AD-755 541

AN INVESTIGATION OF SIGHT-LINE STABILIZATION

Edward J. Finck, et al

Iowa University

Prepared for:

Army Weapons Command

December 1972

and the second states of the second

-

"ran" 11 " 1 .

.

.

.

DISTRIBUTED BY:

National Technical Information Service U. S. DEPARTMENT OF COM AERCE 5285 Port Royal Road, Springfield Va. 22151

÷.



+1

;

ł

AN INVESTIGATION OF SIGHT-LINE STABILIZATION

by

Edward J. Finck and George M. Lance

Department of Mechanical Engineering The University of Iowa Iowa City, Iowa



Project Themis - The University of Iowa "Vibration and Stability of Military and Other Complex Vehicular Systems"

Contract No. DAAF03-69-C-C014

December 1972

Security Classification								
DOCUMENT C	CONTROL DATA - R &	D						
(Security classification of title, body of abstract and ind	lexing ennotation must be en	tered when the	overall report is closellied)					
OR GINATING ACTIVITY (Corporate author) University of Iowa		20. REPORT SECURITY CLASSIFICATION Unclassified						
•		10. GROUP	la					
REPORT TITLE								
An Investigation of Sight-Line	Stabilization							
DESCRIPTIVE NOTES (Type of report and inclusive dates) Technical Report								
- AUTHOR(3) (First neme, middle initial, last neme)								
Edward J. Finck and George M.	Lance							
REPORT DATE December 1972	78. TO FAL NO. OF	PAGES	75. NO. OF REFS					
E. CONTRACT OR GRANT NO.	SE CRIGINATOR'S	NEPORT NUM	1BER(5)					
5. PROJECT NO. DAAF03-69-C-1209	Report	Report No. 45						
с.	W. OTHER REPOR this report)	SD. OTHER REPORT NO(S) (Any other numbers that may be avaigned this report)						
d.			~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~					
UISTRIDUTION OF THIS PE	12- SPCHSORING MI	LITARY ACTI	VITY					
	U. S. Army	U. S. Army Weapons Command						
J. ABSTRACT		<u></u>						
This paper presents the bas	ic considerations	behind :	sight-time					
stabilization. The equations o	f motion that rel	late the g	general pitch,					
toll and yaw motions of a vehicle	e hull to the tra	verse and	elevation					
angles of a sight-line fixed to	the hull are deve	loped.	A detailed					
mathematical model of a feedback	control system t	that will	accomplish					
sight-line stabilization is deve	loped, and a nume	erical opt	timization is					
			The optimization					
performed on a simplified version	n of this detaile	ed model.	THE OUTIMIZATION					
performed on a simplified version routine used is described in ref	m of this detaile Merence [6].	a model.	The optimization					

DD 1 NOT SE 1473 REPLACES DO PORM 1475. I JAN 64. MITCH IS

Unclassified Security Classification

		<u> </u>	LIN	LINK		
	ROLE	WT -	ROLE	#T	ROLE	
				l	1	
feedback			[1	
control	1		1	1		
Suster	1					
sight-i ine					Ì	
stabilization		1				
optimization						
model.						
Derameter						
numerical	1					
	·		•			
	1					
_			l	Í		
•				Í		
		1	1	1		
		[
					1	
			i			
•					i	
				1		
		1				
		1			İ	
. .		ļ		1		
•••		ļ		1		
				[
			i			
				1		
-						
		1				
	1 1	1	1	1		
•		·	••			
		I		1		
			ļ		1	
		1		1		
•		I		1	1	
		1	İ			
	1 1		Į	1	!	
•			1			
•				1		
		1		I		
	Į	1	Į	I		
	1			1		
	1 1	1	[Ì		
•	1 1	-		-	-	

ABSTRACT

This paper presents the basic considerations behind sight-time stabilization. The equations of motion that relate the general pitch, roll and yaw motions of a vehicle hull to the traverse and elevation angles of a sight-line fixed to the hull are developed. A detailed mathematical model of a feedback control system that will accomplish sight-line stabilization is developed, and a numerical optimization is performed on a simplified version of this detailed model. The optimization routine used is described in reference [6].

KEY WORDS

Feed back, control, system, sight-line, stabilization, optimization, model, parameter, numerical.

والاسترادية الأنكأ التلاية المويد وتتمكما لأرضد عارينا

TABLE OF CONTENTS

																						Page
List	of	Tables	•	•	•	•	•	•	•	٠	•	•	•	•	•	•	•	•	•	٠	•	īv
List	of	Figures	•	•		٠	•	٠		•	٠	•	•	•	•	•	•	•	•	•	•	v - vi
List	of	Symbols	•	•	٠	•	•	•	•	•	•	•	•	•	•	•		•			•,	vii - viii

111, **111**

: *

2

A MARINE MARINE A MARINE A MARINE A MARINE A MARINE A MARINE A MARINE A MARINE A MARINE A MARINE A MARINE A MAR

,

Chapters

÷

1.	Introduction	1
2.	Sight-Line Stabilization	4
3.	System Concepts	12
4.	Design	16
5.	Simplified Version	41
6.	Optimization	49
7.	Discussion and Conclusions	59

Appendix

<i>k</i> .	System	Outr	out	•	•	•	•	٠	L	•	٠	٠	•	•	•	•	•	•	•	62
Bibliogr	aphy	••		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	34

i**ii**

LIST OF TABLES

1

(

•

*

-

trije Finistrije Finistrije

F

È

3

le Pa	ge
1. List of Motor Variables	18
2. Definitions of Drive Variables ,	21
3. Load Variables	23
4. List of System Parameters	51
5. Initial Values of Parameters Used in Optimization	53
6. Optimal Parameters	53
7. Sensitivity Check	55
3. Cutput Variables	62

.

