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## THIXOTROPIC PROPERTIES OF WHOLE HUMAN BLOOD

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## THIXOTROPIC PROPERTIES OF WHOLE HUMAN BLOOD

ΒY

JEN AN SU

## A DISSERTATION

## PRESENTED IN PARTIAL FULFILLMENT OF

## THE REQUIREMENTS FOR THE DEGREE

OF

## DOCTOR OF ENGINEERING SCIENCE IN CHEMICAL ENGINEERING

AТ

#### NEW JERSEY INSTITUTE OF TECHNOLOGY

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## Newark, New Jersey 1980

## APPROVAL OF DISSERTATION

THIXOTROPIC PROPERTIES OF WHOLE HUMAN BLOOD

ΒY

JEN AN SU

FOR

DEPARTMENT OF CHEMICAL ENGINEERING AND CHEMISDRY

NEW JERSEY INSTITUTE OF TECHNOLOGY

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MAY, 1980

#### ABSTRACT

The rheological property of whole blood from various human subjects was studied with a Weissenberg Rheogoniometer, modified with a continuously variable speed drive. Experimental data showed a hysteresis loop in the shear stress versus the shear rate plot and a torque-decay in the shear stress versus the shearing time plot which is under a constant shear rate. The rheological equation previously developed by Huang was employed to define the thixotropic parameters of each whole blood sample based upon the recorded rheograms.

The altered thixotropic parameters for the blood from patients with open heart surgery at different clinical stages were quantitatively determined. The viscosity by non-Newtonian contribution during the stage of cardiopulmonary bypass showed tremendously high values for the expired patients. Effect of temperature on the blood from normal healthy adults may imply a particular thixotropic temperature existing in a thixotropic system, at which the thixotropic properties reach minimum. It also reveals that  $37^{\circ}$ C is the optimal temperature for human subjects at normal physiological conditions. The rheological behaviors of blood affected by normal linear alkanols were mainly determined

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by the solubilities of alkanols in water and chemical speciality of the red blood cell. Both hydrophilic and hydrophobic alkanols tended to increase blood thixotropic properties. Amphiphilic alkanols increased blood thixotropy at low concentration and, hemolysed blood to a Newtonian fluid at high concentration.

A theoretical analysis of the artifacts of the torsion head to the experimentally obtained rheograms of torquedecay curve and hysteresis loop demonstrated the dynamic behaviors of the torsion head as well predicted the real rheograms of the tested fluid. The experimental data which have been proved from the study are true hemorheological properties and involve no artifacts.

This investigation has shown the significance of the rheological test of whole human blood. It can be developed as a clinical test, which will supply diagnostic information beyond the standard clinical tests available at this time.

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## DEDICATION

To my wife, Shuh, whose inspiration, encouragement and understanding made it possible; and to my son, Hansen, who has made it worthwhile; and to my parents who taught me the value of education.

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#### CHAPTER I

#### INTRODUCTION

To induce flow of a fluid, a force must be exerted on the fluid so that the viscous forces of mutual attraction between molecules are overcome and the molecules are displaced relative to each other. Rheology is the study of deformation and flow of matter. The physical property that characterizes the flow of simple fluids is the viscosity. The equation that describes the relationship between shear stress and shear rate is called the rheological equation of the fluid at the particular state.

Numerous empirical equations, or models have been proposed to express the steady-state relation between shear stress and shear rate depending on the rheological properties of the fluid at the state. The simplest one which describes the rheological properties of fluids is the Newtonian model.

$$\mathcal{T}_{r\theta} = -\mathcal{H} \dot{\mathcal{Y}}_{r\theta} \tag{I.1}$$

where  $\gamma_{r\theta}$  is the shear stress,  $\dot{\gamma}_{r\theta}$  is the shear rate and,  $\gamma$  the viscosity, a constant.

However, there are many materials that flow but for which the viscosity is not a constant and these are called non-Newtonian fluids. They need two or more rheological parameters to describe their rheological behaviors such as the Bingham model, the Ostwald-de Waele model, the Eyring model ( all being two parameter models ) and the Ellis model, the Reiner-Philippoff model ( all being three parameter models ) (1), of which the apparent viscosities are not constants as those of Newtonian fluids but a function of shear rate or shear stress. All these models are mainly these dealing with fluids with a monotonic rheological properties, for which there is one definite shear stress associated with each value of the shear rate.

Among the non-Newtonian fluids, there are certain materials which have more complicated rheological behaviors. Their viscosities are not just a function of shear rate but also a function of time. This usually indicates that the fluid processes a structure transformation while a mechanical disturbance is induced to the system. The amount of structure change is dependent on the energy (shear rate ) that is forced into the system and how long a time the mechanical disturbance acts on the system. The thixotropic material is characterized by an isothermal, reversible structural breakdown due to the action of a mechanical disturbance on the material. The thixotropic system exhibits the following rheological properties (2):

1. A torque-decay curve (Fig.I.1) will be generated if a suitable single step change shear rate is induced to the system. 2







Fig.I.2 Hysteresis loop

2. A hystersis loop will happen (Fig.12.) if a triangular step change shear rate is induced to the system.

3. A shear-thinning phenomenon will be brought up if the mechnical disturbance continues as the 2 above. That means the hystersis loop will become smaller and smaller and, finally turn to pseudoplastic behaviors.

4. Once the mechanical disturbance is removed, the system will recover to its original structure after certain time. This means that the thixotropic material has memory.

5. The system may have or may not have yield stress.

Since Freundlich introduced thixotropy in 1928, many investigators (47 to 53) have been attracted to study it both empirically and theoretically. Most of equations available in the literature are unable to explain the various thixotropic phenomena. Based on irrevesible thermodynamic principles, using a molecular arrangement parameter to describe the structure breakdown of thixotropic materials during shearing Huang (2) derived an equation containing five parameters which is suitable to describe the rheological behaviors of thixotropic materials. The five parameters can be used to characterize the flow properties of the whole thixotropic system and, simultaneously to avoid the variations in results due to the varying conditions of tests at different shear rates.

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From a macroscopic point of view, human blood is a concentrated suspension of formed elements ( primarily red cells, white cells, and platelets ) in plasma (3). The plasma in turn is a colloidal suspension of the plasma proteins ( mainly serum albumin, serum globulins, and fibrinogen ) in a weak electrolyte of composition. The predominant formed elements are the red cells, which are typically in the form of biocave disc about  $8\mu$  in (42) diameter when relaxed, but which can undergo very severe deformations. They typically make up about 93% by number of the formed elements or about 40 to 45% of the blood volume, and they have very pronounced effect on blood rheology. The platelets are considerably smaller and are present to the extent of only about 5% of the red-cell volume. They have little direct effect on rheology, but play an important role in clotting. The white cells or leucocytes occur in a relatively small numbers, and are of little direct importance in rheology. The major plasma protein, fibrinogen that make red cells tend to aggregate, also play an important effect on the rheological properties of blood.

Recently it was confirmed that blood is a nearly Newtonian fluid at sufficiently high shear rates which can usually be considered so in arterial flow. However at low shear rates which are of most clinical importance in the microcirculation where shear rates tend to low, blood is a complex thixotropic system (37).

Basically, the bulk of thixotropic properties of the blood appear to be due to the reversible aggregation of the red cells. The degree of aggregation of the red cells may be affected due to a number of causes such as physical ( shear rate, time, force fields, etc. ), chemical ( hematocrit, fibrinogen, chemicals, etc. ), and pathological ( heart diseases, diabetes, etc. ) reasons. One of these investigations which has been done in this study is relative to open heart surgery. An extensive research on its pathogenesis attracted many able investigators, and the biochemistry and histology have been studied. Yet at the same time, little attention has been paid to the role of the fluid which has been driven through the heart, and particularly the studies of the altered rheological properties of the blood from patients at various clinical stages were also neglected. Effects of temperature and chemicals on blood rheology are also very significant. Based on the Huang model, the rheological parameters generated from these investigations on the blood under different pathological, chemical, and physical conditions appear to be truly meaningful and valuable.

Theoretical study showed (9) that a Newtonian fluid would generate a hysteresis loop provided that a triangular step shear rate change was induced to the system. The artifact of rheograms due to the influence of torsion head should be eliminated, or at least minimized in order to obtain most accurate experimental results from the system. Thus, to understand the dynamic behaviors of torsion head, a theoretical analysis of the system is necessary, which will provide some critical information in the arrangement of torsion head, and in determining the accuracy of experiments.

The significance of this theoretical analysis is its ability to predict the real rheograms of the tested fluid. The experimentally rheological data for whole blood from this investigation, which have been proved by this theoretical analysis are true hemorheological properties without any artifacts.

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#### CHAPTER II

## THEORY

## 1. The Huang Model - Thixotropic Fluids

Since Freundlich first introduced the term thixotropy in 1928, various attempts have been made, over the years, to define "thixotropy ". Most of the model available in the literature (47, 48, 49, 50, 51) are only specific with respect to a particular thixotropic property. Others (52, 53) which are more general require too many constants to be evaluated, are not quantitative, or have not been rigorously tested.

Recently it has been confirmed that blood, mainly due to the rouleaux formation of red cells, is a thixotropic fluid. Much of the work on blood and its components involves quite advanced mathematics as well a considerable knowledge of haematological terms (3). Casson's equation could be only applied at low shear-rates, and especially for bovine blood which will not form rouleax. Based on an unsuitable assumption that the red cell was a rigid spherical particle and the rouleaux were broken into two equal parts by shearing, Murata (4) theoretically studied the effect of rouleaux on the non-Newtonian viscosity of blood at low shear rates. His derivation finally resulted in an equation much the same as Casson's equation.

More recently, Thurston (5) used a generalized Maxwell

model containing N relaxing spring-dashpot combinations to describe the viscoelastic behaviors of blood. This model would induce uncertain rheological parameters for different blood under same experimental conditions, and brought difficulties to explain the physical meaning of blood thixotropy. Bureau et al. (6) only chose the acceleration constant and the time at the maximum shear rate as parameters from a triangular step change shear rate to correleate the hysteresis shape of blood. Again, these two experimental parameters do not reveal any thixotropic meaning of blood.

Based on irreversible thermodynamic principle as mentioned red cell rouleaux dissociation which is the basis of the model Huang (2), who introduced a molecular arrangement parameter, generalized a rheological equation for timedependent and time-independent non-Newtonian fluids. This equation containing five parameters with their suitable physical meanings is adapted to be used in quantitative analysis of the hysteresis (including single and multiple) and torque-decay phenomena of thixotropic materials.

The Huang equation (Appendix I.2) is:  $-\int_{0}^{t} c |\dot{\gamma}_{r\theta}|^{n} dt$   $T_{r\theta} = T_{0} + \mu \dot{\gamma}_{r\theta} + CA \dot{\gamma}_{r\theta}^{n} e$  (II.1-1) For a single hysteresis loop: the shear rate linearly increases from zero to a maximum value (at time t<sub>1</sub>) and then decreases again toward zero (at time 2t<sub>1</sub>).

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when  $o \leq t \leq t_1$ 

$$\begin{aligned} \mathcal{T}_{r\theta} &= \mathcal{T}_{\theta} + \mathcal{M} \, \dot{\mathcal{Y}}_{r\theta} + CA \, \dot{\mathcal{Y}}_{r\theta}^{n} \, \exp\left(-\frac{C \, \dot{\mathcal{Y}}_{r\theta}^{n+1}}{\alpha(n+1)}\right) \\ \text{when} \quad t_{1} \leq t \leq 2t_{1} \end{aligned} \tag{II.1-2}$$

$$\chi_{r\theta} = \chi_{\theta} + \mu \dot{\gamma}_{r\theta} + CA \dot{\gamma}_{r\theta}^{n} \exp\left(-\frac{C}{d(n+1)}\left[2\dot{\gamma}_{r\theta}^{n+1}(\tau_{1}) - \dot{\gamma}_{r\theta}^{n+1}\right]\right)$$
(II.1-3)

For a torque-decay curve: a single step change shear rate.

$$\mathcal{T}_{\gamma\theta} = \mathcal{T}_{o} + \mathcal{M} \, \dot{\gamma}_{r\theta} + CA \, \dot{\gamma}_{r\theta}^{n} \exp\left(-C \, \dot{\gamma}_{r\theta}^{n} t\right)$$
(II.1-4)

Where

Theoretically this model can be applied to any ranges of shear rates and time. As to the steady state viscosity at a constant shear rate, which most investigators used to test the rheological properties of blood, this too can be obtained from the above model as time goes to infinity. The non-Newtonian contribution of viscosity at a constant shear rate is determined by  $\mathcal{M}_s - \mathcal{M}_s$  where  $\mathcal{M}_s$  is the steady state viscosity at a constant shear rate.

Most investigators in rheology have only considered that the apparent viscosities of thixotropic materials ( blood ) are a function of shear-stress or, shear-rate, and have ignored the importance of time factor. To emphasize the time dependency which will affect the rheological properties of thixotropic materials under a certain shear rate is one of the particular points in the Huang model. The separation of mechanical disturbance ( shear-rate ), time, and other factors which will influence the thixotropic behaviors of blood is another speciality of the model. So to characterize the thixotropic properties of blood quantitatively and qualitatively, the Huang model is able to provide some simple and meaningful index through its rheological parameters which actually are the functions of blood under various physical, chemical, and pathological

conditions. It is possible that the rheological parameters introduced through the Huang equation could be applied in the various branches of science related to technologies of thixotropic materials.

## 2. Dynamic Behaviors of the Torsion Head

In most conventional viscometers, such as two parallel plates, two coaxial cylinders, cone and plate system, etc., the torque is transmitted by the measured fluid to the torsion bar due to the angular movement of the rotating part of the viscometer. Calibration of the torbar constant is usually done experimentally, and sion it is assumed that the angular deflection of the torsion bar is proportional to the supplied torque. Van de Ven (8) analyzed the dynamic behavior of viscometer by assuming the hollow cylinder or bob is suspended by a torsion wire which was given a forced oscillation at the top. He made a flate plate approximation in which he failed to consider the curvature of the bob. Also a little attention has been paid to the artefact of rheograms due to the influence of the mechanical properties of the torsion head. In this analysis, the angular displacement, angular velocity, and the angular acceleration of the whole torsion head induced by the rotating cup all are considered. In the following derivation, both a single step rotation and a triangular step rotation have been forced on the system.

1.3



- $\lambda$  = Angular deflection of torsion bar
- G = Torsion bar constant
- $\gamma$  = Torsion head damping coefficient
- I = Moment of Inertia of torsion head
- M = Viscosity of tested fluid
- R = Radius of rotating cylinder
- L = Length of inner cylinder
- $\Omega$  = RPM of rotating cylinder
- a = Acceleration (deceleration) constant for a triangular step change
- t = Time
- $\dot{\gamma}_{ro}$  = Shear rate
- (1) = Single step change
- (2) = Triangular step change



Equation of motion of the torsion head

$$I\frac{d^{2}d}{dt^{2}} + \eta\frac{d\alpha}{dt} + G\alpha = T(t)$$

$$B.C. \quad \alpha(0) = 0 \quad ; \quad \alpha'(0) = 0 \quad (11.2-1)$$

Assume an incompressible Newtonian fluid in the viscometer. Equation of motion of the fluid

$$\rho \frac{\partial V_{\theta}}{\partial t} = \mu \frac{\partial}{\partial r} \left[ \frac{1}{r} \frac{\partial (rV_{\theta})}{\partial r} \right]$$
(11.2-2)

For a step change

. . . . . ...

$\vee_{\theta}(r, o) = 0$	t = 0		
$V_{\theta}(KR,t) = 0$	t≯o	Υ.	(11.2-3)
$V_{\theta}(R,t) = R\Omega$	t⋧o		

.

Fabisiak and Huang (9) have found that the transient terms are very small, and can be neglected. The torque applied to the inner cylinder is:

$$T(t) = 2\pi K^2 R^2 L \mu \frac{2\Omega}{1-K^2} = A_0 = \text{Constant}$$
 (II.2-4)

.

Similarly for a triangular step change ( hysteresis loop ),

.

•

the boundary conditions for the fluid will be:

$$V_{\theta}(r, 0) = 0$$

$$V_{\theta}(R, t) = 0$$

$$V_{\theta}(R, t) = F(t) = \begin{cases} aRt & j \quad 0 \le t \le t_{i} \\ 2aRt_{i} - aRt & j \quad t_{i} \le t \le 2t_{i} \end{cases}$$
(II.2-5)

where a = angular acceleration constant of outer cylinder. It was shown (9) that the dimensionless group,  $\mathbb{N}_{HF}$  may be defined:

$$N_{HF} = \frac{(1-K^2)R}{2t_i} \int \frac{F_i}{M} \frac{F_i}{\beta_i} Z_o \left( \int \frac{P}{M} \beta_i \tilde{K}R^2 \right) \langle \tilde{\zeta} | (11.2-6)$$

The torque applied to the inner cylinder by an incompressible Newtonian fluid can be simplified as follow:

$$T(t) = \frac{4\pi a L \kappa^{2} \mu t}{1 - \kappa^{2}} = Bt ; \quad 0 \le t \le t_{1}$$

$$= B(2t_{1} - t) ; \quad t_{1} \le t \le 2t_{1}$$

$$(II.2-7)$$

Equation ( II.2-1 ) can be rewritten as follow:

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$$\gamma^{2} \frac{d^{2} d}{dt^{2}} + 2 \xi \gamma \frac{d\alpha}{dt} + \alpha = \frac{1}{G} T(t) \qquad (II.2-8)$$

Boundary conditions:  $\lambda(0) = 0$ 

$$\chi'(0) = 0$$

Where  $\chi = (I/G)^{\frac{1}{2}}$  Time constant  $\xi = \chi / 2(IG)^{\frac{1}{2}}$  Damping factor

Substitute Eq. II.2-4 for a single step change, (40) and Eq. II.2-7 for a triangular step change ( hysteresis loop ) into Eq. II.2-8. Then, apply the method of Laplace transformation to solve Eq. II.2-8. The following solutions were obtained:

<u>Case 1</u>: For small  $\gamma$  and  $\xi$ , or  $\gamma \rightarrow o$ ,  $\xi \rightarrow o$ <u>Step change</u>

$$d = \frac{4\pi \kappa^{2} R^{2} L \mu \Omega}{(1 - \kappa^{2}) G} = \frac{A_{0}}{G}$$
(II.2-9)

Triangular step change

<u>Case 2</u>: For small  $\xi$ , or  $\xi \to 0$ 

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Step change

$$d(t) = \frac{A_0}{G} \left( 1 - \cos \frac{t}{\tau} \right)$$
 (II.2-11)

Triangular step change

$$d(t) = \begin{cases} \frac{B}{G}(t - \tau \sin \frac{t}{\tau}) ; & 0 \le t \le t_1 \\ (II.2-12) \\ \frac{B}{G}\left[2t_1(1 - \cos \frac{t}{\tau}) - (t - \tau \sin \frac{t}{\tau})\right] ; \\ 0 \text{ verdamped.} \quad \le 1 \end{cases}$$

<u>Case 3</u>. Overdamped,  $\xi > 1$ <u>Step change</u>

$$\begin{aligned} & \alpha(t) = \frac{A_{o}}{G} \left[ 1 - \frac{1}{2\sqrt{\xi^{2}-1}} \left\{ (\xi + \sqrt{\xi^{2}-1}) e^{-(\xi - \sqrt{\xi^{2}-1})\frac{t}{\tau}} - (\xi - \sqrt{\xi^{2}-1}) e^{-(\xi + \sqrt{\xi^{2}-1})\frac{t}{\tau}} \right\} \right] \\ & (\text{II.2-13}) \end{aligned}$$

Triangular step change

$$d(t) = \frac{B}{G} \left[ t - 2\xi T + \frac{\chi}{2\int_{\xi^{2}-1}^{\xi^{2}-1}} \left\{ (2\xi^{2}-1 + 2\xi)\int_{\xi^{2}-1}^{\xi^{2}-1} \right) \times \left[ e^{-(\xi+\int_{\xi^{2}-1})\frac{t}{\tau}} - (2\xi^{2}-1 - 2\xi)\int_{\xi^{2}-1}^{\xi^{2}-1} \right] e^{-(\xi-\int_{\xi^{2}-1}^{\xi^{2}-1})\frac{t}{\tau}} \right];$$

$$0 \le t \le t_{1} \qquad (II.2-14)$$

$$d(t) = \frac{2t_{1}B}{G} \left[ 1 + \frac{1}{2\sqrt{3^{2}-1}} \left\{ (\varsigma - \sqrt{3^{2}-1})e^{-(\varsigma + \sqrt{3^{2}-1})\frac{t}{\tau}} - \frac{(\varsigma + \sqrt{3^{2}-1})\frac{t}{\tau}}{G} \right\} - \frac{\beta}{G} \left[ t - 2\varsigma\tau + \frac{\tau}{2\sqrt{3^{2}-1}} \left\{ (2\varsigma^{2}-1) + 2\varsigma\sqrt{3^{2}-1} \right]e^{-(\varsigma + \sqrt{3^{2}-1})\frac{t}{\tau}} + \frac{\tau}{2\sqrt{3^{2}-1}} \left\{ (2\varsigma^{2}-1) + 2\varsigma\sqrt{3^{2}-1} \right]e^{-(\varsigma + \sqrt{3^{2}-1})\frac{t}{\tau}} - \frac{(\varsigma - \sqrt{3^{2}-1})\frac{t}{\tau}}{C} - \frac{(\varsigma - \sqrt{3^{2}-1})\frac{t}{\tau}}{C} + \frac{(2\varsigma^{2}-1) - 2\varsigma\sqrt{3^{2}-1}}{2\varsigma\sqrt{3^{2}-1}} e^{-(\varsigma - \sqrt{3^{2}-1})\frac{t}{\tau}} \right\} \right];$$

<u>Case 4</u>. Underdamping, ξ < | <u>Step change</u>

$$d(t) = \frac{A_{0}}{G} \left[ 1 - \frac{e^{-\frac{5}{2} \frac{t}{T}} S_{1N} (\sqrt{1-\frac{5^{2}}{T} - \frac{t}{T}} - \phi)}{\sqrt{1-\frac{5^{2}}{T}}} \right]$$
  
where  $\phi = +an^{-1} \frac{\sqrt{1-\frac{5^{2}}{T}}}{-\frac{5}{T}}$  (II.2-15)

$$\frac{\text{Triangular step change}}{d(t) = \frac{B}{G} \left[ t - 2\xi \tau + \frac{\tau e^{-\xi \tau}}{\int 1 - \xi^2} 5IN \left\{ \int \overline{1 - \xi^2} \frac{t}{\tau} - 2\xi \tau + \frac{\tau e^{-\xi \tau}}{\int 1 - \xi^2} \right\} \right], \quad 0 \le t \le t_1$$

(II.2-16)

$$d(t) = \frac{2t_{1B}}{G} \left[ 1 + \frac{e^{-5\frac{t}{\tau}} + s_{1N} \left\{ \int 1 - s^{2} \frac{t}{\tau} - \frac{t}{\tau} - \frac{t}{\tau} - \frac{1}{\tau} - \frac{1}{\tau} - \frac{1}{\tau} \right\} \right]$$
  
$$- \frac{B}{G} \left[ t - 2s\tau + \frac{\tau}{\tau} - \frac{e^{-5\frac{t}{\tau}}}{\sqrt{1 - s^{2}}} - \frac{1}{\tau} - \frac{1}$$

Case 5. Critical damping, 
$$\zeta = |$$
  
Step change

$$\alpha(t) = \frac{A_0}{G} \left[ 1 - \left( 1 + \frac{t}{\tau} \right) e^{-t/\tau} \right]$$
 (II.2-17)

# Triangular step change

$$\begin{aligned} d(t) &= \frac{B}{G} \left( t e^{-t/\tau} + \frac{2}{\tau} e^{-t/\tau} + t - \frac{2}{\tau} \right) \\ &= \frac{B}{G} F_{i}(t) \quad ; \qquad \qquad 0 \le t \le t_{i} \\ d(t) &= \frac{B}{G} \left[ 2t_{i} \left\{ 1 - (1 + \frac{t}{\tau}) e^{-t/\tau} \right\} - F_{i}(t) \right] \quad ; \qquad (II.2-18) \\ &\quad t_{i} \le t \le 2t_{i} \end{aligned}$$

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Comparison of the theoretical shear stress and the artificial shear stress

The theoretical shear stress is directly from the solution of Eq.II.2-2. with some suitable boundary conditions (Appendix I.1).

Single step change

$$\left(\mathcal{T}_{r\theta}\right)_{T,S} = -\mu r \frac{\partial}{\partial r} \left(\frac{V_{\theta}}{r}\right) = -\mu \frac{2\Omega}{1-K^{2}} \qquad (II.2-19)$$
  
$$r = KR$$

Triangular step change

The transient terms have been found very small (9), so

$$(\mathcal{T}_{re})_{T.t} = -\mu r \frac{\partial}{\partial r} \left( \frac{V_{e}}{r} \right)_{r=KR} = \begin{cases} -\mu \frac{2at}{1-K^{2}}; & 0 \le t \le t_{1} \\ (II.2-20) \\ -\mu \frac{2a(2t_{1}-t)}{1-K^{2}}; & t_{1} \le t \le 2t_{1} \end{cases}$$

At the same single step change and the same triangular step change, the real shear stress due to the effect of the torsion head will be:

$$(\Upsilon_{r0})_{ii} = -\frac{T}{2\pi L (\kappa R)^2} = -\frac{K_{f} \cdot f \cdot d_{j,i}(\mathcal{T}, f)}{2\pi L (\kappa R)^2}$$
 (II.2-21)

Where i is s (single step change) or t (triangular step change), j is the real Case No., f is a scale

adjusting factor of instrument for clear readings on recorder. The artifact will be:

$$(\Delta \mathcal{T}_{r_{\theta}})_{j,i} = (\mathcal{T}_{r_{\theta}})_{j,i} - (\mathcal{T}_{r_{\theta}})_{T,i}$$
 (II.2-22)

It is obviously that Case 1., in which the influence of the torsion head  $(\mathcal{T}, \boldsymbol{\xi})$  is almost zero is an ideal case. The shear stress derived from Case 2. with very small damping factor  $(\boldsymbol{\xi} \rightarrow \boldsymbol{\circ})$  is in a continuous oscillation with respect to time. This can be corrected by adjusting the factor.

The following typical figures coming from a computer program (Appendix I.2) exhibit how the damping factor combined with a time constant influences the rheogram. This involves three cases - underdamping ( $\xi < |$ ), critical damping ( $\xi = |$ ), and overdamping ( $\xi > |$ ).
In case  $\gamma$  is very small, the system even with a large overdamped coefficient  $\not\leq$  (but never for critical damping) can provide very well responses closing to the ones in ideal case for both a single step change and a triangular step change (see Fig.III.1-2 at  $\gamma = 0.01 \text{ sec}^{-1}$ ).

Explanation of Fig.III.1-2:

- 1. Upper figure : System responses due to a single step change.
- 2. Lower figure : System responses due to a triangular step change.
- 3. Solid lines : Not ideal cases.
- 4. Dashed lines : Ideal cases.



Fig. III.1-2 Dynamic behaviors of torsion head at  $\Upsilon$ = 0.01 sec.(A. System response to a single step change, B. System response to a triangular step change; dashed lines for ideal cases, solid lines for no ideal cases due to the artifacts of torsion head;  $(\Upsilon_{re})_{o,m}$  and  $(\checkmark)_{o,m}$ theoretical maximum shear stress and shear rate for ideal cases during a triangular step change;  $(\Upsilon_{re})_o$ theoretical shear stress at a single step change).  $\Upsilon$  is time constant of torsion head.



Fig. III.1-3 Dynamic behaviors of torsion head at time constant  $\mathcal{L} = 0.1$  sec. ( $\boldsymbol{\xi}$ , damping coefficients of torsion head;  $\boldsymbol{\epsilon}$ , maximum deviation from theoretical line; the other descriptions for this figure are same as Fig.III.1-2).



Fig.III.1-4 Dynamic behaviors of torsion head at time constant  $\gamma = 0.2$  sec. (§, damping coefficients of torsion head; the other descriptions for this figure are same as Fig.III.1-2).



Discussion

Case 1 is an ideal case for both a single step change and a triangular step change.

Case 2. Sine waves are generated for both cases, they can be corrected by the installation of a damping plate placed in a viscous fluid in order to adjust the damping factor.

Case 3. The response due to a single step change will be slow. For the triangular step change, artificial hysteresis loops will happen, their sizes and shapes are dependent on the combination of time constant and damping factor.

Case 4. If a suitable combination of time constant and damping factor are selected, the artifacts for both a single step change and a triangular step change would be very small and can be neglected.

Case 5. The artifact may be very small for a step change, but always generate tremendous artifact for a triangular step change.

So, to minimize the artifacts for both cases, the torsion head must be at underdamping. And, a particular set of time constant and damping factor of the system is only suitable for a specific range of shear rates without obvious errors happened in the rheograms generated by the viscometer with a specific damping fluid. And, from (40), page 88, system parameters  $\tau$  and  $\zeta$ for the underdamping case can be calculated from experimental response of d(t) in a single step change.



A/B = overshot = exp 
$$(-\pi \xi \sqrt{1-\xi^2})$$
  
C/A = decay ratio = exp  $(-2\pi \xi \sqrt{1-\xi^2}) = (A/B)^2$   
f = frequency =  $1/T$ 

These relationships can be further applied to modify the torsion head system.

#### CHAPTER III

#### APPARATUS AND EXPERIMENTAL PROCEDURES

### 1. Apparatus

A modified Weissenberg Rheogoniometer Model R-18 was used in the generation of rheograms including a hysteresis loop and a torque-decay curve. The whole experimental system is shown in a schematic diagram as Fig.III.1-1. The main functions of each part are described as follow:

(a). The double couette cell

In order to minimize the unnecessary chemical reactions between blood and the cell, a gold platted double couvette cell was designed as shown in Fig.III.1-2. All the rings have the same working height as L 2.003 inches, but their inner and outer radii differ. The inner and outer radii of the suspended hollow (bob) were 1.137 inches and 1.218 inches, and those of the annulus (rotating ring or cup) were 1.104 inches and 1.252 inches. The dimensions were selected in such manner that the shear rate developed at the inner and outer surface of the susponded hollow is always the same (Appendix III). The actual gap between the surfaces of bob and of cup is 0.017 inches. The gap between the bottoms of the two rings is 500 micrometer. Thus the errors induced by the end effect can be neglected due to the



Fig.III.l-l Block diagram of the modified Weissenberg Rheogoniometer

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Fig.III.1-2 The double couette cell

large ratios of the ring height to the gaps between bob and cup, and of the shearing area of the vertical surfaces to the shearing surfaces of the cell ends.

A guard ring was also extended from the top of the hollow to reduce the reaction between blood and air. The hollow is attached through a universal joint to the torsion bar, and is floated by a 20 psi. dry compressed air in order to eliminate any mechanical friction. The volume of sample needed is at least 4.20 ml. It must be stressed that the shear rates given by this rotational viscometer are homogenous ones. The equations used to calculate the shear rate and the shear stress are adhered in Appendix III.

(b). Direct reading transducer meter

A type EP597A Sangamo Controls Limited (England) transducer was used. Amplifing ranges contain 5, 20, 50, 200, 500, and 2000 times. Output of the torque from cell can directly be read out in this meter, and can also be transferred to the X=Y recorder.

(c). X-Y recorder

Hewlett Packard 7045A X-Y recorder was connected to the system as shown in Fig.III.1-1. The surface area which can be utilized is 15 inches by 10 inches (X by Y).

(d). Temperature control chamber

The whole rheogoniometer was enveloped by a highly heat-resistant plastic chamber. Eight 60 watt electric

bulbs as heat source were installed around the bottom inside the chamber. Temperature controller can control the viscometer temperature from room temperature up to  $45^{\circ}$ C with an accuracy of  $\pm 0.1^{\circ}$ C

(e). Original motor, gear box, and drive unit

A SLO-SYN Synchronous motor with 1500 rpm was installed, and controlled by a home-made control panel. Gear box has 60 step settings. Drive unit is controlled by a clutch including "Drive", "Brake", and "Off".

(f). Control panel

A home-made electronic device combining with (e) can control the rotating speed of cup from 0 to 146.5 rpm differentially. It also included a time setting. By adjusting the setting in the panel and using the clutch, the following functions for the rotating part of viscometer can be generated:





(g). Refrigerator was kept at  $4^{\circ}C$  for the storage of blood samples. Water bath was used to warm the blood sample at the designed degree and time.

(h). Syringe: 5 c.c. sterile single-use PlastipakB-D syringe was utilized to inject the blood sample into the double couette.

## 2. Experimental procedures

(a). Set the desired experimental temperature, let the rheogoniometer (vicometer) warm overnight in order that its temperature reaches a steady state.

(b). Choose a suitable setting at gear box. For blood, the setting at 2.3218 rpm for the stepping motor is desired, Since it will give the maximum shear rate at 8.0361 sec<sup>-1</sup> for the double couvette (Appendix IV). This (40) low shear rate would not cause any damage to the blood subphases, and would generate a clear hysteresis loop for whole blood.

(c). Adjust transducer meter and X-Y recorder to a suitable scale.

(d). Gently shake and heat the blood sample in water bath at the desired temperature and time, then gently inject it into the viscometer.

(e). For hysteresis loop, use control panel to make a triangular step change at cup ( shear rate linearly accelerates from 0 to 8.036l sec<sup>-1</sup>; then linearly decelerates to 0 ).

