surface bearing is given by:

$$h = h_{c} + Mx$$
 (6.3.2)

The slope (M) of the equivalent plane inclined surface bearing was assumed to change immediately at each instant in time as discussed in Section 6.2. However, the actual bearing surface would change much more slowly. The representation of the bearing geometry by a plane inclined surface was thus expected to give a reasonable prediction of changes in minimum film thickness (h_0) without necessarily representing fully the details of film geometry. These observations were particularly important in determining an expression for squeeze film velocity.

Equation (6.3.2) implies that,

$$\frac{\partial h}{\partial t} = \frac{dh}{dt} + \frac{\partial}{\partial t} (Mx)$$

and that any location (x),

$$\frac{\partial h}{\partial t} = \frac{dh}{dt} + x \frac{dM}{dt}$$

In a full squeeze-film analysis involving changes in the film profile throughout the cycle, it would be necessary to take account of both terms on the right hand side of the equation. However, this introduces considerable complexity into the analytical formulation. Also difficulty is introduced into the numerical procedures since the current value of $\left(\frac{dM}{dt}\right)$ is not known until the solution is obtained. Furthermore, forward extrapolation for $\left(\frac{dM}{dt}\right)$ would add considerably to the numerical effort and computing time and hence it was decided to approximate the squeeze-film velocity by the following expression and to see how rapidly the film thickness changed with time in the final solutions.

$$\frac{\partial h}{\partial t} = \frac{dh_o}{dt}$$
(6.3.3)

In the event, the effect of combined entraining and squeeze-film action was found to maintain a remarkably small cyclic variation of minimum film thickness and hence it was concluded that the approximation to squeeze-film velocity represented by equation (6.3.3) would be adequate for the present purpose. The approximation of the squeeze film velocities will be discussed further in Chapter 7.

The following standard boundary conditions for a plane inclined surface bearing were applied:

Substituting equations (6.3.2) and (6.3.3) into equation (6.3.1), integrating the resulting expression twice with respect to x and applying these boundary conditions yielded the following expression for pressure distribution:

$$p = \frac{12n \times (L - x)}{(2h_{o} + ML)(h_{o} + Mx)^{2}}$$
(6.3.4)

Considering the following expression for applied load,

$$F' = \int_0^L p \, dx ,$$

equation (6.3.4) was integrated and re-arranged to give the following first order differential equation:

$$\frac{dh_{o}}{dt} = \frac{F' M^{3}}{\frac{2ML}{2h_{o} + ML} - \ln\left(1 + \frac{ML}{h_{o}}\right)} + Mu \qquad (6.3.5)$$

The adoption of equations (6.3.2) and (6.3.4) in the derivation of an expression for the coefficient of friction (μ) of a fluid film bearing yielded the following expression:

$$\mu = \frac{nu}{MF'} \left\{ 8 \ln \left(1 + \frac{ML}{h_o} \right) - \frac{12 ML}{2h_o + ML} \right\}$$
$$- \frac{n}{F'M^2} \frac{dh_o}{dt} \left\{ 6 \ln \left(1 + \frac{ML}{h_o} \right) - \frac{12 ML}{2h_o + ML} \right\}$$
(6.3.6)





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In Section 6.2, the iterative procedure for determing the slope (M) of the plane inclined surface required that;

$$\frac{\partial \rho}{\partial x} = 0$$
 at $x = a$.

Equation (6.3.4) implied that:

$$L = \frac{2h_o}{h_o - Ma}$$
(6.3.7)

6.4 The Solution Procedure:

The general form of equation (6.3.5) is as follows:

$$\frac{dh_o}{dt} = f(h_o, t)$$

Equations of this form can be solved by using standard numerical routines for first order differential equations (Hornbeck, 1975). In the present study, solutions were computed using a fourth order Runge-Kutta routine. The following entrainment velocity function was incorporated into the solution procedure;

$$u = \frac{\pi u_A}{2} \left| \cos \frac{2\pi t}{t_p} \right|$$
(6.4.1)

Values of the load per unit width (F') were required in the solution procedure and a cubic spline interpolation routine (Numerical Algorithms Group - EOIADF) was implemented to obtain values of F' at any instant. The half length (a) was also evaluated using the same interpolation routine on the data of Gupta and Walowit (1974).

The slope (M) and length (L) of the equivalent plane inclined surface were calculated at each instant in time by evaluating $\begin{pmatrix} h \\ 0 \end{pmatrix}$ using equations (6.2.1) and (6.2.2). Equation (6.3.7) was then substituted into equation (6.2.3) and a simple bisection routine was used to iterate for the value of M.

It was important to notice that h_0 in equation (6.2.3) represented a steady state value, while h_0 in equation (6.3.7) represented the value of the current time step. After M had been calculated, equation (6.3.7) was used to evaluate L. It was noted that the solution of equation (6.3.7) required a knowledge of the current value of (h_0) which itself required the value of L to be known. The previous value of (h_0) was thus adopted in the current evaluation of L.

The absolute minimum film thickness (h_0) encountered during a complete cycle was given an arbitrary value at t = 0. The Runge-Kutta routine was applied by dividing the cycle into a number of equal time steps. The solution was then marched out until corresponding values of successive cycles agreed within a specified tolerance. In this manner a steady but cyclic solution was calculated for the variation of h_0 with time. The step size was then halved and the final cycle re-calculated. If corresponding values agreed within a specified tolerance the cycle was accepted as an accurate solution for h_0 , Automatic step size halving was employed as a standard method to control round-off and truncation errors (Hornbeck, 1975).

Once the cyclic variation of minimum film thickness (h_0) had been ascertained the pressure distributions (p) and coefficients of friction (μ) were determined using equations (6.3.4), (6.3.5) and (6.3.6). When the entrainment velocity was zero, the slope (M) was zero and the length L was equal to the dry contact length (2a). Furthermore, equation (6.3.5) reduced to,

$$\frac{dh_o}{dt} = -\frac{F'h_o^3}{nL^3}$$

equation (6.3.4) reduced to,

$$p = -\frac{6 \eta x (2a - x)}{h_0^3} \frac{dh_0}{dt}$$

and finally, equation (6.3.6) indicated that

$$\mu = 0$$

The entire solution procedure is summarized by the flowchart shown in Figure 6.4.1. The procedure was implemented using the computer program listed in Appendix E.

6.5 Comparison with the Analysis of Modest and Tichy:

Modest and Tichy (1979) developed approximate closed form expressions for load capacity when sinusoidal normal motions and constant sliding velocity were imposed on a plane inclined surface bearing of infinite width. Their solution included fluid inertia effects and was restricted to normal motions which were small compared with the film thickness.

A check on the derivation of equation (6.3.5) and the magnitude of numerical errors was achieved by solving a **case** which allowed direct comparison with predictions based upon the analysis of Modest and Tichy. Fluid film thicknesses were ascertained using the solution procedure outline in the present chapter with the following imposed conditions:

$$\eta = 0.1 \text{ Pa s}$$

$$u = 0.1/\pi \text{ m/s}$$

$$F' = 318.31 (1 - 0.1 \sin(0.4 \pi t)) \text{ N/m}$$

$$L = 0.05 \text{ m}$$

$$M = 0.0002$$

$$t_{p} = 5 \text{ s}$$

From the analysis of Modest and Tichy it was clear that fluid inertia effects were negligible for this case. The solution was obtained by slightly modifying the computer program listed in Appendix E. The tolerance for convergence was set at 0.0001. The variation with dimensionless time (T) of the coefficient of friction (μ) and minimum film thickness (h_0) are shown in Figure 6.5.1 (included at the end of this chapter), along with a sample pressure distribution and the surface shape at T = 0. The load function (F'_{A}) and the velocity function (u/u_A) are also shown.

The amplitudes of the fluctuations in film thickness were obtained from the computed results. These values were used in the expressions derived by Modest and Tichy to yield:

 $F' = 318.25 (1 - 0.097 \sin(0.4 \pi t)) N/m$

This expression for load was compared to the imposed load and a maximum difference of 0.3% was calculated. This suggested that the sections of the solution procedure involving the time varying behaviour of the plane inclined surface configuration had been correctly formulated. Also for this case the numerical errors were probably small.

6.6 Comparison with the Analysis of Hirano and Murakami:

It was possible to perform a further check on the simplifying assumptions concerning surface deformation which were considered in Section 6.2. Hirano and Murakami (1975) performed a series of experiments in which a compliant Hertzian contact was subjected to cyclic, time varying entrainment velocities. The cyclic variation of the coefficient of friction was recorded as a function of time. The compliant bearing surfaces were photoelastic and thus the stress distribution within them could be monitored. Asperity contact during sliding caused asymmetry in the observed stress distribution because of the large surface tractions developed. Therefore, for each set of lubrication conditions, Hirano and Murakami were able to ascertain whether or not a fluid film separated the surfaces.

The geometry of the experimental apparatus was that of a nominal line contact, and the entrainment velocity was sinusoidal with the following general form:

$$u = \frac{u_A \pi}{2} \left| \cos \frac{2\pi t}{t_p} \right|$$
(6.6.2)

A constant load per unit width was applied.

Four cases were selected to check the solution procedure used in the present study. The details of the lubrication parameters which describe these cases are listed in Table 6.6.1 and include the composite surface roughness value (σ) of the surfaces. The value of composite surface roughness will be compared to film thickness predicted by the present solutions procedure to indicate whether fluid film lubrication was likely to have occurred. The findings of Hirano and Murakami (1975) are summarized in Table 6.6.2.

Case	R (mm)	F' (kN/m)	E (MN/m²)	v	t p (s)	uA (mm∕s)	σ (u _M)	η (N.s/m²)
1	30	20	3200	0.425	0.5	60.0	0.19	1.5
2	30	20	3200	0.425	0.5	20.0	0.19	1.8
3	30	20	3200	0.425	2.08	14.4	0.19	1.35
4	30	20	3200	0.425	0.2	15.0	0.19	1.35

Table 6.6.1 : The lubrication parameters for the cases selected from the analysis of Hirano and Murakami (1975).

Table 6.6.2 : A summary of the findings for the selected cases of Hirano and Murakami (1975).

Strok e length (mm)	Hertzian length (mm)	Asperity contact	Peak friction	Reason for film breakdown
30	1.25	No	0.0104	-
10	1.25	No	0.0079	-
30	1.25	Yes	0.033	Asperity contact
3	1.25	Yes	0.01 → .12	"Film instability"

Modifications were made to the program listed in Appendix E to allow the four cases selected from the work of Hirano and Murakami (1975) to be solved. The tolerance for convergence was set at 0.001. The formula of Swales et al (1972) was used in place of equations (6.2.1) and (6.2.2), with the recognition that it did not apply when,

$$\frac{F'}{(2 \eta u E'R)^{0.5}} < 5$$

However, it was found that this term was never less than 5 for cases 1 to 4.

The results are shown in Figure 6.6.1 (included at the end of this chapter) and include some experimental data from the work of Hirano and Murakami (1975),

Good agreement was shown between the results in Figure 6.6.1, which were calculated using the present solution procedure, and those of Hirano and Murakami. The coefficients of friction measured by Hirano and Murakami had peak values similar to those predicted by the present analysis. If fluid film breakdown was assumed to occur when the film thickness fell to about three times the composite roughness value (Johnson et al, 1972), the fluid film thickness predicted for case 3 indicated regions where asperity contact might have occurred. Case 4 was described by Hirano and Murakami as exhibiting "film instability". The similarity between the film thickness predicted by the present analysis and the measure of the composite roughness suggested that a breakdown in the lubricant film may have occurred in both cases 3 and 4. It was also noted that the peak pressures for all cases were quite close to the Hertzian maximum. This suggested that the equivalent plane inclined surface configuration adopted here gave a pressure distribution similar to that occurring under dry contact conditions.

6.7 Application to the Ankle Joint:

The solution procedure developed in this chapter was applied to the conditions described in Table 5.5.1 for cases A and B. Case A represented the ankle joint in the friction experiments described in Chapter 4 and case B represents the ankle joint in vivo during walking. The conjunction was assumed to be fully flooded for the present solution procedure.

The computer program listed in Appendix E was used with a convergence tolerance of 0.0001. The results are shown in Figure 6.7.1 (included at the end of this chapter).

In Figure 6.7.1, the inlet extent of the plane inclined surface was always less than the starvation parameter (B). Thus, the assumption of a fully flooded inlet zone was not contradicted. Starvation will be discussed further in Chapter 7.

The film thickness predicted for the ankle joint during the friction experiments were about 0.2 µm. When this value was compared with the estimated values of surface roughness (Ra) of articular cartilage 2-6 µm quoted in Chapter 2, it was deemed unlikely that continuous fluid films could be sustained. It was recognized, however, that increases in a parameter such as the reduced radius of curvature (R) might dramatically increase the predicted film thickness. This will be discussed in Chapter 8.

The conditions adopted for case B gave rise to film thickness predictions of about 0.7 μ m. This value was still much smaller than the estimated height of the surface asperities and hence boundary or perhaps mixed lubrication was considered to be likely.

A full discussion of the role of elastohydrodynamic lubrication in ankle joint lubrication will be presented in Chapter 8.

6.8 Concluding Remarks:

The equivalent bearing representing the ankle described in Chapter 5 has been analysed. A number of simplifying assumptions have been made concerning the surface deformation and in the present analysis the ankle joint was represented by a form of plane inclined slider bearing. A solution procedure was developed and implemented on the computer. The results for various cases were generated in a computing time of about 20 sec of Central Processing Unit (CPU) time. The analytical formulation has been checked directly by comparing the theoretical predictions with the results of previous investigators. It was concluded that the present analytical procedure offered a reasonable approach to the solution of a very complex situation in elastohydrodynamic lubrication with considerable uncertainty in the geometry, material properties and imposed conditions for the film conjunction. However, it was deemed to be necessary to investigate further some of the assumptions involved in the plane inclined surface model. This will be accomplished in the next chapter.

Figure 6.5.1 : Results for Comparison with the Work of Modest and Tichy.



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Figure 6.6.1 : The results from using the present solution procedure on the cases listed in Table 6.6.1 and selected from the work of Hirano and Murakami (1975).

<u></u>	3 x σ	
	Case 1	(standard conditions)
	Case 2	(low u _A)
	Case 3	(low u_A and n_s , high t_p)
	Case 4	(low u_A , t, and η)
0	Results	of Hirano and Murakami for

Results of Hirano and Murakami for Case 1
 Results of Hirano and Murakami for Case 2
 Maximum Hertzian pressure

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Figure 6.7.1 : The solution for the conditions listed in Table 5.5.1 for Cases A and B.

	Case A	(for ankle joints during friction experiments).
	Case B	(for ankle joint in vivo during walking).
•	Maximum surface	dry contact stress in the absence of tractions.



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CHAPTER 7

1 1

THE CONSTRAINED COLUMN DEFORMATION MODEL

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7.1 INTRODUCTION

The plane inclined surface bearing model showed reasonable agreement with the investigation of Hirano and Murakami (1975). However, the equivalent bearing which represented the ankle joint was subject to widely varying loads and had a totally different geometry to that considered by Hirano and Murakami. Thus, it was deemed to be necessary to examine the assumptions made in developing the plane inclined surface bearing model. In particular the following assumptions were examined:

- (i) The pressure distribution corresponded closely with the dry contact pressure which would act when surface tractions were absent.
- (ii) The inlet zone was fully flooded.
- (iii) Poisson's ratio of cartilage was chosen to be 0.5 and formulae based on the published data for elastic layers with this value for Poisson's ratio were employed.
- (iv) The cylindrical geometry of the equivalent bearing which represented the ankle joint was approximated as a plane inclined surface configuration.
 - (v) Steady state profiles were adopted at each instant in time.
 - (vi) The squeeze film velocity at all points on the bearing surface was assumed to equal the squeeze film velocity at the point of minimum film thickness.
- (vii) In Chapter 5 a single surface layer which was equal in thickness to the combined cartilage thickness was used in the equivalent bearing to represent the compliant material in the ankle joint.

The analytical complexity which led to the original formulation of the plane inclined surface bearing model prevented a rigorous examination of all these assumptions.

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The basic cylindrical geometry of the ankle joint was preserved in the lubrication analysis presented in this chapter by employing a simple deformation model. This model was first suggested by Higginson (1966) in a study of journal bearings with compliant surface layers. The deformation model considered the surface layer to act as a constrained column. In other words, deformation could only occur in a direction normal to the layer surface. When Poisson's ratio of the layer approached 0.5 the deformations predicted by this model become increasingly inaccurate.

Dowson and Taylor (1967) studied thrust bearings with compliant layers and showed that the constrained column model remained reasonably accurate for a Poisson's ratio of about 0.45. This was also found by Castelli et al (1967) in a similar study of thrust bearings.

Bennett and Higginson (1970) investigated the lubrication of a cylinder sliding on a compliant layer. The constrained column model was employed and the effectiveness of a thin compliant layer in generating lubricant films was noted. Both Dowson and Taylor (1967) and Bennet and Higginson (1970) made reference to synovial joint lubrication in their investigations.

In this chapter the constrained column model was employed with a Poisson's ratio (v) of 0.4. This value was at the low end of the range of Poisson's ratio measured for cartilage in compression as listed in Table 5.3.2.

7.2 Formulation of the Constrained Column Model:

The expression for surface deformation (δ) of a surface layer modelled as a constrained column was derived by Higginson (1966) and Dowson and Taylor (1967), and hence the derivation will not be repeated here. The following expression for surface deformation was used:

$$\delta = \frac{p \cdot d}{E} \left(1 - \frac{2v^2}{1 - v} \right)$$
(7.2.1)

The constrained column model is shown in Figure 7.2.1. It was noted that $\delta = 0$ if v = 0.5, irrespective of the applied pressure (p). However, for v < 0.5, the deflection was directly proportional to the applied pressure. Also no lateral deformation could occur and thus the deformed surface did not bulge upwards at the edges of the contact as shown in Figure 7.2.1.



Figure 7.2.1 : The constrained column deformation model.

Expressions were developed by Bental and Johnson (1968) for a cylinder with an attached elastic layer making contact with a rigid plane without generating any surface tractions. These expressions allowed the half contact length (a) and dry contact stress distribution (p_D) to be calculated and were used in the following form in the present study:

$$\frac{a}{R} = \left[1.5 \frac{d}{R} \frac{F'}{ER} \frac{(1+\nu)(1-2\nu)}{1-\nu} \right]$$
(7.2.2)



Figure 7.2.2 : Comparison of the constrained column deformation model to the full solution of Meijers (1968).

$$\frac{P_{D}}{E} = 0.5 \left(\frac{a}{d}\right) \left(\frac{a}{R}\right) \frac{(1-v)}{(1+v)(1-2v)} \left(1-\left(\frac{x}{a}\right)^{2}\right)$$
(7.2.3)

As stated previously, a Poisson's ratio of 0.4 was adopted in this chapter. The constrained column deformation model provided an approximation for the surface deformation and the accuracy of this approximation was indicated by the graph in Figure 7.2.2 which was developed by Meijers (1968) in his comprehensive study of the deformation of surface layers. The graphs shown in Figure 7.2.2 indicated that the approximation of the constrained column model for v = 0.4 was as good as that for v = 0.3 for the range of a/d in the present study and better than that for v = 0.45.

In the study of elastohydrodynamic lubrication, the following expression has been widely used for the film thickness of a cylinder on a plane configuration,

$$h = h_c + \frac{x^2}{2R} + \delta$$
 (7.2.4)

where h_ is the central film thickness excluding deformation.

For the present analysis equation (7.2.1) implied;

$$h = h_{c} + \frac{x^{2}}{2R} + \frac{p \cdot d}{E} \left(1 - \frac{2v^{2}}{1 - v} \right)$$
(7.2.5)

When the squeeze film velocity was zero, this expression was directly substituted into the Reynolds equation and the subsequent solution involved a single equation.

The conventional method of iterating between the elasticity and Reynolds equations sometimes causes numerical instability when solving for compliant materials subjected to high loads (Swales et al, 1972; Cudworth and Higginson, 1976). Recently Ruskell (1980). developed a procedure in which the elasticity equations were combined directly with the Reynolds equation. The procedure did not exhibit numerical instability for the range of values considered by Ruskell in a study of rectangular rubber seals. Thus, one advantage of adopting the constrained column model to approximate surface deformation lay in the possibility of avoiding numerical instability by solving a single equation which directly combined the elasticity and Reynolds equations.

7.3 The Dynamic Solution Procedure

The strategy for the dynamic solution procedure is outlined in this Section. As in Chapter 6 the squeeze film velocity was approximated by:

$$\frac{\partial h}{\partial t} = \frac{dh}{dt}$$

Also the surface profile at any instant in time was assumed to be that which would result if the instantaneous load and velocity were held constant. However, in the present analysis, the steady state profiles were determined by using the column deformation model and the Reynolds equation with the appropriate boundary conditions. The exact profiles, rather than a plane inclined surface approximation, were then substituted into the dynamic solution procedure.

Initial values for the dynamic routine were supplied by a variation of the plane inclined surface bearing model described in Chapter 6. This was very important since the dynamic solution procedure was very expensive in computer time and thus convergence in as few cycles as possible was desirable.

The dynamic solution procedure is shown in Figure 7.3.1. Parts 1, 2 and 3 correspond to the three main computer programs listed in Appendix F. The use of the data bank, shown in Figure 7.3.1, was particularly important. Key parameters for the steady state profiles which were computed in Part 1, were

FIGURE 7.3.1 : FLOWCHART OF THE DYNAMIC SOLUTION PROCEDURE



transferred to the dynamic solution of Part 3. The steady state profiles were then reconstructed in Part 3 and used in the solution. The uncoupling of the solutions for steady state profiles allowed more computer time to be available for the dynamic routine. A number of interpolation routines were included in the coding of Part 3 to select values at time steps for which Part 1 had not been solved. However, the dynamic solution procedure did not actually require them for the case considered in this chapter, since convergence occurred with a small number of time steps.

7.4 Implementation on the Computer:

The design of a complex numerical solution procedure was accomplished by following certain guidelines in much the same way asstrategic axioms are followed in the game of chess. lt will be shown that substituting the constrained column deformation model into the Reynolds equation yielded a first order differential equation with specified boundary conditions which could be solved for pressure. Bearing in mind that instability could occur at high loads, it was decided to use a "shooting" code instead of a finite difference solution procedure. The shooting code involved solving the specified boundary value problem as an initial value problem. Initial value routines were then used to solve the equation repeatedly as a characteristic parameter within the equation was adjusted until the boundary conditions were satisfied. In the text by Gladwell and Sayers (1980), the advantages of shooting codes were considered to include sophisticated error analysis and the availability of higher order methods. Higginson (1966) reached a similar conclusion when he used a shooting code with

a fourth order Runge-Kutta numerical routine to solve a similar equation. However, Higginson noted that numerical instability still occurred at high loads. In the present study a fourth order Runge-Kutta numerical routine was initially employed. It was found that considerable computing time and an excessive number of steps across the contact were required (up to 10,000). Also, the instability noted by Higginson occurred when single precision (7 digit) arithmetic was used.

In this situation, Hornbeck (1975) recommended that a numerical package routine be incorporated and hence the NAG (Numerical Algorithm Group -Oxford) library routines were used. The danger of introducing error at a particular time step was recognized and thus the NAG libraries were used for all the numerical integrations involved in the overall solution procedure as well as for solving the first order differential equation which arose in the solution of steady state profiles.

The rationale behind this major strategic decision was described by Shampine (1980) who wrote,

"Physical scientists are often so conscious of the defects in their crude models that they presume that crude methods will suffice for the solution of the models. Quite the contrary. Crude accuracy suffices, but the solution must be reliable. This requires very good codes because reliability is difficult to achieve at crude accuracies".

Throughout the numercial analysis in this chapter, step size halving was employed whenever the NAG library for integration (D01GAF) was used. When the routine for solving first order differential equations (D02EBF) was used the tolerance was reduced by 1/10 and the solution repeated until corresponding points agreed to a specified tolerance.

The NAG library routines employed in this chapter are listed in Figure 7.4.1. Also the interpolation routine used in Chapter 6 is included.

A Runge-Kutta-Merson routine (D02BDF) was used to ascertain whether the equation solved for the steady state profiles was stiff. It was found to be stiff, especially so near the exit boundary. A stiff equation has rapidly changing transient terms in the general solution which explode if the numerical solution strays slightly from the true solution (Hornbeck, 1975). Stiffness has been described in some detail by current texts on numerical methods (Hall and Watt, 1976; Gladwell and Sayers, 1980).

The dynamic routine used a fourth order Adams predictorcorrector pair to solve for each time step. A modifier equation was applied to the predictor equation and the corrector equation was iterated until the film thickness converged. A final evaluation of the squeeze film velocity was then obtained. This mode of operation is known as PM(EC)ⁿE where P is the predictor equation, M is the modifier equation, E is the evaluation equation, C is the corrector equation and n is the number of iterations of EC. Details of this numerical routine were described by Lambert (1973). The local truncation error was also estimated based on the P and final C values.

7.5 The Lubrication Parameters for Case C:

The full dynamic solution procedure was solved for a single case in this chapter, which was designated as case C. The parameters are listed in Table 7.5.1 and the discrete values for the applied load per unit width (F¹) are listed in Table 7.5.2. A Figure 7.4.1 Numerical Algorithm Group (NAG) library routines employed in the computer programs of this thesis

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Code	General Operation	Brief Description	
EOIADF	Interpolation	-interpolates by fitting cubic spline functions (simplified form of EO1BAF combined with EO2BBF)	
EOIBAF	Interpolation	-determines cubic spline interpolant to a given set of data	
E02BBF	Curve Fitting	-evaluates a cubic spline from its B-spline representation	
DOIGAF	Quadrature	-integrates a numerically supplied function using third-order finite difference formulae with error estimates according to method of Gill and Miller (1972)	
DO2BDF	Ordinary Differential Equations	-solves first-order ordinary differential equation using a Runge-Kutta-Merson method -a stiffness check is available	
DO2EBF	Ordinary Differential Equations	-solves a stiff first-order ordinary differential equation using a variable order, variable step Gear method and returns the solution at points specified by the user.	

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Parameter	Dimension	Case C	Case Cl
R	m	0.30	0.30
Ь	mm	16.0	16.0
d	mm	2.4	2.4
t p	S	1.0	1.0
^u A	mm/s	6.9382	6.9382
۴Å	kN/m	35.083	35.083
η	Pa.s	0.01	0.01
٤'	MPa	38.095	38.095
U	-	6.071×10 ⁻¹²	6.071×10 ⁻¹²
W	-	3.070×10 ⁻³	3.070×10 ⁻³
S	-	3.810x10 ⁹	3.810x10 ⁹
D	-	8.000×10 ⁻³	8.000×10 ⁻³
В	-	5.333×10 ⁻²	5.333×10 ⁻²
μ	-	0.4	0.5

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Cases C and Cl

t (s)	F' (kN/m)		
0	12.79		
0.05	18.94		
0.1	27.40		
0.15	37.62		
0.2	49.13		
0.25	60.64		
0.3	78.57		
0.35	93.92		
0.4	94.19		
0.45	81.13		
0.5	49.13		
0.55	35.06		
0.6	13.32		
0.65	6.91		
0.7	5.66		
0.75	4.38		
0.8	6.42		
0.85	6.42		
0.9	6.91		
0.95	9.47		
1.0	12.79		

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second set of parameters, designated as case C1, was also considered by using the program listed in Appendix E, which had been applied to generate results in Chapter 6. Case C1 had a Poisson's ratio of 0.5, but in all other respects it was identical to case C. As mentioned previously, the dynamic procedure for the constrained column model adopted a Poisson's ratio of 0.4.

The plane inclined surface bearing model was modified for the Instead of using data from the literature, case C conditions. the results from steady state solutions of the constrained column model were taken from the data bank as shown in Figure 7.3.1. In Chapter 6, the dry contact length was found to be too short to give an iterative solution for the slope (M). Thus the condition $\frac{\partial p}{\partial x} = 0$ at x = a was specified and the contact length extended maintaining this specification. However, for the constrained column model the bearing length was always long enough to achieve an iterative solution for the slope. Thus $\frac{\partial p}{\partial x} = 0$ at x = a was not imposed. This was considered a minor change in procedure. The computer program which implemented the procedure is listed in Part 2 of Appendix F.

Figure 7.5.3 (included at the end of this chapter) shows results for cases C and C1. In addition, the first four graphs include cases A and B for reference.

In Figure 7.5.3, the variation of H_0 with T for case C1 was in the same range as those for cases A and B. The coefficients of friction (μ) also showed a similar variation with time. Since the results for case C1 were in the range of those for cases A and B, it was clear that the conditions described by case C1 were not much different from those for cases A and B. As mentioned previously case C was the same as case C1 except for the Poisson ratio value. Thus, case C which will be used to generate a full dynamic solution in this chapter, imposed conditions quite similar to cases A and B.

However, case C which adopted a lower Poisson's ratio (v =0.4) than case C1 (v = 0.5) exhibited a film thickness some sixty percent larger than that predicted for case C1. This was apparently a consequence of the larger dry contact zone which occurred for case C (v = 0.4) as shown in the plots of pressure distribution in Figure 7.5.3. However, the minimum film thickness of about 0.54 µm remained much smaller than for the heights of the surface asperities of cartilage. This indicated that the selection of a Poisson's ratio in the range of 0.4 - 0.5 was unlikely to change the findings of this thesis significantly.

The results for case C provided a set of starting values for the dynamic routine as shown in Figure 7.3.1.

Generation of the Surface Profiles: 7.6

The surface profiles required at each time step were generated by performaing a solution of the combined Reynolds and elasticity equations for the constant load and entraining velocity. The co-ordinate system adopted for this analysis is shown in Figure For this situation equation (5.2.1) became: 7.6.1.

 $\frac{d}{dx} \left(h^3 \frac{dp}{dx} \right) = 12 \eta u \frac{dh}{dx}$ (7.6.1)F





Figure 7.6.1 : Geometry for steady state solution using constrained column model.

$$p = 0 at x = -b$$
 (7.6.2)

$$p = 0 at x = x_e$$
 (7.6.3)

$$\frac{dp}{dx} = 0 \quad \text{at } x = x_e \tag{7.6.4}$$

$$p > 0 \text{ for } -b < x < x_e$$
(7.6.5)

$$F' = \int_{-b}^{c} p \, dx \qquad (7.6.6)$$

When combined with equation (7.2.5) equations (7.6.1), (7.6.3)

and (7.6.4) reduced to

$$\frac{dp}{dx} = \frac{12nu \left[\frac{x^2 - xe^2}{2R} + A.p \right]}{\left[h_c + \frac{x^2}{2R} + A.p \right]^3}$$
(7.6.7)
where $A = \frac{d}{E} \left[1 - \frac{2v^2}{1 - v} \right]$

The numerical solution procedure consisted of the following five steps for a specified load (F') and velocity (u):

(i) specify
$$x_e$$

(ii) specify h_c
(iii) solve equation (7.6.7) for p
(iv) iterate until equations (7.6.2) and (7.6.5)
are satisfied.
(i.e. $p = 0$ at $x = -b$
 $p = 0$ for $-b < x < x_e$)
(v) iterate until the specified F' approximately
equals that computed from equation (7.6.6).

The initial specification for x_e and h_c were obtained from equations (6.2.1) or (6.2.2) and (7.2.4) along with an interpolation (NAG E01BAF, E02BBF) of the data from Gupta and Walowit (1974). Unfortunately, the author was initially unaware of the study by Bentall and Johnson (1968), otherwise equations (7.2.2) and (7.2.3) would have been used to specify initial values much closer to the required solution. The solution of equation (7.6.7) required the use of the Gear method for solving stiff differential equations (NAG DO2EBF) as discussed briefly in Section 7.5. This method was variable-step, variable-order and employed backward differentiation (BDF) or Adams predictor-corrector pairs, depending on local stiffness. When local stiffness was severe, as it was near $x = x_e$, the BDF formulaewere required and the Jacobian expression for equation (7.6.7) was used in a Newton iteration at each step.

The iteration for h_c was performed with a bisection routine. Coupled with the Gear method, the coding constitutes a "shooting" code for solving equation (7.6.7) subject to the conditions imposed by equations (7.6.2) and (7.6.5).

The integration of the pressure distribution was accomplished using the method of Gill and Miller (1972) (NAG DO1GAF). This method involved using four point finite difference formulae and resulted in a cubic interpolation of the integrand. An indication of the reliability of the answer was achieved by comparing it with the corresponding answer obtained from a process of piecewise quartic interpolation of the integrand.

The iteration for x_e was performed with a bisection routine. Reliability checks were performed by automatically reducing both tolerances and step size within the computer program as outlined in Section 7.4.

The program which solved for the steady state profiles is listed in Part 1 of Appendix F. The results for various points in the cycle for Case C is shown in Figure 7.6.2 (included at the end of this chapter). The profiles shown for T = 0.25 and 0.75 corresponded to u = 0.0157 u_A rather than zero. Thus, these profiles had a slight inclination which would not occur during pure squeezing action.

The almost vertical rise of all the profiles at $x = x_e$ was a consequence of the large expansion of the vertical scale compared to the horizontal one which thus distorted the cylindrical geometry.

The dry contact stress from equation (7.2.3) was included in Figure 7.6.2 and coincided exactly with the computed hydrodynamic film pressures except for a very slight deviation in the inlet pressure sweep. This deviation was so small that it could not be shown in Figure 7.6.2. This supports the assumption that the steady state pressure curve was close to the dry contact stress for the solutions of cases A and B in Chapter 6. Also, the lubrication solution would have the same formulation for layers of half the thickness on both surfaces. However, equation (7.2.3) had the layer on one surface only. Since the contact dimensions and pressures coincided, it was demonstrated that for the constrained column model, two surface layers can be simply added to give a single layer on one surface. One would not expect thin layers with v = 0.5 to behave much differently from those with v = 0.4 and therefore the assumption made in Chapter 5 concerning the construction of an equivalent bearing layer thickness was supported.

Finally, by carefully observing the inlet pressure sweep, it was observed that unless the contact zone approached quite closely to the bearing length (b), lubricant starvation would be avoided.

7.7 The Dynamic Routine:

The co-ordinate system shown in Figure 7.6.1 was again adopted to formulate the dynamic routine. However, for this situation the squeeze film term in the Reynolds equation must be included. Thus equation (5.2.1) became:

$$\frac{\partial}{\partial x} \left[h^3 \frac{\partial p}{\partial x} \right] = 12\eta \left[u \frac{\partial h}{\partial x} + \frac{\partial h}{\partial t} \right]$$

subject to the same boundary conditions as imposed in Section 7.6. However, the surface profile at an instant in time was,

$$h = h_{A} + f(x)$$

where f(x) was the profile from the steady state solutions of Section 7.6.

For the same reasons as specified in Chapter 6, the squeeze film velocity was approximated as

$$\frac{\partial h}{\partial t} = \frac{dh}{dt}$$

The set of equations describing the dynamic situation simplified to:

$$\frac{\partial p}{\partial x} = \frac{12n}{(h_0 + f(x))^3} \left[u (f(x) - f(x_e)) + \frac{dh_0}{dt} (x - x_e) \right]$$
(7.7.1)

subject to the conditions imposed by equations (7.6.2), (7.6.5) and (7.6.6).

The following expression for coefficient of friction was developed from the formulation of Cudworth and Higginson (1976).

$$\mu = \frac{1}{F^{+}} \int_{-b}^{x_{e}} \left(\frac{2\eta u}{h} - \frac{h}{2} \frac{\partial p}{\partial x} \right) dx + \frac{1}{F^{+}} \int_{e}^{b} \frac{2\eta u h_{c}}{h^{2}} dx \qquad (7.7.2)$$

and this was evaluated using numerical integration within the computer program listed in Part 3 of Appendix F.
The numerical solution procedure consisted of the following steps:

(a) specify
$$h_0$$
 at $t = 0$
(b) solve h_0 for one cycle using the following
procedure at each time step
(i) specify h_0 .
(ii) specify x_e
(iii) specify $\frac{dh_0}{dt}$
(iv) solve equation (7.7.1) for p
(v) iterate until equations (7.6.2) and
(7.6.5) are satisfied
(i.e. $p = 0$ at $x = -b$ and
 $p = 0$ for $-b < x < x_e$)
(vi) iterate until specified F' approximately
equals that computed from equation (7.6.6)
(vii) iterate until h_0 converges.
(c) iterate until h_0 converges for the cycle.

The initial specification for h_0 was obtained from a solution generated by the plane inclined surface bearing model. At each time step the intial specification of h_0 was calculated by a fourth order Adam — Bashforth formula. This formula required $(\frac{O}{dt})$ values to be supplied from previous time steps and initially these were supplied by the plane inclined surface bearing model.

The initial specification of x_e was set equal to x_e derived from the steady state solution required to generate the surface profile, and that of dh_0/dt from the previous time step. For the first time step this was obtained from the plane inclined surface bearing model.

The solution of equation (7.7.1)was accomplished by numerical integration using the method of Gill and Miller (1972) (NAG DO1GAF)

which was described in Section 7.6. The first step which occurred at x_e was subdivided to cope with the rapidly changing pressure gradient.

The surface profile required in equation (7.7.1) was obtained from the steady state solution. The present dynamic routine contained steady state solution coding and obtained initial h_0 and x_e specifications from a data bank, the latter being generated by separate runs of the program listed in Part 1 of Appendix F. The built in interpolation routine of the Gear method (NAG D02EBF) was used to generate a large number of surface profile points. Further interpolation was accomplished by a simple linear routine. Thus, although f(x) was a numerically specified function, it was available to equation (7.7.1) at any position (x) and time (t).

The iteration for $(\frac{dh_o}{dt})$ was performed with a bisection routine. Coupled with the numerical integration of the pressure gradient, the coding constituted the evaluator step for the numerical method used to solve h for the cycle.

The integration of the pressure distribution was accomplished by a second application of the method of Gill and Miller. The iteration for x_e was performed with a bisection routine.

The solution of h_0 for each time step was performed using a fourth order Adams predictor-corrector pair. This routine has been discussed in Section 7.4. Step size halving was used to check reliability and the local truncation error was monitored. The convergence to a cyclic steady state was accomplished in the same fashion as described in Chapter 6.

The entire dynamic solution procedure was run for the conditions designated as case C. In general, the tolerances employed in the dynamic solution procedure were set at 0.001. However, to avoid excessive computing times the tolerance for the step size halving employed for the fourth order Adams predictorcorrector pair was increased to 0.0075. The number of lines of coding and the Central Processing Unit (CPU) times for the various parts are shown in Table 7.7.1. The CPU time required for Part 3 was drastically increased if the starting values were not accurate or if some of the internal convergence factors were not optimal. Thus, general use of this procedure would involve enormous computing expense.

Program	Lines	CPU time (s)
Part 1 - generation of steady state profiles	783	568
Part 2 - plane inclined surface bearing model	722	20
Part 3 - dynamic routine	1551	3415
TOTALS:	3056	4003

Table 7.7.1 : The computer resources required for the full dynamic solution procedure.

The results for case C are shown in Figure 7.7.1 (included at the end of this chapter) along with those generated by the plane inclined surface bearing model of Part 2 in Appendix F. It was necessary to impose a small entrainment velocity at T = 0.25and 0.75 for the full dynamic procedure to converge as shown in the entrainment velocity graph of Figure 7.7.1. The minimum film thickness calculated by the plane inclined surface bearing model was almost identical to that calculated by the full dynamic procedure throughout the cycle. Thus, the plane inclined surface bearing model provided a reasonable approximation for the more realistic cylindrical geometry.

The assumption that the squeeze film velocity could be approximated by

$$\frac{\partial h}{\partial t} = \frac{dh_o}{dt}$$

was made for both sets of results shown in Figure 7.7.1. As mentioned previously this assumption was made in order to reduce the analytic and numerical complexity of the solution. In the results shown in Figure 7.7.1, the assumption that the steady state profile existed at each instant in time caused the shape to change rather rapidly throughout the cycle. In Table 7.7.2, the central and minimum film thickness values are listed for various points within the cycle.

A first order backward difference formula was used to estimate squeeze film velocity in Table 7.7.2. It was clear that considerably larger values for squeeze film velocity occurred at the centre of the contact than at the point of minimum film thickness. The approximation adopted for the squeeze film velocity was only exactly correct at the point of minimum film thickness. However, to determine whether the approximation caused significant errors in the calculated film thickness, the role of squeeze film lubrication was examined. In Figure 7.7.2 the dimensionless film thickness is shown for the dynamic solution. Also, the dimensionless film thickness is shown which would occur if squeeze film velocities were neglected. In

t	h	h		$\frac{dh_c}{dt}$
5	μm	μm	µm∕s	µm∕s
0	0.538	0.633	0.090	0.14
0.125	0.542	0.597	-0.025	-0.28
0.25	0.535	0.541	-0.064	-0.39
0.375	0.528	0.578	-0.044	0.29
0.5	0.525	0.594	0.006	0.12
0.625	0.529	0.598	0.044	0.03
0.75	0.527	0.536	-0.063	-0.49
0.875	0.525	0.615	0.084	0.63
1.0	0.538	0.633	0.090	0.14

Table 7.7.2 : E_Stimated squeeze film velocities (dh_c/dt) at x = 0 for the solution shown in Figure 7.7.1.

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Figure 7.7.2 : The dynamic and steady state solutions at various points in the cycle.

other words, the values for steady state film thickness calculated in Section 7.6 are plotted at various points in the cycle.

The squeeze velocity occurring at T = 0.75 was then set equal to -0.496×10^{-6} m/s, which was estimated in Table 7.7.2 to occur at the centre of the contact for the present dynamic solution. This value was large compared with the value of -0.063×10^{-6} m/s occurring at the point of minimum film thickness. Allowing the higher squeeze velocity to occur for 1 /8 of the cycle would cause the minimum film thickness to decrease by

$$\Delta h_{o} = h_{o} - \frac{dn_{c}}{dt} \cdot \Delta t$$

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Using the values listed in Table 7.7.2 for T = 0.75 gave a decrease in minimum film thickness of about 12 percent. Thus, it was considered unlikely that the approximation adopted for the squeeze film velocity would significantly affect the accuracy of the computed results in the present models.

Finally, a comment can be made concerning the assumption that the surface profiles at each instant in the cycle had the shape that resulted when a steady state solution was performed with the constant load and velocity. The extent to which this would occur was not known. However, in Figure 7.7.1 it was shown that the minimum film thickness throughout the cycle was not particularly sensitive to change in the profile shape, since both plane inclined and cylindrical geometry gave a similar result. This indicated that the assumption concerning the profile shape may have a small effect on the accuracy of the dynamic model.

7.8 Concluding Remarks:

A dynamic solution procedure was developed in this chapter for cylindrical geometry. The procedure was applied to the case C conditions which were similar to those considered for the ankle joint in Chapter 6. The film thickness remained reasonably constant throughout the cycle and had magnitudes approximately equal to those calculated for case B in Chapter 6. Results for case C were also calculated using the plane inclined surface bearing model. The remarkable similarity, especially for minimum film thickness, indicated that the plane inclined surface could be used to approximate the true cylindrical geometry.

A number of the assumptions involved in the theoretical models were discussed. Based on the findings of the present chapter it was considered reasonable to assume that the lubrication of the ankle joint was described adequately by the plane inclined surface bearing model developed in Chapter 6. 1 .

 Case B	(for ankle joint in vivo during walking)
 Case A	(for ankle joint during the friction experiment)
 Case C1	(similar to case C except ν = 0.5)
 Case C	(special case for Chapter 7 with $v = 0.4$)

A Maximum dry contact stress for v = 0.5and no surface traction

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• Maximum dry contact stress for v = 0.4 solved using the column model.





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Figure 7.6.2 : The steady state profiles solved by applying load and velocity equal to the instantaneous values at various points in the cycle.

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- - - - - full dynamic solution

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_____ plane inclined surface bearing model

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maximum dry contact stress for the constrained column model



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CHAPTER 8

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THEORETICAL PREDICTIONS OF FEATURES OF

ANKLE JOINT LUBRICATION.
8.1 INTRODUCTION

The plane inclined surface bearing model was developed in Chapter 6 and applied to case B which represented the ankle joint in vivo during walking. The calculated minimum film thickness remained essentially constant throughout the cycle at a value of about 0.6 µm. The more comprehensive study of Chapter 7 provided support for many of the assumptions made in developing the plane inclined surface bearing model. It was also shown in Chapter 7 that decreasing the Poisson's ratio to 0.4, which was at the lower end of the range reported in the literature and specified in Table 5.3.2, resulted in increases of about sixty percent in minimum film thickness. Therefore, if the Poisson's ratio of 0.4 existed and the other conditions specified in case B were applied, the minimum film thickness might increase to about 1 µm. This indicated that changes in some of the assumed parameters for case B, within approximate physiological limits, could significantly influence the estimates for film thickness.

Seven cases are examined in the present chapter in which various groups of parameters in case B are altered to represent individual variations in physiology, activities other than walking and various theories of previous investigators. Film thickness, pressure distributions and coefficients of friction were calculated using the plane inclined surface bearing model described in Chapter 6. The calculated film thicknesses were compared to the measured Ra roughness of 2-6 µm for cartilage quoted in Chapter 2. The coefficients of friction were also compared to the value of 0.01 which was measured in various studies as described in Chapter 4.

8.2 Description of the Specified Cases:

The cases considered in this chapter were designated as B1, B2, ... B7, and a brief descriptive title was specified for each case along with the parameter changes compared with the standard case B, as shown in Table, 8.2.1. The exact details of the parameter values are listed in Table 8.2.2 and the corresponding values of the dimensionless groups are listed in Table 8.2.3 for each case.

Cases B1 and B2 were selected to represent in an approximate fashion athletic actions such as running. The value of effective modulus (E') adopted for case B3 was at the lower limit of the measured values of Johnson et al (1977). The changes in cartilage thickness (d) and reduced radius of curvature, R, were within the ranges specified in the results presented in Chapter 3.

The values assumed for viscosity (n) in cases B4 and B5 were chosen based on investigations into the "boosted" lubrication theory for synovial joints (Walker et al, 1970; Unsworth, 1972; Walker and Gold, 1973) which has been described in Chapter 2. In these experiments a flat ended cylindrical section of a human joint surface was subjected to reciprocating motion. Synovial fluid was introduced between the flat cartilage surface and a glass counterface. After a few second the cartilage surface was quickly frozen and studies with the scanning electron microscope revealed lubricant layers a few microns thick on the surface. Using the squeeze film relationship for a circular plate (Higginson, 1978a) an apparent viscosity of 2 to 3 $N.s/m^2$ was calculated. While it cannot be ascertained whether effective viscosities of this magnitude occur in whole joint lubrication, it is considered important to examine

Table 8.2.1: General description of cases Bl to B7

considered in this chapter compared to case B

Case	Description
В	ankle joint in vivo during walking
Bl	running lightly (u _A x2, t _p x0.5)
B2	running heavily (u _A x2, t _p x0.5, F _A 'x2)
B3	soft conforming joint (E'x0.5, dx1.25, Rx2)
B4	enhanced viscosity (nx300)
B5	enhanced viscosity (nx100)
в6	squeezing with low shear rates (h_x10 at t=0, nx2)
B7	squeezing with high shear rates (h_x10 at t=0)

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Case	R	Ь	d	t	^u A	F۱	η	E'
	(m)	(mm)	(mm)	(s)	(mm/s)	(kN/m)	(N.s/m ²)	(MN/m ²)
В	0.35	15.2	2.4	1.0	19.099	33.726	0.01	42.667
Bl	0.35	15.2	2.4	0.5	38.197	33.726	0.01	42.667
B2	0.35	15.2	2.4	0.5	38.197	67.452	0.01	42.667
B3	0.70	15.2	3.0	1.0	19.099	33.726	0.01	21.333
B4	0.35	15.2	2.4	1.0	19.099	33.726	3.00	42.667
85	0.35	15.2	2.4	1.0	19.099	33.726	1.00	42.667
*B6	0.35	15.2	2.4	1.0	19.099	33.726	0.02	42.667
*B7	0.35	15.2	2.4	1.0	19.099	33.726	0.01	42.667

Table 8.2.2 Parameter values for cases B and B1 to B7

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* $h_0 = 5.986 \, \mu m$ at t=0 for each cycle

Table 8.2.3 Values of the dimensionless groups for

cases B and Bl to B7

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Case	Ux10 ¹¹	Wx10 ³	S×10 ⁻⁹	D×10 ³	Bx10 ²	ν
В	1.279	2.258	4.267	6.857	4.343	0.5
B1	2.558	2.258	2.133	6.857	4.343	0.5
B2	2.558	4.517	2.133	6.857	4.343	0.5
B3	1.279	2.258	2.133	4.286	2.171	0.5
В4	383.7	2.258	0.01422	6.857	4.343	0.5
B5	127.9	2.258	0.04267	6.857	4.343	0.5
в6	2.558	2.258	2.133	6.857	4.343	0.5
B7	1.279	2.258	4.267	6.857	4.343	0.5

this effect in the model adopted in the present study. Finally, the concept of squeeze film lubrication for synovial joints (Higginson, 1978) was examined for cases B6 and B7.

8.3 Results:

The results were generated for cases B and B1 using the computer program listed in Appendix E. The tolerance was specified as 0.001 and in general computing times were about 20 s (CPU). The characteristic load and velocity curves for all cases are shown in Figure 8.3.1. The variation of dimensionless minimum film thickness (H₀) and coefficient of friction (μ) with time (T) are shown in Figure 8.3.2. The minimum value of h₀ and the maximum value of μ for the cycle are listed for each case in Table 8.3.1.

8.4 Discussion:

The variation of h_0 throughout the cycle was small, except in cases B6 and B7 which examined the squeeze film mechanism, as shown in Figures 8.3.2 and 8.3.3. Thus, for the purposes of general discussion the minimum h_0 which occurred in the cycle was considered. From the values listed in Table 8.3.1 it was clear that only massive increases in viscosity gave film thicknesses larger than the estimated Ra roughness of 2-5 µm quoted in Chapter 2. However, it is still possible that the thin film lubrication mechanism described in Chapter 2 may be invoked, or even micro-elastohydrodynamic lubrication associated with asperities on the 'soft' cartilage layers to facilitate effective lubrication.



Figure 8.3.1 : Characteristic load and velocity curves for all cases.



Figure 8.3.2 : Results for cases B, B1, B2 and B3.



Figure 8.3.3 : Results for cases B4, B5, B6 and B7

Table 8.3.1 : Values of minimum h_0 and maximum μ occurring during the cycle.

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Case	Minimum h _o for the cycle (µm)	Maximum µ for the cycle
В	0.566	0.00102
B1	0.852	0.00135
B2	0.690	0.00104
83	0.998	0.000952
в4	16.0	0.0107
B5	8.69	0.00675
в6	1.36	0.000890
B7	0.948	0.000631

The squeeze film mechanism described by Higginson (1978a) does not appear at first glance to be very effective in increasing film thickness values. However, as shown by comparing the minimum values of h_o for cases B6 and B7, viscosity increases enhance the ability of the squeeze film mechanism to preserve fluid films. Also, reasonably thick films are shown in Figure 8.3.3 throughout the stance phase for cases B6 and B7. Thus, if joint surfaces were pulled apart to create thick films during the swing phase, squeeze film lubrication might be effective. It was noted that for the swing phase loading assumed in the present study, thick films were not generated.

The various values for the dimensionless groups which describe the cases considered have been listed in Table 8.2.3. Although considerable variation occurred in the squeeze factor dimensionless group (S) the maximum coefficient of friction which occurred in a cycle could be correlated with $\left(\frac{U}{W}\right)$ as shown in Figure 8.4.1. Cases B6 and B7 were excluded from Figure 8.4.1 because a special condition had been imposed on the steady state cycle. The results shown in Figure 8.4.1 suggested that the ability of the ankle joint to entrain lubricant with high viscosities or entrainment velocities would be an important factor in its potential to sustain fluid film lubrication.

The pressure distributions calculated in the solution of case B3 showed that lubrication starvation would occur. Thus, the film thicknesses calculated were probably not very realistic. In the solution for case B4 the peak pressure was always considerably less than the maximum dry contact stress. This suggested that the viscosity of 3 N.s/m² might have been too



Figure 8.4.1 : The maximum coefficient of friction (μ) occurring in a cycle vs U/W.

high for the plane inclined surface model to provide accurate results.

8.5 Concluding Remarks;

Unless special thin film lubrication mechanisms act, it appears that the ankle joint cannot sustain full fluid film lubrication. The ability to develop and sustain fluid films is greatly enhanced by elastohydrodynamic and squeeze-film action. However, the role of micro-elastohydrodynamic mechanisms has yet to be fully explored. Fluid films in the order of 1.0 µm have been estimated and this value was certainly not entirely negligible compared to the surface roughness of cartilage. The advantages of an increased lubricant viscosity have been clearly demonstrated. Therefore, if synovial joints do experience fluid film lubrication a viscosity enhancing process in combination with conventional and local elastohydrodynamic action may provide the mechanism.

CHAPTER 9

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OVERALL CONCLUSIONS AND RECOMMENDATIONS

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FOR FUTURE WORK

A wide ranging study has been performed on the lubrication of normal human ankle joints. The overall conclusions of this study now follow:

- (i) The surfaces of human ankle joints in a relaxed state exhibit a converging-diverging configuration. Profiles of dissected ankle joints were measured in the direction of motion and found to be essentially circular in the central zone. When other dimensions of the articulating surfaces were considered, it was possible to represent the ankle joint with the geometry of a partial journal bearing with good accuracy. An average reduced radius of curvature of 0.35 m was deduced based upon the measured profiles.
- (ii) Experiments were performed with ankle joints mounted in the simulator used by O'Kelly (1977). Great difficulty was encountered in measuring the friction forces. However, the coefficients of friction which occurred during the experiments were estimated to have been less than 0.01.
- (iii) It was possible to specify an equivalent bearing consisting of a rigid cylinder with an attached compliant layer sliding on a rigid plane to represent the ankle joint for elastohydrodynamic lubrication analysis. Specific values for the dimensions of this bearing were based on the measurements recorded in this thesis.

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- (iv)In the lubrication analysis, the elastic deformation of the surface was initially taken into account by assuming that the deformed bearing shape could be represented by a plane inclined surface configuration. A simple solution procedure was developed for the lubrication of compliant cylindrical surfaces subjected to cyclic time varying load and velocity conditions. The accuracy of this procedure was supported by the agreement with specific cases from the work of Modest and Tichy (1979) and the work of Hirano and Murakami (1975). When the uncertainty in geometry, material properties and imposed conditions for the ankle was considered, the plane inclined surface bearing model was deemed to provide a reasonable approach to a very complex situation in elastohydrodynamic lubrication.
 - (v) Further support for the plane inclined surface bearing model was achieved by the implementation of a dynamic solution procedure which included a more complete, constrained column model of the elastic deformation of soft layers on cylindrical solids. This dynamic solution procedure required large computer resources. However, a solution for a single case with specified parameters which represented the ankle joint gave remarkable agreement with the results of the simple plane inclined surface bearing model.
 - (vi) Solutions were generated for a range of parameters, representing the normal human ankle joint. For the

standard set of parameters, chosen to represent the ankle joint during walking, the minimum film thickness throughout the cycle remained reasonably constant at This was considerably less than the about 0.7 µm. Ra roughness estimated for cartilage of $2 - 6 \mu m$ (Walker et al, 1968; Clarke, 1973; Sayles et al, 1979; Thomas et al, 1980). The maximum coefficient of friction occurring in the cycle was found to be 0.001. Changes in selected groups of parameters failed to increase the film thickness and coefficients of friction significantly from those calculated for the When a large film thickness was introstandard case. duced at the start of the cycle, it decreased rapidly to about 1 µm. Thus, in the present model, squeezefilm action was not capable of preserving thick films which might be generated during the swing phase in walking.

(vii) In the theoretical investigation only one change in the standard set of parameters gave thick films compared with the surface roughness of cartilage and coefficients of friction similar to those measured by previous investigators. When, in an extreme case the viscosity was increased from 0.01 to 3 N.s/m², film thicknesses of about 18 μm and coefficients of friction up to 0.01 were calculated. The massive increase in viscosity was based on apparent viscosities estimated from the results of Walker et al (1970) and Unsworth (1972).

Recommendations for Future Work:

The theoretical models developed in the present thesis have not been verified with experiments for a compliant layered geometry subjected to both dynamic loads and velocities. Friction experiments could be conducted with the appropriate cylindrical geometry. Assuming a reasonable agreement with the theory developed in this thesis, it is further proposed that small cylindrical sections should be shaped from ankle joint surfaces for similar friction experiments. It would be of particular interest to investigate the breakdown of fluid film lubrication for the natural surfaces in the presence of synovial fluid.

This proposed programme is a return to the approach of Walker et al (1970), except that a cylindrical geometry would be used as well as theory for combined entrainment and squeeze film action which is now available. The study could then be extended to the testing of whole joints in a simulator apparatus.

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APPENDIX A

THE COMPUTER PROGRAM FOR CURVE FITTING THE SURFACE PROFILE DATA

An outline of the curve fitting procedure for the ankle joint surfaces was described in Section 3.5 of Chapter 3. The procedure requires the mathematical development of a circle fitting method to use on the data points from each of the profiles. The mathematical development of a circle fitting method was accomplished by Dr. R.D. Pollard (Department of Electrical and Electronics Engineering, Leeds University) and computer coding for it was written by Dr. D.E. Newland (Department of Mechanical Engineering, Leeds University). The present Appendix summarizes their work and incorporates it into a computer program written specifically for the ankle joint surfaces.

The graphical output from the Talycontor was digitized with respect to an arbitrarily selected origin. Consider N data points and $let(x_i, y_i)$ be the co-ordinates of the ith data point. It was useful to apply the following linear transformation to the data.

$$x_{i}^{i} = x_{i}^{j} - \frac{\Sigma x_{i}}{N}$$
(A.1)

$$y_i' = y_i - \frac{\Sigma y_i}{N}$$
(A.2)

Note that

$$\Sigma x_i' = \Sigma x_i - N \frac{\Sigma x_i}{N} = 0$$
 (A.3)

and

$$\Sigma y_{i}^{I} = \Sigma y_{i} - N \frac{\Sigma y_{i}}{N} = 0 \qquad (A.4)$$

The surface profile data obtained from the Talycontor included small amounts of error in both x and y co-ordinates. Furthermore, the radius of the circle of best fit was the quantity required, thus a suitable least squares criterion was

$$E = \Sigma \left[(x_{i}' - A')^{2} + (y_{i}' - B')^{2} - R^{2} \right]^{2}$$
(A.5)

where (A', B') are the centre point co-ordinates in terms of the x' - y' co-ordinate system and R was the radius for the circle of best fit. It was convenient to find eventually the circle of best fit in terms of the original x - y co-ordinate system. This was accomplished using the following reverse transformations.

$$A = A' + \frac{\Sigma x_i}{N}$$
(A.7)

$$B = B^{1} + \frac{2y_{1}}{N}$$
(A.8)

where (A, B) are the centre point co-ordinates in terms of the x - y co-ordinate system for the circle of best fit. The various geometrical terms are shown in Figure A.1.



Figure A.1 : The geometrical terms involved in the circle fitting method.

The standard least square derivation may proceed as follows: To minimize E set

$$\frac{\partial E}{\partial R} = \frac{\partial E}{\partial A'} = \frac{\partial E}{\partial B'} = 0$$

Equation A.5 implies

$$\Sigma z_i = 0 \tag{A.9}$$

$$\Sigma z_i x_i' - A' \Sigma z_i = 0 \tag{A.10}$$

$$\Sigma z_i y_i' - B\Sigma z_i = 0 \qquad (A.11)$$

where $z_i = (x_i' - A')^2 + (y_i' - B')^2 - R^2$

Substituting equation (A.9) into equations (A.10) and (A.11) yields

$$\Sigma z_i \times i' = 0 \tag{A.12}$$

and
$$\Sigma z_i y_i' = 0$$
 (A.13)

Substituting equations (A.3) and (A.4) into the expanded form of equations (A.9), (A.12) and (A.13) yields

$$R^{2} = (A')^{2} + (B')^{2} + \frac{1}{N} \Sigma [(x_{i}')^{2} + (y_{i}')^{2}]$$
 (A.14)

$$2A' \Sigma(x_{i}')^{2} + 2B' \Sigma x_{i}'y_{i}' = \Sigma[(x_{i}')^{3} + x_{i}'(y_{i}')^{2}]$$
(A.15)

$$2A' \Sigma x_{i} y_{i} + 2B' \Sigma (y_{i}')^{2} = \Sigma [(x_{i}')^{2} y_{i}' + (y_{i}')^{3}]$$
(A.16)

Equations (A.15) and (A.16) can be solved for A' and B' as follows:

$$A^{1} = \frac{\Sigma(y_{1}^{1})^{2}\Sigma[(x_{1}^{1})^{3} + x_{1}^{1}(y_{1}^{1})^{2}] - \Sigma x_{1}^{1}y_{1}^{1}\Sigma[(x_{1}^{1})^{2}y_{1}^{1} + (y_{1}^{1})^{3}]}{2[\Sigma(x_{1}^{1})^{2}\Sigma(y_{1}^{1})^{2} - \Sigma x_{1}^{1}y_{1}^{1}\Sigma x_{1}^{1}y_{1}^{1}]}$$
(A.17)

$$B' = \frac{\Sigma(x_{i}')^{2}\Sigma[(x_{i}')^{2}y_{i}' + (y_{i}')^{3}] - \Sigma x_{i}'y_{i}'\Sigma[(x_{i}')^{3} + x_{i}'(y_{i}')^{2}]}{2[\Sigma(x_{i}')^{2} - \Sigma x_{i}'y_{i}' - \Sigma x_{i}'y_{i}']}$$
(A.18)

Equations (A.1), (A.2), (A.7), (A.8), (A.14), (A.17) and (A.18) constitute the required mathematical method yielding A, B and R for the circle of best fit.
A computer program was written to find the circle of best fit. A listing of the program and sample output are included at the end of this Appendix. The computer program has the following features specifically suited to the ankle joint measurements and the curve fitting procedure described in Section 3.5.

(i) A spherically tipped pin was fabricated for use on the cartilage surfaces as described in Section 3.4. For the convex talus surfaces, the radius of the circle of best fit, R, was found for the output from the Talycontor. However, the actual radius of curvature for the surface was,

$$R_{talus} = R - R_{pin}$$
(A.20)

For the concave tibia surfaces the actual radius of curvature was,

$$R_{tibia} = R + R_{pin}$$
(A.21)

The geometrical basis for these relationships is demonstrated by exaggerating the pin size as show in Figure A.2.



Figure A.2 : The geometry of the pin tip correction for talus and tibia surfaces.

- The required input values were defined in the computer (ii)coding (format statements 901-909) and again at the beginning Those values which remained of the output data file. constant throughout the present study were specified in the program rather than being read from the input data file. All the input values were printed at the beginning of the output data file to permit identification and checking of A specified number of data points at the each run. beginning and the end of the input data sequence could be omitted from the circle fit calculation. If the "% DIFF" value (defined and listed in the output file) for one of the points used in the circle fit exceeded the value of "PREC" specified in the input, a message (format statement 801) was printed at the end of the output file. This was an important part of the curve fitting procedure described in Section 3.5.
- (iii) The computer program as listed gave a multi-coloured graphical output. The graph included in this Appendix is the same as the one generated by the listed program, except for the lack of colour. The data points excluded from the circle fit were adjusted for the pin tip radius as if the calculated radis of curvature applied to them and they were plotted in the output graph. This meant that they were not completely accurate but this error was sufficiently small to ensure that the profiles of the joint surface outside the fitted region were as shown in the output graph.