(f). For torque-decay curve, use control panel

to set the shear rate at 3.2144 sec<sup>-1</sup>, which will generally make clear torque-decay curve for whole blood, then suddenly switch the clutch which originally set at "Brake" to "Drive". A shear stress at constant shear rate 3.2144 sec<sup>-1</sup> can also be obtained.

To check if the rheograms can be reproduced, several runs for (e) and (f) should be carried out.

(g). The experimental data from both rheograms have been transferred to the modified Marquardt computer program. Eventually, the five thixotropic parameters in the Huang model have been evaluated. Because of its importance for the main topic of the thesis and its complexity, the actual computer program has been included into the thesis as an Appendix I.3.

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#### CHAPTER IV

#### EXPERIMENTAL RESULTS

# 1. <u>Altered thixotropic properties of blood during</u> cardiopulmonary bypass

Variations of blood rheological properties are always accompanied by changes in physiological, psychological, and pathological factors. Ehrly (10) exhibited circadian rhythm of young female blood viscosity. Dintenfass (11,12) correlated between biochemical and rheological parameters in patients with myocardial infarction, haemophilia and thyroid diseases; also described the influences of ABO blood groups and fibrinogen on thrombus formation and aggregation of red cells in cardiovascular and malignant diseases (13). Schonbein, et al. had found that pathological red cell aggregation in myeloma patients presented higher abnormal shear resistance. Again Dintenfass (14,15) psychological score index related introduced the the elevation of blood viscosity, and assumed a to hypothetical viscoreceptor mechanism. Elevation of any of the blood viscosity factors is a risk factor and a warning sign, especially in the cardiovascular disorder. The orthodox studies on open heart surgery were

mainly with the pathogenetic pathways via abnormalities of blood pressure, metabolism, dietary regime, formation of atherosclerotic plaques, cholesterol level, and so on; but the intrinsic role of blood rheology was paid little attention, or just was partially investigated only at steady state shear rates. Its thixotropic properties including hysteresis loop and torque-decay curve were rather neglected.

This investigation was concerned with the thixotropic properties of blood during cardiopulmonary bypass. The blood was collected at different clinical stages from patients from the time of entering hospital to the time of leaving hospital ( Dr. J. Cohn, St. Barnabas Medical Center, Livingston, New Jersey, 1977-79 ). For each stage, haemoanalysis was done by routine hospital work. For rheological analysis, each sample was collected as 7 ml. alloquots and anticoagulated with 10.5 mg. EDTA (ethylene diaminetetraacetic acid). Then rheograms of hysteresis loop and torque-decay curve were obtained through the modified Weissenberg rheogeniometer at room temperature. The thixotropic parameters were evaluated by a method of non-linear least square parameter estimation based upon a modified Marguardt program on a Univac Spectra 70 digital computer ( Appendix 1.3 ).

The data of hematological evaluation have proved that there are no constituents in blood from all stages from all blood samples that present any abnormality (Appendix II.1-A).

However, the rheological evaluation indicates that the rheological results have shown a significant difference between patients and normal healthy people, and the results at each clinical stage on patients are also different. Fig.IV.1-1 summarizes their rheological data (Appendix II.1-B).

The parameter A, the equilibrium value of structural arrangement is proportional to the number of erythrocytes in the form of ordered rouleaux formation. The decrease in the value for the structural arrangement parameter A, indicates that more individual erythrocytes or fewer rouleaux formations are present within the whole blood sample at the applied shear rate.

The decrease in the value for C implies that the rate constant for obtaining equilibrium between individual erythrocytes and rouleaux arrangement will shift toward the formation of rouleaux forms.

 $\Upsilon_{o}$  is a physical property of blood flow and is directly related or associated with the formation of rouleaux. Variations in this value follow same patterns as A.  $\mu, \gamma_{s}$ and  $\gamma_{s} \mu$  follow same patterns of variation as A. n reflects the order of reaction of rouleaux breakdown, which implies a certain reaction mechanism.

Observations have been made that the high blood viscosity

in non-Newtonian contribution from the expired patients may be due to an excessive aggregation of the red cells. However, the hematological evaluation can not provide any information in this respect. It appear that there could be other causes which easily induce the excessive aggregation of the red cells when some certain shear rates are applied on the blood for specific time intervals.

This investigation implies that the rheological parameters from the Huang model are not only fundamental in indications of pathogenesis and consequences of heart diseases, but that these parameters might supply a solution for prediction and diagnosis. It is also suggested that such rheological tests will allow, in some cases, a more rapid determination of disease when the current laboratory tests are inadequate.



Fig.IV.1-1 Rheological parameters of patients during cardiopulmonary bypass

# 2. Effect of temperature on thixotropic properties

### of blood

There are numerous factors that affect the rheological properties of human blood. Temperature changes may be regarded as a thermal disturbance. In 1963, Cokelet (16) found that the apparent viscosities of plasma and water had same temperature dependence i.e. they followed Arrhenius law with the same active energy but with a different rate constant. The relative viscosity of blood (relative to water) was independent of temperature between 10°C and  $37^{\circ}$ C at shear rates larger than 1 sec<sup>-1</sup>, but the relative viscosity increased with temperature by about 20% at very low shear rates (less than 1 sec<sup>-1</sup>). Chien, et al. (17) and Barbee (18) also discovered that the relative viscosity of blood (relative to plasma) was independent of temperature between  $20^{\circ}C$  and  $37^{\circ}C$  at high shear rates over 50 sec<sup>-1</sup>, but had an exponential relationship with hematocrit as follows:

 $\gamma = \gamma_{o} \operatorname{Exp}(bH)$  (IV.2-1)

Where  $\gamma_o$  is the apparent viscosity of plasma,  $\gamma$  is the apparent viscosity of blood, H is the hematocrit, and b is a constant which is inversely proportional to the shear rate. All the previous results were considering only one rheological parameter (apparent viscosity), and which was evaluated at high steady-state shear rate. Due to their ignorance of the historical significance and hysteresis phenomenon in blood, this brings much difficulty to explain its thixotropic properties. Based on the Huang model, an investigation in the effect of temperature on the whole blood from healthy adults was attempted. The statistical results were plotted in Fig.IV.2-1 and Fig.IV.2-2. The detailed data were listed in Appendix II.2.

From the two figures, one may find that n is constantly independent of temperature, and C has a slightly exponential relationship with temperature. However, the other parameters vs. temperature almost present same shape with the lowest values at 37°C. Once a slight degree deviation from 37°C happens in the whole blood, i.e. the blood has absorbed or released a small thermal energy, the yield stress, Newtonian viscosity, equilibrium constant, steady-state viscosity, and non-Newtonian viscosity will increase tremendously. These phenomena may be explained as follow:

Since blood is a solution containing high molecular weight sustances, such as macroglobulins, albumins, cells, and especially fibrinogen, etc., which are sensitive to temperature and are greatly affected by temperature changes, the temperature changes may cause a certain orientation and



Fig.IV.2-1 Rheological parameters vs. temperature



Fig.IV.2-2 Rheological parameters vs. temperature

morphological changes of the macromelecules, erythrocytes and their rouleaux. At  $37^{\circ}$ C, one may say as a transition point, the flexibility and deformability of erythrocytes arrive at their highest points, and the intramolecular forces reach their lowest points. Thus the rheological resistance of blood drops to its minimum. Once a couple of degree offsetting occurred from the turning point ( $37^{\circ}$ C), the rheological resistance will increase quickly, and then reach to a constant over certain range of temperature.

If the temperature is beyond 37°C, the elevation of the thixotropic properties of blood may be due to the orientation changes of high molecules such as fibrinogen, thus changes will make the aggregation of erythrocytes more firmly. In case the temperature of blood drops below 37°C, the flexibility and deformability of red cells will increase, i.e. RBC will become much stiffer, thus the intercellular friction among red cells in rouleaux will increase. Therefore it needs more mechanical energy to shear the blood and to break its rouleaux. This is probably why the thixotropic properties of blood also increase.

It is worthwhile in a further study to model the temperature dependence of rheological properties of blood mathematically. In general, in gases at low density, the viscosity dependence on temperature follows the following equation:

$$\mathcal{N} = a \int \mathbf{T} + \mathbf{b} \tag{IV.2-2}$$

where a, and b are empirical constants. For the pure Newtonian fluid, the most commonly used expression relating viscosity to temperature (in normal range) is the Arrhenius equation (19).

$$\gamma = A Exp (E/RT)$$
 (IV.2-3)

where R is the gas constant, E the energy of activation for flow, and A, a coefficient depending upon the nature of the liquid. For non-Newtonian fluids, such as certain polymers, another equation sometimes useful in correlating viscositytemperature data in the region of Newtonian behavior is suggested (19):

 $\gamma = a \operatorname{Exp} (-bT) \qquad (IV.2-4)$ 

where a, and b are empirical constants.

However, theoretically it will be very difficult to establish the temperature dependence of the rheological parameters of blood, since blood is a very complex, thixotropic fluid with suspended particles about which there there is relatively little knowledge available. While a certain physicochemical disturbance is induced in blood, the suspended particles may undergo rotation, translation, deformation, aggregation, disaggregation, and other interaction or chemical reaction and so on. But how and why? it will be a worthwhile subject for a further study.

The statistical results show that n is always a constant, independent of temperature; the temperature dependence of other oarameters  $\mathcal{X}_{\bullet}$ , A,  $\mathcal{H}_{\bullet}$ ,  $\mathcal{H}_{\circ}$ ,

The parameter C follows the exponential form as the Arrhenius equation:

$$C = A_0 Exp (-E/RT)$$
 (IV.2-5)



All the previous investigations were based upon the normal healthy blood. For the pathological blood, Reis (43) discovered that for rising temperature from  $0^{\circ}C$  to  $50^{\circ}C$ , the viscosity of blood serum decreased progressively. There was a temperature existing, above which the viscosity started to increase due to certain physico-chemical, and pathological factors. Stoltz, el at. (44) also showed the abnormal relation between plasma viscosity and temperature for the blood containing extra macromolecules. The temperature dependence of pathological blood may have different profiles of the rheological properties.

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# 3. <u>Correlation of thixotropic properties and chemical</u> tests of whole human blood

There is too much unknown in blood. From the molecular level, the whole structure of blood is still mysterious The change in part or in whole blood induced by altered physico-chemical environment has attracted many investigators.

Arellie, et al. (20) discovered platelet aggregation in platet-rich plasma induced by catecholamines (including adrenaline, nonadrenaline, dopamine, and 5-hydroxytryptamine). Newman (21) found that the viscosity of whole blood increased as a result of an increase in cholesterol level, especially more remarkably at the lower shear rates. Also dextran, a plasma expander which influenced the whole blood viscosity was exhibited by Singh (22). Anticoagulant heparin was showed to reduce the storage component of the elastic modulus and to increase the clotting time (24). Using erythrocytes suspended in buffer and morphology altering agents (2,4,6-trinitrobenzeme,2,4-dinitrobenzeme,chloropromazine.HCl, and sodium salicylate), Meiselman (25) exhibited that the rheological effects of the discocyte-echinocyte shape transformation existed at the lower shear rates. Houbouyan, et al. (26) indicated that some antibiotics affected the rheological properties of blood and platelet aggregation.

To deal with the field of molecular rheology, subphases of blood, morphological structure of cells, various amphiphilic agents may be employed to transfer the normal biconcave shape (discocyte) into either the crenated (echinocyte) or cupped (stomatocyte) form (25,26). These agents appear to act as true antagonists, although at high concentrations there is an irreversible process of smooth sphere to haemolysis (27). Sheetz and Singer (28) have proposed a theory for these shape transformations based on an asymetric bilayer model of the RBC (red cells) membrane; echinocyte agents intercalate preferentially into the exterior half of the bilayer whereas stomatocytic agents are suggested to act mainly on the interior half.

The rheological properties of whole blood are mainly determined by the situation of erythrocytes which present complicated response to various chemicals. Motais (29) found that organic anion (mainly acids) transport in red blood cells was determined by the membrane specificity, Missirlis, et al.(30) used micropipette analysis to estmate the haemolytic stress of hypotonic erythrocytes under the influence of lipid-soluble compounds. Jain, et al. (31) exhibited that the difference of intrinsic perturbing ability of alkanols in lipid bilayers arised from a specificity of interaction between alkanols and lipid bilayer.

Systems are studied generally as a whole. An attempt

to isolate certain rheological processes from individual fragments of more complex blood and then combine them in order to explain the functions of the whole blood can not be expected to supply the whole truth In this study, first around seventy chemicals which were considered having certain important effect in blood have been selected on a screening test to see if they can cause any influence in the thixotropic properties of blood. Finally a series of normal alkanols including one  $(C_1)$  to eleven  $(C_{11})$  carbons which were found obviously causing the thixotropic changes in blood have been chosen as a typical example in this study. The other reason is that these alkanols have systematically exhibited different molecular sizes and solubilities in water and lipids, which are main compositions in blood and red cells respectively. (32,35,36)

To each 5.0 ml. of blood which was obtained from Northen New Jersey Blood Bank, East Orange, New Jersey, a certain amount (not exceeding 0.1 ml.) of alkanol was added; then the blood was gently shaked and warmed at 37°C for 30 minutes. Then, the sample was ready for rheological tests at 37°C. The results from this investigation were plotted in Fig.IV.3-1 to Fig.IV.3-7. The detailed data have been shown in Appendix II.3.

The A,  $\mathcal{T}_{o}$ , C, and n were plotted, on a linear

scale, against the number of carbon molecules (or molecular size). The  $\gamma_s$  and  $\mu$  were plotted, on semilog scale, against the number of carbon. One may observe the following phenomena:

(a). Different alkanols have different effects in the rheological properties of the same blood.

(b). Different bloods have different responses to the same alkanol.

(c). In this investigation, all blood, two normal and two abnormal samples follow a similar thixotropic pattern with respect to the eleven alkanols.

(d). Alkanols with  $C_5$  to  $C_9$  can change the thixotropic blood to a Newtonian blood, in which  $C_7$  drops the Newtonian viscosity to the lowest point.

It is also obviously that the results can be grouped according to the solubility of alkanols in water (Fig.IV.3-5). The first group, hydrophilic alkanols, containing methanol  $(C_1)$ , ethyl alcohol  $(C_2)$ , n-propyl alcohol  $(C_3)$ , and n-butanol  $(C_4)$ , shows extreme solubility in water; the second group, amphiphilic alkanols containing normal alkanols with five to nine carbons, shows partial solubility in water and partial solubility in lipids; while the third group, hydrophobic alkanols, composed of 1-decanol and 1-undecanol, exhibits a complete insolubility in water, but is soluble in lipids.





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Fig.IV.3-2 C, n vs. no. of carbon molecules in linear normal alkanols (blood rheological properties affected by normal alkanols)



by normal alkanois)



normal alkanols ( blood rheological properties affected by normal alkanols)



Newtonian



Fig.IV.3-5 Blood rheological properties vs. physical data of alkanols (blood rheological properties affected by, normal alkanols)




 $M_{,,Steady state viscosity; \mu, Newtonian viscosity (dyne-sec-cm<sup>2</sup>) Temperature - 37°C; Incubation - 30 min.$ 



With regard to the effect of concentration of alkanols in the blood rheology, three alkanols ( $C_5$ ,  $C_7$ , and  $C_9$ ) which were found more active to change the rhological properties of blood than others have been choosen as examples. The relationship of  $\gamma_o$ ,  $\mu$ , and  $\gamma_s$  vs. the concentration of the alkanols were plotted in Fig.IV.3-6 and Fig.IV.3-7, which have showed the two normal blood samples (II and III) have similar responses to the amphiphilic alkanols, but not for the abnormal ones (I and IV). Furthermore, if looking in detail, even the two similar ones (normal blood II and III) have showed different responses to the same alkanol  $C_5$  (Fig.IV.3-7). And, no matter whether normal or abnormal, all blood samples are much more sensitive to  $C_7$  alkanol than to others.

To explain these phenomena it will be very difficult from the microscopic viewpoint of blood, since there is too much knowledge indeed needed to develop and to understand the erythrocyte structure. For simplification, let's see the blood from a macroscopic point of view. Blood can be considered as a part water soluble (plasma), and a part water insoluble (erythrocytes) as shown in Fig.IV.3-8.

(a) When the hydrophilic substances  $(C_1 \text{ to } C_4)$  dissolve in plasma, they may modify the exterior surface of the erythrocyte membrane in some way to strengthen the rouleaux formation. Thus it will cause the increase in

Lipid bilayer mosaic with proteins Outside cell: Inside cell: Plasma  $(H_20)$ Cytoplasm (Hemoglobin)  $C_{1} - C_{A}$ Proteins C10-C11 **.** . ÷..... c<sub>5</sub>-c<sub>9</sub> Lipids Apolar P Polar Insoluble in H<sub>2</sub>O (Two phases system of blood)

Fig.IV.3-8 Mechanisms of linear normal alkanols reacting with erythrocytes;  $C_1$  to  $C_{11}$  indicate the alkanols which have 1 to 11 carbon molecules

Membrane structure of erythrocytes:

thixotropic properties of whole blood.

(b). While the hydrophobic substances (C<sub>10</sub> to C<sub>11</sub>) favorably join in the erythrocyte membrane in loose part to reinforce its strength, and make the red cells much stiffer. In other words, the deformability or flexibility of erythrocytes and rouleaux will decrease, that means the thixotropic properties of blood will increase.

(c). While the amphiphilic substances  $(C_5 \text{ to } C_9)$  dissolve in blood, their apolar tails will insert in the erythrocyte membrane, and their polar heads will suspend on the exterior surface of the membrane. At low concentrations, they act as a combination of hydrophilic and hydrophobic substances. Once their concentration presented in blood is beyond a certain level at which the membrane is already saturated by the substances. The residual amphiphilic molecules in plasma will continuously attack the membrane. The haemolysis will occur until the intramolecular force between the molecules in plasma and the intermolecular force which holds the whole membrane as a unit.

(d). The different responses from different bloods to the same alkanol may imply that each individual blood has its own signature (intrinsic ultrastructure of the erythrocyte) and chemical selectivity which were found most favorably to amphiphilic  $C_7$ . The different Newtonian behaviors from the haemolysis caused by the attack of  $C_5$  to  $C_9$  may reveal the different size of fragments broken from erythrocytes.

#### CHAPTER V

#### CONCLUSIONS

Traditionally, most investigators used apparent viscosities at various constant shear rates to evaluate the rheological property of fluid, it would be okay if the fluid were just shear -rate dependent, or a monotonic system. However, to a multitonic system such as blood- a thixotropic fluid, the traditional method would not be suitable to evaluate its rheological properties, since such a system is just dependent upon the shear rate but also the time.

To correct the traditional method, the Huang model which can be applied to very wide ranges of shear rates and time, emphasizes to use rheological parameters to characterize the flow properties of thixotropic system from its hysteresis loop and torque-decay curve. Once the parameters are determined, the apparent viscosity can be evaluated at any shear rate and at any time of shearing. Thus, the use of the parameters will also eliminate the uncertainty of the apparent viscosity of a sensitive thixotropic system such as blood tested at very low shear rate, obtained by different investigators.

Physiologically, low velocities of blood flow occuring in the microcirculation in capillary or small vessels would be mainly influenced by the presence of aggregates of the red cells, which in turn depend on the shear rate and, on the history of the blood and the originate of the blood. Low shear rates also exist particularly in pathological conditions such as circulatory shock and thrombosis. The rheological parameters are relevant to the practice of clinical medicine.

The study of open heart surgery during cardiopulmonary bypass is a typical example, which brings together information essential to clinicians and medical workers studying the causes for circulatory diseases, and for engineers who want to apply concepts of the more developed sciences to the so complex problems of medicine. If a simulation study could be made prior to the operation, it might probably have saved the lives of patients who were expired after open heart surgery. In other words, the highly abnormal rheological syndrome which might be of clinical and diagnostic importance could be predicted. A series of tests might help to discover early or silent conditions of hematological disorders or malignancy. The complex clinical tests could be supplemented, and sometimes replaced , by the new rheological methods.

Although changes in rheological parameters may play an important role in clinical medicine or pathophysiology that exists within blood flow, the diagnostic value is sometime difficult to be specific since different causes of illness may lead to same changes in rheological properties. However,

the rheological parameters, in combination with other changes in the blood such as changes in temperature, inducement of chemicals or other physio-chemical factors, serve to narrow the range of diagnosis required.

The rheological study of blood added with different chemicals also imply its applications to other sciences such as pharmocology, toxicology, and ultrastructures of blood, and so on. The effect of temperature on blood thixotropy shows, at least that a living thing containing a thixotropic blood circulating through its organs has its own body temperature, at which the resistance for blood flow is going to be minimum, and at which its physiological functions are operating normally. It further indicates that each individual thixotropic system may have its own thixotropic temperature, at which its flow properties turn to minimum. The temperature study also paves a way to solve certain thermodynamic problems in the thixotropic system.

The study of dynamic behaviors of the torsion head indicates that the rheogram is controlled by the time constant and damping factor of the head, which in turn are determined by the torsion bar constant and the geometrical and physical properties of the head. This provides an information in its installation, of which

the damping factor can be adjustable by changing the viscosity of damping fluid. To minimize the artefact of rheograms, which is mainly dominated by the torsion head provided that the inertia constant and damping coefficient of the tested fluid comparing with those of the head can be neglected, a suitable underdamping factor combining with a particular time constant is necessary if both a single step change and a triangular step change in the rotating part of the viscometer are assigned to a specific rpm range.

### CHAPTER VI

#### RECOMMENDATION

1. Some unusual lumps in hysteresis loop and torque-decay curve were occasionally found from the pathological blood during cardiopulmonary bypass. A simulation approach by assuming the increase of catchamines in blood owing to certain physical or psychological stress that occurred in the patient , was attempted, but failed to produce results. These lumps may imply some very important pathological factors. A further investigation for their solution would probably bring about significant improvements in preventive medicine.

2. Blood, especially for the particular pathological conditions, usually is not easy to obtain. In order to facilitate the research, using the simulated blood from normal people or other living subjects is recommended.

3. It takes almost 5 ml. of blood sample in the present cell for each experiment. A specific pathological blood is hard to acquire. In order to expand its usefulness, to reduce the size of cell (microviscometer) is therefore recommended.

4. The chemicals in blood in vitro are more stable at 4<sup>°</sup>C than at 37<sup>°</sup>C. The latter temperature may cause their denaturalization and affect the blood rheology. Also Reis (43) and Stoltz (44) indicated that the viscosity of blood was much higher at  $4^{\circ}C$  than that at  $37^{\circ}C$ . Then the rheological parameters obtained at  $4^{\circ}C$  in place of  $37^{\circ}C$  would provide clear and better results. This, in turn automatically involves that a cooling system installed in the rheogoniometer is necessary.

5. There is need for more research to find out if there are any chemicals which are widely involved in our ordinary lives, such as environmental polluters, pharmaceuticals, and food additives and etc., that present any instantaneous or potential danger to the human blood or our health (38).

6. Though the recovery of hysteresis phenomena in blood is fast, it has been observed that the speed sometimes is different due to different blood samples. This may indicate the memorial property of blood. How to define it? How to find it? What is its relation with respect to other variables existing in blood? All these problems are worhty of a future investigation.

7. To accelerate to obtain the experimental results, an automation of the whole system is absolutely necessary.

8. Systematic dictionaries of the rheological parameter vs. various physical, chemical, and pathological factors which affect blood will bring a great advantage to life sciences.

### Appendix 0. Nomenclature

A : Equilibrium yalue of structural arrangement parameter, dyne-sec-cm a : Acceleration constant for a triangular step change, cm-sec<sup>-2</sup>. C : Kinetic rate constant of structural breakdown of rouleaux to individual erythrocytes, secn-1. G : Torsion bar constant, dyne-cm/micrometer. I : Moment of inertia of torsion head, dyne-cm-sec<sup>2</sup>/micrometer. L : Length of the inner cylinder of the single couette cell, cm. n : Reaction order of structural breakdown of rouleaux to individual erythrocytes. R : Radius of the rotating cylinder of the single couette cell, cm. t : Time, sec.  $\prec$  : Angular deflection of torsion bar, micrometer. .....  $\dot{\gamma}_{m}$ : re-component of shear rate. sec<sup>-1</sup>. Two re-component of shear stress, dyne-cm<sup>-2</sup>.  $\mathcal{T}_{\bullet}$ : Yield stress, dyne-cm<sup>-2</sup>.  $\mu$ : Newtonian viscosity, dyne-sec-cm<sup>-2</sup>.  $\mathcal{N}$ : Torsion head damping coefficient. A. RPM of the rotating cylinder in the single couette cell.

### Appendix I.1 - <u>Mathematical Derivation for the Dynamic</u> <u>Behavior of Torsion Head</u>

In a rotating viscometer such as couette, cone and plate and etc., a torque T(t) is transmitted by the tested fluid to the torsion bar due to the angular movement of the bottom shaft (Fig.II.1). For most viscometer design, it is assumed that the torque is proportional to the angular deflection of the torsion bar  $\alpha(t)$ 

In this derivation, the angular velocity and angular acceleration are also being considered. From the derivation, we can established under what contions, the assumption of T(t) is linear with respect to d(t) is held for both a single step change and a triangular step change.

### Equation of motion of the torsion head

$$I \frac{d^2 d}{dt^2} + \eta \frac{d d}{dt} + G d = T(t)$$
  
B.C.  $d(0) = 0$ ,  $d'(0) = 0$ 

Define new parameters:

 $\gamma = (I/G)^{\frac{1}{2}} = ---$  characteristic time constant  $\xi = \gamma / 2 (IG)^{\frac{1}{2}} = ---$  damping factor

Then the equation can be rearranged as follow:

$$\Upsilon \frac{d^2 d}{dt^2} + 2 \Im \Upsilon \frac{d d}{dt} + d = \frac{1}{G} T(t)$$
 (A.I.1-1)

Assume an incompressible Newtonian fluid in the viscometer. Equation of motion of the fluid

$$P\frac{\partial V_{\theta}}{\partial t} = \mu \frac{\partial}{\partial r} \left[ \frac{1}{r} \frac{\partial (rV_{\theta})}{\partial r} \right]$$
(A.I.1-2)

- (A). For a single step change
- B.C.  $V_{\theta}(r, o) = 0$  ; t = 0  $V_{\theta}(\kappa R, t) = 0$  ;  $t \ge 0$  (A.I.1-3)  $V_{\theta}(R, t) = R\Omega$  ;  $t \ge 0$

The solution of Eq.AI.1-2 for (A) is shown in (9):

$$\frac{V_{\theta}}{R\Omega} = \left(\frac{1}{1-K^2}\right)\frac{r}{R} - \left(\frac{K^2}{1-K^2}\right)\frac{R}{r} + \sum_{n=1}^{\infty} E_n e^{-\beta_n^2 t} Z_1(\theta_n r)$$

(B). For a triangular step change

B.C.  $V_{\theta}(r, 0) = 0$  (A.I.1-4)

$$V_{\theta}(\kappa R, t) = 0$$

$$V_{\theta}(R, t) = R \Omega(t) = \begin{cases} aRt & ; o \le t \le t_{i} \\ \\ 2aRt_{i} - aRt & ; t_{i} \le t \le 2t_{i} \end{cases}$$

where a is angular acceleration constant of rotating cylinder.

The solution of Eq.AI.1-2 for (B) is also shown in (9): When  $0 \le t \le t_1$ 

$$V_{\theta} = \alpha \left( \frac{r}{1-\kappa^2} - \frac{\kappa^2 R^2}{1-\kappa^2} \frac{1}{r} \right) t + \sum_{n=1}^{\infty} \frac{\alpha R}{\beta_n^2} E_n \left( 1 - e^{-\beta_n^2 t} \right) Z_i(\theta_n r)$$

When  $t_1 \leq t \leq 2t_1$ 

$$V_{\theta} = a \left( \frac{r}{1 - \kappa^{2}} - \frac{\kappa^{2} R^{2}}{1 - \kappa^{2}} \frac{1}{r} \right) (2t_{1} - t)$$
  
+ 
$$\sum_{n=1}^{\infty} \frac{aR}{\beta_{n}^{2}} E_{n} \left( 1 - e^{-\beta_{n}^{2} t_{1}} + e^{-\beta_{n}^{2} t} \right) Z_{1}(\theta_{n} r)$$

Where

$$g = (P/\mu)^{\frac{1}{2}}; \quad \Theta_n = \mathcal{G}\mathcal{B}_n$$

$$Z_1(\Theta_n r) = J_1(\Theta_n r) Y_1(\Theta_n KR) - Y_1(\Theta_n r) J_1(\Theta_n KR)$$

with  $\mathcal{J}_{I}(\theta_{n}r)$  and  $\bigvee_{I}(\theta_{n}r)$  being Bessel's functions of the first and second kind respectively. The eigenvalue satisfy the following relationship:

 $J_{i}(\theta_{n}KR)Y_{i}(\theta_{n}R) = J_{i}(\theta_{n}R)Y_{i}(\theta_{n}KR)$ 

The coefficient of  $E_n$ :

$$E_{n} = \frac{\frac{1}{1-K^{2}} \left[ Z_{o}(\theta_{n}R) - K^{2}Z_{o}(\theta_{n}KR) \right] - \frac{K^{2}}{1-K^{2}} \left[ Z_{o}(\theta_{n}R) - Z_{o}(\theta_{n}KR) \right]}{\frac{1}{2} \theta_{n}R \left[ Z_{o}^{2}(\theta_{n}R) - K^{2}Z_{o}^{2}(\theta_{n}KR) \right]}$$

The shear stress distribution and the torque applied to the inner cylinder :

$$\mathcal{T}_{ro} = -\mu r \frac{\partial}{\partial r} \left( \frac{V_{o}}{r} \right) = -\mu \dot{v}_{ro}; \quad T(t) = 2\pi \kappa R L \left( -T_{ro} \right) \left| \cdot \kappa R \right|_{r=\kappa R}$$

(A). For a single step change

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$$T(t) = 2\pi \kappa^{2} R^{2} L \mu \left[ \frac{2\Omega}{1-\kappa^{2}} - \sum_{n=1}^{\infty} \theta_{n} \tilde{E}_{n} e^{-\beta_{n}^{2} t} Z_{2}(\theta_{n} \kappa R) \right]$$

The transient term may be neglected in most viscometer. calculation (9), therefore

$$T(t) = 2\pi \kappa^2 R^2 L \mu \frac{2\Omega}{1-\kappa^2} = A_o = \text{Constant} \quad (A.I.L-5)$$

(B). For a triangular step change When  $o \leq t \leq t_1$ 

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$$T(t) = \frac{4\pi a L \kappa^2 R^2 \mu t}{1 - \kappa^2} + 2\pi a L \kappa^2 R^3 \int P \mu \sum_{n=1}^{\infty} \frac{E_n}{\beta_n} Z_o(\theta_n \kappa R) \left(1 - e^{-\beta_n^2 t}\right)$$

-

When  $t_1 \leq t \leq 2t_1$ 

$$T(t) = \frac{4\pi \alpha L \kappa^{2} \kappa^{2} u (2t_{i} - t)}{1 - \kappa^{2}} + 2\pi \alpha L \kappa^{2} \kappa^{3} \int_{PM}^{\infty} \sum_{n=1}^{\infty} \frac{E_{n}}{\beta_{n}} Z_{o}(\theta_{n} \kappa R) (1 - 2e^{-\beta_{n}^{2} t_{i}} + e^{-\beta_{n}^{2} t})$$

It was shown (9), if the dimensionless group

$$N_{HF} = \frac{(1-\kappa^2)R}{2t_i}g \frac{E_i}{\beta_i}Z_o(\theta,\kappa R) <<1$$

the summation terms of T(t) can be neglected, and since for most viscometers,  $N_{\rm HF}$  << 1, so

,

$$T(t) = \begin{cases} Bt \qquad ; \quad 0 \le t \le t, \\ (A.I.1-6) \end{cases}$$

$$B(2t, -t) \qquad ; \qquad t_1 \le t \le 2t, \\ where B = \frac{4 \pi a \lfloor \kappa^2 R^2 \mu}{1 - \kappa^2}$$

Substitue T(t) (Eq.AI.1-5, AI.1-6) into Eq.AI.1-1, and using the method of Laplace transformation to solve Eq.AI.1-1, the following solutions have been obtained: <u>Case 1</u>. For small  $\gamma$  and  $\xi$ , or  $\gamma \rightarrow 0$ ,  $\xi \rightarrow 0$ <u>Single step change</u>

$$\overline{d}(S) = \frac{A_o}{GS}$$
;  $d(t) = \frac{A_o}{G}$ 

Triangular step change

$$\overline{\mathcal{Q}}(s) = \frac{B}{G} \overline{\tau}(s) = \frac{B}{G} x \begin{cases} \frac{1}{S^2} & ; \quad 0 \leq t \leq t_1 \\ \frac{2t_1}{S} - \frac{1}{S^2} & ; \quad t_1 \leq t \leq 2t_1 \\ j & 0 \leq t \leq t_1 \end{cases}$$

$$d(t) = \frac{B}{G} x \begin{cases} t & ; \quad 0 \leq t \leq t_1 \end{cases}$$

$$\begin{bmatrix} c \\ (2t, -t) \end{bmatrix}; t \leq t \leq 2t,$$

<u>Case 2</u>. For small  $\xi$  or  $\xi \rightarrow o$ <u>Single step change</u>

$$\overline{d}(5) = \frac{A_0/G}{5(\tau^2 S^2 + 1)} = \frac{A_0/G}{5} - \frac{(A_0 \tau^0/G)S}{\tau^2 S^2 + 1}$$

$$\mathcal{L}(t) = \frac{\Delta_o}{G} \left( 1 - \cos(t/\tau) \right)$$

Triangular step change

$$\overline{\alpha}(s) = \frac{B/G}{T^2 s^2 + 1} \times \begin{cases} \frac{1}{s^2} & ; \quad 0 \leq t \leq t_1 \\ \frac{2t_1}{s} - \frac{1}{s^2} & ; \quad t_1 \leq t \leq 2t_1 \\ \frac{2t_1}{s} - \frac{1}{s^2} & ; \quad t_1 \leq t \leq 2t_1 \\ (t - \tau sin \frac{t}{\tau}) \\ \alpha(t) = \frac{B}{G} \times \begin{cases} (t - \tau sin \frac{t}{\tau}) \\ 2t_1(1 - \cos \frac{t}{\tau}) - (t - \tau sin \frac{t}{\tau}) \end{cases}$$