C LEAST SQUARES CURVE FIT FOR ANKLE PROFILES C >DIMENSION #(100),Y(100),RD(100),E(100),XI(100),YI(100) DIMENSION XC(100), YC(100) INPUT READ(5,+) NT.NS.NF READ(5,+) K READ(5',*) (YC(I),I=1,NT) 00 401 I=1.100 XC(I)=20.*(I-1) 401 CONTINUE RP=.79375 MAGX=20 MAGY=20 CMAX=28. PREC=+25 CHECK 98 FORMATC + ++++ INPUT DATA ******///) 100 FORMAT(5X, *NO. *, 5x, *X*, 12X, *Y*/) 101 FORMAT(*, 16, 3X, 510.3, 3X, 510.3) 102 FOPMAT(*,///) С

g/

```
907
С
606 FORMAT(//* NOTES: 1/)
103 FORMAT(" (1.) XC IS THE X CC-ORDINATE")
603 FORMATCY (2.) YO IS THE Y CC-ORDINATEY)
104 FORMAT(* (3.) XC AND YC IN EXPANDED FORM MUST BE *)
804 FORMATC*
            IN SAME UNITS AS RP. 1//)
106 FORMAT(// **** THE FOLLOWING POINTS ARE TRANSFORMED AND ..
   +
        *PLCITED *****//)
   WRITE(6,98)
   WRITE(6.901) NT
   WRITE(5,902) NS
   WRITE(6,902) NF
```

902 FORMATCHINS CARRAY POSITION FOR IST LS FIT DATA PT) ... 1.18) 903 FORMATCE NF (ARRAY FOSITION FOR LAST LS FIT DATA FT) .. . 18)

• 18)

FORMATCY NT (NUMBER OF DATA POINTS)

WRITE(6,904) K WRITE(6,90E) RP WRITE(6,90E) MAGX WRITE(6,907) MAGY WRITE(6,9DE) CMAX WRITE(6,905) PREC WRITE(6,60£) WRITE(6,102) WRITE(6,602) WRITE(6,104) WRITE(6,804) WRITE(6,10E) WRITE(6,100) DO 1 1=1.NT WRITE(6,101)I,XC(I),YC(I) 1 CONTINUE WRITE(6,102) C C C PREP С C DO 10 I=1,NT XC(I)=XC(I)/MAGX YC(I) = YC(I)/MAGY 10 CONTINUE N=0 00 50 I=NS.NF N=N+1 X(N)=XC(I) Y(N)=YC(I) 50 CONTINUE C C C C C C LEAST (SUPPLIED BY DR. D.E. NEWLAND) C SIGX=0. SIGY=0. DC 2 I=1,N SIGX=SIGX+X(I) SIGY=SIGY+Y(I) 2 CONTINUE AVX=SIGX/N AVY=SIGY/N 00 3 I=1.N XICI)=XCI)-AVX YICI)=YCI)-AVY 3 CONTINUE SIGS0=0. DC 4 I=1.N SIGSQ=SIGSC+XI(I)++2+YI(I)++2 4 CONTINUE CI=SIGSO/N

A 8

DATA T1/0./ .T2/0./. T2/0./. T4/0./. T5/0./ DC 5 I=1.N T1=T1+YI(T)++2 T2=T2+XI(I)++3+XI(I)+YI(I)++2 T3=T3+XI(I)+YI(I) T4=T4+XI(I)++2+YI(I)+YI(I)++3 T5=T5+XI(I)++2 CONTINUE DENOM=2 . + (TE+ T1-T3+ T3) AI=(T1+T2-T3+T4)/DENCH BI=(T5+T4-T3+T2)/0EN04 A=AI+AVX B=B1+AVY R=SQRT(CI+AI+AI+BI+BI) ERP=0. KD =0 00 11 1=1+N XR=X(I) YP=Y(I) RU(I)=SQRT((XR-A)++2+(YR-B)++2) E(I)=100.+(RD(I)-R)/R EC=ABS(E(I)) IF (EC.GT.PFEC) KD=1 ERR=ERR+(RE(I)-R)++2 11 CONTINUE STDERR=SQRT(ERR/(N-3)) PERERR=300.+STDERF/F

0

RSG=R+R

```
С
С
           ADJUST
      IF(K.EQ.0) RA=R-RP
      IF(K.EQ.1) RA=R+RP
С
          OUTPUT
C ---
196 FORMATCH CONCAVE TIEIA SURFACE PROFILE MEASURED#///)
197 FORMATC + CONVEX TALUS SURFACE PROFILE MEASURED +///)
198 FOPMAT(* ****** ? U T P U T D A T A ******///)
200 FORMAT(" ( X - ",E14.7,2X,") ** 2 + ( Y - ",E14.7,2X,") ** 2 = ".
             514.7///)
    +
201 FORMATC SURFACE RACIUS = 7,514.7,1X,
          I WHEN ADJUSTED FOR PIN TIP RADIUS.
    +
202 FORMAT(3X, *NO. *, 7X, *X-A*, 15X, *Y-B*, 14X, *RD*, 11X, *X DIFF*//;
203 FORMAT( *, 16, 4(3X, E14.7))
204 FORMAT(P R = +,E14.7,2X, +HITH A STANCARD ERROR OF +,E10.3///)
205 FORMATCY AN ESTIMATE OF THE UNCEFTAINTY IN THE RADIUS!.
    + 🖉 • EVALUATION = •, 610.3, • X•)
206 FORMATC! THE BEST FIT CIRCLE IS!/)
207 FORMAT(* RC=SQRT{(X-A)++2+(Y-B)++2)*/)
208 FORMAT(* % CIFF=100.+(RD-P)/R*/)
```

```
20 - FURMAT(* R = BEST FIT RADIUS*/)
210 FORMAT( A = BEST FIT X CG-CRD FCR CENTRE*/)
211 FURMATE B = BEST FIT Y CO-ORD FOR CENTRE ///)
212 FORMATC// **** THE FOLLOWING POINTS ARE USED IN THE LS FIT **
           ******//>
    +
801 FORMATCH CATA IN LS FIT EXCEEDS PRECID
B11 EDRMAT(/* WHERE & UNCERTAINTY = 300. + STANCARD ERRCR / R*/)
    .WRITE(6,198)
     IF(K.E0.0) (FITE(6,197)
     IF(K.00.1) WRITE(6,196)
     WRITE(0,207)
     WRITE(6,208)
     WRITE(6,209)
     WRITE(6+210)
     WRITE(6,211)
     WRITE(6,212)
     WRITE(6,202)
     DO 12 I=1.N
     A = (I) \times = (I) \times A
     Y(I)=Y(I)-E
     WRITE(6,203) I,X(I),Y(I), RD(I), C(I)
 12 CONTINUE
     WRITE(6,102)
     WRITE(6,206)
     WRITE(6,200) A,8,RSG
     WRITE(6,204) R,STDERR
     HRITE(6,201) RA
     WRITE(6,205) PERERR
     WRITE(6,811)
     IF(KD.=0.1) WRITE(6,301)
```

C VISUAL С WARNING ... IN PRESENT FORM GPAPHICS REGUIRES DIMENSIONS IN MM С С DO 51 I=1,NT XC(I) = XC(I) - AYC(I)=YC(I)-B 51 CONTINUE DC 52 1=1,NT XR=XC(I) YR=YC(I) IF(XR.EQ.0.) GCTC 71 THETA=ATAN(ABS(YR/XR)) GOTO 72 71 THETA=ASIN(1.) 72 CONTINUE IF(K.20.1) GOTO 53 IF(XR.LE.O.) XC(I)=XR+RP+CCS(THETA) IF(XR.GT.O.) XC(I)=XR-RP+CCS(THETA) YC(I)=YR-RF+SINCTHETA) GOT0 52

à

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IF (XR.LE.B.) XC(I)=XR-RE+CCD(THETA)
53
    IF(XR.GT.O.) XC(I)=XR+RP+CCS(THETA)
    YC(I)=YR+PF+SIN(THETA)
52
    CONTINUE
    CMAXN=-1.+CMAX
    CALL PAPER(1)
    CALL CTRENT(1)
    CALL BLKPEN
    CALL PSFACE(0.,1.,0.,1.)
    CALL MAP(0.,1.,0.,1.)
    IF(K.EQ.0) CALL PLOTOS(.13,.3, TALUS",5)
    IF(K.ED.1) CALL PLOTOS(.13..3, TIBIA", 5)
    CALL TYPENF (RA,2)
    CALL PLOTES(.28, .275, *% UNCERTAINTY =*, 15)
    CALL TYPENF (PERERR, 2)
    CALL PLOTOS(.13,.255,"(ALL DIMENSIONS IN MM)",23)
    CALL BLUPEN
    CALL PSPACE (+01, +51, +35, +6)
    CALL MAPECHANN, CMAX, 0., CMAX)
    CALL AXES
    CALL GRNPEN
    IF(NS.EQ.1) GOTO 61
    NSM=NS+1
    CALL PTPLOT(XC,YC,1,NS1,248)
    CALL PTPLOT(2., 3., 1, 1, 248)
61
    CONTINUE
    CALL REDPEN
    CALL FTPLOT(XC,YC, NS, NF, 227)
    CALL PTPLCT(2.,5.,1,1,227)
    CALL GRNPEN
    IF(NF.EG.NT) GOTO 62
    NFP=NF+1
    CALL PTPLOT(XC,YC,NFP,NT,249)
    IF(NS.20.1) CALL PTPLOT(2.,3.,1,1,245)
62
    CONTINUE
    CALL BLKPEN
    CALL POSITICO.,0.)
    CALL CIRCLE(PA)
    CALL CIPCLE(PA)
    CALL BLKPEN
    CALL CTRSI2(.=)
    IF((NS.EQ.1).AND. (MF.EQ.N.T)) GUTC 16
    CALL PLOTOS(4.,3., "NOT USED IN LS FIT", 15)
86
    CONTINUE
    CALL PLOTOS(4.,5., USED IN LS FIT+, 14)
    CALL PSPACE (0., 1., 0., 1.)
    CALL MAP(G., 1., 0., 1.)
    CALL CTRSTZI.007)
    CALL PLOTOS(+08++59+PPOSTERICR++9)
    CALL PLOTOS (.38, .58, "ANTERICE", 2)
    CALL BREND
    STOP
    END
```

Executive FILE: J6 EVEC A LEED EXEC SETUP FORTRAN NAGE COGHOST FI 5 DISK &2 DATA FI 6 DISK &3 DATA LOAD &1(CLEAR EXEC PLOTFILE &4 SET BLIP * START

LEEDS UNIVERSITY VM/BSE 6.16 ∢ DATA FILE: XC

57.3 64.8 70.4 75.2 79. 54.7 45. 34.4 21. 5.7 -53. -30.5 -11.8 3.4 16.9 28.4 35.8 49.1 51.5 63. 83.5 83.5 82. 79. 74.8 69. 62.5 -12.5 -34.3 -63.0

3^C

Output

TILL. TO JATA A LEEDS UNIVERSITY UNVERSE FOR	FILE: YC	ATAC	A	LEEDS	UNIVERSITY	VMZESE	6.1
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NT (NUMBER OF DATA FUINTS) NS (ARRAY POSITION FOR IST LS FIT DATA FT) ... 30 NF CARRAY POSITION FOR LAST LS FIT DATA FT) .. 6 25 K (EQUALS D OR 1 FOR TALUS OR TIBIA) 0 RP (PIN TIP RADIUS) 0.7-275005+00 HAGX (MAGNIFICATION OF XC) HAGY (MAGNIFICATION OF YC) 20 CMAX (MAXIMUM RACIUS ALLOWED IN FLOTS) 20 0-28000005+02 PREC (X RANGE FOR INCLUDING DATA IN LS FIT) .. 0.25000002+00

NOTES:

-

(1.) XC IS THE > CO-ORCINATE
(2.) YC IS THE Y CO-ORCINATE
(3.) XC AND YC IN LXPANDED FORM MUST BE IN SAME UNITS AS PP.

**** THE FOLLOWING POINTS ARE TRANSFORMED AND PLOTTED ****

NC .	X	Y
1	0.0	-0.5305+02
2	0.2005+02	-0.3055+02
3	0.4005+02	-0.118F+02
4	0.6005+02	0-3407+01
5	0.3002+02	0.1695+02
6	0+1002+03	0.2845+02
7	0+1206+03	0.3937+02
8	0+140E+03	0.4915+02
9	0-1607+03	0.5735+02
10	0+1805+03	0.6485+02
11	0.2002+03	0.7045+02
12	0+2205+03	0.7525+02
13	0+2405+03	0 . 7 - 0 - + 0 2
14	0+2605+03	0.8155+02
15	0+280E+03	0.9307+02
16	0+300E+03	0.8357+02
17	0-3202+03	0.8357+02
18	0.3402+03	0.8205+02
19	0 • 368 + 03	0.7=0=+02
20	0+3805+03	0+748=+02
21	0+4902+03	0+6-07+02
22	0+420=+03	0+6257+02
23	0++465+03	\$ +547E+u2
27	0+4605+03	0-4505+02
23	0-4-0-+05	6-3447+02

0.5002+03 0.2105+02 26 27 0.5205+03 0.5705+01 0.5402+03 -0.1255+02 28 -0.3435+02 29 0.5605+03 0.5805+03 -0.6305+02 30 Ουτρυτ DATA ***** ***** CONVEX TALUS SURFACE PROFILE MEASURED RD=SQRT((X-A)++2+(Y-B)++2) % DIFF=100.+(RD-R)/R R = BEST FIT RACIUS

A = BEST FIT X CC-ORD FOR CENTRE

B = BEST FIT Y CC-ORD FOR CENTRE

**** THE FOLLOWING POINTS ARE USED IN THE LS FIT ****

٠.

NO.	X - A	7 – P	RD	Z DIFF				
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 13	-0.9911195E+01 -0.88111952+01 -0.78111952+01 -0.63111952+01 -0.58111952+01 -0.58111952+01 -0.38111952+01 -0.38111952+01 -0.19111952+01 -0.81119542+00 0.18860462+00 0.11928052+01 0.31888052+01 0.4188052+01 0.51886052+01 0.4188052+01 0.4188052+01 0.4188052+01 0.4188052+01 0.4188052+01 0.4188052+01 0.4188052+01	0.15773355.02 0.16343347.02 0.16908357.02 0.16908357.02 0.17218345.02 0.17593345.02 0.17593345.02 0.18113345.02 0.18303347.02 0.18503345.02 0.18528355.02 0.18528355.02 0.18528355.02 0.18453345.02 0.18453345.02 0.18453345.02 0.18073345.02 0.18073345.02 0.17803347.02 0.17478355.02 0.17058355.02	0.1857574E+02 0.1856721F+C2 0.18534705+C2 0.18534705+C2 0.1850955F+C2 0.1850955F+C2 0.1850955F+C2 0.18517145+C2 0.18517145+C2 0.18527315+C2 0.1858269E+C2 0.1858269E+C2 0.1858269E+C2 0.18571875+C2 0.18571875+C2 0.18544075+C2 0.1853889E+C2	$\begin{array}{c} 0.19915385+00\\ 0.15215455+00\\ -0.23210415-01\\ -0.12055045+00\\ -0.58109335-01\\ -0.15865145+00\\ -0.15671145+00\\ -0.15671145+00\\ -0.11350055+00\\ -0.11794515+00\\ -0.52264585-01\\ 0.52264585-01\\ 0.14798695+00\\ 0.23564335+00\\ 0.21557207+00\\ 0.21557207+00\\ 0.27325737-01\\ 0.14403625-01\\ -0.65845135-03\\ \end{array}$				
19 20	0.913%2052+01 0.91968052+01	0+16603355+02 0+16073355+02	0.13512915+C2 0.15514505+C2	-0.1407440E+00 -0.1321F41F+C0				

THE BEST FIT CIRCLE IS

(X - 0.1491120E+02) ** 2 * (Y - -0.1435335E+02) ** 2 = 0.3436943E+03

R = 0.1853900E+C2 WITH A STANDARD ERROR CF 0.271E-01

SURFACE RADIUS = 0.1774524E+02 WHEN ADJUSTED FOR PIN TIP RADIUS. AN ESTIMATE OF THE UNCERTAINTY IN THE RADIUS EVALUATION = 0.439E+00 % WHERE % UNCERTAINTY = 300. + STANDARD ERROR / R



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APPENDIX B

EFFECT OF MISALIGNMENT ON SURFACE CURVATURE MEASUREMENTS OF A CYLINDER USING A TALYCONTOR

The Talycontor instrument, made by Rank Taylor Hobson measures surface shape by traversing a lightly loaded stylus across a surface. Vertical and horizontal co-ordinates are recorded graphically. If the axis of a cylinder is placed perpendicular to the direction of stylus motion, the radius of the cylinder can be evaluated from the graphical output. However, if the axis of the cylinder is not perpendicular to the direction of stylus motion and a short distance is traversed, an inaccurate cylinder radius would be evaluated. Equations relating this source of error to misalignment angles are developed in this Appendix. These equations are required in Section 3.6 of Chapter 3 in which an estimate is provided of the accuracy of the surface curvature evaluation for ankle joints.

Two types of misalignment can occur as illustrated in Figure B.1. It is convenient to consider a "tilt" angle in the y-z plane and a "twist" angle in the x-y plane. The stylus is shown in Figure B.1 at point A which is the position of the maximum vertical or z co-ordinate. If the surface slope becomes very steep, the Talycontor cannot function properly. Thus, traversals can be considered as symmetric about point A and over distances of approximately one quarter the circumference of the cylinder.

When the cylinder of radius, r_c is tilted with angle θ , the measured surface profile is part of an ellipse as shown in Figure B.2. The smallest possible evaluation for radius equals the radius of curvature at point A. The radius of curvature at point A can be found using the following standard equation (Tuma, 1970).



Figure B.1 : Geometric definitions for tilt and twist.

B2



direction of Talycontor motion



Figure B.2 : Surface geometry when tilt occurs.



X

Section A-A



Figure B.3 : Surface geometry when twist occurs.

B4

$$r = \frac{\left[1 + \left(\frac{dz}{dx} \mid x = 0\right)^{2}\right]}{-\frac{d^{2}z}{dx^{2}} \mid x = 0}$$

For the ellipse shown in Figure B.2

$$z = (r_c^2 - x^2)^{1/2} \frac{1}{\cos\theta}$$

which implied

$$\frac{dz}{dx} \begin{vmatrix} x = 0 \end{vmatrix} = 0$$

and
$$\frac{d^2z}{dx^2} \begin{vmatrix} x = 0 \end{vmatrix} = \frac{-1}{r_c \cos\theta}$$

Thus, when the tilt angle is θ , the measured radius of curvature r_{TL} is

$$r_{TI} = r_c \cos\theta \tag{B.1}$$

When the cylinder of radius r_c is twisted with angle α the measured surface profile is again part of an ellipse as shown in Figure B.3. In this case, the largest rather than the smallest possible radius equals the radius of curvature at point A. In a similar manner to the derivation of equation (B.1) the measured radius at point A, when twist occurs is,

$$r_{\rm TW} = \frac{r_{\rm c}}{\cos\alpha} \tag{B.2}$$

Equation (B.1) indicated that tilt causes the measured radius to be smaller than the actual cylinder radius. However, equation (B.2) indicates that twist causes the opposite effect. Thus, when both tilt and twist occur together the measured radius may be estimated as

$$r_{\rm M} = \frac{r_{\rm TI} + r_{\rm TW}}{2}$$

Equations (B.1) and (B.2) imply

$$r_{M} = \frac{r_{c}}{2} \left(\cos \theta + \frac{1}{\cos \alpha} \right)$$

which is used in Section 3.6.

(B.3)

APPENDIX C

THE COMPUTER PROGRAM FOR LINEAR REGRESSION

The computer program listed in this Appendix performs linear regression using a least squares criterion. The equations involved in evaluating the least squares terms are found in a standard mathematics handbook (Selby, 1974). The value for standard error is calculated using the following equation:

$$S_{E} = \sqrt{\frac{\Sigma(y_{i} - B_{o} - B_{1}x_{i})^{2}}{N - 2}}$$

where x_i and y_i are the independent and dependent values for a single data point, B_0 and B_1 are the y-intercept and slope of the best fit line and N is the number of data points. The sample output includes a graph which differs from the one which would be generated by the listed program simply by not having multiple colours.

C LEAST SQUARES CURVE FITS FOR LINEAR, POWER AND EXPONENTIAL CURVES. K..... EQUALS 3, 1,2 FOR LINBAR, POWER OR EXPONENTIAL CURVES RESPECTIVELY. N.....NUMBER OF LATA POINTS. N2....NUMBER OF FITTED CURVE FOINTS USED IN PLOT. X..... INDEPENDENT VARIABLE. Y.....DEPENDENT VARIABLE. С C C IMPLICIT REAL*8 (A-H, O-Z) DIMENSION X(60C), Y(60C) REAL-4 XX (600), YY (600), XF (601), YF (601), XHAX, XMIN, YHAX, YMIN С INPUT **READ(5, *) K, N, N2** READ $(5, \cdot)$ (X (I), I=1, N) READ(5, 1) (Y(I), I=1,N)

> ດ ພ

Ċ,	
C	CHECK
2	PORNAT (' K =' .T3.5X.'N ='. T5. 4X. 'N2 ='. T5//)
100	PORMAT(5X. 'N 0.'.6X.'X'.12X.'Y'//)
101	FORMAT(1, 16, 3X, D13, 3, 3X, E10, 3)
102	FOR 1 AT (' ' .//)
	WRITE(5.98) K.N.N2
	WRITE(6,100)
	$DO \ 2 \ I = 1.N$
	WRITE(6. 101) I.X(I).Y(I)
2	CONTINUE
-	WRITE(6, 102)
C C C	PREP
2	X MA X=X (1)
	$X \le IN = X(1)$
	Y M X = Y (1)
	DO^{43} 1 I = 1, N
	IF(X(I),GT,XHAX) X MAX=X(I)
	$IF(X(I) \cdot LT \cdot XM IN) XM IN = X(I)$
	$IP(Y(I) \cdot GT \cdot Y M AX) Y M AX = Y(I)$
	XX(I) = X(I)

.

	$\mathbf{Y} \mathbf{Y} (\mathbf{T}) = \mathbf{Y} (\mathbf{T})$
1	CONTINUE
1	DX = (X + X + X + TN) / N2
	$\mathbf{X}(\mathbf{I}) = \mathbf{D} \mathbf{L} \mathbf{C} 3 1 3 (\mathbf{X} \mathbf{C})$
	Y(I) = DLOGIO(YC)
3	CONTINUE
	GOTO 11
21	CONTINUE
	DO 4 I = 1, N
	YC=Y(I)
	Y(I) = DLOG10(YC)
4	CONTINUE
11	CONTINUE
C	
-	
ř	LEAST
-	
	و ه هي جي جي وي و و و و و و و و و و و و و و و
0	DATA STRUZO, DOZ.ST NOZO, DOZ. ST NOZO, DOZ. ST NUZO, DOZ. STM 520, DOZ
	DALA DUTUVUDV
	SUM 2=SUM 2+YT
	SUM 3=SUM 3+XT
	SUM4=SUM4+XT**2
	SUM 6=SUM 6+YT* * 2
5	CONTINUE
	B1 = (N + SUN1 - SUN2 * SUM3) / (N* SUM4 - SUM3 * * 2)
	BC = SUM 2/N - B1 = SUM 3/N
	F1 = N* SUP4-SU M3 **2
	P 2=N # SUM 6- SUM 2** 2
	CCOEF= B1 + DSOBT(F1/F2)
	DO 5 T=1 N
	V - V / T)

	14#1{1} 6##E_0##E.(VM_D/_D1+VK)++0
÷ -	
, D	CUNTINUE Amprop - Decomm(JUNE ((N. C)))
_	STUERE=USQRT(SUMS/(N=2))
<u> </u>	اي ها جايين جاري من جو اين جو بين جاري من جو اين جو اين جو اي جو
3	
C	DUTPUT
3	
C	
20(DEMAT(//5X, 'Y = ',D14.7,2X,'+ (',D14.7,') · X'//)
201	FOBMAT (11X, "STANDARD ERROR =", D14.7//)
20	2 POBMAT (11X, CORRELATION COEFFICIENT = .D14.7//)
20	3 FORMAT(5X. "Y = ". D14.7.2X."* X ** ". D14.7//)
20	BOREAT 15% . Y = 1, D14.7.2% . I. T14.7. I = ++ + / //
· · · · · · · · · · · · · · · · · · ·	

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```
FORMAT(' ASSUMES POINT (0.,0.) IS ON THE FITTED CUFVE')
205
     FORMAT( ' CANNOT HAVE Y = 0. IN THE INPUT DATA')
206
     FORMAT (* --
                                                                   ____()
888
     FORMAT(/* SPECIAL CHECK FOR MAVERICK POINTS*//)
889
     FORMAT (//* ',2X, 'NO. ',7X, 'X', 9K, 'Y', 9K, 'YCAL', 9X, 'YDIPP'/)
890
     FORMAT (* *,I3,3K,4(D1C.3,2X))
891
     FORMAT(//' LOCK CLOSER IF YEIFF EXCEEDS
892
                                                    •,D10.3//)
     IF (K.EC.1) GCTC 42
     IF(K.EQ.2) GO TO 46
     WRITE(5,888)
     WRITE(6,899)
     WRITE( 6, 890)
     DO 91 I=1.N
     X C = X (I)
      YCAL=BO+B1=XC
      YC = Y(T)
      Y DIPP=DABS(YCAL-YC)
      WRITE(6,891) I,XC,YC,YCAL,YIIFF
 81
      CONTINUE
      EMAX=3.DO- STDERR
      WRITE (6,992) EMAX
      WRITE(6,888)
                    BC, B1
      WRITE(6,200)
      WRITE(6,201) STDERR
      WRITE(6,202) CCDEF
      SOTO 44
  42
      CONTINUE
      B0=10.D3**B9
      WRITE (6,203)
                     B0, B1
      WRITE( 6, 201)
                     STDERR
      WRITE(6,202)
                     CCOEF
      WRITE(6,205)
      GOTO 44
      CONTI NUE
  46
      BJ=10.D0**BJ
      B 1=10.D0**B1
      WRITE (6,2C4) BC, B1
      WRITE( 6, 20 1)
                     STDERR
       WRITE (6,202)
                     CCOEF
      WRITE(6, 206)
  44
      CONTINUE
3-
C
3
            VISUAL
C
2
       N1=N2+1
       DO 7 I=1.N1
  ð
       XP(I) = X EIN+(I-1) * DX
   7
       CONTINUE
       IF(K.EQ.1) GOTO 52
       IP(K.EQ.2) GCTC 55
       DO 8 1=1.81
       YF(I) = B0+B1+XF(I)
```

```
IF (YP (I).GT. YMAX) YMAX=YF(I)
```

8 CONTINUE 30T0 57 52 CONTINUE DO 9 I=1,N1 YF(I)=B)*XF(I)**B1 IF (Y F (I).GT. YMAX) YMA X=YF (I) 9 CONTINUE GOTO 57 56 CONTINUE DO 10 I=1, N1 YF(I)=B0*B1**XF(I) IF(YF(I).GT.YMAX) YMAX=YF(I) 10 CONTINUE 57 CONT IN UE CALL PAPER(1) CALL CIRPNIC(1) XMAX=XMAX • 1.1 XMIN=XMIN*.9 X M IN = X M IN = 1. 1 YMAX=YMAX=1.1 CALL BLKPEN CALL PSPACE(0., 1., 0., 1.) CALL MAF(0.,1.,0.,1.) CALL PLOTCS(.5, .02, .X., 1) CALL PSPACE(.1..5,.1,.9) CALL MAP(G., XMAX, G., YMAX) CALL BCRDEB CALL AXES CALL REDFEN CALL CURVED(XF,YF, 1,N 1) CALL BLUFEN CALL PTPLOF(XX.YY.1,N.224) CALL GREND STOP END

C 6

Executive

FILE: J6 EXEC A LEEDS

EXEC SETUP FORTRAN NAGE COGHOST FI 5 DISK &2 DATA FI 6 DISK &3 DATA LOAD &1(CLEAR EXEC PLOTFILE %4 SET BLIP *

Input

FILE: XLSQ DATA A LEE

0 6 100 4.21 7.46 10.7 13.9 15.2 20.1 6. 9.75 14.5 19.1 21.9 25.3 Output

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APPENDIX D

DESIGN OF THE CAM FOR THE ANKLE JOINT SIMULATOR

The ankle joints in the simulator were subject to dynamic loads imposed by the cam driven hydraulic circuit shown in Figure D.1. When the cam rotated the follower was displaced in a linear fashion from the position corresponding to contact with the minimum cam radius (r_{M}) . The magnitude of displacement can be written as $(r - r_M)$, where r is the instantaneous cam radius. This displacement caused a compression of the nitrogen bag in the accumulator from a minimum gauge pressure (p_M) to an instantaneous gauge pressure (p) in the driving circuit. Balancing cylinder I applied a gauge pressure (p_I) to the piston area (A_{MB}) of the master cylinder to reduce the oil leakage from the driving circuit. In a similar fashion, balancing cylinder II applied a gauge pressure (p_{II}) to the piston area (A_{LF}) of the loading cylinder to reduce oil leakage from the driving circuit and also to balance the weight of the loading assembly.

The gauge pressure (p) in the driving circuit could be set to a specific value (p_M) when the cam was stationary and the follower touched at the minimum radius (r_M) . This was accomplished by opening the value and forcing oil into the driving circuit with the hand pump.

The dynamic load (F) was estimated by applying a simple analysis to the driving circuit. The original design notes of Mr. 8. Jobbins (Department of Mechanical Engineering, Leeds University) formed a basis for the present analysis. Hydrostatic equations were applied in the analysis of the hydraulic circuit and simple thermodynamics was used to describe the compression of the nitrogen.





When the nitrogen bag completely filled the accumulator it had a volume of V_0 and a gauge pressure of p_0 . As mentioned previously, the hand pump was used to force oil into the driving circuit. The volume of nitrogen at another gauge pressure (p_m) is given by;

$$V_{M} = \frac{V_{O} (P_{O} + P_{A})}{P_{M} + P_{A}}$$
(D.1)

where p_A is the atmospheric pressure. However, once the value in the driving circuit was closed and cam rotation began, the nitrogen was subjected to cyclic compression and expansion. With an instantaneous gauge pressure of p and an instantaneous volume of V, this process was assumed to be adiabatic, to yield;

$$(p + p_A)V^{1.4} = (p_M + p_A)V_M^{1.4}$$
 (D.2)

A force balance on the loading cylinder yields:

$$F = P A_{LB} - P_{II} A_{LF} + W$$
 (D.3)

The terms in this equation are shown in Figure D.1, except for (W) which is the weight of the loading assembly. Finally the continuity equation was applied to the hydraulic oil to yield the following expression for the instantaneous volume of nitrogen.

$$V = V_{M} - (r - r_{M}) A_{MF}$$
(D.4)

Equations (D.1), (D.2), (D.3) and (D.4) were combined to yield:

$$\mathbf{F} = \left[\left(\frac{1}{p_{M} + p_{A}} \right)^{0.4} \left(\frac{p_{M} + p_{A}}{1 - \left(\frac{p_{M} + p_{A}}{p_{o} + p_{A}} \right)^{(r - r_{M}) - A_{MF}}} \right)^{1.4} - p_{A} \right]^{A_{LB} + W - p_{II}A_{LF}}$$
(D.5)

The various parameters required to evaluate equation (D.5) are listed in Table D.1. When values of these parameters are

Table D.1 : Parameters for the Cam Design.

Parameter type	Symbol	Definition	Value
Not easily changed	PA W V _O A _{MF} A _{LB} A _{LF}	Standard atmospheric pressure Weight of loading assembly Volume of accumulator Piston area for the front face of the master cylinder Piston area for the back face of the loading cylinder Piston area for the front face of the loading cylinder	$1.01 \times 10^{5} \text{ N/m}^{2}$ 418 N $1.80 \times 10^{-4} \text{ m}^{3}$ $4.56 \times 10^{-3} \text{ m}^{2}$ $4.36 \times 10^{-3} \text{ m}^{2}$ $4.56 \times 10^{-3} \text{ m}^{2}$
Can be altered	^г м Р _М РІІ	Minimum cam radius Gauge pressure of nitrogen when r = r _M and cam stationary Gauge pressure in balancing cylinder II	0.0593 m 1.45 x 10^5 N/m ² 1.68 x 10^5 N/m ²

substituted into equation (D.5) a non-linear relationship emerges between the force (F) on the ankle specimen and the cam radius (r).

The design of the cam used for the experiments described in Chapter 4 was accomplished by an iterative procedure. The required force pattern was first used to generate cam radius values predicted by equation (D.5). This was accomplished by using the first computer program listed at the end of this Appendix. The cam was then cut and attached to the joint simulator. A force transducer was used in place of an ankle specimen to record the dynamic load generated by the simulator.

Various dynamic effects caused higher forces than those predicted by equation (D.5) to be developed by the simulator. Thus, small portions of the cam were removed and pressures p_M and p_{II} adjusted until an acceptable load pattern was recorded. The second computer program listed at the end of this Appendix was used to evaluate the forces predicted by equation (D.5) for a proposed change in cam radius. This ensured that the loading pattern was not altered too drastically.

The second computer program was used to calculate the force pattern predicted by equation (D.5). This is compared with the actual measured forces in Figure D.3. The simple analysis developed in this Appendix provided a useful guide for the cam design. The final cam shape is shown in Figure D.2.

D 5


Figure D.2 : The final cam shape.



Figure D.3 : A comparison of the measured and predicted forces caused by the final cam shape.

```
FILE: FORCE
              FORTRAN A LEEDS UNIVERSITY VM/BSE 6.16
      DIMENSION T(200), F(200), F(200), X(200), Y(200)
     FORMATC' RM = +, E10.3/)
  98
  99 FORMATC PAX AND Y ARE IN META)
      FORMAT( + F IS IN KN. +//)
  91
      FORMATC* *, SX, *T/TE*, SX, *F*, 10X, *F*, 11X, *X*, 11X, *Y*/)
 100
      FORMAT( + 11, 5(E10.3, 2X))
 101
      READ(5,+) N
      READ(5,+) (T(I),I=1,N)
      READ(5,*) (=(I),I=1+N)
      READ(5,+) F"
      PI=3.14153
      RMM=-RM
      WRITE(6,98) RM
                                        NO. 1
      WRITE(6,99)
      WRITE(6,91)
      WRITE(6,100)
      TM=0.
      FH=0.
      DO 1 I=1.N
      RX=R(I)/1000.-.059
      F(I)=1.0737+(1./(1.-26.027+PX))++1.4-.78798
      X(I)=R(I)+CCS(2.*PI+T(I))
      Y(I)=5(I)*SIN(2.+91+T(I))
       IF(T(I).GT.IM) THET(I)
      IF(F(I).GT.FA) FM=F(I)
      WRITE(6,101) T(1),F(1),P(1),X(1),Y(1)
  1
      CONTINUE
      FM=1.1+FH
      CALL PAPER(1)
       CALL CTRESIT(1)
      CALL PSPACE (0., 1., 0., 1.)
      CALL MAP(0.,1.,0.,1.)
      CALL PLOTOS(.2,.3, CAN (ACTUAL SIZT), 17)
      CALL GRNPEN
      CALL PSPACE (+05++6221++35++3221)
       CALL MAP(RMY,RM,RMN,RM)
       CALL AXES
      CALL BLKPEN
      CALL PTPLOT(X,Y,1,N,248)
      CALL CURVEC(X,Y,1,1)
      CALL CURVIC(X+Y,1,N)
      CALL PSPACE (0.,1.,0.,1.)
      CALL "AP(0.,1.,0.,1.)
      CALL PLOTOS(.75,.28,*F*,1)
      CALL PLOTOS(1.,.05,*T/TP*,4)
      CALL PSPACE(.3,1.158,.1,.382)
      CALL MAP(0.,TM,D.,FM)
      CALL AXES
      CALL REDPEN
      CALL PTPLOT(T,F,1,N,248)
      CALL CURVEC(T.F.1.N)
      CALL CURVEC(T,F.1,N)
      CALL GREND
       STOP
       END
```

D8

see program NO.2 for Executive)

0

Input

58 0. .0248 .0528 .0906 .108 .136 .164 .192 .220 .247 .275 .303 .331 .359 .386 .417 .442 .470 .497 .525 .553 .581 .608 .636 .664 .692 .720 .747 .775 .803 .831 .859 .886 .914 .942 .970 .997 1. 60.2 60.9 61.8 63. 64.1 65.8 67.2 68. 79.2 71.2 72.7 73.5 75.1 76.5 76.9 76.7 76.3 76. 75. 73.8 72.1 70.9 69. 64.5 61.5 60.4 60. 59.7 59.4 59.1 59. 59.2 59.8 59.6 59.3 59.5 60. 60.2 A0. RM = 0.8002+02

ROX AND Y ARE IN MM

F IS IN KN.

T/TP F R X Y, 0.0 0.3345+00 0.6025+02 0.6025+02 0.0 0-2435-01 0.3652+00 0.60 95+02 0.6025+02 0.9455+01 0.528E-01 0-4062+00 0.6185+02 0.5845+02 0.2015+02 0.8065-01 0.4645+00 0.6305+02 0.5512+02 0.3065+02 0.103E+00 0.5235+00 0.6415+02 0.4952+02 0.4025+02 0 • 1 36E+ 00 0+6225+00 0+6585+02 0.4325+02 0.4962+02 0.1645+00 0.7155+00 0.6725+02 0.3465+02 0-5765+02 0.1925+00 0.7722+00 0+5905+02 0-2425+02 0.6355+02 0.220E+00 0.9512+00 0.7025+02 0.1325+02 0.6905+02 0.247E+00 0.1052+01 0.7125+62 0.1345+61 0.7125+02 0.2752+00 0.1205+01 0.7275+02 -0.1145+02 0.7185+02 0.3032+00 0.1352+01 0+739E+(2 -0.242E+02 0.6985+02 0.331E+000.1512+01 0.7515+62 -0.3665+02 0.6562+02 0-3595+00 0+1732+01 0.7652+02 -0-4845+02 0.5927+02 0.3862+00 0-180E+01 0.769E+C2 -0.580E+02 0-5055+02 0-417E+00 0-1762+01 0+7675+02 -0.6652+02 0-3825+02 0.442E+00 0.1692+01 0.763E+C2 -0.7135+02 8+2725+02-0.4705+00 0.1645+01 0.7502+02 -0.747E+02 0-1425+02 0.4975+00 0.1492+01 0.7505+02 -0.7505+02 0+1415+01 0.5252+00 0.1338+01 0-7395+(2 -0.7255+02 +0+1159+02 0.553E+00 0-1145+01 0.7212+02 -0.6812+02 -0.2365+02 0.581E+00 0+1025+01 0-7095+02 -0.6195+02 -0.3455+02 0.608E+00 0.8502+00 0+6905+02 -0.537E+C2 -0.4335+02 0.636E+00 0.5455+00 0+545E+C2 -0.4235+02 -0.4861+02 0.6642+00 0.3925+000.6155+02 *0.316E+02 -0.5275+02 0+692E+00 0-343E+00 0.6047+(2 -0.2158+02 -0-5645+02 -0-7202+00 0-326E+00 0.600E+C2 -0.1128+02 -0.5895+02 0.7475+00 0.3145+00 0+597E+62 -0+1135+01 -0-5775+02 0.7752+00 0.3022+00 0+5945+02 0-9295+01 -0.5975+02 0+803E+00 0.2902+00 0.5912+02 0.1935+02 -0.559E+02 0.831E+00 0.2865+00 0.5905+02 0.2875+02 -0.5155+02 0+8592+00 0-2945+00 0+5925+02 0-374-+02 -0.4595+02 0-8862+00 0.316E+00 0.598E+02 0+4512+02 -0-3532+05 0.9142+00 0-3102+00 0.5962+02 0.5115+02 -0.3075+02 0-9425+00 0-2985+00 0-5235+02 0-5548+02 -0-2115+02 0-970E+00 0-3062+00 0.5965+02 0.5845 + 02-0+111E+02 0.9975+00 0 + 326E + 000.6005+02 0.60CE + C2-0+1135+01 0-100E+01 0-3345+00 0.6025+02 0.6025+02 -0.3055-03

Output





```
FILE: CAM
                FORTRAN A LEEDS UNIVERSITY VM/BSE 6.16
        DIMENSION T(200),F(200),F(200),X(200),Y(200)
        FORMATE . RF = ++= 10.3/1
    98
       FORMATC + RYX AND Y ARE IN MM //)
   99
   91
        FORMATC + F IS IN KN.+//)
       FORMATC * * .5X, * T/TP * .9X, * F * .107, * R* .11X, * X* .11>, * Y*/)
  100
       FORMAT( • ,1X,5(E10.3,2X))
  101
        READ(5,+) A
        READ(5,+) (T(I),I=1,N)
        READ(5,+) (F(I),I=1,N)
        READ(5,+) RN
        PI=3.14159
        RMM=-RM
        WRITE(6,98) RM
                                     NO. 2
        WRITE(6,99)
        WRITE(6,91)
 í
        WRITE(6,100)
        TH=0.
        FM=0.
        D0 1 1=1,4
        R(I)=59.+38.4216+(1.-(1.0737/(F(I)+.78758))++.714296)
        X(I)=R(I)+CCS(2.+PI+T(I))
        Y(I)=R(I)+SIN(2.+FI+T(I))
       WRITE(6,101) T(1),F(1),R(1),X(1),Y(1)
        IF(T(I).GT.TM) TM=T(I)
        IF(F(I).GT.FN) FN=F(I)
   1
        CONTINUE
        FM=FM+1.1
        CALL PAPER (1)
        CALL CTRENT(1)
       CALL PSPACE (0., 1., 0., 1.)
        CALL MAP (0.,1.,0.,1.)
       CALL PLOTES(.2..3, * CAM (ACTUAL SIZE) +, 17)
        CALL GENPEN
       CALL PSPACE (.05, .6221, . 35, .5221)
        CALL MAPER PF.RM. RND , RMJ
        CALL AXES
        CALL BLKPEN
        CALL PTPLOT(X,Y,1,N,248)
       CALL CURVEC(X,Y,1,N)
        CALL CURVEC(X,Y,1,N)
       CALL PSPACE (0.,1.,0.,1.)
        CALL MAP (0 . , 1 . , 0 . , 1 .)
        CALL PLOTES(.75, .23, .F.7, 1)
       CALL PLOTOS(1.,.05,*T/TP+,4)
       CALL PSPACE(.8,1.158,.1,.382)
        CALL MAP(0.,TN,0.,FN)
        CALL AXES
        CALL REDPEN
       CALL PTPLOT(T.F. 1.N. 246)
        CALL CURVEC (T.F. 1,N)
       CALL CURVEC(T,F,1,N)
       CALL GREND
        STOP
             . 5
       END
```

Executive

EXEC SETUP FORTRAN NAGE COGHOST FI 5 DISK &2 DATA FI 6 DISK &3 DATA LOAD &1(CLEAR EXEC PLOTFILE &4 SET BLIP *

Input

28 0. .01 .025 .05 .1 .15 .2 .25 .3 .35 .4 .45 .5 .55 .6 .625 .65 .66 .675 .685 .7 .75 .8 .85 .9 .95 .975 1. .1 .15 .24 .4 .7 1. 1.33 1.64 1.9 2. 1.95 1.8 1.38 .55 .52 .305 .1 .06 .04 .04 .04 .04 .04 .04 .04 .04 .04 .1 80.

D15

RM = 0.800E+02

Output

ROX AND Y ARE IN MM

F IS IN KN.

1

1718	r	2	x	. Y
0-0	0.1007+00			
0-1005-01	0.1502+00	0.5345+62	0+5342+02	0.0
0-2505-01	0.100.400	U+551E+02	0.550E+02	0.3452+01
0.5005-01	0.2401+00	0.578E+02	0.5715+02	0.7047+01
0.1005400	0.4001+00	0+6172+02	0.5877+02	0.1917+02
0 1505-00	0.1001+00	0+6705+02	0.5423+02	0.3945+02
0.0002+00	0.1001+01	0.7071+02	0.4157+02	0+572*+02
0.2502+00	0+123=+01	0.738E+C2	0.2285+02	0.702-+02
0+2002+00	0.164:+01	0.760E+02	0.9632-04	0.760-+02
U.SUUL+UU	0+1902+01	0.775E+C2	-0.239E+02	0.7375+02
U + 350E+00	0.2001+01	0.7805+52	-0.4585+02	0+6317+02
0-4002+00	0.195E+01	0.7775+62	-0.6255+02	0.4577.02
0.4502+00	0.180E+01	0.7695+02	-0.7325+02	0.2395402
0+500E+00	0•138E+¢1	0+7425+02	-0.7425+02	0.1997-07
0+5502+00	0.950E+00	0.7025+02	-0.5675+82	
0+6002+00	0.520E+00	0.641E+02	-B-5125+D2	
0+625E+00	0.305E+00	0.5755+15	+0.421=+02	
0.650E+00	0+1002+00	0.5347+12	-8.31 ACA02	-0.421:402
0+6605+00	0.6002-01	0.5197.02		-0-4325+02
0-575E+00	0.400E-01	0+5125+02		-0.4397+02
0.6852+00	0.4005-01	0.5125+62		-0.4565+02
0.700E+00	0.4001-01	0-5128+02		-0+470=+02
0-7505+00	0.4005-01	0.5120+02	-0.1000 07	-0.4275+02
0+800E+00	0.4002-01	8-5125-02	-0.1925-03	-0.5125+02
0.8505+00	0.4005-01	8-5125-02	0.1081+02	-0+487=+02
0.900E+00	0.4007-01	0.5125+02	0+3015+02	-0+4145+02
0.9505+00	0.400-01	0.5125+02	9+414:+62	-0.3015+02
0.975E+an	8.4007-01		U+487.+C2	-0.1591+02
0.1002+01	0.10001	0 5745+02	0.5057+(2	-0.8005+01
· · · · · · · · · · · · · · · · · · ·	- U U - TU U - TU U - TU U	0+0342+02	0+5347+02	-0+2715-03
	and a second			

D16





APPENDIX E

COMPUTER PROGRAM FOR THE PLANE INCLINED

SURFACE BEARING MODEL

.

FORTHAN A LEEDS WAIVERSITY WHIRSE 6.16 FILC: 1

٠.,

FILE: N FEATRAN & LEEDS UNIVERSITY WYRSE 6.16

.

		6		80 5 f
	P 0002	99 FORMATCE 93		0057
E PLANE INCLINED SURPACE NOTEL		101 FORMATC		0055
	* 6014	۸۹		0059
			•	0060
THE GEORGIAN OF A RIGIC CYLINCIR SLIDING CN A LUBRICATED				0061
CLARTIC LARCA (PRP.3) BORCED TO A RIGID FLANE IS APPROXY ATED	P 8887	1400 FCRMATCH TOL CTOLERANCE FOR SS AND STEP SIZED		0062
AS & PLANE INCLINED SURFACE. THE LUBRICANT IS ISCUISCIUS.	* coee	1481 FORMATCH NO CINITIAL GUESS FOR NO AT TIME FERDE		0063
THE LOAD ME WELGCLIV ARE CYCLIC TIPE VARYING.	*	1402 FORMATCO NEER (MAR. NO. OF CYCLES AT SAME STEP SIZE)	- 10	0064
TT IS ASSUNCE THAT THE FILP THICKNESS VARIATICS WITH TIME	4 00100	1403 FORMATCA NHALF CPAR. NO. OF STEP SIZE HALVINGED		0065
CAN BE APPRESENTED AS DIS/DT. THE LENGTH OF THE PLANE	P 89110	1484 FORMATCE NEPTP CINITIAL NO. OF STEPS PER CYCLED		0066
SURFACE IS CHARTEN SUCH THAT CP/CR = 0. AT X = 80PY/2.	¥ 00120	1405 FORNATCO APAT (NO. OF STEPS FRINTED PER CYCLE)		0057
THE INCLINATION OF THE PLANE SLAFACE IS CHOSEN SLCH THAT	· 00130	1486 FORNATCH IPRT (CONVERGENCE FRINT IPTICN)		0066
FOR THE INSTANTANEOUS CONCITIONS OF LOAD AND VELOCITY	. 00140	1407 FORMATCO NPX (NO. OF PRESS. PTG. PRINTED PER DIST.) (15)		0065
THE MINIPUP RECART STATE FILM THICKNESS EQUALS THAT		1409 FORMATCE NET (NC. CF PRESS. CIST. PALATED)		8071
PRESSCIED OF AN APPROPRIATE FORPULA IN THE LITERATURE	# C0160	1409 FORMATCE VF CPRIAT CPTIONS FOR PRESSO DISTOR ACCOUNTS (18)		0071
FOR THE CYLINCRICAL GEOMETRY.	# 00170	1410 FORMAT(* VI CABSOLUTE VISCOSITV)	20	0072
	¥ 00170	1411 FORMAT(* TP (CYCLE PERIOD)		0071
	00150	1412 FORMATCH E CELASTIC MODULUS OF LAYER)		0074
	P 00280	1413 FORMATC" R (PEDUCED RADIUS)	w	8075
INPLICET REAL-#64-11.0-23	· 00210	1414 FGRMAT(* TH (LAVER THICKNESS)		0876
REAL+* ####################################	· 00220	1415 FORMATCO HE (WIDTH OF CONTACT)		8071
• #PR (201), #PH2(901), ##(201), PPA>(41), 80(4001), FCC(4001).	M 00230	1416 FORMATCY UAMP CAMPLIT. OF ENT-VEL-1		0371
+ ####################################	. 00240	1418 FORMATES XFACT ESCALE FACTOR FOR PLOTS		0079
• #1.32,43,44, 11, 12, 13, 14, PFAC 1, HFACT, FFACT, PPAK1, XPH 21	P 00250	1419 FORMATE " HEACT (SCALE FACTOR FOR PLOTS)		0000
COMMON TOL, TOL, HO, VI, TP, S, A, TH, WC, UAPP	P 00260	1420 FORMATCH FFACT (SCALE FACTOR FOR PLOTS)	¥	00 41
COMMON PR4202,413,PHZ(201),BH(400),EFF(401),BHP(401)	4 60270	1421 FORMATCO PFACT (SCALE FACTCR FOR PLCTS)		00.82
COMMCA: A6153,A16153,PD6153,AH6153,W16153,D1(15)	W 00280	C	*	60.83
COMMON TFC 1683 .FE (100), FP (100), 11(100), 011(100), TP(100)	M 09290	C	۲	00.44
COMMON T2+H2+U2+F2+B2+AH2+XH02+FR2+CH1+CH2+DT+BH2+X4	4 60300	1599 FORMATE/* ACTE : FOR SS TOLERANCE EGUALS .1+TCL*/)		0095
COMMCN UE (400) , FPR(400) , FU(400) , BF(400) , x*1(400) , x++(401)	# 00310	111 FORMATE		00*6
COMMCN ##1 (480) . H (4 08) . HST (280) . UC. FPT. 8C. 8C. 7 . 11 . HH	P 80320	112 FORMATC * 11+3(C14.7,2X).10)		0047
COPROX NPERONNALFONSPTPONPATO IPRTONPXONFTONPONA ONF	· A0320	114 FORMAT(* *,6X,*T/TP*,12X,*TIPE*,12X,*LCAD*,13X,*FP*/)		0088
FREVIJ#EEVI+UGJ/EFPG+X4GJJ+EE=D0+CLCEEI=C0+X4G+B6/+GJ	¥ 00 340	115 FGRMAT(* *18+4(C14-7-2K)-12)		.06.89
A =12.C8+AP6+B6/(2.D0+h6+XM6+B6))-((6.D0+1)/(FP6+KP6+c2))	# 80.359	116 FORMATCO ++++ INFUT CATA ++++/)		0000
A	* 00.3E0	117 FORMATE ++++ OUTPUT DATA +++++		0031
¥{ ¥I } =2.08= ¥I + 46+86/ (H6+F #6)	P 00370	WRITE(6-101)		0072
P(X;MG;8G;XMG;FG;LG)=12;D4+V]+{BE-X}+X-{XMG+LG-FG}/	P 00360	WRITE(6+116)		0093
A ((2.08+bG+XPG+26)+(HG+XPG+X)++2)	W 00350	WRITE(6.101)		NAGA
	P 00400	WRITE 66 1988) TOL		89.74
INPUT		WRITE(6-1401) HG		0086
	V 00420	WPITE(6.1412) NPER	5	00.6
READ(5++) TCL+HB+NPER+NHALF+NSPTP+NFRT+IPRT+NPX+NPT+NP	N 00430	MRITE(6.1463) AMALF		0077
READ(5++) VI+TP+E+R+TH+WD	¥ 00440	WRITE(6.14C4) NSPTP		00-0
READES + J UAMP		WRITE(6.1405) NPRT	-	01 00
READ(S.+) JFACT-HFACT-FFACT-PFACT	¥ 00460	MRITERS LANGE IPRI		0100
READ(54+) NA	W 00429			0101
(AP. 1=1.4[)4 ()4 ()4 ()4 ()4 ()4 ()4 ()4 ()4 ()4 (¥ 00470	WRITE (6.14CP) NPT	-	0102
READ(5,+) (A1(1), 1=1.4A)	W 004-0			0102
RTAD(5.+) (PC(1).1=1.NA)	997770 9 60526		.	0104
READ(5.+) BF				0102
			-	0105
ガレベンサ ふちてん しょてん しょうし チェルクジア ダー・ション			-	
READ(50+) (FE(I))III)///	V 00520	MRITE(6.1413) B		01 0 0
READ(5)+) (FE(I))[=1,97)	- 00520	WRITE(6,1412) R WRITE(6,1412) TH	*	01070

5

. .

			FILET	N FERTRAN A LEEUS UNIVERSITE FERTRAN		
ILER H FEATRAN, A LEEDS UNIVERSITE MAUSE LEIS					•	8 166
약상 수업에서 상황하는 것은 것은 것이 있는 것은 것이 있는 것이 있다. 같은 사람에 있는 것은 것이 있는 것이 있는 것이 있는 것이 있는 것이 같은 것이 있는 것이				TCL=.130+TCL1	#	0167
MATTRALLAISE LETT	- VL 	120		IF (CHI.LE.TCL) TOL=TOL1	P	0165
WETTER ALL TATES IF ACT				IFECHILLE.TELD GETO 3	¥	016
INTERALISTS NFACT				1F(*.50.1) 6CTC 4		0170
MARRELITATES FFACT		1 5 6 8	- 1	TOL=.138+TCL1	¥	0171
		128	<u> </u>	CH2=CH1	•	0172
	- V.	1100	•	0 1=-1.00	#	2173
				TECJ. NE.11 ASENSETP/2		0174
	F . VI			TECH.ME.1) AS=NSPTP	•	917:
				01 2884 L=1+NS		0176
		200			#	0177
		1<10		15((J.N. 1).AND. (W. 20.1)) L1=2+L		81.75
		1550	-	OF TO ARSC (NELL) - HST (L))/HEL1))		0175
		15:4	× ⁻	TEROF. GT. DF1) CF1=CF		01.00
		1544	-			
	• •1	12:0	2004	eus ande eus aftes		
		1260		TELECHOLIS AND (CHI.LE.TOL)) SOTE 6		
	· • •	1278	-			0173
		12-0	C	TOTAL SALLA CALL CHOUT		8124
THETTETTMETATION	· · · · · · · · · · · · · · · · · · ·	1290	-			01-2
PPEID PFEEID/DD	- 01	1 200	G		, F	0166
	₩ 01	1 310	•		•	01-1
##ITE46,99)	* 01	1 7 2 0		00 2005 7=10NSP/P	M	
UR TTETE, 114)	₩ 0 1	1320		HST(N)=HCM)		0199
03 1002 I=1.MF	· 01	1 240	2095	CONTINUE		0171
HOITECS, 1123 THEID, TEEID, FEEID, FEEID, 1	w 01	1 350		IF(CH2.LE.TCL) GOTO B	•	01-1
ARE CONTINUE	₩ 01	1360		IF(4.EQ.1) 60TO 2003 '	🗭 -	0192
MRITE(6.99)	· • 01	1.3.70		CONTINUE	¥	0193
MAITE (6.101)	• 01	1 3 90		IFICHI-LE-TCL) GCTC 7		8194
10275 (6.117)	v 81	1356	2003	CONTINUE	۳	0195
	v a1	1400		IFCIPRT.EQ.11 WRITE(6,201)	4	819(
FILM		1417		IF(J.EQ.NHALF) GOTO 2002	P	8191
		1420		GOTO 10		01.9/
FORMATER +++++ COES NOT CONVERGE TO SPECIFIED TOLEMA		1 4 30	9	H0=H1		
FORMATE BOES NOT REACH STEADY STATE			10	DT=DT1/(2.C0++J)		0201
A ROOMATES STEP SIZE IS HALVED"				NSPTP=2+NSFTP	· •	020
			2002	CONTINUE		820
	- 01			WRITE(6.200)		828
			6	CONTINUS		020
1937 VEF 17 1961 - VEF 17		1470	r -			020
	P 01	1970	•	CALL CYOUT	-	020
	- 31	1702	~			920
	- 01	1710	C			020
	• 01	1520		BCAFFF		920
tee Continut	¥ 01	1520	C .			020
DO 2002 Jalenar	₩ Q1	1540	Ç		· · · · ·	021
TOLTICLI	- 01	1550			•	021
CH2=1.0C6	✓ 01	L560		UGEUZ	¥	021
IF(IPRT.50.1) WRITE(61101)	₩ 01	570		FPG=FPZ	P	021
IF (CIPRT-EG-I)-AND-CJ-NC-LJIMEILC-JEUJ)	₩ 01	15#0		FG=FZ	v	021
D0 2983 4=1.APE	· · · · · · · · · · · · · · · · · · ·	1590		86=0Z	v	021
HITMO	₩ 01	1400		x=G=x=Z		021
	• a1	1610		IF(XHG.LQ.C.CO) FRZ=TEVIJ	•	021
CALL NUTRT	u 01	1429		IF(X*G.GT.O.CO) FRZ=FR(VI)	×	921
	· · · · · ·	1 6 30		DO SOOQ I=1+NSPTP		021
	- VI V 01	1640		HG=HCI)	•	627
THE ALL TO AN AND AN TO THE ARC (TPRT-SQ-1)) CALL TUTLY				116-115 (T)		•

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			N 07760
3		7942 F20MAT(* S =*.C11.4)	× 02770
	- UZ 2 IV	7445 FC244760 2 =40211040	N C2780
		20 5000 (I=1-10	W 02740
	• 02220	Hall 6 . 34)	¥ C2F08
		SHOR CONTINUS	N 02*10
TA A DOB FEICISTY VIS	V 0221V	45.45.3003	w 02#20
CANADA FRICISFREVIS	- C27EU	Nal1566.99J	# 02120
	• • • • • • • • • • • • • • • • • • • •	WRIT-66-3013	W 02840
	· 05566-	M- 7=H 7+ # 2+ 68H 2/2+D 93	N 03845
	V 92270	A1 =1	N 02#48
	- 02300	WRITERS, 382) TZ. MCZ. FFZ.LL	N 02870
C	- G2230	DC 5301 J=1+AFRT	W 02980
	. 02320		W CORCA
	· · · · · · · · · · · · · · · · · · ·	TEU-NCPTP/APRT	W 02500
A LAND AND AND AND AND AND AND AND AND AND	P 02340	TFLITOT	W 02910
	W 02330	XHC=H(I)	N 02928
no transformer MZ+BZ+EZ-FZ+UZ)	N: 02350	XHC=HEID+XPICID+CEHCID/2.000	NF PC3 - W
	- U2270	XFO=FRT(T)	M 879A8
		HAITE (6.382) TOLOBHCONFROLL	* 02950
AA-DITUTUTUTUTUTUTUTUTUTUTUTUTUTUTUTUTUTUTU	P 023-0	SOAL CONTINUE	N 02560
042411 #07444.00+CS4FT(FPZ+E/(12+C0+PI+F))	- U2400	NPIT: (6,99)	W 02570
	- UZ-IU - 07470	MR172(6,300)	N 02950
	- 02 429 - 07 430	r	W 83968
	- 12 330	C DIMERSICALESS FARAPETERS	P 0299V
	- UZ		× C3010
	- UZ-JU	EP=2.00+E/.7500	- CJUIU
	N 02420	UAA=UAPE+2+CO/PI	N 03630
	- C2470	UUU=VI+UAA/(CP+*)	- C303V
		E V N = 0 . D0	N 03040
	N 02500	CDC=0.C0	N 03060
	N 02510	NFPI=NF-1	P 03020
	w c1520	D0 7979 I=2+NF"I	N 03080
x = (x - 13 + (BE/NP X)	M 005 30	J=I-1	02020 4
DitKed)=P() offotGotGotFGoUG)	• 02540	JF = (J / 2) + 2	× 03100
ADD CATINE	W 62540	IFCUF-IQ-UP EVEN=EVEN+FPCIP	W 03110
Ax=9H6/(2.C0.TH)	¥ C2548	IF (JF.NE.J) COD=CCD+FP(I)	¥ 03120
CALL EDIACF (NAI+AX+A+PD+VI+SI+NA+PDY)	# 02570	7979 CONTINUE	w 03130
PH2(J)=PDY+4.D0+CS4RT(FPG+5/(12.C0+FI+R))	W C25#0	FAP=((1.3C/NF#I)/3.00)+(2.C0+FP(1)+4.C0+700)+2.C0+144	P 03140
ADDI CONTINUE	W 02500	₩₩₩₽FA₽/{⊆F+₽}	¥ 03150
	¥ 02000	SSS=EP+TP/VI	P 03160
	V C241A	DDC=TH/R	* 03170
	* C2620	ur 172 (6.97)	¥ 031P0
301 FORMAT("	N 02670	Weitersters	02170 4
301 FORMATCO *+68+*TIME*+138+*FC*+118+*F C**+F*//	¥ 02640	WRITECS.79ECD UUU	¥ 03280
302 FJPMAT(* * 11x - 3 CD14 - 7 + 2 X) - 18)	V 02658	WRITECup79810 adda	* (3210
303 FORMATCA TIPE =*+614-7/1	N 57669	WFITF(5,7952) SSS	¥ 03220
304 FCONATE +,78, * #*,148, * PRESSURF */)	W 107670	W-ITE 66079633 USC	r r3270
305 FORMAT(* +11,2(014.7,2X),1E)	+ P7786	c	× 03240
306 F DK 44 T (*	¥ 02199	c .	* 03250
· · · · · · · · · · · · · · · · · · ·	₩ 027CB	W# 1*E(5+39)	V C3260
307 FORMATCH MARAHUM DRY CONTACT STRESS =*+514+7//3	¥ C2718	WRITIC6.JOCH	• 03270
388 FORMATC+ FF =++, 114-7/3	W 02720	IF(4P.16.0) 6779 17	* 03280
309 FORMATCE DEV CONTACT LENGTH #4-014-7/7	v n2734	DC 5001 1=1.10	" C3250
7939 FORMATCH SARS DIPENSIONLESS PARAPETERE SARS-73	* C274P	最先までもというない。	¥ 63200
7950 FORMATE* U =*+011+++	P 02750	5002 CONTINUE	
7961 FORMATCH W #4:011-43			

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	수 있는 것이 가지 않는 것 같아요. 그는 것이 아니는 것이 아니는 것이 가지 않는 것이 하는 것이 같아.	¥	C3317		FF(K)=FRI(I)		03 ° 7	10
	MRITE(=+306)		03329		BHPEKJ=BHEIJ		0346	20
			03330		8FP(K)=8F(1)	•	0384	»0
	WETTERS 3020 T2	•	03740		xMH(K)=x#1(I)		03°f	00
	14 11E (8,302) FRZ		03320		FPP(K)=FPP([]/FAP	Y	03=1	10
	1427234533551 3H2	•	03740	÷ '	UUCK)=UISI)/UAA	*	0397	20
	METTELS.307) PHZ(1)		03370	6000	CONTINUE	¥	63=;	30 📖
	VX7 TC11-384 P	🗰 🐪	03700		FP*4X=0.	v	034	40
			05140		UPAX=3.	•	03.04	50
	DO 3483 I III	w	33400		N=hJPTP+1	H	0346	£0
	x==1==================================	· •	03410		00 6001 I=1.M		03=7	70
		•	03420		[F(FPP(I).GT.FPMAX] PPMAX=PPP()		03.44	#0
	NR17156+3867 X+4P,2	#	03430		IF(UU(I).GT.UPAX) UPAX=UU(I)	· •	0394	c ()
5803	CONTENSE		83447	6001	CONTINUE	M.	04 C f	C 0
		- 🖌 📂	03450		FPMAX=FPMA>+1+1	*	0401	10
	Dg 5184 J=2+12		03460		UMAX=UMAX+1.1	M	C407	20
	TPL=(4+1)+(TF/5PT)	#	23470		CALL PSPACE(G.,1.,0.,1.)	v	040	75
	KKX6J-1J-6+1F7#F1+FT5		n 34=0		CALL *AP(3.,1.,0.,1.)		0404	4L
· .		10	83490		CALL PLGTCS(.06+.37+"H"+L)	¥	G401	t 0
	URITELS, JOE)		03500		CALL PLOTCSC. 47. 1, 1 T + 1		04.27	60
1.414	MQITE(5.99)		03519	С	CALL PLOTOSI.06+.ET.FF. 13	•	040	70
	MRITECO, JDI TPL	•	03520		CALL PLOTOS (. 47+. 54, "T" +1)	•	0401	.0
	UR: 15(6,99)		03520		CALL PSPACE(.115715		0401	90
	MRITE(S,JOE) FPR(KK)	**	03540		CALL WARGO., TF1, D., FFACT)	•	041/	00
	MRITE(6,305) ENCERT	<u>.</u>	03550		CALL BORDEF		C41!	10
	WRITELG.JOFF PHZCJI		03560		CALL AXES	P	041	20
	WR27265,304)	W '	C3570		CALL BLKPEN	¥	041	30
	#1==+PX+1		03590		CALL CURVECCTT.AM.1.AV	v	041	40
	DC 5005 K=1+NI	w	03550		CALL BLKPEN	¥	041	50
	x==1.30={K=1}=(BF{KK}/NPX}=0"KK}/2"	•	C 3600		CALL PSPACE (+11++5/++5/++7)	•	041/	60
		۳.	03610		CALL MAPCO., TPI, O., FFALID	•	341	70
	URITE(6,305) X,X ^e sk	. ۲	03620		CALL BORDI"	v	. 041	80
5005	CONTINUE	w	03630		CALL AKES		041	ç0
5004	CONTINUE		07440		CALL MLAPIN	v	C42/	C 8
	Na112(0+32)	•	03650		CALL CURAFERSTAL ATAMA	*		10
•	WR 112 (6, 300)		03660		CALL FRATI		042	20
17	CONTINCE	•	03670		CALL BLARTAN	•	642	30
C		•	03680		CALL PSPALLADORIAN	۳	042	40
C	VISUAL		03690		CALL #APS 0.0107047447	•	042	50
C		. •	03709		CALL PLUISION TOCING TO TO TO	*	042	60
		*	03710				042	70
			C3720				042	70
		M	03730		$\begin{bmatrix} CALL & PLUFCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC$. *	042	40
		•	C 37 40		CALL MACED TOTAL ALALA	P P	043	00
		•	03750		CALL PAPEDEVICE VICE PARE	Y	043	19
			03760			v	043	20
		*	03770			P P	043	20
	BFP(1)=02	¥	C37#7		CALL DUNCENTER HISTORY	v	043	. 40
		٠	0379		CALL CO VICETTATION	v	C 4 3	10
	R = 14 f = 1		0.3907		CALL DEV =		642	
	FFF \$ 4 = ** = 5 = **************************		03010		CALL PAPED. TP1.C. FP"AX)	· ·	043	.70
		M	03-27			•	U 4 3	
	UC UND A-REAL T	•	03 - 30		CALL ANT	•	5 #U 	:7U
	n=*** T+fes=***T/TP	•	0354U		CALL BLKPEN	•	044	
	MG(K)=A=0.7	•	02,20					