<u>Case 3</u>. Overdamped,  $\xi > 1$ <u>Single step change</u>

$$\overline{\mathcal{A}}(5) = \frac{A_0/G}{S(\mathcal{T}^2 S^2 + 2\S T S + 1)} = \frac{A_0}{G} \left(\frac{1}{5} - \frac{\mathcal{T}^2 S + 2\$ T}{\mathcal{T}^2 S^2 + 2\$ T S + 1}\right)$$

From (45), page 556

$$d(t) = \frac{A_0}{G} \left[ 1 - \frac{(\xi + \sqrt{\xi^2 - 1})e^{-(\xi - \sqrt{\xi^2 - 1})\frac{1}{2}}}{2\sqrt{\xi^2 - 1}} - \frac{(\xi - \sqrt{\xi^2 - 1})e^{-(\xi + \sqrt{\xi^2 - 1})\frac{1}{2}}}{2\sqrt{\xi^2 - 1}} \right]$$

## Triangular step change

When  $0 \leq t \leq t_1$ 

$$\overline{\chi}(s) = \frac{B/G \tau^2}{s^2(s^2+2\frac{s}{\tau}S+\frac{1}{\tau^2})} = \frac{B/G \tau^2}{s^2\left[s+\frac{1}{\tau}(s+\frac{1}{s^2-1})\right]\left[s+\frac{1}{\tau}(s-\frac{1}{s^2-1})\right]}$$

From (46), page 203

$$d(t) = \frac{B}{G} \left[ t - 2\xi \tau - \frac{\tau}{2\sqrt{\xi^2 - 1}} \left( 2\xi^2 - 1 + 2\xi \sqrt{\xi^2 - 1} \right) e^{-(\xi + \sqrt{\xi^2 - 1}) \frac{t}{\tau}} - \left( 2\xi^2 - 1 - 2\xi \sqrt{\xi^2 - 1} \right) e^{-(\xi - \sqrt{\xi^2 - 1}) \frac{t}{\tau}} \right]$$

When  $t_1 \leq t \leq 2t_1$ 

$$\overline{d}(5) = \frac{B/G}{T^2 S^2 + 2STS + 1} \left(\frac{2t_1}{S} - \frac{1}{S^2}\right)$$

.

$$= \frac{2t_1B/G\tau^2}{5\left[5 + \frac{1}{\tau}(\frac{3}{5} - \frac{3^2}{5^2-1})\right]\left[5 + \frac{1}{\tau}(\frac{3}{5} - \frac{3^2}{5^2-1})\right]} - \frac{B/G}{5^2(\tau^2 5^2 + 2\frac{3}{5}\tau 5^{+1})}$$

From (46), page 195

$$\begin{aligned} \alpha(t) &= \frac{2t_1B}{G} \left\{ 1 + \frac{1}{2\int_{y^2-1}^{y^2-1} \left[ (\xi - \int_{y^2-1}^{y^2-1})e^{-(\xi + \int_{y^2-1}^{y^2-1})\frac{t}{\tau} - (\xi + \int_{y^2-1}^{y^2-1})e^{-(\xi - \int_{y^2-1}^{y^2-1})\frac{t}{\tau}} - \frac{B}{G} \left\{ t - 2\xi\tau + \frac{\tau}{2\int_{y^2-1}^{y^2-1} \left[ (2\xi^2 - 1 + 2\xi \int_{y^2-1}^{y^2-1})e^{-(\xi + \int_{y^2-1}^{y^2-1})\frac{t}{\tau}} - (2\xi^2 - 1 - 2\xi \int_{y^2-1}^{y^2-1})e^{-(\xi - \int_{y^2-1}^{y^2-1})\frac{t}{\tau}} \right] \right\} \end{aligned}$$

<u>Case 4</u>. Underdamping,  $\xi < 1$ <u>Single step change</u>

$$\overline{\mathcal{L}}(S) = \frac{A_{o}/G}{S(\mathcal{I}^{2}S^{2} + 2\overline{S}\mathcal{I}S + 1)}$$

From (46), page 192

$$d(t) = \frac{A_{o}}{G} \left[ 1 - \frac{e^{-g\frac{t}{T}} \sin((\sqrt{1-s^{2}} - \frac{t}{T} - \phi))}{\sqrt{1-g^{2}}} \right]$$
  
with  $\phi = tan^{-1} \frac{\sqrt{1-g^{2}}}{-g}$ 

 $\frac{\text{Triangular step change}}{\text{When } o \leq t \leq t_i}$ 

$$\bar{a}(5) = \frac{B/G}{S^2(T^2S^2 + 2\xi T S + 1)}$$

From (46), page 201

$$d(t) = \frac{B}{G} \left[ t - 2\xi T + \frac{Te^{-\frac{5}{T}}}{\int 1 - \frac{5}{2}} \sin \left( \int 1 - \frac{5}{2} \frac{t}{T} - 2\phi \right) \right] = \frac{B}{G} F_{1}(t)$$

When  $t_1 \leq t \leq 2t_1$ 

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$$\bar{\alpha}(s) = \frac{B/G}{\gamma^2 s^2 + 2 \sqrt[3]{2} s + 1} \left(\frac{2t_1}{s} - \frac{1}{s^2}\right)$$

From (46), page 192

$$d(t) = \frac{2t_{i}B}{G} \left[ 1 + \frac{e^{-\frac{2}{5}\frac{t}{T}} \sin(\sqrt{1-\frac{2}{5}^{2}}\frac{t}{T}-\phi)}{\sqrt{1-\frac{2}{5}^{2}}} - \frac{B}{G}F_{1}(t) \right]$$

<u>Case 5</u>. Critical damping,  $\xi = |$ <u>Single step change</u>

$$\vec{d}(5) = \frac{A_{\circ}/G}{5(\gamma^2 S^2 + 2\gamma S + 1)}$$

$$d(t) = \frac{A_{\circ}}{G} \left[ 1 - \left(1 + \frac{t}{\gamma}\right) e^{-t/\gamma} \right]$$

# Triangular step change

When  $o \leq t \leq t_1$ 

$$\chi(S) = \frac{B/G}{S^2(\gamma^2 S^2 + 2\gamma S + 1)}$$

$$d(t) = \frac{B}{G} \left( t e^{-t/T} + \frac{2}{T} e^{-t/T} + t - \frac{2}{T} \right) = \frac{B}{G} F_{2}(t)$$

When  $t_1 \le t \le 2t_1$ 

$$\mathcal{J}(s) = \frac{B/G}{\Upsilon^2 S^2 + 2\Upsilon S + 1} \left(\frac{2t_1}{S} - \frac{1}{S^2}\right)$$
  
$$d(t) = \frac{B}{G} \left\{ 2t_1 \left[ 1 - \left(1 + \frac{t}{\Upsilon}\right) e^{-t/\Upsilon} \right] - F_2(t) \right\}$$

Appendix I.2 - Mathematical Derivation of the Huang Equation

A brief mathematical derivation of the Huang equation is described as follows(2):

Although the system of a time-dependent, homogeneous, and non-Newtonian fluid is under non-equilibrium conditions during shearing at isothermal state; based on irreversible thermodynamics, it can be assumed that there exists within small mass a state of local equilibrium.

Therefore, the rate of generation of entropy due to the shear stress for a fluid with structural change as modeled by Huang is:

$$G' = -\frac{1}{T} \left[ \chi^{ij} \frac{d\gamma_{ij}}{dt} + \chi^{ij} \frac{d\beta_{ij}}{dt} \right] \qquad (AI.2-1)$$

where  $\gamma_{ij}$  is the strain tensor,  $\beta_{ij}$  is the Huang's molecular rearrangement parameter,  $\mathcal{T}^{ij}$  is the stress tensor, t is the time, and T is the absolute temperature.

Huang then relates the contravarient tensor of first and second order in the above equation to the rate of strain, and the rate of molecular rearrangement parameter by the following phenomenological equations:

$$\mathcal{T}^{ij} = \mu \frac{d\gamma^{ij}}{dt}$$
(AI.2-2)  
$$\mathcal{T}^{ij} = -\frac{g}{d\beta^{ij}} \frac{d\beta^{ij}}{dt}$$

where  $\mu$  is the apparent viscosity, and  $\xi$  is the molecular rearrangement coefficient. For a thixotropic fluid, Huang then assumed:

 $d\beta^{ij} = -c_1 \beta^{ij} |\gamma^{ij}|^m \qquad \text{for} \quad |\gamma^{ij}| > o \quad (AI.2-3)$   $d\beta^{ij} = c_2 \left(\beta_e^{ij} - \beta^{ij}\right) \qquad \text{for} \quad |\gamma^{ij}| = o \quad (AI.2-4)$ 

where  $\beta_e^{ij}$  is the equilibrium value of  $\beta^{ij}$  at t = 0, and  $C_1$ and  $C_2$  are rate constants, and n is the order of the rate equation.

An overall apparent viscosity  $\gamma$  can be defined which will relate the shear stress to the rate of strain by considering both the rate of strain effect and the rate of molecular rearrangement effect as follow:

$$\begin{aligned} \mathcal{T}^{ij} &= \mathcal{N} \frac{d\mathcal{T}^{ij}}{dt} = \mathcal{M} \frac{d\mathcal{T}^{ij}}{dt} - \mathcal{Z} \frac{d\mathcal{B}^{ij}}{dt} \end{aligned} \tag{AI.2-5}$$
$$\mathcal{N} &= \mathcal{M} - \mathcal{Z} \frac{d\mathcal{B}^{ij}/dt}{d\mathcal{T}^{ij}/dt} \end{aligned}$$

If the fluid has a yield stress  $\Upsilon_o^{ij}$ ; combining the equations (AI.2-2), (AI.2-3), and (AI.2-5), the Huang equation is obtained:

or

$$\mathcal{T}^{ij} = \mathcal{T}^{ij}_{*} + \mu \dot{\gamma}^{ij} + CA [\dot{\gamma}^{ij}]^{n} e \qquad (AI.2-6)$$

where  $C = C_1$ , the rate constant;  $A = \xi \beta_e^{ij}$ , the molecular rearrangement parameter;  $\dot{\gamma}^{ij} = \frac{d\gamma^{ij}}{dt}$ , the shear rate.

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F	ORTR	AN IV	(VER 45	) SOUR	CE LIS	STING:				0	5/26/7	8 1	15:35:56	Ρ,
-	1		SUBROUT	INE FI	TIT								· ·	
	2	C####	****	*****	******	******	*****	*****	*****	****	*****	****	*****	#
İ		Ċ		THIS	SUBBOL	ITING I	S A MC	DICIC	INE ATTON	OF T	HE SUR	THO	ŤŇE	
- <b>I</b>	5	Č		SNOWJ	O WRIT	TEN BY	R. RC	DBERTS	ON (M.	S.CHE	.1972	• N • C	<u>, E.).</u>	
	6	Ċ		MODIF	IED VE	RSION	PROGRA	AMMED	BY WA	LTER	FABISI	AK		
	7	<u> </u>		THE P	OLLOWI	NG COM	MENTS	ILLUS	TRATE	THE	OPERAT	IONA	IL	
	80	Ċ.		SEGUE	NCE OF	THEN	UNCINE	AN NE	GRESS	IUN S	<u>nakont</u>	INE,	1	•
[	10	C	CALL SU	•••••• 82(Y.X	PARAN	I PRNT.	NPRNT	NDATA	••••		* * * * * *			
	11	Ċ		CODIN	G FOR	CASE I	NITIAL	IZING	GOES	HERE				_ <u>.</u>
	12	C		NPRNT	IS TH	E NUMB	ER OF	OTHER	TERM	S TO	BE PRI	NTEL	)	
	13	<u> </u>	CILL NO	THE T	ERMS I	Q BE P	RINIEL	JARE	IN PR	NT(1)	PRN	T(5)		
	14	C	CALL MU	CODIN	G TO M	AKE FO	N GOFS	S HERE	UEI					
	16	Ċ		THE E	QUATIO	IN TO B	E TEST	EDIS	WRIT	TEN H	ERE			
	17	Ç		IT IS	SETE	QUAL T	O FCNO	Y HAT	)					
	18	ç	CALL DE	RIV(PA	RTL,X,	PARAM,	PRNT,F	CN,I)						
	19	<u>v</u>		IHIS ANALY	TTC DA	DTINE I	S FUR	TTUES	SE OF					
	21	č		CODIN	GTOM	AKE (P	ARTIAL	FCN/	PARTI		RAM' G	nES	HERE	
	22	Ç		MAKE	NPARAM	OF TH	EM AND	CALL	THEM	PART	L(J)	020	riggeritine	
•••	23	C,.,,		* * * * * *		* * * * * *	* * * * * *		* * * * *					* *
	24	Ç		READ	FIRST	CARD 0	F THE	NEXT	CASE	"	······		· • •	•
	25	<u>C***</u> #	COUNON	*****	******	*****	*****	1 D D N	*****	4 # # # #	*****	****	***	¥
	20		INTEGER	τηάτα	(5)/1		101.17	/ * * * X *	15971) 7	CONSI	(4)			
	28		EQUIVAL	ENCE (	IBCH, I	DATA(1	)), (IO	CHAID	ATA(2	55+(1	PCH ID.	ATÁC	3)),	
	29		1(IYCH,I	DATA(4	)),(IX	CH, IDA	TA(5))				· · ·	,	- <u></u>	
	30		DIMENSI	ON SPA	RAM(10	), DPAR	AM(10)	BPAR	AM(10	).G(1	O).IPA	RAM (	9),	
	$\frac{31}{72}$		1 SA(10)	PARIL	CIUIA	(10.11	J, PMAA	(10),	SPHNI	(5),8	MIN(10	)		
	33		NPRNTED	19944	1477 NO 113					•		÷	1	
	34	651	ICOUNTE	0 .			,					•.	•	
	35		IBOUT=0								<b>1</b>		,	
	36	1	HEAD(5,	900,EN	D = 660	NDATA,	NPARAM	NFIX	ED,NV.	AR, IF	PLOT			
÷.	<u> ७/</u> रप्र	<u> </u>	FURMALC	REVDA		THE PR	OGRAM	CONTR	018					
	39	č		NDATA	IS TH	E NUMB	ER OF	DATA	POINT	ŝ. T		IMUM		
	40	Ç		NUMBE	ROFD	ATA PO	INTS I	S 100		- • •				
	41	C		NPARA	MIST	HE TOT	AL NUM	BER O	F PAR	AMETE	RS IN	THE	MODEL	
	42	C		TO BE			E MAXI		UMBER	OFP	ARAMETI	ERS	IS 10,	
-	40	č		THEM	AXIMIN		R OF F	IXED	PARAM	S TERS			TXEN	• .
	45	Č	•	MUST	ALWAYS	BELE	SS THA	N NPA	RAM.	<u>,,,,,,,,,,,</u> ,,,,,,,,,,,,,,,,,,,,,,,,,	1 - 71	141		
	46	C		NVAR	IS THE	NUMBE	R OF I	NDEPE	NDENT	VARI	ÀBLES	IN T	HE	•
-	47	Ç		MODEL	TOBE	TESTE	D. TH	E MAX	IMUM	NUMBE	ROFI	NDEP	ENDENT	
	48 ⊿0	C C		1 CDI U	8653 1 7 10 1	5 5, N AUTO		TRAL	VADTA		7 971			
	97 50	- <u>č</u>		GIVES	TABUL	ATEDR	ESULTS	A	VALUE				TOTTEN.	
	- V	-		त्र <b>व</b> ् गण्डल्				••• 3	- 1 - 103 <b>4</b> 8 1-4		્ય <b>કા</b> ર્યક્રિયે સ્ટેટ્સ			هدي ۽ ا س راب
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RTR	AN IV	(VER 45	) SOURCE LI	STING	FITIT	SUBROUT	INE (	5/26/78	15:35:56	ł
51	C		RESULTS.							
52		IF(NDA)	TA,GT,0) GO	TO 2						
53	Ç		THE PROGRA	M WILL	TERMIN	ATE THE PI	RESENT	CASE IF	NO DATA	
54	C		POINTS HAV	E BEEN	SUPPLIE	D				
55		WRITE(	6,940)							
56	940	FORMAT	(//20X,40HCA	SE TERM	INATED	NO DATA	POINT	'S SUPPLI	leD)	
57		GO TO	660							
58	2	READ(5	,900)NSW1,NS	W2.NSW	3.NSW4.1	VSW5, NSW6				
59	C		READING IN	THE SE	ENSE (SW)	TCH CONTI	ROLS			
60	Ç		SETTING OF	THE SE	ENSE⇒S₩I	TCHESINSI	13			
61	C****	***	***	****	****	****	*****	******	****	- 44
62	Ĉ	NSW	FQUAL TO	ZERO		NOT	AUNA	TO ZERO		
63	Ċ. t	4 T T T A						15.15.1		•
64	C	1	DETATIED	UTPUT (	าท	NO DETA	I ED (		······································	
65	č	*	ONI THE POT	NTER						
66	č.	2		FRIVAT	IVES	STIMAT		RTVATTVES	3	
67	Ċ	<u> </u>	DETATIED B	RINTOL	227.	NSW3 AR		TED DRIN	TAUTE	
48	č	0		LINET	. 5	ON OUTDI	IN CIAR	1888 P111		
00	č	٨						• •		
70			CONCEDENCE	BECTON	1					<b></b>
70	č			NCUIU	•					ć
71	Ч С	F	CALVULAIIU	NOL NO.				din an		
77	÷		HEVE CASE	NUP IU	· · · · · · · · · · · · · · · · · · ·					
10	Y .		NEXI ÇAŞE	DEALAN	.1	Consta				;
/4		0		REGIUN	N		INGE F	GUIUN		
			neatuen			NUT	JESTKE	: U( 31 )		
70	C+++	******	化水水体水水体水体水体	****	********	**********	******	********	****	
//	L.		IFSIINA FO	R PLUI	ITNG UM	IABALALI	VG UP I	IONS		ġ
18		IFCIPPI	LUT.LE.0) GO	10 22				2 57	• • • • • • • • • • •	
79	-	READ(5	,930/YMIN,SP	READ						
80	ç		READING IN	THE PL	OTTING	CONTROLS				
81	<u> </u>		INF HEAL	NG CON	IROLS AP	KE KEMATKE	D ONL	Y IF IFF	LOT IS SE	1
82	C		EQUAL 10 0	NE.					_	
83	ç		YMIN IS TH	E VALUE	OF THE	LEFTSI	JE OF	THE PLOT	í .	
84	Ç		SPREAD IS	THE SPR	READ OF	THE PLOT.	<u> </u>			
85	930	FORMAT	(2F10.0)							
86	Ç		TESTING FO	R MODEL	, PARAME	TERS WITH	FIXE	D VALUES	5	
87	22	IF(NFI)	XED.LE:0) GO	TO 32						
88	24	READ(5	,900) (IPARAM	(1),1=1	,NFIXEI	))				
89	C -		READING IN	THE SU	JBSCRIPI	S OF THE	MODEL	. PARÃMEI	ERS	÷.
90	Ç		HAVING FIX	ED VALU	JES.					
91	C		IPARAM(I)	IS THE	SUBSCR	PT OF THE	MODE	L PARAME	TER	-
92	Ç		HAVING A F	IXED VA	VLNE					
93		DO 26	I=1,NFIXED							
. 94		IF(IPA	RAM(1).GT.0)	GO TO	26	······································	· · · · · · · · · · · · · · · · · · ·			
95	25	WRITE	5,926)							
96	926	FORMAT	(//10X.47HBA	D DATA	FIXED	PARAMETER	S HAV	E ZERO S	UBSCRIPTS	)
97		IBOUT=	1			· · · · · · · · · · · · · · · · · · ·			·	1
68	26	CONTINI	IF							
00	Сфяян	<b>企业</b> 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	5 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	******	******	****	 	<b></b>	****	¥
100	C		THE PATTAU	TNGAR	TNPIT	CONSTANTS	SIIPE		THE DRACE	- - 5
* 4 4	*			AIT MIL	- 6117 M-1	- UTWINNIS	r vvvrr⊓	LICD DY		n
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	101_	32	FFa4.
	102	Ç	FF IS A VARIANCE RATIO STATISTIC.
	103	36	E#,0000005
	104	70	E IS A CONVERGENCE CRITERION,
	106	20 C	TAUELUUL TAU IS A CONVEDGENCE CRITERION
	107	40	THO IS A CONVERSENCE ON THEMTON
	108	C	T IS THE STUDENTIS T.
	109	51	GAMCR=45.
	110	Ç	GAMER IS THE CRITICAL ANGLE,
	111		DELTA8,00001
	112	C	DELTA IS A MULTIPLIER USED IN THE FINITE DIFFERENCE
_	113	<u>C</u>	DERIVATIVES,
	114	~	ZETAB, 10-30 7074 TO A SINCULARITY OFFICEION COR MATRIX INVERSION
	444		ZETA IS A SINGULARITE ONTTERIUN FOR MATRIX INVERSION.
	117	<u>r</u>	LAMBDA-0101
	118	53	XKDB=1.0
	119	Ç	XKDB IS A MULTIPLIER USED TO INCREMENT THE PARAMETERS
	120	C****	********
	121		READ(5,901)(PARAM(I),I=1,NPARAM)
	122	<u>C</u>	READING IN THE INITIAL VALUES OF THE MODEL PARAMETERS.
	123	C	THEY ARE READ SEVEN TO THE CARD,
	124	6 004	FORMATIZETO AN
	122	901	$\frac{\Gamma \cup R \cap A + (/F \perp U + U)}{\Gamma \cup A \cup $
	127	Ċ	READIDIDIDIDIDIDIDIDIDIDIDIDIDIDIDIDIDIDI
	128	C ·	PMIN(I) IS THE MINIMUM VALUE OF THE PARAMETER
	129		READ(7,901) (PMAX(I), IS1, NPARAM)
	130	Ç	READING IN THE MAXIMUM VALUES OF THE MODEL PARAMETERS
	131	Ç	PMAX(I) IS THE MAXIMUM VALUE OF THE PARAMETER
	132	<b>C</b> .	DO 56 I=1,NDATA
	133	26	READ(5,901)Y(I),(X(I,L),LE1,NVAR)
••••	134		KEADING IN THE DATA PUINIS
	176	C C	Y(I,I) IS THE VALUE OF THE DEPENDENT VARIABLE
	137	с Сазвя	医动物性 化化化化化化化化化化化化化化化化化化化化化化化化化化化化化化化化化化化化
	138	¢	STARTING THE NONLINEAR REGRESSION SEQUENCE
	139	-	GALL SUBZ(Y, X, PARAM, PRNT, NPRNT, NDATA)
	140	C	
	141	9999	NSW33ENSW3
	142		
	143		
	145		ΝΝΠΑΤΑΞΝΠΑΤΑ
	146		ICOUNT=0
	147		IBKT=1
	143		NSW11=NSW1
	149		NSW22=NSW2
	150		NSW55HNSW5
•			

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F	DRTR	ΔΝ Ιν	VER 45	) SOUR	CE LIST	ING: F	TTTT	SUBROU	TINE	05/26/78	89 15:35:	56 P/
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_	_151		IFPP=IF	PLOT	N 00 TO	(())						······
	152	<b>F</b> 0	IFTIBUL	JI.NE.V		000-						
	120	27	186431	OTIE	0) <u>60</u> T	0 44						
	<u>155</u>		WRITEL	5.907)N	DATA NP	ARAMAN	FIXED,	NVAR. IF	PLOT.	GAMCR DEL	ΤΔ.	·····
	156		1 55.1.6	E.TAU.L	AMBDA . 7	ΕΤΑ	11 g / 1 g - 1 g					
	157	907	FORMAT	/5X.8H	INDATA =	.13.4	X,9HNP	ARAM =	.12.4	X. 9HNFIXE	D = .	
	158		1 11.4X.	7HNVAR	= .I1.	4X.9H	FPLOT	= .11.4	X,13H	GAMMA CRI	T	
	159		2 1PE10	3,4X,8	HDELTA	= <b>,</b> 1PE	10,3,/	5X, 5HFF	່ສຸ1	PE10.374)	(• 4HT ≓ •	
	160		<u>3 1PE10</u>	3,4X,4	HE = 1	PE10.3	<u>8,4x,6</u> H	TAU =	1PE10	.3.4X.9HL	AMBDA =	
	161		4 1PE10.	3,4X,7	HZETA =	,1PE1	0,3)					
	162	60	NSW3≡NS	SW3-1								
	163		NSW3=MA	AXUCINSM			LIAN OF	HUM . C. T	10	<u></u>		
	164	Ģ		SIART	THE CA		TON OF		MAI	KIX S		
	165	01		I ⊞ I I N M A	MAN							
	100		BO 62		DAM		<u> </u>			· · · · · · · · · · · · · · · · · · ·		<u></u>
	148	62										
	160	02	WRITE(	5.941)(	PMIN(I)	.1=1.1	JPARAM)					
	170	941	FORMAT	/5X.18	HPARAME	TER M	NIMUMS	,1P5E18	.8/12	3X, 1P5E18	.8))	
	171		WRITE	5,942)(	PMAX(1)	. I=1.	PARAM)					
	172	942	FORMAT	(5X,18)	PARAMET	ER MA)	(IMUMS,	1P5E18,	8/(23	X, 1P5E18	8))	
	173	70	WRITE(	5,908)1	COUNT, (	PARAM	(J),J=1	, NPARAM	1)			
	174	90 <b>8</b>	FORMAT	(/5X,1H	1(,12,19	H) MOI	DEL PAR	AMETERS	) "1P5	E18:8/(25	5X,1P5E18	.8))
	175		IF (NSW)	<u>3, EQ, O)</u>	GO TO	73						i
	176	71	IF(IFPL	OT,LE	0) GO T	0 68					and the second second	
	177	G	118 - V1171	185 4	OLLOWIN	G ŞIA	EMENIS	101114	IL I ZE	THE PLOT		
	178	6/	WSFIMIN	A ODAN						<u> </u>		
	1/7	004	"WRILEL	0,900]		VĨ4nE(	2.2./10	Y_1H0	10 V " 1 H	л. <b>Х</b>		
4	0 U 0 4	100	FORMATI	1 / / ^ / 4 # 7 7		<b>V)</b> 1 P C 3		~ <b>*</b> = 11 + <b>*</b> *	· > ^ > T II	<i>•</i> <b>/</b>		
	182	88	WRITE	6.9101	· · ·							
	183	910	FORMAT	(/10X,8	HOBSERV	ED.9X	9HPRED	ICTED,8	X.ioH	DIFFEREN	E)	
	184	73	I=1									
	185		PHIEO,									
	186	C		PHI 1	S THE S	UM OF	THE SQ	UARES Q	IF THE	RESIDUAL	,S	
	187		PHIN=0			-x- x-1-1- x \ <i>1</i> •				Ph		
	188	Ç		TEST	NG FOR	ANALY	LIC OK	ESIIMAT	ED PA	RITAL DEP	RIVATIVE	
	189	U To	TRANCHA	OPIIC		600						and a second
<u> </u>	190	-12	IF CIVOW2			002		<u></u>				_h
	191	~ • • • • •	CALL Mr	ייייייייייייייייייייייייייייייייייייי	V. PADAM	DDNT	JECN.I.	RESTURY	••••	• • • • • • • • •	* * * * • • * * *	
	103	С	UALL N	ייקבעי דאוא	IS THE	ANAL Y	TTC PAR	TTALS O	PTION			
	194	Č		GETF	ARTIALS	AND	UNCTIO	N	11141		<b></b>	·····
•	195	Ċ							• • • • •	· · · · · · · · · · · ·	- 6, 6 8 6 6 6 6 7 9 6 8 8 8 8 6 8 8 8 8	• 1 • • • • • • • • •
	196		CALL DE	ERIV(PA	RTL X.P	ARAM.	PRNT, FC	N,I)				•
	197	C						* * * * * * * *				
	193	75	IF (NFI)	KED LE	0) GO T	0 80						
	199	76	DO 77	II=1,NA	IXED							
	200		IWSEIP	ARAMCI	)							
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1.0.11	AN IV	(VER 4	45 ) S	SOURCI	E LIS	TINGI	FITIT	SUBRI	DUTINE	05/26/	78 15	135156
201	77	PARTI	L(IWS)	, <b>¤</b> 0,								
202	C	· .	TH	IS I	S THE	END	OF THE	ANALYT	IC PART	TALS OP	TION	
203	Ç***	****	*****	****	***	****	****	****	****	***	****	***
204		GO TO	<u> 180</u>									
205	C****	****	不敢走来这	·林林林林· · * · · · · · · · · · · · · · · · · ·	5 TUE	50001 10001	******* ***	242444444 2704171	*******	<b>YI</b> 外海市市市市市	****	***
200	č		- I H M A	ITO T	DADAM	00 T	HAIEP I	- CALL '	THEM DA	N DTCZEC		
207	- <u>c</u>			IFY A	RE MA		OM X(T	L) AND	PARAM(		****	
209	602	CALL	MODEL	CY X	PARA	MPRN	T.FCN.	RESDU		W /		
210	C	· · · · · · · · ·			• • • • •	• • • •	* * * * * * *	• • • • • • • • •	• • • • • • •	• • • • • •	, , , , , , , <b></b>	· · · · · · · · · · · ·
211	606	RWSEF	RESDUE									
212		FSAVE	SFCN									
213		DO 60	<u> 11 = 11 = 11 = 11 = 11 = 11 = 11 = 11</u>	:1.NP	RNT							
214	607	SPRNT	「(II)≓	PRNT	(11)							
215	6	J=1			\		•					
210	800	IF CNP	IXED.		JGU	10 61	8	<u></u>				 
21/	610	10 01	12 113	3 A M # T		0.0	ο <b>η τη</b> (	521				
510	610	- 18 V V - 18 O V T 1	1915 1917	CARLET	111,00	8.01		Ϋ́́ς Τ				
220	618		ARAMI	1) ¥ D	FITA			۵۰۰ پیدار در ۲۵۰۰ با ۲۵۰ و ۲۵۰۰ و ۲۵	······			
221	9 <b>4</b> 9	TWS=F	PARAM	່		,						*
222		PARAN	4(J)=P	ARAM	(J)+D	BW		•				
223	C				• • • • •						······	
224		CALL	MODEL	(Y,X	PARAL	M. PRN	T,FCN,	RESDUE	E)			•••••
225	Ç	****				·	* * * * * * *			· · · · · · · · · ·	· • • • • • •	••••
226	620	PARAP	1())=1	WS		**************************************					******	
227		IF(DE	3W.EQ.	0)081	MEDET.	TA						
228		PARTL	<u>,(J)=+</u>	(RES)	DUE-RI	WS)/D	BW			411.92 1978		· · · ·
229		GO TO	) 622									
230	621	PARTL	,(J)=0	F #								
231	622	J=J+1 				- C (	<u> </u>				~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	
202	6.0.4			(A8)/ • 1 •	15,07	90 H	0 000				•	
233	024	FONER	JEHNO JEHNO	,						· · · ·	• •	
235				1.NP	RNT					······································	······	<b></b>
236	625	PRNT	(11)=5	PRNT	CITY							
237	C		TH	IS IS	S THE	END (	OF THE	ESTIMA	CED BAR	TIALS R		·
238	C****	***	*****	****	***	****	*****	***	*****	****	****	****
239	C		NO	IW USI	E THE	PART	IALS TO	MAKE :	THE PAR	TIALS M.	ATRIX	
240	80	DO 82	2 JJ=1	, NPAI	RAM					· · ·		
241		GUJ	IIGUJ	N+RE!	SDUE*I	PARTL	(11)		•			
242		DO 82	5 IIBN	IJ, NP/	ARAM							
243		A(II,	,JJ)=A	(11,.	JJ)+P/	ARTL	II)*PAF	(IL(JJ)				
244	82	, A ( J J ,	, I I ) 8A	N.L.	, v 17)	••	<b>^</b>					-
245		IF(IF	PLUT,		, GD 1 B 4 ~~	TU 31	5 711 60	ፕሮ ጄቆዳ				
240 	C. # # # #	1 × 1 × 1 × 2	1 M J 1 G W	H H H H H	N. F. T. B. M.	AUNIA	IAI UU	IN OL4	·			······································
241	しょちがま し	*****	188888 CT	·~~*****	~***#** NG TH:	5 DI A'	ጽጽጽጽፕኛ ፕፕ፣NG የ	·******** GCQ11CMC+	• + + + + + + + + =	***	****	*****
240	č		PI	OTTI	NG Y(	T), F	- I + IV	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	•			
250		10=11	YTIY	YMIN	) #1 n O	SPR	EADY+11	)				
	Sof by fee	न भ ज १ १	<b></b>		· ••¥*1	* F * 10 1 1		•				•
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	*******											
												•
·					····							
·								- <b>11-1-1</b> -1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1			· · ·	