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	· 사람들은 방법에 가격 수 있는 것이 있는 것이 같이 있는 것이 있는				CALL JOINER3,73)		04 ° 70
	CUPUECETT SEPP-197		84 4 28		CALL JOINER40840		04 9 20
	154NB -40-53 6CT3 27				CALL BLKPEN		04550
				6882	CONTINUE		05000
		·		29	CONTINUS		05010
			74429	• /	CALL GRENC	, ju	05020
		5	84 46 9				05030
			94414				05 0 48
		· •	04478	•			05040
		•	84458			- 5-	
			64580	C	AND ANT THE CHANT	-	03020
		· 😐	64510	-	2088 001 145 CAGOA		05070
		单 .	84520	C			05080
			84538	C		- 11	02040
			84540		INPLICIT RELATION OF THE MOLING	H	05198
			84559		COPMEN TOLOTOLIOPO, VICTORIO CARDO CARDO AND AND (401)		05110
	09 6893 [=34N5		84563		COPMCN PR (201.41), PHZ(201), PHC (0),		05120
	###T\$#~1.08+#T#1\$+#F##/#P#+##############################		84570		COPNON ACLED ALCIST POCISTANCE POWLED TOLLIDE THEIDE		05130
	#xet1=##13/#				COPPON TF(100), FE(100), FP(100), SII(100), SI		05140
	VALUE TARGET AND AT		843-0		COMMON T2+H2+U2+FP2+F2+B2+XH2+X 4C2+FR2+CH1+CH2+U1+CH2+A		45150
			04240		CONMON UF (400) . FPP(400) . FU(400) . BF(400) . X (400) . X FF(401)	-	
6083	CONTRACTOR AND A CONTRACTOR A	· · · •	04607		CONSCIENT (ABO) - MEABOD - HSTEZEDD - UC .FPT. BC.BCRT.TI.HM		02100
	ADMS7.26MS8.4325.		04619		COPICAL FALLS NEDTO MOST STORT NPY NPT NP NA NF		05170
	" 其主宰其第《王》 [1] [1] [2] [1] [1] [1] [1] [1] [1] [1] [1] [1] [1		24622		COPYCE NPERSONALLY GOT FOR STATES		05180
	Y13.7+MFACT		04630	98	FORMAT(* *•//)		05190
	2 * * 1 · · · · · · · · · · · · · · · · ·		84648	99	FCRNATCY *3		85200
	Y2 HI		04650	1 80	FCRMAT(* *,6X,*TI*E*,13X,*HQ*,11X,*ENT VEC (124)		05210
	W1-WY(M1)		84(68		• • • • • • • • • • • • • • • • • • •		65 2 2 8
	WI-HUATEPOPPETIS/R		04560	101	FORMAT(+ + 18+6(014-7+2X) + C14-7)		05224
			84678	101	FORMATIC ANAL CONVERGES TO SPECIFIED TOLEPANCE ANALE	_	03230
			04520	102	TOTAL AND MANTHIN RELATIVE DIFFERENCE = +C14.73		05240
	¥4=¥1	#	84650	103	PURMAILS START OF STERS PER CYCLE =*-14)		05250
	XXIP = 1.00 + FAC =		04700	104	FORMATE TO STATE TO SET TELED TOLEPANCE	•	\$5268
	CALL FPAME		64710	105	FORMATE +++++ DEES NOT CONVERSE TO SPECIFIC TO THE	P	05270
	CALL PSPACE(0.,1.,0.,1.)		84720		WRITE(6,98)		052=0
	CALL MAPE 3 1 0 1 P		04730		WRITE(6+100)		r5 298
	CALL PLCTCS (-86+.37."H" +1)		04740		NRITE(6.101) TZ.HZ.UZ.FPZ.FZ.HZ.XVZ	` .	05308
	CALL PLOTOS(.471.****1)		04740		DO 1 J=1+NFRT .		05310
	CALL PLOTESS-06+.87.*P*+1)		84739		T-IN SCATAART		05310
		•	04760				05320
		¥	04770				05330
			04790		XH3=4613	M	05340
	CALL IVPINETIFLIA		04790		XU=UE(I)		05350
	CALL PSPACECULINETTING TO THE TANK		84900		XFP=FPR(I)		05360
	CALL MAPEXFACT, XXIP, 0., PFACTI		04/10	•	XF=FUCID	` u	05370
	CALL BORDER		84 928		X8=9F(])		45384
	CALL ANES	-	04 720		XM=XMI(I)		05100
		-	04730		xEa=E01(1)	-	01370
	CALL CLOWERCHERSTER, JANS)		04440		UN TTT / / . IN 13 TPL . MID. XII . XFP . XFP . XH . XH		05400
		•	04759			•	05410
		*	04 56 9	1			65420
	CALL BLKPIN	•	04 4 70		IF(IPRI-10-II) GUID 4		05430
	CALL PTPLJT(0., APH21,1,1,226)	•	04 * *0		IF((CH1.GT.TQL).ON.CCH2.GI.ICCFF GUIS L	¥	05440
	CALL BLKPEN		04950		WRITE(6,999)	v	05450
	CALL F3PAC5(+11++57++15++5)		04300		WRITE(6.192)		05460
	CALL VAP(XFACT,XXIF,0.,HFACT)	-			CONTINUE		A< A 70
	CALL BORDES		04-10	•	TE4CH1.T0.1.261 G07C 3	-	01770
		v	04 120				03440
	UNEL AND A	•	04930				05490
		•	04 547		NACA247 1243 424 4 14 14 14 14 14 14 14 14 14 14 14 14		05500
	CALL POSTORIALATE	•	74 ° 20		M41176001041 49L0L		
	CALL JJINGP2012P						

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3	CONTINUE CONTINUE WRITEIGEDED RETURN EAD		65510 05510 05530 05540 05540	C	CALL E01ACF(NAI,AHR,AH,A,W1,C1,NA,AY) 039Y=2.00+AY+TH H0=HY+(07/2.00)+G1 	P 9 9 9	06060 05070 06020 06090 06100
č	SUBRICE FIRE MINT	4 1 1	455570 05570 05570	ſ	IF(X4.EQ.0.CO) G2=Y(H0,BC,FPY) IF(X4.GT.O.CO) G2=F(T1,H0,8C,UC,FPY,X9) H0=HV+(CT/2.D0)+G2		06120 06120 06130 06140
	ITFLICIT MEAL #86A-H, C-25 CDFTT TOL, TOL1, ME, FI, FP, E, *, TM, MD, LAMP CDFNMW PM23E1, WEI, PP22201; .EMC400; .PF76401; .EMP(401) CDFNGW PF21649, FE2100; .PF015; .M11100; .D11100; .TV(107) COWTON FF21649, FE2100; .FF2, M23, XF2, XF02, FF2, CM1(CD2), CT, EM2, XF CDFNCM T2, F2, UZ, FF2, F2, Z2, Z2, XF2, XF02, FF2, CM1(CD2), CT, EM2, XF CDFNCM T2, F2, UZ, FF2, F2, Z2, Z2, XF2, XF02, FF2, CM1(400), XF4(401) CDFNCM T2, F2, UZ, FF2, KF2, Z2, Z2, XF2, XF02, FF2, CM1(400), XF4(401) CDFNCM T2, F2, UZ, FF2, KF3, XF, XF7, MF1, VF7, MF1, MF1, MF1, MF1, MF1 CDFNCM T2, F2, UZ, FF7, KF7, XF7, XF7, XF7, NF7, MF1, MF1, MF1, MF1, MF1 CDFNCM, SC, CG, CSBT(FF7, KF7, Z2, Z0, MF1, MF1, MF1, MF1, MF1, MF1, MF1, MF1		$\begin{array}{c} 05599\\ 05620\\ 05620\\ 05620\\ 05620\\ 05620\\ 05620\\ 05620\\ 05620\\ 05620\\ 05620\\ 055700\\ 0557000\\ 0557000\\ 055700\\ 055700\\ 055700\\ 055700\\ 055700\\ 055000\\ 055000\\ 055000\\ 055000\\ 055000\\ 055000\\ 055000\\ 055000\\ 055000\\ 055000\\ 055000\\ 055000\\ $	C C C C C C C	M0=HV+(CT/2.00)+62 		06140 06150 06150 06170 06170 06200 06200 06220 06220 06220 06220 06220 06220 06220 06220 06220 06220 06220 06220 06220 06250 06250 06250 06250 06250 06250 06250 06250 06250 06250 06250 06250 06250 06250 06250 06250 06250 06350 06350 06350 06350 06420 06420 06450 06550 0650
	G1=FC T1=T+ST/2+SO VC=U(T1)		04710 04727 04027	с с	SUBRCUTINE INCLIN	.u - 9 4 0 ¥ 9 ¥	65E0 65E0
	CALL EDIAJF (NFI, TI, TF, FP, W11, 311, N°, FPY) Amx=B(T1)/(2, 30, TF)	¥ #	04043 06059		IMPLICIT REAL+3(A-H;O-2) COMMCA TGL;TGLI;FO;VI;TP;C;F;TH;WD;UAMP	₩ () • ()	6550 66 00

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	ET A FORTHAN A LILUS MAININGLEY WAVEST EDIE			LIPER 12 CHEC & FILLY ANIALARYLANAGE COTO
	POWER DITCH	-	04483	FUEL STIN FORTOAL MAGE FRANKST
			04410	
			PECAS	
	FORMAL IN CALL STRUCTURE SALE SUPERAL SECTION CONTRACTOR AND A		66458	FIEL DIGTETTE LA
	CONNOL EN LAGARTANCARE MET CONTAINED TO THE STATE OF THE STATE		84448	SET ALTO .
	FORES WET MARTER STOP MET TOT WET LET LE LE		40000	START
	FRANKTE SALE CHAR BOT ACHIEVED BUILT IN BELATIVE YALTBANCEN		84489	
	PITI-141747453 19897931200		86698	
1997, 19			86788	
	IFINELLE UCHD GOTO P		86718	
	UU=2-70-HI-HI-FORS		06720	
	111=F#Y/4E+#3		66730	
	ATTE DRY/(2. CO. TH)		86740	
	IF (AV. 62.2.(0) HP=1.15900+(1.70/AV)++.427500+P+(UU++.600)/	w	86758	
	A (UL00-2218)	w	05760	
	IF(AT.LT.2.CO) HM=1.33500.41.00/(05 MP(.239604.AT))).R.(44		06770	
	A (14++.208)		067=0	
	8=0.0	۳	96749	
	A30=1.0-3++P		06200	
	DO 1 1=1.5600	w	06*10	
	D=0+AC3	w	05=27	
	8C=80R¥+41.66+0/(2.08+H8))	•	06320	
	XL S={FPY+HF++2}/(12+CQ+VT+UC+BC++2)	w	06940	
	R\$={ { { { { { { { { { { { { { { { { { {		06650	· · · · · ·
	DIFF=xls-qs	۳	06 P.E 0	INDUT
	IF (01FF-LT-0-C0) 6070 2	•	06 ° 70	
	6070 1	•	04.289	FILE: XMB. DATA A LEEDS UNIVERSITY VE/BSE 6+16
- 2	RE=ADC/D	۳.	06000	
	XK=D/HP	w.	05°00	
	IF(XK.JE.1.18830) GCTO 12	•	06710	•0001 •598614dD-6 20 5 20 20 1 20 8 1
	IF(RE-LT-1-12) 6010 9	۳.	06920	•01 1• 16•D6 •35 •0024 •026
	0±0-A03	•	06°30	.03
-		v	04940	04343 2.5 1.25-3 .155
1	CONTINUE	P	06950	13
12	CONVINUS		06960	G1 .2 .25 .5 1. 2. 4. 6. 9. 10. 20. 30.
			06773	1995 .7904 .9697 .8553 .725 .4978 .29 .1556 .1430
			06580	•11 •04591 •02671
			66963	1. 1.005 1.020 1.031 1.126 1.449 2.292 4.201 6.478 9.093
9			07000	12000 30017 32063
			07910	
			07020	U+ +U2 +L +L2 +Z +Z +J +J +J +4 +5 +5 +5 +65 +7 +75 +8 +P9
7	A7+J/00 PONT1402	-	07030	• 77 L• 167 E/1 100 10/1 1001 1641 1010 0011 017 1/00 10/0
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FILE: YHB	OUTPUT	LEEDS UNIVERSITY VP/	/BSE 6.16	
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TOL GTOLE NO CINITI UPER (MAX. UMALF (PA) UPRT (RO. IPRT (RO. IPRT (RO. UPRT (RO. UPT (RO. UP (PRINT. VI (AOSOLU TP (CYCLE E (ELASTIC R (REDUCEC TM (LAYER UD (LIDTH UAMP (AMPL KFACT (SCA MFACT (SCA	RANCE FCR SS AND AL GUESS FOR MO . NO. CF CYCLES N. NO. CF STEP S ITIAL AC. CF STE OF STEPS PRINTE VERGENCE PRINT IN OF PRESS. DIST. M OF CONTACT M CF CONTACT M OF ENT.VEL.M OLE FACTOR FCF PL LE FACTOR FCF PL	STEP SIZE) AT TIME ZEROD AT SAME STEP SIZE) AT SAME STEP SIZE) AT SAME STEP SIZE) AT SAME STEP SIZE) PS PER GVCLE) OPER PTION) ROTSD SS SS CTSD CTSD CTSD CTSD	<pre>0.1000CC02-03 0.57061400-06 20 5 20 1 20 0.10000000-01 0.10000002+01 0.10000002+01 0.160000002+01 0.3800C000-01 0.2400CC02-01 0.3800C000-01 -0.434CC02-01 0.25000002+01 0.25000002+01</pre>	

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NOTE : FOR SS TELERANCE EQUALS .1.TOL

A/TH	A/AH	P/PH		
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0.10000000-00	0.995000000+00	0-10050000+01	2 .	
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0.250000000+00	0.76570000+00	0-10210000+01	Ā, s	
8.50008000+00	8.35530000+00	0-11260000+01	° 5	
8-106000D+01	0.72500000+00	8-14490000+01	Ē	
8-20000000+01	0.49756000+00	0.22420000+01	7	
6.40000000+01	8.29000000+01	0.42010000+01	8	
8-68809060+01	8.19560000+00	0.64790002+01	ġ	
8.88000000+01	0.1420000+09	0.50390000+01	10	
0-100000000+02	0-11000002+00	0.12060002+02	11	
8.200000000+82	0.45910000-01	9. 30170000+02	12	
. 30800000+02	8-26770000-01	0-52630000+02	13	

T/TP	TIME	LCAD	≮ P	

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8C0000002-8		+0+C0802512+0 +0+C080202+0 +0+C080202+0 +0+C08024+0 +0+C08024+0 +0+C08024+0 +0+C08024+0 +0+C08024+0 +0+C08024+0 +0+C0802512+0	4.46269237+05 4.53269237405 6.74692949 6.27676729 8.2864629+05 8.46289+05			
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		8-1107550-01	0+01216923+63		10- 1606/22-0	
00+100000000+00	9-21000303-06	10-01501242-0	8 • 828 5 46 20+ CS	-0-00/18106-0-	0-22689170-01	8.25612470-0
9-+200002+09	0+56666883-06	0.26531700-01	0+62615280+ (5	-0-023520-01	0-21411990-01	0-24474463-0
]. 58988880+08	0-56587360-06	0- 2000 000 -01	0.44961542+05	8-6174C423-04	0-19926295-01	0.45822610-0
1.550000000+00	0+56712680-05	9-24531709-01	0.25864620+05	0-45547040-07	0.18139600-31	0.57462670-0
00+0000009*00	8-5714123-06	0-24270510-01	0.12500000+05	0-12464890-06	0-14654200-01	0-03424200-0
1.65000001+00	0-577+5115-06	0+13632560-01	0-56153653+04	19-C02F012F.0	0-13490913-01	0-1000 #030-0
00+03000002.1	0-57361243-06	0-92705100-02	0-13076925+04	- C - 2464 8010-07	0-12107767-01	0-00512926-0
+ 7500000+00	0 - 57504090-76	0.15695410-15	0.73076922+ 64	-0-10070733-06	0-11133237-01	0.0
	0+57123333-0 e	0-52705103-32	0.53846152+ [4	-0.38678770-07	0-12904857-01	0-67355199-0
	C-21301690-3 €	0+17632562-01	0+73076325+04	0-12035900-06	0-12659760-01	0.12409050-0
30+C000006*	0+56025203-06	3.24279519-01	0+11152313+65	0.15365990-06	0+1+306277-01	0.10766800-0
	96-06110636-0	0+2#531700-01	0+125C00C0+05	0+19765293-C6	0-14839517-01	0-1032 6602-0
		0-10-000000t to	0-15376523+05	0.17294829-06	0-15521319-01	

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3411	E					a. 98356420-05
	8-23601250-04		0-150/6723+03		A-14779850-01	8-13538413-05
	8 - C 84 1 3 8 80 - 0 F	8-26121262-81			0-1000550001	0-3143120-05
00-0000001°0	4-69612110-66	6-24275210-61			10-01695681.8	10-0-10-10-107 · 0
	0.68311527-06	0*11622363-01			6-1 91 66 78 0-81	0.19121930-05
	99-02751526-9				10-0501020-01	
0~5244460-00	0.56966233-06		29-07-27-27-42 29-07-62 29-07-62	-8-14616450-86	0-21533750-01	e-13467150-65
	•• 2955 7820-6e			-6-12441250-06	0 - 2 2 7 4 641 0 - 01	
00+7000000077 * 0			■ 82824620+ 85	-6.90100200-67	6-22689180-01	CB-06121962 0
			8-42615253+ (5	-8-40736470-67	6-21411980-01	
			C+C+SI 36++-8	89-04283489-68	9 • 1 9 9 2 6 2 9 0 - 0 1	
		18-000000000000000000000000000000000000	6-25989620+05	8 - 4554 7895-87		
		6-24276510-01	6-12508803+85	8-13464450-06	8-14654200-01	
		a.1 263 465-01	6.961E3850+84	0- 72108560-07	10-0260521°0	
		6- 32 78 1 60 - 62	9.73876929+64	-0-24647.000-07		
		6.15695410-16	6.73076923+ C4	-0-1001060-06		
		0-92705100-02	0.52646153+ 64			
		8-17632560-01	0.73076923+84	0.12005953-66		
		0-24270510-01	50+01235111°0	0.15366020-06		
		0.25531702-01	8.12500003+05	0-1976F450-66		
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	e-59161250-06		0-21576922+05	19-05220151-01	0-16770559-01	0-13532270-05
			6.1055210+CS	-0-20594190-07	0-1.60 05540-01	0-0178415-02
	0-020212020-00 0 / 0111220-02		0-40807650+C5	-0-01244130-07	0-16964970-01	8.33726590-05
		0.92705152-02	0.46269230+ 05	-0-13552022-06	0-1916670-01	6•141×1430-60
	0.58986252-06	0.10462613-16	0.59269220+ C5	-0-15652570-06	10-052128610	0.0 0.11067100-05
	0-26253480-06	6.92705109-02	0. 745769 29+05	-0-1401 5780-00 000000000000000000000000000000000		
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8. 40003007+80	0.57000530-0é	0-2421222			0.21411980-01	8.3457430-05
80+0200054*8	0.5466862D-06	0-26531700-01		80-03123160-08	0-19926202-01	0.450*2560-05
6* 256C2000+00	0-24577690-06			T0-0419554-8	0-181 3610-01	8 • 57462540-05
6-55000000+00	0.56715123-06			8-13464150-06	0.14654267-01	0.98455467-05
	0.57143093-06	10-21221242•0	0-3615136-04	10-05110121-01	0-13450910-01	0.10002040-04
			0 + C2 6 2 6 4 C 4	10-0-110-0-0-	10-C9750121.0	0.83627830+05
	9 A-39 193 / C°A	A. 156.55413-16	0.7.576920+64	-8-1007(520-C6	0+11133597-01	
		0.52705105-02	0.93f46150+64	-0-39665750-07	0-12904833-01	0-04/4/20-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-
	0-0101010400	0-17632563-01	0.13976920+04	0.1200527D-06	0 •12659733-01	
	0.59027765-06	9-24270517-91	0.11152212+C5	0.15364523-06	0-14376213-01 - ***********	
	0-5630c030-06	9.26531763-01	0.12500000+05	0-13767530-06	10-0040704140 0-0444440	
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. 	8-66431110-06	8-66875390-04	8-64326240-86	8-6444479-8C	6-61369130-66	9.0-0523-685.0	0.59636240-86	8-23673861-66	0-55765229-06	0.68171490-06		6.61484950-66	8 - 6 356 2 3 4 D - 8 4	0.63789530-06	E. 6251 6 460- 86	8 . 5 7 5 0 7 6 9 0 - 8 6	0-6126 0000-06	0-64211220-06	0-64326600-06	80-C0755894-8	0.66632830-86
Ľ		10-00000005-0	0.1000000000	00+G2C2C2C51*0	0-2000000000	80+200000000 · · · ·	0	0-13063650+60		0-0000006-0	8-3888880-88		0-00000009	9-72968000+06		0-1500000+00			8.9800880+08	. 95808000+06	10-0000001-0

DIMENSIONLESS PAPAPETERS \$888 8888

U = 0.1279C-10

M = 0.22582-82 5 = 0.42670+10 0 = 0.68579-02

LEECE UNIVERSITY YM/BSE 6.16 -0114 FILE: Y"B

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114E = 0*0

FP = 0.15076920+05

MAKIMUM DAY CONTACT STRESS = 0.16641550+07 DAY CONTACT LENGTH = 0.13765970-01

	-	~	~	•		Ψ	~	9 2)	•	91	11	12	21	•1	¥) ••	16	17	2	19	20	21	
PRESSURE	•••	9 8+0+55 +8+0 + 8	8.62521255+06	0 * 5 č 2 č 2 2 0 + 0 6	8-18649730+87	0.12182740-07	8.13323340+87	C • 1 + C2 9 2 5 1 9 • 8 1		0-14643210+07	. 10+0959269 0.0	0+13995630+07	0-13273009-07	G.12207960+07	0-14116670+07	0.97142520+06	0-01140430406	9+63216930+06	0.42772060+06	0-22630100+06	6.26095230-09	
×	0-68823830-62	0.61367170-92	6.5500520-62	8.45547570-82	0-37787210-02	0.38826560-02	0.22265900-02	0.14505259-02	78-0165444978	-0.10160599-03	-0.87767130-03	-0-16537273-02	-0-29-020-02		-8.39419330-02	-0-47573980-02	-8.55343649-02	-0-63101290-02	-0 - 70461940 -02	-0.78622633-02	-0.å6363250-02	

TIME = 0.1250006C+00

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FP = 0.36241130+05

ORY CONTACT LENGTH = 0.1746970-01

MAXIMUW DRY CONTACT STRESS = 0.32120293+07

0-61335245+06 0-11596200+07 9. 47244573-02 9. 79043889-02 9. 68 754 749-02

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PRESSURE *

CONTINUES

APPENDIX F

FI

THE CONSTRAINED COLUMN

DEFORMATION MODEL

FILES STOP FERTAAN & LEEDS WAINERSITY NU/ASE 6-16

55C00020 55C00050 55C00050 55C00070 55C00070 55C00070 55C00100 55C00120 55C00120 55C00120 55C00170 55C00170 55C00170 55C00170 55C00120 55C00200	L 1396 FORMAT(* NTIPE (NC. OF TIME STEPS)	33000 53000 55000
\$\$C0090 \$\$C0090 \$\$C0090 \$\$C0090 \$\$C0090 \$\$C0090 \$\$C0010 \$\$C0010 \$\$C00129 \$\$C00129 \$\$C00129 \$\$C00120 \$\$C00120 \$\$C00120 \$\$C00170 \$\$C00170 \$\$C00170 \$\$C00120 \$\$C00200 \$\$C00200	ISTE FORMATE MILLE ECTER OF THE STEPS	SICUA
35C00000 55C00070 55C00070 55C00070 55C00070 55C00100 55C00120 55C00120 55C00120 55C00120 55C00170 55C00170 55C00200 55C00200 55C00200	1397 FORMATCY UP (LOWER LIFIT FCH UP)	<pre>> 3 2 C 04 > 5 2 C 04 > 5 2 C 04 > 5 2 C 00 </pre>
53C00000 53C00070 53C00070 53C00070 53C00100 53C00100 53C00120 53C00120 53C00120 53C00120 53C00170 53C00190 53C00200 53C00200	1000 FORMAT(* VI (ABSOLUTE VISCESITY)*014.711000 FORMAT(* TP (FERIOD OF CYCLE)*014.711401 FORMAT(* E (ELASTIC MODULUS CF LAYER)*014.711701 FORMAT(* R (REDUCED RADIUS)*014.711702 FORMAT(* TW (LAYER THICKNESS)*014.711703 FORMAT(* TW (LAYER THICKNESS)*014.711402 FORMAT(* TW (CUIDTH CF BEARIAG)*014.711402 FORMAT(* TR (TALUS RADIUS)*014.711713 FORMAT(* THETA CANGULAR AMPLITUDE IN CEGREES)*014.711407 FORMAT(* NST CINITIAL NUMBER OF STEFS)*014.711408 FORMAT(* DT:L CINITIAL NUMBER OF STEFS)*014.711409 FORMAT(* DT:L CINITIAL NUMBER OF STEFS)*014.711409 FORMAT(* DT:L CINITIAL RELATIVE TCLERANCE FOR CO2EEF)*014.711410 FORMAT(* DT:L CINITIAL RELATIVE TCLERANCE FOR CO2EEF)*014.711411 FORMAT(* PTGL CRELATIVE INLET PRESSURE TCLERANCE)*014.711414 FORMAT(* FPTGL CICLERANCE FOR FOR FILP PLCTS)*014.711514 FORMAT(* FACT CISCALE FACTOR FOR FILP PLCTS)*014.711514 FORMAT(* HFACT CISCALE FACTOR FOR FILP PLCTS)*014.711614 FORMAT(* FFTGL CISCALE FACTOR FOR FILP PLCTS)*014.711614 FORMAT(* FACT CISCALE FACTOR FOR FILP PLCTS)*014.711614 FORMAT(* FACT CISCALE FACTOR FOR FILP PLCTS)*014.71	<pre>> 3:000 > 3:000</pre>
53C000070 53C00070 53C00070 53C00070 53C00100 53C00127 53C00120 53C00120 53C00120 53C00120 53C00170 53C00200 53C00200	1700 FORMATC* IF CELASTIC MODULUS CF LAYERD	<pre>> 33000 > 55000 > 55000</pre>
-SEC00070 SEC00070 SEC00100 SEC00100 SEC00127 SEC00120 SEC00120 SEC00120 SEC00120 SEC00120 SEC00120 SEC00200 SEC00200	1401 FORMATC* E CELASTIC PODULUS CF LATERP *014-71 1701 FORMATC* R (REDUCED RADIUS) *014-71 1702 FORMATC* TH CLAYER THICKNESS) *014-71 1703 FORMATC* UC (WIDTH CF BEARIAG) *014-71 1402 FORMATC* PR (POISSONS RATIC) *014-71 1402 FORMATC* RT CTALUS RADIUS) *014-71 1403 FORMATC* RT CTALUS RADIUS) *014-71 1404 FORMATC* RT CTALUS RADIUS) *014-71 1405 FORMATC* RT CTALUS RADIUS) *014-71 1407 FORMATC* RT CTALUS RADIUS) *014-71 1408 FORMATC* THETA CANGULAR AMPLITUDE IN CEGREES) *014-71 1409 FORMATC* NET CINITIAL NUMBER OF STEFS) *014-71 1409 FORMATC* DT:L CINITIAL NUMBER OF STEFS) *014-71 1409 FORMATC* DT:L CINITIAL RELATIVE TCLERANCE FOR CO2EEF) *014-71 1409 FORMATC* PTGL (RELATIVE INLET PRESSURE TCLERANCE) *014-71 1411 FORMATC* FPTGL (RELATIVE LGAD CAPACITY TOLERANCE) *014-71 1414 FORMATC* FPTGL (TOLERANCE FOR FOR STEP DEPENDEACE) *014-71 1514 FORMATC* FFTGL (SCALE FACTOR FOR FILP PLCTS) *014-71 1514 FORMATC* FFTGL (SCALE FACTOR FOR PLCTS) *014-71 1514 FORMATC* FFTGL (SCALE FACTOR FOR PLCTS) *014-71 1614 FORMATC* FFTGL (SCALE FA) 53000) 53000) 52000) 52000) 52000) 52000) 52000 52000 52000 52000 52000
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SSC00120 SSC00140 SSC00120 SSC00160 SSC00170 SSC00170 SSC00200 SSC00200 SSC00210 SSC00220	1713 FORMAT(* THETA CANGULAR AMPLITUDE IN CEGREES)	\$\$C00
SSC00140 SSC00120 SSC00160 SSC00170 SSC00170 SSC00170 SSC00200 SSC00200 SSC00200	1407 FORMAT(* MI (INLET EQUNDAPY) 1408 FORMAT(* NST CINITIAL NUMBER OF STEFS) 1409 FORMAT(* DTL CINITIAL RELATIVE TELERANCE FOR COZEEF)) 55C00 55C00) 55C00) 55C00 55C00 55C00 55C00
SEC00120 SEC00160 SEC00177 SEC00180 SEC00190 SEC00200 SEC00220	1408 FORMAT(* NET CINITIAL NUMBER OF STEFE)	SSC00 SSC00 SSC00 SSC00 SSC00 SSC00
SC00160 SC00177 SC00180 SSC00190 SSC00200 SSC00210 SSC00220	1409 FORMAT(* DT:L CINITIAL RELATIVE TELERANCE FOR COZEEF) *.014.75 1410 FORMAT(* PTOL CRELATIVE INLET PRESSURE TELERANCES	3500 5500 5500 5500 5500
SSC00179 SSC00180 SSC00190 SSC00280 SSC00280 SSC00220	1410 FORMATCY PTOL CRELATIVE INLET PRESSURE TELEGANCED "1014.7) 1411 FORMATCY FPTOL CRELATIVE LGAD CAPACITY TOLERANCED) \$100) \$100) \$100 \$100 \$100
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SSC00170 SSC00200 SSC00210 SSC00220	1414 FORMAT(" FRIGL CIOLERANCE FOR FR STEP DEPENDENCED	SSC00
SEC00200 SEC00210 SEC00220	1514 FORMATCH NEACT ESCALE FACTOR FOR FILM PLCTS)	5400
SSC00210 S1C00220	1614 FORNATCO XFACT (SCALF FACTOR FOR PLOTS)	
5500220		i sscat
******	1416 FORMATCH F1 CHARMEDELL IN TYAL AT THERE PENTS	55000
SSE 06.238	1417 FORMATCH FS (WFENFAF), INTIAL NF CHERCH	
55588348	TATE FORMATIO FY MATHERS ANTITAL WE TATE FOR DECEMBER OF DETAIL	- 32LUU
******	TAG FORMATIO FA JUNCH-MUMARA, TATTAL NO CHCCCS	52000
330 00 230	1417 FORMATA' TA UNIMERA OF MATIAL NU GUISSI COCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC	52000
331(7280		22006
2200270	1422 FURNATUR 12 UNLEER OF POINTS PRINTED	SSCOO
22005=0	1423 FORMATE IPT CPRINT OPTION FOR CONVERGENCE DATAS	SSCOO
S 5C 00 2 90	1523 FORMATC MAGN (PRINT OPTION FOR 1 CYCLE)	SECOO
S 5C 00 3 CO	C	SECOO
55000310	C	55000
SSC00320	132 FORMATC" *•6%•*AHJTH*•11%•*12%•*AJAH*•12%•*P/PN*)	\$5000
\$\$C00330	133 FORNATC [*] *+1×+4(C14+7+2×)+16)	SSCOD
S S C 80 340	WRITE(5,101)	SSCOR
SEC00370	WRITE(5,116)	\$5000
SSC00360	WRITE(5,101)	SSCOO
5500370	WEITE(5.39)	sscon
5500370	NRT1545.13665 NTIV-	- 32190 - 46500
SC00 190		5:00
50000000		52000
CC00400		22000
		22000
57200420	WRITESPINER -	SSCOO
5007430		S2C00
2090449	WRITE(5+17C2) TH	SECOD
2030420	WRITE(5,1702) WD	SSC01
5000460	WRITE(5:14C2) PR	SSC010
5000479	WRITEG5,1712) RT	SSCOL
500499	WRITICS,1712) THETA	SSCOIS
5000450	WRITE(5,14C7) XI	SSCOL
seérsen	WRITE(5,14GR) NST	SECOL
SC 00 510	WRITE(S.14G3) DTCL	SSCOL
SC 00 5 20	WPITE(5-1410) PTCL	SSCOL
50 20 4 20	WRITE(5-1411) FPTGL	55001
5030*40		CCC010
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		Jace I
	S C 0 2 0 S C 0 2 0	SCC0020 1419 FGRMAT(* F4 (HM6UHMMF4, INITIAL H6 GUESS) *014.79 SSCC0260 1421 FGRMAT(* I1 (MU*BER OF POINTS PLETTED) *014.79 SSC00270 1422 FORMAT(* I2 (NL*BER OF POINTS PLETTED) *119 SSC00270 1422 FORMAT(* IPT (PRINT OFTION FOR CONVEMEENCE DATA) *119 SSC00270 1323 FORMAT(* NAGN (PRINT OFTION FOR 1 CTCLE) *118) SSC00270 1323 FORMAT(* ',6X,*AM/TH*,11X,*A/TH*,12X,*A/AH*,12X,*F/PM*) 150 SSC00370 132 FORMAT(* ',6X,*AM/TH*,11X,*A/TH*,12X,*A/AH*,12X,*F/PM*) 150 SSC00370 132 FORMAT(* ',6X,*AM/TH*,11X,*A/TH*,12X,*A/AH*,12X,*F/PM*) 150 SSC00370 WITE(5,101) * *18) SC00370 WITE(5,101) * * SC00370 WITE(5,101) * * SC00370 WITE(5,1360) VI * * SC00370 WITE(5,1360) VI * * SC00370 WITE(5,1360) VI * * SC00370 WITE(5,170) T * * SC00370 WITE(5,170) T * * SC00370 WITE(5,170) T * * SC00470

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		5101119		\$\$\$01670
	WRITELS, 1614) A MFACTOR Street Stree	\$\$C01120		\$2001689
	MR17E45,14141, 71	\$5001137		\$201690
	CONSTERNING RECEIPTION CONTRACTOR	55001140		35001700
	MAITERS-1414 F3	SSC01150		=\$ \$C 01 710
	MITCOPLANDA FR	35041168		\$201720
	URITEES, 14519 II	55001170		2201130
		55001180		25001140
	NATERS, LAEST INT	55001150		2201120
	WRITE(5)1523) MARK	5501200		35001760
	WRITE(5,77)	S 2001 210		22001110
	WRITE(SUISC)	2201550	CALL SUZBER INF TA . BT/ (TP. 168. CA) + CABS(DC OS((2. 08+PI/TP)+TC))	22001180
	MRITESSTRA MARKET	55001230		2201140
	WRITE(S+132)	SSCC1240		22001-00
	¥RITE(5,79)	StC#125#	84112439777 Norther 4, 1961 MT	2201410
	00 467 I=1 mm	SSC01240		2201450
	ANCIDEACID/ALCID	SEC01270		SSC01 = 30
	MEILE(20135) WHEIDDHELDDHTELDDHELDDHE	S5C01280		SSC01 #40
467	CONTINUE	55061278		SEC01850
	WRITE(5+10C)	S3CC1300	WRITE(5,106)	\$\$C#1P6#
	00 1010 I=3+AF	\$501310		\$\$C01970
	TF(])=TH(])+TP	SEC01 320	c LI-II	SEC01488
	FPI(I)=FE(I)/WD	S 5C 01 3 30		SSC01890
1010	CONTINUE	55001 340	IFCUX-LT-UPDI UN=UNG	S\$C01900
	WRITE(5,99)	SSC01350		SSC01910
	WRITE(5+114)	SSC01360	C COMPARISONS	\$\$01720
	00,1011 I=1+AF	S\$C 01 370	C BATIC OF ALL AND THE FOR DETESTING BATIC OF ALL	SSC01930
	WRITERSOLLSD THEIDOTERIDOPERIDOPPLEIDOL	55001 380	501 FORMAT(* VARIOUS ESTIMATES FLAT FLISTERS = 1010-7/3	SSC01749
1811	CONTINUE	SSC01 350	TOI FORMAT(* *,5%, MMIN = ,CI4, 7% APART = , 014, 7/1	SSC01950
	日本までもあっても	55001400	789 FCRNAT(* ", TR, TA TY, UI4-(+14) FF + STAG (ATA BY SUPTAT)	\$\$01968
	WRITE(5,101)	55C#1410	604 FORMAT(* (1.) FOR SURFACE LAVER CALLS FORMULAS BY FORKE ANE".	SSC01970
	WRITE(5,117)	55001420	685 FORMATES (2.) FOR SURFACE LATER CALME FORMOLUS OF FORME AND F	SSC01980
	WRITE(5,101)	55001430	CT VARNUMT)	SSC01990
	WRITE(5,99)	SSC#1447	606 FORMATC' CT.) FOR RIGID SUMPACE USING FORMULA BEDMILAS I	SSC02000
C		55001458	431 FORMATC (4.) FOR ELASTIC SURFACES USING PENTITA BY SLALFS 1	SSC#2010
č	C CND	\$\$01469	607 FORMATE (5.) FOR ELASTIC SURFACES USING FURNUE OF SALLS F	SSC02020
Č		\$\$001.470	608 FORMATCY +,5%, MAIN = HCEN = ,514-777	SSC02030
4779	FORMATCH INCEX NO. (NT) = + 167)	550014=0	609 FORMATC" (E.) FOR FLASTIC SURFACES USING FURDER OF MERPERBUGHT)	\$\$502040
4760	FORMATE EATRAINPENT VELOCITY EUWS = +514+77	5501490	610 FORMATC" (7.) FOR ELASTIC SUFFACES USING FURTURE OF HUNDER OF	\$\$02050
4781	FORMATCH LEAC PER UNIT WIDTH (FP) = ",UI4.177	5501500	AHX=(2.00/1H)+DSQRT(FP+P+.7=L0/(2+P1))	S5C02060
4782	FORMATET TIPE ETC3 = +014-7/3	\$\$501510	CALL ED2BEF(NA4,AK,AC,AHX,AY,D)	\$\$02970
	HFq=hF+4	5*001520	ATT	5502040
	NA4=YA+4	55601530	CALL EQ288F(NA4,PKI,PCI,AVX,PDY,U)	\$\$02050
	LWRK=6+NA+16	55001540	XC=AY+TH	SSC02100
	L WRX1 = 6+4F+16	5.001.540	PDR Y=P 3 Y+ 4 + CO+ DS GRT (FP+ 5/ (12 + CO + F I + R))	\$5002110
	CALL PAPER(1)	53001550	UU=2•30•VI•UN/(E+R)	55002120
	CALL CTAFNT(1)	51001320	WWIFFP/CE+R)	SCC02170
	A#=(TH/E)+(1.C0-2.C0+(PR++2)/(1.00-PR))		IF(4V.GE.2.90) H#=1.157D0+(1.D0/AV)++.4275C0+F+(UU++.630)/	55002148
	CALL EDIBAF(NF,TF,FFI,FKI,FCI,NF4,Fb,LWPKI,D)			55002140
	CALL EDIBAFENA, AN, A, AK, AC, NA4, A W, LWRK, OF	32602370	IF(AY.LT.2.CO) H4=1.335D0+(1.CO/(35¥P(.239606+#1))+++(000+.8LU)/	55002140
	CALL EGIBAFENA, A.FCR. PKI, PCI, NA 4, AU, LWRK, O)	53661647	C(WW++-200)	SCC02100
	NST1=457	32441614	HCH=H#/.795C0	SSC02198
	IPTS=IPT	52041720	HRIGIC=1+22408+VI+UM+R/FP	CCC03164
	073L1=3T0L	2201230	5P=5/.7500	SCC02127
	DT=TP/hTIYE	2 4 5 U I 6 4 M	UX=VI+UM/(EP+R)	JILVERV
	NTPP=hTIHE+1	2 2 C 0 1 6 3 0		

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a construction de la construction d La construction de la construction d	\$\$682210	Dx=xI-xE	SSC02770
	5502228		\$5082780
www.2.m2 - 3.m. F. (Ux. +	esca2218	CALL COZEDFCAC, AI, 1, PCS OTL, 1, FCH, 1, FLDER TOUT OTTOTTOTTOTTOTTO	SSC02790
MEN7 + MAN2 / - /4D8	55642348	KL2=KL2+1	5502700
100 0 1 - 7 17 8 - 8 - (111 EDE) / (UV 2 C 0)		KL 3=KL 3+1	SSC02710
MCM - MAR - 25508		PC=PCS(1)	SSC02820
	316 82268	TELPC_LT.8.081 6019 5	55682438
	22042274	1F (PC . 61. P1) 6070 6	55042 * 40
	22002264		55002850
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PNZEFECTFL	STC82348	L OFTENTING THE REQUIRED HE USING DISECTION	
C IFEIPIERS GOID IGAN	\$\$\$\$2319	C DELEMINATION AND RECEIPTION AND AND AND AND AND AND AND AND AND AN	32002-14
WAIIERS+383 P	<u>\$\$</u> C 0 2320		25685968
URITES.644J	22065330		2202930
WRITE (5, 285) XE PERT	\$ \$C #2 340	JCOUNT = L	5202700
URITE(5+607)	\$5082358	H 8 = H 8 - H A	SSC02717
WEILESTOID Nª MCH	55002360	B CT08	SSC02728
unitessable !	55602370	6 IF(JCOUNT-EG-I) MAEMA/2-DU	SSC02930
MRITERSAGED HAIGID	54092390	JCOUNT = 0	SEC02940
NRTTERS-0313	SSC 82 358	H0 = H 8 + H A	SEC02950
MATTERS, TASE ANE PHZ	55002400	6010 8	SSC02760
	53502400 66683A18	9 CONTINUE	5502970
TTE CS-7012 HMH2 HCH2	52102410	[\$5082568
	32602440		687879568
	23C02420		CCCA1888
	2202440	THE EDEMATE CALCULATED FP = ",D14.7,JX, "FOR XE =",E14.7,JX,	32003040
	52082437	120 FORMER OF FF 29-F10-3-4 2 19-191	SSCUJULU
WRITESSIDI Heneren	5502469	AND FORMATER - SEFECTETED FP EVACIA-71	2202050
WRITE(S,LOU)	SSC02470	119 FURALLY COUPEER TO THE COUPE	2203030
MAITE (5,57)	SSC824P0	C C CONTRACTOR CONTRACTOR CONTRACTOR CONTRACTOR CONTRACTOR	SSC 0 3040
C1868 CONTINUE	S\$C02498	C SOLVING LUAD CAPACITY FOR THIRE AT COLOR FORM	SEC03020
	S\$C02509	C	SEC03060
	55002510	PCS(1)=0-D0	SEC03970
	S\$C02520	xc=xE	SSC03088
	55082530		SEC03090
h to the second s	SSC82549		S SC 0 3 1 0 0
IC OUNT=2	5502558	CALL DOZEBF (AC+XI+1+PCS+D+L+I+FCH+I+PEDER+UBCH+UC+FCFFC	SSC03110
KL 1 = 0	\$\$602568	KL3=KL3+1	S\$C03120
KL 3=0	55602578	NPLUS=NST+1	\$\$503138
XA = XF + F 1	5567588	CALL COIGAF(X,PSTCRE,NPLUS,FPC,EE,0)	55003140
	32602360	KL1=KL1+1	66003150
	32602330	FPC=-FPC	32CU3150
	22665604	15(1PT-50-0) 6010 1597	22603150
	5202610	FF = 1 00 - 30 + FABS(EE)/FPC	22003110
	5502620		22003140
	S 5C 0 2 6 3 0		22002140
118 PUKHAIL NU ATPLIT	55002640		SEC03200
84 CONTINUE	SSC02650		S\$C03210
Ng=N=GU=1 . L G= L . L G= L . L . L . L . L . L . L . L . L . L	55C026EP	UIFF SUABSLEFFELL AFT	SSC03220
NA =H0 +F 3	S 5C 02 670	JFCDIFF.L: FFIJLJ GUID GL	SSC03230
JC CUNT#2	55C02680	IF(FP.GT.FFC) GOIC 82	S 5C 0 3 2 4 0
KL2=1	S \$C02698	IF(FP.LT.FFC) GUTC 43	S\$C03250
6 CONTINUE	\$\$602767	C	S\$C03260
IFCIPTOIDO1) WRITECSOIIGD MOOKL2	55002710	C DETERMINING THE REQUIRED XE USING BISELFISH	S\$C03270
C	66080390	Č	\$\$032#0
C SOLVING PRESSURE FOR TRIAL HE USING DOZEBF	SCU2720 CCA3710	A2 IF(ICCUNT.EQ.1) XA= MA/2.00	55003251
		ICCUNT=0	55061100
PCS(1)=0_00	32602799	xE = xE + xA	
	22002/20		

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	6010 84	SSC03320	<u> </u>	YORE CORRERT PRESSURE OR DES	25062680
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	ICOUNT=1	\$2643348			22003400
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	CONTINUE	2209334			22003450
C		22682248	43#1		22003440
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C	THE REAL PROPERTY AND THE RETAINING SECTION !!	22693446			22003400
	FORMATER STORAGE THEM IN ANTERED CONTRACTOR	\$\$\$\$3418		Wateswa:	52003770
		2203420			22087250
		\$\$C#3+3#			35083778
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879	CONTINUE	55C03250	C .	NAME ARCONDE ARITARIITY CHECK	55094040
C	THE REPORT OF ANTITAL CALFULATION USING DOIGAF	\$\$0353	C I	LUBAL FREGATER RELAREALATE CHECK	\$204090
C	SOLVING INTEGNALS FOR FRICTION GROOD COLOR	\$2003240	C		S 5 C 0 4 2 0 0
C		SSC03550		3770L-71*81C*	SSC04110
		2503260			S SC 04120
	FR23-FR2	SEC03570			55C04138
	IF (HO.LT.O.CU) ATTUSATION (CONTRACTOR CONTRACTOR CONTR	\$\$C03580			S 5 C 0 4 1 4 0
	IF(HG.GT.D.CUJ ATILISAN TELSAN TELS	SEC 83570			SEC04150
		2203600			SEC04160
		2203619			SEC04170
	DEN2=N#+(RE==2//2000, De/(2,De+N3))+(.50#+(1.50/2/27)+	SSC03620			SSC 041 20
	IF (HO-L T. O-LOJ A INT - (A D-Y C/ (A A + X - X T) + (+ X T)))) -	\$2003630		IFTERLIGENER AND THE TO	\$\$C84178
		\$5003640			\$2084200
	C(#1/CENI+XE/JENZ/1/ 00/00/00/00/00/00/00/00/00/00/00/00/00	SEC03630		FLI=FL FLI=FL FR=H#F/(MH==2)====FR/HX	SSC04210
	[F(H 8.67.8.494 + 111-44/27/27133-(XI/CEN1+XE/3EN2)]	2203660			SSC04220
	C(DATARC-RIJITI)-CRIPTCAL PARTERINTS	SEC 03670		11={1/2/*<	SSC04230
		SSC03680			SSC04240
C		ssco3690			\$\$C04250
C	RELIAPILIT	SEC03700			SSC042E0
C	THE REAL PROPERTY CHECK PRESSURE RELIABILITY CHECK //	SEC03710	-		SSC04270
662	FORNATE OT DECREASED FOR FO FOR FP PELIABILITY CHECK!/)	55C03720	76		SSC04200
721	FORNATE NE. UP STEPS DOUBLE FOR FA RELYAEILITY CHECK #/)	SSC03730			55004290
948	FORMATE HE. OF 31573 DOUBLE 1 11. 11. 11. 12. 14. 31FF. 1/1	SSC03740			S SC 04 3 0 0
741	FORHATCH VIR, PLLC VIZAV PLL VISH VISH VISH	s\$C#375#			55004310
742	FORMAT(* *,1X,**(U1**/*/*/****************************	5503760		WRITE (5) 10CJ	SSC04320
943	FORMATE T (GA . TPLL JALK FILL AND A TRACE BOIFF - /)	SSC03770			\$\$04330
751	FORMATET TOTAL TOTAL TOTAL TOTAL	SEC03780			\$5004340
944	FORMAT(* * 11+3(UI4+F+2A) * CONVERCE TO SPECIFIED TOLERANCES*/)	SEC 03790		MKIIL(3,74I)	\$\$004350
999	FORMATE PELIABILIT UNLERS COVERT TRIFAMES ADJUSTER //)	SEC03900			SSC 04 360
951	FOPMATEY AUSOLUTE AWELT FREESONE TELEVINE BEOTFER	S2C03*10		NAI152001001	· SSC04370
952	FORMAT(+, 7, + PICLO + 11A + PICLO + 1 A + PICLO + 1 A + PICLO + 1	SEC33820	6792	CONTINUE	\$\$204378
953	FORMATET TELEVISE THE FEETERS THE CHECKS STOLENES	52C03830		NST=NST/Z	SSC04390
753	FORMATIV FINAL DIL FUR TELEVILLATI UNLEND TO THE CKS 24.16/1	\$203840	-	67T7 P	55004408
954	FORMATET FINAL ROA OF SILFS FOR HELLETING CONTRACTOR	\$203850	79	CONTINUL	
783	FORMATCH ICTAL NUPBLE OF CALLS IN DURING CONTERN				

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FILES SEC FEATRAN & LEEDS UNIVERSITY WARDE 6.15

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9 1

			55004960
	55004418	IF(MG.GT.O.CO) XINT=(1.UG/(2.UUFNG/)+(0.54K/)+(0.54K/)+	5504970
	55004420	CEDATANE-XI/XYI)-CATANEX*/XYEUP-CATALEALEALEALEALEALEALEALEALEALEALEALEALEA	SSC04980
AASTLUTE INLET PRESSURE TOLEPANCE CHECKED	55084439	FRD=(¥1+U4/FPCJ)+(F=2+2.)U=FR2=A14+7	55004950
	04440322	DFR=DABS((FRJ-FRJ)FRU)	\$\$C@50@#
PT412PT2C-PTCL	55004450	IF(JFR.GT.FFTOL) GOTO 329	55005010
DP I= GABSI (FTA-PT)/PTN)	55004460	6013 796	\$\$C05020
IF (JPT FTOL) GOTC 723	55784478	329 CONTINUE	SSC 05 0 3 0
BATG 722	SSCRAAPD	IF(IPT.EQ.C) 60T0 6323	\$ \$C 05 0 40
	800AA44	WRITE(5.108)	S\$C050 50
IFEIPT.EQ.89 SCTC 6321	80740722	HRITE(5+99)	550850 60
M	SCC44519	NRITE(5,948)	SSC85070
untries.951)	53204325	HRITE(5.751)	\$\$205088
	2:[04340	MRITE(5,944) FROFRDODFR	55035038
WATCH STATE TAPTN DFT	2504334	WETTE (5-100)	55085108
	225.54240	A333 CONTINUE	50007100
	2204220		3 CC U J I I V 8 CC 05 1 30
6J21 CONTINUE	55C045E0		33007120
HST=457/2	SSC04570		2202130
011=031-010-00-0100-0	55C84590		22002144
p I = P T N	55004590		\$205130
6010 8	55004600	WRITELS-TT	SSC05160
722 CONTINUE	55004610	MEITERS LOCA	SEC 05170
c	5504620	WRITE(5.97)	\$2005180
C FP RELIABILITY CHECK	55004630	WRITE(5,995)	S\$C05150
	55004540	WRITE(5+982) STL	55005200
SFTOL=.130+FPTCL	55004650	MRITE(5,984) AST	55005210
CALL EBIG AF (X .PSTORE .NPLUS .FPCD .ERRCR .0)	55604660	WRITE(5,995) KL3	\$\$\$\$05220
	SCC04678	WRITE(5,100)	55665230
DEPENANS((FPCD-FPC) /FPCD)	52CU4070	6326 CONTINUE	66005240
15 (06P - ST - SFT0L) 6010 719	23694679		52003240
	2504630	r FIXED	220022-0
	52604760	·	32003200
15 CONTROL 60-83 6010 6322	25604110		55007270
	55004720	C FRAME ESTIMATE FOR PARTHUM PRESSURE	55665270
WPIII JAJAV	55664 130		52605270
BRLILGJY77#	25294149		55007300
WRITE JOICAT	5504750		22002210
WRITE 1347927	SSC04760		SSC05320
	SSC04770	ERT=11410000	S SC05 3 30
MRITESSIGUP	55004790		\$\$205340
6322 CONTINUE	55004790	C	\$\$\$\$\$350
	S?C04 ° 00	C NININUM AND CENTRAL FILM INTERNESS	\$5005360
60T0 \$	SSC04910	C	\$5005370
720 CCATINUE	SSC04/20	H#I4=H0+XE++2/(2+C0+K)	\$\$C053 80
	SSC04830,		5505390
C FR RELIABILITY CHECK	55084940	DO 199 I=1.NST	\$\$\$205400
C	SSC 04850	J8 = I + 1	\$\$605410
MPLUS=MST+1	SCOARED	xc = x (38)	55005420
CALL COIGAFCX.FX2.NPLUS.FR2.EP2.0)	55000230	PC=PSTORE(J8)	01000000000000000000000000000000000000
5872-582		HX=H0+6XC++2)/62+C0+R)+A4+FC	0000000
TE H 0-L T-0-CO3 XY=050FT (-H0/(2-C0+4))	256 84 450	IFCH1_EQ_HPIND HM1=HX	5200740
TE (40-GT-0-CD) KY1=CSORT(2+C0+H0+R)	2204400	TECHNYL FOLDIA HWZEHX	51103410
$r_{r_{r_{r_{r_{r_{r_{r_{r_{r_{r_{r_{r_{r$	2204400	TECHTLITAND XHPIR=XC	SECURAEU
	55004-10	TERMENT TANDAR APRAL	5505470
	S\$CC+920	17 1740 1997 BUT 1997 BUT 1997	SSC054#0
DENZEHU+4R2+021/42,0047	S\$C04930	NI-NA	S\$C05499
TERDELEGTER TALE TO CALLER AND	25004940	IFERCELIEUSCUP GERGE AZZ	\$\$\$605500
CCDL9G(CHU-)IAT)+CHU-XLAAT)/CCUVALATI	S\$C04950	P1=rc	
CEKI/JENE+XE/CENZPP			
· · · · · · · · · · · · · · · · · · ·			•

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AB1 CONTINUE 218 880 \$5085529 NPLUS= MPLUS+NB NCISHX \$\$\$\$\$538 NCANENB+1 N24J8+1 22005-47 IF (XX:C.EQ.XIP) 60T0 9928 199 CONTINUE SSC 85555 DO 462 1=1.MPLUS #2#-1.00-34423 \$\$085569 K=NPLUS+1-J PTEPSTORE (N2) SSC#5570 MC2=N0+#2++==/42-00+RJ+AN+P2 J##+1 55005584 IF (#1.LT. #2) SCTC 7521 X(J)X(K) \$\$\$\$\$590 PSTOREEJJEFETCREEKE MC SHC 2 35045640 482 CONTINUE NCZWIC1 SEC05610 X(1)=XIP 6010 1522 SSC05620 PSTORE(1)=0.00 7521 CONTINUE \$\$685638 MPLUS=hPLUS+1 HC SHC 1 \$\$\$648 NCAV=NCAV+1 HC 22PC2 \$\$685658 9928 CONTINUE 7522 CONTINUE 51099668 ENC=100.D0+CABSCENC-HCZ3/HC3 C 55085678 PRINTING DATA AT SPECIFIED SPACING E1=DAESCENPIN-H=13/H=IN3 C 55085688 E2=0#85((H#1-N#2)/H#1) C 55085658 M2=NPLUS/12 EN##51+188+C8 SSC05788 IF (22.GT. 21) EH4=2+100.08 JHD=0 SSC05710 EXHN=DABS(CA/XHPIN)+100.00 WRITE(5,99) SEC05728 RATIC=HTIN/HC WRITE(5,99) SSC05730 MRITE(5.107) 35005740 CUTPUT 00 3 I=1. AFLUS C 55085750 ICC=(I/N2)+N2 55005760 IFECICC.NE.IJ.AND.CI.NE.NPLUSJ.AND.CI.VE.IJ.AND.CI.NE.NCAVJJ 187 SSC#577# FORMAT(* *,1X,4(014.7,2X),18,18) + 60TO 3 SSC05780 108 FORMATCY CALCULATED LOAD CAPACITY (FP) =*,C14.7/) J#0=J#0+1 107 S5C05790 FORMAT(* H0 =*+025-18/) PC=PSTORE(I) 111 FORMAT(* PPAX =* .C14.7.8X. .*ESTI "ATED & ERRCR =* .C14.7) 55005888 $x_{c=x(1)}$ 161 SEC 05 910 FORMATCY CAVITATION POINT (RE) =*+025-18/0 HX=H0+XC++2/(2+D0+R3+AH+PC 162 SSC05#20 FORMATC" HPIN ="+C14.7.8x. "ESTIMATEC & EARCH ="+D14.7) DDPD=(12.DE+VI+UM/(+0+XC++2/(2.DE+R)+AM+PC)++3) 191 5105430 192 FORMATC" HEEN =" ,D14.7,8%,"ESTIMATED & ERROR =" ,D14.7) C+((XC++2-XE++2)/(2.CO+R)+AP+PC) 55075948 FORMAT(* HP/HC =*+314.7) IF(XC.GE.XE) DGPC=0.00 193 SSC85810 FORMATIS FINAL NC. OF STEPS IN CONTACT ZONE =".16/) WRITEES,1083 XC+PC+CDPD+HX+I+J*D 397 55005960 5656 FORMATES FINAL DTL FOR DO2EEF = + D14.7/) CONTINUE 3 S\$C05778 FORMATC* HF (HXE) =*+014.7/} 622 \$\$\$285889 C FORMATE FRICTION COEFFICIENT (FRD) =*+C14.7/) 637 FIXED DATA C \$\$\$\$5899 FORMATES XEFIN =",D14.7,TX, "ESTIPATED & ERADA =",J14.7) 493 С SSC05900 FORMATCY FINAL CONVERGED VALUES *//) WRITE(5,100) 510 S\$C05910 FORMATCH VALUES WHICH DEPEND ON SHALL STEP SIZE //) 511 WRITE(5,99) SSC05929 WRITE(5.511) \$\$205930 CONSTRUCTING THE EXIT PROFILES WRITE(5,161) PMXD,ERP C \$\$005940 WRITE(5,191) HHIN, CHH С S*C05950 WRITE(5,492) XHMIN, EXHM MB=CXE+XIJ/CX SSC05960 WRITE(5.1921 HC.EHC XXED=XE=DX+N9 SSC05970 WRITE(5+193) RATIC xIP=-1.00+>I \$\$\$\$95988 DO 40 I=1.4FLUS WRITE(5.99) \$\$\$\$\$\$\$ K=MPLUS-I+1 WRITE(5,100) \$5004000 J=K+NB SEC04017 C X(J)=X(X) CONVERGED DATA С SSC 06029 PSTORE(J)=PSTORE(N)

SSC06033

S5C86049

SSC06050

С

WRITE(5,99)

WRITE (5,510)

35085510

PERTRAM A LEEDS UNIVERSITY VO/BST 6-16 FILE: SSCO

40 CONTINUE

00 401 I=1.NB

X(I)=XXED+(I-1)+OH

FCATRAN A LEEDS UNIVERSITY SMUBSE 6.16 FILE: SSC8

PITCRE(1)=0.00

\$\$006067

SSC060 70

SSC86888

\$\$606090

\$\$\$\$61.00

55016110

SSC06120

55086138

5506140

SSC06150

35086160

55006170

\$\$086189

SSC06179

SSC06280

SSC06210

35086228

\$\$06230

SSC#6240

5<006250

SSC 06260

S\$C06270

\$\$506280

SSC06270

SSC06300

55006310

SSC06320

SSC06330

35006340

\$\$\$\$#6350

\$5046360

5106370

SSC06380

SSC06 779

55006400

\$\$C06410

SSC06420

SSC06430

\$\$06440

\$5086458

SSC 06460

SSC06470

SSC06480

5506490

SSC05507

S\$C06510

SSC06520

SSC06530

SSC06543

55006550

SSC06560

SSC06570

55006589

SSC06559

S\$C06600

FILE: SSCB FCATRAN A LEEDS UNIVERSITY VE/BSE 6.16

2 States WRITE(S.199) FPCD WAITE(5.111) H0 MRITE(5.162) NE WRITE (5,422) HIE WRITE(5.637) FRO WRITEES,3971 AST MRITEE5,56262 37L -----S. Barger & PLADE WRITCES,+> TC.ZE.FHID.HHIN.HO VISUAL ------CONDITIONING FOR PLOTS KK1=# NE =NPLUS/II HTL=. TO HEACT $\mathbf{M}\mathbf{M}\mathbf{P}=\mathbf{0}$ 03 4009 I=1.4PLUS ICC=(I/\1)++1 IF ((ICC_NE.I).AND.(I.NE.NPLUS).AND.(I.NE.NCAV) +.AND.(I.NE.IJ) GOTO 4848 NNP=11P+1 XC=X(I) PC=PSTORE(1) HX=H0+XC++2/(2.00+RJ+AH+PC XX(NNP)=XC PP(NNP)=PC IFCHR.GE.HTLD GCTC 4008

HH(KK1)=HX ADDE CONTINUE PMAX=PMXD+1-100 XXE=-1.JO+>FACT

KK1=KK1+1 XX1(KK1)=XC

8

C

C

C

C

C.

C

С

2

PLOTTING USING GHOSTBO CALL PSPACE (0..1..0..1.) CALL PLOTOS(.05,.37,"H*,1)

> CALL PLCTCS(.+7..54.****1) CALL PLCTCS(.23..47.*TIME =*.7) CALL TYPENE (TC+4) CALL PSPACE(+07++57++05++4) CALL MAP (XFACT, XXE, 0., HFACT) CALL BOPDER CALL AKES CALL GONPEN CALL CURVECCERI, HH, 1. KK1)

FILE: SSCB FORTRAN & LEEDS UNIVERSITY VM/85E 6-16

55066610	CALL BLKPEN	S SC 071 E 0
SSC06620	CALL PSPACE (.07 57 58 93)	S\$C07170
SSC86637	CALL MAP(XXI-XXE-00-0PMAX)	SSC07190
51006640	CALL BORDER	S\$C07190
SSC05650	CALL AXES	\$\$07200
SECOLLED	CALL GRAPEN	\$5007210
\$\$586670	CALL CURVEGEXX.PP.1 .NP)	S 5C 0 7 2 2 0
\$2005580	CALL BLKPIN	SSC07230
55086650	CALL FRAME	\$507240
5506700	CPU=CFUTI *{>DU}	S SC 07 250
\$\$506718	NEITERS.6328) CPU	S\$C07260
SSC06720	IPT=IPTS	S\$C87279
\$5086738	c	SSC07210
55095740		=====\$\$\$\$\$7290
\$\$506750	C C	\$5007300
55005760	1867 CONTINUS	SSC07310
S\$C06779	c	SEC07320
S\$C06780		=====\$\$\$\$\$7330
55006758	C	SSC 07348
55006680	CALL BRENG	\$\$C07358
SSC06810		\$\$\$\$07360
55000000		\$\$\$\$67370
55006910		55007388
88006200		52007380
CCALASA		
85004849		S\$C07410
55005925		\$ \$ \$ 6 7 4 2 8
5100070	SUBRUUIIME FLAVACGFC39FJ	52007420
55000000		\$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$
55006360	COMPAN W SCALE BY A TOP COMPANY	52607460
5200710	COMMON ALTERING A AN VE VI FU AT MET	32CU/4EV
5200720	CUMPEN TIM COULD REAM 942 941 924 931 9331	25007478
55060720		32007400
32000440		55607470
32006730	F(1)=(12.00*V */(F0*(AC**2)/(2.00*R)*AH*PC)**3)*((XC**2	2508/200
32005760		\$\$07510
52006570	RETORM	55007520
32005-00	END	5507530
22006440		SSC07540
5500000	C	SSC07559
2201010	SUBROUTINE OUTPUTERSOL, PCS)	S2C07560
5507020	C	SSC07570
5507038		SEC07580
SEC 07040	IMPLICIT REAL+R(A-H,J-Z)	SSC07590
55007050	COPMEN X(9CO),PSTORE(9000)	S SC07600
5207060	COMMON VILLEDHOR AND	55007610
S 5C 07 07 0	DIMENSION FCS(1)	SSC07620
2200000	I=JI=JI	SSC07630
55C07050	X(JI)=XSOL	S5C07640
2201101	PSTORE(JI)=#CS(1)	SSC07650
S°C07110	NSOL = X = +JI + C H	SSC07660
S\$C07120	IF(JI.EQ.NST) #SOL=#I	SSC07679
S 5C 071 30	RETURN	S\$C076 90
SSC07149	END	S 5C 0 7 6 7 9
\$5007150	C	SSC07700

FORTRAN & LEEDS UNIVERSITY V#/BSE 6-16

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A LEEDS UNIVERSITY VM/85E 6.16 FILE: JSSCB ENEC

for connected running

EXEC SETUP FORTRAN LOSF NAGE CCGHCST FI & DISK XSSCB CATA FT & DISK YSSCB CATACRECFN F LRECL 120 HLOCK 120 FI & DISK BANK DATA LOAD SSCRICLEAR EXEC PLOTFILE PSECO SET BLIP . START

INPUT

FILE: XSSCB DATA

183. 217. 251. 285. 339.

LEEDS UNIVERSITY V9/85E 6.16

32 -10898510-3 .01 1. 16.06 .3 .8024 .0265 .4 .022085 9. -.016 1000 1-0-7 -001 -001 .001 1.12-6 -.02 .1 1.25 .01 1.02 200 20 0 -1 12 ·1 ·2 ·25 ·5 1· 2· 4· 6· 8· 10· 20· 30· .995 .9804 .9697 .8953 .725 .4978 .29 .1956 .1430 .11 .04591 .02677 1.005 1.020 1.031 1.126 1.449 2.282 4.201 6.478 9.099 12.06 30.17 52.63 39 8. .05 .1 .15 .175 .2 .25 .3 .35 .375 .4 .425 .45 .475 .5 . 525 .55 .575 .6 .625 .65 .675 .7 .71 .725 .75 .76 .775 .8 .825 .85 .865 .875 .89 .9 .925 .95 .975 1.000000001 339. 502. 726. 957. 1123. 1302. 1607. 2082. 2489. 2557. 2496. 2408. 2150. 1675. 1302. 1051. 925. 590. 353. 238. 153. 150. 150. 170. 116. 116. 129. 116. 170. 190. 170. 129. 150. 150.

and the second 55007710 SSC#7729 SUBROUTINE PEDERVEXC.PCS.PU) SSC87720 IMPLICIT REAL+BEA-H.O-Z) S\$C07750 COMMON #6 30001.PSTORE(9000) 55087760 CONNEN VIAL MAND ROAN AXE AXI .CX .JI .NST \$\$207778 DIPERSION FACE, 11, PCS(1) SSC#7780 PC#PCS(1) SSC#7798 FUEL.13#12.CO.VI..U".A. . CHE-XC+.2/#+1.508-XE..2/4-2.CO.A" +PC)/ 55007968 C((HE+#C++2/(2.D8+#)+AH+PC)++4) SSC07910 and a second And a second s RC TURN 55007820 END \$\$\$\$07*30

DIKE A LEEDS UNIVERSITY MM/RSE 6.16 FILE: KSSCB

for batch running

SCONTROL ALL LIF EREADFLAG ED STACK DESBUF ASTACK 1888 2 5868 &STACK FI 4 DISK #SSCB DATA & STACK SGTACK FE 5 DISK YSSCB DATA CRECFY F LRECL 120 BLACK 120 ASTACK FI 8 DISK BANK DATA SSTACK FI PLOTTER CISK PSSCB PLOT A (RECF" F LRECL 129 BLOCK 129 STACK EXEC SETUP FORTRAN LOSE NAGE COGNEST LOAD SSCB GENHOD SSCB EXEC BATCH PENSUP RUN SSCB JD FILES

FILE: SSCA

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LEEDS UNIVERSITY WARSE 6.15 • OUTPUT Allo

ILET YSSCB

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LEEDS UNIVERSITY WHARE 6.16 < DATA FILC: YSSCB

0-944128629-05 0-90367329-05 0-91132060-05 0-49122060-05 0-39660360-05 0-39660360-05 1-27356230+65 0-42754725+05 8-60641510+05 0-73566047+05 0+0242457+05 0+56450577+05 20+03+25121-0 0+37622640+05 0-431320E9+05 0-13943400+05 U-22264157+05 0-13320759+05 8-64150940+04 0.44911320+04 8-65856600+04 0-56603770+04 0-56603770+04 0-43773583+04 0+3773563+04 9+C+6021+9+ 9-4667923+04 0 • 71658110 + 04 9-64150940+04 0 * 4 8 4 1 B 1 B 1 B 1 B 4 B 4 1-56603770+04 0-71658110+04 1- 69056600+04 1+ 6 14 2 6 7 5 0 + 0 + 3-947169ED+04 I+10754723+05 0-12752453+05 t 0-16070000+04 20+0000622-0 0-50200000+03 8-72600000+02 0+0000CL56*0 0-11330000+0+ 0+13020002+04 0-2032000-04 0- 2484 E 00 + 0 + 0. 25570000+0+ 0.24960000+0+ 0-240800000+0+ 0-16750003+0+ 0-21500000+0+ 0-12020000+04 0-13510007+04 0-92900000 0+ 32 20 00 C3 + 0 3 0+ 20000000 +0 3 0-21-0000-03+03 0-1:500000+0; 0-15000000+03 0-17000000-03 0+11600000+03 0+15000003+03 0+11500000+03 0. 1230 C000 + 03 0-17000000+03 0-15000000+02 0-17000000+03 0-11600003+03 0.129000C)+03 0.15000000+03 0+1903000+03 0-19300000+03 0.2170C800+02 0* 25100000+03 0- 2550 00 6C + 0 3 LCAC *** 0.1000000.000 00+00001110 0-250300000 1-0-0000005-0 0 * 2 0 60 00 0C + 0 0 0.-3060 000 -0 0 1-3580 400-00 00+00002400 0+00000000000 00+0000050** 0-200000000000 0 • 5 250 0000 + 0 h 0+2000000000000 0-60000000000000 0.62500000+00 1 - 6 5 0 0 0 0 0 0 0 + 0 0 0.67500005+00 00+00000002-0 0-71000000+00 0+1250C000+00 0-15000000+00 1.7600C000+00 0+0000000000000 0 * 0 250 0 00) + 0 0 0-17500003+0 0 • 92000000 • 90 0*2000003+0 0~87500003+00 0+0000006056-0 9.9250800000 0-350000000+00 0.97500000+00 1 - 1 000 000L + 0 1 ATA TIPE 0 -1-1000000+00 0+15000800+00 0-17500000+00 .200000000000 0+5200000+00 2 0.5000000-01 - 35000000000+86 1-37508080+00 -+0000000+-I)- 42508080+00 99+109000007 ** 00+000052+*(0+00000885+00 00+00000055-0 1.57500000+00 0-62500000-00 0+6200000000000 0-67533400-00 00+0000001-0 0+52503330+00 00+00000111+0 1.72500000+00 - 75008003+00 00+C000009+00 00+C00C0511+0 0-30000000+00 0+32500003+00 0-35000300+00 3+365 30003+00 0 * 875 0 3 9 0 0 + 0 0 0+830000000+00 9-9000000-00 0+9250000+00 0+000000000000 0-9750000-400 0+10000000+01 • 1/19 Э ******* o **** 117 0.16900001-38 9 - C000 0007 * 0 6-1000C00C-01 0-2400 COC-02 68+0003880+*8 0.22095005-01 8-26596085-91 10+10010076-9 • 1 000 C00C-02 0-1000C00C-02 8-1106C00E-05 0-11260000+01 90-10030001-09 C-10000001+00 0 • 1 00 0 0 0 0 0 0 0 1 0.1000C002-02 -8-2008000 E-0 1 0-12500000+01 9-1000C00C-01 9-102000000+01 0 • 1 0 2 1 0 0 C 2 • C 1 0 • 1 4 4 2 8 8 CU+ 0 1 0.22420003+01 10+0000000+01 10+_0001+9*0 1-12069003+02 1+30170007+02 0-5262000-+02 10+û000=6C6" (6-1020C00C+61 197 19 1000 000 000 000 (Migu=MisF4, INITAL NO GUESS) MAGN CPRINT OPTICH FOR 1 CYCLED 0*2200000400 0.9804000+03 0.963700CD+00 0+ 61530000+00 0- 7250000 +00 0-250000000000 00+000c46+ 00 0-15562392+00 8+ 14 5200 CD + 00 0-11000000+00 0-453100CC-01 0- 2677C0C7-01 A/AH 0-1000000000000 0-26036000+00 8+250000000+00 00+00000005*0 10+00000001-0 10+0000000+-0 0-2000000000000 10+0000009900 1 • 3,000 0000 • 01 20+C000.0001+0 0 • 2 60 C C 0 00 + 0 2 1+3003 C003+3 2 « A/TH * 6*5633340400 0-25731170-00 0-22847203+00 0-10050253+00 0.13793100+01 0.13795107+02 0-30674853+02 0-55999860+02 0-11205573+04 0-401 76750+01 0-30303030+02 0-43563499+03 AH/TH TPING TAINT

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TIME (TC) = 0.0 INDEX NO. CATE

FILET YSSCO DATA A LEEDS UNIVERSITY VY/ASE 6.16

ENTRAIMENT VELCEITY (U4) = 8.10896510-01

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LOAD PER UNIT WICTA (FP) = 0.12792450+05

- (1.) FOR SURFACT LAYER USING DATA BY GUPTA A = 0.62771430-02 PHAN = 0.15285210+07
- (2.) FOR SURFACE LAYER USING FORPULAS BY MCCRE AND VARNLP NMIN = 8.44348270-06 NCEA = 0.55772920-06

- (3.) FOR RIGIO SLAFACE USING FORPULA BY PARTIN HMIN = NCEA = 0.31283950-08
- (4.) FOR ELASTIC SURFACES USING HERTZIAN FORMULAS A = 0.63055710.01 PMAX = 0.53810960.06
- (3.) FOR SLASTIC SURFACTS USING FORMULA BY SHALTS HMIN = 0.57510070-06 HCEN = 0.12552570-05
- 6.) FOR ELASTIC SURFACES USING FORMULA BY VARNUM HNIN = 0.18453660-05 HCEN = 0.13145263-05

(7.) FOR ELASTIC SURFACES USING FORMULA BY MERPEBRUGH NMIN = 0.10500650-05 NCEN = 0.13518790-05

₽ . DP x H 0.16000880-01 8.0 0.33664612-03 1 0.14429840-01 8.0 0.25701240-63 136 8-12839960-01 0.0 0.0 0.10475397-63 272 0.11250080-01 .0.0 0.0 0.12092013-03 908 0.96602020-02 1.0 8.0 0-65511980-04 544 8-88703210-02 8.0 6. 6 8-17527630-04 6*0 8-73805940-02 0.76809510-06 739 0.64584410-02 0.27596280+96 -8.30872810+89 0.69841000-06 916 0.48705613-02 0-72662000+06 -0-23302440+04 0.70552150-06 952 0-33006890-02 0-10369390+87 -0.15734022+09 9.72268622-06 1036 0.17108000-02 0-12269280+97 -0-91659392+09 0-74252260-06 1224 0-12091950-03 0-12966030+07 -0-55905620+07 0-76603617-06 1360 -0.14637610-02 0-12455850+07 0.6955960+08 0.73454222-05 1496 -9-39588410-02 8+19751200+07 0.14527010+09 0-83208877-06 1632 -0.46487220-02 0.76411432+06 6.22077150+09 0.95517527-06 176ê -0.62335022-02 8.37337360+06 0.25567502+09 9.55256252+06 1904 -0.78254325-02 8.43516700+04 0. 774(4870+97 0-12425992-04 2040 -0.94193630-02 8-14332470+84 0-39464285+06 0-57922415-64 217E

FILE: VSSCB DATA A LEEDS UNIVERSITY VM/8SE 6.16

8-11202630-03 2312 -0.11085240-01 0.11106130+04 8.10349527+06 8-18033510+04 0.42725722+75 0.17457050-03 2448 -8.12598120-01 25.84 -#.14188000-01 8.95528510+03 8. 21623400+05 0.24554540-03 2720 -8-15777880+81 8.92989170+83 0.12356480+85 0.32454720-03 -0.1600000-01 0.92644280+03 0.11509120+05 0.33671102-03 27.39

VALUES WHICH DEPEND ON SHALL STEP SIZE

PMAX = 8.1296975C+07	ESTIPATED % ERROR = 0.36769720-03
H4IN = 0.6823041C-06	ESTIMATED & ERPOR = 0.14457130-01
XHMIN = 0.73572130-02	ESTIMATED % ERROR = 0.15869570+80
HCEN = 0.76794720-06	ESTIPATED % ERROR = 0.2509079D-01
MM/HC = 8.88912500+00	

h

FINAL CONVERGED VALUES

CALCULATED LOAD CAPACITY (FP) = 0.12796070+05

H0 =-0.900205167500603331D-04

CAVITATION POINT (XE) = 0.738059395409001919D-02

HP (HXE) = 0.76889510-86

FRICTION COEFFICIENT (FRD) = 0.30243010-03

FINAL NO. OF STEPS IN CONTACT ZCHE = 2000

FINAL DTL FOR D02E8F = 0.12969790-81

++++++ CPU = 0.1350+02

INDEX NO. (NT) = 2 TIME (TC) = 0.3125000-01 ENTRAINMENT VELOCITY (UN) = 0.10689100-01

LOAD PER UNIT WIDTH (FP) = 0.1638535C+05

VARIOUS ESTIMATES FOR POISSONS FATIO CF .5

(1.) FOR SURFACE LAYER USING DATA BY SUPTA

A = % Astronoctor-of PMAN = % Astronoctor 64.1 PTM EUVACE LATT WINN FORMULS OF ACOUNTRY PMAN = % Astronoctor ESTIMATE I FARMA = % Astronoctor 64.1 PTM EUVACE LATT WINN FORMULS OF ACOUNTRY PMAN = % Astronoctor ESTIMATE I FARMA = % Astronoctor 64.2 PTM EUVACE LATT WINN F % ASTRONOCTOR ESTIMATE I FARMA = % Astronoctor ESTIMATE I FARMA = % Astronoctor 64.3 PTM EUVACE LATT WINN F % ASTRONOCTOR ESTIMATE I FARMA = % Astronoctor ESTIMATE I FARMA = % Astronoctor 64.3 PTM EUVACE LATT WINN F % MALLS PMAN = % Astronoctor FIMAL CONVERCED VALUES 64.3 PTM EUVACE WINN F % MALLS PMAN = % Astronoctor FIMAL CONVERCED VALUES 64.3 PTM EUVACE WINN F % MALLS PMAN = % Astronoctor PMAN = % Astronoctor 64.3 PTM EUVACE WINN F % MALLS PMAN = % Astronoctor PMAN = % Astronoctor 64.3 PTM EUVACE WINN F % MALLS PMAN = % Astronoctor PMAN = % Astronoctor 64.4 PTM EUVACE WINN F % MALLS PMAN = % Astronoctor PMAN = % Astronoctor 64.4 PTM EUVACE WINN F % MALLS PMAN = % Astronoctor PMAN = % Astronoctor 64.4 PTM EUVACE WINN F % MALLS PMAN = % Astronoctor PMAN = % Astronoctor 64.4 PTM EUVACE WINN F % MALLS PMAN = % Astronoctor	FILES VISE	DATA A LEE	DE UNIVERSITY W	/BSE 6.16		FILE: VSSCB DATA A LEEDS UNIVERSITY VN/OSE 6+16
A = 0.45035000-00 PPAD = 0.12010720-07 A = 0.4503100-00 PPAD = 0.12010720-07 C1.0 PPAD = 0.1201070-07 C1.0 <			1. 5 mm		· · ·	
(4.) FOR SUDVACE LATTE USING FORMULS TO HOUSE AND UNMERN MCT = 5.03300-02 CENTRAL DELATES USING FORMULS TO HOUSE AND UNMERN (5.) FOR SUDVACE WITHS FORMULS BY ANTIN MCT = 5.03300-02 CENTRAL DELATES USING FORMULS BY ANTIN (5.) FOR SUDVACE WITHS FORMULS BY ANTIN MCT = 5.03300-02 CENTRAL DELATES USING FORMULS BY ANTIN (5.) FOR SUBJECT USING FORMULS BY ANTIN MCT = 5.03300-02 CENTRAL DELATES USING FORMULS BY ANTIN (5.) FOR SUBJECT USING FORMULS BY ANTIN MCT = 5.03300-02 CENTRAL DELATES USING FORMULS BY ANTIN (5.) FOR SUBJECT USING FORMULS BY ANTIN MCT = 5.03300-02 CENTRAL DELATES USING FORMULS BY ANTIN (5.) FOR SUBJECT USING FORMULS BY ANTIN MCT = 5.03300-02 CENTRAL DELATES USING FORMULA BY ANTIN (5.) FOR SUBJECT USING FORMULS BY ANTIN MCT = 5.03300-02 MIT = 5.03300-02 (5.) FOR SUBJECT USING FORMULA BY ANTIN MCT = 5.03100-02 MIT = 5.03000-02 (5.) FOR SUBJECT USING FORMULA BY ANTIN MCT = 5.02000 FINAL DL FAR COMPACE USING FORMULA BY ANTIN MIT = 5.030000-01 5.0 CENTRAL DELATES USING FORMULA BY ANTIN MIT = 5.030000-01 5.0 CENTRAL DELATES USING FORMULA BY ANTIN MIT = 5.030000-01 5.0 CENTRAL DELATES USING FORMULA BY ANTIN MIT = 5.0000 FINAL DL FAR COLLE FORMULA	A = 7.679	56942-82 P	MAN = 8.124107204	•67		PNAX = 0.15300500-07 ESTIMATED % ERROR = 0.25453020-03
Willy = A. ALTITATED #4. Subsciences MCRT = 4.36235627-06 ESTPATED # EARINE # 4.30243510-01 (3.) PTX COLD EXPANDED #4 MCRT = 4.000000000 ESTPATED # EARINE # 4.3024350-001 (4.) PTX COLD EXPANDED #4 PART = 4.000000000 FARA # 4.0000000000 (5.) PTX FLATED # MCRT # 5.00000000000 PART # 5.00000000000000000000000000000000000	15 1 500 SUSEA	CE LANCE HETHE				NMIN = 0.00020100-00 ESTIMATED & ENTON = 0.1502010-00
(1.) PT 4/412 Superior with NET IN FORMULA BY ANTIN (4.) PT 14511 (Superior) With NET IN TERMINS (4.) PT 14511 (Superior) With NET IN TERMINS (5.) PT 14511 (Superior) With NET IN TERMINS (6.) PT 15111 (Superior) With NET IN TERMINS (7.) PT 145111 (Superior) With NET IN TERMINS (7.) PT 145111 (Superior) With NET IN TERMINS (7.) PT 15111 (Superior) With N	101 IV = 8.	4C271690-06 H	CEN = 0.50656210-	-86		HCEN = 0.7263562C-06 ESTIMATED % ERROR = 0.2249358D-01 HW/HC = 0.8897886D+80
(4.) FOR TLAYTC 2007ACCS WITHS MATTING FORMULA BY SUALTS FINAL CONVERGED VALUES (5.) FOR TLAYTC 2007ACS WITH FORMULA BY SUALTS CALCULATEE LGAD CARACITY (FP) = 6.1637333D+65 (6.) FOR TLAYTC 2007ACS WITH FORMULA BY SUALTS CALCULATEE LGAD CARACITY (FP) = 6.1637333D+65 (6.) FOR TLAYTC 2007ACS WITH FORMULA BY SUALTS CALCULATEE LGAD CARACITY (FP) = 6.1637333D+65 (6.) FOR TLAYTC 2007ACS WITH FORMULA BY SUALTS CALCULATEE LGAD CARACITY (FP) = 6.1637333D+65 (6.) FOR TLAYTC 2007ACS WITH FORMULA BY SUALTS CALCULATEE LGAD CARACITY (FP) = 6.163737466875610-03 (6.) FOR TLAYTC 2007ACS WITH FORMULA BY SUALTS CAUTATION POINT (KE) = 0.401637677466753468095610-02 (6.) FOR TLAYTC 2007ACS WITH SUARTS 2007AC (7.) FOR TLAYTC 2007ACS 0.2007277-03 (6.) FOR CONTRACTS WITH FORMULA BY SUALTS WITH SUARTS 2007AC (7.) FOR TLAYTC 2007ACS 1 (7.) FOR TLAYTC 2007ACS 0.2007277-03 (7.) FOR TLAYTC 2007ACS 0.2007277-03 (7.) FOR TLAYTC 2007ACS 0.2007277-03 (7.) FOR TLAYTC 2007ACS 1 (7.) FOR TLAYTC 2007ACS 0.2007207-03 (7.) FOR THAYTC 2007ACS 0.2007207-03 (7.) FOR THAYTC 2007ACS 0.2007207-03 (7.) FOR THAYTC 2007ACS 0.2007207-03	(3.) FOR AIGID NAIN # NG	SURFACE USING F EN = 8-23748780-	CANULA BY PARTIN			
(5.) F 00 [LATIC 200+2013] EASTER STRUCTURE OF STRUCTURE TO ALLES (6.) F 00 [LATIC 200+2013] EASTER STRUCTURE TO ALLESS (6.) F 00 [LATIC 200+2013] MECH = 0.12230070-03 (7.) F 00 [LATIC 200+2013] MECH = 0.12230070-03 (7.) F 00 [LATIC 200+2014] MECH = 0.122120070-03 (8.) F 00 [MIC 1] MECH = 0.12220070-03 (8.) F 00 [MIC 1] MECH = 0.12220070-03 (8.) F 00 [MIC 1] MECH = 0.12220070-03 (8.) F 00 [MIC 1] MECH = 0.12020070-03 (8.) F 00 [MIC 1] MECH = 0.1202007007 </td <td>(4.) FC4 ILAST 4 + 8.713</td> <td>IC IUNFACES USIN 16622+01 Pi</td> <td>NERTZIAN FCRAUL</td> <td>AS 06</td> <td></td> <td>FINAL CONVERGED VALUES</td>	(4.) FC4 ILAST 4 + 8.713	IC IUNFACES USIN 16622+01 Pi	NERTZIAN FCRAUL	AS 06		FINAL CONVERGED VALUES
Maria = 0.22862200-46 Maria = 0.12820010-05 CALCULTUE CUD CAACLIN (PF) = 0.1037350-001 (6.) FGR TLISTIC SUPFACES USING FORMULL BY ACREARINGH Maria = 0.128100-06 Maria = 0.12360700-05 CANTATION POINT (ACD = 0.0016370540075510-02 (7.) FGR TLISTIC SUPFACES USING FORMULL BY ACREARINGH Maria = 0.1025771446373584100-05 MB = -0.1025771446373584100-05 (7.) FGR TLISTIC SUPFACES USING FORMULL BY ACREARINGH Maria = 0.1221000 MB = 0.1221000 (7.) FGR TLISTIC SUPFACES USING FORMULL BY ACREARINGH Maria = 0.1025771446373580100 = 0.26152747070-03 FINAL AC. OF SILPS IN CONTACT ZCRE = 2000 (7.) FGR TLISTIC SUPFACES MF (MRC) = 0.26120797-03 FINAL AC. OF SILPS IN CONTACT ZCRE = 2000 (7.) FGR TWO-01 0.0 0.0 0.0000577-051 1.3 (7.) FGR TWO-01 0.0 0.0000577-051 1.3 ******** (7.) FGR TWO-01 0.0 0.0 0.0000577-051 1.3 (7.) FGR TWO-02 0.0 0.0000577-051 1.3 ******** (7.) FGR TWO-03 0.0000577-051 1.3 ******** CPU = 013500-802 (7.) FGR TWO-03 0.0000577-051 1.35 ******* CPU = 013500-802 (7.) FGR TWO-03 0.0000597 0.0000597 0.00000597 0.00005977-051 1.	15.1 FOR ELAST	IC SURFACES US INC	FOPHULA BY SWAL	ES .		
(6.) FOR TLATIC SUPPACES USING FORMULA BY VARAWY N = ===.105377744873984100-03 (7.) FOR TLASTIC SUPPACES USING FORMULA BY HEREARUGH N = ==.105377744807-06 (7.) FOR TLASTIC SUPPACES USING FORMULA BY HEREARUGH N = ==.105377744807-06 (7.) FOR TLASTIC SUPPACES USING FORMULA BY HEREARUGH N = ==.10537744807-06 (7.) FOR TLASTIC SUPPACES USING FORMULA BY HEREARUGH N = =.10537744807-06 (7.) FOR TLASTIC SUPPACES USING FORMULA BY HEREARUGH N = =.10537744807-06 (7.) FOR TLASTIC SUPPACES USING FORMULA BY HEREARUGH N = =.10537744807-06 (7.) FOR TLASTIC SUPPACES USING FORMULA BY HEREARUGH N = =.10537744807-06 (7.) FOR TLASTIC SUPPACES USING FORMULA BY HEREARUGH N = =.10537744807-06 (7.) FOR TLASTIC SUPPACES USING FORMULA BY HEREARUGH N = =.10537744807-07 (7.) FOR TLASTIC SUPPACES USING FORMULA BY HEREARUGH N = =.10537744807-07 (7.) FOR TLASTIC SUPPACES USING FORMULA BY HEREARUGH N = =.10537744807-07 (7.) FOR TLASTIC SUPPACES USING FORMULA BY HEREARUGH N = =.10537744807-07 (7.) FOR TLASTIC SUPPACES USING FORMULA BY HEREARUGH N = =.10537754007007 (7.) FOR TLASTIC SUPPACES USING FORMULA BY HEREARUGH N = =.10537754070707 (7.) FOR TLASTIC SUPPACES USING FORMULA BY HEREARUGH N = =.10537754070707 (7.) FOR SUPPACES USING FORMULA BY HE	907 IN = 6.4	92763930+06 M	EN = 0-12021019-	05		CALCULATED LUAD CAMACITY (FPF) = 0-16373350+05
(7.) FOR LIASTIC SUPACES USING FORMULE BY MERETABUCH MMEY = 6.93137870-06 CAVITATION PDIVI (RE) = 0.26123626371468075610-02 (7.) FOR LIASTIC SUPACES USING FORMULE BY MERETABUCH MMEY = 6.93137870-06 MECEN = 0.1216270-03 (7.) FOR CALENDARY MECEN = 0.12216270-03 (7.) FOR CALENDARY MECEN = 0.1330056C-01 (7.) FOR CALENDARY CAVITATION PDIVI (RE) = 0.26727970-03 (7.) FOR CALENDARY FINAL BCL OF STEPS IN CONTACT ZENE = 2000 (7.) FOR CALENDARY FINAL BCL OF STEPS IN CONTACT ZENE = 2000 (7.) FOR CALENDARY CAVITATION PDIVI (RE) = 0.26727970-03 (7.) FOR CALENDARY CAVITATION PDIVI (RE) = 0.25030056C-01 (7.) FOR CALENDARY CAVITATION PDIVI (RE) = 0.2000 (7.) FOR CALENDARY CAVITATION PDIVI (RE) = 0.23300-62 (7.) FOR CALENDARY CAVITATION PDIVI (RE) = 0.23300-62 (7.) FOR CALENDARY CAVITATION PDIVI (RE) = 0.2000 (7.) FOR CALENDARY CAVITATION PDIVI (RE) = 0.2000 (7.) FOR CALENDARY CAVITATION PDIVI (RE) = 0.2001 (7.) FOR CALENDARY CAVITATION PDIVI (RE) = 0.2000 (7.) FOR CALENDARY CAVITATION PDIVI (RE) = 0.2002 (7.) FOR CALENDARY CAVITATION PDIVI (RE) = 0.2002 (7.) FOR CALENDARY CAVITATION PDIVI (RE) = 0.2002	(6.) FOR ELAST!	C SUMFACES USING	FCRHULA BY VARN	UN		H0 =-0.106377744687938410D-03
W = 123111 SUP AC:S 02 AC NET WHILL BY ACCANCER ON ACCOUNT WE A 0.12702300-45 W = 0.1226324000-06 FRICTION COEFFICIENT (FRD) = 0.26727970-03 FINAL DC. OF STEPS IN CONTACT 2CHE = 2000 FINAL DC. OF STEPS IN CONTACT 2CHE = 2000 FINAL DC. OF STEPS IN CONTACT 2CHE = 2000 FINAL DC. OF STEPS IN CONTACT 2CHE = 2000 FINAL DC. OF STEPS IN CONTACT 2CHE = 2000 FINAL DC. OF STEPS IN CONTACT 2CHE = 2000 FINAL DC. OF STEPS IN CONTACT 2CHE = 2000 FINAL DC. OF STEPS IN CONTACT 2CHE = 2000 FINAL DC. OF STEPS IN CONTACT 2CHE = 2000 FINAL DC. OF STEPS IN CONTACT 2CHE = 2000 FINAL DC. OF STEPS IN CONTACT 2CHE = 2000 FINAL DC. OF STEPS IN CONTACT 2CHE = 2000 FINAL DC. OF STEPS IN CONTACT 2CHE = 2000 FINAL DC. OF STEPS IN CONTACT 2CHE = 2000 FINAL DC. OF STEPS IN CONTACT 2CHE = 2002 FINAL DC. OF STEPS IN CONTACT 2CHE = 2002 FINAL DC. OF STEPS IN CONTACT 2CHE = 2002 FINAL DC. OF STEPS IN CONTACT 2CHE = 2002 FINAL DC. OF STEPS IN CONTACT 2CHE = 2002 FINAL DC. OF STEPS IN CONTACT 2CHE = 2002 FINAL DC. OF STEPS IN CONTACT 2CHE = 2002 FINAL DC. OF STEPS IN CONTACT 2CHE = 2002 FINAL DC. OF STEPS IN CONTACT 2CHE = 2002 FINAL DC. OF						CAVITATION POINT (XE) = $0.001632657348869561D-02$
FRICTION COEFFICIENT (FRD) = $0.26727970-03$ FINAL NC. OF STEPS IN CONTACT 2CHE = 2000 FINAL NC. OF STEPS IN CONTACT 2CHE = 2000 FINAL NC. OF STEPS IN CONTACT 2CHE = 2000 FINAL DIL F3R C0226F = $0.15300502-03$ 6.16001007-01 6.0 6.160122717-01 6.0 6.160122717-01 6.0 6.122277-01 6.0 6.122277-01 6.0 6.122277-01 6.0 6.122277-01 6.0 6.122277-01 6.0 6.122277-01 6.0 6.122277-01 6.0 6.122277-01 6.0 6.0 6.1013127-07 6.0 6.1013127-07 6.122277-01 6.0 6.0123372-02 6.0 6.0120372-02 6.0 6.0120372-02 6.0120372-00 6.0203372-02 6.01413137-06 71 6.0203320-02 6.12020000 -015 6.0203320-02 6.13020000 -010 6.0203320-02 6.1142200-09 6.0726170-06 117 6.0312220-01 6.13020000 -0.12020000 -0.100000	H#IV = 8.1	12 30-7 ACES US 140	EN = 0.12716290-	25 85		NP (HXE) = 0.72634480-06
Image: Construction of the second s		***				FRICTION COEFFICIENT (FRD) = 0.26727970-03
X P DP H 0.14600:000-01 0.0 0.3202907-03 1						FINAL NC. OF STEPS IN CONTACT 2CNE = 2000
xp $3p$ N0:1600:001-010:00:00:20029897-031330:1201:46375-010:00:1202277-010:00:1202277-010:122277-010:00:1472267-032640:122277-010:00:1002207-033390:122377-010:00:1072607-033390:122377-010:00:1002207-033990:122377-010:00:1074607-036650:0023757-020:00:1074607-036650:0023757-020:00:1074607-036650:00321257-020:00:1074607-036650:00321267-020:10726070:1725400-06-0:23012370400:00321257020:10204070:1725400-060:1071000:00321267-020:10204070:172541627060:1717-060:00321267-030:142971070:1782400-060:1301000:1312237-030:142971070:1782407-06113510:00327527-020:13774600-660:137710-6613560:0131370-600:13131237-020:3131370+600:137711-050:013237-200:3131370+660:01301370+700:178210-7030:013237-210:13012370-600:10377170-700:13325510-7030:127527-020:13131370+600:13377121-650:1275327-020:13131370+600:1325171-7030:13337920-020:13271870+600:1332517-7030:13337920-020:13377810-700:1332517-7030:13337920-020:1332510-7032:234600:135237920-02<						FINAL DTL FJR C02EBF = 0.1530050C-01
0.1600:000-01 0.0 0.32020897-03 1	X (. P	90			
e.14414757-01 0.0 e.24062297-03 133 e.1222577-01 0.0 0.6772627-03 266 e.1222577-01 0.0 0.68153257-03 399 e.1222577-01 0.0 0.68153257-03 399 e.1222577-01 0.0 0.68153257-03 399 e.602037537-02 0.0 0.0 0.101726270-03 399 e.602037537-02 0.0 0.0 0.101726270-03 399 e.602037537-02 0.0 0.0 0.101726270-03 667 e.602037537-02 0.0 0.0 0.101776670-05 665 e.603321326-02 0.127266160-09 0.61728170-06 1164 ENTRAIMMENT VELCCITY (UN) = 0.10068910-01 e.1493250-02 0.13276200+09 0.61728170-06 1164 ENTRAIMMENT VELCCITY (UN) = 0.20924571-05 e.14943203-02 0.13278120+09 0.61728170-06 1167 1171 e.1494320-02 0.14728170-09 0.727867317-06 1165 1177 e.14943200-07 0.1327870-09 0.72286120-01 1165 1177 e.14943230-02 0.14728770-09 0.7228170-06 1165	0.16003900-01	0.0	0.0	0.32029897-03	1	****** CPU = #+3350+#2
0.1221760-01 0.0 0.1672267-03 266 0.122277-01 0.0 0.1633220-03 399 0.1622877-02 0.0 0.0 0.1833220-03 399 0.1623872-02 0.0 0.0 0.1837220-05 665 0.00283720-02 0.0 0.0 0.1847600-05 532 0.00283720-02 0.0 0.0 0.1847600-05 665 0.0028372150-02 0.0 0.1847600-05 665 0.0013250-02 0.0 0.72664420-05 6.66 0.0013250-02 0.5726600-06 0.2002590-05 0.6212012970-06 1054 0.1633250-02 0.1826200-09 0.60725170-06 1157 0.64294220-07 0.137560-09 0.72567510-06 1330 0.4294220-07 0.137560-09 0.72567510-06 1336 L0AD PER UNIT WIGTH (FP) = 0.209245710-05 0.414537120-07 0.1375570-09 0.7251130-06 1336 L0AD PER UNIT WIGTH (FP) = 0.20924570-05 0.41437470-06 0.2355220-09 0.1425770-06 1356 1356 1356 0.41432330-02 0.14728970-07 0.123570-05 143572	8.14416753-81	0.0	T - 0	8-24062692-03	132	
0.1122257-01 0.0 0.0013320-02 0.0 0.00233520-02 0.0 0.00233520-02 0.0 0.00233520-02 0.0 0.00233520-02 0.0 0.00233520-02 0.0 0.00233520-02 0.0 0.00233520-02 0.0 0.00233520-02 0.0 0.00233520-02 0.0 0.0023520-02 0.0 0.0023520-02 0.0 0.0023520-02 0.0 0.0023520-02 0.0 0.0023520-02 0.0133200-05 0.0023520-02 0.0023520-02 0.0133200-02 PMA1 0.022040390-01 -0.47433230-02 0.004752500-03 0.10255170-03 0.10355170-03 0.2145170-03 0.10355170-03 0.103555170-03 0.103555170-03	0-1291-663-01	3.3	0.8	0.16752862-03	266	
0.96256937-02 0.0 0.4993937-03 532 0.6023152-02 0.0 0.1047460-05 665 INDEX NO. (NT) = 3 0.60133270-02 0.0 0.72614420-05 665 INDEX NO. (NT) = 3 0.60133270-02 0.0 0.72614420-05 665 INDEX NO. (NT) = 3 0.63138212-02 0.5442130-06 0.2303277047 0.6154212007 0.632237047 0.61642210-06 10068910-01 0.632371260-02 0.12200010-07 -0.2303277047 0.64726270-06 1064 ENTRAINMENT VELOCITY (UN) = 0.10068910-01 0.64296230-04 0.1530050-07 -0.22440170-07 0.7256170-06 1157 0.64296230-04 0.1530050-07 0.7256170-06 1330 L0AD PER UNIT WIGTH (FP) = 0.20924570-05 -0.6135212-02 0.149705070 0.747560-06 1576	0.11222573-01	6.6		0.10353250-03	399	
0.0020375-02 0.0	8.96254547-02	0.0		9.49936940-04	532	
0.00143377-02 0.0 0.0 0.02244027-05 666 0.4033022-02 0.5424320-06 -0.2032573-06 794 TIME (TC) = 0.62500000-01 0.43342137-02 0.72246040706 -0.2032573-06 931 0.32371262-02 0.12600000-07 -0.154262009 0.64729170-06 1064 0.42946220-09 0.1520050+07 -0.15426160-06 0.70266077-06 1157 0.42946220-09 0.14720970-07 0.72567510-06 1330 L0AD PER UNIT WIGTH (FP) = 0.20924570-05 -0.15541430-02 0.14720970-07 0.73752006 0.722567510-06 1330 L0AD PER UNIT WIGTH (FP) = 0.20924570-05 -0.4743230-02 0.14720970-07 0.73752006 0.72250750-06 1576	0-80283957-92	8-0	8.8	8.18474603-05	665	INDEX NO. (NT) = 3
0.4031002-02 0.5422302+06 -0.205020000 0.45362292-06 744 TIME (TC) = 0.62500000-01 0.40302152-02 0.572860010+07 -0.23012570+09 0.657150132-06 931 0.4030325-02 0.14657120+07 -0.78266160+08 0.70456677-06 1157 0.40396220-00 0.1250050+07 -0.78266160+08 0.70456677-06 1157 0.402946220-01 0.12720770+07 0.77357512-06 1330 L0AD PER UNIT WIGTH (FP) = 0.20924570+05 -0.11512312-02 0.12746070+07 0.7735620-09 0.72567512-06 1356 -0.31512312-02 0.12946220+07 0.147735200+09 0.72567512-06 1576 -0.47433237-92 0.39464750+06 0.22549620+09 0.62219402-06 1725 -0.47433237-92 0.39464750+06 0.2254020+09 0.62219402-06 1725 -0.47433237-92 0.39464750+06 0.2254020+09 0.62219402-06 1725 -0.47433237-92 0.39464750+06 0.2254020+09 0.6251970-05 1725 -0.47935227-02 0.39123300+05 0.2254020+09 0.614375710-05 1725 -0.47935227-02 0.394725350+03 0.6251710+05 <	8-08163273-82	4-0	9.0	8.72624482-86	66 E	
0.4334213-02 0.7226040-06 -0.23032970-09 0.61151313-06 931 0.32371262-02 0.12600010-07 -0.15429620+09 0.60729170-06 1064 0.42946230-08 0.12657120-07 -0.72567510-06 1157 0.42946230-08 0.127047067 0.72567510-06 1330 LOAD PER UNIT WIGTH (FP) = 0.2052457C+05 -0.15514330-02 0.1470870+07 0.73758200+09 0.72567510-06 1330 LOAD PER UNIT WIGTH (FP) = 0.2052457C+05 -0.47433230-02 0.1470870+07 0.14775720-09 0.72567710-06 1462	0.64313052-02	0-54426330+06	-4. 306368 22 +89	8-65822950-06	79#	TIME (TC) = 0.6250000D-01
0.3237126C-02 0.1280010+07 -0.159296220+09 0.68729170-06 1964 ENTRAINMENT VELCCITY (UN) = 0.1006891C-01 0.164003250-02 0.46571220+07 -0.78266160+08 0.70567510-06 1157 0.42906220-09 0.12994220+07 0.72567510-06 1330 LOAD PER UNIT WIGTH (FP) = 0.20924576+05 -0.41532120-02 0.1472897D+07 0.73756200-09 0.7251920-06 1462	0-45342153-02	0- 57236840+06	-0.23032593+09	8-67158132-06	931	
0.16403360-02 0.14657120+07 -0.78256160+08 0.70456679-06 1197 0.42946220-04 0.15300050+07 -0.22480170+07 0.72567510+06 1330 LOAD PER UNIT WIGTH (FP) = 0.2092457C+05 -0.15501430-02 0.1472897D+07 0.7358200-09 0.72567510+06 1462 -0.31512332-02 0.34464750+06 0.22554600+09 0.7625170+06 1576 -0.47633230-02 0.57374660+06 0.22554600+09 0.499420+06 1462 -0.47633230-02 0.57374660+06 0.22554600+09 0.499420+06 1462 -0.47633230-02 0.57374660+06 0.2013019D+09 0.994420+06 1462 -0.47633230-02 0.57374660+06 0.2013019D+09 0.99442049-06 1462 -0.47633237D-02 0.57374660+06 0.2013019D+09 0.494320+07 0.473570+05 -0.47635020-02 0.31551270-03 0.414575710+05 0.4145752910+05 0.4145752910+05 -0.11336642-01 0.99476530-03 0.4752910+05 0.4355217-03 2374 -0.12733770-01 0.77965200+03 0.4752910+05 0.43552520+03 2527 (2.) FOR SURFACE LAYER USING FOR*ULAS EV MCOKE AND VAPNL*	0.32371260-02	9-1200010+07	-0.15429620409	0-68727179-86	1964	ENTRAINMENT VELCCITY (UM) = 0.10068910-01
0.42946230-00 0.15300050+07 -0.22480110+07 0.72567510+06 1330 L0AD PER UNIT WIGTH (FP) = 0.20924576+05 -0.155114330-02 0.14720970+07 0.73750200-03 0.7756200-03 1463 -0.47433233-02 0.39464750+06 0.22554660+09 0.82151460-65 1725 -0.63455130-02 0.57379660+06 0.30130190+09 0.99442047-06 1862 VARIOUS ESTIMATES FOR POISSONS FATIO CF .5 -0.63455130-02 0.53123300+05 0.22564620+09 0.49757910+05 1375 -0.63455130-02 0.53123300+05 0.22564620+09 0.49757910+05 1375 -0.63455130-02 0.5312300+05 0.22564620+09 0.49757910+05 1375 -0.79425027-02 0.5312612300+05 0.49757910+05 1375 -0.79425027-02 0.532512300+03 0.47522910*05 0.46352517*03 2261 A = 0.72136430-02 PMAX = 0.22040990*07 -0.12733770-01 0.7765200+03 0.47522910*05 0.40332517*03 2374 (2.) FOR SURFACE LAVER USING FORMULA BY MCCKE AND VARNUM -0.163306120+03 0.12775160+05 0.316503*0^*03 2577 (2.) FOR SURFACE LAVER USING FORMULA BY MARTIN HMIN = 0.3582937D-06 HCEN	8.16403363-82	0.14657120+07	-0.78266160+08	0.70456677-06	1157	
-0.15541433-02 0.1472897D+07 0.7375230C+08 0.75066872-06 1462 -0.31512332-02 0.1294422D+07 0.14973555+09 0.76221530-06 1576 -0.47433233-02 0.573766D+06 0.2013019D+09 0.994280+0-06 1862 VARIOUS ESTIMATES FOR POISSONS FATIO CF .5 -0.79425022-02 0.3912330D+05 0.2540764D+09 0.14757710+05 1375 -0.79425022-02 0.3912330D+05 0.2540764D+09 0.14757710+05 1375 -0.95375923-02 0.1356158D+04 0.6126174D+06 0.45350250-04 212E (1.) FOR SUPFACE LAYER USING DATA RY CUPTA -0.11136632-01 0.776520D+03 0.4252510+05 0.16032517-03 2261 A = 0.7213643D-02 PMAX = 0.2204099D+07 -0.12733770-01 0.776520D+03 0.42255666D+05 0.23556242-03 2374 -0.14336262-01 0.7265573D+03 0.2255666D+05 0.23556242-03 2374 -0.16336262-01 0.7265573D+03 0.1277516D+05 0.3165030-03 2567 -0.15927955-01 0.6970632D+03 0.1277516D+05 0.3165030-03 2566 -0.16030202-01 0.4930532D+03 0.1277516D+05 0.31650300-03 2566 -0.16030202-01 0.4930532D+03 0.1277516D+05 0.32233752-03 2566 -0.16030202-01 0.4930532D+03 0.12775100-05 0.3223752-03 2566 -0.16030202-01 0.4930532D+03 0.12775100-05 0.322	0-42946210-04	0.1520 0050+07	-0-22480170+07	0.72567512-06	1330	LOAD PER UNIT WICTH (FP) = 0.20924570+05
-0.3151233-02 0.1294220+07 0.14973552+09 0.70221530-06 1576 -0.47433233-02 0.59464759+06 0.22554600+09 0.82519463-05 1725 -0.63459130-02 0.57379660+06 0.30130199+09 0.99442209-06 1A62 VARIOUS ESTIMATES FOR POISSONS FATIO CF .5 -0.79425027-02 0.39123309+05 0.25907640+09 0.14957910+05 1975 -0.95379527-02 0.39123309+05 0.25907640+09 0.14957910+05 1975 -0.95379527-02 0.39123309+05 0.21263100+06 0.45350250-04 212E (1.) FOR SUPFACE LAYER USING DATA MY GUPTA -0.1136662-01 0.90472530+03 0.407522910+05 0.16392517-03 2261 A = 0.72136430-02 PMAM = 0.22040990+07 -0.12733770-01 0.77965200+03 0.497522910+05 0.16392517-03 2374 -0.143302657-01 0.72655730+03 0.22556660+05 0.23556247-03 2527 (2.) FOR SURFACE LAYER USING FOPMULAS BY MCCKE AND VAPNUM -0.15927950-01 0.69306320+03 0.12775160+05 0.3165057-03 2560 HNIN = 0.3582237D-0E HCEN = 0.45667130-06 -0.16050012-01 0.03615330+03 0.12775160+05 0.3165057-03 2566 -0.16050012-01 0.037515330+03 0.12775160+05 0.3165057-03 2566 -0.16050012-01 0.037515300+03 0.12775160+05 0.3165057-03 2566 -0.16050012-01 0.037515300+03 0.12775160+05 0.3165057-03 2566 -0.16050012-01 0.037515300+03 0.12775160+05 0.3165057-03 2566 -0	-8-15541433-02	0.14728970+07	0.73758200+09	0. 750668 72-06	1463	
-0.4743233-92 0.99464759+06 0.22564680+09 J.82519463-65 1725 -0.63459130-02 0.57379660+06 0.3013019D+09 0.99442847-06 1862 VARIOUS ESTIMATES FOR POISSONS RATIO CF .5 -0.79425027-02 0.39123309+05 0.254076470+09 0.14757710+05 1375 -0.95375727-02 0.13581580+0 0.61261740+06 0.45350257-04 212E (1.) FOR SUPFACE LAVER USING DATA RY GUPTA -0.1136632-01 0.99478530+03 0.12634100+06 0.10037517-03 2261 A = 0.7213643D+02 PMAN = 0.22040990+07 -0.12733775-01 0.77965200+03 0.47522910+05 0.16392517-03 2334 -0.143350657-01 J.7265573D+03 0.22556660+05 0.23556247-03 2527 (2.) FOR SURFACE LAVER USING FORMULAS BY HECKE AND VARNUM -0.15927955-01 0.69306320+03 0.1277516D+05 0.3165057-03 2567 -0.16030012-01 0.0361533D+03 0.1277516D+05 0.3165057-03 2660 HMIN = 0.3582237D-06 HCEN = 0.4566713D-06 -0.16030012-01 0.0361533D+03 0.12471547+05 J.3233752-03 2666 -0.16030012-01 0.0361533D+03 0.12471547+05 J.3233752-03 2666 -0.16030012-01 0.0361533D+03 0.12471547+05 J.3233752-03 2666 -0.16030012-01 0.03761533D+03 0.12471547+05 J.3233752-03 2666 -0.16030012-01 0.03761533D+03 0.12471547+05 J.32033752-03 2666 -0.16030012-01 0.03761533D+03 0.12471547+03 J.32033752-03 2666 -0.16030012-01 0.03761533D+03 0.12471547+040444444444444444444444444444444444	-0-31512332-02	0.12944220+07	0-14973592+09	0-76221530-06	1576	
-0.63454132-02 8.57374660+06 0.2013019D+09 8.99442847-06 1862 -0.79425027-02 0.39123309+05 8.2540764D+09 0.1475771D+05 1375 -0.95375922-02 8.13581580+0 4 8.61261740+06 0.45350257-04 212E -0.95375922-02 8.13581580+0 4 8.61261740+06 0.4037517-03 2261 -0.11136642-01 8.90478530+0 2 0.12634100+06 0.10037517-03 2261 -0.12733777-01 0.77965200+0 3 0.47522910+05 0.16592517-03 2374 -0.12332420-01 0.72655730+03 0.42556660+05 0.23556242+03 2527 -0.1433262-01 0.72655730+03 0.22556660+05 0.23556242+03 2527 -0.15927952-01 0.69706320+03 0.12775160+05 0.316582517-03 2560 -0.16830072-01 0.69706320+03 0.12775160+05 0.31658257-03 2560 -0.16830072-01 0.697015330+03 0.12775160+05 0.31253752-03 2566 -0.16830072-01 0.697015330+03 0.12471547+05 0.3203752-03 2566 -0.16830072-01 0.697015330+03 0.12471547+05 0.32037752-03 2566 -0.16830072-01 0.697015330+03 0.12471547+05 0.32037752-03 2566 -0.16830072-01 0.697015330+03 0.12471547+05 0.32037752-03 2566 -0.16830072-01 0.17754522-09	-0-47433233-92	8. 39464750+06	0-22554680+09	J. 82519463-66	1725	
-0.79425027-02 0.39123309+05 0.25407649+09 0.14957910+05 1995 -0.95395920-02 0.13581580+04 0.61261740+06 0.45350250-64 212E (1.) FOR SUPFACE LAYER USING DATA RY EUPTA -0.11136682-01 0.90478530+03 0.12634100+06 0.1003*51*-03 2261 A = 0.7219E430+02 PMAH = 0.22040990+07 -0.12733770-01 0.77965200+03 0.47522910+05 0.16352519+03 23*4 -0.19330260-01 0.72655730+03 0.22556660+05 0.23556249+03 2527 (2.) FOR SURFACE LAYER USING FORMULAS BY HOOKE AND VARNUM -0.15927950+01 0.69706320+03 0.12775160+05 0.31650259+03 2560 -0.16030012*01 0.09815330+03 0.12775160+05 0.31650259+03 2566 -0.16030012*01 0.09815330+03 0.12471547+05 0.3203750+03 2566 -0.16030012*01 0.09815330+03 0.12471547+05 0.43023750+03 2566	-0-63454130-02	6.57379660+06	0.20130190+09	8.99442847-06	1862	VARIOUS ESTIMATES FOR POISSONS FATIO CF .5
-0.9537592-02 8.13581580+0 4 8.61261740+06 0.4535025-04 212E (1.) FOR SUPFACE LAYER USING DATA WY GUPTA -0.111366d2-01 8.90478530+0 3 0.12634100+06 0.1002351^-03 2261 A = 0.72136430-02 PMAM = 0.22040990+07 -0.12733770-01 0.77965200+0 3 0.47522910+05 0.16392510-03 2334 -0.10330262-01 J.72655730+0 5 0.22556660+05 0.23566240+03 2527 (2.) FOR SURFACE LAYER USING FORMULAS BY HOOKE AND VARNUM -0.15927950-01 0.69706320+0 3 0.12775160+0 5 0.31650350+0 3 2560 -0.16030010-01 0.09815330+0 3 0.12471547+0 5 0.32033750+0 3 2566 -0.16030010-01 0.09815330+0 3 0.12471547+0 5 0.42033740+0 25667 -0.16030010-01 0.09815330+0 3 0.12471547+0 5 0.42033740+0 2567 -0.16030010-01 0.09815330+0 3 0.12471547+0 5 0.4203040+0 2567 -0.160300000+0 00000+0 00000+0 00000+0 00000+0 0000+0 00000+0 0000+0 0000+0 0000+0 0000+0 000+0 000+0 000+0 000+0 00+00+	-0.79425027-02	0.39123300+05	8-25407640+09	0.14757710-05	1998	
-0.11136632-01 0.90478530+0 2 0.12634100+06 0.1003551-03 2261 A = 0.7213643D-02 PMAH = 0.2204099D+07 -0.12733770-01 0.7796520D+03 0.47522910+05 0.16392517-03 2334 -0.10330362-01 0.7265073D+03 0.22556660+05 0.23556240-03 2527 (2.) FOR SURFACE LAYER USING FORMULAS BY HOOKE AND VARNUM -0.15927950-01 0.6930632D+03 0.1277516D+05 0.3165030-03 2660 HNIN = 0.3582937D-06 HOEN = 0.4566713D+06 -0.16030012-01 0.0381533D+03 0.12471540+05 0.3203750-03 2666 (3.) FOR RIGID SURFACE USING FORMULA BY WARTIN HMIN = HOEA = 0.17754522-09	-0.95375920-02	8-13581580+04	8-61251740+06	0.45350257-04	2128	(1.) FOR SUPFACE LAYER USING DATA BY EUPTA
-0.12733779-01 0.77965200+03 0.47522510+05 0.16392519-03 2334 -0.14335462-01 J.72652730+03 0.22556660+05 0.23556240-03 2527 (2.) FOR SURFACE LAYER USING FORMULAS BY HOOKE AND VARNUM -0.15927953-01 0.69306320+03 0.12775160+05 0.31650350-03 2660 NNIN = 0.35829370-06 HOEN = 0.45067130+06 -0.16030010-01 0.63815330+03 0.12471540+05 0.31233750-03 2666 (3.) FOR RIGID SURFACE USING FORMULA BY MARTIN HMIN = HOEA = 0.17754520-04	-9-11136682-01	8.90478530+43	0-12634103+06	0-10023517-03	2261	A = 0.72176430-02 PMAN = 0.22040790+07
-0.10333462-01 J.7265573D+03 0.22556660+05 0.23556247-03 2527 (2.) FOR SURFACE LAYER USING FORMULAS BY HOOKE AND VARNUM -0.15927953-01 0.6990632D+03 0.12775160+05 0.31650357-03 2660 NNIN = 0.3582937D-06 HOEN = 0.4506713D+06 -0.16090012-01 0.6981533D+03 0.12471547+05 J.32J33757-03 2666 	-0.12733773-41	8.77965200+03	0.47522510+05	0-16352517-03	2374	
-0.15927953-01 0.69306320+03 0.12775160+05 0.31650353-03 2660 NNIN = 0.35829370-06 HCEN = 0.45067130-06 -0.16030032-01 0.63815330+03 0.12471542+05 0.3233752-03 2666 	-0.19330462-01	0.12655730+0.3	0.22556660+45	0.23556242-03	2521	(2.) FOR SURFACE LAYER USING FORMULAS BY MCCKE AND VARNUM
-0.16830012-01 0.63815330+03 0.12471547+05 0.3233792-03 2565 (3.) For Rigid Surface Using Formula by Wartin HMIN = HCLA = 0.17754522-04	-0-15927953-01	8.69386320+83	0-12775160+05	0.31650357-03	2660	HNIN = 0.3582937D-06 HCEN = 0.45667130-06
(3.) FOR RIGID SURFACE USING FORMULA BY WARTIN HMIN = HCLA = 0.17754522-04	-0-16830012-01	07815330+03	0-12471542+45	9.32323752-03	2565	
						(3.) FOR RIGID SURFACE USING FORMULA BY WARTIN HMIN = HCEA = 0.17754522-09

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VALUES ANICH DEFEND ON SMALL STEP SIZE

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(4.) FOR ELASTIC SUBFACES USING FERTZIAN FORMULAS A = 0.90456870+01 PMAX = 0.68656530+06
LEEDS UNIVERSITY WH/BSE 6.16 .

DATA

DATA FILE: BANK

.843750060200CC3800

• 566187332875836597E-06 -• 59746768465210529AE-04 752699.610739192023 -5622582 °59124P17005-02 -975000300000CC8000 .6657636371112185845-86 -.5153828928431623485-84 862116.836492039721 -6017387422510418925-02 .906258080808086006 -.5756249769021719635-04 •6962671113482139d4E-06 1020138.58680407416 -5545867323277674955-02 .937500039880668388 -.7062473518772522946-04 .700771736444171975E-06 1127979.46261229932 -6 982952184736121655-82 .96875880000000000000 -.781675545822437912-04 .7026811332898464438-06 1296979.40653449160 .7300593952339354415-02 1-00000000000000000000 -. 7002851670659137425-04 •6d2804102783248392E-06

1230057.76532484492 1796402+43875099852 2893125.59496485605 2417072.53743135976 2724481.97486385979 3845899,3570 7*88464 3362678.77915116563 3664 947 . 2628 46620 ** 4086675.57267739747 4521678-85384966899 4859327.27965151402 4996502.52940892451 4895516.75624421714 4668215-00827P03253 3545013-06784642455 3186586.32733419100 2710627.71430471332 2251024-0 6298423080 1441923-75687258213 1024399-45773702438 838356-275292502904 7141 69. 95551 32 15042 7:09:0.123711741403 614672.834478848606 655558.50 6946300999 EE9777. 935973043546 862631.975717167443

1256579.48715427518

1000 .7388593954898619195-82 -682-841827670172722-06 .801638657346889561E-02 --1863777446829884185-83 -6462453941378462665-86 -868613345494771616E-82 .625000000000CC008002-01 -.1250738762268855870-83 .7 3761 821 4464184 1785-82 .9375030900000888964E-01 --143585528099754953--03 -546427533634445493E-86 -1007260221202602770-01 -12500508308900000000 +.1 6865291 23755315275-03 .484678484392216387E-86 -1069711571322582662-01 -1562508808080666668808 -.1.982474756036124195-93 .4157377319629364335-86 -1136903164192495912-01 -187588888888886668888 • 324940365094385423E-06 -• 2127616683752131175-02 -1188415146005550320-01 -2187500:0000000000000 -.2351279648927255685-83 .232704755401304d185-06 -124067655366900476-01 .25000000000000000000 -.2564889565201730462-93 •51 32 71 03 211 36 76 455E -0 7 +1 310019888 56524.6412-01 .281250 030 000 00000 -.2957774617693728195-03 • 221 308 27ª 44 45 57 32 9E-8 € -1379110741146449695-01 -31250089030900000000 .3025642636296069795-06 -.3161926901585090365-03 -1428607025779466337-01 - 343750 000400 000000 -.3397517913937572535-03 -358219740375414159E-06 -144863091805001731E-81 .3750000000006668890 -. 3453(54512866494935-03 •401554234951520915E-06 -1 433916792589412885-01 .486250000000000000000 -.342195610725652341-03 .4 377 31 3327 116 614185-06 .1406232421326352405-01 . 4 37 50 00 00 00 00 00 00 00 -.3262514724062292355-03 •467381446391183950E-0**6** 1287208454352043335-01 .468750880000868800 -.2755867920170602585-03 •503146314463282540E-06 -1156878080661882025-01 -200000000000CC0000 -.222458925776114464--03 .5370492732275614115-06 -106698525173432823E-01 -.1991215985855441935-03 • 554527875035913023E-06 •9723323 94664747 46JE-02 -5625000000000000000 •5652966737176408705-06 -•156937307913147C35F-03 •778208342939725600E-02 -573750000000000000 -.1002569291269886775-03 •603849840751100285E-06 +655932941378033034E+02 • 62500000000000000000 -.7102095811016008605-04 •61022772485858094*8*E-06 -5-856495352534938AE-02 .456250000309000309 -.574033211169610*055-04 • 572236635190771631E-06 -5476863029220194195-02 -6475000000000000000 -.4 943796567277261261-04 .4931543348634424562-06 -5540E7539488474741E-02 ·71673000000000000 -- 507744603912477517-04 -347457312541376535E-0£ -5162970047436363232-02 .75990000000000000000 -.4433719265465672640-04 +40220 7227507390555-07 .5247235338219340755-02 .78125000000000000000000 -.454864458277265883°-04 • 357937493835107713E-06 +604406327764=097431+02 .81250J0J0000C00000 •466939061505539947E-06 -•60359211955359577#F-04 .6019183751637045475-02

OUTPUT

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PSSCB



TIME = 0.0000E 00





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		PL100810	C	CHECK	PLIGOSEG	J
		FLICECZU	[PLI C0570	1
	FLANZ JACKINED SLAFACE NOETL	PLI00030	77		FLID0320	j •
		-LI08846	141		PL199370 Pl100600) •
	A THE SECONDARY AS A STOLE ON THAT A A THE ALL AND A THEORY AND		r	••••••	-LIUU600	7 8
	A FEATLE ANTE BEACHT OF A AIGIT BLAT IS ADDALATED		č		P1100610	, 1
č	AS A RAF INFITED SUFFICE INFINE TANT IS TENSOLIS.	PL 100090	1486	FORMATCH TOL CTOLFRANCE FOR SS AND STEP STEED	PL 100630	Ĵ
Č	THE 5 349 AND VELOCITY APE CYCLIC TIPE VARVING.	PLIMAN	140	FCRNATE HO (INITIAL GUESS FCR HO AT TIPE ZERC) ".E19.7)	PL 100640	j
Ē	IT IS ASSUMED THAT THE FILE THICKNESS VARIATICS WITH TIME	PL 1 00 1 00	1402	FORMATE NEER CHAR, NO. OF CYCLES AT SAME STEP SIZED ". 18)	PL 100650	j
Č	CAN BE APPROXIMATED AS OPE/DT. THE LENGTH OF THE PLANE	PL100110	1403	S FORMATE NHALF (PAL. NO. OF STEP SIZE HALVINGS)	PLIDOGES	
5	SURFACE IS CHOSEN SUCH THAT CP/CH = 0. AT H = 80RY/2.	PL100120	1404	FORMATE NEFT CINITIAL NO. CF STEPS PER CYCLED ",18)	PL100670)
. C	THE INCLINATION OF THE PLANE SURFACE IS CHOSEN SUCH THAT	PL I00130	1485	5 FORMATC" NFRT (NO. OF STEPS PRINTED PER CYCLE)	PLIBOGRE	1
C	FOR THE INSTANTANEOUS CONCETTENS OF LEAD AND VELCEITY	PLI00140	1 40 6	5 FORMATCY IPRT (CONVERGENCE PRINT OPTICN)	PL100650	ł
C	THE MINIPUM STEADY STATE FILM THICKNESS EQUALS THAT	PL100150	1401	FORMATCY NPP (NO. OF PRESS. PTS. PRINTED PER DIST.) *.IB)	PLI00700	,
C	PREDICTED BY SOLUTIONS GENERATED USING THE COLUMN MODEL.	PL100160	1408) FORMATCY NPT (NO. OF PRESS. DIST. PMINTED)	PLI00710	
. C		PLI00178	1489	FORMATE NP (PRINT OPTIONS FOR PRESS. DIST.)	PL108728	
C		PLI00100	1410) FORMAT(" VI (ABSCLUTE VISCOSITY)	PL I 00 7 3 0	
C		FL100190	1411	FORMATCE TP (PERIOD)	PL 100 740	
	IPPLICIT REAL+9CA-H+0-Z)	PLI00200	1412	FORMATCO E (ELASTIC MODULUS OF LAYFO)	FLI00750	
	REAL+4 PHAN, TP1, HFACT, FFACT, TT(4011, HH(401), FF(401),	PL100210	1413	FORNATC R (REDUCED RADIUS)	FLI00760	
	• XPR(201) , XI(201) , F (C (401), XP (Z),	PL100220	1919	FORMATE TH CLATER THICKNESS	PLI00770	
		PL100230	1413	PORMATE WE CHIDIN UP CONTACTS CONCERCENCESCOCOCCESCOCO "CIACTS F	PL IDO 720	
	• XI 9729739X797107297397	PL100240	141/	FURTAIL UPT CAPTLIE UP ENIS VELSE SCORESSCORESSCORES "SLIGSIS"	LI00790	
	CONTRA DE COLORDO DI 1977 1 2 REVANDO 2 REVANDA 2 REVAND	51 100 230 ·	1419	$ \begin{array}{c} \mathbf{r} \mathbf{r} \mathbf{r} \mathbf{r} \mathbf{r} \mathbf{r} \mathbf{r} r$		
		PL 100220	1428	FORMATCH LEACT (SCALE FACTCA FOR PLCTS)		
	COMMON WERERS AFERERS PKI(FR) PCI(FR) FRI(100) FET(100)	PL 1002#0	1421	FORPATEL HEACT (SCALE FACTOR FOR FILM DIOTS)		
	COMMCN AN(900) .Fu(616) .MKI(68) .HCI(68)	PL180290	1422	FORMATCY FFACT (SCALE FACTOR FOR FRICIION PLOTS) *-F14-7) P	1100 440	
	COMMON TF (188), FE (188), FP (188), TP (188)	PL100300	1423	FORMATCY PFACT (SCALE FACTOR FOR FFICTION PLOTS)	LI00850	
	COMMON TZ + Z + UZ + FPZ + FZ + BZ + XHZ + XHDZ + FRZ + CH1 + CH2 + DT + EHZ + XH	PL100310	C			
	COMMON UE(400).FP9(400).FU(400).BF(400).xMI(400).xPP(401)	FL100328	C	P	L100 970	
	COPMON FRI(400),H(400),HST(2000),UC,FPY,8C,8C4Y,H*,U*0	PL188338	1599	FORMATE/* NCTE : FOR SS TOLERANCE EQUALS .1+TÓL*/) P	1100880	
	COPHON NPER, NHALF, NSPTP, NPRT, IPRT, NFT, NFT, NP, NA4, NF4, NH4	PL100340	1693	FORMATE/243 ; CATA BANK*//) P	LI00990	
	FR (VI)=((VI)+UG)/(FPG+X9G))+(8.D8+CLC6(1.C8+X46+86/+6)	PL100350	111	FORMATC ⁹ • 6 # • * TO* • 15 # • * X E • • 14 # • * PD* • 13 # • * MCCL* / P	LI00900	
	A -12.C8+XP6+86/(2.D0+H6+XP6+86))-((6.D8+V1)/(FP6+XP6+2))	PLI00360	112	FORMAY (,13,4(C14,7,2X),18)	1100910	
	A • { DL C { } . J0 + XH G + BG / HG } - 2 . C 0 + XH G + BG / { 2 . C 0 + HG + XH G + B G }) + F G	PLI00370	114	FOR 4AT& * (4X,*T/TP*(10X,*TIP**,5X,*LCAC*(11X,*FP*/) P	LI08929	
		PL109360	113		L100-30	
		PLINU370	110		LI00940	
C		PLI00400			1100450	
č	IMPUT	PITONACS			1700930	
ē		Pt 100410				
	READ(5) TCL.MO.NPER.NHALF.ASPTP.NPRT.IPRT.NPX.NPT.NP	PL100440		WATTE(6+1400) TCL	1100900	
	READ(5++) VISTPSERSTHEND	PL100450		WRITE(6+1401) H0 P	1 101 000	
	READ(5,+) LAPP,PCIS,UND	FLIDDAGD		WRITE(6,1402) MPER P	LT01010	
	READ (50+) SFACTONFACTOFFACTOPFACT	PL 100 4 70		URITE(6,1403) NHALF P	LI01020	
	READ(5,+) NF	PLICOARD		VPITE(6+14C4) NSPTP P	LI01030	
	READ(5,+) (IN(I),I=1,MF)	PL100490		WPITE(6,14G5) NPRT P	LI01040	
	READ(5,+) (FE(I),I=1,NF)	PLICOSCO		WRITE(6,140E) IPAT F	LI01050	
	READ(5,+) AH	PL100514	I	WRITE(6,1407) NPA P	L1010E0	
	UU 6291 [=],4W	FLI00529	1	WRITE(6,14C4) NPT 0	LI01070	
	KIAUGA94J IOGIJ9XEGIJ9POGIJ9NACOLGIJ9EUAAAA	PL190530		WRITE(6,1909) NP P	LI01090	$\mathbf{\lambda}$
50		PLI07540		WEITC691410F VI 0	LIG1090	11
6		rt00220		Nutif(001411) it. b	LI GI 1 00	9