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(			91
C	FORTRAN LV (	VER 45 ) SOURCE LISTING; FITIT SUBROUTINE	E 05/26/78 15:35:56 P
6	251 252 253	$\frac{1PP=((FCN=IMIN/4100,2SPREAD)+10}{1F(10,EQ,IPP) GO TO 808}$	· · · · · · · · · · · · · · · · · · ·
<b>.</b>	254 C 255 804	Y(1) OUT FIRST	
(	256 257	IP2=IPCH I1=I0	
C	258 259	I2=IPP GO TO 816	
6	260 C 261 808	UNLY UNE CHARACTER IP1=IYCH IP2-IBCH	
Q.	263	11=10 12=1PP	
C	265 266 C	GO TO 816 FCN OUT FIRST	
C	267 812 268	IP1=IPCH IP2=IOCH	
6	269 270 271 C	I1=IPP I2=I0 ZERO PLOTS IN THE LEFT HAND COLUMN	
Ψ,	272 C 273 C	II IS ITS OWN BLANK COUNTER OVERFLOWS PLOT X IN COLUMN 112	
<b>(</b>	274 C 275 816	UNDERFLOWS ALSO PLOT X IN COLUMN TH IF(12,LE.111) GO TO 819	3 N
Ç	276 8 <u>1</u> 7 277 278	I2=111 IP2=IXCH IF4I1 IT 111N 60 TO 810	
ا ۲	279 818 280	115111 1.2.00 IP1=IXCH	2
•	281 282	IP2=18CH G0 T0 825	
(	233 819 284 822	IF(I1.GE.10) GU TO 825 I1=10	
C	285 286 287 823	IP1=IXCH IF(12.GT.10) GO TO 825	
•	288 289 825	ÎP2=IBCH I1M1=I1	
	290 291	I1M2=I2-I1-1 IF(I1M1.GT.0) GO TO 832	
(	292 820 293 824 294 928	IF(11M2,GT,O) GU TU 828 WRITE(6,928)IP1,IP2 FORMAT(1H,120A1)	
•	295	GO TO 844 WRITE(6,928)IP1,(IBCH,II=1,I1M2),IP2	
¢	297 298 832	GO TO 844 IF(I1M2.GT.0) GO TO 840	
	299 836 300	WRITE(6,928)(IBCH, II=1, I1M1), IP1, IP2 GO TO 844	
G.			
C			
6			

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			onuor rio	ITNOT FIL	-1 0000	OUTINE	05/20//	8 15:35	156
301	8 <u>40</u>	WRITE(6,92	8)(IBCH,I	I=1,11M1)	, IP1, (IBC	H.II=1,	11M2), ÍP	2	
302	Ç "	EN	D OF PLOT	TING SEQU	ENCE	<u>,</u>			
303	C****	***	****	****	****	***	***	***	***
304	844	GO TO 314							
305	318	WS=RESDUE							
306	·	IF (NSW3.EQ	.0:0R.1.G	T.NDATA)	GO TO 314				
307	308	IF (NPRNT, G	T.0) GO T	0 312	-				
308	310	WRITE(6,92	5)Y(1),FC	N.WS					·····
309	925	FORMAT(5X,	1P6E18;8/	59X 1P2E1	8,8)				
310		GO TO 314		-	-				
311	312	WRITE(6.92	5)Y(1),FC	N.WS. (PRN	:(JJ),JJ=	1.NPRNT	)		
312	314	WS=RESDUE	***	11 # TOME # 11 1111		98 P 193 24 19 1	•		
313		PUIEPHIAWS	年三月						
314		TELL GT.ND	ATAN GO T	0 313				· · · · · · · · · · · · · · · · · · ·	*************
745	÷.	- +	MINE GO T						
746	•	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	あり詰まっ					•	
270	7.7	<u>60 10 375</u>					<u> </u>	· · · · · · · · · · · · · · · · · · ·	
31/	515	CONTINUE							
310	315								
319		IF(I.LE.NI	ILDA) GO	TO 72					
320	84	IF (NFIXED.	LE.07 GO	TO 88					
321	85	DO 87 JJ∋1	NPIXED						
322		IWS=IPARAM	(37)	· · · · · · · · · · · · · · · · · · ·					
323		DO 86 II=1	NPARAM	•				<u></u>	
324		A(IWS,II)=	0,						
325	86	A(II,IWS)=	0.						:
326	87	A(IWS, IWS)	51.						
327	88	GO TO (90.	704.703),	TBKA					
328	90	DO 92 1=1	NPARAM	\$ wites					.•
329	<u>c</u>	SA SA	VE SQUARE	ROOTS OF	DIAGONAL	FI EMEN	TS anar		•
330	92	SALLY=SORT			μ/π/ <sup></sup> γ/··//we	los lige los l ( los f ∓	1 61		
331	• •	Do 106 1=1	NPARAM						
-332		<u>no in jei</u>	NRARAM						
222		10-6711/46 10 700 044	х х зх х тите махиц						
770		- MOBOALIJEO Teluc ct (	₩₹₩) ₩₹₩)	<b>n</b> Q				•	
		1+[W3+91+0	+/ 44 10	90				4 	<i></i>
	116	A(I,J) En.							
335	20								
335	90	GO TO 100							
335 336 337	98	GO TO 100 A(I,J)=A(I	,J)/WS						
335 336 337 338	98 100	GO TO 100 $A(I,J) \equiv A(I)$ CONTINUE	, J)/WS				••••••••••••••••••••••••••••••••••••••		<u>-</u>
335 336 337 338 339	98 100	GO TO 100 A(I,J)=A(I CONTINUE IF(SA(I),G	,J)/WS T.O.) GO	TO 104					
335 336 337 338 339 340	98 98 100 102	GO TO 100 A(I,J)=A(I CONTINUE IF(SA(I),G G(I)=0.	,J)/WS T.O.) GO	TO 104					
335 336 337 338 339 340 341	98 100 102	GO TO 100 A(I,J)≡A(I CONTINUE IF(SA(I),G G(I)=0. GO TO 106	,J)/WS T.O.) GO	TO 104					
335 336 337 338 339 340 341 341 342	98 98 100 102 104	$\begin{array}{c} GO \ TO \ 100 \\ A(I,J) = A(I) \\ \hline CONTINUE \\ IF(SA(I),G) \\ G(I) = 0. \\ \hline GO \ TO \ 106 \\ G(I) = G(I) / \end{array}$	, J)/WS T.O.) GO SA(I)	TO 104					
335 336 337 338 339 340 341 342 343	98 98 100 102 104 106	GO TO 100 A(I,J)=A(I CONTINUE IF(SA(I),G G(I)=0. GO TO 106 G(I)=G(I)/3 CONTINUE	,J)/WS T.O.) GO SA(I)	TO 104					
335 336 337 338 339 340 341 342 343 343	98 100 102 104 106	$\begin{array}{c} GO & TO & 100 \\ A(I,J) = A(I) \\ \hline CONTINUE \\ IF(SA(I),G) \\ G(I) = 0, \\ \hline GO & TO & 106 \\ \hline G(I) = G(I)/3 \\ \hline CONTINUE \\ \hline DO & 110 \\ \hline I = 1 \\ \end{array}$	,J)/WS T.O.) GQ SA(I)	TO 104					
335 336 337 338 339 340 341 342 343 344 345	98 100 102 104 106	GO TO 100 A(I,J)=A(I CONTINUE IF(SA(I),G G(I)=0. GO TO 106 G(I)=G(I)/3 CONTINUE DO 110 I=1 A(I,J)=1	,J)/WS T.O.) GQ SA(I) ,NPARAM	TO 104					
335 336 337 338 339 340 341 342 343 344 345 346	98 100 102 104 106 110	GO TO 100 A(I,J)=A(I CONTINUE IF(SA(I),G G(I)=0. GO TO 106 G(I)=G(I)/3 CONTINUE DO 110 I=1 A(I,I)=1. PUT7=PHI	,J)/WS T.O.) GO SA(I) ,NPARAM	TO 104					
335 336 337 338 339 340 341 342 343 344 345 346	98 100 102 104 106 110 120	GO TO 100 A(I,J)=A(I CONTINUE IF(SA(I),G G(I)=0. GO TO 106 G(I)=G(I)/3 CONTINUE DO 110 I=1 A(I,I)=1. PHIZ=PHI	, J)/WS T.O.) GO SA(I) ,NPARAM	TO 104					
335 336 337 338 339 340 341 342 343 344 345 346 347 348	98 100 102 104 106 110 120	GO TO 100 A(I,J) = A(I CONTINUE IF(SA(I),G G(I)=0. GO TO 106 G(I)=G(I)/3 CONTINUE DO 110 I=1 A(I,I)=1. PHIZ=PHI WE	,J)/WS T.O.) GO SA(I) ,NPARAM 	TO 104	}				
335 336 337 338 339 340 341 342 343 344 345 346 345 346 347 348	98 100 102 104 106 110 120 1132	GO TO 100 A(I,J) = A(I CONTINUE IF(SA(I),G G(I)=0. GO TO 106 G(I)=G(I)/3 CONTINUE DO 110 I=1 A(I,I)=1. PHIZ=PHI WE DO 1133 II	,J)/WS T.O.) GO SA(I) ,NPARAM NOW HAVE =1,NPARAM	TO 104	)				
335 336 337 338 339 340 341 342 343 344 345 346 347 346 347 348 349	98 100 102 104 106 110 120 C 1132	GO TO 100 A(I,J) = A(I CONTINUE IF(SA(I),G G(I)=0. GO TO 106 G(I)=G(I)/ CONTINUE DO 110 I=1 A(I,I)=1. PHIZ=PHI WE DO 1133 II III=II+25	, J)/WS T.O.) GO SA(I) ,NPARAM -NOW HAVE ⇒1,NPARAM	TO 104	}				
335 336 337 338 339 340 341 342 343 344 345 344 345 346 347 348 349 350	98 100 102 104 106 110 120 C 1132	GO TO 100 A(I,J) = A(I CONTINUE IF(SA(I),G G(I)=0. GO TO 106 G(I)=G(I)/ CONTINUE DO 110 I=1 A(I,I)=1. PHIZ=PHI WE DO 1133 II III=II+25 DO 1133 JJ	,J)/WS T.O.) GQ SA(I) ,NPARAM NOW HAVE ⇒1,NPARAM ≠1,NPARAM	TO 104					
335 336 337 338 339 340 341 342 343 344 345 346 347 346 347 348 349 350	98 100 102 104 106 110 120 0 1132	GO TO 100 A(I,J) = A(I CONTINUE IF(SA(I),G G(I)=0. GO TO 106 G(I)=G(I)/ CONTINUE DO 110 I=1 A(I,I)=1. PHIZ=PHI WE DO 1133 II III=II+25 DO 1133 JJ	,J)/WS T.O.) GQ SA(I) ,NPARAM NOW HAVE ⇒1,NPARAM ¥1,NPARAM	TO 104	<b>}</b>				
335 336 337 338 339 340 341 342 341 342 344 345 346 347 348 349 350	98 100 102 104 106 110 120 C 1132	GO TO 100 A(I,J)=A(I CONTINUE IF(SA(I),G G(I)=0. GO TO 106 G(I)=G(I)/ CONTINUE DO 110 I=1 A(I,I)=1. PHIZ=PHI WE DO 1133 II III=II+25 DO 1133 JJ	,J)/WS T.O.) GQ SA(I) ,NPARAM NOW HAVE ⇒1,NPARAM ¥1,NPARAM	TO 104	<b>,</b>				
335 336 337 338 339 340 341 342 341 342 343 344 345 346 347 348 349 350	98 100 102 104 106 110 120 1132	GO TO 100 A(I,J) = A(I CONTINUE IF(SA(I),G G(I)=0. GO TO 106 G(I)=G(I)/ CONTINUE DO 110 I=1 A(I,I)=1. PHIZ=PHI WE DO 1133 II III=II+25 DO 1133 JJ	,J)/WS T.O.) GO SA(I) ,NPARAM NOW HAVE ⇒1,NPARAM ¥1,NPARAM	TO 104	<b>)</b>				
335 336 337 338 339 340 341 342 341 342 343 344 345 346 347 348 349 350	98 100 102 104 106 120 120 1132	GO TO 100 A(I,J)=A(I CONTINUE IF(SA(I),G G(I)=0. GO TO 106 G(I)=G(I)/ CONTINUE DO 110 I=1 A(I,I)=1. PHIZ=PHI WE DO 1133 II III=II+25 DO 1133 JJ	,J)/WS T.O.) GO SA(I) ,NPARAM NOW HAVE ⇒1,NPARAM ¥1,NPARAM	TO 104	<b>)</b>				
335 336 337 338 339 340 341 342 343 344 345 346 347 346 347 348 349 350	98 100 102 104 106 110 120 1132	GO TO 100 A(I,J)=A(I CONTINUE IF(SA(I),G G(I)=0. GO TO 106 G(I)=G(I)/ CONTINUE DO 110 I=1 A(I,I)=1. PHIZ=PHI WE DO 1133 II III=II+25 DO 1133 JJ	,J)/WS T.O.) GO SA(I) ,NPARAM NOW HAVE =1,NPARAM ≠1,NPARAM	TO 104	)				
335 336 337 338 339 340 341 342 343 344 345 344 345 346 347 348 349 350	98 100 102 104 106 110 120 C 1132	GO TO 100 A(I,J) = A(I CONTINUE IF(SA(I),G G(I)=0. GO TO 106 G(I)=G(I)/ CONTINUE DO 110 I=1 A(I,I)=1. PHIZ=PHI WE DO 1133 II III=II+25 DO 1133 JJ	,J)/WS T.O.) GO SA(I) ,NPARAM NOW HAVE ⇒1,NPARAM ¥1,NPARAM	TO 104	•				
335 336 337 338 339 340 341 342 343 344 345 346 347 346 347 348 349 350	98 100 102 104 106 110 120 C 1132	GO TO 100 A(I,J) = A(I CONTINUE IF(SA(I),G G(I)=0. GO TO 106 G(I)=G(I)/ CONTINUE DO 110 I=1 A(I,I)=1. PHIZ=PHI WE DO 1133 II III=II+25 DO 1133 JJ	,J)/WS T.O.) GO SA(I) ,NPARAM NOW HAVE ⇒1,NPARAM ¥1,NPARAM	TO 104	<b>)</b>				
335 336 337 338 339 340 341 342 343 344 345 346 347 346 347 348 349 350	98 100 102 104 106 110 120 C 1132	GO TO 100 A(I,J) = A(I CONTINUE IF(SA(I),G G(I)=0. GO TO 106 G(I)=G(I)/ CONTINUE DO 110 I=1 A(I,I)=1. PHIZ=PHI WE DO 1133 II III=II+25 DO 1133 JJ	,J)/WS T.O.) GO SA(I) ,NPARAM NOW HAVE ⇒1,NPARAM ¥1,NPARAM	TO 104	<b>}</b>				

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	FORTRA	N IV	(VER 45	) SOURCE	LISTING	FITIT	SUBROUT	INE 05/2	6/78	15:35:56	P/
(	351	1133	ACLILI	J)=A(11.	11)						
	352	1134	CONTINUE	NT.NE.OY	60 70 46	3					
	354	C****	**********	*********	8444444444 	·******	*****	******	*****	***	*
	355	Ç		STARTING	THE FIF	ST ITERA	TION				
	356	152	LAMBDA=(	).01	_						
	357	154	<u>DO 161</u>	$J=1 \cdot NPAR/$	<u>AM</u>						
	358	, 161	SPARAM	J)=PARAM(	(J) IN COPRES	DANDS TO					
	360	163	106121	SPARAMIN	J) CURRES	гумра н	2 · [# [] 1 4			•	
	361		WSENDATA	-NPARAM	NFIXED						<u></u>
	362		ICOUNT=1	COUNT+1							
	363	<u></u>	SESSORT	PHIN/WS	)						<b></b>
	364	Ç	T m a bi Chi 17	SE IS TH	IE STANDA	RD ERROP	OF THE	ESTIMATÉ		an a	
	362	100	IF (NGWG)		1 TO 169					107 - 1 <i>1</i> 4	ччн <b>,</b>
_	347	167	WRITE	911)PHI	7.55.LENG	TH. GAMMA	ALAMBDA				
	368	911	FORMAT	14X.3HP	11.15X.3	IS E 12X	6HLENGTH	,ŻX,5HGÃM	MÃ.7X	•	
	369	* 63 ster	1 6HLAMBI	JA, 10X, 24	HESTIMAT	ED PARTI	ALS USED	/5X,1P2E1	8.8.1	P3E13.3)	
	-370		GO TO 16	<b>;9</b>							
	371	168	WRITE(6,	,912)PHI7	Z, SE, LENG	TH, GAMMA	,LAMBDA	•			
	372	912	FORMATC	14X.3HPF	11,15X,31	<u>S E,12X,</u>	6HLENGTH	<u>,7X,5HGAM</u>	<u>MA . 7X</u>	<b>,</b>	
	373	:	1 GHLAMBI	JA,10X,22	2HANALYTI	C PARITA	ILS USED/	5X:1P2E18	-8, <u>1</u> P	3213,3)	
	375	165	CONTINUE	]9							;
-	376	166	WOTTERA	939)				· · · · · · · · · · · · · · · · · · ·			
	377	939	FORMATCA	34X 22HF	TP CORRE	LATION N	ATRIX)		·		
	378	111	DO 114 1	1=1.NPAR/	AM						
	379	114	WRITE(6,	,937) I,	(A(I,J),	J=1,NPAF	RAM)				
	380	937	FORMAT	10X,15,2	2x,10F10	4/(10X)1	LOF10,4))				
~	381		IF (NSW2)	<u>, EQ.0) GC</u>	<u>) TO 1161</u>						
	382	9.07	FORMATE	/ 4 J 3 J 8 8 1 2 / 4 J X - 3 4 8 1 2	4) 30, LAME	10A 15 F. 19X.	AUL AMBDA	. ToY!	• •		
	384		1 24HEST]	MATED P/	ARTIALS U	ISED/5X 1	P2E18.8.	18613.3)			19 1 - 19 19
	385		GO TO 10	59			n				
	386	1161	RITE(6)	909)PHI7	Z, SE, LAME	DA		•			
	387	909	FORMATCA	14X,3HPF	11,15X,3H	IS E,12X,	6HLAMBDA	,10X,			
	388		1 22HANAL	YTIC PAP	TIALS US	ED./5X.1	P2E18.8,	1PE13.3)			
	389	169	GO TO 20	10							
	390	104	PHILEPHI	UE NOW L	INC DUT			<u>, , , , , , , , , , , , , , , , , , , </u>			
	392	Ŷ	DO 170 .	I=1.NPAR/	1885 F 11 1 V M	GANDDA/					
	393		IF(Å9\$(I	PARAM(J)	ABSCPA	RAM(J))+	TAU)).GE	.E) GO TO	172		
	394	170	CONTINUE								
	395		WRITE(6	,923)			· · · · · · · · · · · · · · · · · · ·				
_	396	923	FORMATC	.H1,50X,1	9HPASSED	EPSILON	TEST)				
	397	4 7 0	GO TO 70				,				
	390	172	IF (NSWD)	EQ.0) G(	) 10 1720 ) 10 172						
	400	1/20	TE'NSW4	FO.1) GC	7 10 173		- <del></del>		,		
			4 P. A 17 W FI PE 1		· 14 T.T					· · · · · · · · · · · · · · · · · · ·	
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FORT	FRAN IV	(VER 45 ) SOURCE LISTING: FITIT SUBROUTINE 05/26/78 15:35:5	jó I		
40	)1	NSW4=NSW4-1			
40 40	2 171	GO TC 173	4 mm.		
40	14 924	RITE(0,924) Format/1H1.30X.40HCASE TERMINATED: REQUIRE MORE ITERATIONS)			
40	15	GO TO 700	<u> </u>		
40	16 173	XKDB=1.0			
40	,7	IF(PHIL, GT, PHIZ) GO TO 190			
1 40° 40	,8 1/7	XLSALAMBDA			
41	9 10	DU 1/0 JELINFARAM RDADAM(1)=PARAM(1)			
41	1 176	PARAM(J)=SPARAM(J)			
41	.2	IF(LAMBDA.GT,,0000001) GO TO 175			
41	<u>.3 1175</u>	, DO 1176 J=1.NPARAM	·····		
41	4		-		
41	2 +1/- 2 +1/-	SPARAM(J)=MARAM(J)			
41	7 175	i LAMRDA=LAMBDA/10:			
41	48	IBK1=2			
41	9	GO TO 200			
42	.0 177	PHL4=PHI			
42	1 6	WE NOW HAVE PHILLAMENALLU)			
42	187	1 F (Phigh, GI) - Chi 27 GV IV 10 404	*********		
42	4 187	SPARAM(J)=PARAM(J)			
42	25	GO TO 60	:		
42	16 184	LAMBDARXLS			
42	.7	DO 186 J=1.NPARAM			
42	8	SPARAM(J)=BPARAM(J)			
43	9 100 Ka	PARAAVUJEBEARANVUJ			
43	1 190	4 TRK1=4			
43	2	XLS=LAMBDA			
43	13	LAMBDA=LAMBDA/10;			
43	4	DO 185 J=1, NPARAM			
- 43: 47	5 182	PARAM(J)=SPARAM(J)	-		
43	לא 1877 רי	50 TU 200 Terbut FE PH173 AA TA 496			
43	(R 191		*****		
1 43	19	IBK1=3			
44	0 192	LAHBDA=LAMBDA+10;			
44	1 195	DO 193 J=1,NPARAM			
497 44	2 193				
- 44	3 192				
44	4 <b>*</b> * *	WE NOW HAVE PHI(LAMBDA*10)			
44	6 180	IFCPHIT4.GT.PHIZ) GO TO 198			
44'	7 196	DO 197 JE1, NPARAM			
44,	ə <b>19</b> 7	SPARAM(J)=PARAM(J)			
44	9				
49) 	0 <b>t</b> aŭ	IF(GAMMA,GE,GAMQK) BU TU 192	с		
ł			•		
-					
1			-		
1					
				95	
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	FORTR	AN IV	(VER 45 ) SOURCE LISTING: FITIT SUBROUTINE 05/26/78	15:35:56	Р
	451	1 9 9	XKDB=XXDB/2.		
· [	452		DO 1199 J=1, NPARAM	······	
	453		IF(ABS(DPARAM(J)/(ABS(PARAM(J))+TAU)),GE,E) GO TO 195	•	
	454	1199	CONTINUE		
•	455		DO 1200 J=1, NPARAM		
	456	1200	PARAM(J) #SPARAM(J)		
	457		WRITE(6,934)		
	458	934	FORMAT(1H1,50X,25HPASSED GAMMA EPSILON TEST)		
	459		GO TO 700		
Ĺ	460	<u>.C</u>	SET UP FOR MATRIX INVERSION		
	461	200	CONTINUE		
	462	1102	DO 1103 II=1,NPARAM		
r	463		<u>III=II+25</u>	•	
	464		DO 1103 JJ=1, NPARAM		
	-465	1103			
L	466	.1104	DO 202 IH1.NPARAM		
	467	202	A(I,I)=A(I,I)+LAMBDA		
	468		IBKM91.		•
ſ	469	Cere			\$P
	470	404	CALL GJR(A, NPARAM, ZETA, MSING)		
	.4/1	6	GET INVERSE OF A AND SULVE FOR DPARAM(J)IS		
L	472		THIS IS THE MATRIX INVERSION ROUTINE		
	473	C .	NPAHAM IS THE SIZE OF THE MATRIX		
	474	Ç	· · · · · · · · · · · · · · · · · · ·	• • • • • • • • • • •	
r	4/2	445	CO TO (410,000)/MSING		
	4/0	- 412 -	SU IV (410)/10/2 JOAM This is the End of the Matrix inversion"	$\sum_{i=1}^{n} \frac{1}{i} \sum_{i=1}^{n} \frac{1}{i} \sum_{i$	
	4//		INTO TO THE END OF THE WATNEY THAT WATNEY	and the second	
L	4/0	C *****		********	**
	4/9	4	SULVE FUH UPAKAM(J)		
	480	<u>41</u> 0	DU 42U IHINNAKAM DDADAMAINED		
Г	401		DO 424 L-4 MOADAW		
	402	491	DDADAM(I) = Q(I) = DDADAM(I)		
	400	430	Deverwit)=XKDB#DevevW(t)		
L	404	<u>420</u>	DEARABLY FANDS DEARABLY	·	
	207 286	÷	IENGTHEN.		
	497		DTG=0.		
Г	<u> 407</u>	<u></u>			
	489	-	DO 250 J=1 NRARAM		
	490		LENGTH=LENGTH+DPARAM(J)+DPARAM(J)		
L	401		DTG=DTG+DPARAM(J)+G(J)		
	402		GTG=GTG+G(J)**2		
	403		IF(SA(J).EQ.0.) GO TO 699		
Г	404		DPARAM(J) = DPARAM(J)/SA(J)	· · · ·	
	405		IF (PARAM(J) + DPARAM(J), LT. PMIN(J)) DPARAM(I) = ABS ( DPARAM	(J)) · · · · ·	
	406		IF(PARAM(J)+DPARAM(J), GT, PMAX(J)) DPARAM(J)==DPARAM(J)	••••••	
L	407		PARAM(J)=PARAM(J)+DPARAM(J)		
	49A	2 <b>5</b> n	CONTINUE		
	409	9- V	KIP=NPARAM#NFIXED		
	500		IF(LENGTH+GTG.LE:0.) GO TO 1257		
Г			are strated in the state and a state and the state of the		
Γ	-00			and the second	
	200			•	