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							PLI01660
			PL101110		TCL=TOL1		PLIC1670
	$\sum_{i=1}^{n} a_{i} e_{i} e_{i$	WEITER6,14127 5	FL101127		CH2=1.06		PL101680
		METTER6,1413D R	PL 181138		IF (IPRT-EQ-1) WRITE (6 0101)		PL1016=0
		WETTER6,14149 TH	FL 101140		IF ((IPRT. EG. 1) . AND. (J. WE. 1) JUNI TELE		PLI01700
l to d		WRITERS, 1415) 60	PL101150		DQ 2883 M=1.WPER		PLI01710
		HAITSES, 14178 UAMP	P1 101168		N1=H8		PLI01720
		HRTTER.LAID POIS	PI 101 1 70	C			PLI01730
		HRITEELIAIS) UPB	PI 101180	•	CALL NUMRT		PL101740
		METTERS, 1428) RFACT	DI 161 198	C			PL 101 750
	1.1	MRTTELG.LAID NFACT	BL TA1 208	č			PL101760
		MATTELLIG22 FFACT	01 101 210	•	IF((J.EQ.1).AND.(F.EQ.1).ANC.(IPRT.EQ.I))	CALL CARCE	PLI01778
		MAITERS-1421) NFACT	PL101210	c ·			PL101790
		METTERS 1422) PRACT	PL141224	•	TOL=.100+TCL1		PLT01750
		WETTCHAISES	PL101230		IF(CHI.LE.TCL) TOL=TOL1		#1 TO1 884
1.14		WETT (6.99)			TEACHILE.TELI GOTO 3		PI TA1 918
		W# 1 1 1 4 5 5 5	PLIVIZED		TF4H_EQ.1) 60TC 4	-	PI 761 838
		UNT TEEL . 493	PL101240		TOL=.100+TCL1		DI 101070
		METTEE416833	PLIUL270		CH2=CH1		PL101 200
			PE1012-0	J	0F1=-1.00		01701940
-1. ¹			PL101230		TELLING 1) ASENSPTP/2		
		WATTERLASS TORES. SERIS.PECIS.HNC^LCI.I.S.	PE 101 300		TELM NE 11 ASENSPTP		PLIUIAEU
			PLIUISIU		nn anna latais		PLISI770
	Tens		PL101320				PLIUIEPO
			P[101330		TEACH, NE. 13, AND. (P.EQ.13) 11=2-1		PL101 - 70
			PLI01340		DE-DARSERMELTA-HST(L))/H(L1))		PLIDI400
		DU IGEI INANN'	FL101350		TELOBLET DELL DELEDE		PLICI410
			PLI01360		ITTUESTICE DE L'ON		FLI01920
			PL101370	2004			PL101730
	1991	CONTINUE	PLI01320		CW1=0FI F TOLD AND (CW1+LEATOL)) GCTC 6		PLI01440
			PLI01390	-			PL101950
		DO IGUE ATION"	PLI01407	C	TALLART FO TH CALL CHOULT		PLI01968
			PL101410	-	TECTARIOEROTE CALL CAUSE		PL101970
	7665	CONTINUE	PLI01420	C			PLI01980
		WRITE(6,973	PLI01430	•			PLI01990
		WRITE(6,101)	PLI01449		D0 2003 M=1 MSP IP		PLI 0 2000
		WIFE(6+117)	PL101450		HSTCH3=HCH7		PLI02010
C	****		PL101460	2005	CONTINUE		PL 102020
C		FILM	PL101470				PL102030
С		THE HAT CONTRES TO SPECIFIED TOLEPANCE ++++++	PLICIAPO	_	IF(4.50.1) 6010 2003	•	PL102040
	200	FORMAT(++++++ COLS TUP CONTROL STATE +++++++++++++++++++++++++++++++++++	PL101450	8	CONTINUE		PLI02050
	201	FORMATCH +++++ DUES NUT REACT STEACH STRATE	PLI01500		IF(CH1.LE.TCL) GOID 9		PL102060
	203	FCRMATE STEP SIZE IS HALVED	PL101510	2003	CONTINUE		PL102070
			PL101520		IF(IPRT-19-1) WRITE(6,201)		PL1020PC
			PL101530		IF(J.EQ.NHALF) GOTO 2002		PLI02090
		NH 4=NH+ 4	PLI01540		60TC 10		PLI02104
		LVRK1=6+NF+16	PL101550	9	H0=H1		PLI02110
		LVR=6+NH+16	FL 101 560	10	DT=DT1/(2.C0++J)		PL102120
		CALL EDIBAF (NH+TO,XE,XEK+XEC+WH+A,AU,LW+U)	PL101570		NSPTP=2+NSFTP		PL102130
		CALL EDIBAF (NH, TG, PC, PKI, PCI, MA 4, AV, LW, U)	PL 101 5#0	2002	CONTINUE		PLIC2143
		CALL EDIBAF (NF, TF, FP, FKI, FCI, "F4, FW, Lb" KI, UT	PL101550		WRITE(6,200)		PL102150
		CALL EDIBAF (ANDTOPHOLDHKIDHCIDANGAADDELMADDE	PL 101 408	6	CONTINUE		PL102160
		CH1=1.06	PI 101 410	C			PL 102170
		DT=TP/ASP?F	51101620	-	CALL CVOUT		FL102180
		NSENSFTP	PI T01630	с			P1102140
		TCL1=TOL	C1 731 640	Č			Ø1 182280
		071=27	Q1 101 460	ē	FCCEFF		7 64 96 6 98
		DO 2002 J=1,NHALF		-			

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			PL102760
	PL102210	300 FORMAT(*	PL102770
	FL102220	301 FORMAT(* * • EX. TIP: • 138 • • • • • • • • • • • • • • • • • • •	PL102790
The second se	PL102230	302 FORMATC + ,1X,4CD14-7,2X, 12	PL102750
	FL182249	303 FORMAT(* TIPE =*,014-7/)	PLI02900
	PL102250	304 FORMATC + ,7X, * X+,11X, * PRE SEURE */	PL102910
	PL102268	305 F044ATCP +,12,2(C14.7,2X)+12)	PLI02820
	PL 182278	JOG FORMATE	PL102/30
	81 182 289		PL102440
2443242	21 1 42 298	307 FORMATCH MADIPUP DRY CONTACT STRESS 10001000	PL 102 - 50
IPPERSO PARA DEL FRZEV(VI)	B1 782 388	368 FORMATE FF ="+014-7/)	P1 182860
TRETAL AT	B. 102310	389 FORMATE DPY CONTACT LENGTH 2", C19.7/)	PLI02879
TO 2274415		7999 FORMATCO SESS DIMENSIONLESS FARAPETERS SESSOFF	DI TODARA
		7966 FORMATCO U 20,011.49	DI 182858
		7041 FORMATCO N = 0.011.4)	RI 182988
		704 FORMATCH S #4.011.4)	PL102700
	PL182338	700 FOOMATCH C 19.011.4)	PLIUE-10
	FL102360		PL102720
	P[1423/0		PLI02730
	PLIGSSE		PLIEZY90
	PLI02370	2004 CONTRACT	PLIC2730
	P1102400		FLI02760
IF SINGE LUCE COUPERATE	PL182410	C BRITING ON CRANNEL O	PLI02970
IF CIMES ST ST SUBJ FRACTION COLD	PLI02420	C	PLI02980
LUICID=ACAID	PLI02430		PL102990
3000 CONTINUE	PL102443	07 5015 I = I + # SP I P	PLI03000
	PLI02450	ICC=(I/2)+2	PLI03010
C PRESS	#LI82460	IFFICC.WE.ID GOTO SUIS	PLI03020
C	PLI02479	WRITE(8++) H(I)	PL103030
PI=3.1415926535897731200	PL102440	SOIS CONTINUE	PL103040
	PL192490	NSQ=NSPTP-7	PL103050
00 4080 I=1+h1	PL 102509	DO 5016 I=hSQ+NSPTP	PI TA3860
X={I-1}+EB2/NPX3	F1 1 02510	ICC=(I/2)+2	PI 183878
PR(1,1)=P()+Z+BZ+XPZ+FZ+UZ)	PI 102*28	IF(ICC.NE.I) GOTO 5016	
ADA CONTINUE	#1 1n25 18	WRITE(8,+) FU(1)	PL103444
CALL ED2BEFEWIA, FRI , PCI , TZ , PCY, 0)	DI 102540	Self CONTINUE	PL103070
PH2(1)=PDY	DE 102556		PL103100
M2 sup 1 + 1	PLIVE 33V		PLIGJIIG
00 4881 J=2-N2	PLIV2340	un TIF(6-304)	P(103120
1 = (P[102370		PLIUSISU
	PLIDZSTU		PLI03140
	P[1023-0		PL103150
	PLID2600		PLI03160
	PL102610	LL=1 	PLI03170
	PLI02620	WIIEGSJUZY IZANIANCZYNICZYNICZYN	PLI03180
	PL102630	DO SOL JEIMPRI	PLI03190
	PLI02540	LL = J+1	PLI03200
	PL102650	I = J+ NSP IP/ RFK I	PLI03210
	PL102669	TPL=I+DT	FLI03220
DC 4002 K=1.NI	PL102670	XH0=HCIP	FL103230
X=(K-1)+(86/NFX)	PL102690	XHC=H{I}+X [#] I{I}+{EH{I}/2+007	PL183240
PR (K + J)=P(# +HG +BG +K ~ 4 + F 4 + U 5)	PLI02690	XFR=FPI(I)	PL 103250
4002 CONTINUE	PLI 02700	WRITE(6,302) TPL, WOO, XHC, XFR, LL	PLI03260
CALL EQ288F (NH4 #PKI #PCI #TH#FUT#U#	PL102710	5801 CONTINUE	PLT63270
PH2CJ)=PDY	FL 102 720	WRITE(6,99)	FI 103280
4031 CONTINUS	01 TA2778	NAILE(0,300)	PITALSEA A
·	p1 102746	C T	
C OUTPUT	B1 102750	C DINENSIONLESS FARAPETERS	
(************************************	4 4 6 1 . 4	• · ·	y y

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PILES PLISP FORTRAN & LEEDS UNEVERSITY UN/BSE 6.16

FILE: PLISP FCATAAN A LEEDS UNIVERSITY VM/85E 6.16

* ***				PL 103860
		PL103310	17 CONTINUE	PL103*78
C	and the second	PLI03320	(PLI03##0
	EP=2.00+E/(1.00-PCIS++2)	PL103330	C VISUAL	PLI03890
	unasun MP+2-Ce/PI	PL103340	[PL103900
	WUUTV BEREAF CEPP RI	PL103358	CALL PAPER (1)	PLI03910
	FAR#33. BR3C3 Jackson Report Programmer	PL103360	CALL CTRENT(1)	PL 103920
	WHAT HE VE COMPANY	PL103370	CALL BLIPER	PL103=30
	SSS2CF+ TP/NU Save extended to the	PLI03340	TP1=1.	PLI03940
2.1.1.1		PL183378	TT(1)=12	b[103420
		PE183480		PF103-60
	URETE FRETTATA	PL183418	FF []) = F 42	PL103770
		PL 183428		PLI837CO
	WRITE (SATTER UND	PL183430		PL I03450
	MELLER'S 222	FL 1 05449		PLI04000
	WRITE CEVERTURE	PLI83458		PLI04010
C		PLI83460		PLIGAUZU
		PL183479	DO PODO Talinoria	PLI04030
	[F (MP .58.8) 0010 17	PLI034#0		PLI04040
	00 5002 I=1+10	PLI83490		PLIC4050
	URETE (6477)	PLIG3560		PLIO4OED
5882	CONTINUE	PLIC3510		PL104070
	WRETE (6, JOE)	PL103520		PLI040#0
	HRTTE(6,77)	el103230		PLI04090
	WRITE (6.302) 12	PL103540		PLI04108
	WRITE(6,300) PWL	PL103550	FFFERJEFFRELDFFAF	PLI04110
	WRITELGAJUTP DNC	FF1832ED		PLI04120
	WRITE(6)JUIJ PRESLI	PL183570	COON CONTINUE	PLI04130
	URITE(6,304)	PLI03580	₽₽ЧАХ∓U = 	PLI04140
		PLI83570		PLI04150
	D0 3003 4-1044 -	PLIDJGUU	- M-M-24-24-24	PLI0416
		PL103613	DU GUUL L'LIM TELEODLID. ET.FOMAX) FPMAX:FPP(I)	PLI04170
		PL103620	TERMETA CT. SWANA SINAY TUNE []	PLI04120
	ANTICIPATION AND TO	PLI03620		PL104190
2043		PL103640	6001 CUNITAUC	PL104200
	N2247171	PLI03650	······································	PLI04210
		bliggeeg	UNAA-UNAA-144 CALL DEBACE/Destedestal	PL104220
	1PL=(3=1+ <td>PL 103670</td> <td>CALL PERALCIDATION CONTRACT</td> <td>PLI04230</td>	PL 103670	CALL PERALCIDATION CONTRACT	PLI04230
		bringen	CALL HAPLOVOVOVOVO	PLI04240
	WEILESDDDDD	PL103690	CALL PLOTESCOUPERT " 75"	PLI84258
	UNTTELE.99)	FL103700	(ALC PLUTCSA, 06, -87, 4F(1))	PLI04260
	UN116107777	PLI03710		PLI04270
		01103720	CALL PLUICS (11 - 87 - 15 - 5)	PLI04250
	WW112109777	FL103730	CALL PSPAC: (011,0,0) V015V055	PLI04290
	MATERS SUCCESSION AND AND AND AND AND AND AND AND AND AN	PL103740		PLI04300
	BR11210130.7 DR144	PL103750	CALL BURDL	PLI04310
	WR1126093017 VN2407	PLIDJ7ED	CRLL WRID	PLI04320
	N1-N0X-1 N2 - 1 - 2 - 2 - 2	PL103770	CALL DUATEN	PLI04330
	74-77773 77 5775	PLI037#0	CALL CURFICULFARMER FOR	PLI04340
		FLI03750	LALL DERACTINES	PLI04350
		PLI03 900	CALL POPALLICITICS FFACTS	PLI04360
	AF FFRENJER Motter: Safe Y.Y.P.K	PL103910	LALL MARTJOSIFSTVATI (441)	PL104370
-	NUT 12 1 0 10 1 1 10 10 10 10 10 10 10 10 10 1	FLI03#23	CALL DUMDL"	PLID4320
2002		PL103930	CALL ARED CALL BINDER	PLI04350
3004	し 3月1 - 1136 318 ナデアナイビー 99 3	PLIC3940	LALL DUNTEN AALL CHANGESTINGS, 86, 9, 99	PL104400
	UNT 21 2 2 7 7 7 1 1 1 1 2 2 2 2 2 2 2 2 2	PLI03950	LALL LURVELETTOFFILM	
	Rufise Aaa			

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FILES PLISP FORTRAD A LEEDE UNEVERSITY WI/BSE 6.16

FILE: PLISP FORTRAN A LEEDS UNIVERSITY VM/USE 6-16

PL104460

F 20

					MFI84-64
		PL104418		CALL PLOTCE(.47.54, X, I)	PLI04570
1. A.		FL 164 420		CALL PLOTCS(.23,.51,"T =",4]	PLICATED
	CALL ULARLA			CALL TYPENEGTPL1.4)	FLI04778
	CALL PSPACESU. 11 U I P			CALL PSPACE(.11+.17+.58+.93)	PL 105000
	CALL PATEROJO 100000			CALL HAPEXFACT.XXIP.0.,PFACT)	P1 105010
	CALL PLOTES6.8637. W 23	DF1044:0			P1 785020
	CALL PLCTC5C.472.474.19	PLI#4468			
	CALL PLCTCS6.0627. "LF", 21	FLI84478		CALL RACJ	PETR2030
	CALL PLOTCS (.4724. 77.1)	FLI94420		CALL DURFER	MFI02040
	CALL PSPACE (.1157155)	PL104470		CALL CURVE(CRA, APHOID ALA	AFI02026
	CALL MARCO-STRINGSUPAX)	PLI04500		CALL CURAT ((XX + XPR + I + 41 +	PLI039EN
		PL184518		CALL BLKPEN	PL105070
		PI 184528		CALL PTPLOT(8.,XPH2,1.1,226)	PL105020
		BI T 84 5 18		CALL BLRPEN	PL105090
	CALL BLATIN	BIT PASAG		CALL PSPACE(-11+-57+-15+-5)	PL105100
	CALL CURVECTIONCELOW			CALL HAPEYFACT.XXIP.0., HFACT)	. 105110
	CALL #SPACE(.11,.77,.5873)	ME104260			PL103124
	CALL MAP(8.,TP1,8.,FPMAX)	PL104570			META2T34
	CALL BORCEF	PLIDASCO		CALL BLAPE	PL105140
	CALL AXES	PLI84590		CALL POSITRAIOTIP	PL105130
		PLI04600		CALL JOIN(>2,TZ)	PL105160
		PLI64619		CALL JOIN(>3, Y3)	PL105170
		P1104620		CALL JOINER4, YAB	PL105190
		BI 104 6 10		CALL BLKPEN	PL105190
	CALL BEARLH		6883	2 CONTINUE	PI 105268
	9(2 = Alm 2 + 2		29	CONTINUE .	01105210
	N2=NPT+1	PL104630			-LIUJERU
. • •	DC 6882 J=1+N2	PL104660			PL103220
	TPL={J-1}+ {TP/NPT}	PLI84678			PL103230
	TPL1=TPL	FLI04620	-		-PLI05240
	17={ J-1 }+NSPTP/NPT+1	PLI04690	Ç		PLI05250
		PL104780	C		PLI05260
	**************************************	PL104710		SUBROUTINE CYOUT	PLI05270
		PL104720	С		-PLI05220
		PL 184736	C		PL1052*8
		FITCATAD		INPLICIT REAL+8(A-H+0-Z)	PL105300
		84 T 84 758		COMNON TOL TOLISHO, VISTP, STR.TH, WD, UAPP	PLT05310
				COMMCN PR(201.41).PF2(201).PH(400).BFP(401).BHP(401)	01705328
	XXCI)=-1-34-CI-13-BFFX/WX-CWWX/2-UU	PL104760		COMMON NE (64) - PO (64) - TO (64) - HMC QL (64)	-LIUJJ24
	XX{]}=XX{]}/R	PL104//0		COMMON REFERENCE OF PRICESS FRICESS FRICIOSS FCICIOS	MEI02330
	XPR(I)=PR(I,J)/EP	PLI84780			PL105340
6083	CONTINUE	PLI04798			PLIDSJED
				COPMON THEIDOJALECTODIALLETTODIA LETTODIA	DI 185368
	XPHZ=FHZ(J)/EP	brige=co		THE REPORT OF THE WAR AND THE TOTAL TOTAL STREET, AND THE TOTAL STREET, AND THE ST	Letenee.
	XPHZ=FHZCJ)/EP K1=4X(1)	PLI04-00 PLI04510		COMMON TZ+HZ+UZ+FFZ+FZ+BZ+XHZ+XHCZ+FRZ+CH1+CH2+U1+CH2+A	PL105370
	ЩРИZ=FH2CJ)/EP K1=4X(1) V1=-9=MFAC7	PLI04510 PLI04510 PLI04520		CONNON TZ+NZ+UZ+FZ+FZ+FZ+FZ+KZ+XNCZ+FRZ+CH1+CH2+U1+0H2+A Common ue(400)+FPR(400)+FU(400)+EF(400)+XM(400)+XM(401) Common ue(400)+FPR(400)+FU(400)+EF(400)+XM(400)+XM(400)	PL105370 PL105380
	ДРНZ=FH2CJ)/EP K1=AXC1) Y1=.9=HFACT 	PLI04-00 PLI04510 PLI04520 Pli04520		CONNON TZ+NZ+UZ+FZ+FZ+FZ+BZ+XMZ+XNCZ+FRZ+CH1+CH2+U1+BH2+A CONNON UE(400)+FPR(400)+FU(400)+EF(400)+XMI(400)+XMM(401) Connon FRI(400)+H(400)+HST(2000)+UC+FPY+BC+BCAY+HM+UM0	PL105370 PL105380 PL105390
	XPHZ=FHZCJJ/EP K1=4X(1) V1=.9+HFACT X2=X1	PLI04PC0 PLI04510 PLI04720 PLI04*30 PLI04*30		CONNON TZ+NZ+UZ+FZ+FZ+FZ+BZ+XMZ+XMCZ+FRZ+CH1+CH2+U1+BH2+A COMMON UEC400+FPRC400+FUC4C0+EFC400+XMI(400+XMMC401+ COMMON FRI (400++HC400+HST(2000+UC+FP+BC+BC+C+M+UM0 COMMON MPER+NHALF+NSPTP+MPRT+IPRT+NP+NP+NP+NA++F4+NH4	PLI05370 PLI05380 PLI05390 PLI05400
	XPHZ=FHZCJJ/EP K1=#X(1) Y1=.9+NFACT X2=K1 Y2=HX	PLI04-00 PLI04910 PLI04920 PLI04930 PLI04940	98	CONNON TZ+NZ+UZ+FZ+FZ+FZ+BZ+XMZ+XMCZ+FRZ+CH1+CH2+U1+6H2+A COMMON UE(400)+FPR(400)+FU(4C0)+EF(400)+XMI(400)+XMM(401) COMMON FRI(400)+H(400)+HST(2000)+UC+FPY+BC+BCRY+HM+UM0 COMMON NPER+NHALF+NSPTP+NPRT+IPRT+NPX+NPT+NP+NA4+AF4+AM4 FGRMAT(4 +2)	PLI05370 PLI05380 PLI05380 PLI05400 PLI05400
	XPHZ=FHZCJJ/EP K1=#X(1) Y1=.9+NFACT X2=X1 Y2=HX X3=XX(41)	PLI04*00 PLI04910 PLI04920 PLI04930 PLI04940 PLI04950	95 99	CONNON TZ, NZ, VZ, FPZ, FZ, BZ, XMZ, XMCZ, FRZ, CHI, CHZ, UI, BHZ, A COMMON UE(400), FPR(400), FU(400), EF(400), XMI(400), XMM(401) COMMON FRI(400), H(400), HST(2000), UC, FPY, BC, BCRY, HM, UM COMMON MPER, NHALF, NSPTP, MPRT, IPRT, NPX, NPT, NP, NA4, NF4, NM4 FORMAT(***,)	PLI05370 PLI05380 PLI05390 PLI05400 PLI05410
	XPHZ=FHZCJJ/EP K1=AX(1) Y1=.9+HFACT X2=X1 Y2=HX X3=XX(4)) Y3=HX+XX*+EFPX+1.56/R	PLI04-00 PLI04430 PLI04430 PLI04440 PLI04450 PLI04460	98 99	CONNON TZ+NZ+UZ+FZ+FZ+FZ+FZ+KRZ+XNCZ+FRZ+CHI+CHZ+UI+OHZ+A COMNON UE(400)+FPR(400)+FU(400)+EF(400)+XM(400)+XM(401) COMMON FRI(400)+N(400)+NST(2000)+UC+FPY+BC+BCRY+H++UM0 COMMON NPER+NHALF+NSPTP+NPRT+IPRT+NPX+NPT+NP+NA4+AF4+AM4 FORMAT(***) FORMAT(***)	PL105370 PL105370 PL105370 PL105400 PL105410 PL105420
	XPHZ=FHZCJJ/EP K1=#X(1) Y1=.9=HFACT X2=X1 Y2=HX X5=XX(41) Y3=HX=XX ⁴ =EFPX=1.E6/P X4=X3	PLI04900 PLI04910 PLI04930 PLI04930 PLI04950 PLI04950 PLI04970	98 99 100	CONNON TZ+NZ+UZ+FZ+FZ+FZ+FZ+KRZ+XRCZ+FRZ+CHI+CHZ+U1+CHZ+A COMMON UE(400)+FPR(400)+FU(400)+EF(400)+XMI(400)+XMI(401) COMMON FRI (400)+H(400)+HST(2000)+UC+FPY+BC+BCRY+H++UM0 COMMON MPER+NHALF+NSPTP+NPRT+IPRT+NP+NP+NP+NA++F4+NH4 FORMAT(**)+/> FORMAT(**) F	PL105370 PL105370 PL105370 PL105400 PL105410 PL105430 PL105430
	XPMZ=FH2CJ)/EP K1=#X(1) Y1=.9=HFACT X2=X1 Y2=HX X3=XX(41) Y3=HX+XX**EFPX+1.56/R X4=X3 Y4=Y1	PLI04-50 PLI04510 PLI04520 PLI04540 PLI04560 PLI04560 PLI04570 PLI04593	98 99 100	CONNON TZ+NZ+UZ+FZ+FZ+FZ+FZ+RZ+XNCZ+FRZ+CHI+CHZ+U1+CHZ+A COMMON UE(400)+FPR(400)+FU(4C0)+EF(400)+XMI(400)+XMM(401) COMMON FRI(400)+H(400)+HST(2000)+UC+FPY+BC+BCRY+H+UH0 COMMON NPER+NHALF+NSPTP+NPRT+IPRT+NPX+NPT+NP+NA++F4+NH4 FORMAT(**++/) FO	PL105370 PL105370 PL105370 PL105400 PL105410 PL105420 PL105430 PL105440
	XPHZ=FHZCJJ/EP K1=#X(1) Y1=.9+NFACT X2=X1 Y2=HX X3=XX(41) Y3=HX+XX*+EFPX+1.E6/R X4=X3 Y4=Y1 XX1Px-1.00+DFACT	PLI04-00 PLI04510 PLI04520 PLI04530 PLI04560 PLI04560 PLI04570 PLI04590	98 99 100 101	CONNON TZ:NZ:UZ:FPZ:FZ:BZ:XMZ:XNCZ:FRZ:CHI:CHZ:UISHX:XA CONNON UE(400);FPE(400);FU(400);EF(400);XMI(400);XMI(401) CONNON FRI (400);H(400);HST(2000);UC:FPY;BC:BCRY:HM:UH CONMON MPER;NHALF:NSPTP;MPRT:IPRY:NPX:NPT;MP;NA4:NF4;NH4 FORMAT(* *;/) FORMAT(* *) FORMAT(* *: *FP*;12X:*SQ VEL*;10X:*LENGTH*;11X:*SLOPE*/) FORMAT(* *;X:*SQ VEL*;10X:*LENGTH*;11X:*SLOPE*/) FORMAT(* *;X:*CD14:7;2X;C14:7)	PL105370 PL105370 PL105400 PL105400 PL105410 PL105430 PL105430 PL105450
	XPMZ=FHZCJJ/EP K1=AX(1) Y1=.9+MFACT X2=X1 Y2=HX X3=XX(4)) Y3=HX+XX**EFPX+1.E6/R X4=X3 Y0=Y1 XX1P=-1.00+ DFACT CALL F=AME	PLI04-00 PLI04430 PLI04430 PLI04440 PLI04460 PLI0460 PLI0460 PLI0460 PLI0460 PLI04600	98 99 100 101 102	CONNON TZ:NZ:UZ:FPZ:FZ:BZ:MZ:XNCZ;FRZ:CHI:CHZ:UISHX:A COMMON TZ:NZ:UZ:FPZ:FZ:BZ:MZ:XNCZ;FRZ:CHI:CHZ:UISHX:A COMMON UE(400);FPT(400);FU(400);EF(400);XMI(400);XMI(401) COMMON FRI (400);H(400);HST(2000);UC:FPY;BC:BCRY:HM:UM0 COMMON MPER:NHALF:NSPTP;MPRT:IPRT:NP;NP;NP;NP;NP;NP;NP FORMAT(**;/) FORMAT(**;/) FORMAT(**;) FORMAT(**;X:SQ:VEL*;10X;*LENGTH*;11X;*SLOPE*/) FORMAT(**;X:SQ:VEL*;10X;*LENGTH*;11X;*SLOPE*/) FORMAT(**;X:SQ:VEL*;10X;*LENGTH*;11X;*SLOPE*/) FORMAT(**;X:SQ:VEL*;10X;*LENGTH*;11X;*SLOPE*/) FORMAT(**;X:SQ:VEL*;10X;*LENGTH*;11X;*SLOPE*/)	PL105370 PL105370 PL105400 PL105400 PL105420 PL105420 PL105430 PL105430 PL105460
	XPMZ=FH2CJJ/EP K1=AX(1) Y1=.9+NFACT X2=X1 Y2=HX X3=XX(Y1) Y3=HX+XX**EFPX+1.EG/P X4=X3 Y4=Y1 XX1Px-1.D0+DFACT CALL F=A*E CALL F=A*E CALL PSPACE(0.+1.+0.+1.)	PLI04-00 PLI04430 PLI04430 PLI04440 PLI04460 PLI04460 PLI04970 PLI04970 PLI04900 PLI04910	98 99 100 101 102 103	CONNON TZ:NZ:UZ:FPZ:FZ:BZ:MZ:XNCZ;FRZ:CHI:CHZ:UISHX:A COMMON UE(400);FPT(400);FU(400);EF(400);XMI(400);XMI(401) COMMON FRI(400);H(400);HST(2000);UC:FPY;BC:BCRY:HM:UM0 COMMON MPER:NHALF:NSPTP;MPRT:IPRT:NPX:NPT;MP;NA4:NF4;NM4 FORMAT(**;/) FORMAT(**;/) FORMAT(**;) FORMAT(**	PL105370 PL105370 PL105400 PL105400 PL105410 PL105420 PL105430 PL105450 PL105460 PL105470
	XPMZ=FH2CJJ/EP K1=AX(1) Y1=.9=MFACT X2=X1 Y2=HX X5=XX(41) Y3=HX+XX**EFPX*1.E6/P X4=X3 Y4=Y1 XXIP=-1.00*FACT CALL F=AME CALL PSPACE(0101.) CALL MAF(0101.)	PLI04-00 PLI04400 PLI04430 PLI04440 PLI04460 PLI04570 PLI04570 PLI04590 PLI04900 PLI04920	98 99 100 101 102 103 104	CONNON TZ:NZ:UZ:FPZ:FZ:BZ:MZ:XNCZ;FRZ:CHI:CHZ:UISHX:A COMMON UE(400);FPR(400);FU(400);EF(400);XMI(400);XMI(401) COMMON FRI (400);N(400);HST(2000);UC:FPY;BC:BCRY:HM:UM0 COMMON MPER;NHALF;NSPTP;MPRT:IPRT:NPR;NPT;MP;NA4;AF4;AM4 FORMAT(* *;/) FORMAT(* *;/) FORMAT(* *;EX:*SQ VEL*:13X;*N0*:11X;*EAT VEL*:12X; "FP":12X;*SQ VEL*:10X;*LENGTH*:11X;*SLOPE*/) FORMAT(* *;X;CD14:7); FORMAT(* *:X;CD14:7); FORMAT(* *:*** CCNVERGES TO SPECIFIED TCLERANCE ******) FORMAT(* *:*** NLMBER OF STEPS PED CYCLE =*:I4);	PL105370 PL105370 PL105400 PL105400 PL105410 PL105420 PL105430 PL105440 PL105450 PL105450 PL105460 PL105460
	XPMZ=FH2CJJ/EP K1=AX(1) Y1=.9=MFACT X2=X1 Y2=MX X5=XX(41) Y3=HX+XX*EFPX+1.56/R X4=X3 Y4=Y1 XXIP=-1.00=>FACT CALL F=AME CALL PSPACE(01.+0.+1.) CALL MAF(01.+0.+1.) CALL MAF(01.+0.+1.)	PLI04-00 PLI04400 PLI04440 PLI04440 PLI04460 PLI04460 PLI04600 PLI04900 PLI04900 PLI04910 PLI04910	98 99 100 101 102 103 104 105	CONNON T2:N2.U2.FP2;F2;B2;M2:XNC2;FR2;CH1:CH2:U1:0H2:A CONNON UE(400);FP2(400);FU(400);EF(400);XM(400);XM(401) CONNON FRI (400);H(400);HST(2000);UC;FPY;BC;BCR;HM;UM COMMON MPER;NHALF;NSPTP;MPRT;IPRT;NP;MP;MP;MP;MP;MA4;NF4;NH4 FORMAT(* *;/) FORMAT(* *;/) FORMAT(* *; X; SQ VEL*;10X;*LSGTH*;11X;*SLOPE*/) FORMAT(* *; X; SQ VEL*;10X;*LSGTH*;11X;*SLOPE*/) FORMAT(* *; X; SG VEL*;11X;*SGTH*;11X;*SLOPE*/) FORMAT(* *; X; SG VEL*;11X;*SGTH*;11X;	PL105370 PL105370 PL105400 PL105400 PL105410 PL105430 PL105430 PL105450 PL105460 PL105470 PL105460 PL105460
	XPMZ=FH2CJJ/EP K1=AX(1) Y1=.9+MFACT X2=X1 Y2=HX X3=XX(4)) Y3=HX+XX**EFPX+1.E6/R X4=X3 Y0=Y1 XX1P=-1.00+DFACT CALL F2AME CALL PSPACE(0.+1.+0.+1.) CALL PLCTCS(.06+.37,*H*+1) CALL PLCTCS(.06+.37,*H*+1)	PLI04-00 PLI04430 PLI04430 PLI04440 PLI04460 PLI04460 PLI0460 PLI04970 PLI04900 PLI04930 PLI04930 PLI04930	98 99 100 101 102 103 104 105	CONNON T2+N2+U2+F2+F2+F2+F2+K2+XNC2+FR2+CH1+CH2+U1+OH2+A COMMON UE(400)+FPR(400)+FU(400)+EF(400)+XM(400)+XM(401) COMMON FRI(400)+N(400)+NST(2000)+UC+FPV+BC+BC+BCR+H++UH0 COMMON MPER+NHALF+NSPTP+NPRT+IPRT+NP+NP+NP+NP+NA4+NF4+NH4 FORMAT(**+*** FORMAT(**+**********************************	PL105370 PL105370 PL105400 PL105400 PL105410 PL105420 PL105430 PL105430 PL105450 PL105460 PL105460 PL105460 PL105460 PL105460
	<pre>XPMZ=FH2CJJ/EP X1=AX(1) Y1=.9+NFACT X2=X1 Y2=HX X3=XX(Y1) Y3=HX+XX**EFPX+1+E6/P X4=X3 Y4=Y1 XXIP=-1+D0+PFACT CALL F=A*E CALL PSPACE(0+1+0+1+) CALL PSPACE(0+1+0+1+) CALL PLCTCS(+0(+1+0+1+)) CALL PLCTCS(+0(+1+0+1+))</pre>	PLI04-00 PLI04430 PLI04430 PLI04440 PLI04460 PLI04460 PLI04970 PLI04970 PLI04900 PLI04930 PLI04930 PLI04930	98 99 100 101 102 103 104 105	CONNON TZ:NZ:UZ:FPZ:FZ:BZ:MZ:XNCZ;FRZ:CHI:CH2:UI;0H2:A COMMON TZ:NZ:UZ:FPZ:FZ:BZ:MZ:XNCZ;FRZ:CHI:CH2:UI;0H2:A COMMON UE(400);FPT(400);FU(400);EF(400);XMI(400);XMI(401) COMMON FRI (400);HST(2000);UC:FPY;BC:BCRY:HH:UH0 COMMON NPER;NHALF:NSPTP;NPRT:IPRT:NPR:NPT;NP;NA4:NF4;NH4 FORMAT(* *;/) FORMAT(* *;/) FORMAT(* *; SQ YEL*;10X;*LOGTH*;11X;*SLOPE*/) FORMAT(* *; SQ YEL*;10X;*L:NGTH*;11X;*SLOPE*/) FORMAT(* *; X:G(D14:7;2X);C14:7) FORMAT(* *; X:G(D14:7;2X);C14:7) FORMAT(* *; AXIMUM RELATIVE DIFFERENCE =*;C14:7) FORMAT(* *; AXIMUM RELATIVE AXIMUM REL	PL105370 PL105370 PL105400 PL105400 PL105410 PL105420 PL105430 PL105430 PL105460 PL105460 PL105460 PL105460 PL105460 PL105460

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FILES PLISP FORTRAN A LEEDS UNIVERSITY SPIDSE C-16

123

		,			PL1060€0
		PL105510		CALL COSDER COMA PART OUT FOIL COLUMN	PLI06070
	WRITE(6.101) T2,HZ,LZ,PPZ, 2002,A**	FL105520		FPZzFPY	PLI06090
	D0 1 J=1,NFRT	+LI8553#		BHZ=2.D8+AT	PLI060 90
	I=J+NSP TP/NPAT	PL105540		BCRY=ENZ	PL106100
	TPL=07+1	PL165550	C		PLI06110
	208=4617	#L185568		CALL INCLIN	PL106128
	NU=UECI +	FL185570	C		PL106130
	XFF=FPRCIP	FL105540		XPZ=XP	PLI06140
	xF=FU(1)	PL 185578		82=8C	PLI06150
	Lashf(t)	P1 105697		1F(XHZ.20.C.D0) FZ=T(HZ.0Z.0=PZ)	PLI06160
	XH=XV1623	PI 105610		IF(XH2.GT.8.C0)	PL106170
	XERSFRE(1)	P1 185628		T=T2	PL106120
	METTERSIBLE TPL . MAG. XU. XFP. X*. XC. XF	PI 1 196 18		FC=F2	PL 1061 4
	continus	EL TASSAS		DO 1 I=1,NSPTP	PL 106200
•	15(1981-59.1) 6010 4			HV=HO	Pt T06 210
	TEACHIL GT. TOLLOR. (CN2.6T.TCL)) 6010 2			61=FC	RI T 66 2 20
		P1103004		T1=T+CT/2+C8	PL100220
					PL1092JU
-		01183844		CALL FAZBEFINFA.FKI FCI TI FPY,0)	
•	CONTINUE DA LOGE BOTE 3	PLI03870		CALL FROREFINHA. XEK, XEC . TI ,AY,0)	PLIUGZEU
		PLIDS/00		CALL TOZAPE (NHA . HKI . HCI . TI. HH. O)	PL1062E0
	WR I TL(6+73/	PLI05710			0L106270
	WRITE 66 JUST CHI	PL105723		H0-HKA(0T/2-00)061	PLI06270
	AMIIER PIRAN HOLIN	PL105730		H0-H + + C / / 2 - C + - + -	PLI06270
	6070 3	PL105740	C		PLI06300
- 2	CONTINUE	PL105750		CALL INCLIM	PLI06313
	WRITE(60105)	CLI05760	C		PLI06320
3	RETURN	PL105770		IF (XHolde Using Concerts Molecolic FRY att	PLI06330
		PLI057*0		IF (XM. 61.0.LU) U2=P (I LIM) (CCOUC) (F VAN)	PLI05340
C		PL105790		NO = NV+ (DT/ 2 . CU) = 62	PLI06350
C		PLI05#00	C		PLI06368
	SUBROUTINE NUMET	PL105910		CALL INCLIN	PL 106 370
С		#1 105#20	C		FL106380
C		PL105430		IF(XP.EQ.O.CO) GJ=Y(HO,BC,FPY)	PL 106 390
-	IMPLICIT REAL+B(A-H,O-Z)	PLT 05=40		IF(X4.G7.0.C0) G3=F(T1,40,8C,UC,F*+,X*)	PL T06400
	COPYCA TOL: TOL: HO, VI.TP.E.R.TH. WO.LAWD	Pt165254		T1=T+CT	P1 106410
	CONNEN PR (201, 41), PHZ(201), BH (408), BF P(481), EHP(481)	PI 105960		UC=U(T1)	BI T06 420
	CONNON X5(64),P3(64),T0(64),H4CCL(64)	PL 105 A 10		CALL [0288F(NF4,FKI,FCI,T1,FFY,0)	EL 106420
	COPHON JEK(68), XEC(68), PKI(68), PCI(68), FKI(104), FCI(104)	DI TOSOPA		CALL E0280F(N+4, NEK, XEC, T1, AY, 0)	FL109430
	COMMEN AN(400) FUC-16), HKI(68), HC:(68)	01105900		CALL E028BF (NH4 + HKI +HCI +T1 +HP+0)	
	COMMON TECIOD, FECIOD, FP (100), TP(100)			808Y=2.C0+AY	
	COMMON TZ+H2+U2+FP2+FZ+BZ+X#Z+X#C2+FR2+CH1+CH2+JT+EHZ+AW			M0=NV+01+G2	P[10480
	COMMON US (408) FPR(400) .FU(400) .BF(400) .X"I(400) .X"(401)	P[103-10	r		PL106470
	COMMON FRI(480) . H(400) . HST(2000) .UC .FPY .BC. 207 .H .UNG	PL103720	•	CALL INCLER	PLID64EU
	COMMON NOT ANNAL F. SETTANPRT. PRT. NP. NP. NP. NP. NA4 . NF4. NH4	FL105930	~		FLI06470
	CUMUM W _ FARSE C (C ((2 . CG + P) / TP) + 7)]	PL105-40	.	TEAN ED-D-COL GALVENDARC (FPT)	PLI06500
	0(1)-00-FSCRT4FFT+8+(1,00-P01S++2)/(5+P1))	PLIGSGED		TEAM GT. A.CAL GALFETIAHA BC.UC (FFY (XP)	PL106510
	BI 1 4 4 4 5 4 5 4 4 5 4 4 5 2 4 4 5 1 4 5 1 5 5 7 4 2 4 4 5 3/ (12.33 + VI)/	PL105°60		HA-HHA4 DT/4- CO3+ 4G1+2-DO+ 62+2-CO+ 63+ G4)	PL106520
	TI 1000000000000000000000000000000000000	PLI05970		NA+UA44 A11 COPAL ANT FRAME OF PARTY AND	PLI06530
	$A = \{2, 0\} \cup \{1, 1, 2\} \cup \{1, 1, 2\} \cup \{1, 2\} \cup $	PLIOSABO			PL106540
	T (NU + CL + T) = Leady 1100	FLI05950		UL-UII/ 0111 - TODDOG(NEASENTSECTSTSEPTSO)	PLI06550
	PI = 3 • 1 9 1 3 7 4 8 3 3 8 7 / 7 4 1 4 4	PLIDADOD		CALL SUZDERIGE ANA SEE SEE STATION	PLI06560
	TZ=0+00	PL106010		CALL LUZDER (RETARACESTSTETTUR	PLI06570
	HZ = H0	PL 106020		CALL SUZUEP (NHAANKI MULTATATATAT	PL106540
		PLI06030		BURY=2.0U*AT	PLI06590
		PL10504 J	C		PLIGEOG
	CALL E0289F(NF4+FK1+FL1+12+F7+0) CALL E0268F(NF4+REK+XEC+T2+AY+0)	FLI0=050		CALL INCLIN	

	0. •			67178
	•	bf100010		07188
C		FL106620		87190
- 8 M		bfielen		67266
1	IF (XA-GI-G-CU) F C-F C F HOUSE F C-F C F HOUSE F C-F C F F F C F F F C F F F C F F F C F F F C F F F C F F F C F F F C F F F C F F F C F F F C F F F C F F F C F F F C F F F C F F F F F C F F F F F C F	PL106543		87210
್ ಇನ್ನೇ ಕ್ರಾ		PLI06620		67220
4,47	UE (E)=UC	PLIDEEED		
4 S	T FRACIER FOR THE STATE OF THE	PLI06677		
	INCITERBORY	PL186648		
		PLI86698		
	XNTCI+III	PL106700		
	FUE II=FC	PLI06710		
1	CONTINUE	FL106720		
	RCTURY CONTRACTOR	PL106730		
		PLI06740		
C		PLIC6750		
		DI 106760		
6	CHARGET THE SHELLS	P1 786778		
~				
L		01 106 790		
C		PL100770		
	TOTAL TOL TOLL AND WINTPAE A THOUD VAMP	PL100-00		
	COMICH TOLETTLAT 3-PH2 (2013 - EN(4 38) - EFP(4813 - EHF (4813	PL100-10		
		FLIU5-2J		
	CCP708 FLCC400 PKI460 PKI460 PCI460 FKI41040 FCI41040	ME100-20		
	COMMON ACREEFICATION MET(68) HEI(58)	MFI40		
	CONTCH ANCHOUSE STORE SPECIALS TPEIDES	PL106-20		
	CONNON THE SUBJECT OF THE AND A STORE STREET ON CHI +CH2+CT+ PMZ+XM	PL106=50		
	COMMON 72, H2, U2, H72, H2, GL, H4, GAR, OF (408) - X41(408) - X4P(401)	PLI06=70		
	COMMON UE (400) of PRC 400 of T 2000 b -UC - FPY - 8C + 8C RY -HP +U"D	PLI06520		
	CONNEN FRICEOUP, HEEUDE HAT TORT MET AND TAN AS AFA.NHA	PLI06890	· · · · ·	
	CCHNON NPER WHALF WASPIF WENT OF RUTE T TO RELATIVE TOLERANCE"	PLI06900		
188	FORMATCH ++++ D WAS NOT ACHIEVED BOLLT IN ALLENDED	PLI06910		
	PI=3.14159265358979312D#	PL 106920		
	IF CUCALTAUP 09 GOTO B	PLI06=30		
		PLI06943		
		PL106958	A A A A A A A A A A A A A A A A A A A	
	00 1 I=1,50000	PL 106°E0	FILE: JPSP EXEC A LEEDS UNIVERSITY UPPOSE BUT	
	0204400	PL 106 970		
c	BC =808 Y+ (1. C9+C/(2. C0+H0))	PI 106980		
•	SC = SDP Y	PL T06990	EXEC SETUP FORTRAN NAGE CCGHOST	
	X1 S=(FPY+HP++2)/(12-D0+VI+UC+BC++2)	P1 167090	FI & DISK BANK DATA	
	85=((H4/0)++2)+(DL0E(1.C0+C/HP)-2.C0+C/(2.C0+H++C))	BL 107010	FI 5 DISK XPSP DATA	
	NT FF = XL S-95	CI 107020	FI & DISK YPSP DATA	
	TECOTEE 1 1-0-203 6010 2	01 1070 30	ET A DISK STPSP CATA	
		DI TO 70 40	I DAD PLISP (CLEAR	
		-1101040	EVER DI OTETIE PPSP	
<		PL107030		
	RE-07 FT	PLIDICED		
		PLI0/070	J 3 180 1	
		FLI079=7		
		CLI07050		
		PL107109		
1	CONTINUS	PL107110		
12	CONTINUE	PLI07120		
	D=1.C6	PLI07130		
	WRITEC6.1007	PL107140		
	GD TO 9	PL107150		

FILE: PLISP FORTRAN A LEEDS UNIVERSITY WH/BSE 6.16

8 X4=0.00

FILE: PLISP FERTRAN A LEEDS UNIVERSITY VP/RSE 6-16

PL107160

FZZ

INPUT

FILE: BANK DATA A LEEDS UNIVERSITY VP/BSE 6.16

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. 5464275336344454735-06	1 4598552889977576535-03	
.12508888888888888889	.1007560881505602775-01	2417072.53743135976
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- 51 1271 61211 36 764555-47		
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		466888363728775757
12223:327744,	-1 130110 2411 4644 6695-41	A591678
*********************		4283013402304768077
		4637367 66 1703L 11402
• 336 2177 8 437 5 4 1 4 1 38 2 4 4		
		4776302.32740272431
+911334224731328713L-VB		
-4465394649006666994	•1 432716/72307412961-WI	4233210+73624421914
•43/731332/11661418:-UB	342173810723852341:-03	
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•461381442031193330F=0e	JZE2:14/24UE22:2::-U:	
• 468/509000009809990	•128/208434332043332-01	3745.013+06750482457
•2431463144632222402-06	2733867830170E0337*-03	
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• 554827878035513023E-06	19912159(5855441035+03	
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• 365296673717640970E-0E	1569373079131476255-03	
. 59 37 50 000 000 000 000	•7782083429357256005-02	1441523.75698259213
•603949840751100295E-06	1002560291269806775-03%	
.6 250000000000000000	.6559329413780336342-02	1924399.45773702438
.610527724858580948E-06	7102096811016002605-04	
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812500600000440000	-6044063273643287417-03	869777, 585921041502
4663390615055155477-04 -		9634446304342V433"C
8437500090000000000	-60151837516326475-03	8696 11 . 97671 716 744 1
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FILE: BANK CATA A LEEDS UNIVEPSITY VM/855 6.16

•566187332075636597E-06	5974676846521858885-04	
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.9062593630000080000	.6017387422510414925-02	862116.836482038721
-696267111348213984E-06	5926248769021719632-04	
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.7887517364441719958-86	78 62 4735 1977252 2945-84	
• 9687580000000C00000	.6882962184726121655-02	1127979.46261229932
.702631183289E46445E-06	7816759490224379125-04	
1.0033000000000000000	.7380593552338254412-02	1296979_40653849168
· 682804102783248392E-06	9082851678659137425-84	

#### INPUT

FILE: XPSP CATA A LEEDS UNIVERSITY VN/BSE 6.16

.005 .54199230-6 20 5 16 16 1 20 8 1 .01 1. 16.06 .3 .0(24 .0265 .01049851 .4 .10898510-3 -.067 3.7 .001 .2 39 0. .05 .1 .15 .175 .2 .25 .3 .35 .375 .4 .425 .45 .475 .5

.525 .55 .575 .6 .625 .65 .675 .7 .71 .725 .75 .76 .775 .8 .825 .85 .965 .875 .89 .9 .925 .95 .975 1.0000000001 339. 502. 726. 997. 1133. 1302. 1607. 2092. 2489. 2557. 2496. 2403. 2150. 1675. 1302. 1051. 929. 590. 353. 239. 183. 150. 150. 170. 116. 116. 129. 116. 170. 190. 170. 129. 150. 150. 183. 217. 251. 255. 339. 33

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#### OUTPUT

FILE: YPSP DATA A LEEDS UNIVERSITY VY/OSE 6-16

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8.375888889+88 8.14446310-81 8.49965830+87 8.48155430-86

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TOL (TOLERANCE FCR SS AND STEP SIZE)       0.50000000-02         MD (INITIAL GUESS FCR M0 AT TIME ZEPC)       0.54155530-06         MPER (MAX, NG, GF CYCLES AT SAME STEP SIZE)       20         MNALF (NAR, NG, GF CYCLES AT SAME STEP SIZE)       20         MNALF (NAR, NG, GF CYCLES AT SAME STEP SIZE)       16         MPTR (NG, GF STEPS PRINTED PER CYCLE)       16         MPTR (NG, GF STEPS PRINTED PER CYCLE)       16         MPT (NG, GF STEPS PRINTED PER CYCLE)       10         MPT (NG, GF STEPS PRINTED PER CYCLE)       10         MPT (NG, GF PRESS, DIST.)       20         MPT (NG, GF STEP STOR PRESS, DIST.)       1         VI (AASOLUTE VISCCSITV)       0.100000000         VI (AASOLUTE VISCCSITV)       0.10000000000         R (REDUCED RADILS)       0.1000000000         VI (AASOLUTE VISCCSITV)       0.1000000000         VI (AASOLUTE VISCCSITV)       0.10000000000         MP (PRINT OPTICNS FOR PRESS, DIST.)       0.10000000000         VI (AASOLUTE VISCCSITV)       0.1000000000000         VI (AASOLUTE VISCCSITV)		
TOL (TOLERANCE FCR SS AND STEP SIZE)	SOOD INPUT DATA COO	
TOL (TOLERAWCE FCR SS AND STEP SIZE)       0.50000000-02         MD (INITIAL GUESS FCR NO AT TIME ZEPC)       0.5019523C-06         MPER (MAX, NO, CF CYCLES AT SAME STEP SIZE)       20         WHALF (WAR, NO, CF STEP SIZE MALVINGS)       5         NSPTP (INITIAL AC, CF STEPS PEP CYCLE)       16         NPRT (NO, CF STEPS PRINTED PER CYCLE)       16         NPRT (NO, CF PRESS, PTS, PRINTED PER CYCLE)       16         NPT (NO, CF PRESS, PTS, PRINTED PER OIST.)       20         MPT (NO, OF PRESS, DIST, PRINTED PER OIST.)       1         VPX (NC, CF PRESS, DIST, PRINTED PER OIST.)       20         MPT (NO, OF PRESS, DIST, PRINTED PER OIST.)       20         MPT (NO, OF PRESS, DIST, PRINTED PER OIST.)       1         VI (ABSOLUTE VISCCSITY)       0.10000000-01         E CELASTIC WOULUS OF LAVER       0.10000000-01         E CELASTIC WOULUS OF LAVER       0.2650000-02         UD (ADDTM OF CONTACT)       0.2650000-02         UD (ADDTM OF CONTACT)       0.2650000-02         UD (ADDTM OF CONTACT)       0.10090510-03         NFACT (SCALE FACTOR FOR FILM PLCTS)       0.27000000-00         MM (LAVEL IMIT FOR ENT. WELL)       0.27000000-00         MM (LOWER LIMIT FOR FILM PLCTS)       0.27000000-00         MFACT (SCALE FACTOR FOR FILM PLCTS)       0.27000000-00 <th></th> <th></th>		
HDCINITIALGUESSERGEFGE MAD AT TIPE ZEPC)0.5419523C-06MPERMMALFCVAR.MD. GF STEP SIZE20MMALF(VAR.MD. GF STEP SIZE16MPRT(NO. GF STEPS PER CYCLE)16MPRT(COWERGEACEPRINTED PER CYCLE)16MPRT(COWERGEACEPRINTED PER CYCLE)16MPRT(NO. GF STEPS.PIS.PRINTED PER CYCLE)20MPT(NO. GF PRESS.PIS.PRINTED PER CIST.)20MPT(NO. OF PRESS.DIST.20MPT(NO. OF PRESS.DIST.20MPT(NO. OF PRESS.DIST.20MP (PRINT OPTICAS FOR PRESS.DIST.)20MP (PRINT OPTICAS FOR PRESS.DIST.)0.10006009-01TP (PERIOD)		
WG CINITIAL WESS FOR HE AT THE ZETT STEP STEPUSATIFIZENPER (MAX. NG. GF STEP STEP STEP STEP STEP)20NARTF (INITIAL AC. CF STEPS PEP CYCLE)16NPRT (NG. GF STEPS PRINTED PER CYCLE)16NPRT (NG. GF STEPS PRINTED PER CYCLE)16NPT (NG. GF PRESS. PTS. PRINTED PER DIST.)20NPT (NG. GF PRESS. DIST. PRINTED PER DIST.)20NP (PRINT OPTICNS FOR PRESS. DIST.)1VI (ABSOLUTE VISCCSITY)0.10000009-01E (ELASTIC NOULUS OF LAYER)0.10000009-01E (ELASTIC NOULUS OF LAYER)0.2650000-02ND (aIDTN OF CONTACT)0.2650000-02ND (aIDTN OF CONTACT)0.1009051D-03NFACT (SCALE FACTOR FOR FILM PLCTS)0.37000000NFACT (SCALE FACTOR FOR FILM PLCTS)0.370000000NFACT (SCALE FACTOR FOR FILM PLCTS)0.370000000NFACT (SCALE FACTOR FOR FILM PLCTS)0.370000000NFACT (SCALE FACTOR FOR FILM PLCTS)0.370000000	FOL FIDLERAWLE FOR 33 AND 31EF 31ELF 00000000	
WHALF (MAR. NO. OF STEPS 1121 MALVINGS)20MMALF (MAR. NO. OF STEPS PRINTED PER SIZE MALVINGS)16MPRT (NO. OF STEPS PRINTED PER CYCLE)16IPRT (CONVERGENCE PAINT GPTION)1MPX (NC. CF PRESS. PTS. PRINTED PER DIST.)20MPT (NO. OF PRESS. DIST. FRINTED)1MP (PRINT OPTICMS FOR PRESS. DIST.)20MP (PRINT OPTICMS FOR PRESS. DIST.)1VI (ABSOLUTE VISCCSITV)0.1000CCD+01E (ELASTIC MODULUS OF LAYER)0.1000CCD+01E (ELASTIC MODULUS OF LAYER)0.2000CCD+01C (ADTM OF CONTACT)0.2000CCD+01UAMP (AMPLIT. OF ENT. VEL.)0.10090E1D-01UM (LOWER LIMIT FOR ENT. VEL.)0.10090E1D-01MFACT (SCALE FACTOR FOR FILM PLCTS)0.3700COE+01FACT (SCALE FACTOR FOR FILM PLCTS)0.3700COE+01	WU CINITIAL BUILD FOR HU AT TITL (175)	• ••34177236-40
WALF (NAR. W., GF STEP SIZ: WALFINGS)1NSPTP (INITIAL AC, CF STEPS PEP (VCLE)16WPAT (NO, OF STEPS PRINTED PER (VCLE)16IPAT (CONVERGENCE PAINT GPTION)1WPX (NC, CF PRESS, PTS, PRINTED PER DIST.)20MPT (NO, OF PRESS, DIST. FRINTED)20MPT (NO, OF PRESS, DIST. FRINTED)1VI (A0SOLUTE VISCCSITV)0.10000009-01VI (A0SOLUTE VISCCSITV)0.10000000-01E (ELASTIC "ODULUS OF LAYER)0.10000000-00R (REDUCED RADILS)0.2400000-02WD (JIDTM OF CONTACT)0.2400000-02WD (JIDTM OF CONTACT)0.1007951D-03NFACT (SCALE FACTOR FOR FILM PLCTS)-0.6699957E-03NFACT (SCALE FACTOR FOR FRICTICN PLOTS)0.3700000-00FACT (SCALE FACTOR FOR FRICTICN PLOTS)0.3700000-00PACT (SCALE FACTOR FOR FRICTICN PLOTS)0.3700000-00PACT (SCALE FACTOR FOR FRICTICN PLOTS)0.3700000-00	MPER CHARGE NUG OF CILLS AT SAFE SILF SIZEF OF	
NERTY CHAITINE NC. CF STEPS PEN CYCLED	MMALF (MAR, MU, GF STEP SIZE MALVINGE)	
IPRT (NO. OF STEPS PRINTED PER CYCLE)16IPRT (CONVERGENCE PRINT GPTION)1VPX (NC. CF PRESS. PTS. PRINTED PER DIST.)20MPT (NO. OF PRESS. DIST. FRINTED)8VI (ABSOLUTE VISCCSITV)0.10000007-01TP (PERIOD)0.10000007-01E (CLASTIC MODULUS OF LAYER)0.10000007-01E (CLASTIC MODULUS OF LAYER)0.10000007-01CREDUCED RADILS)0.2000000-00TM (LAYER THICKNESS)0.200000-02WD (dIDTM OF CONTACT)0.10070210-01POIS (POISSCNS FATIC)0.10070210-01VII (AMER LIMIT FOR ENT. VEL.)0.10070210-03RFACT (SCALE FACTOR FCR PLCTS)-0.66939572-03RFACT (SCALE FACTOR FCR FRICTICN PLCTS)0.37000000+00MARCT (SCALE FACTOR FCR FRICTICN PLOTS)0.37000000+00PACT (SCALE FACTOR FCR FRICTICN PLOTS)0.37000000+00MFACT (SCALE FACTOR FCR FRICTICN PLOTS)0.37000000+00MFACT (SCALE FACTOR FCR FRICTICN PLOTS)0.2000000-00	ASPTP CINITIAL ACC CF STEPS PER CYCLEP	16
IPRT (CONVERGENCE PRINT GPTION)       1         WPX (NC. CF PRESS. PIS. PRINTED)       20         MPT (NO. OF PRESS. DIST. FRINTED)       1         VI (ADSOLUTE VISCCSITV)       1         VI (ADSOLUTE VISCCSITV)       0.10000000-01         E (ELASTIC MODULUS OF LAYER)       0.10000000-01         E (ELASTIC MODULUS OF LAYER)       0.10000000-00         R (REDUCED RADILS)       0.200000-02         WD (dIDTM OF CONTACT)       0.200000-02         WD (dIDTM OF CONTACT)       0.1000000-02         WD (dIDTM OF CONTACT)       0.000000000	NPRT (NO, OF STEPS PRINTED PER CYCLE)	• 16
WPX (NC. CF PRESS. PTS. PRINTED PER DIST.)       20         NPT (NO. OF PRESS. DIST. FRINTED)       1         WP (PRINT OPTIONS FOR PRESS. DIST.)       1         VI (ABSOLUTE VISCCSITV)       0.10000000-01         E (ELASTIC "ODULUS OF LAVER)       0.10000000-00         E (ELASTIC "ODULUS OF LAVER)       0.2000000-02         WD (AIDTM OF CONTACT)       0.200000-02         WD (JIDTM OF CONTACT)       0.10070210-01         WAMP (AMPLIT. OF ENT. VEL.)       0.10070210-01         WMM (LOWER LIMIT FOR ENT. VEL.)       0.10070210-03         NFACT (SCALE FACTOR FOR FILM PLCTS)       0.37000000-01         FFACT (SCALE FACTOR FOR FILM PLCTS)       0.3700000-01         MFACT (SCALE FACTOR FOR FILM PLCTS)       0.3700000-01	IPRT (CONVERGENCE PRINT GPTION)	
MPT (NO, OF PRESS. DIST. FRINTED)       0         MP (PRINT OPTICNS FOR PRESS. DIST.)       1         VI (A0SOLUTE VISCCSITV)       0.10000009-01         P(PERIDD)       0.10000000+01         E (LASTIC "ODULUS OF LAYER)       0.10000000+00         R (REDUCED RADILS)       0.2400000-02         WD (JIDTM OF CONTACT)       0.2650000-01         WAP (AMPLIT. OF ENT. VEL.)       0.10070510-01         WB (LOWER LIMIT FOR ENT. VEL.)       0.10070510-03         NFACT (SCALE FACTOR FOR FILM PLCTS)       0.37000000+01         FFACT (SCALE FACTOR FOR FILM PLCTS)       0.3700000+01         WFACT (SCALE FACTOR FOR FILM PLCTS)       0.3700000+01         WFACT (SCALE FACTOR FOR FILM PLCTS)       0.3700000+01         WFACT (SCALE FACTOR FOR FILM PLCTS)       0.3700000+01	NPX (NC. CF PRESS. PTS. PRINTED PER DIST.)	20
MP (PRINT OPTICAS FOR PRESS. DIST.)       1         VI (ABSOLUTE VISCOSITY)       0.10000007-01         TP (PERIOD)       0.10000007-01         E (LASTIC MODULUS OF LAYER)       0.10000007-01         R (REDUCED RADILS)       0.10000000-00         TH (LAYER THICKAESS)       0.200000-02         WD (JIDTM OF CONTACT)       0.2658000-01         UAMP (AMPLIT. OF ENT. VEL.)       0.1007010-01         POIS (POISSCNS FATIC)       0.40000000         WM (LOWER LIMIT FOR ENT. VEL.)       0.1007010-01         NFACT (SCALE FACTOR FCR PLCTS)       -0.66999571-01         MFACT (SCALE FACTOR FCR FRICTICN PLCTS)       0.3700000-01         MFACT (SCALE FACTOR FCR FRICTICN PLCTS)       0.3700000-01         PACT (SCALE FACTOR FCR FRICTICN PLCTS)       0.3700000-01         PACT (SCALE FACTOR FCR FRICTICN PLCTS)       0.3700000-01	NPT (NO. OF PRESS. DIET. FRINTED)	
VI (ABSOLUTE VISCCSITV)       0.10000000-01         TP (PERIOD)       0.1000000-01         E (LASTIC *000LUS OF LAYER)       0.1000000+01         E (LASTIC *000LUS OF LAYER)       0.1000000+00         R (REDUCED RADILS)       0.200000+00         TM (LAYER THICKNESS)       0.200000+00         VD (JDTM OF CONTACT)       0.2658000-02         VD (JDTM OF CONTACT)       0.10090510-01         VAMP (AMPLIT. OF ENT. VEL.)       0.10090510-03         NFACT (SCALE FACTOR FOR FILM PLCTS)       0.37000000+01         FFACT (SCALE FACTOR FCR FRICTICN PLOTS)       0.37000000+01         VFACT (SCALE FACTOR FCR FRICTICN PLOTS)       0.2000000+00	MP (PRINT OPTIONS FOR PRESS. DIST.)	• • •
TP (PERIOD)       0.10000000+01         E (LASTIC MODULUS OF LAYER)       0.1000000+00         R (REDUCED RADILS)       0.300000+00         TM (LAYER THICKNESS)       0.2400000-02         WD (JDTM OF CONTACT)       0.260000-02         WD (JDTM OF CONTACT)       0.10090510-01         VAMP (AMPLIT. OF ENT. VEL.)       0.10090510-01         POIS (POISSENS FATIC)       0.10090510-03         NFACT (SCALE FACTOR FOR PLOTS)       -0.66939577-01         NFACT (SCALE FACTOR FOR FILM PLCTS)       0.37000000+00         PATCT (SCALE FACTOR FOR FILM PLCTS)       0.3700000+01         PATCT (SCALE FACTOR FOR FILM PLCTS)       0.3700000+01         PATCT (SCALE FACTOR FOR FILM PLCTS)       0.3700000+01         PFACT (SCALE FACTOR FOR FILM PLCTS)       0.3700000+01         PFACT (SCALE FACTOR FOR FILM PLCTS)       0.2700000+01	VI CABSOLUTE VISCOSITY)	0.10000007-01
E (ELASTIC *000LUS OF LAYER)       0.16006600-08         R (REDUCED RADILS)       0.20000000         TM (LAYER THICKNESS)       0.2400000-02         WD (dIDTM OF CONTACT)       0.2600000-02         WD (dIDTM OF CONTACT)       0.2600000-02         WD (AUDTM OF CONTACT)       0.2600000-02         WA (AUDTM OF CONTACT)       0.26000000         WA (AUDTM OF CONTACT)       0.100700100         WA (CONTACT)       0.100700100         WA (LOWER LIMIT FOR ENT. VEL.)       0.10070510-03         WFACT (SCALE FACTOR FOR FILM PLCTS)       -0.66999577-01         WFACT (SCALE FACTOR FOR FILM PLCTS)       0.97959555-03         WFACT (SCALE FACTOR FOR FILM PLCTS)       0.37000000+01         WFACT (SCALE FACTOR FCR FRICTICN PLOTS)       0.2700000+01         WFACT (SCALE FACTOR FCR FRICTICN PLOTS)       0.2000000-00	TP (PERIOD)	• • • • • • • • • • • • • • • • • • •
R (REDUCED RADILS)       0.20000000         TM (LAYER THICKNESS)       0.2400000-02         WD (JDTM OF CONTACT)       0.2650000-01         WAMP (AMPLIT. OF ENT. VEL.)       0.10090510-01         WD (LOWER LIMIT FOR ENT. VEL.)       0.400000000         WM (LOWER LIMIT FOR ENT. VEL.)       0.10099510-03         NFACT (SCALE FACTOR FOR PLOTS)       0.3700000000         FFACT (SCALE FACTOR FOR FILM PLOTS)       0.3700000000         WFACT (SCALE FACTOR FOR FILM PLOTS)       0.3700000000000000000000000000000000000	E (ELASTIC MODULUS OF LAYER)	0-1600668D+08
TM (LAYER THICKNESS)       0.24006000-02         WD (JIDTM OF CONTACT)       0.26580000-01         WAMP (AMPLIT. OF ENT. VEL.)       0.10070510-01         POIS (POISSCNS FATIC)       0.10070510-01         WM (LOWER LIMIT FOR ENT. VEL.)       0.10070510-03         WFACT (SCALE FACTOR FOR FILM PLCTS)       0.37000000+01         PFACT (SCALE FACTOR FOR FILM PLCTS)       0.37000000+01         PFACT (SCALE FACTOR FCR FILM PLCTS)       0.3700000+01         PFACT (SCALE FACTOR FCR FILM PLCTS)       0.3700000+01	R (REDUCED RADILS)	0.3CC0CC0D+00
WD (dIDTM OF CONTACT)       0.26588000-01         WAMP (AMPLIT. OF ENT. VEL.)       0.1089810-81         POIS (POISSCNS FATIC)       0.1089810-81         WM (LOWER LIMIT FOR ENT. VEL.)       0.1089910-03         WFACT (SCALE FACTOR FOR FILM PLCTS)       -0.66999972-01         MFACT (SCALE FACTOR FOR FILM PLCTS)       0.37800000000         FFACT (SCALE FACTOR FOR FILM PLCTS)       0.3790500000000000000000000000000000000000	TH (LAYER THICKNESS)	0.2400600-02
UAMP (AMPLIT. OF ENT. VEL.)       0.10090210-01         POIS (POISSCNS FATIC)       0.10090210-01         UMB (LOWER LIMIT FOR ENT. VEL.)       0.10090210-03         NFACT (SCALE FACTOR FOR PLOTS)       -0.66999977-01         HFACT (SCALE FACTOR FOR FILM PLOTS)       0.37000000+01         FFACT (SCALE FACTOR FOR FILM PLOTS)       0.3700000+01         HFACT (SCALE FACTOR FOR FILM PLOTS)       0.3700000+01         FFACT (SCALE FACTOR FOR FILM PLOTS)       0.3700000+01	WD (dIDTH OF CONTACT)	0.265886000-01
POIS (POISSCNS FATIC)	WAMP CAMPLIT. OF ENT. VEL.)	0.10078510-01
UMB (LOWER LIMIT FOR ENT. VEL.)	POIS (POISSCNS FATIC)	8.40086000+00
NFACT (SCALE FACTOR FOR PLOTS) ************************************	UND (LOWER LIMIT FOR ENT. VEL.)	0.10899510-03
HFACT (SCALE FACTOR FOR FILM PLCTS)	REACT ESCALE FACTOR FOR PLOTS	-0.66999572-31
FFACT (SCALE FACTOR FCR FRICTICN PLOTS) 0.95955555-03 HFACT (SCALE FACTOR FCR FILM PLOTS) 0.37006005+01 PFACT (SCALE FACTOR FCR FRICTICN PLOTS) 0.26080000+00	NFACT (SCALE FACTOR FOR FILM PLCTS)	0.3780COOE+01
NFACT (SCALE FACTOR FOR FILM PLOTS)	FFACT (SCALE FACTOR FOR FRICTICN PLOTS)	0.99999955-03
PFACT (SCALE FACTOR FCR FRICTICN PLOTS) 0.20000000+00	HFACT (SCALE FACTOR FOR FILM PLOTS)	0.37306005+01
	PFACT (SCALE FACTOR FCR FRICTICN PLOTS)	8.2088000+09