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ORTRA	NIV	(VER 4	5 ) S(	DURÇE	LISTI	NG: F	ITIT	SUBROU	TINE	05/26/7	8 15	5:35:5	6
501		IF(KI	P.EQ.1	L) GO	TO 12	57							
502		CGAM=	DTG/S(	JRT(LE	NGTH*	GTG)							
503		JGAM=	1										
504		IF(CG	AM. GT	,0) 6	O TO :	253							
505	251	CGAM=	ABS(CC	GAM)									
506		JGAM=	2										
507	253	GAMMA	357.29	957795	\$*(1,5	70728	8+CGAM	+(-0.21	21144	+CGĂMi (C	.0742	261	
508		L-CGAM	*.0187	7293))	) + SQR	T(1,=	CGAM)	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,					
509		GO TO	(257)	295),	JGAM								
510	255	GAMMA	s180,•	-GAMMA	1	•							
511		IFCLA	MBDA.L	-T,1.C	)) GQ	TO 25	7						
512	1255	WRITE	(6,922	2) XL . 0	AMMA								
513	922	FORMA	T(1H1)	30X,2	4HPAS	SED G	AMMA L	AMBDA T	EST.5	X. 1P2E13	(,3)		
514	·	GO TO	700					,				·····	······
515	1257	GAMMA	=0.					· ·					
516	257	LENGT	H=SQR1	CLENG	STH)			•			1 - 1 - 1		•
517		IBK2=	1										
518		GO TO	300										
519	252	IF (NS	W3 .EC	3,0) 0	0 TO	256							
520		WRITE	(6,90	JHHI.	LAMBD	A.GAM	MAILEN	GTH					
521	905	FORMA	T(/15)	K, 3HPH	11,12X	6HLA	MBDÄ,7	X, 5HGAM	IMA, 8X	, 6HLENGT	H/ / 6)	X,	
522		1 PE1	8.8.1F	°3613.	3)	-							
523	254	WRITE	(6,904	FT (DP/	RAM	).J=1	, NPARA	M)					
524	904	FORMA	T(/5X)	20HP/	RAMET	ER IN	CREMEN	TS,1P56	18.8,	/(25X.IF	5E18	.8))	
525	256	GO TO	(164)	177+1	94,18	7), IB	K1			•		• • •	:
526	C		CAL	CULAT	E PHI							· · ·	
527	300	1=1				•							•
528		PHI=0								مىرىمى مەربىي		• '	
529		PHIN=	<u>.</u>										
530	<b>c</b>								· · · · · ·			<b></b>	· · · ·
531	008	CALL	MODEL	Y X F	ARAM	PRNT.	FCN.I.	RESDUE					
532	C								······				
533		IFCRE	SDUE.	SE.1.6	33) G	άτο	699						
534		IFCI.	GT.ND/	ATA) C	ÎO TO	305							
535		PHINE	PHIN+	RESIDUE	*RESD	UF							
536	305	1=1+1			••••	•							
537	÷ • #	IFel.	LE.NT		GO TO	800							
538		q=1Hq	HIN	- in H A -	<u>~~      </u>					· · · · · · · · · · · · · · · · · · ·		·····	
539	316	GOTO	(252)	780.7	704.76	2.766	,772),	IBK2			•	•	
54n	C####	*****	****	****	****	****	***	***	****	***	****	****	• <b>* *</b>
541	Ċ		TH		ТНЕ с	ONFIN	ENCEL	IMIT CA	LCIILA	TION			
542	699	WRITE	(6.94)	3)	· · · · · · · · · · · · · · · · · · ·		tertt≂ing Ma		r we ser uit ter P3	• <b>A</b> (-) (3)			
547	947	FORMA	インノノマリ	18.384	ICASE	TERMI	NATED	RESULT	S ÅAV	ค คะักพพ	IIP N		
544	~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~	GO TO	660		- VAVE	1 - 11 - 4	нала т. Б. М. К.			- DCANN	<u> </u>		
545	700	<u>הלי המ</u>	2 .1=1.	NPARA	М								
546	700	PARAM		ARAM									
~~~ "5"{7"	102		(8.07)	τ <u>ν</u> ην. Γ.Υ.η.Δ.1		RAMIN	FTXENT	NVARTE		TAIL			
519	Q 77 77	FORMA	T(/RY)	AHNDA	· αφιστ' Α \ΤΔ ·=		Y GUNR		11161 10.1	1 00 Y 00 NP 1 V	EN =		
540	100		V 77 LINI	/AD =	יואיי ¥1 ∠	11914 5V 60	NF	10240 1	1 4 2 4 4 A 4 4 A	ハチアロバアエ/ ロヤーニー <sup>**</sup> ドロ	1024 M	7	
247 -660-		1 1114 9		710121411	1141	28128	rr H /		1 <b>1</b> 7 X <b>1</b> 4		GTA	21	
220	i	C 4X14			/*\$/*X	POLIA	n - 14	LETATOS				,	
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	1021-0			
552				
553 C	THIS WILL PRINT THE Y, YHA	T. DELTA	Υ.	
554	ICOUNT=ICOUNT=1		•	
555			•	**************************************
554	CO TO 61			
557 70A	1 T T T T T T T T T T T T T T T T T T T			
559 704	TOKAS			
550 70.				
540				
561 703	CONTINUE		······································	
562 706	WSENDATAENPARAMENFIXED			
543	TE(WS.1E.0) GO TO 660			
564	SE=SORT(PHI/WS)			
545				
565	TEINSW2, EC. 0. GC 'TO 700			
547 709	WPITE(6.003)PUI7.SE.LAMRDA			
568 568	nniiseiseiseeseenteiseisennoon Go to 708			
540 70	WRITE(6.909) PHIZ.SE.LAMRDA			
570 70P	DA 1123 TIEL NPARAM			
574	111-11-11-08 - 2			
271	111=11-FF7 DA 4497 11=1 NDADAM			
577 140				·····
574 C	UE NOW HAVE MATRIX A			i
575 140	нс ири науч натита а L трим-9			
574				
577 6	WE NOW HAVE CHA INVERSE			
578 74	I DO 711 HE1.NDARAM			
570 /1	F(A(J,J)   F(J)   GO TO 713	2- P	·	
580 744	SA(1) = SQRT(A(1,J))			
584	$c_{0} = 715$			
582 71		······		
593 74	KST4			ور این
534	WRITE(6.916)	•		
585 916	FORMAT(/40X.11HPTP_INVERSE)			
586 23	1 KST=KST=5			
587	KEND=KST+4			
588	IF(KEND, IT, NBARAM) GO TO 719			·····
589	KEND=NPARAM	a de la compañía de l		
590 71	DO 712 I=1 NPARAM			
591 712	WRITE(6,918)1, (A(1, J), J=KST, KEND)	,		······································
592 91	FORMAT(5X, 13, 195618.8)			
593	IF(KEND.LT.NPARAM) GO TO 234			
594	IF(IHOUT.EQ.0) GO TO 717		······································	· · · · · · · · · · · · · · · · · · ·
595	WRITE(6,936)		•	
596 936	FORMAT(//25X.25HNEGATIVE DIAGONAL	ELEMENT		•
597	GO TO 660			
598 71	DO 718 IH1,NPARAM			
599	DO 718 J=1.NPARAM			
600	WS=SA(I) +SA(J)		· · · · · · · · · · · · · · · · · · ·	
~ A A	en werden nammen staff.		•	
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404		terue		0 80 744					<b>.</b>
601	744	$\frac{1}{\sqrt{7}}$		0 10 110					
002 607	, 71,4		₩. 1740						
- 000 - 604	) L 746		- A ( T - 1) /	ШS					•
605	710	CONTIN		<u>n ç</u>					
604	, 170 1	000710	Lad NDA						
600	) 1 ማ ማ ስ		- J≈⊥≢N≞A ⊶1	NAM					
405	120	MOTTE/	<del>241</del> 6.917)						
6000	) ) Q479		1/937,99 1/937,99	HDADANGTED	COBBELA	TTON MATDIN	<b>N</b>		
610	1 11	KST=-9	11201120	HE ANAME I GN	<b>AAUNGMU</b>	TOR NATUTA			
611	721	KSTEKS	T+10						
612	) / [	KENDEK	5740						
613	• •	TECKEN	D. LT. NPA	RAM) GO TO	722				
614	, 	KEND=N	PARAM		,			· · · · · · · · · · · · · · · · · · ·	
615	5 722	Dn 724	T=1.NPA	RAM					
616	724	WRITE	6.935)1	(A(TAU)	KST.KEND	)	1. Sec. 1. Sec		
617	935	FORMAT	(5X.13.2	X 10F10.4)					
618	}	IFIKEN	D.LT.NPA	RAM) GO TO	721				
619	с		GET T*	SE*SORT(C(	1.1)				
620		DO 726	J=1.NPA	RAM					
621	726	SA(J)=	SE*SA(	J		•			
622	1112	DO 111	3 11=1.N	PARAM				· ·	
623		<u>II=II</u>	+25		،	• •• •• •• •• •• •• •• •• •• •• •• •• •		· · · · · · · · · · · · · · · · · · ·	
624		DO 111	3 JJ≘1.N	PARAM					
625	5 1113	AIIJ	J)=A(III	( L L .					
526	1114	CONTIN	UE				******		
627	740	WRITE(	6,919)						N 2
628	919	FORMAT	(/16X,3H	STD, 19X, 13	HONE-PAR	AMETER,23X,	13HSUPPORT	PLANE/4	X.
629		1 4HPAR	A,7X,5HE	RROR , 13X.5	HLOWER, 1	3X.5HUPPER,	13X, SHLOWE	R,13X,	
630	•	2 SHUPP	ER)						
631		WSENPA	RAM-NFIX	ED					
632	?	CO 750	J=1.NPA	RAM			· · · · · · · · · · · · · · · · · · ·	·······	
633	5	IF(NFI	XED,LE;0	) GO TO 74	3		•	•	
634	741	DO 742	I=1.NFI	XED					
635		IF(J.E	G. IPARAM	(I)) GO TO	746			·····	
636	742	CONTIN	UE						
637	743	HJTD=S	QRT(WS+F	F)*SA(J)					
638		STE=SA	(J)						
639	)	OPLESP	ARAM(J)-	SA(J)#T					•
640		OPU=SP	ARAM(J)+	SA(J)#T					
641	,	SPL=SP	ARAM(J)-	HJTD					
642		SPU=SP	ARAM(J)+	HJTD					
643		WRITE(	6,927)J,	STE, OPL, OP	U, SPL, SPI	ل 			
644	927	FORMAT	(5X,12,1	P5E18.8)				·	
645	i	GO TO	750						
646	746	WRITE	6,913) ]		· · · · · · · · · · · · · · · · · · ·				
647	913	FORMAT	(5X,12,1	OX,22HPARA	METER WAS	S NOT USED)			
648	750	CONTIN	ŲΕ	· /· 3.					
649	C****	****	***	***	***	***	***	***	***
650	с	- <u></u>	NON-LI	NEAR CONFI	DENCE LI	MIT CALCULA	TION		1
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		•							
						······································			
						******		4. 4. 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	,
		· · · · · · · · · · · · · · · · · · ·							
								· · · · · · · · · · · · · · · · · · ·	

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651		1			
652		WS=NPARAM=NFTXED			
653		WS1=NDATA=NPARAM=NFIXED		•	
654		PKN=WSZWS1			
655		PC=PHI7#(1,+EF#PKN)		·····	
656		WDITE(A.920)PC			
650	900	COMATIZIEV 27 HNONI INGAR CONFI	PENCE LIMITE	nv"	
659	<u> </u>	450001  CRITICAL = .1061518			. V.
450	٠				
660	0.04	FORMAT(/5X,4WPARA.6X,7HLOWER B	11X.9HIOWED P	PHT CovT	
661	764	THIPPER B. 11X. 9HUPPER PHI)			
662	•	TESS34			
447		100700 J=1 NRARAM			
660		TOVOT1	· · · · · · · · · · · · · · · · · · ·		ter and the second s
-004		TRULT NDVDVM			
-007	750	DU /24 JUHANAM			
000	152	PARAM(JJJFSFARAM(JJJ			
667		IF(NFIXED.LE.D) GO TO 750			
668	754	UO 756 JJH1,NF1XED			
669		IF(J.EQ.IPARAM(JJ)) GO TO 787			
670	756	CONTINUE	•	and the second second	
671	758	DD=-1,	•		
672		IBKN=1			
673	760	DEDD			
674		PARAM(J)=SPARAM(J)+D+SA(J)			
675		IBK2=4			
676		Go To 300			
677	762	PH14=PHI			
678	192	15/0414_65.0CN 60 TO 770	میں بیم مرکز کو کار	444 το τοποιο 442 το τοποιο 442 το τοποιο	e filosofie de la factoria de la composición de la composición de la composición de la composición de la compos Composición de la composición de la comp
4/0	764	D-D-DD		·····	
600	704				
200 204	725	5255797999519195797 99 10 100 11 10 10 10 10 10 10 10 10 10 10 10 10 1			
001	/05	FARABIG183FARABIG177495A/9/			
052		18KC-77			
003					
<u> </u>	766	HIDSHI			
585		IF(PHID, LT, PC) GO TO 764			
686		IF(PHID.GE.PC) GO TO 778			
687	770	D=D/2.			
688		IF(D/DD,LE,,001) GO TO 788			
689	771	PARAM(J)=SPARAM(J)+D+SA(J)			
690		IBK2=6			
691		GO TO 300			
692	772	PHID=PHI			
693	7 7 1,44	IF(PHID.GT.PC) GO TO 770			
694	778	XK1=PHTZZN+PHT1Z(1.+N)+PHTNZ(N)	+(D=1,))		
605	,,,,	XK2==(PU17#(1_+n)/n+n/(1_=n)*P	HI1+PHIN/(Na/	1.111	
604		▞▞▙▆▘▝▞▞▋⋠⋦᠅ၭ╈⋠∁₩₮₹₽₽₽₽₹Ň₩₮₽₽₽₹ ¥⋭⋭⋹⋻Ц₮₮щ⋳だ	· · · · · · · · · · · · · · · · · · ·	* ****	•
607			(2)7(2.4444		
09/		899319961117697669968768768769787 80 4996396411766976	10111 C + 84 ( 4)		
090		90 IU (//97/8477185N DADAMA N			
699	779	MAKAM(J)#SPAKAM(J)#SA(J)#BC			
700		GO TO 781		•	
				•	
				n an	· · · ·
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<b>U</b> T T T	V IV	VER 45 ) SOURCE LISTING; FITIT SUBROUTI	NE 05/26/78	15:35:56
701	784	PARAM(J)=SPARAM(J)+SA(J)+BC		
702	781	1BK2=2	· · ·	<b>1</b> 999-1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 19
703		GO TO 300		
704	780	GO TO (782,786), IBKN		
705	782	IBKN=2		
706		DD=1,		
707		BL=PARAM(J)		
708		PL=PHI		
709		GO TO 760		
710	786	BU=PARAM(J)		
711		PURPHI		
712		GO TO (783,795,785,789), IBKP		
713	783	WRITE(6,918)J,BL,PL,BU,PU		
714	-	GO TO 790		
715	/95	WRITE(6,915)J, BU, PU		
/10	915	FORMAT(2X, 12, 30X, 12218, 8)		
71/	705			
/18	785	WRIIE(0,910),, BL; FL		
719	707			
720	/8/	WRIIE(0,910/J		
721	720			
-722	-044	MUTICIONATION TO TON TONNONE EURIND		
720	714	CO TO 790		
706	722	GO TO (701.702). IPKN		
706 (	/03			
720 0	4 704	DEFELE FOMEN LUTHI		
708	147	100 TO 780		•
700	707		د د. د ۱۹۹۵ . مربع المربع ا	· · · · · · · · · · · · · · · · · · ·
727	~ /72	DELETE LIDDED DOINT		
731	703	IRKP=3		
-732-				
733 (	2	LOWER IS ALREADY DELETED, SO DELE	TE BOTH	
734	794	IBKP=4		
735		GO TO 780	·····	•
736	790	JONTINUE		
/		THIS THE END OF THE NONLINEAR REG	RESSION SEQUE	NCF
/.5/ 5		*************************************	****	******
738 (				
738 (	560	CONTINUE		
738 738 739 740	560	CONTINUE NSW3=NSW33		******
738 ( 739 ( 740 741	560	CONTINUE NSW3=NSW33 ICOUNT=0		
738 738 739 740 741 742	560	CONTINUE NSW3=NSW33 ICOUNT=0 NSW4=NSW44		
739 739 740 741 742 743	560	CONTINUE NSW3#NSW33 ICOUNT=0 NSW4=NSW44 IFPL0T=IFPP		
737 738 739 740 741 742 743 743 744	560	CONTINUE NSW3=NSW33 ICOUNT=0 NSW4=NSW44 IFPLOT=IFPP NDATA=NNDATA		
737 738 739 740 741 742 743 743 744 745	560	CONTINUE NSW3=NSW33 ICOUNT=0 NSW4=NSW44 IFPL0T=IFPP NDATA=NNDATA NSW1=NSW11		
737 738 739 740 741 742 743 743 744 745 746	560	CONTINUE NSW3=NSW33 ICOUNT=0 NSW4=NSW44 IFPLOT=IFPP NDATA=NNDATA NSW1=NSW11 NSW2=NSW22		· · · · · · · · · · · · · · · · · · ·
737 738 739 740 741 742 743 743 744 745 746 747	560	CONTINUE NSW3=NSW33 ICOUNT=0 NSW4=NSW44 IFPLOT=IFPP NDATA=NNDATA NSW1=NSW11 NSW2=NSW22 NSW5=NSW55		
737 738 739 740 741 742 743 744 745 745 746 747 743	560	CONTINUE NSW3=NSW33 ICOUNT=0 NSW4=NSW44 IFPLOT=IFPP NDATA=NNDATA NSW1=NSW11 NSW2=NSW22 NSW5=NSW55 IBOUT=0		
737 738 739 740 741 742 743 744 745 745 746 747 743 749	560	CONTINUE NSW3=NSW33 ICOUNT=0 NSW4=NSW44 IFPLOT=IFPP NDATA=NNDATA NSW1=NSW11 NSW2=NSW22 NSW5=NSW55 IBOUT=0 READ(5,900)ININ		
737 738 739 740 741 742 743 743 745 745 745 746 747 743 749 750	560	CONTINUE NSW3=NSW33 ICOUNT=0 NSW4=NSW44 IFPLOT=IFPP NDATA=NNDATA NSW1=NSW11 NSW2=NSW22 NSW5=NSW22 NSW5=NSW55 IBOUT=0 READ(5,900)ININ READ(5,900)ININ	RIABLE	
737 738 739 740 741 742 743 743 745 745 745 745 746 747 743 749 750	560	CONTINUE NSW3=NSW33 ICOUNT=0 NSW4=NSW44 IFPLOT=IFPP NDATA=NNDATA NSW1=NSW11 NSW2=NSW22 NSW5=NSW22 NSW5=NSW55 IBOUT=0 READ(5,900)ININ READ(5,900)ININ	RIABLE	
737 738 739 740 741 742 743 743 745 745 745 746 747 743 749 750	560	CONTINUE NSW3=NSW33 ICOUNT=0 NSW4=NSW44 IFPLOT=IFPP NDATA=NNDATA NSW1=NSW11 NSW2=NSW22 NSW5=NSW55 IBOUT=0 READ(5,900)ININ READING IN THE PROGRAM CONTROL VA	RIABLE	
737 738 739 740 741 742 743 744 745 745 746 747 743 749 750	560	CONTINUE NSW3=NSW33 ICOUNT=0 NSW4=NSW44 IFPLOT=IFPP NDATA=NNDATA NSW1=NSW11 NSW2=NSW22 NSW5=NSW55 IBOUT=0 READ(5,900)ININ READING IN THE PROGRAM CONTROL VA	RIABLE	
737 738 739 740 741 742 743 744 745 745 745 746 747 743 749 750	560	CONTINUE NSW3=NSW33 ICOUNT=0 NSW4=NSW44 IFPLOT=IFPP NDATA=NNDATA NSW1=NSW11 NSW2=NSW22 NSW5=NSW55 IBOUT=0 READ(5,900)ININ READ(5,900)ININ READING IN THE PROGRAM CONTROL VA	RIABLE	
737 738 739 740 741 742 743 744 745 745 746 747 743 749 750	560	CONTINUE NSW3=NSW33 ICOUNT=0 NSW4=NSW44 IFPLOT=IFPP NDATA=NNDATA NSW1=NSW11 NSW2=NSW22 NSW5=NSW55 IBOUT=0 READ(5,900)ININ READ(5,900)ININ READING IN THE PROGRAM CONTROL VA	RIABLE	

	751		GO	TOC	662	,99	98,0	651)	<u> </u>	IN		0111					<u>.</u>			<u></u>	
	752	9998 C	RE	AD(9	+90 R	1)( EAD	ING	AMC. IN	NEW	UJ=1 VALI	JES	OF T	HE	MODEL	PAF	AME	TEF	RS.			·
	755 755 756	662	RE ENI		777	7															
																. <u></u>					
				i												<u> </u>		4			
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and the second 
FORTRAN IV (VER 45 ) SOURCE LISTING; GJR SUBROUTINE GJR(A, N, EPS, MSING) 2 3 C GAUSS-JORDAN RUTISHAUSER MATRIX INVERSION Ć 4 C WITH DOUBLE PIVOTING 5 6 DIMENSION A(10,10), B(10), C(10), P(10), Q(10) ( 7 INTEGER P.Q 8 MSING=1 9 DO 10 K=1,N ( 10 PIVOTSO. 11 DO 20 I=K,N € : 12 DO 20 J=K,N 13 IF(ABS(A(I,J))-ABS(PIVOT))20,20,30 14 C 15 C 30 PIVOTEA(I,J).

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DETERMINATION OF THE PIVOT ELEMENT 16 P(K)=1 17 0(K)=1 18 20 CONTINUE 19 IF(ABS(PIVOT)-EPS)40,40,50 20 50 IF(PEKN=K)60,80,60 21 60 DO 70 J≡1,N\* 22 L=P(K) 23 Z=A(L,J) 24 A(L,J)=A(K,J)25 70 A(K, J)=Z 26 80 IF(G(K)=K)85,90,85 27 85 DO 100 I≡1,N Ż8 -L=Q(K) 29 Z=A(I,L) 30 C EXCHANGE OF THE PIVOTAL COLUMN WITH THE KTH COLUMN A(I,L) = A(I,K)31 32 100 A(I,K) = Z33 90 CONTINUE 34 DO 110 J=1.N 35 C JORDAN STEP 36 iF(J-K)130,120,130 B(J)=1./PIVOT 37 120 38 C(J)=1. 39 GO TO 140 40 130 B(J)=+A(K,J)/PIVOT 41 C(J) = A(J,K)42 140 A(K,J)=0. 43

SUBROUTINE

05/26/78

110 A(J,K)=0, 44 DO 10 1=1,N 45 DO 10 J=1,N 46 10 A(1,J)=A(I,J)+C(I)+B(J) 47 DO 155 M=1.N 48 C REORDERING THE MATRIX 49

K=N=M+1 IF(P(K)=K)160,170,160 102

15:35:56

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F	ORTRA	NIV	(VER 45	) sou	RCE LIS	TING: (	GJR	SUBI	ROUTIN	E 09	5/26/7	'8	15:35	103 <b>:5</b> 6	ΡΑ
	51	160	DO 180	I=1.N											
	52		L=P(K)	· ·											
	53 ≈⊿			L) -×(T.K	•										
	55	180	A(I,K):	<del>= 8 × + + 15</del> = Z	<i>I</i>										
	56	170	IF(Q(K)	)-K)19	0,155,1	.90									
	57	190	DO 150	J=1.N											
	50 59		ZaA(L,	ίĽ									•		
	60		A(L.J)	ACKI	)	· · ·								<u> </u>	
	61	150	A(K,J)												
	62 63	155	RETURN	JE											
	64	40	WRITE(2 FORMAT	2,45)P (16H0\$	(K),Q(K INGULAR	MATRI)	T X3H	1=13,3H	JsI3.	7H P	IVOTEE	16,	8/)		
	66	· • • •	MSING	2				ч 			••••				
	67 68		GO TO 1 End	151											
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1		SUBROUTIN	E SUBZ(	Y, X, PARAM,	PRNT, NP	RNT, NDAT	Ä)			
2 3 4	<u>C</u>	*********** Common Y( NPRNT=1	100),X(	********* 100,5),707	######## AM(10),	<sup>\$\$</sup> ******* PRNT(5),	******** CONST(4)	·##### )	****	i 44
5		RETURN END	<u></u>							
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					. <u></u>					•
•		<u></u>		4.	· · · · · · · · · · · · · · · · · · ·			yah.		; ,
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		SUBROUTI	NE MODE	L(Y,X	PAR	AM, PRN	T, FCI	N.I.R	ESpue	)			······		
21	****	********* Common V	*******	*##### //100	****	******	***** (), DI	****	*****	1444 172	*****	***	***	* * * * *	₽.
4 (	7	QUINON I	TESTINO	6 NE T	<i>ンノ∎</i> 「 '₩□ T'	HIYNTP	DP.IC		77040 1	1211	47				
5 (	3		THIS SU	BROUT	INF	WILL T	EST	A HYS	TEPES	SIS		AND	٨		
6 (	Ŝ		TORQUE	DECAY	CUR	VE	~~~ ,		14//6-			And	~		
7 (	3		PARAM(1	) REP	RESE	NTS TH	E YI	ELD S	TRÉSS	5					
8 (	3		PARAM(2	) REP	RESE	NTS TH	EVIS	SCOSI	TY						
9 (	G		PARAM(3	) REP	RESE	NTS A	RATE	CONS	TANT						
_10_(	<u> </u>	`	PARAM(4	) REP	RESE	NTS A	LUMP	ED PA	RAMET	ER				·	
11	a .		PAKAM(:	REP	RESE	NTS IH		DEK 0	F THE	RA	TEE	QUAT	ION		•.
12 1	2 71		へくすぎます。 すれ エロロー	12 14		ይልጽ ጥል 12 ኩሪህክ	CLIDVI		21111	E W	HEN	<b>U</b> SED			
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45 (	# **	•	X(1.2);		VADI	ARIE W	HINH HINH	LEST		ំលុះ ពេរ		OFNT		YE	
16 (			DETERM	NE. WH	FTHE	R IT I	S REI	PRESE		VE	08 T	HEIII	BALLOV	F."	
17 (			DOWNCUF	VE. O	RTH	E TORO	UE-DE	ECAY	CURVE	V 64	UF 1		CONT	. 649 8	<u>. An Arth</u>
18 (	Ż		CONST(1	) IS	THE	MAXIMU	M SHE	EARR	ATEF	OR	THE	UPCU	RVE O	RDC	JWN
19 (	3		CONST(2	) is	THE	CONSTA	NT SI	HEAR	RATE	FOR	THE	TOR	QUE-D	EACY	Ç
20 (	4	·······	CONSTIC	) 15	A PR	OPORTI	ONAL	ITY C	ONSTA	NT	BETW	EEN	THE		
21 1	<b>)</b> - 11		SHEAR F	ATEA	NDT	IME									
22		T=X(1,1)	• · · ·	100 - 100 - 100 - 100 - 100 - 100 - 100 - 100 - 100 - 100 - 100 - 100 - 100 - 100 - 100 - 100 - 100 - 100 - 100			` 								
23		PRNT(1)=	T												
24		T1=CONST	(1)												i,
25		TZECUNSI	(2)									·····			
20	7	ALPMAZUU	NSI(3) Tue poi	LOUTH	G VA		S A D C	- ner	TNHT	τn	n i Min		94 L.L #7		1000
28 (			1715 FUL Monsi 1	0.05 0.05	TCOTI	=U	0 711	- 451	1 NEW	10	21.04	La <u>1</u> l' l	INE		
- 29		AONE=PAR	AM(5)+1	• 0	1401			••• •••			2				
30		ATWORALP	HA#AONE												
31		ATHREE=T	++AONE												
32		AFOUR=T#	PARAM (	5)								······································			
33		AFIVE=T1	* AONE									• .			
34		ASIX=T2*	*PARAM(	5)											
35		ASEVEN=P	ARAM(3)	*PARA	M(4)	*AFOUR									
36		AEIGHTEP	ARAM(3)	#PARA	M(4)	*ASIX									
3/		A.INE PA	RAM(3)*	ASIX#	X(I):	1)							·		
38		ATENSPAR									•			i e s	
39		BUNESAIE	<u>N#AIMK</u> E NJE 1VE-		c							· .			
40		BTURFF=A	TENSOTL		<u> </u>										
42		BEOUR=PA	RAM(4)*	AFOUR											
43		BFIVE=PA	RAM(3)*	AFOUR											
44		BSIX=BON	E+ALOG(	T)											
- 45		BSEVEN=B	ONE/AON	E			1. T.								
46		BEIGHT=2	.O*AFÍV	E+ALO	G(T1	)									
47		BNINERAT	HREEAL	QG(T)											
48		BTENRATE	N*(BEIG	HT-BN	INE)										
49		CONE=BTH	REE/AON	E											
50	•	CTWO=PAR	AM(4)*A	SIX											1999 - 1999 1999 - 1999 1999 - 1999
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			*****								· ·				• <u> </u>
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r	<u>51</u>		CTHREE=P	ARAM	3) # ASI)	X				<del></del>			
	52	С	CFUURBAL	199112 THE F	0110WI	MANINE) Ng Ciat	EMENTS	TEST	THE D.	Δ.Τ.Δ. Έ	011	To	
	54	č		DETER	MINE W	HETHER	IT IS	REPRES	SENTAT		FTHE	UPCUR	VET
	55	Ċ		DOWNC	URVE.	OR THE	TORQUE	-DECA	CURVI				
	56		IF(X(I,2	).GT.	10,0)	GO TO 4	0			-			
	57		IF(X(1,2	),GT,	2.0.AN	D, X11.2	).LT.3	.0) G(	D TO 2	0			
	58	Ç		THIS	EQUATIO	ON REPR	ESENTS	THE	JPCURV	1 1 1 1			
	59		FCN=PARA	M(1)*	PARAM	2)*T+AS	EVEN*E	Xb(=8(	DNE)				
	60		<u>GO TO 30</u>		10 0 1 1 A - X 1	AN DEPD	COPUES	miller 1	Solliand	DUM			· · · ·
	61	10 20		THIS	EQUATIO	UN REPR	FACNIA	· TRE	UQWNCU!	RVE			
	63	<b>F</b> U	- FUN=FARA - Go to to	191 <b>4 - 4 4</b> #	er Mitt Alti V	C141-40			INKELI				
-	64	C	40 10 30	THIS	FQUATIO	ON REPR	ESENTS	THE	TOROUE	DECA	Y CUR	VF	
	65	40	FCN=PARA	M(1)+	PARAM	2)*T2+A	EIGHT*	EXP(-	ANINE)			* bon	
	66	30	RESDUERY	(1)-F	CN								
	67		RETURN									· · · · · · · · · · · · · · · · · · ·	
	68		END										
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	1		SUBROL	ITINE	DERI		RTLX	PARA	M.PRN	T.FCN	1. I Š					
	2	Ç###	***	****	****	***	****	***	****	* * * * * *	****	***	****	***	***	*****
	3		COMMON	Y(10	)0 <b>),</b> X	(100	,5),P	ARAMC	10),P	RNT (S	3),CO	NST	(4)			
	4	C		INS	SERT	THE	VARIO	US PA	RTIAL	DERI	VATI	VES	ÍN Ť	HIS		
	5	C		SUE	BROUT	INE	ONLY	IF AN	ALYTI	C PAF	RTIAL	S AP	RE TO	BĘ	USED	
	6		DIMENS	ION F	PARTL	(10)										
	7		T = X (I)	1)												
	8		T1=CON	IST(1	>											
	9		T2=C0N	IST(2)	)								•			
	10		ALPHA	CONS	[(3)											
	11	Ç		THE	FOL	LOWI	NG VA	RIABL	ES AR	E DEF	INED	ΤO	SIMP	LIFY	THE	
	12	¢		MOI	DEL T	0 86	TEST	ED								
	13		AONE=F	ARAM	(5) + 1	,0	<u></u>									
	14		ATWO=A	LPHA	AONE											•
	15		ATHREE	=T**/	IONE											
~~~	16		AFOUR	T##P/	RAMC	5)						·				
	17		AFIVE=	T1##/	IONE	<b>.</b> .										
	18		ASIX=T	2##P/	RAMC	5)			_							
	19		ASEVEN	=PARA	AM(3)	*PAR	AM(4)	#AFOU	₹							
	20		AEIGHT	=PAR/	AM (3)	*PAR	AM(4)	*ASIX								
	21		ANINE	PARA	1(3)*	ASIX	*X(I,	1)								
	22	. <u></u>	ATENSP	AHAM	3)/A	TWO								·		
	23		BONERA	TEN#A	ATHRE											
	24		0 [ W Q = 2	. U≇Ar	1.0000	ATHR										
	25		BIHREE	PALE	A A A A A		n									
	20		BFOOHS	PARA	1(4)**		r D									
	2/		0 P C I V H C	PARAP	1107*	AF U U I 7 N	ĸ									. f .
	20		DOLATE		LUQ			ىپەر «بىلە ھەلەر يەر مەلمە بەسمە		• .			4			
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	-10-		BTENEA	TENA	RETG	HT_RI	NINEY	• • • • • • • • • • • • • • • • • • • •								*****
	27		CONE=B	THREE		F	• • • • • •									
	34			ARAMO	41.44	STY .			•					•		
•	75		CTUDER	-PADA	M(3)	BAGIN	v									·····
	36				7214	(1.0)	⊷ ANITN	FN								
	37			ARAM	5)-1	.0	**17 # 13									
	38		ATWORA	I.PHA	AONE											
	39		ATHREE	= T + + 4												
	40		AFOURS	T##PA	RAMO	5)										
	41		AFIVES	T1**4	ONF	· · · · · · · · · · · · · · · · · · ·								·		
	42		ASIX=T	2##94	RAMC	5)										
	43		ASEVEN	PARA	M(3)	*PARA	AM(4)	#AFOU	ર							
	44		AEIGHT	=PARA	M(3)	*PAR	AM(4)	#ASIX								
•	45		ANINE	PARAN	1(3)*	ASIX	+X(1-	1)								
	46		ATEN=P	ARAM	31/A	TWO		•								
~~	47		BONE=A	TEN+4	THRE	Ę							·····	· · · · · · · · · · · · · · · · · · ·		*****
	48		BTWO=2	.0+AF	IVE-	ATHR	EE									
	49		BTHREE	=ATEN	HBTW	0										
	50		BFOUR	PARAM	1(4)*	AFOUR	२									
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-	FORTRAN IV	(VER 45 ) SOURCE LISTING: DERIV SUBROUTINE 05/26/78 15:35:56 P
	51	BFIVE=PARAM(3)+AFOUR
Γ	52	BSIX=BONE+ALOG(T)
	53	BSEVEN=BONE/AONE
L	54	BEIGHT=2.0#AFIVE*ALOG(T1)
	55	BNINE#ATHREE#ALQG(T)
	56	
r-	57	
	50	
1.	27 60	
L	61	CFOUR=ALOG(T2) + (1, 0 = ANINE)
	62 G	THE FOLLOWING STATEMENTS TEST THE DATA POINT TO
	63 ¢	DETERMINE WHETHER IT IS REPRESENTATIVE OF THE UPCURVE.
Γ	64 Ç	DOWNCURVE, OR THE TORQUE-DECAY CURVE
	65	IF(X(I,2),GT,10,0) GO TO 40
	66	IF(X(I,2),GT,2.0,AND,X(I,2),LT.3.0) GO TO 20
	67 Ç	THE FOLLOWING PARTIAL DERIVATIVES ARE FOR THE UPCURVE
	68	PARTL(1)=1.0
<b></b>	69	PARTL(2)=T
	70	PARTL(3)=BFUUR*EXP(=BUNE)*(1,U*BUNE)
	71	PARIL(4) - ASEVENAEVP( = DONE) + (A) OG(T) - DOIV+DOEVENS
	73	LAUIEVONEVACKUKEKUKMBONENKUKEKUNADOTVADOTVAROCKEV)
	74 C	THE FOLLOWING PARTIAL DERIVATIVES ARE FOR THE DOWNCURVE
	75 20	PARTI(1)=1.0
1	76	PARTL(2)=T
	77	PARTL(3)=BFOUR+EXP(-BTHREE)+(1.0-BTHREE)
	78	PARTL(4)=BFIVE*EXP(-BTHREE)
L	79	PARTL(5) = ASEVEN + EXP( = BTHREE) + (ALOG(T) = BTEN+CONE)
	80	PARTL(5)=-BSEVEN+ATWO+EXP(-ATHREE)
	81	<u>GO TO 30</u>
	82 C	THE POLLOWING PARTIAL DERIVATIVES ARE FOR THE TORQUES
	83 C	DECAY CURVE
L	84 40	PARIL(1)=1;0
	02	FARILIZ/#16 31071 (3)=07W0xEV0/=1NINE)=(1,0=ANINE)
	80 87	PARTI (4)=CTHREF#EXP(+ANINE)
	88	PARTL(5)=AEIGHT#FXP(=ANINF)+CFOUR
	89 3n	CONTINUE
	90	RETURN
<b>L</b>	91	END
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01/04/80 11:06:01 PAGE

1	DIMENSION TAV(50), FN(50), EV(50), ASS(50), ASR(50), GS(50), TTS(50), 1TSS(50), GA(50, 50), GD(50, 50), GB(50, 50), TTB(50, 50), TSB(50), 00(500),
3	2GC(50), GV(50), W(50), WW(100), YW(100), WS1(100), WS2(100), WR1(100).
4	3AS2(50), AR1(50), AR2(50), AS1(50), WR2(100), DLGC(50),
	4DLTSS(50),DLASS(50),DLTSR(50),DLASR(50),DLQQ(50),DLGS(50),DLGV(50)
6	5.DLW(100),DLWW(100),DLYW(100) .
	OULASI(50), ULASZ(50), ULARI(50), ULARZ(50) 
. 9	EQUIVALENCE (WW(r)) TSR) (WW(22) ASR)
10	EQUIVALENCE (YW(1), GC), (YW(22), GV)
	EQUIVALENCE (DLW(1), DLTSS), (DLW(22), DLASS)
12	EQUIVALENCE (DLWW(1), DLTSR), (DLWW(22), DLASR)
13	EQUIVALENCE (DLYW(1),DLGC),(DLYW(22),DLGV) EQUIVALENCE (DE4(4),DLTES),(DE4(20),DLAS4)
15	EQUIVALENCE (WR1(1) DI ISR) (WR1(22) DI AR1)
16	EQUIVALENCE (WS2(1), DLTSS), (WS2(22), DLAS2)
1.7	EQUIVALENCE (WR2(1), DLTSR), (WR2(22), DLAR2)
18	633 FORMAT (///,30X, RELATIONSHIP OF INPUT SHEAR RATES VS, TIME!/)
19	634 FORMAT (15X, 'TIME(SEC)', 10X, 'DL, T, ', 8X, 'DL, SH, R. (STEP CHANGE)', 4X,
	$\frac{1}{3} + 5 + 5 + 5 + 5 + 5 + 5 + 5 + 5 + 5 + $
22	4 FORMAT (6F10-4)
23-	
24	30 FORMAT ('1')
25	983 FORMAT (110,1F10;4)
26	
2/	100 FURMAT (110, $3$ F10,4) 704 FURMAT (12, $4$ $4$ $4$ $4$ $4$ $4$ $4$ $4$ $4$ $4$
20	201 FURTHER C. J. 1/////JIUKJAKIATFID, 4/4/100, 4/10000000000000000
30	302 FORMAT (10X, 'NR='110, 5X, 'NI='110, 5X, 'S='F10, 4, 5X, 'MM='110, 5X,
31	1 * NN=* 110///)
32_	
33	405 FURMAI (111,30X,1TA=0,01,1X,1SEC1,10X,1E=0.01//) the start state of the start
	201 FORMAT (11) 20Y LEEPINITION(1)
36	66 FORMAT ('0',10X,'TT1='F10',4,1X,'SEC',10X,'TSS(1)='F10.4,'DYNE/CM-
37	1CM'10X, 'TSR(MAX)='F10,4, 'DYNE/CM-CM'/)
	<u>666 FORMAT ('0',10X,'TA='F10,4,1X,'SEC',5X,'E='F10,4,5X,'GS(1)='F9,4</u>
39	1,'/SEC',5X,'GV(MAX)=1F9,4.'/SEC'/)
40	202 FURNAL (10X, HERADIUS, UPATHE STATING CYLINDER, UMM)
42	205 FORMAT (10X.'R =ARBITRARY RADIUS BETWEEN RI AND R2. CM')
43	208 FORMAT (10X, 'A=ACCELERATION CONSTANT OF THE ROTATING CYLINDER')
4.4	209 FORMAT (10X, 'B=LENGTH OF THE COUVETTE')
45	210 FORMAT (10X, 'Q=TIME, SEC')
4 () 4 7	219 FURMAL CLUX, 111 FILME AT MAXIMUM SHEAR RATE, SEC. 1)
48	221  FORMAT (10X)  INR=SECTIONAL CONSTANT FOR RADIUS (1)
49	222 FORMAT (10X, 'UA, UB, UC=DELTA FUNCTIONS IF (UA, ETC.) 0.0.1')
50	
	Annualise T. A. Computer measure for the dynamic hobertion

Appendix I. 4. Computer program for of torsion head the dynamic behavior

109

110 01/04/80 11:06:01 PAGE

> م مارک گرون در در مرکز که مرکز میکند. به در میکند از میکند هدار در محمد کور کوری در در در در در در در در در