NOTE : FOR SS TELERANCE EQUALS .1+TOL

DATA BANK

TO	XE	PC	HPCOL
9.0	0.73805940-02	0.12459752+07	0.68260417-06
0.31250000-01	0.80163870-02	0.15300589+07	0.64624543-06
0.62500002-01	0.86861330-02	8-17964020+07	0.60041347-66
0.93750000-01	0.93761020-02	0.20531260+07	0.54642750-06
8-12500000+00	0-10075610-01	0.24170920+07	8.48467740-06
0.15625007+00	0-10697120-01	8.27244822+07	0.415-3770-06
0.15750003+00	0.11309032-31	0.20450999+07	0.324 4842-05
0.21575000+00	0-11244150-01	0-33626912+07	0-232704E2-C6
0.250990000+00	0.12406770-01	0.3664947:+07	0+51227150-07
8-28125000+33	0-13190200-01	0.40950760+37	0.22114830-06
0.31250003+00	9-13701110-01	0.45219780+07	0.30256437-06
0.34375000+00	8.14286070-01	0.48553273+07	0.35E219E2-06

		10.01 0.01		E 3 1 30 - 66	
0.40623000	00 0.14337				
8.43/586804	<b>96 8.1900</b> 2.	20-01 0.4	63213U+0/ 0+46/	20140-06	17
8.468750034	00 0.12772(	80-01 0+3°	5450133+07 8.303	14637-06	16
0.50000000	•0 <b>0 0.1</b> 126#i	180-01 0.3	L865870+87 8+537	C4830-06	17
8.531250004	08 8.186678	150-01 0.2	1106283+07 0.554	2752-86	18
8.562508804		40-82 0.2	2510240+07 0.565	29670-06	19
8.573750024	00 0.778200	30-02 8-14	419240+07 0.683	E4980-06	28
8.625888804	08 8-655932	90-02 0.1	243990+87 8.610	2770-06	21
8.65625860	08 8-550564	90-02 0-8	035630+06 0.572	23660-06	22
8-687584804	88 8.547684	30-02 0.71	415000+06 8-493	15430-86	22
8-71275860	08 8.554861	50-02 0.7	851017+86 8-347	\$5733-86	24
. 75488888	AA A.614291			28930-07	2*
				E 3 7 80	26
0./8123000				53720-00	
8.81526880+		30-02 0.00	9//803+86 8+488		~ ~ ~
0+54313003+	09 0.601910	40-02 0.50	263200+06 0.=22	12729-66	20
<b>0.475004</b> 80+		30-02 0.75	255560+86 8.665	78 260 - 86	29
. 8. 70625000+	00 8.601738	70-02 0.86	211620+06 0+676	26719-06	38
0.93750000+	00 0.454586	70-02 0-10	201953+07 0.780	19170-06	31
0.76875002+	00. 0.688296	20-02 0.11	275752+07 0.7020	EE120-06	32
	81 8.738059	40-02 0-12	969790+47 0.682	0410-06	33
1/1P	TIME	LCAD	<b>FP</b>		
0.0	1.1	0.33503+03	8.12792450+85	1	
0-50099-01	0.50000-01	. 0.50200+03	C.18943400+05	2	
0-10000+00	6.10000+08	0.72600+03	6.27396230+05	3	
8.15080+80	C.1508D+88	0.95700+03	6.37622640+05	4	
8-17500+08	0-17500+00	0-11230+04	0.42754720+05	5	
8-20007+68	8.29080+08	8-13620+04	0.45132082+05	ž	
8-25000+08	0-2500(+00	0.14879+84	8.68641515485	;	
0-30000+00	0.30000400	8-2012000	0.0004131.~03	-	
	<b>4</b> •JSUUU+UU	8.29275409	0.73724330403		
0.37303+00	0.37300+08	0.22210.04	8.76970379+93	10	
0.40000+00	0.4000+30	8.24760+04	8.74182620+02	11	
0.42500+00	C+42500+00	0+24080+04	0.90867925+05	12	
0.45002+00	0.4500C+00	0+2150D+04	0+8113202C+05	13	
0-47500+00	0.4750C+00	0+16750+04	0.63207555+05	14	
0.50000+00	8.50000+00	0.13820+04	0.49132080+05	15	
0-52500+00	0.5250C+00	0.10510+04	0.35660382+02	16	
0.55000+00	6.55002+00	0.92900+03	8.35056600+05	17	
0+57500+00	C.5750C+06	0.59000+02	C+2226415C+05	18	
0.60000+08	C.64400+04	0.35200+02	0.13320750+05	19	
0+62500+00	C-6250C+08	0-21869+01	0.95811320+04	20	
0 5000+00	0.6500C+00	0.18300+03	0.69056600+04	21	
0-67503+30	0.67505+00	0-15007+07	A-56603770+04	22	
0.70000+00	0.70000+00	0-15000+01	8-56603770+0A	21	
0-71000400	C-7100C+00	0.17665+01	f_64150940404	5 i 9 A	
0.22500400	0.83500-00	0-11600-02	A 4171540.04	27	
0.75000400	0 75000400	A 11400405	• • • • • • • • • • • • • • • • • • •	6 U 2 C	
0 76000-00	0.70000-00	A 11001401	0 40/7050 AAA	20	
0 775000 V 00	U.FOUULTUU	0.11/00-03	U. 422/722U+U4	21	
U. 77303400	u + / / 343+00	A* 11603+33	+0+28CL11C+04	28	

### OUTPUT

FILE: STPSP DATA A LEEDS UNIVERSITY UN/BSE 6-16 renamed START for input into Part 3

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.5421624356463694355-06 -546256610496753555E-0E .5462784994117613962-06 .5432677302041424475-06 -536591412120166557E-06 .5347739739882216395-06 •531254530397278495E-UE .5289995688905773015-0f -528279145858270514E-06 .5290821669168896555-06 .531524785649668432E-06 -532710331462224C73E-06 -529664563866363339E-06 .5262326632612669295-06 •527659692196855543E-0€ -535073057384107251E-06 .5432852765876593382-06 -.256041251582353091E-07 . 337923639725167262E-07 -1193435140152696405-06 .9774160379982693832-07

PART 3

FCRTRAN LEEDS UNIVERSITY VY/DSE 6.16 FILE: TCA

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FORTRAN & LEEDS UNIVERSITY VM/BSE 6.16 FILE: TCA

PART 3         Treasure         Control         Provide and the second	۵		C FROM CHANNEL 3	TCAODSE
Control         Control <t< td=""><td>A CARACTERIA AND A PART 3. A CARACTERIA AND A CARACTERIA A</td><td>TCAC6828</td><td>E Contraction of the second seco</td><td>TCA00574</td></t<>	A CARACTERIA AND A PART 3. A CARACTERIA AND A CARACTERIA A	TCAC6828	E Contraction of the second seco	TCA00574
C         TCANDING         TCANDING         TCANDING           C         TCANDING         TCANDING         TCANDING         TCANDING           DICTORING (TANDARGAD), STRICTORD, FREIGHT, FCICHA)         TCANDING         TCANDING         TCANDING           DICTORING (TANDARGAD), STRICTORD, FREIGHT, FCICHA)         TCANDING         TCANDING         TCANDING           DICTORING (TANDARGAD), STRICTORD, FREIGHT, FCICHA)         TCANDING         TCANDING         TCANDING           DICTORING (TANDARGAD), STRICTORD, STRI		TCARGOJO	NTP=NT+1	TCAODSE
Comparison         Transform         Transform         Basis Continue         Transform           Bit Continue         Transform         Basis Continue         Basis Continue         Transform           Bit Continue         Transform         Basis Continue         Basis Continue         Transform           Bit Continue         Transform         Transform         Transform         Trans		TCADDDAD	00 8361 I=1.NTP	TCA00 594
Tex.ICIT AL-SLA-W.d-70         TCANNER         TCANNER<		TCARDES	READ(3,+) HST(1)	TCA00600
Direction stitutes present pres	THELICTT #644-946A-M-0-73	TCARGOS	8361 CONTINUE	TCA00610
Direction resident, restant, restan	ATTERATE TELAND STIAND SATEAD STUCAD STUCAD STICAD STICAD	10409830	READ(3.+) PPC4	TC400620
Dimension production relation relatin relatin relation relatin relation relation relation		TCARDORD	READ(3.e) > 703	TCA00630
DirEction       TCANNER				TCADOGA
Directorial in Construction Constructing Constructing Construl Construction Construction Construction Co		TC 440 0 70		TCARD 650
Difference         TCR00100				TCADD665
Bir Frid Link Find Control and Cont		10 894110		10400470
Diplation interview and the set (1, set, set, set, set, set, set, set, set	DIM_ASION (C3(248),U=3(240)	10497128		TCANAGE
REAL-+ THILESSEPTION FLOWER, FUT 2000, FLOWER, FUT 10, FLOWER, FUT 10, FLOWER, FUT 10, FLOWER, FUT, FLOW	DIPLASION INCOLONIA COLONACCOLONIANES	10400120		1000000
REAL** TY1200MWC240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0240FX0244FX0240FX0240FX0240FX0240FX0240	REAL+4 XX1 (2000) +XX (2000) +WW (2000) +PP (2000) + FAC + XX + WF AC + + FF	-TCA00140		70400 700
E2AL*4_IMB.PFPA.PFPAT.A11402_H32_H32_H32_H32_H32_H32_H32_H32_H32_H3	REAL 4 TT(248), HAP(248), FRN(248), UU(248), FPP(248)	TCA00130	777 FURNATE* */)	
COPAGE #15149917#11.0004176	RCAL+4_UMA>+FPHAB+FFACT+KJ1+XJ2+XJ3+XJ4+TJ2+TJ2+TJ4	TCADDIED	100 FORMAT()	
COPACH WH, W, M, W, L, PZ, TOL, WYCL, JPPCL         TCABBIE         TCABBIE         TCABBIE         TCABBIE         TLAB         TCABBIE         TCABBIE <thtcabbie< th="">         TCABBIE         TCABBIE</thtcabbie<>	COPMON #656 COD + FX6 20000	TC#00170		TCA00720
COPPORE VILLENDE, ************************************	COPACH HH, FP,F1,F2, CTCL, PTCL, FTCL	TCAODIED	101 FORMAT(*	TLA80730
Common E.p.W. HTP.LMTP.FAE.PEF.TC TC TCG0220 114 FORMATC *,417/TP.100.* TIEC.98.*CLC1*119.FFP/7) TCG0720 115 FORMATC *,417/TP.100.* TIEC.98.*CLC1*119.FFP/7) TCG0720 115 FORMATC *,11.2011.4227.42.42.718 TCG0720 TCG0720 116 FORMATC *,11.2011.4227.42.42.718 TCG0720 TCG0720 116 FORMATC *,11.2011.4227.42.42.718 TCG0720 TCG0720 117 FORMATC *,11.2011.4227.42.42.718 TCG0720 T	COMMON VISLANDORSVENTE SXISCASED	TCA00190	+ loss - sequences - set - second	TCA00740
Control Toless, #36681, #P56681, #F56681, #F56681, #F56681, #F568256 CONTOR NST LIL #9 INFIGE #F5681, F576681, #F56821, #F568256 CONTOR NST LIL #9 INFIGE #F5683, F576681, #F56821, #F568256 CONTOR NST LIL #9 INFIGE #F5682, F576821, #F5682, F57682, F5782, F578	CO443N_E,PF,TH,HPC,HPT,FXE,XEF,TC	TC#00200	114 FORMATC* *,4x,*T/TP*,10x,*TIME*,5X,*LCAC*,11X,*FP*/)	TCA00750
CONVER ANALAGED, JEEGEGD, MEIGED, PETIGED, MEIGED, MEI	CJ#40N_TO(E4),XB664),PB6643,H*CCL6643,HE6643,H*K6623,H*C6623	TCA00210	115 FORMAT(* *;1x;3(011.4;2x);C14.7;18)	TCA00760
CONTROL MST JJ, WF JF 12, 2 MC 24 MF 3, M MF (C 102 C 2 J 0 MF 1/ 1/ 1/ 1/ 1/ 1/ 1/ 1/ 1/ 1/ 1/ 1/ 1/	COMMEN AUCAGD), XEK(E0), XEC(E0), PHICED, PEICED, HKICED, HCICED)	TCA00220	116 FORMATCO ++++ INPUT CATA ++++/	TCA0777
ULT = r = r = r = r = r = r = r = r = r =	CONMON MST .JI .NP . IPT. I 2 .NCAV .MS . ANA	TC#00230	117 FORMATCY ++++ GUTPUT DATA +++++/)	TCA00780
CALL STTIP       TCA00250       C       TCA00250         PII3.1413526355977931220       TCA00270       1312 FORMAT(* HPC4 (SG. VEL. FROF I-4 TIVE STCP)       *.014.7) TCA00250         C       IMPUT       TCA00270       1312 FORMAT(* HPC3 (SG. VEL. FROF I-1 TIVE STCP)       *.014.7) TCA00250         C       IMPUT       TCA00270       1312 FORMAT(* HPC3 (SG. VEL. FROF I-1 TIVE STCP)       *.014.7) TCA00250         C       TCA00270       1313 FORMAT(* HPC3 (SG. VEL. FROF I-1 TIVE STCP)       *.014.7) TCA00250         C       TCA00300       C       *.014.7) TCA00250       C         C       TCA00300       C       *.014.7) TCA00250       *.014.7) TCA00250         C       TCA00300       C       *.014.7) TCA00250       *.014.7) TCA00250         C       TCA00320       1400 FORMAT(* VI (ABSCLUTE VISCOSITY)       *.014.7) TCA00250       *.014.7) TCA00250         C       TCA00320       1400 FORMAT(* VI (ABSCLUTE VISCOSITY)       *.014.7) TCA00250       *.014.7) TCA00250         C       TCA00320       TCA00320       1400 FORMAT(* VI (ABSCLUTE VISCOSITY)       *.014.7) TCA00250         C       TCA00320       TCA00320       1400 FORMAT(* VI (ABSCLUTE VISCOSITY)       *.014.7) TCA00750         READ(4.0.4 VI, FL, FL, FL, FL, FL       TCA0030       TCA00320       1400	UG T) = {P I++2+THETA+RT/(T <b>P</b> +188+C0 )	TC#06240		TCA00750
PI=3_112392632597931220       TCA00260       1212 FORMAT(* MFC (SG, WEL, FROF I-3 TIFE STEP)       *,014-7) TCA00270         C       IMPUT       TCA00260       1312 FORMAT(* MFC1 (SG, WEL, FROF I-3 TIFE STEP)       *,014-7) TCA00270         C       IMPUT       TCA00260       1312 FORMAT(* MFC1 (SG, WEL, FROF I-3 TIFE STEP)       *,014-7) TCA00270         C       TCA00260       1313 FORMAT(* MFC1 (SG, WEL, FROF I-3 TIFE STEP)       *,014-7) TCA00280         C       TCA00260       1313 FORMAT(* MFC1 (SG, WEL, FROF I-3 TIFE STEP)       *,014-7) TCA00280         C       TCA00310       TCA00310       TCA00310       TCA00310       TCA00310       TCA00310       TCA00310       *,014-7) TCA00280         READ(4,+) PT, TH(TA, FI       TCA00310       TCA00320       1400 FORMAT(* VI (ABSCLUTE VISCOSITY)       *,014-7) TCA00280         READ(4,+) PT, TH(TA, FI       TCA00310       TCA00320       *,014-7) TCA00280       *,014-7) TCA00280         READ(4,+) PT, TH(TA, FI       TCA00310       TCA00310       TCA00310       *,014-7) TCA00280       *,014-7) TCA00280         READ(4,+) PT, TH(TA, FI       TCA00310       TCA00310       TCA00310       *,014-7) TCA00280       *,014-7) TCA00280         READ(4,+) PT, FILTA, FIL       TCA00310       TCA00310       TCA00310       *,014-7) TCA00310       *,014-7) TCA00310	CALL SETTIP	TC400250	C	TCAODROS
C       INPUT       TCA00270       1312 FORMAT(* MPD3 (S0. VEL. FACP 1-2 TIFE STEP)	PI=3.1415926535897931200	TCA00260	1212 FORMAT(" HPC4 (SG. VEL. FROM I-4 TIME STEP)	TCA00810
C       INDUT       TCA00290       1312 FORMATC* HPC2 (SG. VEL. FMCP I-2 TIME STEP)       *.014.7) TCA00290         C       TCA002300       C       TCA00300       C       TCA00280         C       FROM CHANNEL 4       TCA00300       C       TCA00300       C       TCA00300         READ(4) VI.IP.E.R.TM.MO.PR       TCA00320       1001 FORMATC* VI (ABSCLUTE VISCOSITV)       *.014.7) TCA00280       *.014.7) TCA00280         READ(4) FILE       TCA00310       C       *.014.7) TCA00280       *.014.7) TCA00280         READ(4) FILE       TCA00310       TCA00310       *.014.7) TCA00280       *.014.7) TCA00280         READ(4) FILE       FILE       TCA00310       TCA00310       *.014.7) TCA00280       *.014.7) TCA00280         READ(4) FILE       FILE       TCA00310       TCA00310       *.014.7) TCA00280       *.014.7) TCA00310       *.014.7) TCA00310         READ(4) FILE       FILE       TCA00310       TCA00310       *.014.7) TCA00310       *.014.7) TCA00310       *.014.7) TCA00310         READ(4) FILE       FILE       TCA00310       TCA00310       *.014.7) TCA0		TCA09270	1312 FORMAT(" HPD3 (SQ. VEL. FRCP I-3 TIPE STEP)	TCA00820
Commentation       TCA00200 1013 FCRMAT(* MFC1 (SG. VEL. FRCP I-1 TIVE STEP)       *,014.7) TCA00700         C       FROM CMANNEL 4       TCA00200 C       TCA00200 C         C       FROM CMANNEL 4       TCA00200 C       *,014.7) TCA00700         READ(4.0) VI.TP.E.0.TM.CO.PR       TCA00200 I000 FORMAT(* VI (ABSCLUTE VISCOSITV)       *,014.7) TCA00700         READ(4.0) FTMETA.21       TCA00200 I000 FORMAT(* VI (ABSCLUTE VISCOSITV)       *,014.7) TCA00700         READ(4.0) FTMETA.21       TCA00200 I000 FORMAT(* VI (ABSCLUTE VISCOSITV)       *,014.7) TCA00700         READ(4.0) FTMETA.21       TCA00200 I000 FORMAT(* VI (ABSCLUTE VISCOSITV)       *,014.7) TCA00700         READ(4.0) FTMETA.21       TCA00200 I000 FORMAT(* VI (ABSCLUTE VISCOSITV)       *,014.7) TCA00700         READ(4.0) FTMETA.21       TCA00200 I000 FORMAT(* VI (ABSCLUTE VISCOSITV)       *,014.7) TCA00700         READ(4.0) FTMETA.21       TCA00200 I000 FORMAT(* VI (ABSCLUTE VISCOSITV)       *,014.7) TCA00700         READ(4.0) FTMETA.21       TCA00200 I000 FORMAT(* VI (ABSCLUTE VISCOSITV)       *,014.7) TCA00700         READ(4.0) FTMETA.21       TCA00200 I000 FORMAT(* VI (ABSCLUTE VISCOSITV)       *,014.7) TCA00700         READ(4.0) FTMETA.21       TCA00200 I000 FORMAT(* VI (ABSCLUTE VISCOSITV)       *,014.7) TCA00700         READ(4.0) FTMETA.21       TCA00200 I000 FORMAT(* VI (ABULE) *		TCA00280	1512 FORMAT(" HPC2 (Sq. VEL. FRCM I-2 TIME STEP)	TCA00830
C       TCA00300       TCA003000       TCA003000		TC# 80 290	1413 FORMAT(" HPC1 (Sq. VEL. FRCP I-1 TIME STEP)	TCADDEAD
C       FROM CHANNEL 4       TCA00310       C       TCA00310         READ(4,+) WI, TP,E,R,TN, MD,PR       TCA00320       1400 FORMAT(* VI (ABSCLUTE VISCGSITV)       *,014,71 TCA00400         READ(4,+) PR,THCTA,RI       TCA00320       1400 FORMAT(* VI (ABSCLUTE VISCGSITV)       *,014,71 TCA00400         READ(4,+) PR,THCTA,RI       TCA00320       1400 FORMAT(* VI (ABSCLUTE VISCGSITV)       *,014,71 TCA00400         READ(4,+) FR,TC,FR,TA,RI       TCA00300       1400 FORMAT(* VI (ABSCLUTE VISCGSITV)       *,014,71 TCA00400         READ(4,+) FR,TC,FR,TATR       TCA00300       1400 FORMAT(* VI (ABSCLUTE VISCGSITV)       *,014,71 TCA00400         READ(4,+) FR,TC,FR,TCL,FFTCL,FFTCL,FFTCL       TCA00500       1404 FORMAT(* TK (CARTILAGE THICKASS)       *,014,71 TCA00400         READ(4,+) ECL,MT,VTF,PAX       TCA00500       1405 FORMAT(* NC (ANGULA AMPLITUCE IN CEREES)       *,014,71 TCA00400         READ(4,+) ECL,MT,TTF,FTCL,FFTCL,FFTCL       TCA00400       1406 FORMAT(* TK (HCATILAGE THICKASS)       *,014,71 TCA00400         READ(4,+) ECL,MT,TTF,FTCL       TCA00400       1405 FORMAT(* NC (ANGULA AMPLITUCE IN CEREES)       *,014,71 TCA00400         READ(4,+) EFTCL,FFTCL,FFTCL       TCA00400       1408 FORMAT(* TK (HCATILAGE THICKASS)       *,014,71 TCA00400         READ(4,+) EFTMACT,FFACT       TCA00400       1405 FORMAT(* TK (HCATILAGE THICKASS)       *,014,71 TCA00400 <td></td> <td>TC#00300</td> <td>c</td> <td>TCADO PER</td>		TC#00300	c	TCADO PER
READ(4+*) WI.TP.E.R.TW.WD.OPR       *010.75 TCA0039       1400 FORMAT(* VI CABSCLUTY VISCOSITY) ************************************	C FROM CHANNEL A	TCA00310	c	TCADERER
READ(4,+) WI, PR C,R, TH, MD, PR       TCA00330       1401 FORMAT(* TF (FERICD)       * D14-33 TCA00400         READ(4,+) FORMAT(*) TCA00330       1402 FORMAT(*) TF (FERICD)       * D14-33 TCA00300       * D14-33 TCA00300         READ(4,+) FORMAT(*) FORMAT(*) FORMAT(*) FORMAT(*)       READ(4,+) FORMAT(*) FORMAT(*)       READ(4,+) FORMAT(*) FORMAT(*)       * D14-33 TCA00300         READ(4,+) FDAID       TCA00350       1404 FORMAT(*) FORMAT(*)       * D14-33 TCA00300       * D14-33 TCA00300         READ(4,+) FORL       TCA00350       1404 FORMAT(*) FORMAT(*)       * D14-33 TCA00300       * D14-33 TCA00300         READ(4,+) FORL, FFTCL, FFTCL       TCA00350       1405 FORMAT(*) FORMAT(*)       * D14-33 TCA00300       * D14-33 TCA00300         READ(4,+) CEL, *FTCL, *FTCL, *FTCL       TCA00350       1405 FORMAT(*) FORMAT(*)       * D14-33 TCA00300       * D14-33 TCA00300         READ(4,+) CEL, *FTCL, *FTCL       TCA00350       1405 FORMAT(*) FORMAT(*)       * D14-33 TCA00300       * D14-33 TCA00300         READ(4,+) CEL, *FTCL, *FTCL       TCA00400       1406 FORMAT(*) FORMAT(*)       * D14-33 TCA00300       * D14-33 TCA00300         READ(4,+) CEL, *TF***********************************		TCA00 120	1400 FORMATCH WI CABSCLUTE VISCOSITY)	TCA00 #21
READ(4+>) PT, THETA, >I       TCA00:40       1402 FORMAT(* E CELASTIC MODULUS CF CARTILAGE)       *,014.)       TCA00:99         READ(4+>) FPDAID       TCA00:99       1403 FORMAT(* R (REDUCED RADIUS)       *,014.)       TCA00:99         READ(4+>) FDAID       TCA00:90       1403 FORMAT(* R (REDUCED RADIUS)       *,014.)       TCA00:99         READ(4+>) FDCL, PTCL, FPTCL, FPTCL       TCA00:90       1405 FORMAT(* R (REDUCED RADIUS)       *,014.)       TCA00:99         READ(4+>) FDCL, PTCL, FPTCL, FPTCL       TCA00:90       1405 FORMAT(* R (CARTILAGE THICMARCES)       *,014.)       TCA00:90         READ(4+>) FDCL, PTCL, FPTCL, FPTCL       TCA00:90       1406 FORMAT(* R (CARTILAGE THICMARCES)       *,014.)       TCA00:90         READ(4+>) FDL       TCL, PTCL, FPTCL, FPTCL       TCA00:90       1406 FORMAT(* R (FORLSCALL)       *,014.)       TCA00:90         READ(4+>) FDL       TCL, PTCL, FFTCL, FFTCL       TCA00:90       TCA00:90       *,014.)       TCA00:90       *,014.)       TCA00:90       *,014.)       TCA00:90       *,014.)       *,014.)       TCA00:90       *,014.)       *,014.)       TCA00:90       *,014.)       *,014.)       *,014.)       TCA00:90       *,014.)       *,014.)       *,014.)       TCA00:90       *,014.)       *,014.)       *,014.)       TCA00:90       *,014.)       *,014.) </td <td>PEADEAAA) NIATPERATIAN ADAPR</td> <td>TCA00 130</td> <td>1401 FORMATCH TE (PERICO)</td> <td>TCARDARA</td>	PEADEAAA) NIATPERATIAN ADAPR	TCA00 130	1401 FORMATCH TE (PERICO)	TCARDARA
READ(4,0) PPDAID       TCA00300       1403 FORMAT(* R (REDUCED RADIUS)       *.014.71 TCA00300         READ(4,0) F1,F2,F3,F4       TCA00300       1404 FORMAT(* TH (CARTILAGE TH)(CRESS)       *.014.71 TCA00300         READ(4,0) F1,F2,F3,F4       TCA00300       1404 FORMAT(* TH (CARTILAGE TH)(CRESS)       *.014.71 TCA00300         READ(4,0) F1,F7CL,FFTCL       FTCA00300       1405 FORMAT(* PR (FCISCAS RATIC)       *.014.71 TCA00300         READ(4,0) CTCL,FFTCL,FFTCL       TCA00300       1406 FORMAT(* R (FLUCKESS)       *.014.71 TCA00300         READ(4,0) CTCL,FFTCL,FFTCL       TCA00300       1406 FORMAT(* R (FLUCKESS)       *.014.71 TCA00300         READ(4,0) CFUL       TCL0NT,*TF,NRX       TCA00300       1407 FORMAT(* R (TALUS RADIUS)       *.014.71 TCA00300         READ(4,0) CFUL       TCL0NT,*TF,NRX       TCA00400       1408 FORMAT(* THETA (ANGULAR A*PLITUCE IN CEGRES)       *.014.71 TCA00300         READ(4,0) CFUL       TCL0NT,*TF,NRX       TCA00400       1407 FORMAT(* THETA (ANGULAR A*PLITUCE IN CEGRES)       *.014.71 TCA00300         READ(4,0) CFUL       TCL0NT,*TF,NRX       TCA00400       1504 FORMAT(* TH)       *.014.71 TCA00300         READ(4,0) CFUL       TCA00400       1514 FORMAT(* TH)       TCA00400       *.014.71 TCA00300         READ(4,0) CFUL       TCCOMATC       TCA00400       1514 FORMAT(* TH)       .014.71 TCA003		TCADDIAD	1482 FORMATCH F (FLASTIC MODULUS OF CARTILAGES	TCARDESE
READ(4,*) F1,F2,F3,F4       TCA00360       1004 F0RMAT(* TH (CARTILAGE THICHAESS)       *014.71 TCA00370         READ(4,*) ECC.,FTCL,FFCL,FFTCL       TCA00370       1405 F0RMAT(* UK (ULDIM OF AWKLE)       *014.71 TCA00370         READ(4,*) ECC.,FTCL,FFTCL,FFTCL       TCA00350       1407 F0RMAT(* UK (ULDIM OF AWKLE)       *014.71 TCA00370         READ(4,*) TCLO,FTCL,FFTCL       TCA00350       1407 F0RMAT(* PR (CLUS CAR AT (C) PR (C)		TCA88 158	1483 FORMATCE & CEFANICED RADIUS	TCAROSAR
READ(4+) RAWAL JIANST, I2+I3       TCA00370       1405 FORMAT(* WC GWIDTH OF ANKLE)       *D14.75 TCA00120         READ(4+) CTCL, FTCL, FTCL, FTTCL       TCA00370       1405 FORMAT(* WC GWIDTH OF ANKLE)       *D14.75 TCA00120         READ(4+) CTCL, FTCL, FTCL, FTTCL       TCA00370       1405 FORMAT(* WC GWIDTH OF ANKLE)       *D14.75 TCA00120         READ(4+) CTCL, FTCL, FTCL, FTCL, FTCL       TCA00370       1405 FORMAT(* WC GWIDTH OF ANKLE)       *D14.75 TCA00120         READ(4+) CTCL, FTCL, FTCL, FTCL, FTCL, FTCL       TCA00370       1405 FORMAT(* PR (GWIDTH OF ANKLE)       *D14.75 TCA00120         READ(4+) CTUL       TCA00400       1407 FORMAT(* TETA (ANGULAR AMPLITUCE IN DEGREES)       *D14.75 TCA00120         READ(4+) CTUL       TCA00400       1407 FORMAT(* THETA (ANGULAR AMPLITUCE IN DEGREES)       *D14.75 TCA00120         READ(4+) CTUL       TCA00400       1407 FORMAT(* MI CINL OF ANKLE)       *D14.75 TCA00120         READ(4+) CTUFFACT, FFACT       TCA00410       1409 FORMAT(* MI CINL OF ANKLE)       *D14.75 TCA00120         READ(4+) LPT, MAGM       TCA00410       1415 FORMAT(* MI CINL OF ANKLE)       *D14.75 TCA00120         READ(4+) LPT, MAGM       TCA00410       1415 FORMAT(* MI CINL NET INCREPTIN)       *D14.75 TCA00120         READ(4+) LPT, MAGM       TCA00410       1415 FORMAT(* MI CINL NET INCREPTIN)       *D14.75 TCA00140         READ(4+) LPT	PEADEAL F1.F2.F3.FA	TCA00360	1404 FORMATCH TH (CARTINAGE THICKNESS)	TCADOSIS
READ(4,+) CTCL(PTCL(FPTCL       TCA00390       1400 FORMAT(* PL CPC)STOR RAT()       *(014.7) TCA00390         READ(4,+) CTCL(NT,*TF,NPX       TCA00350       1407 FORMAT(* PL CPC)STORS RAT()       *(014.7) TCA00390         READ(4,+) CFUL       TCA00300       1408 FORMAT(* THETA (AAGUAR APPLITUCE IN CEGRESS)       *(014.7) TCA00390         READ(4,+) UP0       TCA00400       1408 FORMAT(* THETA (AAGUAR APPLITUCE IN CEGRESS)       *(014.7) TCA00390         READ(4,+) UP0       TCA00400       1408 FORMAT(* THETA (AAGUAR APPLITUCE IN CEGRESS)       *(014.7) TCA00390         READ(4,+) UP0       TCA00400       1408 FORMAT(* THETA (AAGUAR APPLITUCE IN CEGRESS)       *(014.7) TCA00390         READ(4,+) UP0       TCA00400       1514 FORMAT(* THETA (AAGUAR APPLITUCE IN CEGRESS)       *(014.7) TCA00390         READ(4,+) PT,*AGN       TCA00400       1515 FORMAT(* PLC), INTIAL NET INCREMENT)       *(014.7) TCA00390         READ(4,+) NF       TCA00400       1415 FORMAT(* F2 (MAEKEFF2, INITIAL NET INCREMENT)       *(014.7) TCA00390         READ(4,+) NF       TCA00400       1416 FORMAT(* PLAIN)       *(014.7) TCA00390       *(014.7) TCA00390         READ(4,+) NF       TCA00400       1415 FORMAT(* F2 (MAEKEFF2, INITIAL NET INCREMENT)       *(014.7) TCA00390       *(014.7) TCA00390         READ(4,+) NF       TCA00400       1415 FORMAT(* F2 (MAEKEFF2, INITIAL NET INCREMENT)       *(014		TCA00170	1AR5 FORMATCO NF CUIDTH OF AMILES CONCERNMENT OF CONCERNMENT OF CUIDTH	TCARGON
READ(4,*)       File	REAJIA-6 F7() 67() 67() 587()	76400370	1405 FORMATER DE EDITIONE PARTIES	TCA00 529
READ(4,*) (FUL       TCA0030       TWO FORMATC THETA CANGUAGA AMPLITUCE IN CEGRESS       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01***       *01****       *01****       *01****       *01****       *01****       *01****       *01****       *01****       *01****       *01*****       *01*****       *01*****       *01*****       *01***********************************		*(=00350		TCA00920
READ(4,*) UP0       TCA00400	READING A FEW	TCA00350	TARE FORMATIC RECEIVED RULES AND THEFT IN PROFESSION CONCERNMENT ( ) 11707	TCA00740
READ(4,+) DF       READ(4,+) DF       READ(4,+) DE       READ(4,+) DE <td< td=""><td></td><td></td><td>1406 FORMATES INTER CANNER AFFLIGTTIN SCORESS COCCOCCO (UT407)</td><td>1 CAU9720</td></td<>			1406 FORMATES INTER CANNER AFFLIGTTIN SCORESS COCCOCCO (UT407)	1 CAU9720
READ(4,*) FRUT, FRUT, FRUT       TCA00421       D14 FORMATC* FL CHURLE LT FRUCKLE LT FRUCKLE		1CAU0410	THUT FUNNATION AT ATTLET DULINATION CONCORDENCESCONCOCCOCCOCCO PULSE	1CA00760
READ(4,+) AF       T(A0040       INIS FORMAT(* F2 (MA=H0+F1, INITIAL N2 = CMEPEND ************************************	RLAJE9+J JFJCI9FFACI9FFACI	TC#00427	1314 FURMATCH HPLAID (FRLAI IF HRLI LOUALS ZEU)	TCA00970
READ(4,*) NP       TCAD(4,*) NP <td< th=""><th>RLAJE9+7 IFF9FAWN</th><th>10400430</th><th>1413 FURNARIY FI UNA-HUFFID INITIAL NO SCREPEND COCCOCCO VULG-IJ</th><th>ICA00580</th></td<>	RLAJE9+7 IFF9FAWN	10400430	1413 FURNARIY FI UNA-HUFFID INITIAL NO SCREPEND COCCOCCO VULG-IJ	ICA00580
READ(4,+) (T*CI),I=1,*F)       TCA00455       TCA00455       TAIT FORMAT(* F2 CH*DAI=HNDI+F3, INITIAL HAPD INCREPENT)*,DI4.7) TCA01000         READ(4,+) (FECI),I=1,MF)       TCA00455       TCA00455       TCA00455       TAIT FORMAT(* F3 CH*DAI=HNDI+F3, INITIAL HAPD INCREPENT)*,DI4.7) TCA01000         READ(4,+) AN       TCA00455       TCA00455       TCA00455       TCA00455       INITIAL HAPD INCREPENT)*,DI4.7) TCA01020         READ(4,+) AN       TCA00455       TCA00457       1415 FORMAT(* M3 CINITA L XE INCREPENT)*,DI4.7) TCA01020         READ(4,+) AN       TCA00457       1415 FORMAT(* M3 CINITA L XE INCREPENT)*,DI4.7) TCA01020         C       TCA00457       1415 FORMAT(* M3 CINITA L XE INCREPENT)	R140(4,+) NF	TCAURAAN	1416 FURMARY F2 CAAFEFFFF2, INITIAL ASP INCREMENT	TCA00950
READ(4,+) (FE(I),I=1,MF)       TCA00460       1415 FORMAT(* F4 (XA=XC+F4, INITIAL XE INCREMENT)	READCA.+D CIVCID.I=1.0 "FD	TCA00459	1417 FORMATE FS (H-DAL=HHD1+F3, INITIAL HPD INCREPENT) V.D14-7)	TCA01000
READ(4,+) AN READ(4,+) AN RE	READ(4,+) (FE(1),I=1,WF)	TCA00460	1415 FORMATCY F4 (XA=X5+F4, INITIAL XE INCHEWENT)	TCA01019
Image: Contrained and the state of the	READ(4,+) AH	TC#00470	1419 FORMATCH NA CINIT. NO. OF STEPS AT CURRENT TIPE STEP) 141	TCA01028
<pre>Incomparison of the second secon</pre>		TCA00489	1519 FORWATCH NAL (NO. OF SUB-STEPS IN FIRST STEP)	TCA01020
TCA0050" 1421 FORMAT(* NST (INITIAL NO. CF STEPS FOR PROFILE )	J FROM CHANNEL 2	TCA00490	1420 FORMATCY II (NG. GF PTS. PRINTED AT CURRENT TIPE STEP)	TCA01049
D0 4351 I=1;hH       TCA00510       1422 FORMAT(* I2 (NO. CF PTS. PRINTED FOR PROFILE) ************************************		TCA00509	1421 FORMATCH NST (INITIAL NO. CF STEPS FOR PROFILE )	TCA01050
READ(2,++) TC(I), KB(I), PB(I), HB(I)       TCA00520       1522 FORMAT(* I2 (NO. OF PTS. PLCTTED)	D0 4351 I=1+hM	TCA00513	1422 FJRMAT(* I2 (NO. CF PTS. PRINTED FOR PROFILE)	TCAG1060
0351 CONTINUE       TCACM531       1424 FORMAT(* CTCL (INITIAL ABSCLUTE TCLERANCE FOR E02EEF) ***********************************	READ(2,+) TC(I),KB(I),PB(I),H4CCL(I),HB(I)	TCA98529	1522 FORMAT(* 13 (NO. OF PTS. PLCTTED)	TCA01070
TCENHD=TOENHD=1.000C000000100	8351 CONTINUE	TC4 CP 531	1424 FORMAT(* CTCL (INITIAL ABSCLUTE TGLERANCE FOR COZEEF) *,D14.7)	TCA01080
TCADD550 1426 FORMATCH FPTCL CRELATIVE LOAD CAFACITY TOLERANCED ***** ******************************	TCENH3=T0EAH3+1=083E0000000120	TCA 30 549	1425 FORMATCE PTOL CRELATIVE INLET PRESSURE TOLERANCED	TCA01058
		TCAGOSEG	1426 FORMATCH FRTCL CRELATIVE LOAD CAFACITY TOLERANCED	TCA01100

#### TCAG1060 TCA01076 η ..... *,014.70 TCA01058

TCAODSEE TCA00570

..... * 014.73 TCA01108 & く

		70.01110	MR17565-14183 F4	[[AU1680
	TORNATION FRIDA CRELATIVE FRICTION COEFF. TCLERANCED ".DIA.TJ	ICAGITIO	IN IT 5 45. 14 192 NX	TCADIETO
1.1	1326 FURNIS TTOL ATINE STEP TOLERANCES	ICAULI2U	WETTERSISISE NEL	1CHOT 040
	SALE FORMATION ME CENTITAL NO. OF TIME STEPS	ICNOLIJA	UNTTECSIDED IL	10401830
	IF THE THE TTP CAC. OF TIME STEPS PRINTED	ICAULINU	UNTIFES-14:11 NST	ILAUL/UW
	1826 FURNIS MEN 180, OF PRESS, CIST, FRINTED)	TC#01130	UNTTERS1452) 12	TCAGE/10
	1726 FURNITE STILL STATE ON CPU TIME)	ICAULIGO		TCAUL 720
	2026 PORTATION UND ALONET LINET FCR ENT. VEL	TC#011/0	WETERS 14:41 DTCL	TCAU1 / 20
	1538 FORMATE STATT ACTAL & FACTOR FOR PLOTS	TCABIING		TCA01740
	1638 FORMATE AFAIT SALTON FOR FILM PLCTSD	TCA01150		TCA01750
	1730 FORMATE WALL SCALF FACTOR FOR FORTELLEN PLETS)	TCA81280		TCA01760
	1830 FORMATTO FFECT CALLS OF TOM SOR CONFREENCES	TCA01210	BALILIJALJEV V VV	TCA01770
	1431 FORNATC IFT CRIMIN CONTON FOR CHE TIME STEP!	TCA01220		TCA01720
	1531 FORNATED FOR CREATE CELL	TCA01230	UNITEDUTED NOT	TCA01 750
	1432 FORMATES SHOW AND THE SHOW O BE EVENLY SIVISIELS BY 4*/)	TCA01240		TCA01400
	1433 FORMAT(* (1.) WA AND NAI SHOULD BET FUCFED AN/24/3	TCA01250	WRITE CONTRACT WA	TCA01910
	1434 FCRMATCH (2.) II AND IS SHOULD HER JAKSTER)	TCA01260		TCA01020
	1435 FORMAT(* (3.) IZ SHULL HITE FORMALE - LATTOL #/)	TCA01270	WRITE(3,1328) UNO	TCA01730
	1036 FORMATE (4.) FOR SS TULE MARKE CONTRES AT FUELLY /3	TCA01280	WRITE(3,1628) AFACT	TCA01849
	1937 FORMATCH (2.) MTP AND MPX SHOULD DIVILL HT LUIMET FO	TCA01270	WRITE(5.1738) WRACT .	TCA01 850
Ċ		7CA01300	WRITE(S+1830) FFACT	TCAOL P60
Č		TCA01310	WRITE(5.1431) IPT	TCA01 # 70
-	2472 FORMATC///24%+DATA BANK*//3	TCA01320	WRITE(5,1531) MAGR	TCAOL AAO
	2473 FORMAT(* * 68,* 10* 138 * * * 148 * 10* 138 * * * * * * * * * * * * * * * * * * *	TCA01330	C	TCAALESA
	2471 FORMATCO 4.1X.5(C14.7,2X), INJ	TCA01340	WRITE(5,1432)	TCA01970
3	2477 FORMATC///20X++PREVICUS CYCLE+//J	TCA01350	WRITE(5,1433)	TCAN1910
3	PATE FORMAT(8x, *H0*/)	TCA81360	MRITE(5+1434)	TCA01 510
	AF9 FORMAT(* * 1X,014.7.18)	TCA01 370	WRITE(S,1435)	TLPUL 720
•	WRITE(5.101)	TCA01 380	NR1TE45+1436)	TCAUL 730
	METTS(5.116)	TC 441 344	WRITE(5,1437)	TCA01 440
	MRITE(5-101)	TCADIADO	WR ITE (5,99)	TCA01 950
r		TCARLAIR	WRITE(5+101)	TCA01960
ž	FROM CHANNEL 3	70401410	DO 1981 I=1.WF	TCA01970
ž		70401420	TFeTD=TP(I)+TP	TCA01980
	LBTTF(5,1212) HPD4	TCA01430	FPI(I)=FE(I)/WD	TCA01959
	WETTERS.13125 HH03		1801 CONTINUE	TCA 02000
	MATTER-15121 HAC2	10001420	LB TTF (5,99)	TCA02010
	UNTTERS.14133 HUE1		un TTF (5-114)	TCA 02 0 20
		TCA01470	00 1002 I=1.WF	TCA02030
		TCA01428	UNTIFES 1150 THEID. THEID. FEED. FRIED.	TCA02040
~		TCA01470		TCA02050
Ľ	CALLER CHARDEL A	*CA01200		TCA020E0
C	PRUM CHANNEL Y	YCA01510		TCA62070
C	AND TTAT TAROL MT	TCA01520		TCA02080
	WKIILIJAAUUF VA	TCA01530		TCA02050
		TCA91549		TCA02100
		TCA01550		TCA02110
	WRITE(S)+LAUS/ M	TCA01560	DO IDUS LAIONN TOGTA-VACTA-PRETA-HYCOL (I)+HB(I)+I	TCA02120
	NR II.COALAGAT IN	TCA01570	MUTITED ATAILS INTELEMENTED BATTAN	TCA02130
	WRITE(5+1402) WU	TCA01540	1003 CONTINUE	TCA02140
	WRITESSEAUDP P4	TC#01590		TCA02158
	WRITE(5:140/) (1	TC#0160°	C FRUM CHANNEL J	TCA02160
	WRITESSIACED THEIA	TCA01617	c	TCA02170
	WRITE(5414057 HI	TCA01620	WRITE(5)24777	76402140
	WRITE(5,1514) HEDALD	TCA01630	4R[TE(5+24/2]	TCA02190
	WRITE(5,1415) *1	TCA01640	DO 1004 T=1*MI.	TCA02200
	WRITERS, 1416P F2	TC#01650	INI=I-I	10445140
	WRITE(5,1417) F3			

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	MRTTFES_24258 HSTELS_INI	TC#62210	1	IF(UM.LT.UPG) UM=UPG	TCA02768	)
1040		TC482228			TCA02779	)
i i ja manana a	MOTTLS_9951	TCA02230		CALL E0288F(NF4,FKI,FCI,T8,FP,0)	TCA02788	•
		TCA82240		FPS(1)=FP	TCA02790	)
a state and a state of the		TC182258		ETS(1)=0.00	TCA0200	}
		TCA 02 260		FRST(1)=FRC	TCA02810	)
		TC 882 238		MC1) THAT	TC402726	1
		10482288		NY 956 1 3 300 F 1	TC#02#3#	)
6		T#482398			TC#02840	)
<u> </u>		TCARSING		TERMALE_NE_2) VRTTE(5.758)	TCA02750	)
		76483318			TCA028E0	)
	ALL PAPERSIA	10402310		TERMALE_NT.25 WETTERS.75515 TA.MYT1.TT.WA.MYD1.FP.FR0.IT	TC#02970	)
C		16802320	~		TCA02787	3
		TCA 02 JUV	•	90 9476 IT=1-NT	TCA02950	1
		TCA02340	~		TC#02900	
9	Ma 1 = 2 = 0 =	TCA 02350	Ľ		TCA02910	i i
g	PU1#8.28	TC.#42300		16-51-51	TCA82928	
	F 4 2 NF + 4		~	ATTAL 0 C 00 7 P 007 F 1 - 1	TC482938	
		10802300			TCA02940	
L		10402370	<u> </u>		TC402980	
L1		1CA72400			Transaca	
C/	ALL EDIBAFENFOTFOFPIOFKIOFCIONFOFUOLUMKOUD	10402410			10402700	
C/	LL 2018AF (RH + T C + RE + RE + X C + WH 4 + A + + L E + 0 )	10472429	C C		TCA02770	
CA	ALL EDIBAF (AH, TO, PB, PKI, PCI, MH4, AB, LWF, U)	TCA02430			10402788	
ÇA	ALL EDIBAFCAP, TO, MPCGL, MPR, MPC, AMA, AM, CWR, DD	TCA02440	200	PORMAT(* TIPE = "CI4.7, 4X, "EN VEL = ", UI4.7, 4X, "PP = ", UI4.7/)	1002930	
CA	LL_EQIBAF (NH, TO, HE, NKI, HCI, MH4, A & LVR, 98)	TCA02450	201	PORMATE · · · · · · · · · · · · · · · · · · ·	TCAUSOUU	
10H	ALF=1	TCAU24EP	202	PURNATE ++++ PREFILE ITERATION ++++/	TCA03010	
ET		TCA82470			TCA03020	
f R	0=-1.00	TCA82470		IF(U=.[T.UFD] U=UHO	TCA03030	
<b>#</b> \$	STIN=NST	TCA02490		CALL SU2BEF (NF4,FKI,FCI,TC,FF,W)	TCA03040	
NX.	z N= N z	TC#02500		IF(IPT-50-0) 60T0 7810	TC#03050	
DT	=TP/NT	TCA02510		URITE(5,99)	TCA03060	
TT	CL1=TTOL+.130	TCA82520		WRITE(5,200) IC,UP,FP	TCA03070	
C=======		=TCA02530	7810	CONTINUE	TCA03080	
C		TCA02540		ICCUNT=2	TC#03090	
C	TIME CYCLE LOCP - START	TCA82550		KL1=0	TCA03100	
C		TCA02560		KL 3=0	TCA03110	
C == == == == = = = = = = = = = = = = =	*** ***********************************	=TCA82570		HMDAI=DABS(FPDI)+F3	TCA03120	
7550 FJ	RMATE/P *16X1*TIME*19X1*PIN FILM TH*14X1*X TPUNC ERR*17X+	TCAC2580		IF(HMD1.EQ.0.CO) HMCAI=HMDAI0	TCA03130	
•	*ENT VEL**9X**SQ VEL**9X**LCAC PER UN**6X**FRIC COEFF*//)	TCA02590		IF(IPT-EQ.C) GOTO 1697	TCA03140	
7551 FO	PMAT (* *,1%,7(C14-7,2%),14)	TCA02600		WRITE(5+101)	TCA03150	
9922 FO	RMAT(//* *)	TCA02610		WR ITE(5,202)	TCA03160	
7880 CO	NTINUE	TCA92620		WRITE(5,101)	TC403170	
KT I	1=NT/NPX	TCA02630	1697	CONTINUE	TCA03180	
KNF	M=NT/4TP	TC#02543	С		TCA03150	
IFC	(NHALF.5G.2) WRITE(5,101)	TCA02650	C FI	NDING STEACY STATE PROFILE	TCA03200	
IFC	(NHALF.56.2) GDTO 3060	*C#02669	C		TCA03210	
- IF C	(NHALF.56.1) WAITE(5,9922)	TCA02670		CALL SURF	TCA03220	
HPD	D44=H*D4	TCA026 .0	C		TCA03230	
HMD	033=H4D3	TCA82690		RE=KEF	TCA03240	
hMD	22=1402	TCA02701		XA=XE+F4	TCA03250	
HMC	011=n=01	TCA02710		PT=PTCL+PM	TC#03260	
HNT	11=H4T1	TCA02720		IF(IPT.50.0.) GOTC 1972	TCA03270	
3060 CON	ITINUE	TCA02730	1	WRITE(5,101)	TCA03280	•
T0=	=0 • C 0	TCA02740		WRITE(5.201)	TCA03250	h
UP=	:U(TD)	TCA02750		WRITE(3.101)	TCA03300	<u>8</u> .
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					TCA03860
	TCA03310			CALL COIGAF (X51, DF31, MXF1, FC1)CLIPE	TC##3#70
1645 Chai yan	TC403720				TC483828
	TCA83338				TCA03850
	TCA03340	-		XLE XA: YUM	TCA03400
FORMATIC OMP/DT =+.C14.7.3X."PXI =*.D18.3.3X.* ( EE =*.	TCA83320	Ę		TAL AFWAINER OF CENTACT ZONE	TCA03710
	1CAU3 384	2			10403450
1116 FORMATES MM 2*,C14.7,163		•		00 18 1=1+FX	TCAU3730
	10003300			xC=xE5+(1-1)+DX	TCA03550
SOLVING FOR PH USING A 4TH ORCER ACAMS PETHOD - PHEEDE HOLE	TCARSAR			FXT=H8+XC++2/(2.C8+R)-H9	TCA83949
	10463418			IFENCALTANEFO CALL INTPENCAFUTD	TCA83978
	TCA03420			DPS(I)=12.C0+VI+(UN+(FXT-FXE)+HHC+(XC-XE))/(H+(+FXT)++3	TCABSTA
C PREDICTCR	TCA83438			X\${[]=XC	TCA03950
	TCA83448		10	CONTINUE	TCA94 090
HNTP=H9T1+CUT/24.CU3-C33.CU4H-01-37.CU4H-022.CU5H-00.CU5	TCA03450			CALL COIGAFENS, OPS, NX, PC, E22, UP	TC#04011
C	TCA03460			KL 3=KL 3+1	TCA04020
C MODIFIEN TO FREDICTOR	TCA#347#				TCA04030
C	TC#03498				TCAB4040
	TCA03490			KL2=KL2+1 	TCA04020
	TC#03500			IF (TPT-10-1) WALL'S MADE AND	TCA04060
	TCA03510			$[F[P[o]] \circ \bullet \circ Loff = 0 \ o \ o \ o \ o \ o \ o \ o \ o \ o \$	TCA 04 070
	TCA83528				TCA94020
	TCAUSSSU	~			TCA04070
	10403240	2		STERNINING THE REQUIRED SQUEEZE. VELOCITY USING DISECTION	TCA 04 1 00
IADAM=0	TEADISCO	ž	•		TCA04110
	TCA01578	•	5	IF (JCOUNT-EQ.0) HPDA=HNDA/2.00	TCA84120
AAAA CONTINUE	TC403520		-	JCOUNT=1	TCA 84 134
86 CONTINUE	TCA03550			NHO=HHO+HHCA	TCA04140
	TCA83609			6010 8	TCA 04 150
IFCIPT-EQ.1) WRITECT-11183 WHITERLY	TCA03610		6	IF (JC CUNT.E8.1) HPDA=H4DA/2.00	TCA04120
KL210	TCA03620			JCOUNT=0	TCA04190
	TCA03639			HND=HMD-HMCA	TCAGAISE
C EVALUATER - START	TC#03640			6010 8	TCA04200
	TCA03650	С			TCA04210
	TCA036E0	С			TCA 04 2 20
	TCA03670	C	ε	VALUATOR - FINISH SECTOR	TCA04230
	TC#03680	C	_		TCA04240
SOLVING PRESSURE DISTRIBUTION FOR TRIAL SO VEL USING COLGAF	TCA83698		9	CONTINUE	TCA04250
	TCA03700	~		PLEIVANOTPOIN ANIA 1220	TCA04260
	TCA73710	с —			TC#84270
DX1=D #/ 4 X1	TCAU3720	Ē	Ľ	UKRECTER	TCA04280
45 = NCA V	TCAU3/30	C		MMT=MMT1+(CT/24,00)+(9,00+HPC+19,C0+HM01-5,00+HP02+HM03)	TCA04250
NXP1=NX1+1	1CA03740	~			TCA04309
C	10403750	ř	C	ONVERSENCE CHECK FCR CORRECTCR	TCA 04 310
C (1.) SUB-DIVICED FIRST STEP	TCA03770	č			TCA04320
c	TCA037P0	•		TTCLA=FT0L+.00100	TCA04330
DC 5501 I=1.NAP1	TCA03150			DH=DAESCCHPT-H#TOJ/HMTJ	10404540
	TCA03900			IFCOH-LE-TTCLA) GOTC 9090	10804330
PRIITUPRIVEZEZAULUTITT	TCA03#10			H#TO=H4T	TCA043EU
1-1,1,0,1,0,1,7,7,0,0,1, 1,0,1,7,0,0,7,0,1,7,7,7,7,7,7,7,7,7,7,7,	TCA03=20			6010 9444	
LT LL = 19+17 FALT - FALT - FALT - FALT - FALT - FALT - KET - KET - KET - KET - FALT -	TC#03P30	9	090	CONTINUE	10404JE4
	TC#03840				TCADAADA
sai cating	TCA03858			ET=100.00+19.00+DABS(UM=1)/(2/0.00=n=1)	