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51
    2121 FORMAT (10X, AS=DEFLECTION OF THE TORSION BAR AT A CONSTANT, 1X,
2122 FORMAT (9X, 'AR=DEFLECTION OF THE TORSION BAR DURING A LINEAR', 1X,
 53
54
         1 ACCELERATION OF THE //, 12X, ROTATING CYLINDER, NICRO )
215 FORMAT (1)X, WO=CONSTANT REVOLUTION RATE OF THE ROTATING CYLINDER,
 56
 57
         11/SFC')
-58-
     -216-FORMAT-(10X, TK=TORSION-BAR-CONSTANT, DYNE-GM/MICRO1)--
     2171 FORMAT (9X, 'TSR=THEORETICAL SHEAR STRESS, DYNE/CM, CM')
59.
 60
     2172 FORNAT (19X, ASR=ARTIFICIAL SHEAR STRESS, DYNE/CM, CM)
 61
     -313 FORMAT (10%, TA=+F10, 4, 10%, E=0, 0+/)-
      402 FORMAT (30X, STEADY STATE FLOW AT CONSTANT ROTATING RATE, 1X,
1'AFTER A STEP CHANGE!/)
 62
63
 64
     <del>4.31_FORMAT_(15%, 'TIME',13%, 'SH</del>EAR<del>_RATE',1</del>0%, 'TH<del>EO-S</del>HEAR-STRESS',1<del>0</del>%,
 65
         1'ARTI-SHEAR STRESS!/)
     5031 FORMAT (1,15X, DET. 1,12X, DL, SH, RATE 1,9X, DL, THEO, SH, STRESS 1,9X,
66
6-7---
       -1 'DL ARTI, SH, STRESS '/)-
     4032 FORMAT (10X, F10, 4, 10X, F10, 4, 15X, F10, 4, 15X, F10, 4)
 6 g
     4.33 FORMAT (10X, 110, 10X, F10, 4, 15X, F10, 4, 15X, F10, 4)
 69
     404 EORMAT ( / , 30X, + UNSTEADY STATE FLOW DURING A-LINEAR+1X,-
.7.Q.
         1 ACCELERATION AND DECELERATION ()
 71
      501 FORMAT ('0', 10X, 1PLOT OF SHEAR STRESSES (Y-AXIS) VS, TIME
 72
                                                                       7.3....
    _____IAFTER_A_STEP_CHANGE_)___
74
     504 FORMAT ('0', 10X, 'PLOT OF SHEAR STRESSES (Y-AXIS) VS. SHEAR RATE
75
         1DURING A LINEAR ACCELARATION AND DECELERATION()
     505 EDRMAT (101,10X, FLOT OF SHEAR RATES (Y-AXIS) VS, TIME (X-AXIS))
7.6
 77
     600 FORMAT (50X, UNDERDAMPING!/)
78 601 FORMAT (SOX, 'CRITICAL DAMPING'/)

79 602 FORMAT (SOX, 'OVERDAMPING'/)
80
     206 FORMAT (10X, 'TA=TIME CONSTANT OF THE TORSION HEAD, SEC')
     207 FORMAT (10X, 'E=DAMPING COEFFICIENT, 0')
81
82_3_51_FORMAT_(12X+JDL,T,(DIMENSIONLESS_TIME=TIME(10SEC)/TIME_CONST,TA*)_____
83
     3052 FORMAT (10X, 'DL, S, R. (DIMENSIONLESS SHEAR RATE#SHEAR RATES (STEP), / ...
         1,13X, 'CHANGE/TRIANGULAR STEP)/(CONST./MAX.) SHEAR PATE (AFTER A!,/
84
85
       _2,13X, 'STEP_CHANGE/DURING_A_TRIANGULAR_STEP_CHANGE)_)
     3053 FORMAT(10X, 'DL. (THEO/ARTE) S.S. (DIMENSIONLESS SHEAR STRESS',/
86
        113X, '(THEORETICAL/ARTEFACT) = SHEAR STRESS(THEORETICAL/ARTEFACT)',/,
87
     901 FORMAT (10X, 'GS(1)=SHEAR RATE FOR A STEP CHANGE')
 88...
 89
 90
      902 FORMAT (10X, 10V(MAX)=MAX, SHEAR RATE DURING A LINEAR ACCLERATION
     _____1AND_DECELERATION:/,12X, TRIANGULAR_STEP_CHANGE.)____
9.1
     903 FORMAT (10X, 'TT1=TOTAL TIME FOR A TRIANGULAR STEP CHANGE')
92
 93
     904 FORMAT (10X, 'TSS(1)=THEORETICAL SHEAR STRESS FOR A STEP CHANGE')
 9.4___
    -905-FORMAT (10X, TSR(MAX) = THEORETICAL MAX, SHEAR STRESS-FOR A TRIANGUL
    1AR STEP CHANGE:)
1234 FORMAT (19X, MM=NO, OF TA!)
1235 FORMAT (19X INNENO, OF TA!)
95
96
97 1235 FORMAT (10X, INN=NO. OF E.)
98
          WRITE (6,201)
         WRITE (6,202)
99
100 _____WRITE (6,203)_
```

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111

101       WRITE (6,205)         103       WRITE (6,200)         104       WRITE (6,210)         105       WRITE (6,212)         106       WRITE (6,212)         107       WRITE (6,212)         108       WRITE (6,212)         109       WRITE (6,212)         100       WRITE (6,212)         111       WRITE (6,212)         112       WRITE (6,221)         113       WRITE (6,221)         114       WRITE (6,220)         115       WRITE (6,221)         116       WRITE (6,221)         117       WRITE (6,221)         118       WRITE (6,221)         119       WRITE (6,201)         110       WRITE (6,201)         120       WRITE (6,203)         121       WRITE (6,901)         122       WRITE (6,901)         123       WRITE (6,901)         124       WRITE (6,3050)         125       WRITE (6,3050)         126       WRITE (6,3050)         127       WRITE (6,3050)         128       WRITE (6,3050)         129       FAD (5,902)         120       WRITE (6,303) U,A,WO,KI1	( N -		
102       MRITE (6,209)         103       WRITE (6,210)         104       WRITE (6,211)         105       WRITE (6,212)         107       WRITE (6,212)         108       WRITE (6,212)         109       WRITE (6,212)         110       WRITE (6,212)         111       WRITE (6,212)         112       WRITE (6,217)         113       WRITE (6,22)         114       WRITE (6,22)         115       WRITE (6,22)         116       WRITE (6,22)         117       WRITE (6,22)         118       WRITE (6,22)         119       WRITE (6,22)         119       WRITE (6,20)         120       WRITE (6,902)         121       WRITE (6,902)         122       WRITE (6,903)         123       WRITE (6,904)         124       WRITE (6,905)         125       WRITE (6,904)         126       WRITE (6,205)         127       WRITE (6,3052)         128       WRITE (6,3052)         129       WRITE (6,202)         130       1980       READ (5,101)         131       READ (5,101)		101	WRITE (6,205)
<pre>103 WRITE (6,209) 104 WRITE (6,210) 105 WRITE (6,212) 106 WRITE (6,212) 107 WRITE (6,212) 107 WRITE (6,212) 108 WRITE (6,214) 119 WRITE (6,214) 110 WRITE (6,214) 111 WRITE (6,214) 111 WRITE (6,217) 112 WRITE (6,217) 113 WRITE (6,221) 114 WRITE (6,222) 115 WRITE (6,222) 115 WRITE (6,223) 115 WRITE (6,224) 116 WRITE (6,224) 117 WRITE (6,225) 118 WRITE (6,1234) 120 WRITE (6,1234) 120 WRITE (6,1234) 122 WRITE (6,903) 122 WRITE (6,903) 122 WRITE (6,903) 123 WRITE (6,3050) 124 WRITE (6,3050) 125 WRITE (6,3050) 126 WRITE (6,3050) 127 WRITE (6,3050) 128 WRITE (6,3050) 138 1980 READ (5,1) U,A1,A2,B,TK,A 131 SP0 READ (5,20) NN, KY, VNEN, MANN 133 P90 READ (5,20) NN, KY, VNEN, MANN 134 WRITE (6,303) U,A,MC,T1 137 WRITE (6,303) U,A,MC,T1 137 URIE (6,303) U,A,MC,T1 137 WRITE (6,303) U,A,MC,T1 139 CS+4PIFRIT=NI+NM(A)((1,D-RK+RK)+TK)) 144 UD 1000 MTA=1,MM 145 E=EEV(NE) 146 D0 2 I=1,N1 147 U,CS+4(I=1,N) 148 URIE (I,A) 149 URIE (I,A) 149 URIE (I,A) 140 URIEL (I,A) 141 URIEL (I,A) 141 URIEL (I,A) 144 URIEL (I,A) 144 URIEL (I,A) 145 URIEL (I,A) 145 URIEL (I,A) 146 URIEL (I,A) 147 URIEL (I,A) 147 URIEL (I,A) 148 URIEL (I,A) 149 URIEL (I,A) 149 URIEL (I,A) 140 /pre>			WRITE (6,208)
104 WRITE (6,210) 105 WRITE (6,221) 106 WRITE (6,221) 107 WRITE (6,212) 108 WRITE (6,215) 110 WRITE (6,215) 111 WRITE (6,215) 112 WRITE (6,220) 113 WRITE (6,220) 114 WRITE (6,220) 115 WRITE (6,220) 115 WRITE (6,221) 116 WRITE (6,221) 117 WRITE (6,221) 119 WRITE (6,223) 120 WRITE (6,201) 122 WRITE (6,001) 122 WRITE (6,002) 123 WRITE (6,002) 124 WRITE (6,002) 125 WRITE (6,002) 125 WRITE (6,002) 126 WRITE (6,003) 127 WRITE (6,004) 128 WRITE (6,005) 128 WRITE (6,005) 129 WRITE (6,005) 129 WRITE (6,005) 120 WRITE (6,005) 121 WRITE (6,005) 122 WRITE (6,005) 123 WRITE (6,005) 124 WRITE (6,005) 125 WRITE (6,005) 125 WRITE (6,005) 126 WRITE (6,005) 127 WRITE (6,005) 128 WRITE (6,005) 129 WRITE (6,005) 129 WRITE (6,005) 120 WRITE (6,	(	103	WRITE (6,209)
105       MR1TE (6,2121)         107       MR1TE (6,2121)         108       MR1TE (6,2121)         110       MR1TE (6,215)         111       MR1TE (6,2172)         112       MR1TE (6,2172)         113       MR1TE (6,2172)         114       MR1TE (6,2172)         115       MR1TE (6,221)         114       MR1TE (6,222)         115       MR1TE (6,222)         114       MR1TE (6,222)         115       MR1TE (6,222)         116       MR1TE (6,206)         117       MR1TE (6,207)         118       WR1TE (6,904)         120       MR1TE (6,904)         121       MR1TE (6,904)         122       MR1TE (6,905)         124       MR1TE (6,3050)         125       WR1TE (6,3050)         126       WR1TE (6,3052)         127       MR1TE (6,3052)         128       WR1TE (6,3052)         129       WR1TE (6,3052)         120       WR1TE (6,3052)         122       WR1TE (6,3052)         133       P98 READ (5,100) NM, (LAY(MTA), MLA=1,MM)         134       MR1TE (6,302) NR, NL,S, MM, NN         135	(	104	WRITE (6,210) guadar maningar na shiraran na shiraran ka shiraran ka shiraran ka shiraran ka shiraran ka shira
<pre>106 WRITE (6,2121) 107 WRITE (6,2122) 108 WRITE (6,2122) 109 WRITE (6,215) 110 WRITE (6,215) 111 WRITE (6,2172) 112 WRITE (6,2172) 113 WRITE (6,2219) 114 WRITE (6,220) 115 WRITE (6,222) 115 WRITE (6,222) 117 WRITE (6,222) 119 WRITE (6,223) 120 WRITE (6,203) 121 WRITE (6,904) 122 WRITE (6,904) 122 WRITE (6,905) 123 WRITE (6,905) 124 WRITE (6,905) 125 WRITE (6,905) 126 WRITE (6,3050) 128 WRITE (6,3050) 128 WRITE (6,3050) 128 WRITE (6,3050) 128 WRITE (6,3050) 129 WRITE (6,3050) 129 WRITE (6,3051) 130 1980 READ (5,1) U,R1,R2,B,TK,A 131 SREAD (5,1) U,R1,R2,B,TK,A 133 997 READ (5,10) NM,(U,MC,S,T1 134 WRITE (6,302) NM,(EV(NE),NE=1,NM) 135 WRITE (6,302) NM,(EV(NE),NE=1,NM) 136 WRITE (6,303),R1,R2,B,TK 137 READ (5,10) NM,(U,MC,S,T1 138 WRITE (6,302) NM,(EV(NE),NE=1,NM) 139 SREAD (5,92) NM,(EV(NE),NE=1,NM) 134 WRITE (6,303),R1,R2,B,TK 135 WRITE (6,302) NM,(EV(NE),NE=1,NM) 134 WRITE (6,302) NM,(EV(NE),NE=1,NM) 134 WRITE (6,302) NM,(EV(NE),NE=1,NM) 135 WRITE (6,302) NM,(EV(NE),NE=1,NM) 136 WRITE (6,302) NM,(EV(NE),NE=1,NM) 137 RFRL/R2 138 WRITE (6,302) NM,(EV(NE),NE=1,NM) 140 CR=4P1=R1=R1+BB=U+ND/((1,0-RK+RK)+TK)) 141 CT=TK/(22EUER1=R4=D) 142 D0 1000 NTA=1,NM 143 TA=TAV(NTA) 144 O0 2[=1,N] 145 O2 [=1,N] 146 O1 0(7A 146 O1 0(7A 147 O2 150 OB=0A=T1 050 /pre>			WRITE (6,211)
107       WRITE (6,2122)         100       WRITE (6,215)         110       WRITE (6,215)         111       WRITE (6,2172)         112       WRITE (6,2172)         113       WRITE (6,221)         114       WRITE (6,221)         115       WRITE (6,203)         120       WRITE (6,204)         121       WRITE (6,904)         122       WRITE (6,905)         124       WRITE (6,905)         125       WRITE (6,3050)         126       WRITE (6,3050)         127       WRITE (6,3050)         128       WRITE (6,3050)         1290       PACA (5,11) WR, NI, NO, S, T1         132       929 READ (5,10) WM, (UX(MEA, MEA=1,MM)         133       999 READ (5,310) WA, RZ, PJ TK         134       RRITE (6,323) U, A; MZ, PJ TK         135       WRITE (6,323) U, A; MZ, PJ TK	1	106	WRITE (6,2121)
108       MRTFE (6,215)         110       WRTFE (6,215)         111       WRTFE (6,214)         112       WRTFE (6,214)         113       WRTFE (6,217)         114       WRTFE (6,217)         115       WRTFE (6,220)         115       WRTFE (6,220)         116       WRTFE (6,220)         117       WRTFE (6,220)         118       WRTFE (6,220)         119       WRTFE (6,203)         120       WRTFE (6,1239)         121       WRTFE (6,903)         122       WRTFE (6,903)         123       WRTFE (6,903)         124       WRTFE (6,905)         125       WRTFE (6,3050)         126       WRTFE (6,3052)         127       WRTFE (6,3052)         128       WRTFE (6,3050)         129       WRTFE (6,3050)         130       1960 READ (5,100 MR, MR,NL,MC,S.T1         131       READ (5,11) MR,NL,MC,S.T1         132       907 READ (5,200 MR, CEV(MC), ME=1,NN)         133       998 READ (5,301, R1,R2,B,TK,A         133       998 READ (5,301, NR,R2,B,TK,A         134       WRTE (6,302) MR,NL,GY,MM,NN         135       MRTE (6,30		107	WRITE (6,2122)
109       WRITE (6,215).         111       WRITE (6,216).         111       WRITE (6,217).         113       WRITE (6,217).         114       WRITE (6,221).         115       WRITE (6,222).         116       WRITE (6,222).         117       WRITE (6,222).         118       WRITE (6,223).         119       WRITE (6,205).         118       WRITE (6,203).         120       WRITE (6,1234).         121       WRITE (6,901).         122       WRITE (6,902).         123       WRITE (6,903).         124       WRITE (6,904).         125       WRITE (6,3052).         126       WRITE (6,3052).         127       WRITE (6,3052).         128       WRITE (6,3052).         129       WRITE (6,3052).         130       1900 READ (5,10) NR.NI, NO.S.T1         131       READ (5,11) N.R.NI, NO.S.T1         132       9976 READ (5,202). NN. (EV(NE).NE1.NIN)         133       MRITE (6,303) U.A.MUC, T1         134       WRITE (6,303) U.A.MUC, T1         135       NRITE (6,303) U.A.MUC, T1         136       NRITE (6,303) U.A.MUC, T1         137 </th <th></th> <th>1-0-8</th> <th></th>		1-0-8	
110 WRITE (6,217) 111 WRITE (6,2172) 112 WRITE (6,2172) 113 WRITE (6,220) 114 WRITE (6,221) 115 WRITE (6,220) 116 WRITE (6,221) 117 WRITE (6,220) 119 WRITE (6,220) 120 WRITE (6,1233) 122 WRITE (6,1233) 122 WRITE (6,902) 123 WRITE (6,902) 124 WRITE (6,903) 125 WRITE (6,905) 126 WRITE (6,3050) 128 WRITE (6,3050) 128 WRITE (6,3050) 129 WRITE (6,3050) 130 1960 READ (5,11 U.R1,R2,B,TK,A 131 READ (5,11 U.R1,R2,B,TK,A 131 READ (5,11 U.R1,R2,B,TK,A 133 999 READ (5,92) NN, (EV(NE1,NE1,NN) 134 WRITE (6,303,U,A,NN,S,T1 135 NRITE (6,303,U,A,NN,S,T1 136 WRITE (6,303,U,A,NN,S,T1 137 READ (5,11) NR,N, (LAV(MTA),MTA=1,MN) 138 WRITE (6,303,U,A,NN,S,T1 139 099 READ (5,92) NN, (EV(NE1,NE=1,NN) 134 WRITE (6,303,U,A,NN,S,MM,NN 135 NRITE (6,303,U,A,NN,S,MM,NN 136 WRITE (6,303,U,A,NN,S,MM,NN 137 RK=R1/R2 138 PLE3,4416 139 CS44PI+R14R1*B4U*V/((1,0-RK*RK)*TK) 140 CR=4PI=R1*R1*BHU*V/((1,0-RK*RK)*TK) 141 CTR=1K/(22PI=R1=R1*E) 142 D0 1000 NTA=1,NM 143 TA=TAV(NTA) 144 D0 1000 HE=1,NN 145 E=EV(NE) 146 D0 2 [=1,N] 148 GT=0/TA 149 GA=0 150 GB=0A=T1	r`	<b>109</b>	WRITE (6,215) and a start of the
<pre>111 WHITE (6,2172) 112 WRITE (6,2172) 113 WRITE (6,220) 114 WRITE (6,220) 115 WRITE (6,222) 116 WRITE (6,222) 117 WRITE (6,203) 118 WRITE (6,203) 119 WRITE (6,1233) 120 WRITE (6,1233) 120 WRITE (6,1235) 121 WRITE (6,903) 122 WRITE (6,903) 123 WRITE (6,903) 124 WRITE (6,903) 125 WRITE (6,205) 126 WRITE (6,205) 126 WRITE (6,3052) 128 WRITE (6,3052) 129 WRITE (6,3052) 129 WRITE (6,3052) 120 WRITE (6,3052) 120 WRITE (6,3053) 130 1980 READ (5,11) WR.NI.WO.S.T1 132 9972 READ (5,12) WRITE (6,302) 133 9978 READ (5,12) WR.NI.WO.S.T1 134 WRITE (6,302.) 135 WRITE (6,302.) 136 WRITE (6,302.) 137 WRITE (6,302.) 138 WRITE (6,303.) 134 WRITE (6,303.) 134 WRITE (6,303.) 135 WRITE (6,302.) 136 WRITE (6,302.) 137 RK=RI/R2 138 WRITE (6,302.) 148 WRITE (6,302.) 144 URITE (6,302.) 144 URITE (6,302.) 145 E=EV(NE) 145 E=EV(NE) 146 D0 2 I=1,NI 148 OT=0/TA 144 OT=0/TA 145 OT=0/TA 145 OT=0/TA 146 OT=0/TA 146 OT=0/TA 147 OT=0/TA 147 OT=0/TA 148 OT=0/TA 140 OT=0/TA 144 OT=0/TA 144 OT=0/TA 144 OT=0/TA 145 OT=0/TA 144 OT=0/TA 145 OT=0/TA 144 OT=0/TA 145 OT=0/TA 144 OT=0/TA 145 OT=0/TA 145 OT=0/TA 146 OT=0/TA 146 OT=0/TA 146 OT=0/TA 147 OT=0/TA 148 OT=0/TA 148 OT=0/TA 148 OT=0/TA 149 OT=0/TA 140 OT=0/</pre>	•	110	
<pre>112 MRITE (6,219) 113 WRITE (6,229) 114 WRITE (6,220) 115 WRITE (6,221) 116 WRITE (6,221) 117 WRITE (6,220) 117 WRITE (6,203) 119 WRITE (6,203) 120 WRITE (6,1234) 122 WRITE (6,903) 122 WRITE (6,903) 122 WRITE (6,903) 123 WRITE (6,903) 124 WRITE (6,905) 125 WRITE (6,3052) 126 WRITE (6,3052) 127 WRITE (6,3052) 128 WRITE (6,3052) 129 WRITE (6,3052) 133 999 READ (5,11) WR.NR.MO.S.TI 132 9376 READ (5,11) WR.NR.MO.S.TI 133 999 READ (5,023) NN.(EV(NE).NE=1.NN) 134 WRITE (6,301).RI.R2.B.TK 135 WRITE (6,303) U.A.WO.TI 137 RREAL/R2 138 PL=3.1446 139 CS=44PI #RI*RI*BU#WO/((1.0-RK*RK)*TK) 141 CT=TK/(2*PI*RI*RI*BU#WO/((1.0-RK*RK)*TK)) 144 DO 1000 NTA=1.NM 143 TA=TAV(KTA) 145 E=EV(NE) 146 DO 2 I=1.NI 147 CT=ALV(2*PI*RI*RI*BU#WO/(11.0-RK*RK)*TK) 148 OT=O/TA 148 OT=O/TA</pre>		·	
114 MRITE (6,220) 115 MRITE (6,221) 116 MRITE (6,222) 117 MRITE (6,222) 118 MRITE (6,222) 119 MRITE (6,223) 120 MRITE (6,1234) 120 MRITE (6,1234) 120 MRITE (6,1234) 121 MRITE (6,025) 122 MRITE (6,005) 123 MRITE (6,005) 124 MRITE (6,005) 126 MRITE (6,3050) 128 MRITE (6,3052) 129 MRITE (6,3052) 130 1960 READ (5,11) MR,NI,NO,S.TI 132 9876 READ (5,11) NR,NI,NO,S.TI 132 9876 READ (5,11) NR,NI,NO,S.TI 133 999 READ (5,10) MR, CEV(NE=1.NN) 134 MRITE (6,3052) MRITE (6,3053) 135 MRITE (6,302) MR, MAXAMANAN 136 MRITE (6,302) MR, MAXAMANANAN 137 MRITE (6,302) MR, MAXAMANANANANANANANANANANANANANANANANANA	[	112	WRITE (8,219)
<pre>115 WRITE (6,221) 116 WRITE (6,222) 117 WRITE (6,203) 119 WRITE (6,1234) 120 WRITE (6,1235) 121 WRITE (6,903) 122 WRITE (6,901) 122 WRITE (6,903) 124 WRITE (6,904) 125 WRITE (6,905) 126 WRITE (6,3050) 128 WRITE (6,3050) 128 WRITE (6,3050) 129 WRITE (6,3050) 129 WRITE (6,3052) 129 WRITE (6,3052) 129 WRITE (6,3052) 130 1980 READ (5,11) WR,NI,W0,S,TI 132 9376 READ (5,12) WRI,R2,B,TK,A 131 READ (5,11) NR,NI,W0,S,TI 132 9376 READ (5,122,NN,(EV(NE),NE=1,NN) 133 999 READ (5,922) NN,(EV(NE),NE=1,NN) 134 WRITE (6,302) NR,NI,R2,B,TK 135 WRITE (6,302) NR,NI,S,MM,NN 136 WRITE (6,302) NR,NI,S,MM,NN 137 RK=RI/R2 136 Pl=3,1416 139 CS=4+Pl=R1=R1=B=U=WD/((1.0+RK=RK)=TK)) 140 CR=4+Pl=R1=R1=B=U=WD/((1.0+RK=RK)=TK)) 141 CT==IK/(22+Pl=R1=R1=R1=R1=N) 142 D0 1000 NTA=1,NN 143 TA=TAV(MTA) 144 D0 2 I=1,NI 147 OS=(1=1,N] 148 GT=0/TA 148 GT=0/TA 149 GA=0 150 DB=0A-T1 150 DB=0A 150 DB=0A-T1 150 DB=0A 150 DB=0A-T1 150 DB=0A 150 DB=0A-T1 150 DB=0A 150 DB=0A-T1 150 DB=0A 150 DB=0A 150 DB=0A 150 DB=0A-T1 150 DB=0A 150 DB=0A-T1 150 DB=0A 150 DB=0A</pre>		114	WRTTE (6.220)
116 NR1FE (6,222) 117 NR1FE (6,222) 118 NR1FE (6,224) 120 NR1FE (6,234) 120 NR1FE (6,1234) 121 NR1FE (6,901) 122 NR1FE (6,902) 123 NR1FE (6,903) 124 NR1FE (6,904) 125 NR1FE (6,305) 126 NR1FE (6,3051) 127 NR1FE (6,3052) 129 NR1FE (6,3052) 129 NR1FE (6,3052) 129 NR1FE (6,3052) 130 1980 READ (5,11) NR,NL,NO,S,T1 132 9876 READ (5,11) NR,NL,NO,S,T1 132 9876 READ (5,110,NR,NL,NO,S,T1 133 999 READ (5,982) NN, (EV(NE),NE=1,NN) 134 NR1FE (6,303) NN, (EV(NE),NE=1,NN) 135 NR1FE (6,303) NA,NU, AU, ATA 136 NR1FE (6,303) NA,NU, AU, AU 137 RK=R1/R1=R1=R1=R1=R1=R1=R1=R1=R1=R1=R1=R1=R1=R		115	
117       WRIFE (6,205)         118       WRIFE (6,1234)         120       WRIFE (6,1236)         121       WRIFE (6,901)         122       WRIFE (6,903)         123       WRIFE (6,904)         124       WRIFE (6,903)         125       WRIFE (6,904)         126       WRIFE (6,905)         127       WRIFE (6,3050)         128       WRIFE (6,3052)         129       WRIFE (6,3052)         120       188         131       READ (5,11) NR.NI, NO.S.T1         132       9876         133       998 READ (5,100) MM. (TAV(MTA)_NTA=1_+MN)         134       WRITE (6,301), R1/R2, B,TK         135       WRITE (6,301), R1/R2, B,TK         136       WRITE (6,301), NI, FR2, B,TK         137       PREAD (5,982) NN, EV(VE), NE=1,NN         138       999 READ (5,982) NN, VEV(VE), NE=1,NN         136       WRITE (6,303) U, A, WO, T1         137       RK=R1/R2         138       PI=3,1416         139       CS=4*PI*R1*R1*B*U*WO/((1,0-RK*RK)*TK)         140       CR=4*PI*R1*R1*B*U*W/(1,0-RK*RK)*TK)         141       D0 1000 MTA=1, MM         142       D0 1000 MTA=1, MM <th></th> <th>116</th> <th></th>		116	
<pre>118 WRITE (6,207) 119 WRITE (6,207) 119 WRITE (6,207) 120 WRITE (6,236) 121 WRITE (6,901) 122 WRITE (6,902) 123 WRITE (6,904) 125 WRITE (6,904) 125 WRITE (6,3050) 126 WRITE (6,3050) 128 WRITE (6,3052) 129 WRITE (6,3052) 120 WRITE (6,3052) 130 1980 READ (5,1) U.R1,R2,B,TK,A 131 REAR (6,301) WR,I,K0,S,T1 132 9376 READ (5,10) WR,I,K0,N,TA=1,MN) 133 999 READ (5,10) WR,I,K0,N,TA=1,MN) 134 WRITE (6,301) R1/R2,B,TK 135 WRITE (6,302) WR,WICK(MTA),MTA=1,MN) 134 WRITE (6,301) R1/R2,B,TK 135 WRITE (6,302) WR,MI,GY,MM,MN 134 WRITE (6,301) R1/R2,B,TK 135 WRITE (6,302) WR,MI,GY,MM,MN 136 WRITE (6,302) WR,MI,GY,MM,MN 137 RK=R1/R2 138 P1=3,1416 139 CS=4*P1*R1*R1*B*U*W0/((1.0-RK*RK)*TK) 140 CR=4*P1*R1*R1*B*U*M/((1.0-RK*RK)*TK) 141 CT==TK/C2*P1*R1*R1*B=U*M/((1.0-RK*RK)*TK) 142 D0 1000 MTA=1,MM 143 TA=TAV(MTA) 144 OD 2 I=1,NN 145 E=EV(NE) 144 GT=0/TA 149 QA=G 150 QB=QA-T1</pre>		117	WRITE (G.206)
<pre>119 WRITE (6,1234) 120 WRITE (6,235) 121 WRITE (6,901) 122 WRITE (6,902) 123 WRITE (6,903) 124 WRITE (6,905) 126 WRITE (6,3050) 128 WRITE (6,3052) 129 WRITE (6,3053) 120 WRITE (6,3053) 120 YRITE (6,3053) 130 1960 READ (5,1) U.R1,R2,B,TK,A 131 REAP (5,11) NR,NI,W0,S,T1 132 9274 READ (5,10) MM, (TAV(MTA),MTA=1,MM) 133 999 READ (5,982) NN,(EV(NE),NE=1,NN) 134 WRITE (6,302) NR,NL,S,MM,NN 134 WRITE (6,303) U,A,W0,T1 135 NRITE (6,303) U,A,W0,T1 137 RK=R1/R2 138 P1=3,1446 139 CS=4*P1*R1*R1*B*U*M0/((1.0+RK*RK)*TK)) 141 CTm=TK/(2*P1*R1*R1*B) 142 D0 1000 NTA=1,MM 143 TATAV(MTA) 144 D0 1000 NTA=1,MM 145 E=EV(NE) 146 D0 2 [1-1,N] 148 GT=0/TA 149 QA=0 150 QB=QA-T1 150 QB=CA-T1</pre>	r <b>~</b>	118	WRITE (6.207)
120       WRITE (6, 1235)         121       WRITE (6, 901)         122       WRITE (6, 902)         123       WRITE (6, 903)         124       WRITE (6, 905)         125       WRITE (6, 3050)         126       WRITE (6, 3052)         127       WRITE (6, 3052)         128       WRITE (6, 3052)         129       WRITE (6, 3052)         129       WRITE (6, 3052)         130       1960 READ (5, 11) U, R1, R2, B, TK, A         131       READ (5, 110) MM, (TAV(MIA), MIA=1, MM)         132       9376 READ (5, 100) MM, (TAV(MIA), MIA=1, MM)         133       999 READ (5, 982) NN, (EV NE), NE=1, NN)         134       WRITE (6, 303) U, A, WO, ST1         135       NRITE-(6, 302) NN, NE, SMM, NN         136       NRITE (6, 303) U, A, WO, T1         137       RK=RI/R2         138       P1=3,1416         139       CS=4*P1*R1*R1*B*U*A/((1.0-RK*RK)*TK))         140       CR=4*P1*R1*R1*B*U*A/((1.0-RK*RK)*TK))         141       CTa=IK/(2*P1*R1*R1*B*U*A/((1.0-RK*RK)*TK))         142       D0 1000 MIA=1, MM         143       TA=TAV(MTA)         144       D0 1000 MIA=1, NM         145       E=EV(NE		110	WRITE (6.1234)
121 WRITE (6,901) 122 WRITE (6,902) 123 WRITE (6,903) 124 WRITE (6,905) 126 WRITE (6,905) 127 WRITE (6,3051) 128 WRITE (6,3052) 129 WRITE (6,3052) 129 WRITE (6,3053) 130 1960 READ (5,1) U.R1,R2,B,TK,A 131 READ (5,11) NR,NI,W0,S,T1 132 9376 READ (5,100) MM, (TAV(MTA),MTA=1,MM) 133 999 READ (5,982) NN,(EV(NE),NE=1,NN) 134 WRITE (6,301) R1,R2,B,TK 135 WRITE (6,302) WR,NI,S,MM,NN 136 WRITE (6,303) U,A,WC,T1 137 RK=R1/R2 138 P1=3.1416 139 CS=4*P1*R1*R1*B*U*W0/((1.0-RK*RK)*TK)) 141 CT==TK/(2*P1*R1*R1*B*U*W0/((1.0-RK*RK)*TK)) 142 D0 1000 NTA=1,MM 143 TATAV(MTA) 144 D0 1000 NTA=1,NN 145 E=EV(NE) 146 D0 2 I=1,N1 147 G=S*(I=1,0) 148 GT=0/TA 149 GA=G 150 GB=GA=T1		120	WRITE (6.1235)
122 WRITE (6,902) 123 WRITE (6,903) 124 WRITE (6,904) 125 WRITE (6,055) 126 WRITE (6,055) 127 WRITE (6,0553) 128 WRITE (6,0653) 130 1980 READ (5,11) WR.NI,NO.S.T1 132 9376 READ (5,11) NR.NI,NO.S.T1 132 9376 READ (5,101) MM, (TAV(MTA), MTA=1,MM) 133 999 READ (5,982) NN. (EV(NE),NE=1,NN) 134 WRITE (6,302) NN.F.V(NE),NE=1,NN) 134 WRITE (6,302) NR.NI,S.MM,NN 136 WRITE (6,302) NR.NI,S.MM,NN 137 RK=R1/R2 138 PL=3,1416 139 CS=44*PI*R1*R1*B*U*W0/((1.0+RK*RK)*TK)) 140 CR=4*PI*R1*R1*B*U*A/((1.0+RK*RK)*TK)) 141 CT==TK/(2*PI*R1*R1*B*U*A/((1.0+RK*RK)*TK)) 142 D0 1000 NTA=1,MM 143 TA=TAV(MTA) 144 D0 1000 NR=1,NN 145 E=EV(NE) 146 D0 2 I=1,NI 148 QT=0/TA 149 QA=0 150 QB=QA=T1	r-,	121	WRITE (6.901) exception with the set of set of the set
123 WRITE (6,903) 124 WRITE (6,903) 125 WRITE (6,905) 126 WRITE (6,3050) 128 WRITE (6,3052) 129 WRITE (6,3052) 129 WRITE (5,3052) 130 1960 READ (5,1) U,RI,R2,B,TK,A 131 READ (5,1) U,RI,R2,B,TK,A 132 9376 READ (5,10) MM, (TAY(MTA),MTA=1,MN) 133 999 READ (5,982) NN, (EV(NE),NE=1,NN) 134 WRITE (6,302) MR,NI,S,MM,NN 135 WRITE (6,302) WR,NI,S,MM,NN 136 WRITE (6,303) U,A,WO,T1 137 RK=R1/R2 136 PI=3,1416 139 CS=4*PI*R1*R1*B+U;WO/((1.0-RK*RK)*TK)) 141 CTa=TK/(2*PI*R1*R1*B+U;MO/((1.0-RK*RK)*TK)) 142 D0 1000 MTA=1,MM 143 TA=TAV(MTA) 144 D0 1000 ME=1,NN 145 E=EV(NE) 146 D0 2 I=1,NI 149 CA=0 150 GB=0A-T1		122	WRITE (6,902)
<pre>124 WRITE (6,904) 125 WRITE (6,905) 126 WRITE (6,3050) 128 WRITE (6,3052) 129 WRITE (6,3052) 129 WRITE (6,3052) 129 WRITE (6,3052) 130 1980 READ (5,11) WR,NI,W0,S.T1 132 9876 READ (5,11) NR,NI,W0,S.T1 132 9876 READ (5,11) NR,NI,W0,S.T1 132 9876 READ (5,982) NN, (EV(NE),NE=1,NN) 134 WRITE (6,301), R1;R2,B,TK 135 WRITE (6,302) NR,NI,S,MM,NN 136 WRITE (6,303) U,A,W0,T1 137 RK=R1/R2 138 PI=3,1416 139 CS=4*PI*R1*R1*B*U*W0/((1.0~RK*RK)*TK) 140 CR=4*PI*R1*R1*B*U*W0/((1.0~RK*RK)*TK) 141 CT==TK/(2*PI*R1*R1*B=U*A/((1.0~RK*RK)*TK)) 142 D0 1000 NTA=1,NN 143 TA=TAV(MTA) 144 D0 1000 WE=1,NN 145 E=EV(NE) 146 D0 2 I=1,NI 149 GA=0 150 GB=0A-T1</pre>			WRITE (6,993)
125 WRITE (6,905) 126 WRITE (6,3051) 127 WRITE (6,3052) 129 WRITE (6,3052) 120 WRITE (6,3052) 120 WRITE (6,3052) 130 1960 READ (5,1) U,R1,R2,B,TK,A 131 READ (5,1) U,R1,R2,B,TK,A 132 9876 READ (5,10) MM, (TAV(MTA),MTA=1,MM) 133 999 READ (5,982) NN, (EV(NE),NE=1,NN) 134 WRITE (6,301),R1,R2,B,TK 135 WRITE (6,302) NR,NI,S,MM,NN 136 WRITE (6,302) NR,NI,S,MM,NN 136 WRITE (6,302) U,A,W0,T1 137 RK=R1/R2 138 PL=3,1416 139 CS=4+P1+R1+R1+B+U+W0/((1.0-RK+RK)+TK)) 140 CR=4+P1+R1+R1+B+U+W0/((1.0-RK+RK)+TK)) 141 CT==TK/(2+P1+R1+R1+B) 142 D0 1000 MTA=1,MM 143 TA=TAV(MTA) 144 D0 1000 NTA=1,NN 145 E=EV(NE) 146 D0 2 I=1,NI 147 C=S*(I=1,0) 148 CT=0/TA 149 CA=0 150 OB=CA=T1	, <b>-</b>	124	WRITE (6,904)
126       WRITE (6,3051)         127       WRITE (6,3052)         128       WRITE (6,3052)         129       WRITE (6,3052)         130       1980 READ (5,1) U,R1,R2,B,TK,A         131       READ (5,100) MM, (TAV(MTA)_MIA=1,MM)         132       9376 READ (5,982) NN, (TAV(MTA)_MIA=1,MM)         133       999 READ (5,982) NN, (TAV(MTA)_MIA=1,MM)         134       WRITE (6,301), R1,R2,B,TK         135       WRITE (6,302) NR,NI,S,MM,NN         136       WRITE (6,303) U,A,WC,T1         137       RK=R1/R2         138       P1=3,1416         139       CS=4*PI*R1*R1*B*U*W0/((1.0+RK*RK)*TK))         140       CR=4*PI*R1*R1*B*U*A/((1.0+RK*RK)*TK))         141       CT==TK/(2*PI*R1*R1*B*U*A/((1.0+RK*RK)*TK))         142       D0 1000 NTA=1,MM         143       TA=TAV(MTA)         144       D0 1000 NTA=1,MM         145       E=EV(NE)         146       D0 2 I=1,NI         147       C=S*(L-1,0)         148       GT=0/TA         149       QA=0         150       QB=QA=T1	i.	125	WRITE (6,905)
<pre>127 WRITE (6,3050) 128 WRITE (6,3052) 129 WRITE (6,3052) 130 1980 READ (5,1) U.R1,R2.B.TK.A 131 REAP (5,1) NR.NI,N0,S.T1 132 9876 READ (5,10) MM, (TAV(MTA),MTA=1,MM) 133 999 READ (5,982) NN, (EV(NE).NE=1,NN) 134 WRITE (6,301) R1,R2,B,TK 135 WRITE (6,302) NR,N1,S,MM,NN 136 WRITE (6,302) NR,N1,S,MM,NN 137 RK=R1/R2 138 PI=3,1416 139 CS=4*PI*R1*R1*B*U*W0/((1.0+RK*RK)*TK)) 140 CR=4*PI*R1*R1*B*U*W0/((1.0+RK*RK)*TK)) 141 CT==TK/(2*PI*R1*R1*B) 142 D0 1000 NTA=1,MM 143 TA=TAV(MTA) 145 E=EV(NE) 146 D0 2 I=1,NI 147 CE\$*(I=1,0) 148 CT=0/TA 149 CA=0 150 OB=CA=T1</pre>		126	WRITE (6,305)
128 WRITE (6,3052) 120 WRITE (6,3053) 130 1980 READ (5,11) U.R1,R2,B,TK,A 131 READ (5,11) NR,NI,WO,S,T1 132 9876 READ (5,982) NN, (TAY(MTA),MTA=1,MN) 133 999 READ (5,982) NN, (EV(NE),NE=1,NN) 134 WRITE (6,301) R1,R2,B,TK 135 NRITE (6,302) NR,NT,S,MM,NN 136 WRITE (6,303) U,A,WO,T1 137 RK=R1/R2 138 PI=3,1416 139 CS=4*PI*R1*R1*B*U*W0/((1.0~RK*RK)*TK)) 140 CR=4*PI*R1*R1*B*U*W0/((1.0~RK*RK)*TK)) 141 CT==IK/(2*PI*R1*R1*B) 142 D0 1000 MTA=1,MM 143 TA=TAV(MTA) 144 D0 1000 ME=1,NN 145 E=EV(NE) 146 D0 2 I=1,NI 147 C==*(1-,0) 148 QT=0/TA 149 CA=C 150 OB=QA=T1	r <b>~.</b>	127	WRITE (6,3050) the figure of the second state of the second state of the second s
129 WRITE (6,3C53) 130 1980 READ (5,1) U,R1,R2,B,TK,A 131 READ (5,1) NR,NI,NO,S,T1 132 9876 READ (5,100) MM, (TAV(MTA),MTA=1,MM) 133 999 READ (5,982) NN,(EV(NE),NE=1,NN) 134 WRITE (6,301) R1;R2,B,TK 135 WRITE (6,302) NR,NI,S,MM,NN 136 WRITE (6,302) NR,NI,S,MM,NN 137 RK=R1/R2 138 PI=3,1416 139 CS=4*PI *R1*R1*B*U*W0/((1.0~RK*RK)*TK)) 140 CR=4*PI *R1*R1*B*U*W0/((1.0~RK*RK)*TK)) 141 CT==TK/(2*PI*R1*R1*B) 142 D0 1000 MTA=1,MM 143 TA=TAV(MTA) 144 D0 1000 NE=1,NN 145 E=EV(NE) 146 D0 2 I=1,NI 147 C=S*(I=1,0) 148 GT=0/TA 149 CA=0 150 GB=QA=T1	<b>к</b> .	. 128	
<pre>130 1980 READ (5,1) U,R1,R2,B,TK,A 131 READ (5,11) NR,NI,W0,S,T1 132 9376 READ (5,982) NN,(EV(NE),NE=1,NN) 134 WRITE (6,301) R1;R2,B,TK 135 WRITE (6,302) NR,NI;S,MM,NN 136 WRITE (6,303) U,A,W0,T1 137 RK=R1/R2 138 PI=3,1416 139 CS=4*PI*R1*R1*B*U*W0/((1.0-RK*RK)*TK)) 140 CR=4*PI*R1*R1*B*U*A/((1.0-RK*RK)*TK)) 141 CT==TK/(2*PI*R1*R1*B*U)*A/((1.0-RK*RK)*TK)) 142 D0 1000 MTA=1,MM 143 TA=TAV(MTA) 144 D0 1000 NE=1,NN 145 E=EV(NE) 146 D0 2 I=1,NI 148 QT=0/TA 149 QA=Q 150 QB=QA=T1</pre>			
131 READ (5,11) NR,NI,WO,S,T1 132 9876 READ (5,100) MM, (TAV(MTA),MTA=1.MM) 133 999 READ (5,982) NN, (EV(NE),NE=1.NN) 134 WRITE (6,301) R1,R2,B,TK 135 NRITE (6,302) NR,NI,S,MM,NN 136 WRITE (6,303) U,A,WO,T1 137 RK=R1/R2 138 PI=3.1416 139 CS=4*PI*R1*R1*B*U*W0/((1.0~RK*RK)*TK) 140 CR=4*PI*R1*R1*B*U*A/((1.0~RK*RK)*TK) 141 CT==IK/(2*PI*R1*R1*B) 142 D0 1000 MTA=1,MM 143 TA=TAV(MTA) 144 D0 1000 NE=1,NN 145 E=EV(NE) 146 D0 2 I=1,NI 147 O=S*(I=-1.0) 148 QT=O/TA 149 GA=0 150 OB=OA=T1	. ~	130	1980 READ (5,1) U,R1,R2,B,TK,A
132       9476       HEAD       (5,100)       MM, (TAV(NTA), NIA=1, MM)         133       999       READ       (5,982)       NN, (EV(NE), NE=1, NN)         134       WRITE       (6,301)       R1;R2,B,TK         135       WRITE       (6,302)       NR,NI;S;MM,NN         136       WRITE       (6,303)       U,A,WO,T1         137       RK:RI/R2         138       PI=3+1416         139       CS=4*PI*R1*R1*B*U*W0/((1.0=RK*RK)*TK))         140       CR=4*PI*R1*R1*B*U*A/((1.0=RK*RK)*TK))         141       CT==TK/(2*PI*R1*R1*B)         142       D0 1000 NTA=1,MM         143       TA=TAV(MTA)         144       D0 1000 NTA=1,NN         145       E=EV(NE)         146       D0 2 I=1,NI         147       C=S*(I=1,0)         148       GT=0/TA         150       GB=CA=T1	<b>.</b> .	131	READ (5,11) NR, NI, WO, S, T1
133 999 READ (5,982) NN, (EV(NE), NE=1, NN) 134 WRITE (6,301)_R1; R2, B; TK 135 NRITE (6,302) NR, NI, S; MM, NN 136 WRITE (6,303) U, A, WO, T1 137 RK=R1/R2 138 PI=3+1416 139 CS=4*PI*R1*R1*B*U*WQ/((1.0=RK*RK)*TK)) 140 CR=4*PI*R1*R1*BU*A/((1.0=RK*RK)*TK)) 141 CT==TK/(2*PI*R1*R1*B) 142 DO 1000 NTA=1, MM 143 TA=TAV(MTA) 144 DO 1000 NE=1, NN 145 E=EV(NE) 146 DO 2 I=1, NI 147 C=S*(I=1, O) 148 QT=Q/TA 149 GA=C 150 QB=QA=T1		<u>isz</u>	-98/6 REAU (5,100) MM, (TAV(MTA), MIA=1, MM)
134       WRITE (0,301)_R1;R2;B,TK         135       WRITE (0,302)_NR;N1;S,MM;NN         136       WRITE (0,303) U,A,W0,T1         137       RK=R1/R2         138       PI=3,1410         139       CS=4*PI*R1*R1*B*U*W0/((1.0-RK*RK)*TK))         140       CR=4*PI*R1*R1*B*U*A/((1.0-RK*RK)*TK))         141       CT==TK/(2*PI*R1*R1*B)         142       D0 1000 MTA=1,MM         143       TA=TAV(MTA)         144       D0 1000 NE=1,NN         145       E=EV(NE)         146       D0 2 I=1,NI         147       Q=S*(I=1,0)         148       QT=0/TA         149       QA=0         150       QB=QA=T1	c <b>~</b> .	133	999 READ (5,982) NN, (EV(NE), NE=1, NN)
132	•	134	
130       NRTHE (0,3/3) 0, A, W0, T1         137       RK=R1/R2         138       PI=3,1416         139       CS=4*PI*R1*R1*B*U+W0/((1.0-RK*RK)*TK))         140       CR=4*PI*R1*R1*B*U+A/((1.0-RK*RK)*TK))         141       CT==TK/(2*PI*R1*R1*B)         142       D0 1000 NTA=1, MM         143       TA=TAV(MTA)         144       D0 1000 NE=1, NN         145       E=EV(NE)         146       D0 2 I=1, NI         147       O=S*(I=1, 0)         148       QT=0/TA         149       GA=0         150       QB=QA=T1			
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	,	177	NKIIC (0;000) U;A;NU;11 DK-D1/00
$\begin{array}{c} 139 \\ 139 \\ CS = 4*P  I *R1 *R1 *R1 *B*U *WO/((1.0-RK*RK)*TK)) \\ 140 \\ CR = 4*P  I *R1 *R1 *B*U *A/((1.0-RK*RK)*TK)) \\ 141 \\ CT = -IK/(2*P  I *R1 *R1 *B) \\ 142 \\ DO \ 1000 \ NTA = 1, NM \\ 143 \\ TA = TAV(MTA) \\ 144 \\ DO \ 1000 \ NE = 1, NN \\ 145 \\ E = EV(NE) \\ 146 \\ DO \ 2 \ I = 1, NI \\ 147 \\ Q = S*(I-1,0) \\ 148 \\ QT = Q/TA \\ 149 \\ QA = Q \\ 150 \\ QB = QA = T1 \\ \end{array}$	•	138	
140       CR=4*PI+R1*R1*B*U*A/((1.0+RK*RK)*TK))         141       CT==IK/(2*PI*R1*R1*B)         142       D0 1000 NTA=1, MM         143       TA=TAV(MTA)         144       D0 1000 NE=1, NN         145       E=EV(NE)         146       D0 2 I=1, NI         147       Q=S*(I=1,0)         148       QT=0/TA         149       GA=0         150       QB=QA=T1		1.39	CS-4+DT+B7+D