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Industrie         TCANNE         Provide the second				TCA84768
ATT 74         TC4422         TC4422<	*****	TCA84418		TC804970
Jose Start Finite         ICGN 700         ICGN 700 <thicgn 700<="" th="">         ICGN 700         <thicgn 700<="" th=""></thicgn></thicgn>		TCA84428		7CA04 980
		TCA84430		TC884770
Continue		1020440	ASTRIAIS	TCA05000
Commentation         Control         State Press		TC284458		TCAUSULE
Liss C Liss C Liss S B I're Liss S C Liss S C Liss S B I're Liss S C Liss S B I're Liss S C Liss		TC#34460		15482028
American         American         Strike         Str	CALCULATED FP 2",C14.7.3%,"FCR HE 2",014.7.	TCA 84 4 10		TCA05030
11         TORMANT ************************************	120 Former 18, 16 FT 210-119-30* 2 1*0193	TCROAASD		10403840
Jack Print Pr	CONNATES SPECIFIED FP 17,014.73	TCAG4470		TCAUSULU
1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1         1		TC#84300		ICAUSUEU
Aug         Notestimulation         Notestimulation         Notestimulation           00 3010 11,4M0         TCA00500         TCC001,1000         TC0001,1000         TC0001,1000           1/2 CC001,1000         TC0001,1000         TC0001,1000         TC0001,1000         TC0001,1000           2/2 CC001,1000         TC0001,1000         TC0001,1000         TC0001,1000         TC0001,1000           2/2 CC001,1000         TC0001,1000         TC0001,1000         TC0001,1000         TC0001,1000           2/2 CC001,1000         TC0000,1000         TC0000,1000         TC0001,1000         TC0001,1000           2/2 CC001,1000         TC0000,1000         TC0000,1000         TC0000,1000         TC0000,1000           2/2 CC000,1000         TC0000,1000         TC0000,1000         TC0000,1000         TC0000,1000           2/2 CC000,1000         TC0000,1000         TC0000,1000         TC0000,1000         TC0000,1000         TC0000,1000           2/2 CC000,1000,10000,		16484310	TE CUC - LT-REFS CALL INTPENCSFRTS	10403070
00         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100         100		1044720		TCAUSUUU
ICC:::::::::::::::::::::::::::::::::::	00 1210 Ist.WB	TC	TECT-FO-1D HEE=HSC	16407070
IFIC:         TOTAL         TOTAL <th< td=""><td>100-201241+4</td><td>·[AU4340</td><td>Fy1(I)=2-Df+VI+U#/HSC-HSC+CFS(I)/2+D0</td><td>1045100</td></th<>	100-201241+4	·[AU4340	Fy1(I)=2-Df+VI+U#/HSC-HSC+CFS(I)/2+D0	1045100
Aux al         Treat         Treat         Treat         Treat         Treat         Treat           CALL SOLGAPERING         TREATS         TREATS         TREATS         TREATS         TREATS           PERFORM         TREATS         TREATS         TREATS         TREATS         TREATS         TREATS           PERFORM         TREATS         TREA	166TCC.45.13 6CTC 1010	16894329 4048454	TR26 CONTINUE	TCAUSLIC
CALL ESIGNATION         FEBSOR         FEBSOR <t< td=""><td></td><td>TCA04519</td><td>DYFXDX</td><td>TCA05120</td></t<>		TCA04519	DYFXDX	TCA05120
Framework         Transmission         Transmission <td>CALL CALGAFERS.DPS.L.PC.E.B.</td> <td></td> <td>ATTA CONTINUE</td> <td>TCAUSIJU</td>	CALL CALGAFERS.DPS.L.PC.E.B.		ATTA CONTINUE	TCAUSIJU
NLIMELDAI         TYCDING-DEFINES         TYCDING-DEFINES         TYCDING-DEFINES           NSGLIDARGE         TYCDING-DEFINES         TYCDING-DEFINES         TYCDING           PSLULDARGE         TYCDING-DEFINES         TYCDING-DEFINES         TYCDING           C         SOLVING LOAD CAPACITY FOR TAIAL XE USING EDIGAF         TYCDING-CLANGED         TYCDING-CLANGED         TYCDING-CLANGED           C         SOLVING LOAD CAPACITY FOR TAIAL XE USING EDIGAF         TYCDING-CLANGED         TYCDING-CLANGED         TYCDING-CLANGED           C         SOLVING LOAD CAPACITY FOR TAIAL XE USING EDIGAF         TYCDING-CLANGED		TCAGASGO		TCA05140
TSR/LIPSCID         TSR/LIPSCID         TSR/LIPSCID         TSR/LIPSCID           1010 CONTINUE         TCA04200         MPFMAD1         TCA04200         TCA04200           1010 CONTINUE         TCA04200         MPFMAD1         TCA04200         TCA04200           C         SOLVING LIAD CARCITY FOR TRIAL XE USING EDIDAF         TCA04200         TCA04200         TCA04200           C         SOLVING LIAD CARCITY FOR TRIAL XE USING EDIDAF         TCA04200         DST/T LIPSCID         TCA04200           C         SOLVING LIAD CARCITY FOR TRIAL XE USING EDIDAF         TCA04200         DST/T LIPSCID         TCA04200           C         SOLVING LIAD CARCITY FOR TRIAL XE USING EDIDAF         TCA04200         TCA04200         TCA04200         TCA04200           C         SOLVING LIAD CARCITY FOR TRIAL XE USING EDIDAF         TCA04200         TCA04200         TCA04200         TCA04200           KLIXKLI-1         TCA04200	KL 32KL 3+1	TC 404 570	xyFJ=xE-DXF+NBB	TCA05140
PEILING         PEILING <t< td=""><td></td><td>TCA04610</td><td></td><td>TCA05160</td></t<>		TCA04610		TCA05160
1818 CONTINUE         TENESCO	24= J = PC	TCA84628	MRP = NRA + 1	TCA05170
C         SOLVING LJAD CAPACITY FOR TRIAL XE USING EDISAF         TERMENT	TATE CONTINUE	TCARASIA	IF(NAP.GE.4) 6370 8277	TCA05120
C         SOLVITE L2AD CAPACITY FOR TAIAL XE USING EDIGAP         ICAN         ICAN         COTO 2278         ICAN         ICAN         CALL CDIGAF(XSR,PS,JL,FPC,EE,G)         ICAN		TCAGACAG		TCA05150
CALL C0164F4RSA,PS,JL,FPC,EL,00       TC004060       B277 C0NTRUE       TC004         KLISHLI-1       TC004670       D0 7927 Tel.NBP       TC005         KLISHLI-1       TC004670       D0 7927 Tel.NBP       TC005         KLISHLI-1       TC004670       D0 7927 Tel.NBP       TC005         KLISHLI-1       TC004670       TC00470       TC007         KLISHLI-1       TC00470       TF4100470       TC007         KLISHLI-1       TC00470       TF4100470       TC007         MCTCS.120       TC00470       TF420-TAUT       TC007         WRITCS.1215       FP       TC00470       TF4104740       TC007         WRITCS.1215       FP       TC00470       TF4104740       TC007         URTTCS.1215       FP       TC00470       TF4104740       TC007         URTTCS.1215       FP       TC00470       TF4104740       TC007         IF6179.032(FP-FPC)/FP       TC00470       TC00470       TF4104       TC0037         IF6179.032(FP-FPC)/FF       TC00470       TF4104       TC0037       TC0037         IF6179.0310       TC00470       TF4104       TC0037       TC0037       TC0037         IF6179.04110       FF11400       TC00470       TF410400 </td <td>SOLVING LOAD CAPACITY FOR TRIAL XE USING EDIGAF</td> <td>TCARALSO</td> <td>6010 8278</td> <td>TCA05200</td>	SOLVING LOAD CAPACITY FOR TRIAL XE USING EDIGAF	TCARALSO	6010 8278	TCA05200
CALL C0164F(ISR, PS, JL, FPC, EE, #)       100 7927 1=1, NBP       100 7927 1=1, NBP         KLISKLISI       100 7927 1=1, NBP       100 7927 1=1, NBP       100 7927 1=1, NBP         KLISKLISI       100 7927 1=1, NBP       100 7927 1=1, NBP       100 7927 1=1, NBP         KLISKLISI       100 7927 1=1, NBP       100 7927 1=1, NBP       100 7927 1=1, NBP         KLISKLISI       100 7927 1=1, NBP       100 7927 1=1, NBP       100 7927 1=1, NBP         KLISKLISI       100 7927 1=1, NBP       100 7927 1=1, NBP       100 7927 1=1, NBP         FRITHON TO CONTRACTOR TO THE		TCARAGER	APTT CONTINUE	TCA05210
RLISHLISI       TCONCOM	CALL COIGAF (XSR, PS, JL, FPC, EE, 0)	TCA04630	DO 7927 I=1,NBP	TCA05220
HLJ=HLJ-1         TCAMPS         FT = H0 = RC + 2/2 - C + R - HH         TCAMPS           FFC=FFC         TCAMPS         TCAMPS         TCAMPS         TCAMPS           LFG10-CDSTELFFC)         TCAMPS         TCAMPS         TCAMPS         TCAMPS           LFG10-CDSTELFFC)         TCAMPS         TCAMPS         TCAMPS         TCAMPS           LFG10-CDSTELFFC)         TCAMPS         TCAMPS         TCAMPS         TCAMPS           MUTTECS.LSTFCL         TCAMPS         TCAMPS         TCAMPS         TCAMPS           DETERMINING         TFTTECS.LSTFCL         TCAMPS         TCAMPS         TCAMPS           LFCDUTF.LSTFCLS         GTO GS         TCAMPS         TCAMPS         TCAMPS         TCAMPS           LFCDUTF.SG.LSTFCLS         GTO GS         TCAMPS         TCAMPS         TCAMPS         TCAMPS           LFCOUTS         GTO GS         TCAMPS         TCAMPS         TCAMPS         TCAMPS         TCAMPS           LFCOUTS	KL1=KL1+1	TCAGA688	KC=KKCD+GI-13+DKF	TCA05230
FPC=-FPC         TCA00700         IF4C_LT_XFF         CALL INTP(XC_FFT)         TCA002           IF4(F)_CADSCEL/FFC)         TCA00710         MCC_TX_FFC, TALL         TCA00720         TCA00710         TCA00710 <td< td=""><td>KL 3=KL 3+1</td><td>TCARAGER</td><td>F x T=H 0+ xC++ 2/62+ C0+ RJ-HM</td><td>TCA05240</td></td<>	KL 3=KL 3+1	TCARAGER	F x T=H 0+ xC++ 2/62+ C0+ RJ-HM	TCA05240
Efeilos-Costient-FECS       TCANADIA       TCANADIA       TCANADIA         IF (FF-CG.0) & GGTC 1:300       TCANADIA       TCANADIA       TCANADIA         WRITE(5,124) FPC, WILLEL, ML1       TCANADIA       TCANADIA       TCANADIA         WRITE(5,124) FPC, WILLEL, ML1       TCANADIA       TCANADIA       TCANADIA         WRITE(5,124) FPC, WILLEL, ML1       TCANADIA       TCANADIA       TCANADIA         JUSS CONTINUE       TCANADIA       TCANADIA       TCANADIA         DIFFICALS, FPC, MFC       TCANADIA       TCANADIA       TCANADIA         DIFFICALS, FPC, MFC       TCANADIA       TCANADIA       TCANADIA         DIFFICALS, FPC, MFC       GGTC 1:20       TCANADIA       TCANADIA         IF(FP, GC, FFC, MULL       GGTC 42       TCANADIA       TCANADIA         IF(FP, GC, FFC, GGTC 42       TCANADIA       TCANADIA       TCANADIA         IF(FP, GC, FFC, GGTC 62       TCANADIA       TCANADIA       TCANADIA         C       TCANADIA       TCANADIA       TCANADIA       TCANADIA         C       TCANADIA       TCANADIA       TCANADIA       TCANADIA         C       TCCUNT, GG, JA A=XA/2, DO       TCANADIA       TCANADIA       TCANADIA         GGTC 64       TCCUNT, GG, JA A=XA/2, DO<	FPC=-FPC	TCA04700	IFERCALT-REFT CALL INTPERCORNY	TC#05250
IF(IPT:C0.05 GGTC 1200       TCA00720       TCA00720       TCA00720       TCA00720       TCA00720         WRITEC3.120 SPC.NIL.EE.WL1       TCA0730       TCA0730       TCA0730       TCA0730       TCA00720         UMITEC3.120 SPC.NIL.EE.WL1       TCA0730       TCA0730       TCA0730       TCA0730       TCA00730         1500 CUNTINUE       TCA0740       T927 CUNTINUE       TCA00730       TCA00730       TCA00730         DIFFIDADS(PPC)/FP       TCA0740       T927 CUNTINUE       TCA00740       T927 CUNTINUE       TCA00730         DIFFIDADS(PPC)/FP       TCA00740       TGA0740       T927 CUNTINUE       TCA00740       T727 CUNTINUE       TCA00740       T727 CUNTINUE         DIFFIDADS(PPC)/FP       TCA00740       TGA0740       T727 CUNTINUE       TCA00740       T727 CUNTINUE       TCA00740       T727 CUNTINUE       TCA00740       T727 CUNTINUE       TCA00740       TCA00	EE=100.C0+C/BS(EE/FFC)	TCA04710	HSC=FXT+HNT	TCAUSZEU
WRITE(5,124) FPC, NI, SE, SE, KLI         TCA00750         R2(1) + RC         TCA00710           1300         CONTINUE         TCA00700         T927 CONTINUE         TCA00710           DIFF = DADS(FP-FPC)/FP         TCA00710         CALL C016AF(H2,FH1,HMP,FR1,ER1,D)         TCA00710           IF(DIFF,L2,FPTC) GOTO S1         TCA00710         CALL C016AF(H2,FH1,HMP,FR1,ER1,D)         TCA00710           IF(IFP,G1,FFC) GOTO C2         TCA00710         FR1=FP1         TCA00710           IF(IFP,G1,FFC) GOTO C3         TCA00710         FR1=FP1         TCA00710           C         TETEMINING THE REDULAED NE USING BISECTICM         TCA00710         FR2=FR2           C         TEFENENCHIC         TCA00710         FR2=FR2         TCA00710           C         TEFENENCHICHIC         TCA00710         FR2=FR2         TCA00710 </td <td>IFCIPT.EQ.C) GGTC 1500</td> <td>TCA84728</td> <td>Fx2{[]=2.08+VI+U#+HxE/{HSC++2}</td> <td>TCA05210</td>	IFCIPT.EQ.C) GGTC 1500	TCA84728	Fx2{[]=2.08+VI+U#+HxE/{HSC++2}	TCA05210
WRITE(5,11:1) FP       TCA04700       T927 CONTINUE       TCA051         1300 CONTINUE       TCA04700       FR1.6R1.0D       TCA052         DIFF:DDASS(FP-FPCL/FP       TCA0510       TCA0510       TCA0510         IFIDIFF.GT.FFCD.GOTO S1       TCA05700       FR1=-FP1       TCA0510         IF(FP.GT.FFCD.GOTO 62       TCA05700       FR1=-FP1       TCA0510         IF(FP.GT.FFCD.GOTO 62       TCA05700       FR2=-FP2       TCA0510         IF(FP.GT.FFCD.GOTO 63       TCA05700       FR2=-FP2       TCA0510         IF(FP.GT.FFCD.GOTO 64       TCA05700       FR2=-FP2       TCA0510         ICOUNT=50       TCA0510       TCA0510       TCA0510       TCA0510         ICOUNT=6       TCA05400       C       TCA0510       TCA0510         ICOUNT=6       TCA05400       C       FR11AFILITY       TCA0510       TCA0510         ICOUNT=6       TCA05400       TCA05400       FR21	WRITE(3,124) FPC,1E,EE,KL1	10404730	x2(I)=xC	TCA05270
1398 CCWTINUE       TCA04720       CALL C016AF4X3,FX1,NMP,FR1,CR1,00       TCA053         DIFF:DAB36FP-FPC)/FP       TCA04720       CALL D016AF4X3,FX1,NMP,FR1,CR1,00       TCA053         DIFF:DAB36FP-FPC)/FP       TCA053       TCA05760       CALL D016AF4X3,FX1,NMP,FR1,CR1,00       TCA053         IF(DIFF:DATFC) GOTO S1       TCA05760       FR2=-FR2       TCA053         IF(FP,LT.FFC) GOTO B3       TCA0570       FR2=-FR2       TCA053         C       DETERMINING THE REQUIRED XE USING BISECTICM       TCA05470       FR2=-FR2       TCA053         C       DETERMINING THE REQUIRED XE USING BISECTICM       TCA05470       FR2=-FR2       TCA053         C       DETERMINING THE REQUIRED XE USING BISECTICM       TCA05470       FR2=-FR2       TCA053         C       DETERMINING THE REQUIRED XE USING BISECTICM       TCA05470       FRCAVERR2/FPC       TCA053         C       DETERMINING THE REQUIRED XE USING BISECTICM       TCA05470       FCA05470       TCA053         C       DETERMINING THE REQUIRED XE USING BISECTICM       TCA05470       FCA05470       TCA053         C       DETERMINING THE REQUIRED XE USING BISECTICM       TCA05470       FCA05470       TCA053         S       IF(ICCUNT.E0.1) XA=XA/2.D00       TCA05470       FCA05470       TCA054       TCA05470	URITECS:1153 FP	TCA 84 740	7927 CONTINUE	TC#05290
DIFF=DABS(FP-FPC)/FP         TCA053           IF(DIFF=L2, EPTCL)         GCTO 51         TCA053           IF(FP_GT_FFC)         GCTO 51         TCA053           IF(FP_GT_FFC)         GOTO 62         TCA057           IF(FP_GT_FFC)         GOTO 63         TCA057           IF(FP_GT_FFC)         GOTO 63         TCA057           C         TCA057         FR2=FP1           C         TCA057         TCA057           C         DETERMINING IFE REQUIRED NE USING BISECTION         TCA057           C         TCA0576         FR2=FR2/FPC           C         TCA0578         FRELARD/FPC           C         TCA05790         FR2=FR2/FPC           C         TCA05790         FR2=FR2/FPC           C         TCA05790         TCA05790           ICOUNT=6         IFCICUNT.5G.ID NA=XA/2=00         TCA05970           ICOUNT=6         TCA054700         TCA054700           SIF(ICCUNT.5G.0) NA=7A/2=00         TCA054700         TCA054700           ICOUNT=1         TCA054700         TCA054700         TCA054700           ICOUNT=1         TCA054700         TCA054700         TCA054700           ICOUNT=1         TCA054700         FR11011111         CHECK*//1 <td>1508 CONTINUE</td> <td>TCA 84758</td> <td>CALL COIGAF(XS,FX1,NXP,FR1,ER1,0)</td> <td>TCA05300</td>	1508 CONTINUE	TCA 84758	CALL COIGAF(XS,FX1,NXP,FR1,ER1,0)	TCA05300
IF(D)FF4LC.#PTCL>GCTO 91       TCA053         IF(FP.GT.FFC; GOTO 62       TCA0570         IF(FP.GT.FFC; GOTO 63       TCA0570         C       TCA0570         DETERMINING THE REQUIRED XE USING BISECTICM       TCA0570         G2       IF(ICCUNT.EG.1) XA=XA/2.D0       TCA0570         ICCUNT.E0       TCA0570       TCA0570         ICCUNT.E0       TCA0570       FRCAVEFRE/FPC         TCCOUNT.E0       TCA0570       TCA0570         ICCUNT.E0       TCA0570       FRCAVEFRE/FPC         TCCOUNT.E0       TCA0570       TCA0570         ICCUNT.E0       TCA0570       TCA0570	DIFF =DABS (FP-FPC)/FP	TCADATED	CALL COIGAF(X2,FX2,NBP,FR2,EP2,0)	TCA05310
IF(FP.GT.FFC) GOTC 62       T(200776       FR2=-FR2       T(200376         IF(FP.LT.FPC) GOTC 63       T(200376       FRCOM=FR1/FPC       T(200376         C       DETERMINING THE REQUIRED XE USING BISECTICM       T(2004796       FRCM=FR1/FPC       T(200376         C       DETERMINING THE REQUIRED XE USING BISECTICM       T(2004796       FR=FRC0M+FFCAV       T(200376         C       DETERMINING THE REQUIRED XE USING BISECTICM       T(2004766       T(2003766760       T(200376760         C       IF(ICCUNT.EG.1) XA=XA/2.D0       T(200476760       T(200476760       T(20057760       T(20057760         ICOUNT=0       T(2004760       T(2004760       T(2004760       T(20047600       T(20047600 <td>IFEDIFF-LE-FFTCL) GCTO 91</td> <td>TCA84770</td> <td>FR1=-FP1</td> <td>TCA05320</td>	IFEDIFF-LE-FFTCL) GCTO 91	TCA84770	FR1=-FP1	TCA05320
IF(FP.LT.FPC) GOTO #3       TCA053         C       DETERMINING IFE REQUIRED XE USING BISECTION       TCA054PC0       FRCAVER2/FPC       TCA053         C       DETERMINING IFE REQUIRED XE USING BISECTION       TCA054PC0       FRCAVER2/FPC       TCA053         C       DETERMINING IFE REQUIRED XE USING BISECTION       TCA054PC0       FRCAVER2/FPC       TCA053         C       DETERMINING IFE REQUIRED XE USING BISECTION       TCA054PC0       FRCAVER2/FPC       TCA053         C       If(ICCUNT.5G.I) XA=XA/2.D0       TCA054PC0       TCA054PC0       TCA053         ICOUNT=0       TCA054PC0       TCA054PC0       TCA054PC0       TCA0550         GOTO 84       TCA054PC0       TCA054PC0       TCA054PC0       TCA054PC0       TCA0550         60TO 84       TCA054PC0       TCA	IF(FP.GT.FFC) GOTC 42	TCADATED	FR2=-FR2	TCA05330
C       DETERMINING THE REQUIRED XE USING BISECTION       TCADARCO       FRCAVEFR2/FPC       TCADARCO       FRCAVEFR2/FPC       TCADARCO         C       DETERMINING THE REQUIRED XE USING BISECTION       TCADARCO       FRCAVEFR2/FPC       TCADARCO       TCADARCO       FRCAVEFR2/FPC       TCADARCO	IF(FP.LT.FPC) 69T0 E3	TCA04790	FRCON=FR1/FPC	TCAU5340
C       DETERMINING THE REQUIRED XE USING HISELTICM       TCA04920       TCA04920       TCA052         62       IF(ICCUNT.EG.1) XA=XA/2.D0       TCA04920       C       RELIAPILITY       TCA053         1COUNT=0       TCA04920       C       RELIAPILITY       TCA054         32       IF(ICCUNT.EG.1) XA=XA/2.D0       TCA04920       C       RELIAPILITY       TCA053         32       ICOUNT=0       TCA04920       C       RELIAPILITY       TCA054         33       IF(ICCUNT.EG.0) XA=XA/2.D0       TCA04920       C       TCA04920       TCA054         83       IF(ICCUNT.EG.0) XA=XA/2.D0       TCA04920       C       RETRONTO       TCA054         1COUNT=1       TCA04920       TCA04920       TCA05470       948       FORMAT(* MC. CF STEPS DOUBLED FOR FP RELIAPILITY CHECK*/> TCA054       TCA05470         1COUNT=1       TCA04920       YA       TCA04920       YA       TCA05471       TCA054         NE XEE-XA       TCA04920       YA       TCA04920       YA       TCA05471       TCA05471       TCA05471         1COUNT=1       TEXE-XA       TCA04920       YA       FORMAT(* MC. CF STEPS DOUDL*,12K,*K********************************		TFADAPED	FRCAV=FR2/FPC	TCAUSSED
C       TCA0420       TCA0420       TCA053         B2 IF(IC:UNT.EG.1) XA=XA/2.D0       TCA04020       RELIABILITY       TCA053         IC:OUNT.E0       TCA04020       RELIABILITY       TCA053         XE=XE.XA       TCA04020       C       TCA054         GOTO 84       TCA04020       C       TCA054         B3 IF(IC:UNT.E0.0) XA=XA/2.D0       TCA04020       TCA04020       TCA054         I:OUNT.E0.0) XA=XA/2.D0       TCA04020       TCA04020       TCA054         B3 IF(IC:UNT.E0.0) XA=XA/2.D0       TCA04020       TCA04020       FSTEPS DOUBLE: FCR FR RELIABILITY CHECK*/)       TCA054         B3 IF(IC:UNT.E0.0) XA=XA/2.D0       TCA04020       TCA04020       FORMAT(* NC. CF STEPS DOUBLE: FCR FR RELIABILITY CHECK*/)       TCA054         B3 IC:UNT.E0.000 XA=XA/2.D0       TCA04020       948       FORMAT(* NC. CF STEPS DOUBLE: FCR FR RELIABILITY CHECK*/)       TCA054         K:=XE:XA       TCA04040       948       FORMAT(* NC. CF STEPS DOUBLE: FCR FR RELIABILITY CHECK*/)       TCA054         K:=XE:XA       TCA04040       948       FORMAT(* NC. CF STEPS DOUBLE: FCR FR RELIABILITY CHECK*/)       TCA054         K:=XE:XA       TCA04040       948       FORMAT(* NC.CF STEPS DOUBLE: FCR FR RELIABILITY CHECK*/)       TCA054         K:=XE:XA       TCA040400	C DETERMINING THE REQUIRED WE USING BISELTION	TCARAPIR	FREFRCON+FFCAV	1CA05360
82       IF(ICCUVT-EG.1)       MA=XA/2.000       TCADAP20       C       RELIAPILITY       TCADAP20       TCADAP20       TCADAP20       TCADAP20       TCADAP20       C       TCADAP20       TCADAP		TCA 04 920		TCA05370
ICOUNT=0       TCADARAD       TCADARAD <td< td=""><td>82 IF(ICCUNT-EG-1) XA=7A/2-DD</td><td>TCADAPID</td><td>C RELIAPILITY</td><td>TCA05380</td></td<>	82 IF(ICCUNT-EG-1) XA=7A/2-DD	TCADAPID	C RELIAPILITY	TCA05380
XE=XE+XA       TCADAAED       662       FORMAT(* NC. OF STEPS DOUBLED FOR PRESS. RELIABILITY CHECK*/)       TCADAAED         GOTO 84       TCADAAED       662       FORMAT(* NC. OF STEPS DOUBLED FOR PRESS. RELIABILITY CHECK*/)       TCADAAED         83       IF(ICCUNT.EQ.D) XA=JA/2.D0       TCADAAED       948       FORMAT(* NC. OF STEPS DOUBLED FOR FR RELIABILITY CHECK*/)       TCADAED         1COUNT=1       TCADAAED       948       FORMAT(* NC. OF STEPS DOUBLED FOR FR RELIABILITY CHECK*/)       TCADAED         1COUNT=1       TCADAAED       948       FORMAT(* NC. OF STEPS DOUBLED FOR FR RELIABILITY CHECK*/)       TCADAED         1COUNT=1       TCADAAED       948       FORMAT(* NC. OF STEPS DOUBLED FOR FR RELIABILITY CHECK*/)       TCADAED         1COUNT=1       TCADAED       TCADAED       948       FORMAT(* NC. OF STEPS DOUBLED FOR FR RELIABILITY CHECK*/)       TCADAED         1COUNT=1       TCADAED       TCADAED       948       FORMAT(* NC. OF STEPS DOUBLED FOR FR RELIABILITY CHECK*/)       TCADAED         12:1:1:1:1:1:1:1:1:1:1:1:1:1:1:1:1:1:1:	ICOUNT=0	TCAGARAG	C	TCA 05 3 50
GOTO 84       TCA04P60       721       FORMAT(* NC. ČF STEPS DOUBLED FOR FF RELIABILITY CHECK*/)       TCA054         83       IF(ICCUNT.EQ.0) XA=XA/2.00       TCA04P60       721       FORMAT(* NC. CF STEPS DOUBLED FOR FF RELIABILITY CHECK*/)       TCA054         ICQUAT=1       TCA04P60       948       FORMAT(* NC. CF STEPS DOUBLED FOR FF RELIABILITY CHECK*/)       TCA054         NE=XE=XA       TCA04P60       941       FORMAT(* *,XX,*POLO*,12X,*FASU*,13X,*X*,12X,*A.DIFF.*/)       TCA054         60T0 84       TCA04P60       942       FORMAT(* *,XX,*POLO*,12X,*FASU*,10X,*X*,12X,*A.DIFF.*/)       TCA054         81       CONTINUE       TCA04P60       751       FORMAT(* *,4X,*FFCLC*,11X,*FFNEW*,10X,*R.DIFF.*/)       TCA054         61       CONTINUE       TCA04P10       751       FORMAT(* *,6X,*FFCLC*,11X,*FFNEW*,10X,*R.DIFF.*/)       TCA054         61       CONTINUE       TCA04P10       751       FORMAT(* *,6X,*FFCLC*,11X,*FFNEW*,10X,*R.DIFF.*/)       TCA054         61       CONTINUE       TCA04P10       751       FORMAT(* *,1X,*PCLD*,11X,*FRNEW*,10X,*R.DIFF.*/)       TCA054         61       CONTINUE       TCA04P10       751       FORMAT(* *,1X,*PCLD*,11X,*PCLEAPLE       TCA054         62       FRICTICN       TCA04P10       751       FORMAT(* *,1X,*PTAEW*,11X,*R.DIFF.*/)       TCA	XE=XE+XA	TCADASED	662 FORMATCO NC. OF STEPS DOUBLED FOR PRESS. RELIABILITY CHECK "/	TCA05400
83       IF(ICCUNT.EQ.0) XA=XA/2.00       TCA04E70       948       FORMAT(* NC. CF STEPS DOUBLED FOR FR PELIAPILITY CHECK*/)       TCA054         ICQUAT=1       TCA04E70       941       FORMAT(* *, IX, *POLO*, 12X, *FREM*, 13X, *X*, 12X, *A.CIFF.*/)       TCA054         NE=XE=XA       TCA04#*0       942       FORMAT(* *, IX, *POLO*, 12X, *FREM*, 13X, *X*, 12X, *A.CIFF.*/)       TCA054         60T0 84       TCA04*00       943       FORMAT(* *, IX, *FREM*, 10X, *R.DIFF.*/)       TCA054         81       CONTINUE       TCA04*01       751       FORMAT(* *, IX, *FRNEM*, 10X, *R.DIFF.*/)       TCA054         6       FRICTION       TCA04*01       751       FORMAT(* *, IX, *FRNEM*, 10X, *R.DIFF.*/)       TCA054         6       FRICTION       TCA04*01       751       FORMAT(* *, IX, *FRNEM*, 10X, *R.DIFF.*/)       TCA054         6       FRICTION       TCA04*01       751       FORMAT(* *, IX, *FRNEM*, 10X, *R.DIFF.*/)       TCA054         6       FRICTION       TCA04*01       751       FORMAT(* *, IX, *POLD*, 11X, *POLD*, 11X, *R.DIFF.*/)       TCA054         6       FRICTION       TCA04*01       751       FORMAT(* *, IX, *POLD*, 11X, *POLE*, 10X, *R.DIFF.*/)       TCA054         6       FRICTION       TCA04*01       752       FORMAT(* *, IX, *POLD*, 11X, *POLE*, 11X,	6010 84	TCADAPED	721 FORMATCH NC. OF STEPS DOUBLED FOR FF RELIABILITY CHECK //	TCA05410
ICQUAT=1       TCA04#*0       941       FORMAT(* *,JX,*POLD*,12X,*FAEW*,13X,*X*,12X,*A.CIFF,*/)       TCA054         RE=xxE=xa       TCA04#*0       942       FORMAT(* *,JX,*POLD*,12X,*FAEW*,13X,*X*,12X,*A.CIFF,*/)       TCA054         G0T0 84       TCA04*00       943       FORMAT(* *,JX,*FAEW*,10X,*R,01FF,*/)       TCA054         81       CONTINUE       TCA04*01       943       FORMAT(* *,6X,*FRVEW*,10X,*R,01FF,*/)       TCA054         81       CONTINUE       TCA04*01       751       FORMAT(* *,4X,*FRVEW*,10X,*R,01FF,*/)       TCA054         61       CONTINUE       TCA04*01       951       FORMAT(* *,4X,*PTNEW*,11X,*R,01FF,*/)       TCA054         61       CONTINUE       TCA04*07       952       FORMAT(* *,7X,*PT0L0*,11X,*PTNEW*,11X,*R,01FF,*/)       TCA054         752       FOR*AT(* *,1X,50014,7,2X)/)	83 IF(ICCUNT.EQ.0) XA=JA/2.JO	TCANAF JD	948 FORMAT(" NC. CF STEPS DJUBLEC FOR FR PELIAPILITY CHECK"/)	TCAU5420
NE=xE=xA       TCAC4493       942       FORMAT(* *,1%+4(D14-7,2%))       TCAD54         GQT0 84       TCAD4901       943       FOPMAT(* *,6%,*FPCLC*,11%,*FPNFW*,10%,*R,DIFF.*/)       TCAD54         81       CONTINUE       TCA04910       751       FORMAT(* *,6%,*FRCLC*,11%,*FRNFW*,10%,*R,DIFF.*/)       TCA054         62       FRICTICN       TCA04910       751       FORMAT(* *,1%,50C14-7,2%)/)       TCA054         C       FRICTICN       TCA04920       944       FORMAT(* *,1%,50C14-7,2%)/)       TCA054         C       FRICTICN       TCA04920       951       FORMAT(* *,1%,50C14-7,2%)/)       TCA054         C       FRICTICN       TCA04920       951       FORMAT(* *,1%,50C14-7,2%)/)       TCA054         C       FRICTICN       TCA04920       951       FORMAT(* *,1%,50C14-7,2%)/)       TCA054         C       TCA04920       951       FORMAT(* *,1%,50C14-7,2%)/)       TCA054         C       TCA04920       952       FORMAT(* *,7%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570L0*,11%,570	IC0U4T=1	TCANARED	941 FORWAT(* *, JX, *POLD *, 12X, *FNEH*, 13X, *X*, 12X, *A.CIFF.*/)	10403430
60T0 84       TCA04000 943 FOPMAT(**,EX,*FPCLC*,11X,*FPN*U*,10X,*R,DIFF.*/)       TCA054         81 CONTINUE       TCA04910 751 FORMAT(**,6X,*FRCLC*,11X,*FRNEW*,10X,*R,DIFF.*/)       TCA054		TCAC4893	942 FORMAT(* *+1#+4(D14-7+2%)/)	10000000
B1 CONTINUE       TCA04910       751 FORMAT(* **6X,*FRCLC*,11X,*FRNEW*,10X,*FR.DIFF.*/)       TCA054         C       FRICTICN       TCA04910       751 FORMAT(* **1X,3CC14.7,2X)/)       TCA054         C       FRICTICN       TCA04928       951 FORMAT(* ABSCLUTE INLET PRESSURT TCLERANCE ADJUSTEC*/)       TCA054         C       FRICTICN       TCA04928       951 FORMAT(* ABSCLUTE INLET PRESSURT TCLERANCE ADJUSTEC*/)       TCA054         C       FRICTICN       TCA04928       951 FORMAT(* **,7X,*PT0LD*,11X,*PTNEW*,11X,*R.DIFF.*/)       TCA054         VS #VCAV       TCA04928       952 FORMAT(* **,1X,*PT0LD*,11X,*PTNEW*,11X,*R.DIFF.*/)       TCA054         DD 7929 I=1.*NX       TCA04950       953 FORMAT(* **,1X,3C014-7,2X)/)       TCA054	6010 84	TC404909	943 FOPMAT(* **EX**FPCLC**11X**FPN****10X**R*DIFF**/)	TEAU3930
TCAC4920       944       FORMAT(* *,1%,3(C14,7,2%)/3       TCAD5         C       FRICTICN       TCAC4920       951       FORMAT(* ABSCLUTE INLET PRESSURE TCLERANCE ADJUSTEC*/)       TCAD5         C       FRICTICN       TCAC4920       951       FORMAT(* ABSCLUTE INLET PRESSURE TCLERANCE ADJUSTEC*/)       TCAD5         C       TCAC4920       951       FORMAT(* 4,7%,*PT0L0*,11%,*PTNEW*,11%,*R+DIFF.*/)       TCA054         NS #MCAV       TCA04950       953       FORMAT(* *,1%,5C014-7,2%)/)       TCA054         DD 7929       I=1.*N%       TCA04950       953       FORMAT(* *,1%,5C014-7,2%)/)       TCA054	BI CONTINUE	TC404910	751 FORMAT(* *+6X+*FRCLC*+11X+*FRNFW*+10X+*R+DIFF+*/}	10403460
C FRICTICN TCACASE 951 FORMAT(* AESCLUTE INLET PRESSUR® TCLERANCE ADJUSTEC*/) TCACASE 		10404920	944 FCRMAT(* *+1%+3(C14+7+2%)/)	TUA05970
TCA04 940 952 FOF MAT(* *,7X,*PTOLD*,11X,*PTNEW*,11X,*R-DIFF.*/) TCA054 95±WCAV TCA04950 953 FORMAT(* *,1X,5(D14,7,2X)/) TCA059	C FRICTICN	TCANASIA	951 FORMAT(* ABSCLUTE INLET PRESSURE TOLERANCE ADJUSTED*/)	1LAU3480
95#VCAV TCA04950 953 FORMAT(**,1X,3(D14,7,2X)/) TCA059		TCADA 940	952 FOFMAT(* *.7X,*PTOLD*,11X,*PTNEW*,11X,*R-DIFF-*/)	1000470
DD 7929 I=1.NX	4 S = 4C A V	TCA04950	953 FORMATCP \$12x35014-7+22#/}	16443360
	00 7929 I=1+NX			

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TCA86868

+ 32

	TCA85518	7001 CONTINUE	TCA06070
	TC485528		TCA06080
STORE CURRENT PRESSURE VALUES	TCA85530	C GLOBAL PRESSURE RELIABILITY CHECK	TCAC6050
	TC405540	C	TCA06100
DC 4547 [=1.JL	TCA85558		TCA05110
PPDCIJ=PSCIJ	TCAC5560		10100154
4367 CONTIAUT	TCA#5578	SPTOLEPT	
	TCA85528		1000140
C DONSTINE MARELE OL 21722	TCA85558		TCACCIC
	TCA95600	DC left tertar	TCAUGICU
	TC#85610		
C	TCA05620		10406100
C SOLAIME ANESSINE DISTAL DULLON GALAGE COLONY	TCA65637	FL-F3387 17-71/3369	TCA06288
C	TC483649		1040200
	TCA05650	1711Canbary 0010 1000	TCA04220
Dalacator	TCAUSGEU		TCA06230
	TCA836/4	TE COPR . GT. SPIOL) GOTO 77	TCA06240
	TCAUSEE	7660 CONTINUE	TCA06250
C	TC#83678	60TO 78	TCA06266
	758657189	77 CONTINUE	TC406270
C po took t=1.WIP1	10443710	IF(IPT.EQ.0) GOTO 7651	TCA96289
	70445738	WRITE(5.108)	TC406250
x x = + + + + 2 / £ 2 + D C+ R ) -++N	TCANSTAN	WRITE(5,99)	TCA06300
TEAXCALTAREFU CALL INTPERCAFUTI	TCA85758	WRITE(5,662)	TCA06310
DPS1(I)=12-D0+VI+(UN+(FXT-FXE)+NPD+(XC-XE))/(NHT+FXT)+++	10405768	WRITE(5,941)	TCA06320
X51(I)=#C	1CA05770	WRITE(5,942) PPD(J) PC, XC, CPR	TCA 06 3 30
TOO CONTINUE	TCA05780	WRITE(5,100)	TCA06340
CALL COIGAF (XS1, DFS1, MXP1, PC1, EE, 0)	TCA05750	7651 CONTINUE	TCA06320
KL3=KL3+1	TCA05#00	60TO 8	TCA06360
45 = NCA V	TCA05910	78 CONTINUE	TCA06370
XEE=XE+OX	TCA05820		TCA06388
	TCA05#30	C ABSOLUTE TOLERANCE FOR INCLT PRESSURE CREEK	TCA06 390
C (2.) REPAINDER OF CONTACT ZUWE	TCA85748	C C	TCA06409
	TCA05850	PTN=PX+PTUL	TCA06410
D0 7061 I±1.4X	TCA05960	OPTEDAUSC (PIN-FIJ/FIJ/FIJ/	TCA 06420
	TCA05#70	IFEDFIGE FILL COLL FOR THE	TCA06430
FRT=HO+RC++2/(2+)C++Fmm	TCA05980		TCA06440
IF CACOLIDATED CALL AND CALCULATED DO CACONED DO CALCONED DO CALCO	TCA05890	723 CONTINUL	TCA06450
	TC#05907		TCAU646U
ROLIFAL December 1810	TCA05910		TCAUB470
	TCA05920	URTTELS_9723	10805470
FR-0000 BC /1 N=0.70	TEAUSYJU	UPITERS.9521 PT.PTN.OPT	
	1(405440	MRTTF(5.100)	TCA06510
	1CAU3730	7452 CONTINUE	TCA06310
	TC105C70	N#=N#/2	TCA06530
	16803770	PT=PTN	TFAREAD
IFEICC.NE. 1) ECTC 7COL	10833720	GOTO B	10406558
JL=JL+1	10803777	722 CONTINUE	TCA06560
CALL COLGAFEXS.DPS.I.PC.EE.01	TCARABIA	C	TCA06570
PC=PC+PC1	VC106020	C SOLVING LOAD CAPACITY USING COLGAF	TCA06580
KL 3=KL 3+1	TCA06030	C	TCAD6540
XSR(JL)=XS(I)	TC#05040	C SFTOL=FPTOL++100	T C A 06 680
PS(JL)=PC	TC406050	C IFLUM.EQ.UPOD SFTCL=FPTOL	
IF(PC.GT.PX) PX=PC		•	

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					TCA07160	
		77486618		FxT=H0+XC++2/{2.00+P}-H4	TCA07178	
	SETOL TEPTOL	TCA86628		IF(XC.LT.XEF) CALL INTP(XC.FXT)	TC407170	
	CALL CAIGAFEXSR. PS. JL. FPCD. ERROR. 8)	TCA06438		NSC=FXT+N4T	TCA071 90	
	EL128L1+1	1046648		F x 2 ( I ) = 2 = 2 = 0 = VI = UP=H XE/( PSC + + 2)	TCA07200	
	Rt. Satt Soler and	76406458		#2(1)=#C	TC467210	
	FBCDz+FPCD	Transse	8927	CONTINUE	TCA07220	
<u> </u>		10406478		CALL COIGAF (#Sof #1,NXP,FR1,ER1,0)	TCA07230	
· .	RE PELTABLETTY CHECK			CALL CO16AF(#2,F#2,NBP,FR2,E#2,5)	TC487248	
		TCA4669		FR12-FR1	TCA07250	
•				FR2=-F*2	TCAB7260	
	TETAL STALL SOTO 719	70400700		FRCON=FR1/FPCO	TCA87278	
•.	2010 276			FRCAV=FR2/FPCC	TCA07288	
				FRD=FRCON+FPCAV	TCA07290	
	161101.50.01 6010 7653			DFR=3ABS(CFRD-FR)/FRD)	10407388	
	MO TTE 45 -1883	1 LAND 7 4 4 7 CARL 7 5 8		IFEDFR.GT.FRTOL) 6010 329	TCA07310	
				SCT0 796	10407320	
	「「「」」」 にん コンシント		329	CONTINUE	10107320	
	8711119077647 MATTCAL 4478			IF (IPT. FQ. 8) 60TO 6323	70407340	
	WALLEY JEAN FREAFPED. JFP			Lette(5.100)	TC407340	
				unite(5.99)	11407534	
		10406.444		untte(5-948)	10407380	
/63		TLAU5-10		uertr(5.751)	10407370	
		TCAUGGZU		METE(5-944) FR-FRD-DFR	10407380	
720	COMITANC	10406230			10407350	
C		TCADESA	6323		TCAU7400	
<b>. C</b>	PR RELIADILITY CHECK	16406437			TCA07410	
C		TCAOSTEV	784		TCA07420	
	734764V 80 7878 741.8F	TLAUSH TU	6		TCA07430	
	00 /723 1+19N4	TCAD6884	C		TC#07440	
		10486477	C		TC407450	
		TCACGUE	0000	FORMATCH BELIARTITTY CHECKS SATISFY SPECIFIED TOLERANCES */)	TCA07460	
	022647=022607	TCAG6410	7778	FORMATE ETHAL NC. OF STEPS FOR PRESSURE INTEGRATIONS = + 18/)	TCA07470	
		TCA05920	121	FORMATCH ETHAL NO. CE STEPS FOR LCAS INTEGRATION =++18/1	TCA07489	
172	G CUNTINUL Argental	TCA06930	1211	FORMATER TETAL NO. OF CALLS TO DOLGAF IN TIME ITERATIONS =". IE/)	TCA07498	
	NAF=7871	TCAB6744	783		TCA07508	
	X2411-44	TCAC6950	122		TC407510	•
		TCA067ED	123		TCA07520	
	UU 3728 A-Senar	TCA06970	1233	$F(\mathbf{r}, \mathbf{r}, \mathbf{r}) = F(\mathbf{r}) = F(\mathbf{r}) + F($	TCA07530	
		TCADG480	1244	FORMATE INCLUSE TO THICKNESS (HMT) = 0014.7)	TCA07540	
	PX 1=MU+RC += 27 (2+000= 7=0	TCA46950	124	FORMATIC HINLIGHTEL FILCHER STATES	TCA07550	
		TCA07000	122		TCA07560	
		TCA07010	127	PORMATE ALBERT THE CONTRACT AND A CO	TCA07570	
		TCA07020	128	FORMATIC CURRENT FILE STEP FEED TA HNY = 4016-3/3	TCA07588	
		TCA07030	129	FURNALS ELIMATEL A HORE ENGLA IN THE POLICY AND A THE POL	TCA07598	
572	e continue	TC#07949	159	PORTALLY PRICING CLEVELET CONTRACT STATISTICS	TCA07600	
	DXF=CX	TCA07050	875	FORMATON CAVITATION DUR VALUE	TCA07610	
828	1 CONTINUE	TC#07060	576	FORMATE SE LAVIENTION DD CALL - TELEVILL	TCA07620	
	NUBRE XE +XI J/UAF	TCA07070		IF ((NNALF ONZOZIONNU OLIFICLUOUIF UVIU 7070	TC#07620	
	XXED=xE=0xF+998	TCADIOAD			TCA07640	
	H2 = ACTA	TCA07090		IF(ICLI-M2-11) 6017 7370	TCA07650	
	NBP=N30+1	TCA07109		IF(IPT-10-0) 0010 1698	TCA07660	
	IF("8F.GE.4) GCTC 8282	TC#07110		WRITE(50101)	TCA07679	
	DXF=JXF/2.CQ	TC#07120		WRITE(5,9950)	TCAD7680	
	GOTO 7291	TCA07137		WRITE(5.121) NA	TCA07650	$\mathbf{r}$
828	2 CONTINUE	TC#07149		WRITE(5,1277) JL	TCA07708	ļη
	DQ 9927 I#1,880	TCA07150		WRITE(5,9dE) KLJ		5
	XC=XXED+CI-1J+CXF					()
						~~~

FILES TEA FERTRAN A LEEDS UNIVERSITY VOIDSE 6-16

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* ***					TCA03260
		76207710	C		TCA07270
	WRITE(5.181)	TCA87729	Č I	PRINTING DATA AT SPECIFIED SPACING	TCADE 288
	WRITE (5.77)	TCA67738	Č		TCA07250
169	A CONTINUE	76467748		WRITE(5+123)	TCA08300
	WITE(5.1223) IT	TCA87758		N3=JL/[]	TCA08319
	NETTERS-12441 TC	75407768		J=C=0	TCA98320
	MRITE(5-188)	TCA02778		DO 2222 I=1+JL	TCA09338
2		TCA87788		ICC=(I/N3)+N3	TCA 08 340
	GENERATING PREFILE	TCA07798		IF ((ICC+NE+ID+AND+CI+NE+JLD+AND+CI+NE+ID+AND+CI+NE+NC+ND+	TCA08350
. ē		76487988		• 6010 2222	TCADE368
-	NSEVCAV	TCA87838		J=0=J=0+1	TCA08379
	00 1102 I=1+4L	TCAA7928		WRITE(5.122) XSRCI).PSCI).HSCI).Jac	10488389
	ECARSR(I)	TCA87838	2222	2 CONTINUE	TCA07 378
	FET=HE+XC+=2/{2_C0+R}-NM	TCAATPAG		URITE(5,99)	TCAGRAGO
	IFENC.LT.REFD CALL INTPENC (FUT)	TCA87850		WRITE(5,101)	TCADEALD
	NS (I) = MYT+FXT	TCA07868	C		TCARRA 28
118	> CONTINUE	10407978	č I	PRINTING CURRENT TIME STEP VALUES	TCADEA 10
c		TC407898	Ċ		TCARRAR
ē i	POMSTRUCTING THE EXIT PROFILE	10107858	•	WRITE(5,128)	Transase
-		TCA07908		WRITE(5,125) HHD	TCARRAGE
•	DX = 4 . C 8 + D X	TCA07910		WRITE(5,124) HMT	TCAGRATE
	MR = C + KI >/CX	TCA#7920		URITE(5,125) ET	TCARRAGE
	XXFD=XE=DX+NE	TC107910		WRITE(5,155) FRD	TCADSAGE
	¥10=-1.00+)I	TCANTON		WRITE (5.127) OHNT	TCAORSON
	no es Islad	TCAOZOSE		MRITE(5,075) HE	TCA08518
	fz.ll-1+1	TCA07960		WRITE(5,976) XEF	70408520
		TCA07338		WRITE(5-101)	
	x SR(J) = XSR (K)	70407580	c		TCASSEA
	PS(J)=PS(K)	TCAA7958	č	CONDITIONING FOR GRAPHICS	1 [# 40 3 4 4
	NS(J)=HS(K)	TCADEGO	č		16404540
40	CONTINUE		•	KK1=0	1 (A U C J C U
••	NS XNC AV	TCA03030		N1=JL/I3	
	DO 401 I=1+N8	76409023			ICAUESEU
	XC=XXED+(1-1)+OX		c	N1 = 1	ILAU8370
	XSR(I)=XC		•	IF (IT_EQ.6) M1=1	1 CA0= 6 00
	PS(1)=0+00	7644446		NNP = 0	1CAU-610
	FXT=H8+XSR (I)++2/62 -D0+R)-H"	TCA08070		MTL=HFACT+.5	
	IF (XC.LT. XEF) CALL INTP (XC.FXT)	TCADADAD		00 4000 I=1.JL	
	HS(1)=FXT+FPT	TCARRAGO		TCC=(T/N1)+h1	ILAUGEQU
481	CONTINUE			IFCCICC.NE.IJ.AND.CI.NE.JLJ.AND.CI.NE.VCAVJ	10409630
	JL=JL+NB	TC408100		+_AND_([.NE.1)) 60T0 4000	ILAU78EU
	NCAV=\B+1	TCA00130		MNP = N h P + 1	ICADS670
	IF (XXED_EQ_XIP) GCTC 9728			XC=XSR(I)	10404680
	00 +92 I=1.JL	TCA08140			10408690
	Kz.u + 1 - T			PO(NHP)=PS(I)	10409700
					TCA03710
	X3R(J)=XSR(K)	10404100		TECHNEGENTLA GOTC 4000	TCA 14 720
	PS(4)=PS(K)				TCA08720
	HS(J)=HS(K)	1080-170		XX1(XX1)=XC	TCAUS740
402	CONTINUE	10400130		- HHEKKI) =HX	TCA04720
TV4	KSR(1)=FIP	ICAUSZUU	A000	CONTINUE	TCAD4760
	PS(1)=0.30	VCAUM 210	4000	00 A999 1=1.NNP	TC#08779
	HS(1)=H0+K1F++2/(2+50+R)-H#+H#T	1240-220			TCADE 790
-		1 C A U 5 2 3 U	4777	DNNN=DN+1_1C0	TCAGB130
	NCAY=ACAV+1	12243		WYF=-1_CO+NFACT	TCA08800 C
49 24	CONTINUE	TCAU3250		MUPTTATAE	70
7740					14

FILE: TCA FCATMAN A LEEDS UNIVERSITY WHAT 6-15

TCA09368

		77208418	NR T1 = NP T	TCA0º 370	
~		TC488#23	0N#T1=3N#T	TCA09380	
200	ALATTING USING GNOSTOR	TCAREASA	NST=NSTIN	TCA09350	
200		10103348		TCA09400	
		14447344 Teasee		TC404410	
		10000000	TCS(L)=TC	TCA 89428	
1		10100200		TCA89438	
		ICAGETIO		TCARGAAR	
		TEAUSPEU		TELOSASA	
	CALL PLOTESCOVICE A VICTOR	TCA88870			
	CALL PLOTESCOULD AND AND AND AND AND AND AND AND AND AN	TCA000		10407400	
	CALL PLOTESC.4734, 47.11	TCA84710		10407470	
	CALL PL:TCS(-23,-47. TIME = 47.	TCA05920		TCA07480	
	CALL TYPERETTCION	TCADA 730	FRSTELJEFRE	1CV84048	
	CALL PSPACE (.07,.57,.05,.4)	TC#04740	IPT=IPT3	TCA07506	
	CALL MARCHFACT, XDE, 8. HFACT)	TCA85750	CPU6=CPUTIP(IDU)	TCA07510	
	CALL BORDEP	TCA08760	WRITE(6,+) IT,CPU6	TCA09520	
	CALL ATES	TCA04970	C = = = = = = = = = = = = = = = = = = =	TCA09530	
	CALL STATES	TCA08380	9876 CENTIAUE	TC409548	
	CALL CURVECENT MM-1-KK1)	75404998		TCAB9558	
		70403000		=10403560	
	A 1			TCA09570	
	VIIIIALI - VIII	10007017			
	CALL POSTINGATION	TEN07027		16407360	
	#J2=#J1	TC#09020	EVENDY STATE	10409370	
	A75=HF(1)	TCABABAN		ICA09600	
	CALL JOIN(XJ2+T2+	TCA02050	CALL CONTRACTOR AND	TCA07610	
	M93=XXI6XXI)	TCA02060	FSS FURTHER AND MUMBER OF STEPS 24-161	ICA09620	
	AA3=HH(KK1)	TC#09070	4553 FORMATE	TCA09638	
	CALL POSITA(NJ3,TJ3)	TCA09970	3241 FORMATC/	TCA09640	
	E L X = + L X	TCA09090	IF(NHALF-16-2) 6010 9881	TCA09650	
	167=967	7CA09100	NTP=11+1	TCA09660	
	CALL JOINCHJANTJAN	TCA 09110		TC409670	
	CALL BLKPEN	TCA09120	DO 9879 IT=L.YTP	TCA09620	
	CALL PSPACE(.071.571.581.93)	TC A09 1 10	DH1=DABSCCFCITD-HSTCITDD/HCITDD	TCANTATO	
	CALL MADEXFACT-XXE-8-+PMMM)	70409140	IF(DH1.GT.CH) DH=CH1	77409700	
	CALL BERDER	70409156	9879 CONTINUE	70409710	
		10×07130		TCA09730	
		1040-160	DCPU=CPU-CFU1	10407720	
		TCA04170		1(497739	
	CALL CONTECTANT FARME	TCA07120		ICA09740	
_		=TCA09190	UNITERS, 75635 (M)	TCA09/20	
C # 2 2	* = = * = = = * * * * * * * * * * * * *	1C# 03500		TCA0º76	
C	FINISH	TCA09210		TCA09770	
C	TIME CICCE LOCA	TCA0º220		TCA09780	
С		=TCA09230	WRITE(S,4523) WI	TCA09790	
C 2 = =		TCA09240	WRITE(5,3241) CPC	TCA09800	
- 787	IB CONTINUE	TCA09250	IF(DH.LE.TTCLI) HHALF=2	TCA09810	
	IHu={IT/KHP}+Kuu	TCA09260	IF (CDH.LE.TTOL1).AND.(PCPU.GI.LPLL)) USIC COUL	TCA09820	
	IF(NHALF.16.2) GCT: 6712	TCA09270	DD 9877 IT=1,NTP	05 P C0 A 11	
	IFECIMENTS.ITS.ANC.CIPT.SQ.QDD GCTC 6712	TEACTOR	HSTEITD=HEITD	TCAN9840	
	1F(197.50.1) WRITE(5,99)	TCANZOGA	9877 CONTINUE	10403850	
	MRITE(5+751) TC++WT+ET+UP+FPC+FF0FPC+IT	TCB0 233	IF (PCFU-GT-CJUL) CT TO 8883	TFANSALA	
	1F(1PT_50_1) WRITE(5,39)	10407209	IF(DH.GT.TTCL1) GOTC 9890	TCARGON	
		7CAU-310		16807770	
0/1		1040-320	A TAF IL TY	11,207020	>
		*CA09330		TCADYUSO	_n
		1211340	CONTRACTOR CIER SIZE IS HALVED!/)	10403408	Γn.
		TCA07350	YZZI FURMATLY' STEF SILL IS INCOMPT		- Č
	N=01=0-0				γ

FEATRAN & LEEDS UNIVERSITY VH/85E 6+16 FILE: TCA FEATRAN A LEEDS UNIVERSITY VEVOSE 6-16 5911 FORMAT(* *.11,3(C14.7.2X)) C 6292 #CRMATE// + + + CONVEREES + + +*//) PRINTING FINAL CYCLE С TC107720 C TC407748 fts(1)=0.00 TCA 87750 MRITE(5.7558) TC407760 INTERPOLATION OF SO VEL FOR TIME STEP SIZE HALVING 00 598 I=1+ATP1 TC#87778 14=1-1 10409980 INN={ IN/KHP >+ KPH TC409958 IFEEENS.NE. IPD.ANC. CI.NE. 133 GOTE 598 TC#10000 TCA10010 398 CONTINUE TCA18828 С TCA10030 FINAL GRAPHICS C TCA10049

TCA10460

TC#18470

TCA10420

TC#10490

TCA10500

TCA10510

TCA10520

TCA10520

TCA10520

TCA13930

TCA10940

TCA10 950

TCA10960

TCA10970

TCA10980

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WRITE(5)92211

WRITE(5.7553) CH

WRITE(5,4553) NT

CUTPUT

WRITE(5,3241) CPU

IFCOH.LE.TICLE WRITE(5,6292)

IFEDH.GT.TTCL) ARITEES, 52911

5910 FORMATC//* *.6x.*TIME*.6X.*PIN FILM TH*.6K.*FRICTICN*//)

IFEDH.GT.TTOLI GOTO 8388

WRITE(5,999)

HHALF=2

TCA10540 TCA10550 TR(1)=TP-3.C0+97 WRITE(5,75%1) TCS(1),H(1),ETS(1),UHS(1),HMOS(1),FPS(1),FRST(1),IM TCA10560 TR423=TP-2.C0+07 TRESS=18-21 TCA10580 TREADETP TCA10590 HR (1)=H#344 TCA10600 HR(2)=H=033 TCA10610 H4(3)=H#322 TCA10050 C CALL BLKPER TCA10620 HREAD=NYD11 TCA10960 CALL EDIBAFCO, TR. HR. HRK. HRC. E. HRW. OB. B. TCA10630 TP1=TP TCA10070 00 6800 I=1.NTP1 TCA10640 TCAIDORS TT(I)=TCS(I) TIME STEP SIZE NALVING TCA10650 TCA10090 HUNCI)=H(I) TCA106ED TCA10100 FRR(I)=FRST(I) TCA10670 NT=2+ NT **TCA10110** UU(1)=U45(1) TCA10690 DT=TP/NT TCA10120 FPP(I)=FPS(I) TCA10690 TR4=TP-3-30+CT TCA10130 6898 CONTINUE TCA10708 TR2=TP-DT TCA10140 CALL ED288F (8 .HRK ,HRC .TR4 .HPC4.0) UMAX=0. TCA10710 TCA10150 CALL ED2BEF (8.HRX,HRC.TR2.HPC2.0) FPMAX=0. TCA10720 TCA10160 D0 6801 I=1.NTP1 TCA10730 H403=H4322 TCA10170 IF (FPP (I).GI.FPHAX) FPMAX=FPP(I) TCA10740 HHD1=H4C11 TC#10120 IFCUUCID.GT.UPAKD UPAK=UUCID TCA10750 NHT1=HMT11 TCA10150 6801 CONTINUE 6010 9858 TCA10760 TCA10200 FPMAX=FPMAX+1.1 TCA10770 7861 CONTINUE TCA10210 UMAX=UMAX+1.1 TCA10780 TCA10220 NIN FILM TH RELIABILITY CHECK TCA10790 С TC#10230 PLOTTING USING CHOSTOD TCA10800 TCA10240 С TCA10#10 NTP1=%T+1 С TCA10250 CALL BLKPEN TCA10820 J=Ö TCA10260 CALL FRAME 0H=8.C8 TCA10230 TCA10270 CALL FSPACE (0.+1.+0.+1.) TCA10 940 00 9852 IT=1,NTP1 TCA10280 CALL #AF(0.,1.,0.,1.) TCA10950 ICT=(IT/2)+2 TCA10290 IF(ICT.NE.IT) GOTC 5882 TCA10 PEB TCA10300 CALL PLOTCS(.47,.01,*TIME*,4) TCA10 270 J=J+1 TCA10310 CALL PLOTCS(-01+-97+*F*+1) DH1=CABS(CHCIT)-HST(J))/HCIT)) TCA10550 TCA10320 CALL PLOTOS(.47..54. *TINE*,4) IFCONI.GT.CH) DH=CH1 TCA10890 TCA19330 CALL PSPACE(.07..57..05..4) TCA10900 9882 CONTINUE TCA10340 CALL WAF(0.,TP1,0.,FFACT) CPU=CPUTIN(XCU) TCA10 910 TCA10350

TCA10360

TCA10370

TC#103P9

TCA10350

TCA10407

TCA10410

TCA13427

TCA10430

TC#10440

TCA10457

CALL BCRDER

CALL REDPEN

CALL BLKPEN

CALL BORDER

CALL REDPEN

CALL AYES

CALL CURVECCTT.HPP.1.NTP1)

CALL MAP(0.,TP1.0.,FFACT)

CALL PSPACE(.07+.57+.58+.93)

CALL AXES

CALL CUMPE (cTT,FAR,1,MTP1) TCAIL020 COMMON RESERVENTION CALL FRAPE TCAIL020 COMMON WT,FFFF,FF,2000,FTCL,FFTCL CALL MPTA TCAIL020 COMMON WT,FFFFF,FF,2000,FTCL,FFTCL CALL PSRACT(000.1.0 TCAIL020 COMMON WT,FFFFF,FFT,TR,MTC,WTT,FEC,EFF,TC CALL PSRACT(000.1.0 TCAIL020 COMMON WT,FFFFF,FTTCL(00),WTT,FEC,EFF,TC CALL PLOTCS(-0137,000,FTFF,20) TCAIL020 COMMON AU(400),RER(60),WTCL(60),WTCL(60),WKI
CALL CURE CONSTRUCTION TCAIL00 TCAIL00 <td< th=""></td<>
CALL BIRPEA TCAIL030 CONNON VI, UP, NB, RAAR, NE, AI, SI, FP CALL BIRPEA TCAIL030 CONNON VI, UP, NB, RAAR, NE, AI, SI, SI, FP CALL PRACT(80.1.08.01.0) TCAIL030 CONNON VI, UP, NB, RAAR, NE, AI, SI, SI, FP CALL PRACT(80.01.00.01.0) TCAIL030 CONNON VI, UP, NB, RAAR, NE, AI, SI, SI, FP CALL PLOT(S(.01.0.37, FP, 02) TCAIL030 CONNON AU(000), XER(60), NCC(60), MRI(60), MRI(6
CALL BLWIL: YCAIL000 COMMON E_pP_(intro, intro, free,
CALL PSPAC:(0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
CALL #AFG.0.1.0.01.01.01.01.01.01.01.01.01.01.01.
CALL PLOTICIC-010-010*TINE*+00 TCAIL070 CLMMON MATHOR WITHET,000 CALL PLOTCS (-070-010*TINE*+00) TCAIL090 EXTERNAL FCAPEDERV,0UTPUT CALL PLOTCS (-070-050+00) TCAIL090 EXTERNAL FCAPEDERV,0UTPUT CALL PLOTCS (-070-050+00) TCAIL090 EXTERNAL FCAPEDERV,0UTPUT CALL PLOTCS (-070-050+00) TCAIL000 TCAIL000 CALL *AP00-TPlo00-UPARD TCAIL100 TCAIL100 CALL *AP00-TPlo00-UPARD TCAIL1100 * CALL AXES TCAIL100 * CALL AXES TCAIL100 * CALL PLOTES (-070-370-500-933) TCAIL1100 KL13=0 CALL BAPEA TCAIL100 KL13=0 CALL BAPEA TCAIL120 CALL 100NT=2 CALL BAPEA TCAIL120 KL13=0 CALL BAPEA TCAIL120 KL13=0 CALL BAPEA TCAIL120 CALL 1020BF (NHA,NEK,NEC,TC,NEF,0) CALL BAPEA TCAIL120 CALL 1020BF (NHA,NEK,NEC,TC,NEF,0) CALL BAPEA TCAIL120 CALL 1020BF (NHA,NEK,NEC,TC,NEF,0) CALL BAPEA TCAIL20 CALL 1020BF (NHA,NEL,NEC,TC,FC,0) CALL BAPEA TCAIL20 CALL 1020BF (NHA
CALL PLOTEST.0.07.0.03.017.FPP.20 TCAIL090 EXTEGNAL FCLOPEDERV,0UTPUT CALL PLOTEST.0.05.0.017.070.05.0.01 TCAIL090 EXTEGNAL FCLOPEDERV,0UTPUT CALL PSPACE(0.07.070.05.0.01 TCAIL100 97 FORMAT(* *) CALL PSPACE(0.07.070.05.0.01 TCAIL100 97 FORMAT(* *) CALL APE0.0.702.05.0.01 TCAIL100 97 FORMAT(* *) CALL APE0.0.702.05.0.01 TCAIL1100 97 FORMAT(* *) CALL APE0.0.702.000.004ATD TCAIL1100 100 FORMAT(* *) CALL APE0.0.004ATD TCAIL1100 * * CALL APE0.0.004ATD TCAIL1100 * * CALL APE0.0.004ATD TCAIL120 * * CALL APE0.0.004ATD TCAIL120 * * CALL APE0.0.004ATD TCAIL120 COUNT=2 CALL SUPEC.0.07.0.37.0.50.0.933 TCAIL190 KL1=0 CALL PSPACE(0.07.0.37.0.50.0.933) TCAIL190 KL1=0 CALL PSPACE(0.07.0.72.0.0.0FPMAR) TCAIL190 KL1=0 CALL MPE0.0FPMAR) TCAIL190 CALL 102.00FFMAR) CALL MPE0.0FPMAR) TCAIL1200 CALL 100.0FPMAR)
CALL PLOTESG.0005.05/07/02/0 TCA1100 TCA1100 TCA1100 TCA1100 TCA1110 CALL PLOTESG.07.055.040 TCA1110 TCA1110 TCA1110 TCA1110 TCA1110 CALL PSPACE(.07.055.040) TCA1110 TCA1110 TCA1110 TCA1110 TCA1110 CALL PSPACE(.07.057.055.040) TCA1110 TCA1110 TCA1110 TCA1110 TCA1110 CALL ARES TCA1110 TCA1110 TCA1110 TCA1110 TCA1110 TCA1110 CALL ARES TCA1110 T
CALL PLOTES (47,14,011,00,05,4) TCA11100 TCA11100 TCA11100 CALL #APE0TP1.0.0F3.0 TCA11110 TCA11110 * * * * * * * * * * * * * * * * * * *
CALL PSPACE(.077703047) TCA11110 100 FORMAT(*
CALL *APE0+.TP1+6UMAXD TCA11120 * CALL BORDSP TCA11130 C CALL AXES TCA11130 C CALL CURVECCTT.UU+1+NTP1D TCA11130 C CALL BURYEA TCA11130 C CALL BURYEA TCA11130 C CALL CURVECCTT.UU+1+NTP1D TCA11130 C CALL BURYEA TCA11130 C CALL BURYEA TCA11130 C CALL PSPACE(-07+.57+.58+.93) TCA11170 KL130 CALL BURYEA TCA11170 KL30 CALL BORDEA TCA11200 CALL E0280F(NH4+XEK+XEC+TC+XEF+0) CALL AXES TCA11200 CALL E0280F(NH4+KK+XEC+TC+XEF+0) CALL AXES TCA11200 CALL E0280F(NH4+KK+XEC+TC+XEF+0) CALL AXES TCA11210 CALL E0280F(NH4+KK+K+K+0,0) CALL AXES TCA11210 CALL E0280F(NH4+KK+K+0,0) CALL CURVEC(TT+FPP,1+NTP1) TCA11210 CALL E0280F(NH4+KK+K+0,0) CALL CURVEC(TT+FPP,1+NTP1) TCA11210 CALL E0280F(NH4+KK+0,0) CALL CURVEC(TT+FPP,1+NTP1) TCA11210 CALL E0280F(NH4+KK+0,0) CALL CURVEC(TT+FPP,1+NTP1) TCA11220
CALL BORDSER TCAILING C
CALL AXES TCA11147 C PREP CALL ARDPEA TCA11150 C ICOUNT=2 CALL BURPEA TCA11170 KL1=0 CALL PSPACE(.07,.57,.50,.93) TCA11170 KL1=0 CALL PSPACE(.07,.57,.50,.93) TCA11170 KL1=0 CALL BURPEA TCA11170 KL1=0 CALL MAP(0.,TP1.00FP4AX) TCA11170 KL3=0 CALL BORDEA TCA11170 KL3=0 CALL AXES TCA11170 KL3=0 CALL BORDEA TCA11200 CALL 50288F(NH4, XEC, TC, XEF, 0) CALL AXES TCA11210 CALL 50288F(NH4, YEC, TC, YEF, 0) CALL APEDPEA TCA11210 CALL 50288F(NH4, PKI, PCI, TC, FP, 0) CALL CURVEC(TT, FPP, 1, NTP1) TCA11210 CALL 50288F(NH4, PKI, PCI, TC, FP, 0) CALL CURVEC(TT, FPP, 1, NTP1) TCA11230 XA=XEF+F2 @888 CONTIAUE TCA11240 AM=(TH/F)+(1)-00-2=D0+(PR+2)/(1.D0-PR)) C MRITING NEW STARTING VALUES GR CHANVEL 7 TCA11250 DTI=DTOL+PN
CALL AEDPEN TCAILISD CALL CURVEC(TT,UU,1,WTP1) TCAILISD CALL BERPEN TCAILISD CALL BERPEN TCAILISD CALL PSPACE(.07, .57, .50, .93) TCAILIRD CALL MAP(0, .77), 0., 67, .57, .50, .93) TCAILIRD CALL MAP(0, .77), 0., 67, .50, .93) TCAILIRD CALL MAP(0, .77), 0., 67, .57, .50, .93) TCAILIRD CALL MAP(0, .77), 0., 67, .57, .50, .93) TCAILIRD CALL MAP(0, .77), 0., 67, .57, .50, .93) TCAILIRD CALL MAP(0, .77), 0., 67, .57, .50, .93) TCAILIRD CALL MAP(0, .77), 0., 67, .57, .50, .93) TCAILIRD CALL MAP(0, .77), 0., 67, .93, .93) TCAILIRD CALL BORDER TCAILIRD CALL AMES TCAILIRD CALL AMES TCAILIRD CALL CURVEC(TT, FPP, 1, NTP1) TCAIL200 CALL CURVEC(TT, FPP, 1, NTP
CALL CURVEC(TT,UU,1,NTP1) TCA11169 ICOUNT=2 CALL BLKPEA TCA11170 KL1=0 CALL PSPACE(.07,.57,.58,.93) TCA11170 KL1=0 CALL PSPACE(.07,.57,.58,.93) TCA11170 KL1=0 CALL PSPACE(.07,.57,.58,.93) TCA11170 KL1=0 CALL PSPACE(.07,.57,.58,.93) TCA11170 KL3=0 CALL PSPACE(.07,.57,.58,.93) TCA11170 KL3=0 CALL MAP(0.,TP1,0,FPMAR) TCA11170 MMM=20 CALL BODDEA TCA11200 CALL 50288F(NH4,NEK,NEC,TC,NEF,0) CALL AXES TCA11210 CALL 50288F(NH4,NKI,HCI,TC,FP,0) CALL CURVEC(TT,FPP,1.NTP1) TCA11220 CALL 50288F(NH4,HKI,HCI,TC,FP,0) CALL CURVEC(TT,FPP,1.NTP1) TCA11230 XA=XEF+F2 A888 CONTINUE TCA11240 AM=(TH/E)+(1.000-2.00+(PR+2)/(1.00-PR)) C WRITING NEW STARTING VALUES GN CHANNEL 7 TCA11250 DTL=DTOL+PM
CALL BLKPEA TCA11170 KL1=0 CALL PSPACE(.07,.57,.50,.93) TCA11170 KL3=0 CALL MAP(0.,TP1,0.,FPMAX) TCA11200 CALL 1020BF(NH4,XEK,XEC,TC,XEF,0) CALL AXES TCA11210 CALL 1020BF(NH4,PKI,PCI,TC,FP,0) CALL AXES TCA11210 CALL 1020BF(NH4,PKI,PCI,TC,FP,0) CALL CURVEC(TT,FPP,1,NTP1) TCA11220 CALL 1020BF(NH4,PKI,PCI,TC,FP,0) CALL CURVEC(TT,FPP,1,NTP1) TCA11230 XA=XEF+F2 40888 CONTINUE TCA11240 AM=(TH/E)+(1.00-2.00+(PR+2)/(1.00-PR)) C WRITING NEW STARTING VALUES ON CHANNEL 7 TCA11250 PT=PTGL+PM C WRITING NEW STARTING VALUES ON CHANNEL 7 TCA11250 DTL=DT0L+PM
CALL PSPACE(.07,.57,.58,.93) TCAII190 KL3=0 CALL MAP(0.,TP1,0.,FPMAX) TCAII190 MMM=0 CALL BORDER TCAI1200 CALL E0288F(NH4,XEC,TC,XEF,0) CALL AXES TCAI1210 CALL E0288F(NH4,PKI,PCI,TC,FP,0) CALL AXES TCAI1210 CALL E0288F(NH4,PKI,PCI,TC,FP,0) CALL FEDRER TCAI1220 CALL E0288F(NH4,PKI,PCI,TC,FP,0) CALL CURVEC(TT,FPP,1,NTP1) TCAI1220 CALL E0288F(NH4,PKI,PCI,TC,F0,0) & 6888 CONTINUE TCAI1230 XA=XEF+F2 & 6888 CONTINUE TCAI1240 AM=(TH/E)+(1.00-2.00+(PR+2)/(1.00-FR)) C WRITING NEW STARTING VALUES ON CHANNEL 7 TCAI1250 DTL=DTOL+PM
CALL MAP (0., TP1, 0., FPMAR) TCA1120 TCA1120 CALL 50288F (NF4, XEC, TC, XEF, 0) CALL BORDER TCA11200 CALL 50288F (NF4, XEC, TC, XEF, 0) CALL AXES TCA11210 CALL 50288F (NF4, YEC, TC, YEF, 0) CALL AXES TCA11210 CALL 50288F (NF4, YEC, TC, YEF, 0) CALL AXES TCA11210 CALL 50288F (NF4, YEC, TC, FP, 0) CALL PEDPEA TCA11220 CALL 50288F (NF4, YEC, TC, FP, 0) CALL CURVEC(TT, FPP, 1, NTP1) TCA11220 CALL 50288F (NF4, YEC, TC, FP, 0) & 8888 CONTINUE TCA11230 XA=XEF+F2 & 6888 CONTINUE TCA11250 PT=PTGL+PN C WRITING NEW STARTING VALUES ON CHANNEL 7 TCA11250 DTL=DT0L+PM
CALL BORDER TCA11200 CALL 10288F(N+4,XEK,XEC,TC,XEF,0) CALL AXES TCA11210 CALL 10288F(N+4,XEK,XEC,TC,XEF,0) CALL AXES TCA11210 CALL 10288F(N+4,YEK,XEC,TC,XEF,0) CALL AXES TCA11210 CALL 10288F(N+4,YEK,YEC,TC,XEF,0) CALL AXES TCA11210 CALL 10288F(N+4,YEK,YEC,TC,FP,0) CALL PEDPER TCA11220 CALL 10288F(N+4,HKI,HCI,TC,F0,0) CALL CURVEC(TT,FPP,10NTP1) TCA11220 CALL 10288F(N+4,HKI,HCI,TC,F0,0) A888 CONTINUE TCA11230 XA=XEF+F2 A888 CONTINUE TCA11240 AM=(TH/E)+(1.00-2.00+(PR+2)/(1.00-PR)) C WRITING NEW STARTING VALUES OR CHANNEL 7 TCA11250 DTL=DTOL+PN
CALL AXES TCA11210 CALL 50288F(NH4,PKI,PCI+TC,FP,0) CALL PEDPEA TCA11210 CALL 50288F(NH4,PKI,PCI+TC,FP,0) CALL PEDPEA TCA11220 CALL 50288F(NH4,PKI,PCI+TC,FP,0) CALL CURVEC(TT,FPP,1,NTP1) TCA11220 CALL 50288F(NH4,PKI,PCI+TC,FP,0) B000 CONTINUE TCA11230 XA=XEF+F2 B000 CONTINUE TCA11240 AM=(TH/E)+(1,00-2,00+(PR+2)/(1,00-FR)) C WRITING NEW STARTING VALUES ON CHANNEL 7 TCA11250 C TCA11250 DTL=DTOL+PH
CALL FEDREA TCAIL220 CALL 5028EF (NH4+HKI+HCI+TC+F0+0) CALL CURVEC(TT+FPP+1+NTP1) TCAIL230 XA=XEF+F2 4888 CONTINUE TCAIL240 AM=(TH/E)+(1+00-2+00+(PR+2)/(1+00-PR)) C HRITING NEW STARTING VALUES ON CHANNEL 7 TCAIL250 PT=PTGL+PN
CALL CURVEC(TT,FPP,1;NTP1) CALL CURVEC(TT,FPP,1;NTP1) CALL CURVEC(TT,FPP,1;NTP1) CALL CURVEC(TT,FPP,1;NTP1) CALL CURVEC(TT,FPP,1;NTP1) TCA11230 TCA11240 TCA11240 TCA11250 DT=DTGL+PM CALL CURVEC(TT,FPP,1;NTP1) CALL CURVEC(TT,FPP,1;NTP1) TCA11230 TCA11250 DT=DTGL+PM CALL CURVEC(TT,FPP,1;NTP1) CALL CURVEC(TT,FPP,1;NTP1) TCA11230 TCA11230 TCA11230 TCA11240 TCA11250 TCA1250
4888 CONTINUE TCA11240 AM=(TN/E)+(1.00-2.00+(PR+2)/(1.00-PR)) C TCA11250 PT=PTGL+PN C TCA11250 DTL=DTGL+PN
C URITING NEW STARTING VALUES ON CHANNEL 7 TCA11250 DTL=DTGL+PH
C HRITING NEW STARTING VALUES ON CHANNEL 7 TCA11260 DTL=DTOL+P#
MAIIE (/ • •) HULV
URITE(7,•) H=022 TCA11340 RL2=1
WRITE(7,+) HPULL TCALLISO 8 CONTINUE
6010 8885 TCA11368 TCA11368 IF(IPT-EQ-1) WRITE(0,110) RUME2
8886 CONTINUE TCA11370 C
WRITE(7,+) HRDA TCA11390 C SOLVING PRESSURE DISTRIBUTION FOR TAILE NO DOLAR DOLAR DOLAR DOLAR DOLAR DOLAR DOLAR
<u>₩RITE(7,+) F#C3</u> TCA11390 C
WRITE(7,+) HMC2 TCA11400 PCS(1)=0.00
WRITE(7,++) HMD1 TCALL+10 XC=XEF
8885 CONTINUE TCAIL628 DX=XI-XEF
CALL GREND TCATTAIO JI=0
STOP TCALLARC CALL COZEPFAXCONIOPCSODTLOISCONIOPCIONO202000
END KL2=KL2+1

TC411469

TCA11470

TC#11490

TCA11510

TCA11529

TCA11530

TCA11540

TCA11550

С

С

C

5

PC=PCS(1)

GOTO 9

JCOUNT=1

IF(PC.LT.0.CO) GOTO 5

IF(JCOUNT.E0.0) HA=HA/2.00

DETERMINING THE REQUIRED HO LISING DISECTION

IF(PC.GT.PT) GOTC 6

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SUBROUTINES

IMPLICIT REAL+9(A-H+0-2)

SUBRCUTINE SURF

C-----TC#114°0

С

С

С

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D

TCA12029

TCA12030

TCA12040

TCA12059

TCA12060

TCA12070

TCA12090

TCA12050

TCA11560

TCA11 570 TCA11580 TCA11598 TCA11600 TCA11610 TCA11620 TCA11620 TCA11640 TCA11650 TCA11660 TCA11679 TCA11689 TCA11650 TCA11700 TCA11710 TCA11720 TCA11730 TCA11740 TCA11750 TCA11760 TCA11770 TCA11780 TCA11798 TCA11500 TCA11 810 TCA11220 TCA11630 TCA11640 TCA11850 TCA11860 TCA11970 TCA11980 TCA11950 TCA11900 TCA11919 TCA11920 TCA11930 TCA11340 TCA11950 TCA11960 TCA11970 TCA11980 TCA11990 TCA12000 TCA12010

	THE ALL AND A THE ADDRESS AND		FIL	E: TCA	ECULUAN & CEEDS ANTACHDILL PROCESS	
FIL	E: TCA FEATRAN A LEEDS UNIVERSITY UPDGE COLE				·	
eux Antonio de la			_ .		A AN- 1/01A-7-283/3	TCA12660
		1CA12110		A FORMATC	CLOBAL OF TABLETT AND EISCRETE ERRCR CHECKED"/)	TCA12670
	Nexted -NA	TC#12120	77	9 FORMATC	CONCRETS TO SPECIFIED TOLEMANCES //)	TCALZOR
e trans a	CONTRACTOR AND MARMANA DA	TCA12138	77		ACCOUTE THEFT PRESSURE TOLERANCE ADJUSTEC "/)	TCA12670
6 - S)6	IF IF COUNT - EUGLE MARMAR CONT	TC#12148	75	1 PURMATE	- 24. + BTOL OF -1 1X - + FTNE H* +11X + R.DIFF +/)	TCA12700
		TCA12150	75	Z PURMAIL"	• • • • • • • • • • • • • • • • • • •	TCA12710
		TCA12160	73	S PURAIL	STAAL OTL 27-010-7/2	TCA12/20
	GOT'S E	TCA12170	78	S PURTAIL	NO OF STEPS TO SATISFY SPECIFIED TOLERANCES = ,167)	TCA12730
	CONTINC	TCA12190	78	IQ PURMATLY	TACHEASTAG NUMBER OF STEPS FOR ACCURATE .	1CA12/40
· C		TCA12170	76	S PURMAIL	DEALT - THTEPPOLATION /)	TCA12734
ç	10-0	TC#12200		•		TCA12760
C		TCA12210	C		THE REFSSURE VALUES	16412770
12		TCA12220	C	STURE CURR		TCA12/00
		TCA12230	ç	880/11-51		TC#12790
្មា	> PURIANCE CONSTRUCTION OF CONSTRUCTION	TCA12240			**** *******	TCA12804
ç	THE LOSS CHARTER FOR TRIM ASE USING DOZEDE AND COLGAP	TCA12250		1014301		1C415410
C	SOFATAA Frank Cash Catta And	TCA122E0				TCA12724
C		TCA12270		PPULLI-P		TCA12830
		TCA12250	43	PL CONTINUE		TCA12448
		TCA12290	, C		N AND DOUBLE NST	TCA12750
		TCA12:00	L L	DECREMAE D		TCA12760
	JI = 0	TCA12310	Ŀ	071-071-	. 160	TCA12870
		TCA12320		012-312-		1012020
		TCA12330	~	M31 - C - H3		TCA12890
		TC#12340	Č,	CALNTHE DA	ISCHAF DISTRIBUTION USING DOZEOF	TCA12900
		TCA12350	C	2011140	LUS ONE DIGINISOFTEN CONTRACTOR	TCA12910
		TC412360	C			TCA12920
		TCA12370		NFLU3-NJ	TEN/NET	TCA12930
		TCA12340		UA+(A1-A)		TCA12940
	ITTELS 1980 FOC AFF SEE SKL1	TC#12350		AC-ALF		TCA12720
		TCA12400		PLSCIF-V		TCA12760
	WEITESJAAJV -	TCA12410			THE CHC .XT .1 .PCS .DTL .1.FCN.1.PEDERV.OUTPUT.W2.20.0)	TCA12470
134		TC#12420		CALL DUZ		TCA12980
	TEAD TEELE FEPTCL & SCTO 81	TCA12430			STOF OFLIANILITY CHECK	TC#12990
	TED CT FEID GOT F2	TCA12440		ACABAC LUTY		ICVI2000
	TEAR TTERT GOTE 83	TC#12420	L			TCA13010
-	AF GF GC I GF I G G G G G G G G G G G G G G G G	TC#12460		1-1		TCA13020
5	ACTERNIATING THE REQUIRED XEE USING BISECTION	TCA12470		V-1 COTOL11	18•9T	TCA13030
5	REITWART ALL ACCOUNTS AND	TCA12480		5FIUL-01		TCA1 3040
۰ م م	TRATE DUNT - FO- 18 XA=XA/2+D 0	TCA12490		1-1-1	, , , , , , , , , , , , , , , , , , , 	TCA13050
92		TCA12500				TCA13060
		TCA12510				TCA13070
		TCA12520		TEARC CT.	PRAXE PRAXEPC	TCA13080
	TELEVINT - FR-01 XA= XA/2.D0	TCA12520				TCA130=0
		TC#12540		10=01/2/	12 COTO 76	TCA13100
		17412550		1.1.1		TCA13110
	A67 = A67 - A4	TCA12560		002-74956	PC-FP3(4))	TCA13120
-		TCA12570			SPT3L1 6010 77	TCA13130
10	· · · · · · · · · · · · · · · · · · ·	TC#12580	•	173JFR431 2 CONTINIE	· · · · · · · · · · · · · · · · · · ·	TC#13140
ر د	AFIYAFTITTY	TCA12590		0 LUNIINUL 6010 70		TCA13150
L C		TC#12600		9 16/101 C	0. 0) SCTC 1501	TCA13160
	EDDWATER DTL DECREASED FOR GLIBAL PRESSURE RELIABILITY CHECK"/)	TCA12610	1	# 173171424 UBTTE#E-1		TCA13170
121	FORMATIC NC. OF STEPS DCUBLED FOR FP RELIABILITY CHECH*/)	TCA12620				TCA13190
721	FCWMAT(* * 78.*PCL)* +128,*PREN* +138,*** +128,** A.GIFF.*/)	TC412530		146721119 - 2137141		TCA13190
774	FORMATCH 4.1X.4(C14.7.2X)/)	TCA12640			AST PROCUTAPCANCACER	1CU13500
943	FORMATCH * .EX. * FPCLC* .11X. * FPNF W* .1CX. * R. DIFF. */)	TCA12610		Mutice 11:	······································	

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FILE: TCA

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FILE: TCA FORTRAN & LEEDS UNIVERSITY WH/BSE 6.15

32.1

FILE: TCA FORTRAN & LEEDS UNIVERSITY UN/OSE 6-16

FILE TCA FERINA A LELOO ON FOR THE			
			1[#1]/64
	TCA13210	MATTE (20100)	TCALSFID
WE 27565.1867	*CA13220	1509 CONTINUE	TCALITED
1961 NST=NST/2	TCA11730	1569 CGNTINUE	TCA13770
	TCA1-240		TCA13888
TO CONTANT	TCA11248	C INCREASING NET FOR ACCURATE PROFILE INTERPOLATION	TCA13910
· · · · · · · · · · · · · · · · · · ·	TCA13268		TC#13#28
		TF (NUN 50.1) SCTC 9461	TCA13#30
C ABSOLUTE TOLEMANCE TON ENDED TO DE TO	TCA1327	MCT=6CT+18	TCATSAA
	TCAISSEN	TETTT-FG.6) 6010 1303	TFALLASA
	TCA13270		TCA1166
OPT=ZABSCCFIN-FIJ/FIN/	TCA13388		
IFCOPTOBIOFICLI GITT /20	TCA13310		ICHI3410
6010 722	TCA13350	AKILF COFTAGE	T[A13=80
723 IFCIPT.E0.01 60TO 1503	TCA13330	1565 CONTINUE	TCALSHAD
URITE(5,100)	TCA13240	NN 7=1	TCA13900
WRITE(5.951)	TCA13350	6010 3	TC#13910
un 11545-9513	TCA13760	9461 CONTINUE	TCA13920
WATTERS 9531 PT. PTN. CPT	TCA1137A	C	TCA13930
	TCA11380	C GENERATE PROFILE	TCA13940
			TCA13950
1383 CONTRACT CONDITION	ICA13374	4M T N = 1 - 0.6	TCA11968
	TCAISAUU		TCAS1378
	TCA13+10		F(=13-70
PT=PTN	TCA13420		TC#13980
6017 E	TCA13430		TCA13990
722 CONTINUE	TCA13440		TCA14000
	TCA13450	IF(FXXoLToPHINE MPINORAA	TCA14010
SOLVING LCAD CAPACITY USING DELGAP	TC#13460	FX{I)=FXX	TCA14020
	TCA13478	92 CONTINUE	TCA14030
SET 11 = 100 + FP 10L	TCALLAPO	00 797 I=1+APLUS	TCA14040
CALL FOIGAFER.FR.NPLUS.FPCC.ERRCR.S)	TCATIATA	FX(I)=FXCIJ-HPIN	TCA14050
		797 CONTINUE	TCALADER
	10413300		70414070
	1C#13510		
C PP RELIABLETT CREEK	YC#13520		ILAI4070
	TCA13530	(VCA14090
	TCA13540	GUU FURTAIL VERVA VANA TANA TAN	TCA1410W
IF(DFD.GI.SFTOL) GJIC /X>	TCA13550	601 FORMATIC TERMINAL NO DE CIERC IL IAZA	TCA14110
6010 720	TCA135EO	986 FORMATCH FINAL HOUSE CALLS TO DODERE STATE	TCA14120
719 IF(IPT.EQ.0) 60TC 1502	TCA13570	1301 FCRMATCH FINAL NO. CF CALLS TO DUZLER O VISIO	TCA14130
WRITE(5+100)	TCA13580	IFCIPT.EQ.00 GOTO 1507	TCA14140
WRITE(5+721)	TCA13590	WRITE(5,100)	TCA14150
MRITE(5,943)	TCA13600	WRITE(5,996) NST	TCA14160
LATTESS 944) FPC+FPCD+DFP	76413610	WRITE(5,1301) KL3	TCA14178
	ICALJELU	URTTE(5+100)	TCALAISS
	TCA13620	SAT CONTINUE	10414150
	TCA13620		10414170
6010 a	TCA13640		TCA14200
729 CONTINUE	76#13650		TCA14210
THE WE WE TE CATTERY PERCIFY TO FRANCES	TCA13660		TCA14220
PRINTING FINAL STL AND THE TO SATISFY SPECTFICS TOLE AND D	TC#13670		TCA14230
	TCAISERD		TCA14240
IF(4#4.50.1) 6070 1569	TCA13650	DO 40 I=1,NPLUS	TC#14250
IFCIPT.EQ.C) GCTC 1509	TCA13700	K=NPLU3-I+1	TCA14260
MRITE(5.99)	10413310	J=K+NB	TC#14270
WETTE (5.10C)	10-10-40	X(J)=X(K)	TCA14280
	* (#1)/20	FX(J)=FX(K)	TCALAJER
	1CA13/50		+UH1+230 +CA1A1AA
W74 - 48 J # / 78 / 8 Hott / 6 G at 1 (7)	17413740		1041-306
単代上に広ちづき2つにす。 スパート	TCA13750	PA 441 1-1449	
日本エイビモンタブライア・マンド			

FILES TEA FERTMAN & LEEDS UNIVERSITY WARSE 6-16

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	xc1)=xx=0=0=0	TCA14318		SUBROUTINE CUTPUT(XSOL.PCS)	TCA14968
	Fx(I)=+8+x(I)++2/{2+00+4}-++"I4	TC#14 320	ç		TC#14=70
481	CONTINUE:	TCA14330	ç		16974440
	103 = 10 - 10 - 10 - 10 - 10 - 10 - 10 - 10	TC#14340			TC 414 5 40
		TCA1434			TCA14500
	IF (IXED-E0.XIP) WOTG 7720	TCA14360			TCA14820
	00 462 I=1, APLUS	TCA14378			76414630
	K = NP L US + I - I	TCA14388			TC#14~30
	134+1	TC#14378			76414964
		TC#14488			76414968
	FRCJJEFACKI	TCA14410			16014788
482	CONTINUE	TC#14420			1CA14770
		TCA14430			TCA14868
	FE(1)=H9+EIP++2/(2, 30 R)-HFIR	TCA14440			10019770
		10814450			1CA15000
	MCVATACIA+1	ICA144EU		TEATE CANNET ARAI TAA Agarta Canada	10012010
7728	CONTINUE	ILA144/0		AFTURA	10412020
	m = 4 L C 0 2	10814470			1001000
		TCA14490			1(12040
	NJ=4P/12	ILA14388	2		TCA15030
	IFCIPT.CO.8) GOTO ISB	10=14510			TCALDUEU
	W# 115 (5, 99)	10414320	~	SUDRUGIINE FEUERALAC OF SOF DI	TCA15070
	URITE (5.600)	1CA14330	- C		TCA10000
	D0 45 [=1,RP	TCA14740	.		16813070
		FL#14327		CDWDW W (EFTAD) - SV(SAA00)	10412140
_	IFEELCONTO ID CANDOLICATION FOR AND CLORE OF A	10014300			
4	>ANJA(FX(I)-MEABACUSANDACIANCACIANS) GUID 43	1(#14578			TCALS 120
	WRITESS GOID RELPT ALL TO	10814340		COMMON FIRE THE AND ANT FUE NET	10412138
45	CONTINUE	1LA14370		CJENUM EDEFFDIMENTUDETIDEXCONCENTE Common Topical March Dockson American Marchen Marchen	1CA13140
		10=14688			1CA13130
		10414010		COMMON ACTUSIACTICSIACTICSIALISSIALISSIANICSIANICSSIA	10413160
1249		TCALLEZU		CUMUM NJI 464 977 917 19129NGA 989 3989	TC#15170
		TC#14630		D1-200441	TCALSIED
C		TCA14540		ГС-ГСЗХХ/ Вила 1.1.717. ГААНТАНМААМА/ИА-ИСААЗ/ВАТ КААХУРГААЗ/В_З ААААМАЛСА/	TCP15170
C		10014030			1CA15200
6	FURAALT THE SCHLER - OFR - E 1	· [#] 40C0			TCA15210
~	SUBRUUIANE FLAVACIFLS (F	TCA14070			TCA15220
Canada		TCA14000	r		TCA15230
		TCA1470	Č-		TCA15250
	175111 157403 - 1772/		•		16813239
		TCA14 720	c		TCA15330
		TCA14720	č-		TCA15200
		TCA1A7A0	•	THELICIT REAL PLANUAR 21	TCA15390
	COMMON TOPEST VERSEN DERICAL METTISAL HREELLANDESS WESS AND SCAL	TCA14768			10413270
	$ \begin{array}{c} \textbf{L} \\ \textbf$	TCA14740			TCA15 110
		TCA147709			TCA15320
	TWENSICH BESELL FELL	TCA14780		COPMON FARETHANGENHTAFEFATC	TC#45320
		TCA14750		CONHON TO CAR A RECAR SOR ICA SON CONTELAS AND RECAR AND RECAR	TCA15 148
F	[[]]=[]2.]0+VI+U#/(H0+(XC++2)/(2-00+R1+AM+PC3++3)+((XC++2	TCALABAR		COMMON AN(400) . VERCERS, NECCESS PRICEDING TEESING TEESING	TCA15350
	xEFee21/cs_CA+R1+APePC1	12414010		COMMON INSTALTANDA IPTA 12 AN CANA MA	10415340
		TCA14920		IF (NCAV_EQ.1) GOTO 3	70415370
E		10-17-27		001 1 1 # 5 + 6	TCA15300
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	TCA15410	••	-/JEU: 7J7: 4070(17) - 04	
2 H\$=1-1	TCA15429	.6824041027870172925-06		1230857.96835484495
	TC#15430	.31250300300000000000000000	- 10417774468358# 4105-03	
	TCA15449	.6462453941378402662-01	A4441 1345898771 6165-02	1796402+40875089052
FXR=FXC45F	TCA15420	.6250000C0000CC0CC0E-JI	- 1050738762268055875-93	
	TCA15460	.600413352756574830L-UA	n 1741821 AA6 4184 178E-02	2093125.59496485605
₽XT≠₽X₹+€€₽X₩≠₽X₹J₽€X₩+J₩+J>=€XC+₩K₽	TCA15478	.93750888000000000000000	1486055200997598535+03	
	TCA154#0	.54642753363444:4731-00	1007560881505602775-01	2417072.53743135976
3 FX7=FX(1)	TC#15490	.125000000000000000	-1484528153755315275-83	_
e continue	TCA15504	.48467740429221E307L-VE	1869711571322592665-01	2724481.87486305875
s in Return in the second	TCA15510	.136258000000000000	- 1905474756036124195-03	
END		.4159377218629364332-04	1130503164152495915-01	2645699.32707908464
		.1875000000000000000		
		.3344403650443074232-04	118841514608558328-81	3362690./7915116563
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		-21251102112616437-04	1 310019868565246415-01	4086075.57267739787
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		.221388277444357327-04	-1 37=110741146449695-01	4521878.05384966099
			-3161526301585000365-03	
		- JUZJ64 26 J62 7606 7700 00	-1428607025779466395-01	4859327.27965151402
		- 343/30000000000000000000000000000000000	-3357117913837172535-03	
		• 335217/203/24141302-00	144663091905001731E-01	4996502.52940852451
		- 3730300000000000000 AA155A38A9515273155-06	- 3453654512466494935-03	
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ETTER TOA EASE A LEEDS UNIVERSITY VP/BSE 6-16		A 7101 AACAR1181950F-06	3262514724062282155-03	
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	•	501146114463353940E-06	2755869820176603585-03	
EVER STUP FORTRIA LOSP NAGE CCGPCST		544440444054440544	-115687809066198202E-01	3186586.82733419188
ET DISK RANK DATA		S 170A9 37 1227561411E-06	2224589257761144645-03	
ET DISK START CATA		-5312500000000000000	-106698925173432823E-01	2710627.71439871332
FT & DISK XICA DATA		S54827878035513023E-06	1991215905*5544103*-03	
FT & DISK TICA DATA (RECEN F LRECL 120 BLOCK 120		-54250000000000000	.972332354664749463E-02	2251024.06298423000
FT 7 DISK STARTN CATA		-5652966737176409705-06	156937307913147 0355-03	
I DAD TEASELEAR		-5937500000000000000	.7782093429397256005-02	1441923.79688238213
FARC PLOTFILE PTCA		6033498407511002355-06	1002560291269806775-03	
SET ALIP +		6250000000000000000	.6359:29413780330:45-02	1024399.45773702438
START		6105277248585809485-06	7102086811016008605-04	
		65625000000000000	.5905644535253493885-02	630356-275242502504
		5722366351807716312-06	574E33211169610#065-04	
		647500000000C00000	.5476863029220194195-02	1141 89.92221 32 12042
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		.347457312541376535E-0E	5077446639124775175-04	
		.75000000000000000000	.5162970047436363235-02	0390/2+C3997CC900VC
		. 30220972295073E055E-07	4423719265465672642-04	
		.731250000000000000	.5247235339219340752-02	033339930 C77C3 4937 ;
		.3579374598951077135-06	4548644582772653837-04	8/6111 52F871043594
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•566127332975626577-36 •8753993399899986889 •6753943259989986889 •6573426271342295955-96	~\$462388058886668008 .4342671112485158846~84	• 93756303848668888 7887317364441719955-86		

INPUT

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5

.53825370-6 .54225110-(- 59233960-- 32542160-(-53134722-6 -52615660-0

.52542980-4 . 52631712-

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.52526990-6 .52526990-6

.53209390-6

.53841830-6

--22979863-1

-10946282-5 -90085560-7 1-039796658 -

DATA FILE: XTCA

INPUT

339. 582. 726. 997. 1133. 1382. 1687. 2882. 2489. 2557. 2496. 2489. 2150. 1675. 1382. 1851. 929. 599. 351. 238. 173. 150. 150. 170. 116. 116. 129. 116. 178. 198. 170. 129. 150. 150. 3* 54* 5** 52** ** 545* 6 . 775 1000000000000 N. 21 .92 •01 1. 16.D6 •3 •8824 •8265 •4 •022865 3. ••016 - 25 150. 170. 116. 116. 129. 183. 217. 251. 285. 339. • •05 •1 •15 •175 •2 --02 1-15-6 1.5-2 9 .825 .85 .865 .525 .55 .575 .6 100. 11 1. 100. 286 88 28 288 .0075 16 16 -10698513-3 -0001 1-0-1 7 •

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t/tp | TIME | LC#0 | FP | |
| TP (PERIOD) . | | | 0.168008000461 | | | | | |
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8 - 50000 | C+0
1 - 6-52600-01 | Un 33703403 | 0+12/92425+03
A_18943480+05 | |
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| PR (POISSCAS | PATICH | | 9.4000000000 | 0-17500+0 | 8 8-1750C+00 | 8-11330+04 | 0.42754725+05 | |
| RT (TALUS RAD' | [US] | | 8.22095000-01 | 0+20003+0 | 0. 0.20000+00 | 0.13020+04 | 8.45132080+05 | |
| THETA CANGULAR | AMPLITUCE | IN DEGREES) | 8.5000000001 | 9-25090+0 | 0 0-25000+00 | 0-16077+04 | 0-60641510+05 | |
| XI CINLET BOUP | D#443 | | 0.160000000-01 | 8-30000+0 | 0 0-30900+00 | 0-20825+04 | 0.78566040+85 | |
| HADAID (HACAI | IF H#01 50 | UALS 2500) | 0.10000302-87 | 0-35003+0 | 0 0.35000+00 | 0.24573+04 | 0.93924530+05 | - |
| F1 (HA=H0+F1+ | INITIAL HO | INCREVENTS | 8-10880001-02 | 0+37500+0 | 0 0.37500+00 | 0.21179+04 | 8.96490370+05 | 1 |
| F2 (XA=XEF+F2) | INITIAL X | LF INCKLELATE ADDAR | ···· 0·I000000000 | 0.40000+0 | 0 0+0000+00 | 0.24760+04 | | I |
| F3 (MNUAL=MHUL
F4 (MNUAL=MHUL | | INCREMENTS | 10000000000000000000000000000000000000 | 0-4530040 | 0 0.45000+00 | 0-21507+04 | 0-81132080405 | |
| P4 EKA=AL+F49
NV (TNET, NO. | OF STEPS AT | T CURRENT TIME STEEL | | 8-47503+0 | 0 0.47590+00 | 0-16350+04 | 8-6 320 7550+85 | |
| NEL CHO. OF SU | 8-STEPS IN | FIRST STEPT | | 8-50002+0 | 0.50000+00 | 0-13023+04 | 8-45132020+05 | ī |
| II CHO. OF PTS | . FRINTED A | AT CURRENT TIME STEP | P) • 20 | 0+52500+0 | C-5250D+08 | 0.10510+04 | 0-39660380+05 | ī |
| NST CINITIAL N | C. CF STEPS | S FOR PROFILE) | 200 | 0+55003+0 | 0.55300+00 | 0. 92900+03 | 0-3505660C+05 | 1 |
| 12 (NO. OF PTS | . FRINTED F | FOR PROFILED | 28 | 0+57500+0 | 0 0.57500+00 | 0.59000+03 | 0+22264150+05 | 1 |
| IS (NO. OF PTS | . FLOTTEC) | | 100 | 0+60033+0 | 0.6000C+00 | 0.35200+93 | 0.13320755+05 | 1 |
| DTOL CINITIAL | ABSOLUTE TO | CLERANCE FOR COREFT | ··· 0.1000C00C-07 | 0+62500+0 | 0.62500+00 | 0+2380D+03 | 0.89811320+04 | 2 |
| PTOL CRELATIVE | INLET PRES | SSUPE TELEMANCED | 0.10900005-02 | 0.65000+0 | 0-6500C+00 | 0-14300+03 | 0.69056630+04 | 2 |
| PTOL CRELATIV | E LOAD CAPA | CITY ICLEMANCED | •••• 0 -500000C-J2 | 0.67509+0 | 0.01000.00 | 0.12000+03 | 0.56603770+04 | 2 |
| FRIUE CRELATIV | E PHILIIGN
B ToleDamer | LULFF ILLTANLLY . | •••• ••••••••••••••••••••••••••••••••• | 0.2100340 | 00+00000+00
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| IPX (NO. OF PR | ESS, MIST- | PRINTED | | 0-76000+0 | 0.76000+00 | 0.12500+03 | 0.48679257+14 | 2 |
| PUL (LINIT ON | CPU TIMEN | | 0.1890(902+04 | 0.77502+01 | 0.77500+00 | 0.11600+02 | 0.43773520+04 | 2 |
| HO CLOVER LIN | LT FOR ENT. | VEL.) | 3.10996510-03 | 0.90070+00 | 0.90000+00 | 0.17005+02 | 0.64153940+04 | 2 |
| FACT ESCALE FI | ACTER FER P | LOTS) | 0.2000005-01 | 0+32503+01 | C.d2503+06 | 0.19000+03 | 0-71698110+04 | Ĵ |
| FACT (SCALE F | ACTOR FOR F | ILM PLOTSH | ••• 0·1100C007-05 | 0 - 950 00+ 00 | 0+95002+00 | 0.17000+03 | 0.64150940+04 | 3 |
| FACT ESCALE FI | CTCR FOR F | PICTICN PLOTS | ··· 0.5555595-03 | 0.86593+00 | 0+9+500+00 | 0.12900+03 | 0.48679250+04 | 3. |
| PT (PRINT OPT) | CN FJR CON | VEPGENCED | ••• 0 | 0+37503+00 | 0.87502+00 | 0.15007+93 | 0.56603777+04 | 3 |
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| 64750800400 8.55956490-82 8.7994500 8.79915900 8.79915900 8.79915900 8.79915900 8.79915900 8.79915900 8.79915900 8.79915900 8.79915900 8.79915900 8.79915900 8.79915900 8.79915900 8.79915900 8.79915900 8.79915900 8.7991600 8.79916000 8.79916000 8 | 0+62503807+00 | 6 • 6 E E A T 2 G A - 0 Z | | - 5723 16 60- 06 | -0-2251413 |
| 6.915000000 0.534725000 0.130730000 0.534725000 0.51625000000 0.5365550000 0.6335520000 0.536572000 0.5365720000 0.51625000000 0.5365550000 0.63355720000 0.5365720000 0.5365720000 0.51625000000 0.5365550000 0.63355720000 0.556519000 0.6335720000 0.51250000000 0.5365750000 0.63355720000 0.653550000 0.6335720000 0.6125000000 0.5365250000 0.653550000 0.653550000 0.653550000 0.6125000000 0.5562550000 0.5562550000 0.5562550000 0.556259000 0.93750000000 0.56225500000 0.7626770000 0.556279000 0.556279000 0.93750000000 0.56225500000 0.652165900 0.7007917000 0.70529740000 0.93750000000 0.56225500000 0.7025612000 0.7052970000 0.7052970000 0.937500000000 0.725612000 0.70262170000 0.7052970000 0.7052970000 0.937500000000 0.725612000 0.7026212000 0.7052970000 0.7052970000 0.9375000000000 0.7256120000 0.7052970000 0.7052970000 0.7052970000 | .45525000+00 | 8*250264a0-05 | | | +0-C2615+6+-0- |
| 7187500500 0.5540675062 0.72572000 0.7077677 0.7077677 0.7077677 0.707777 0.7072777 0.707777 0.7072777 0.7077777 0.7072777 0.7072777 0.7072777 0.7072777 0.7072777 0.7072777 0.7072777 0.7072777 0.7072777 0.7072777 0.7072777 0.707777 0.7072777 0.7072777 0.7077777 0.70727777 0.7077777 | | 6+5476E63D-02 | | | -8.58774460-64 |
| 0.7503003+00 0.51629705-02 0.6395750500 0.53575700 0.51629705-02 0.8125003+00 0.524723595-02 0.69355850+06 0.55618770 0.55618720-06 0.8125003+00 0.524723595-02 0.659750506 0.65519170 0.6553917 0.6553917 0.8125003+00 0.5237525920-06 0.65518770 0.65518720 0.655193746760-09 0.8125003+00 0.5617700 0.665381767 0.655193746760-09 0.655193746760-09 0.8750030-00 0.56177670 0.655116970 0.6551816970 0.65518170 0.6551746760-09 0.89525003-00 0.56177670 0.7027195790 0.65526700 0.702719770 0.702719770 0.955250300-00 0.656267730 0.702719770 0.702719770 0.702719770 0.702719770 0.955250300-00 0.656267730 0.70271970 0.70271970 0.70271970 0.70271970 0.9552503000-00 0.72256370-02 0.1277770 0.70279170 0.702701970 0.702701970 0.955757090 0.702791970 0.72259407 0.702791970 0.7252900 0.7262970 | 00-00024012-00 | 0-55406750-02 | | | -0-0612554-0- |
| .81250000000 0.5247235000000000000000000000000000000000000 | 00+0000051 -0 | 0.51629705-02 | | | |
| 81250000+00 0.60440630-02 0.66977000+05 0.56618730-06 0.59746760-05 0.443750000+00 0.80191840-02 0.66258200+06 0.56618720-06 0.556397970-06 0.4537500000+00 0.801726002+02 0.76269460+06 0.66518260-06 0.55639970-07 0.906255000+00 0.56218679-06 0.66518270-06 0.65627497-07 0.70274770-07 0.91726000+00 0.662116599-07 0.70079170-06 0.70276170-06 0.70276170-07 0.93750000+00 0.662216699-07 0.7027919770-06 0.70276170-07 0.702624790-00 0.93750000+00 0.668279670-02 0.112779709-07 0.70276120-06 0.70276129-07 0.93750000+00 0.702799579-07 0.12279709-07 0.702791970-06 0.702791970-07 | 00+000+00 | 50-05211250-05 | 0-65555850+86 | | |
| 041750000000 0 <t< th=""><th></th><th>0.6344 0630-02</th><th>0 • COS11638 • 0</th><th></th><th></th></t<> | | 0.6344 0630-02 | 0 • COS11638 • 0 | | |
| 0.97500002.00 0.56225030-02 0.75269460.06 0.66578260-06 -0.23757579970-04
0.996250003-00 0.66173670-02 0.86211699-06 0.69626179-06 -0.79629749-09
0.937500039-00 0.654946779-02 0.10201959+07 0.70079170-46 -0.706297495-09
0.954575900-00 0.6688296279-02 0.11279759+07 0.7026129-06 -0.72167590-09
0.954575900-01 0.72205940-02 0.11279759+07 0.66290410-06 -0.50020520-09 | | 0-19101840-02 | 0. E6263200+06 | en - n° / el 996 • 0 | |
| 9.9720000-00 0.6817.870-02 0.86214690.06 0.69626170-06 -0.595634970-07
0.93750000-00 0.6817.870-02 0.10201990+07 0.70079170-06 -0.70624740-04
0.93750000+00 0.65835677-02 0.10201990+07 0.70260120-06 -0.70167590-04
0.95375000+00 0.668829620-02 0.11279790+07 0.70260120-06 -0.70167590-04
0.10008800+01 0.72805940-02 0.12965750+07 0.68290410-06 -0.50020520-04 | | | A. 75269960+06 | 0.66578260-66 | |
| ●906250003400 | | | 0-04211640+06 | 0.69626717-C6 | |
| 0.93750009400 0.654756679-02 0.112797979747 0.76266129-66 -0.78167590-04
0.9637500400 0.68829620-02 0.112797979747 0.78266129-66 -0.78167590-04
0.18888809401 0.72285940-02 0.12965759+07 0.68290419-66 -0.50020520-04 | 9940952986*8 | | | 0.70079170-46 | -0.70624745-04 |
| ▶,96575900+00 0.68829620-02 0.11/77777777 0.68290410-06 -0.90020520-04
■.18888800-01 0.72885940-02 0.12965753+07 0.68290410-06 -0.90020520-04 | 0-93750057+00 | | | 0.7076120-66 | -0-161675-0-04 |
| 1.1888800+01 0+72885940-02 8+12965753487 8+88258417-40 0-7288 | | 0 .68829620-02 | | | -8-50020520-04 |
| | 1.1.80000000000000000000000000000000000 | 0 . 72205940-02 | 6* 15462120 + 61 | | |

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FREVI DUS CYCLE

0.53525379-06 0.54235159-35 0.54235563-05 0.53953172-05 0.53154729-05 0.53154723-05 0.53154723-05

8-52607620-06 7 8.52542959-06 8 8.52631717-86 5 8-52416697-36 10 0.52974927-86 11 8.52678530-06 12 8.52365012-06 13 8.52526887-86 14 15 0.53289390-86 0.53841830-36 16

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OUTPUT DATA ++++

| TIPE | MIN FILT TH | S TRUNC ERR | ENT VEL | SØ VEL | LOAD PER UN | FRIC CHEFF | |
|----------------|---------------|----------------|-----------------|-----------------|----------------|-----------------|----|
| 9.8 | 0.53891830-06 | G. g | 8.10898510-01 | 8.908*5560-07 | 0.12792450+05 | -6.100000000+01 | (|
| 0.62500000-01 | 8.54241673-06 | 9-11307790-01 | 9-10068910-01 | 0.3134C8CD-07 | 0-202 24570+05 | 0.25466390-03 | 1 |
| 0.1250000D+00 | 8-54249120-06 | 0.12254190-01 | G. 77064110-02 | -0.24990000-07 | 0-32497710+05 | 0.14500240-03 | 2 |
| 8.19753803+00 | 8-53965470-96 | 0.75607740-02 | 0.41706770-62 | -1. 60864330-07 | 0-45914340+05 | 8-66268410-04 | |
| 8.25008000+00 | 8.53555140-06 | 0.17578670-02 | 0-10898510-03 | -0.63932800-07 | 0-60641510+05 | 0.12012880-05 | 4 |
| 0.31250007+00 | 0.53166640-05 | 0.12402240-01 | 0.41766730-62 | -0.61841250-07 | 0-831 62960+05 | 0.45402920-04 | |
| 0.3750000D+00 | 8-52825720-86 | 0-12892870-01 | 0.77064110-02 | -0.43663310-07 | 0.96490570+05 | 8.75175200-04 | e |
| 0.43750000+00 | 0.52617990-06 | 9-75099122-02 | 0-10068910-01 | -0.23665170-07 | 0-87224720+05 | 0.10412039-03 | 7 |
| 8.500000000000 | 8-52553230-86 | 8-66089630-02 | 0-10852510-01 | .0.49687610-08 | 8-49132060+05 | 0.16268710-03 | |
| 0.56250003+00 | 0.52641982-06 | 8.93312997-02 | 0.10060410-01 | 0.19075270-07 | 0-2917607*+05 | 0.21095060-03 | 9 |
| 0.62500000+00 | 0-52826980-06 | 0-15154360-01 | 0.77064110-02 | 0.44046200-07 | 8-89811320+04 | 0.34233550-03 | 10 |
| 8.68753000+00 | 0.52933410-06 | 0.37904100-01 | 0.41706792-02 | -0.16194750-07 | 0+522 76599+04 | 0-26357110-03 | 11 |
| 4.75000000+00 | 0.52703560-06 | 0.60974180-01 | 0-10459510-03 | -0.62912010-07 | 0-43773550+04 | 0.75401840-05 | 12 |
| 0.81250000+00 | 0.52370970-06 | 0.00624680-02 | 0.417 67 50- 62 | -0.22777920-07 | 0.70252960+04 | 0.22598530-03 | 13 |
| 0-87500002+00 | 9-52531830-06 | 8-2911986D-01 | 0.77864110-02 | 8-83790580-07 | 0-56603770+04 | 0-45862840-03 | 14 |
| 0.93750000+90 | 0.5.215142-06 | 0.40266230-01 | 0.19060912-01 | 0-10945370-06 | 0.89154100+04 | 0+44028557-03 | 15 |
| 0-10000000000 | 0.51847510-06 | 8. 47555140-01 | 0-10050510-01 | 6.56077940-67 | 8-12792450485 | 8-37388710-03 | 16 |

******** "AXI*UP RELATIVE DIFFERENCE = 0.30571030-03

NUMBER OF STEPS = 16

+++++ CPU = 0.4553+03

STEP SIZE IS HALVED

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FILE: YTCA DATA A LEEDS UNIVERSITY VP/HSE 6.16

STEP NO. # . TIME (TC) = 0.12500036+00

| X · | P | | | |
|----------------|-------------------------|--------------------------------|-----|-----------|
| 8.14803003-31 | 0.0 | 8.23807160-83 | 1 | 1 |
| 8.14639860-01 | 0.0 | 8.18861490-83 | 12 | 1 |
| 8-13875273-31 | 6.0 | 0.11634272-03 | 24 | 3 |
| 8-11510690-01 | 0.0 | 8-52231220-04 | 36 | 4 |
| 8.10076473-81 | . | 8-63849740-86 | 47 | 9 |
| 8. 79468920-82 | 6.6428316D+05 | 8.54231770-06 | 48 | · · · · • |
| 8.93015040-02 | 8.75514980+06 | 0.54994500-06 | 60 | 7 |
| 8.68169157-92 | 0-13715280+07 | 0.5575740C-06 | 12 | 8 |
| 8-52523270-02 | 8-15263542+07 | 0-56571410-06 | 84 | 9 |
| 8-36877380-02 | 8.21539670+87 | 0.57510765-06 | 76 | 10 |
| 8-21231503-92 | 0.23554252+07 | 8.58534530-06 | 107 | 11 |
| 0.55856140-03 | 0.24343270+07 | 8.59689090-86 | 126 | 12 |
| -0.10050270-02 | 8.23937890+07 | 8-61012510-96 | 132 | 13 |
| -0.25706160-92 | 0.22371210+07 | 8-62562910-86 | 144 | 14 |
| -0.41352040-02 | 8-1967#962+07 | 8.64436865-86 | 15E | 15 |
| -0.56777920-92 | 8.15700410+07 | 8.6680 290 0-0 6 | 162 | 16 |
| -0.72643910-02 | 0-11083190+07 | 0.70077040-06 | 120 | 17 |
| -8.88289690-82 | 8-52879240+06 | 8.7557733D-06 | 192 | 19 |
| -0.10393560-01 | 0.42481337+04 | 6.11636860-04 | 204 | 19 |
| -0.11958150-01 | | 8.69795100-04 | 21€ | 20 |
| -0.13522730-01 | 0.22509852+04 | C.13622952-03 | 222 | 21 |
| -0.15097320-01 | 0-22403770+04 | 8-21093090-03 | 240 | 22 |
| -0.16000000-01 | 8 • 22 2 45 7 3 3 + 0 4 | 8.25811765-03 | 247 | 23 |
| | | | | |

CURRENT TIME STEP VALUES

SQUEEZE VELOCITY (HPD) =-0.24992760-07

CAVITATION BOUNCARY (XE) = 0.10076470-01 SS CAVITATION BE (FEF) = 0.10075610-01

MINIMUM FILM THICKNESS (MMT) = 0.54241950-06 ESTIMATED & TRUNC. ERROW IN HMT = 0.2270-04 FRICTION COEFFICIENT (FPO) = 0.14796930-03 MODIFIER TERM (CHMT) =-0.10277790-11

PASE 805

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STEP NO. = .

TIME (TC) = 0.2500000+00

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|---------------------------------------|------------------|---------------|------|----------|
| 8_16000003-01 | 0.0 | 0.17066180-03 | 1 | 1 |
| 8-14473923-01 | 9.0 | 8.73152225-04 | 44 | 2 |
| 8-12981990-81 | 0.0 | 8-21430750-04 | 88 | 3 |
| 8-1258845D-01 | 0.0 | 0.77751200-05 | 97 | • |
| 8-11338979-01 | 8+62825873+06 | 0.52193070-06 | 132 | · • |
| 0-97531490-02 | 8-14345580+97 | 0.53644532-06 | 176 | 6 |
| 8-41342140-82 | 8-21153580+97 | 8-53710270-06 | 220 | 1 |
| 8-66142990-02 | 8.26713950+37 | 0.53780910-06 | 264 | 9 |
| 8-58423049-82 | 8-31823530+07 | 0-53857250-06 | 30: | 9 |
| 8-34704390-02 | 8-34122473+07 | 8-53540232-06 | 352 | 10 |
| 0-10765130-02 | 0.15970730+07 | 0-54031122-06 | 396 | 11 |
| 0-32558797-03 | 8-34646880+07 | 8-54131572-96 | 440 | 12 |
| -8-12453319-02 | 8-36187597+77 | 0-54243515-06 | 454 | 13 |
| -0-28172632-02 | 6. 14 189420+07 | 8-54371000-06 | 525 | 14 |
| -0-43331340-02 | 0-31305140+07 | 0-54517750-06 | 572 | 15 |
| -0-59611130-12 | 8.21479473+87 | 0-54691535-06 | 616 | 16 |
| -0. /5310390-02 | 8.22341317+07 | 0-54504970-06 | 660 | 17 |
| -0-91049640-02 | 8.14113290+87 | 9-55193672-06 | 704 | 19 |
| -0-10676493-01 | 8.79124467+86 | 8-55575230-86 | 748 | 19 |
| +0-12243810+01 | A. #1784 117+ #5 | 0-56618227-56 | 792 | 20 |
| -0-13820740-01 | -8-51221647+03 | 8-62457280-84 | AJE | 21 |
| -0-15392670-01 | +0-53464317+03 | 8-11899260-81 | 48.0 | 22 |
| -0_1_0000000-01 | -0-53519740+03 | 6-17076900-03 | 497 | 23 |
| | | | | |

CURRENT TIME STEP VALUES .

SQUEEZE VELOCITY (HMD) =-0.63943667-07

MINIMUM FILM THICKNESS (MMT) = 0.53543310-06 ESTIMATED & TRUNC. ERROP IN HAT = 0.1000-02

FRICTION COEFFICIENT (FRD) = 0.11901850-05 MODIFIER TERM (CHMT) = 0.76339070-10

CAVITATION BOUNCAPY (XE) = 0.12580460-01 SS CAVITATION BC (XEF) = 0.12406770-01

STEP NO. = 12

TIME (TC) = 0.33500030+00

FILE: YTCA DATA A LICOS UNIVERSITY VP/BSE 6.16

| X | p | H . | | |
|----------------|----------------|---------------|-----|----|
| 8.160000000-01 | 0.0 | 8.77457745-04 | 1 | 1 |
| 0.14792720-01 | 8-8 | 6.15528462-04 | 5 | 2 |
| 8-14497940-81 | 8.0 | 8.65011350-06 | 6 | 3 |
| 8-13269320-81 | 8. 39763095+86 | 8-53189110-06 | 10 | • |
| 8-11743930-01 | 0-19725992+07 | 0.53502952-06 | 15. | 5 |
| 8-18219540-01 | 8-27192070+07 | 0.53531650-06 | 28 | 6 |
| 8.86751480-92 | 8-34302712+97 | 0.54320030-06 | 25 | 7 |
| 0.71707560-02 | 8-4005-270+07 | 8.54757280-06 | 30 | 8 |
| 0.56463540-02 | 0-44574442+07 | 8.55357070-06 | 35 | • |
| 8-41219720-82 | 8.47796360+07 | 8.55914350-06 | 40 | 10 |
| 8-25975910-02 | 0.49784783+87 | 0.56504850-06 | 45 | 11 |
| 8-19731990-92 | 0.50573190+07 | 8.57146000-06 | 58 | 12 |
| -8-45120313-03 | 0.50176672+97 | 8.57247130-06 | 55 | 13 |
| -0.19755950-02 | 8-48692180+97 | 0-58E20E6C-06 | 60 | 14 |
| -0.34999970-02 | 8.45058573+37 | 0.59443270-06 | 65 | 15 |
| -8.58243795-82 | 0-42459132+07 | 8.60459880-06 | 70 | 16 |
| -0.65497710-02 | 0-3781843D+07 | 0-61192030-06 | 75 | 17 |
| -0-30731620-02 | 8-32227610+07 | 0.62507730-06 | | 18 |
| -0.75975540-02 | 8-25744733+07 | 0-64530730-06 | | 19 |
| -8-11121950-01 | 8-18437690+07 | 0.66641900-06 | 90 | 28 |
| -8-12646340-91 | 8-10405940+87 | 8-69742472-06 | 95 | 21 |
| -0-14170730-01 | 8-18165700+86 | 8-77223050-06 | 100 | 22 |
| -0.15695120-01 | 0+22879593+04 | 0-61636987-04 | 105 | 23 |
| | 0-2225483"+84 | 8-77738135-84 | 106 | 24 |
| | | | | • |

CURRENT TIME STEP VALUES

SQUEEZE VELOCITY (HPD) =-0.43664227-87

MINIMUM FILM THICKNESS (MMT) = 0.52806640-06 Estimatej & Trunc. Enror in MMT = 0.1070-02

FRICTION CCEFFICIENT (FPD) = 0.7512248D-04 Modifier Term (CMPT) = 0.8021639C-10

CAVITATION BOUNDARY (XE) = 0.14497340-01 SS CAVITATION 9C (XEF) = 0.14496310-01

STEP NO. = 16

TIME (TC) = 0.50000000+00

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| . X | ₽ | M | | |
|----------------|---------------|----------------|-----|----|
| 0.16003800-01 | 8.0 | 8.20419615-83 | 1 | 1 |
| 0.14738949-01 | 8.0 | 8.13757583-83 | 11 | 2 |
| 0.13222575-01 | | 8.68923460-84 | 22 | 3 |
| 0.11706310-01 | | 8.57254580-05 | 33 | • |
| 8.11565460-81 | | 8.57510850-86 | 34 | 5 |
| 8.16196840-81 | 0-67827610+06 | 8.53121180-06 | 44 | 6 |
| 8-86737760-02 | 8.13693630+07 | 0-53807640-06 | 55 | 7 |
| 8.71575180-82 | 8.19349150+87 | 0.54549580-05 | 66 | 8 |
| 8.56412450-82 | 0-23947210+07 | 0.55349112-06 | 11 | 9 |
| 8-41249790-82 | 8-27447780+07 | 8.56218410-86 | 88 | 10 |
| 0.26857140-82 | 8.25953147+87 | 6.57170573-06 | 99 | 11 |
| 8-10924480-02 | 8-31353790+07 | 0-59222750-06 | 110 | 12 |
| | 0.31667597+17 | 8.55358412-06 | 121 | 13 |
| 8.19480530-82 | 8.38893780+87 | 8.60730189-06 | 132 | 14 |
| 8.34563490-82 | 8.27823920+07 | 8.62265425-66 | 143 | 15 |
| 0.49726140-02 | 0-26050832+07 | 0.64082975-06 | 154 | 16 |
| 0.64575800-02 | C.21956480+87 | 0.66310312-06 | 165 | 17 |
| 0.40051450-02 | 8-16761782+07 | 8.69206680-06 | 176 | 19 |
| 0.95214110-02 | 8-18426712+07 | 6.73433160-06 | 187 | 19 |
| 8.11837630-01 | 8-29585440+86 | 8.92586320-96 | 198 | 28 |
| 0-12553940-81 | 0.35927080+04 | 0.49342505-04 | 207 | 21 |
| 0-14070213-01 | 0.31323729+04 | 8-10755240-03 | 226 | 22 |
| 8.15586470-01 | 8.38367430+04 | 6.1 8253100-03 | 231 | 23 |
| 0.168088800-01 | 8.38164780+84 | 8-28429970-03 | 234 | 24 |

CURRENT TIME STEP VALLES

SQUEEZE VELOCITY (HHD) = 0.58752470-08

TINITUT FILT THICKNESS (FPT) = 0.52540160-06 ESTIMATED & TRUAC. EROR IN HAT = 0.5210-03

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FRICTION COEFFICIENT (FRC) = 0.16409190-03 Modifier Term (CHMT) =-0.69511450-10

CAVITATION BOUNCARY (XE) = 0.11568450-01 SS CAVITATION BD (XEF) = 0.11568790-01

STEP NO. = 20

X

TIME (TC) = 0.6250000+00

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A LEEDS UNIVERSITY WW/RSE 6.16 ATAC FILE: YTCA

| 10-300001110 | 0.0 | ちゅーいのり じいいいの * ● | e -1 | - |
|---|-----------------|----------------------|-------------|---------------|
| 10-00611961-01 | 0-0 | 6-26796515-03 | ~ | N |
| 0-13090390-01 | C • 0 | 8-214664248 | • | • |
| 10-000000000000000000000000000000000000 | 0.0 | 0-15007660-03 | 21 | • |
| 59-02199966. | 0.0 | キローいた しきまいの チョロ | 26 | n |
| .93618620-02 | | + 18915+5+-# | 5 | • |
| .6782552-32 | 0.0 | 0+55756610-05 | 42 | • |
| . 65572980-62 | | 0.57224625-06 | • | æ |
| .52833933-32 | 8-24273675+86 | 9-2494912-96 | 5 | • |
| -36249539-02 | 0-00100-00 | 8-2264341-0 6 | 36 | 10 |
| .28459242-02 | 0-19042539+06 | 6-5752782-36 | 5 | 11 |
| .46651410-03 | 6-10117410+07 | 6-59750855-86 | 70 | 12 |
| -11121752-02 | 6-10178900-07 | 6-52524145-06 | 11 | 13 |
| -26912053-92 | 8 - 59849030+66 | 6+6620316C-06 | • | : |
| . 42702152-02 | 8-64265549+06 | 8.7165P41C-86 | 16 | 15 |
| .58492240-82 | 0+2382282+06 | e.e3733110-06 | 56 | 16 |
| -74232340-02 | 6-20460245+04 | 8-28530435-84 | 105 | 17 |
| -96672433-02 | | 8-64156825-04 | 112 | 19 |
| .10566250-01 | 0-14712897+03 | C+1 1570690-03 | 117 | 6 |
| .12165253-01 | 50+0620545+0 | 6.175576EC-03 | 126 | 0
N |
| .15744270-01 | 8-64867673+03 | C+2437599C-03 | 112 | 21 |
| .15323280-11 | 8+42152613+83 | 6.32025515-03 | 140 | 22 |
| -16000000-01 | 8-61 643793+03 | 6-355521C-63 | 541 | 23 |
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CURRENT TIME STEP VALUES

SQUEEZE VELOCITY (M40) = 0+44060019-07

MINIMUN FILY THICKAESS (MMT) = 0.52851950-06 Estimated & Trunc. Erage in MMT = 0.7995-02

FRICTION CCEFFICIENT (*40) = 0.14254060-03 Modified Term (compt =-0.59914420-09

CAVITATION BOUNCARY (XE) = 0.6557290C-02 SS CAVITATION 3C (XEF) = 0.65593292-02

4 N STEP NO. = TIME (TC) = 0+75300333+60

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ч 9 9 0+38277596-03 0+36294145-03 8.10300003-31 8.14426690-31

| 8-12826692-01 | 8.0 | 8.23831570-83 | 126 | 3 |
|-----------------|--------------------|----------------|------|----|
| 0.11225690-01 | 8.3 | 0.1EE17242-C3 | 176 | • |
| 8.76266843-32 | 8.8 | 0.11056430-03 | 240 | 5 |
| 0.992-6935-02 | 8.0 | 8.62422652-04 | 390 | 6 |
| 8-542-6520-82 | 0.0 | 8-24946320-64 | 36C | 7 |
| 8-53333440-82 | | 8-35169172-05 | 401 | |
| 8- 48266910-42 | 8-87213820+85 | 8-52711780-86 | 428 | |
| 8-12256800-12 | 8-48448530+46 | 8-52559146-96 | 480 | 10 |
| 8-16266790-82 | 8-58734467+66 | 8-53256545+86 | 544 | 11 |
| 8-36677770-84 | 8.63979753486 | 8-5162747-86 | 680 | 12 |
| | 8-566365 30436 | 8.54122155-86 | 660 | 11 |
| | 17541400436 | A SAACA 317-04 | 738 | 14 |
| | A. 42233 500 + 0 5 | 0.54585130_64 | 720 | |
| | | | | 15 |
| -0.63/332/3-02 | -0.12778313-02 | 0.23895375404 | 848 | 16 |
| -8.79733290-92 | -8+28721 370+82 | 8-62183290-84 | 788 | 17 |
| -8.95733299-92 | -8. J224924D+82 | 0.10889426-03 | 568 | 14 |
| -0.11173330-01 | -0.33401330+02 | 8.16421961-03 | 1020 | 19 |
| -0.12773332-01 | -8.34863850+82 | 8-22807632-03 | 1089 | 20 |
| -0-14573330+01 | -8.34378760+02 | 8.30846755-03 | 1140 | 21 |
| -0.15773330-01 | -8-34566647+02 | 6.30139192-03 | 1200 | 22 |
| -0.1 -000000-01 | -8-34567989+02 | 9.38281380-03 | 1201 | 23 |
| | | | | |

CURRENT TIME STEP VALUES

SQUEEZE VELOCITY (HMO) =-0.62917240-07

MINIMUM FILM THICKNESS (MMT) = 0.52665410-06 ESTIMATED & TRUNC. LRROR IN MMT = 0.5580-02

FRICTION COEFFICIENT (FRD) = 0.75209520-05 MODIFIER TERM (CMPT) = 0.26789940-09

CAVITATION BOUNCARY (XE) = 0.53333430-02 SS CAVITATION BC (XEF) = 0.51629700-02

STEP NO. = 28

TIME (TC) = 0.9750300C+00

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| 0.1.0000000-01 | 8.9 | 0-37458785-03 | 1 | 1 |
|----------------|-----|---------------|----|---|
| 0-14914260-01 | 0.0 | 0.31564650-03 | 7 | |
| 0.13430930-31 | 0.5 | 0-24723155-03 | 14 | 3 |
| 0-11587690-01 | 0.0 | 0.10244782-03 | 21 | 4 |
| 0-10374410-01 | 0.7 | 0-12730160-03 | 28 | |

| 9.84611210-02 | .0 | 8.78796895-04 | 35 | 6 |
|-----------------|---------------|---------------|-----|----|
| 0.73479390-92 | 8.0 | 0.37905540-04 | 42 | 1 |
| 8-58345580-82 | | 0.46277320-05 | 45 | |
| 0.56123660-32 | 0.0 | 8.55677640-06 | 58 | 9 |
| 8-43212643-82 | 6.25054860+96 | 8.53997790-06 | 5E | 10 |
| 8.28877770-82 | 8-47755110+76 | 8-56831490-06 | 62 | 11 |
| 8-1294-930-82 | 8-67446820+96 | 8.58464550-86 | 71 | 12 |
| -8-21957287-83 | 8.76816532+06 | 8.61488272-86 | 77 | 13 |
| -8.17319780-92 | 8.73376112+06 | 8.65481820-06 | 84 | 14 |
| 8.32451647-92 | 8.57430240+05 | 8.71298712-06 | 91 | 15 |
| -B. 4755458C-02 | 8-26823240+:6 | 8-83697502-86 | 98 | 16 |
| 9-62717352-82 | 8-28929130+04 | 8.13662992-84 | 105 | 17 |
| 0.77850210-02 | 8-77254740+03 | C_4697889C-84 | 112 | 18 |
| 0.7298 3070-02 | 8-46084772+03 | 2-92034896-04 | 119 | 19 |
| 0.10811599-01 | 8-35305132+03 | 6-14274750-03 | 126 | 20 |
| 0-12324480-01 | 8-30415462+83 | 8-20109756-03 | 132 | 21 |
| 8-13438160-81 | 8-2/404300+93 | 8-26708260-03 | 140 | 22 |
| 8-15351450-01 | 8-25263519+73 | 8-34876190-03 | 147 | 23 |
| 0.1600400D-01 | 6.25794700+03 | 8-37458990-03 | 150 | 24 |

CURRENT TIME STEP VALUES

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SQUEEZE VELOCITY (HPO) = 0.83983450-07

MINIMUM FILM THICKNESS (HMT) = 0.52515610-06 ESTIMATED X TRUAC. ERROR IN HMT = 0.1010-02

FRICTION COEFFICIENT (FRO) = 0.45835950-03 MODIFIER TER4 (CHMT) = 0.1347224C-09

CAVITATION BOUNCARY (X5) = 0.56193660-02 SS CAVITATION BC (XEF) = 0.56225930-02

STEP NO. = 32

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TIME (TC) = 0.10000000001

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| 0-160000000-01 | 0.0 | 0.33650140-03 | 1 | |
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| 0-14859270-01 | 0 | 8.27773215-03 | E | |
| 0.13455630-01 | 0.0 | 0.21159130-03 | 12 | |
| 0.12052942-01 | 9.3 | 0.1519596C-03 | 1* | |
| 0.10650333-01 | 0.0 | 0 9894045-04 | 24 | |
| 0.92476790-32 | 6.3 | 0.52357510-04 | 30 | |
| 8-79450300-02 | 0.0 | 8-12009070-00 | 36 | |

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| 8./3774380-82 | 8.8 | 9.57816682-86 | 38 | - 考 |
|-----------------|---------------|---------------|-----------|-----|
| 8.64423810-82 | 8.24455643+36 | 0.54617940-06 | 42 | 9 |
| 8-50397320-02 | 8.53152112+36 | 8.55545142-06 | 47 | 10 |
| 6.36370932-02 | 8.96956152+36 | 0.57424250-06 | 54 | 11 |
| 8.22344353-82 | 0.10963500+97 | 8-55107650-06 | 68 | 12 |
| 0.83179590-03 | 0.12491702+37 | 8.61041855-06 | 6E | 13 |
| -8.57886340-43 | 8.13155650+07 | 8-63321095-06 | 72 | 14 |
| -8-19735127-02 | 0.12832667+07 | 8.66095510-06 | 76 | 15 |
| -8.33761610-02 | 8-11398072+37 | 8-67646255-06 | 94 | 16 |
| -0.47788990-02 | 8-37256552+06 | 0.74615605-06 | 58 | 17 |
| -8-61814583-02 | 8.46316570+06 | 0.83256535-06 | 96 | 19 |
| -0.75841072-02 | 8-10245650+04 | C-62615720-05 | 192 | 19 |
| -0-69967560-82 | 0.14507527+84 | 8-44553022-84 | 107 | 20 |
| -8-18389402-31 | 8.59836252+93 | 6.95817595-09 | 114 | 21 |
| -0-11792030-01 | 8-84576142+83 | 8-14166210-03 | 120 | 22 |
| -8-15194793-01 | 8-73070795+83 | 0-20007020-03 | 126 | 23 |
| +0-14597350-01 | 8-79626393+03 | 6-26503972-03 | 132 | 24 |
| -8-168899800-81 | 8.72567650+83 | 6-33656620-03 | 138 | 25 |

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CURRENT TIME STEP VALUES

SQUEEZE VELOCITY (HPD) = 8.90071570-07

NINIMUM FILM THICKNESS (HMT) = 0.53823160-06 ESTIMATED & TRUNC. ERROR IN HMT = 0.5170-02

FRICTION COEFFICIENT (FPO) = 0.3734284C-03 NODIFIER TERN (CHMT) =-0.3955858C-89

CAVITATION BOUNCARY (HE) = 0.73774800-02 SS CAVITATION BC (KEF) = 0.73805940-02

******** MAXIPUN RELATIVE DIFFERENCE = 0.56711210-02

NUMBER OF STEFS = 32

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