141       CT==IK/(2*PI*R1*R1*R1*B)         142       DO 1000 NTA=1, MM         143       TA=TAV(MTA)         144       DO 1000 NE=1, NN         145       E=EV(NE)         146       DO 2 I=1, NI         147       Q=S*(I=1,0)         148       QT=0/TA         149       QA=Q         150       QB=QA=T1		140	
142 DO 1000 NTA=1,MM 143 TA=TAV(MTA) 144 DO 1000 NE=1,NN 145 E=EV(NE) 146 DO 2 I=1,NI 147 O=S*(I-1.0) 148 QT=0/TA 149 GA=0 150 OB=QA-T1		1.41	CT3=IK/(2*PI*R1*R1*R)
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$		142	DO 1000 NTA=1.MM
144 DO 1000 NE=1, NN 145 E=EV(NE) 146 DO 2 I=1, NI 147 O=S*(-I-1, 0) 148 QT=Q/TA 149 GA=Q 150 QB=QA-T1		143	TA = TAV(MTA)
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$		144	DO 1000 NE=1.NN
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$		145	E=EV(NE)
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$		146	DO 2 I=1,NI STREAM ST
148 QT=Q/TA 149 QA=Q 150 QB=QA-T1	:	147	Q=\$*(- <u>1</u> -1,0)
149 CA=Q 150 OB=QA-T1	~	148	QT=Q/TA
1500B=QA=T1	٠	149	Q A = Q
		150	QB=QA-T1
	•		การการการการการการการการการการการการการก
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(	151	QC=QA-2*T1 TT1=2*T1		x
C	153 154 	J=(NI+1)/2 UA=QA -UB=QB		
(`	156 157 	UC=QC IF (UA-0.0) 40,40,41 -UA=0.0		
(`	159 160 41 	GO TO 42 UA=1.0 -IF <del>(UB-0.9) 50,51</del>		
C	162 50 163 164 51	UB=0.0 GO TO 52 		
C	165 52 166 60 <del></del>	IF (UC-0.0) 60.60.61 UC=0.0 -GO TO 62		
(	168 61 169 62 170	UC=1.0 E=EV(NE) -IF (5-1.0) 70,71,72		
(`	171 70 172 173	X=SQRT(1:0-E*E) XT=X*QT P=ATAN(-X/E)		
(	1/4 175 C 126	EC=EXP(-E*QT) CASE THREE,TA IS NOT EQUAL TO ZERO,E<1.0,UNDER AS=CS*(1.0-(EC*SIN(XT+P))/X)	DAMPING	
(	177 178 179	AA=CR*(Q-2*E*TA+(TA*EC/X)*SIN(XT-2*P)) AD=CR*2*f1*(1.0+(EC*SIN(XT-P))/X)- 1CR*(Q-2*E*TA+(TA*EC/X)*SIN(XT-2*P))		
(	180 151 182	AR=AA*(UA~UB)+AD*(UB-UC) ATS=CT*AS ATR=CT*AR		
(	183 184 71 185 C	GO TO 80 EC=EXP(-Q/TA) _CASE FOUR,TA_IS_NOT_EQUAL_TO_ZERO,E=1.0.CRITIC	AL-DAMPII	١G
(	. 186 187 1 <u>88</u>	AS=CS*(1,0-(1.0+0/TA)*EC) FA=Q*EC+2*EC/TA+Q-2/TA <u>FD=2*T1*(1.0-(1.0+0/TA)*EC)</u>		
(	189 190 191	AA=CR*FA AD=CR*(FD-FA) -AR=AA*(UA-UB)+AD*(-UB-UC)		
V	192 193 <u>194</u>	ATS≈CT*AS ATR≈CT*AR G0_T0_80	and gains as had been any series of the second s	
(`	195 72 196 <u>197</u>	X=SQRT(E*E=1;0) XP=E+X XN=E=X		
Ċ	198 199 200C	EP=EXP(-XP*QT) EN=EXP(-XN*QT) CASE_FIVE,TA_IS_NOT_EQUAL_TO_ZERO.E>1.0		
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(	FORTRAN IV	(VER 45 ) SOURCE LISTING:	01/04/80	113 11 <b>1</b> 06:01
Ċ	201	AS=CS*(1.0~(XP*EN~XN*EP)/(2*X))		
C	203 204 205	-GE=G-2+E+TA TE=TA/(X+2) DP=2+E+E=1.0+2+E+X DN=2+E+E=1.0+2+E+X		
C	206 207 208	AA=CR*(QE+TE*(DP*EP-DN*EN)) AD=2*T1*CR*(1.0+(1/(2*X))*(XN*EP-XP*EN))- 1CD*(0E+TE*(DP*EP-DN*EN))		
C	209 210	AR=AA*(UA-UB)+AD*(UB-UC) ATS=CT*AS		
Ċ	212 80 213 214 C	ASS(I)=ABS(ATS) ASR(I)=ABS(ATR) THEORETICAL SHEAR STRESS AND SHEAR RATE		
C	215 216 217	DO 2 MF1.NR R=R1+(M+1)+0:1+(R2=R1)		
(`	218 219 220	GS(M)=2*R1*R1*WO/((1.0-RK*RK)*R*R)+SUMS TTS(M)=-U*GS(M) TSS(L)-APS(TTS(1))		e transferra a langa a saga
(	221 222 222	SUMA=0,0 GA(M,I)=(2*R1*R1*A/((1.0-RK*RK)*R*R))*Q+SUM	A	e a gala e tel ant de la cara
(	224 225 224	GD(M,I)=(2*R1*R1*A/((1.0-RK*RK)*R*R))*(-QC) GR(M,I)=GA(M,I)*(UA-UB)+GD(M,I)*(UB-UC)	+SUMD	<u>, , , , , , , , , , , , , , , , , , , </u>
(`	227 228	K=I+NI GV(K)=GR(1.1)		
(	230 231 272	TSR(I) = ABS(TTR(1, I)) $OO(I) = OT$		annin,
C	233 234 2	QQ(L)=QQ(I) CONTINUE		
C	236 237 237		and and a first of the second seco	
C	239 240	DLASS(I)=ASS(I)/TSS(1) DLASS(I)=ASS(I)/TSS(1) DLTSR(I)=TSR(I)/TSR(J)		
(	242 243	DLOQ(I) = OQ(I) / TT1 $DLOS(I) = GS(1) / GS(1)$ $DLOS(I) = GS(I) / GS(1)$		
C	245 246 266	DLGV(I)=GV(I)/GV(J) CONTINUE		
C	248 249 250	WRITE (6,666) TA,E,GS(1),GV(J) WRITE (6,66) TT1,TSS(1),TSR(J) JE (E=1.0) 700.711.712	<u></u>	dennen an a change an
<b>(</b> *				
<b>(</b>	Annon margana arazzo uza e aza anter terten enten araz	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	an a	
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(`	251 700 252	WRITE (6,600)
(	253 711 254 255712	WRITE (6,601) GO TO 677 WRITE (6,602)
(	256 677 257 C 258 C	WRITE (6,402) WRITE (6,4031) -DO-3-1=1-NI
C	259 C 260 C	Q=S*(I-1,0) QQ(I)=Q
C	261 C 262 C 263 C 264 C	$C_{I} = 1 + N_{I}$ $C_{I} = 00(I)$
C	265 C 3 266	CONTINUE WRITE (6,5031)
C	268 269 	Q = S * (I - 1.0) QQ(I) = Q/TA -L = I + NL
C	271 272 273 363	DLGC(L)=DLGC(I) WRITE (6,4032) QQ(I),DLGC(I),DLTSS(I),DLASS(I) CONTINUE
¢	274 275 C 276 C	WRITE (6,404) DO 4 I=1,NI D=S*(I-1,0)
(`	277 C 278 C 279 C	CQ(I)=Q L=I+NI OQ(L)=OQ(I)
(`	280 C 281 C 282 C	GV(I)=GR(1,I) K=I+NI GV(K)=GR(1,I)
(	283 C 284 C 4 285	WRITE (6,4032) QQ(I), GV(I), TSR(I), ASR(I) CONTINUE DO 464 I=1,NI
(	286 287 288	Q=S*(I-1.0) QQ(I)=Q/TA -DLGV(I)=GV(I)/GV(I)
(	289 290 291	L = I + N I $DLGV(L) = DLGV(I)$ $WRITE (6, 4032) = OQ(I), DLGV(I), DLTSR(I), DLASR(I)$
(	292 464 293 	CONTINUE NP=2*NI 
<b>(</b> _`	295 C 296 C 297	CALL XYPLOT (NP,QQ,W) WRITE (6,30) CALL XYPLOT (NP,QQ,DLW)
C	298 299 300 C	WRITE (6,501) WRITE (6,30) _CALL_XYPLOT_(NP,GV.WW)
(`		
C		
C	4. <u>1</u> .	

(

(`	3	301	С	WRITE (6.30)
	·	302		CALL-XYPLOT (NP, DLGV, DLWW)
~ `	. 3	303		WRITE (6,504) respectively and the second
		\$04 05	•	「WRITE」(0ょうひ)に行っていたがにはなったか。 パント しょうほうがく しょうかい しょうかい しょうかい かいかく 一部 一部 かがない しょうかい
		シリラー		UPITE (6.504)
•	, r , r	307	1000	CONTINUE
		308-	-6351	-WRITE-(6,30)
	3	509		WRITE (6,633)
		10	(750	WRITE (6,634)
	لائ ۲	11		
•	. C	S13		0=3+(1-1,0)
	7	514		DLGC(I)=GS(1)/GS(1)
١	3	515	and a start of the second	DLGV(I) = GV(I)/GV(J)
	3	16		L=I+NI
	č	\$17		00(L)=00(1)
•	3	18	754	WEITE ( $\phi$ , 4032) Q, QQ(I), DLGC(I), DLGV(I) CONTINUE
	3	20	149 1	WRITE (6.30)
	3	21	3522	NP=2*NI
	3	22		G=S+(1-1,0)
	3	23	· · · · · · · · · · · · · · · · · · ·	CO(I)=O/TT1
•	3	524		CALL XYPLOT (NP,QQ,DLYW)
	3	25		WRITE (0,000) $PEAD (5,100) MM (TAN/MTAN MTAH1 MM)$
1	3	27	•	DO 1001 MTA=1. MM
•	3	528		DO. 1001 I=1.NI
	3	29-	;·	Q=5*(1-1,0)
•	3	330		QA=Q
	3	531		
		33		U = U A
1	3	34	•	
	3	35		VC=QC
	3	36	÷	IF (UA-0,0) 43,43,44
	3	537	43	
	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	א8- זמי	A A	
•	ר אין ד ג	4n	44	
	3	<u>41</u>	53	
	3	42		GO TO 55
	3	43	54	UB=1.0
	3	44	55_	1F (UC = 0, 0) = 63, 63, 64
	ະ 72	1972. 146	00	UUEDING CALLER AND
	3	47	64	UC=1.6
	3	48	Ç	CASE ONE TA=0.0, E=0.0
	3	49	65	AS=CS
	3	50		AA=CR#QA
			•• <sup>10</sup> •• ••	
	<u></u>	****		
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C	351	AD=CR*(-QC)
C	353	AR=AA*(UA=UB) +AD*(UB=UC) ATS=CT>AS
<b>`</b>	354	ATR=UT*AR
C	356 357 C	AR1(I)=ABS(ATR) CASE TWO,TA IS NOT EQUAL TO ZERO,E=0.0
c		GT=Q/TA
ì	360	AS = CS + (1, 0 - COS(GT))
Ċ	362 363	$AD = CR * (2 \times T1 * (1 \cdot 0 - COS(QT)) - (Q - TA * SIN(QT)))$ $AR = AA * (UA - UB) + AD * (UB - UC)$ $NATURAL = EDECUENCY$
r.	365	FN(MTA)=1.0/(2*Pt*TA)
Ę	366	ATS=CT*AS
¢ .	368	AS2(I)=ABS(ATS)
ν.	369	AR2(I)=ABS(ATR)
6.	371	WRITE (6,405)
K	372	WRITE (6,402)
	374	DO 703 I=1,NI
C.	375	Q=S*(I-1,0)
	377	$\frac{1}{1 - 1 + NI}$
Ę.	378	00(L)=00(I)
	379 ***	DLGS(I) = GS(I) / GS(I)
1	381	D[GC(I)=D[GC(I)]
	382	DLAS1(I) = AS1(I) / TSS(1)
C	383 384 703 385	WRITE (6,4032) QQ(I),DLGC(I),DLTSS(I),DLAS1(I) CONTINUE WRITE (6,404)
e.	386	DO 704 I=1.NI
<b>K</b> .	387	Q=S*(I-1.0)
~	389	L = I + N I
(	390 391	QQ(L)=QQ(I)
1	392	DLGV(L) = DLGV(I)
L.	393	DLAR1(I) = AR1(I) / TSR(J)
	395 704	CONTINUE
C	396	WRITE (6,30)
	<u>397</u>	$\frac{CALL XYPLOI (NP, QQ, WS1)}{WPITE (6, 501)}$
C	399	WRITE (6,30)
	4.0.0	CALL XYPLOT (NP, DLGV, WR1)
Ċ	· · · · · · · · · · · · · · · · · · ·	
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	401	WRITE (6,505)
	402	-DO 709 MTA=1; MM
(	400	
	4 <del>05</del>	NRTE (6,402)
c	406	WRITE (6,5031)
(	407	DO 705 I=1.NI
	408	-Q=S+(!-1,0)
T	409	QQ(I)=Q/TA
	410	
	412	
<b>(</b> )	413	
	414	$\frac{DLAS2(1) = AS2(2) / TSS(1)}{DLAS2(1) = AS2(2) / TSS(1)}$
$\sim$	415	WRITE (6,4032) 00(1), DLGC(1), DLTSS(1), DLAS2(1)
C	416 - 705	CONTINUE
	417	WRITE (6,404)
<b>(</b> )	418	DO 706 I=1.NI
•	419 420	Q = S * (I - 1, 0)
	421	
C	422	$p_{0}(1) = p_{0}(1)$
	423	DLGV(1)=GV(1)/GV(J)
£	424	DLGV(L)=DLGV(I)
۹.	425	DLAR2(I) = AR2(I) / TSR(J)
	426	<u> </u>
(	427 706	CONTINUE
	420	CALL VVDLOT (ND OD HCO)
	430	WPITE (6,501)
(	431	WRITE (6,30)
	432	CALL XYPLOT (NP, DLGV, WR2)
e .	433	WRITE (6,505)
<b>X</b> .	434	WRITE (6,30)
	435	CALL XYPLOT (NP, QQ, WR2)
ť	430	WRITE (0,500)
•	438	
<b>.</b>	439 9666	STOP
C	440	END #
	L	
(		
•		
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0		
C.		
	, man balang makang pang ang pang ang kanang pang ng kabapatén ng kanan kang mang pang ng kanang kanang kanang Ng	
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5		الاس المحفظ المعربية المحمد المحمد والمحمد المحمد المحمد المحمد المحمد المحمد المحمد المحمد المحمد المحمد المحم ويحمد المحمد ا ويحمد المحمد ا
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		,我们就是你们的问题,我们就是你们的问题,你们们就是你的问题,我们就是你们的问题,你们就是你们的,你们就是你们就是你们的,我们就是你们的,我们就能能能不能能能不能

118 R1=RADIUS OF THE STATIONARY CYLINDER, CM R2=RADIUS OF THE ROTATING CYLINDER, CM R\_=ARBLIRARY\_RADIUS\_BETWEEN\_R1\_AND\_R2,\_CM A=ACCELERATION CONSTANT OF THE ROTATING CYLINDER B=LENGTH OF THE COUVETTE O=TIME,SEC G=SHEAR RATE, 1/SEC AS=DEFLECTION OF THE TORSION BAR AT A CONSTANT ROTATING RATE WO.MICRO REDEELECTION OF THE TORSION BAR DURING A LINEAR ACCELERATION OF THE ROTATING CYLINDER, MICRO U=NEWTONIAN VISCOSITY, POISE NO=CONSIANT\_REVOLUTION\_RATE OF THE ROTATING\_CYLINDER 1/SEC TK=TORSION BAR CONSTANT, DYNE=CM/MICRO TSR=THEORETICAL SHEAR STRESS, DYNE/CM.CM ASR=ARTIFICIAL-SHEAR-STRESS, DYNE/GM-GM T1=TIME AT MAXIMUM. SHEAR RATE, SEC. NI, SESECTIONAL CONSTANT FOR TIME, O NR=SECTIONAL CONSTANT FOR PADIUS; 0 UA, UB, UC=DELTA FUNCTIONS IF (UA, ETC.) 0,0,1 TA=TIME CONSTANT OF THE TORSION HEAD, SEC E=DAMPING COEFFICIENT, O MM=NO. OF TA NN=NO. OF E GS(1)=SHEAR RATE FOR A STEP CHANGE GV(NAX)=MAX, SHEAR RATE DURING A LINEAR ACCLERATION AND DECELERATION TRIANGULAR STEP CHANGE TTI=TOTAL TIME FOR A TRIANGULAR STEP CHANGE TSS(1)=THECRETICAL SHEAR STRESS, FOR ADSTEP/CHANGE 的复数激素 TSP(MAX)=THECRETICAL MAX, SHEAR STRESS FOR A TRIANGULAR STEP CHANGE DU\_I, (DINEXSICALESS\_TIME=TIME(10SEC)/TIME\_CONSTATA-FOR TA=2.0,5=0.0,DL,T,=TIME/2\*T1 DL.S.R. (DIMENSIONLESS SHEAR RATE=SHEAR RATES (STEP CHANGE/TRIANGULAR SIEP)/(CONSI./MAX.) SHEAR RATE (AFTER A STEP CHANGE/DURING A TRIANGULAR STEP CHANGE) DL. (THEO/ARTE) S.S. (DIMENSIONLESS SHEAR STRESS) (IHECREIICAL/ARIEFACI)=SHEAR\_STRESS(THEORETICAL/ARTEFACI) /THEORETICAL SHEAR STRESS AT MAX. SHEAR RATE

Cardiopulmonary Bypass							
Parameter	Sample	N	x	S.D.	P		
	N	18	15.2	1.2			
	1	6	14.7	1.3	-		
	2	13	13.0	1.2	0.01		
hemoglobin	3	11	8.1	0.9	<0.01		
	4	8	10.8	1.9	< 0.01		
	5	4	12.0	0.5	<0.01		
	N	18	45.7	3.5	-		
	1	6	43.3	3.3			
	2	13	38.1	3.3	< 0.01		
hematocrit	3	11	25.6	2.7	< 0.01		
	4	8	31.7	5.3	<0.01		
	5	4	35.6	1.2	<0.01		
	N	18	4.80	0.54			
	1	6	4.91	0.27	-		
	2	13	4.47	0.48	<b>〈</b> 0.05		
red blood	3	11	2.66	0.35	<0.01		
count	4	8	3.51	0.67	<0.01		
	5	4	4.09	0.10	<0.02		
	N	18	216	58			
	1	6	297	92	{ 0.02		
	2	13	298	53 <sup>.</sup>	٢٥.01		
fibrinogen	3	11	154	34	<b>८०.01</b>		
	4	8	293	63	₹0.01		
	5	4	489	71	٢٥.01		
	N	18	7.4	0.5			
	1	6	7.7	0.6	-		
	2	13	6.5	0.4	<0.01		
total protein	3	11	4.2	1.0	<0.01		
	4	8	5.4	0.4	<0.01		
	5	4	7.4	0.4	-		

Appendix II.1-A <u>Hematological Parameters During</u> Cardiopulmonary Bypass

# Appendix I1.1-A - Continued

Parameter	Sample	N	-	S D	.P
<u>101000001</u>	N N	18	58.9	5.0	
	1	6	54.8	1.8	
	2	13	55.9	3.6	
albumin	3	11	56.0	5.6	_
	4	8	61.9	6.7	_
	5	4	49.8	3.0	<0.01
	N	17	2.7	0.8	-
	1	6	3.4	0.4	∢0.05
	2	13	3.3	0.7	<0.05
αl gropuriu	3	11	3.2	0.7	<0.05
	4	8	4.2	1.1	<0.01
_	5	4	4.8	0.8	<0.01
	N	17	8.5	1.3	-
	1	6	10.7	10.0	<0.01
1	2	13	10.0	2.1	<0.02
$\alpha_2$ globulin	3	11	11.4	6.8	
	4	8	7.3	1.8	-
	5	4	12.1	3.4	<0.01
	N	17	11.9	1.1	-
	l	6	12.7	0.5	-
ß "lohultu	2	13	12.7	1.3	-
(> globulin	3	11	11.6	1.8	-
	4	8	11.1	2.3	-
	5	4	13.5	0.8	<0.01
	N	17	17.7	4.4	_
	1	6	18.4	1.7	-
	2	13	18.1	3.7	-
7 globulin	3	11	17.3	3.9	-
	4	8	15.5	2.3	-
	5	4	19.8	2.6	-

Rheological			_					
Parameter	Sample	<u>N</u>	x	S.D.	<u>P</u>			
	N	21	0.196	0.042	-			
	1	6	0.168	0.054	-			
$\gamma_{\circ}$	2	13	0.141	0.040	<0.001			
	3	12	-		-			
	4	8	0.069	0.035	<0.001			
	5	4	0.127	0.017	<0.01			
	N	21	0.116	0.016				
	1	6	0.116	0.025				
	2	13	0.091	0.015				
μ	3	12	0.047	0.010	<0.001			
	4	8	0.066	0.015	<0.010			
	5	4	0.093	0.007				
	N	21	0.125	0.038	-			
	l	6	0.111	0.021	-			
C	2	13	0.111	0.034				
~	3	12		-	<b>-</b>			
	4	8	0.107	0.041				
	5	4	0.080	0.025	< 0.05			
	N	21	0.407	0.101				
	l	6	0.377	0.152	_			
$\Delta$	2	13	0.350	0.143	-			
	3	12	_					
	4	8	0.182	0.047	<0.001			
	5	4	0.276	0.114	<b>Հ0.05</b>			

Appendix	II.1-B	Rheological	Parameters	During
		Cardionulmor	ary Bypass	

Rheological		[			
Parameter	Sample	N	<u> </u>	S.D.	• P
	N	21	1.661	0.340	
	1	6	1.646	0.137	-
	2	13	1.578	0.275	
N	3	12	-	_	_
	4	8	1.526	0.155	-
	5	4	2.048	0.627	-
	N	21	0.184	0.039	
	1	6	0.174	0.043	-
$\mathcal{A}$	2	13	0.138	0.029	<0.001
ίs.	3	12	0.048	0.009	< 0.001
	4	8	0.090	0.025	<0.001
	5	4	0.136	0.014	-
	N	21	0.068	0.022	
	l	6	0.058	0.018	-
od - W	2	13	0.048	0.016	< 0.01
"Ls -/	3	12	0.0004	0.0007	< 0.001
	4	8	0.024	0.010	< 0.001
	5	4	0.044	0.008	< 0.05

Appendix II.1-B - Continued

	Between 13 Patients Who Survived and Two Patients Who Expired After Cardia Surgery												
		ratients	wno Expi	red Alter	Cardie Su	rgery							
Rh.P.	Pre-(	Operative S	tudy	Post-Card	liopulmona	ry Bypass study							
	X	l	2	X	1	2							
7.	0.141	0.137	0.133	-	-								
N	0.091	0.090	0.097	0.047	0.070	0.041							
C	0.111	0.084	0.162	-	-								
A	0.350	0.293	1.945	-		-							
N	1.578	1.786	0.403	-		-							
M's	0.138	0.129	0.194	0.048	0.204	0.153							
<i>M</i> 5- И	0.048	0.039	0.097	0.0004	0.134	0.112							

Appendix II.1-B Comparison of Rheological Parameters

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Rh.P. : Rheological parameters.

X : Mean value of 13 survivors.

Rheological	1	1	1	}	
Parameter	Temperature	N	X	S.D.	<u>P</u>
	22.8°C	21	0.196	0.042	-
	28.0	10	0.172	0.044	0.0026
	32.0	10	0.178	0.041	0.0004
ч.	35.0	10	0.183	0.038	-
	37.0	10	0.120	0.033	-
	39.0	10	0.183	0.038	-
	41.0	10	0.181	0.039	0.0002
				19 N. 2	
	22.8	21	0.116	0.016	0.05
	28.0	10	0.112	0.019	0.0002
	32.0	10	0.106	0.015	0.0001
м	35.0	10	0.097	0.016	0.052
	37.0	10	0.084	0.013	-
	39.0	10	0.093	0.010	0.12
	41.0	10	0.097	0.013	0.052
	22.8	21	0.125	0.038	0.529
	28.0	10	0.122	0.020	0.347
	32.0	10	0.139	0.026	0.720
С	35.0	10	0.167	0.048	0.081
	37.0	10	0.134	0.034	
	39.0	10	0.153	0.053	0.343
	41.0	10	0.153	0.033	0.215

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Appendix II.2 <u>Rheological Parameters from the Effect</u> of Température on Blood

Þ.

Appendix II.2 - Continued

Rheological	Temberature	N	x	S D	q l
<u>1 21 211 211 2121 2121 2121 2121 2121 </u>	22.8	21	0.407	0,101	
	28.0	10	0.300	0.090	0.009
	32.0	10	0.333	0.066	_
	35.0	10	0.374	0 128	0.0002
A	37 0	10	0.213	0.056	_
	39.0	10	0.399	0.196	0.004
	41 0	10	0.336	0.109	0.0014
	41.0	10	0.))0		0.0014
	22.8	21	1.661	0.340	0.303
	28.0	10	1.701	0.262	0.478
	32.0	10	1.623	0.223	0.153
M	35.0	10	1.490	0.369	0.045
,	37.0	10	1.790	0.295	-
	39.0	10	1.514	0.298	0.184
	41.0	10	1.593	0.158	0.033
	22.8	21	0.184	0.030	-
	28.0	10	0.171	0.033	0.0002
	32.0	10	0.171	0.027	
A	35.0	10	0.166	0.029	-
15	37.0	10	0.121	0.023	-
	39.0	10	0.163	0.024	-
	41.0	10	0.169	0.025	-
	22.8	21	0.068	0.022	-
	28.0	10	0.059	0.015	0.0002
	32.0	10	0.065	0.013	-
M-H	35.0	10	0.068	0.017	-
's /	37.0	10	0.037	0.012	-
	39.0	10	0.071	0.017	-
	41.0	10	0.072	0.016	-

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Appendix	II.3	Rheological	Parameters	from	the	Effect
		of Alknols	on Blood			

Note:

C1 to C4 : No. of Pure Blood Sample (Control).
1 to 11 : The number indicates the carbon number
of the alkanol which has been added to
5.0 ml. of the pure blood sample.
0.1 to 0.005 : ml. of the pure alkanol added to
5.0 ml. of the pure blood sample.
Incubation : at 37°C for 30 minutes.
S : Sample.
V : ml. of alkanol added to the control.

Samplë & Alkanols				Rheolog	<u>ical Par</u>	ameters		
5	$\sim$	γ.	м	C	A	n	Ms	Ms-M
 C	1 <u>-</u> 1 \	0.0844	0.0800	0.0547	0.0622	3.1840	~ <b>0.</b> 1059	~0:0259
1	0.10	0.0963	0.0682	0.0206	0.1258	2.6984	0.1059	0.0377
2	0.10	0.1702	0.1145	0.0738	0.2885	1.3385	0.1853	0.0708
	0.05	0.0913	0.0867	0.0805	0.0521	3.1817	0.1147	0.0280
3	0.10	0.1377	0.1037	0.0456	0.0915	3.2345	0.1815	0.0481
	0.05	0.0974	0.0860	0.0809	0.1354	1.9355	0.1235	0.0375
4	0.10	0.2072	0.1355	0.0759	0.4315	1.2900	0.2250	0.0895
	0.05	0.1033	0.0891	0.0361	0.0634	3.6344	0.1253	0.0344
5	0.10	0.1536	0.1904	0.0269	0.3440	1.9676	0.2558	0.0684
	0.05	0.1169	0.1055	0.0412	0.1628	1.7969	0.1500	0.0445
6	0.10	0.0000	0.0423	0.0000	0.0000	0.0000	0.0423	0.0000
	0.05	0.1261	0.1190	0.0091	0.1427	2.7400	0.1676	0.0480
7	0.10	0.0000	0.0353	0.0000	0.0000	0.0000	0.0353	0.0000
	0.05	0.0896	0.0945	0.0040	0.0631	3.9301	0.1235	0.0290
8	0.10	0.0000	0.0988	0.0000	0.0000	0.0000	0.0988	0.0000
	0.05	0.1046	0.1208	0.0344	0.2595	1.7266	0.1676	0.0468
9	0.10	0.0000	0.1588	0.0000	0.0000	0.0000	0.1588	0.0000
4	0.05	0.1308	0.1409	0.0301	0.0706	3.1957	0.1853	0.0444
10	0.10	0.0764	0.1268	0.0502	0.0881	3.0723	0.1544	0.0276
	0.05	0.0873	0.0887	0.0592	0.5127	0.8494	0.1368	0.0481
11	0.10	0.0999	0.0903	0.0497	0.2085	1.6492	0.1332	0.0429
	0.05	0.1271	0.0963	0.0487	0.2712	1.5707	0.1500	0.0537

Appendix II.3 - Continued

S	$\checkmark$	τ.	м	С	А	N	Ms	Ms-M
C2	-	0.0806	0.0600	0.0425	0.1196	2.2536	0.0900	0.0300
1	0.10	0.0828	0.0837	0.0401	0.1260	2.1390	0.1164	0.0327
	0.05	0.0969	0.0711	0.0394	0.1081	2.5765	0.1094	0.0383
2	0.10	0.0865	0.0900	0.0647	0.0910	2.2829	0.1217	0.0317
	0.05	0.0736	0.0772	0.0773	0.1028	2.1026	0.1058	0.0286
3	0.10	0.0969	0.0901	0.0581	0.1089	2.0269	0.1252	0.0351
	0.05	0.0926	0.0812	0.0564	0.0856	2.5970	0.1147	0.0335
4	0.10	0.0942	0.1001	0.0707	0.1615	1.9805	0.1393	0.0392
	0.05	0.1152	0.1049	0.0721	0.2189	1.4041	0.1464	0.0415
	0.02	0.0956	0.0818	0.0725	0.1533	1.6082	0.1200	0.0382
5	0.10	0.0000	0.1588	0.0000	0.0000	0.0000	0.1588	0.0000
	0.05	0.0945	0.1018	0.0521	0.0810	2.7056	0.1368	0.0250
6	0.10	0.0000	0.0353	0.0000	0.0000	0.0000	0.0353	0.0000
	0.05	0.0000	0.1199	0.0000	0.0000	0.000	0.1199	0.0000
	0.02	0.1178	0.1135	0.0185	0.0586	3.9991	0.1500	0.0365
7	0.10	0.0000	0.0325	0.0000	0.0000	0.0000	0.0325	0.0000
	0.05	0.0000	0.0649	0.0000	0.0000	0.0000	0.0649	0.0000
	0.02	0.0257	0.0596	0.0155	0.0491	2.4563	0.0706	0.0110
	0.005	0.1118	0.1028	0.1233	0.1464	1.7576	0.1412	0.0384
8	0.10	0.0000	0.0466	0.0000	0.0000	0.0000	0.0466	0.0000
	0.05	0.0398	0.0912	0.0620	0.3445	1.4685	0.1111	0.0199
9	0.10	0.0000	0.0564	0.0000	0.0000	0.0000	0.0564	0.0000
	0.05	0.1104	0.1105	0.0627	0.2897	1.5793	0.1640	0.0535
	0.02	0.1098	0.0885	0.0468	0.1288	2.5020	0.1279	0.0394
10	0.10	0.0860	0.0705	0.0645	0.1081	2.4780	0.1023	0.0318
11	0.10	0.0608	0.0743	0.0670	0.2697	1.3094	0.1094	0.0351

Appendix II.3 - Continued

V	20	м	С	A	m	Ns	N5-1
-	0,0716	0.0563	0.1078	0.1237	2.1768	0.0811	0.0248
0.10	0.1266	0.0881	0.1033	0.2184	1.6263	0.1341	0.0460
0.05	0.0565	0.0527	0.0905	0.0899	2.4550	0.0776	0.0249
0.10	0.1088	0.0840	0.0667	0.1902	2.0729	0.1288	0.0448
0.05	0.0369	0.0382	0.0301	2.2631	0.3562	0.0829	0.0447
0.10	0.1364	0.0839	0.0585	0.1627	2.3690	0.1376	0.0540
0.05	0.0720	0.0741	0.0827	0.1451	1.9083	0,1058	0.0317
0.10	0.0625	0.0750	0.0294	0.0777	4.0822	0.1023	0.0273
0.05	0.0379	0.0503	0.0681	0.0765	2.0545	0.0642	0.0139
0.10	0.0000	0.0706	0.0000	0.0000	0.0000	0.0706	0.0000
0.05	0.1702	0.1337	0.0269	0.2685	2.0898	0.2029	0.0692
0.02	0.1002	0.0822	0.0603	0.1945	1.9441	0.1200	0.0378
0.10	0.0000	0.0396	0.0000	0.0000	0.0000	0.0396	0.0000
0.05	0.0000	0.0635	0.0000	0.0000	0.0000	0.0635	0.0000
0.02	0.0804	0.0829	0.0396	0.0896	2.8835	0.1129	0.0300
0.10	0.0000	0.0282	0.0000	0.0000	0.0000	0.0282	0.0000
0.05	0.0000	0.0706	0.0000	0.0000	0.0000	0.0706	0.0000
0.02	0.0472	0.0796	0.0294	0.0762	2.1098	0.0970	0.0174
0.10	0.0000	0.0466	0.0000	0.0000	0.0000	0.0466	0.0000
0.05	0.0351	0.0679	0.0795	0.0918	2.0166	0.0819	0.0140
0.10	0.0000	0.0522	0.0000	0.0000	0.0000	0.0522	0.0000
0.05	0.0449	0.0846	0.0532	0.1351	1.6320	0.1041	0.1095
0.02	0.0658	0.0645	0.0263	0.0822	2.8202	0.0924	0.0279
0.10	0.0276	0.0415	0.0243	1.5484	0.4731	0.0758	0.0343
0.10	0.0446	0.0607	0.0476	0.0461	3.1744	0.0758	0.0151
	- 0.10 0.05 0.10 0.05 0.10 0.05 0.10 0.05 0.02 0.10 0.05 0.02 0.10 0.05 0.02 0.10 0.05 0.02 0.10 0.05 0.02 0.10 0.05 0.02 0.10 0.05 0.02 0.10 0.05 0.02 0.10	- 0.0716 0.10 0.1266 0.05 0.0565 0.10 0.1088 0.05 0.0369 0.10 0.1364 0.05 0.0720 0.10 0.0625 0.05 0.0720 0.10 0.0000 0.05 0.0379 0.10 0.0000 0.05 0.1702 0.02 0.1002 0.10 0.0000 0.05 0.0000 0.05 0.0000 0.05 0.0000 0.05 0.0000 0.05 0.0000 0.05 0.0000 0.05 0.0000 0.05 0.0000 0.05 0.0351 0.10 0.0000 0.05 0.0449 0.02 0.0446	$\begin{array}{c cccc} - & 0.0716 & 0.0563 \\ \hline 0.10 & 0.1266 & 0.0881 \\ \hline 0.05 & 0.0565 & 0.0527 \\ \hline 0.10 & 0.1088 & 0.0840 \\ \hline 0.05 & 0.0369 & 0.0382 \\ \hline 0.10 & 0.1364 & 0.0839 \\ \hline 0.05 & 0.0720 & 0.0741 \\ \hline 0.10 & 0.0625 & 0.0750 \\ \hline 0.05 & 0.0379 & 0.0503 \\ \hline 0.05 & 0.0379 & 0.0503 \\ \hline 0.05 & 0.1702 & 0.1337 \\ \hline 0.02 & 0.1002 & 0.0822 \\ \hline 0.10 & 0.0000 & 0.0396 \\ \hline 0.05 & 0.0000 & 0.0396 \\ \hline 0.05 & 0.0000 & 0.0396 \\ \hline 0.02 & 0.0804 & 0.0829 \\ \hline 0.10 & 0.0000 & 0.0282 \\ \hline 0.05 & 0.0000 & 0.0706 \\ \hline 0.02 & 0.0472 & 0.0796 \\ \hline 0.02 & 0.0472 & 0.0796 \\ \hline 0.10 & 0.0000 & 0.0466 \\ \hline 0.05 & 0.0351 & 0.0679 \\ \hline 0.10 & 0.0000 & 0.0522 \\ \hline 0.05 & 0.0449 & 0.0846 \\ \hline 0.02 & 0.0476 & 0.0415 \\ \hline 0.10 & 0.0276 & 0.0415 \\ \hline 0.10 & 0.0446 & 0.0607 \\ \hline \end{array}$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	- $0.0716$ $0.0563$ $0.1078$ $0.1237$ $0.10$ $0.1266$ $0.0881$ $0.1033$ $0.2184$ $0.05$ $0.0565$ $0.0527$ $0.0905$ $0.0899$ $0.10$ $0.1088$ $0.0840$ $0.0667$ $0.1902$ $0.05$ $0.0369$ $0.0382$ $0.0301$ $2.2631$ $0.10$ $0.1364$ $0.0839$ $0.0585$ $0.1627$ $0.05$ $0.0720$ $0.0741$ $0.0827$ $0.1451$ $0.10$ $0.0625$ $0.0750$ $0.0294$ $0.0777$ $0.05$ $0.0379$ $0.0503$ $0.0681$ $0.0765$ $0.10$ $0.0000$ $0.0706$ $0.0000$ $0.0000$ $0.05$ $0.1702$ $0.1337$ $0.0269$ $0.2685$ $0.02$ $0.1002$ $0.0822$ $0.0603$ $0.1945$ $0.10$ $0.0000$ $0.0396$ $0.0000$ $0.0000$ $0.05$ $0.0000$ $0.0282$ $0.0000$ $0.0000$ $0.02$ $0.0844$ $0.0829$ $0.0396$ $0.0896$ $0.10$ $0.0000$ $0.0282$ $0.0000$ $0.0000$ $0.02$ $0.0472$ $0.0796$ $0.0294$ $0.0762$ $0.10$ $0.0000$ $0.0282$ $0.0000$ $0.0000$ $0.05$ $0.0449$ $0.0846$ $0.0532$ $0.1351$ $0.02$ $0.0472$ $0.0795$ $0.0918$ $0.10$ $0.0276$ $0.0415$ $0.0243$ $1.5484$ $0.10$ $0.0276$ $0.0415$ $0.0476$ $0.0461$	- $0.0716$ $0.0563$ $0.1078$ $0.1237$ $2.1768$ $0.10$ $0.1266$ $0.0881$ $0.1033$ $0.2184$ $1.6263$ $0.05$ $0.0565$ $0.0527$ $0.0905$ $0.0899$ $2.4550$ $0.10$ $0.1088$ $0.0840$ $0.0667$ $0.1902$ $2.0729$ $0.05$ $0.0369$ $0.0382$ $0.0301$ $2.2631$ $0.3562$ $0.10$ $0.1364$ $0.0839$ $0.0585$ $0.1627$ $2.3690$ $0.05$ $0.0720$ $0.0741$ $0.0827$ $0.1451$ $1.9083$ $0.10$ $0.0625$ $0.0750$ $0.0294$ $0.07777$ $4.0822$ $0.05$ $0.0379$ $0.0503$ $0.0681$ $0.0765$ $2.0545$ $0.10$ $0.0000$ $0.0706$ $0.0000$ $0.0000$ $0.0000$ $0.05$ $0.1022$ $0.0822$ $0.0603$ $0.1945$ $1.9441$ $0.10$ $0.0000$ $0.0396$ $0.0000$ $0.0000$ $0.0000$ $0.05$ $0.0000$ $0.0282$ $0.0000$ $0.0000$ $0.0000$ $0.05$ $0.0000$ $0.0282$ $0.0000$ $0.0000$ $0.0000$ $0.05$ $0.0000$ $0.0282$ $0.0000$ $0.0000$ $0.0000$ $0.05$ $0.0000$ $0.0766$ $0.0000$ $0.0000$ $0.0000$ $0.05$ $0.0000$ $0.0766$ $0.0000$ $0.0000$ $0.0000$ $0.05$ $0.0000$ $0.0766$ $0.0000$ $0.0000$ $0.0000$ $0.05$ $0.0000$ $0.0766$ $0.0000$ $0.$	$\begin{array}{ c c c c c c c c c c c c c c c c c c c$

Appendix II.3 - Continued

S	$\checkmark$	Z.	μ	С	A	$\sim$	Ms.	Ms-M
C <sub>4</sub>	-	0.3736	0.1614	0.0773	0.5050	1.5982	0.3088	0.2474
1	0.10	0.5743	0.2362	0.0685	0.7531	1.3840	0.4588	0.2226
	0.05	0.4371	0.1900	0.0778	0.5327	1.6269	0.3617	0.1717
2	0.10	0.7409	0.2343	0.0903	0.6852	1.6463	0.5029	0.2686
	0.05	0.4698	0.1840	0.0632	0.5478	1.9426	0.3617	0.1717
3	0.10	0.4173	0.1950	0.0810	0.7860	1.3358	0.3706	0.1756
	0.05	0.3640	0.1835	0.0838	0.6778	1.3747	0.3353	0.1518
4	0.10	0.5785	0.2684	0.0611	0.9183	1.5300	0.4941	0.2257
	0.05	0.4048	0.1961	0.0858	0.8291	1.4055	0.3706	0.1745
5	0.10	0.2492	0.3695	0.0838	0.4254	1.2335	0.4658	0.0963
	0.05	0.7213	0.4439	0.0351	1.1456	1.7890	0.7411	0.2972
	0.02	0.5434	0.2331	0.0563	0.8345	1.6153	0.4367	0.2036
	0.01	0.4930	0.2186	0.0833	0.8777	1.3885	0.4235	0.2049
6	0.10	0.0000	0.1059	0.0000	0.0000	0.0000	0.1059	0.0000
	0.05	0.6983	0.1955	0.0137	0.1225	2.4727	0.2206	0.0351
	0.02	0.4144	0.1991	0.0406	0.4955	1.9768	0.3573	0.1582
7	0.10	0.0000	0.1059	0.0000	0.0000	0.0000	0.1059	0.0000
	0.05	0.0000	0.1588	0.0000	0.0000	0.0000	0.1588	0.0000
	0.01	0.5913	0.2503	0.0640	0.5408	1.6445	0.4588	0.2085
	0.005	0.3928	0.1928	0.0827	1.0362	1.1058	0.3661	0.1633
8	0.10	0.0000	0.1306	0.0000	0.0000	0.0000	0.1306	0.0000
	0.05	0.0000	0.2117	0.0000	0.0000	0.0000	0.2177	0.0000
	0.01	0.5619	0.2158	0.0624	0 <b>.56</b> 62	1.7319	0.4235	0.2077
	0.005	0.4419	0.1914	0.0794	0.6882	1.3571	0.3723	0.1809
9	0.10	0.0000	0.2117	0.0000	0.0000	0.0000	0.2117	0.0000
	0.05	0.1481	0.1881	0.0047	0.0279	0.0014	0.2294	0.0413
	0.01	0.4894	0.2136	0.065 <b>7</b>	0.7343	1.7782	0.4147	0.2011
10	0.10	0.2884	0.4213	0.0522	0.3481	1.6234	0.5294	0.1081
}	0.05	0.4621	0.2469	0.0977	0.9640	1.4437	0.4367	0.1901
11	0.10	0.4182	0.2142	0.0963	0.7802	1.7356	0.3810	0.1668
	0.05	0.3611	0.1915	0.0916	0.5394	1.8906	0.3309	0.1394

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#### Appendix III. Equations for the Calculation of Shear Rate and Shear Stress on a Double Couste

The double couette was shown in Fig.III.1-2.

Assuming an incompressible Newtonian fluid flows at steady state in  $\theta$  -direction only i.e.  $\bigvee_r = \bigvee_z = o$ Equation of motion of the fluid in  $\theta$  - direction

$$0 = \frac{d}{dr} \left[ \frac{1}{r} \frac{d}{dr} (rV_{\theta}) \right]$$
(A.III-1)

(A) Inner couvette ;  $r_1 \leq r \leq r_2$ 

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B.C.  $V_{\theta}(\tau_{1}) = 2\pi\tau_{1}\Omega$  with  $\Omega$  [=] rad/sec

$$V_{\theta}(r_2) = 0$$

The solution of Eq.AIII-1 is

$$\begin{aligned} V_{\theta}(r) &= \frac{2\pi r_{1}^{2} \Omega}{r_{2}^{2} - r_{1}^{2}} \left( \frac{r_{2}^{2}}{r} - r \right) \\ \dot{\gamma}_{r\theta} \bigg|_{r=r_{2}} &= r \frac{d}{dr} \left( \frac{V_{\theta}}{r} \right) \bigg|_{r=r_{2}} = - \frac{4\pi r_{1}^{2} \Omega}{r_{2}^{2} - r_{1}^{2}} \quad sec^{-1} \\ \mathcal{T}_{r\theta} \bigg|_{r=r_{2}} &= -\mu \dot{\gamma}_{r\theta} \bigg|_{r=r_{2}} \\ \mathcal{T}_{2} &= 2\pi r_{2} L \mathcal{T}_{r\theta} \bigg|_{r=r_{2}} = 4\pi L \mu \Omega \frac{r_{1}^{2} r_{2}^{2}}{r_{1}^{2} - r_{1}^{2}} \end{aligned}$$
(B). Outter couette ;  $r_3 \leq r \leq r_4$ 

 $B.C. \quad \bigvee_{\theta}(r_3) = 0$ 

$$V_{\theta}(r_4) = 2 \pi r_4 \Omega$$

The solution of Eq.AIII-1 is

$$\begin{aligned} V_{\theta}(r) &= \frac{2\pi r_{4}^{2}}{r_{4}^{2} - r_{3}^{2}} \left( r_{-} \frac{r_{3}^{2}}{r} \right) \\ \dot{\gamma}_{r\theta} \Big|_{r=r_{3}} &= r \frac{d}{dr} \left( \frac{V_{\theta}}{r} \right) \Big|_{r=r_{3}} = \frac{4\pi r_{4}^{2} \Omega}{r_{4}^{2} - r_{3}^{2}} \sec^{-1} \\ \tilde{\gamma}_{r\theta} \Big|_{r=r_{3}} &= -\mu \dot{\gamma}_{r\theta} \Big|_{r=r_{3}} \\ \tilde{\gamma}_{r\theta} \Big|_{r=r_{3}} &= 2\pi r_{3} L \left( -\tilde{\gamma}_{r\theta} \right) \Big|_{r=r_{3}} \cdot r_{3} = 4\pi L \mu \Omega \frac{r_{3}^{2} r_{4}^{2}}{r_{4}^{2} - r_{3}^{2}} \end{aligned}$$

(C). Design condition

In order to have the same  $\dot{\gamma}_{r\theta}$  and same  $\gamma_{r\theta}$  on the surfaces at  $r_2$  and  $r_3$ , the double couette should have:

$$\dot{y}_{r\theta}\Big|_{r=r_2} = -\dot{y}_{r\theta}\Big|_{r=r_3}$$
 so that  $T_{r\theta}\Big|_{r=r_1} = -T_{r\theta}\Big|_{r=r_3}$   
or  $\frac{r_1^2}{r_2^2 - r_1^2} = \frac{r_4^2}{r_4^2 - r_3^2}$ 

(D). Calculation of shear stress from total torque

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$$T = T_{2} + T_{3} = \text{Total torque applied to both}$$

$$= 4 \pi \mu L \Omega \left( \frac{r_{1}^{2} r_{2}^{2}}{r_{2}^{2} - r_{1}^{2}} + \frac{r_{3}^{2} r_{4}^{2}}{r_{4}^{2} - r_{3}^{2}} \right)^{\frac{r_{2} \& r_{3} \text{ surfaces}}{r_{2} \& r_{3} \text{ surfaces}}$$

$$\frac{T_{2}}{T} = \frac{r_{2}^{2}}{r_{2}^{2} + r_{3}^{2}}$$
or
$$T_{2} = T \left( \frac{r_{2}^{2}}{r_{2}^{2} + r_{3}^{2}} \right) = 2 \pi L r_{2}^{2} (\mathcal{T}_{r_{\theta}}) \Big|_{r=r_{2}}$$

$$\therefore (\mathcal{T}_{r_{\theta}}) \Big|_{r=r_{2}} = (-\mathcal{T}_{r_{\theta}}) \Big|_{r=r_{3}} = \frac{T}{2 \pi L (r_{2}^{2} + r_{3}^{2})}$$

(E). Calculation of total torque from the measurement of Y in X-Y recorder

$$Y_m =$$
 the reading in Y of the X-Y recorder corres-  
ponding to the maximum angle deflection of the  
torsion bar.

$$Y =$$
 reading of Y at the X-Y recorder.

$$\varkappa$$
 = angle deflection of torsion bar.

$$T = G \cdot d = G \cdot R \cdot \frac{Y}{Y_m}$$

$$\begin{aligned} (\mathcal{T}_{r\theta})\Big|_{r=r_{2}} &= (-\mathcal{T}_{r\theta})\Big|_{r=r_{3}} = \frac{G \cdot R \cdot Y/Y_{m}}{2\pi L (r_{2}^{2} + r_{3}^{2})} \\ (\dot{\gamma}_{r\theta})\Big|_{r=r_{2}} &= (-\dot{\gamma}_{r\theta})\Big|_{r=r_{3}} = -\frac{4\pi r_{1}^{2}\Omega}{r_{2}^{2} - r_{1}^{2}} \end{aligned}$$

.

For 
$$\Omega$$
 , see next Appendix.

so,

## Appendix IV. <u>Calculation of the RPM of viscometer in</u> <u>Weissenberg Rheogoniometer. Model 18</u>



 $\begin{array}{ccc} \underline{\text{Input shaft}} & \underline{\text{Couette}} \\ 1500 \text{ rpm (motor )} & \underline{\Omega}_{o} \text{ rpm} \\ \underline{99999 \times 60}_{256 \times 200} \times 5 & 585.93 \text{ rpm} & \underline{\Omega} & ? \\ & & & & & & \\ & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & \\ & & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & &$ 

- Note:
  - 1. Constant speed of motor is 1500 rpm.
  - 2. Control panel sets at 99999 with high switch 5 (low switch l) giving the new impulse driven motor at the above speed (585.93 rpm).
  - 3.  $\Omega_o$  is determined by the gear box setting (see Weissenberg manual, Appendix 1).

so,

$$\Omega = \frac{585.93}{1500} \Omega_0 (rpm)$$
  
=  $\frac{585.93}{1500} \Omega_0 \times \frac{2\pi}{60}$  sec<sup>-1</sup>

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