LIST OF FIGURES

• • •

nen La ser a ser an La ser andre ser andre ser andre ser andre ser andre ser andre ser andre ser andre ser andre s

<u>-</u>---

્યાર ભાષા છે. કાંગ્રે છે. તે આવે કે આવ્યું કે આવે છે. આ ગામમાં આવે છે. તે પ્રાથમિત છે. ગામ છે. પ્રાથમિત

· · / • / • · •

5

•

ţ

Figure	Page
1. Incorrect gradient	. 2
2. Stabilization Geometric Requirements	. 5
3. Axes of Rotation	. 9
4. Equivalent Base Motion Vectors	. 11
5. Disturbed System	. 13
6. Directed System	. 14
7. Partial Block Diagram of Hydraulic Motor	. 17
8. Drive Variables	. 20
9. Motor and Load	. 24
10. Block Diagram Manipulation to find $\frac{1}{2}$ /V	. 25
11. Reduced Block Diagram for q Input Only	. 28
12. Motor and Load for Inertial Inputs Only	. 31
13. Velocity Loop	. 32
14. Pole Zero Plot of Equation (33)	. 33
15. Root Locus of Velocity Loop	. 34
16. Position Loop	. 35
17. Pole Zero Plot of ϕ/V_v	. 36
18. Root Locus of Position Loop	. 38
19. Final System	. 40
20. Simplified Version of Motor Load Relation	. 44

C

.

.

•

· · · · · · ·

1 migan at 1 state

C

Figure	Page
21. Velocity Feedback	44
22. Position Feedback	45
23. Final Simplified Version of Figure 19	47
24. Frequency Response Magnitude Plot	56
25. Frequency Response Phase Plot	57
26. Transient Response	58

vi

C

and the state of the state of the state of the state of the state of the state of the state of the state of the

ź

£

È.

LIST OF SYMBOLS

Symbol

£

el - Nu

1

2

e_s --- sight-line unit vector E --- elevation angle T --- traveise angle p --- pitch r ---- roll q ---- yaw J_{T} ---- traverse inertia J ---- elevation inertia EE J_{ET}^{---} component of elevation inertia in travse inertia $\overline{\omega}$ --- base angular velocity K₆ --- pressure feedback gain G₆ --- pressure feedback transfer function KP --- servo valve gain GV --- servo valve transfer function DM ---- hydraulic motor average displacement CP ---- valve orfice damping coefficient V_{μ} ---- effective volume of hydraulic under compression β ---- bulk modulus of hydraulic fluid s ---- Laplace transform variable θ_m --- motor angle in radians (inertial component)

vii

Symbol

€

 τ_{m} --- motor torque P_L --- pressure applied to motor input Q_{C}^{---} compressibility flow \boldsymbol{Q}_{D} --- displacement flow through motor \boldsymbol{Q}_{L} --- total load flow through metering orfice i --- input current to servo valve V_{c}^{+} --- motor and value configuration input current $M_{\rm T}$ --- traverse drive motor M_{E}^{---} elevation drive motor R --- radius of J_T ring gear r' --- radius of M_{T} pinion gear $\boldsymbol{\theta}_m^{\text{ '}-\!\!-\!\!-\!\!-}$ motor angle needed to compensate for qKL --- motor shaft compliance J_{m} --- motor and gear inertia N --- gear ratio $\Delta\theta$ ---- motor shaft twist angle $G_q \longrightarrow q$ stabilizing transfer function $q_c \xrightarrow{---} input for q stabilization$ θ --- actual motor angla

CHAPTER 1

•

Correction and a second

1

INTRO JUCTION

The optimization of feedback control systems is a topic that has received much attention during recent years. Analytical techniques have been developed for a great variety of problems, but the application of these techniques to complex problems can become extremely difficult, if not impossible. This difficulty in applying analytical techniques has been one of the influential factors on the rise of numerical techniques for optimization.

Numerical techniques can be divided into .wo categories: direct search and indirect search. All indirect methods employ the use of the gradient of the performance surface in one manner or another. For systems with highly oscillatory or even discontinous performance surfaces, which are frequently encountered in the feedback control systems area, it is very easy to calculate an incorrect gradient, thus affecting the convergence of the optimization technique. An incorrect gradient is she in fig. 1.

Because of the difficulty involved in calculating the gradient of the performance surface, direct methods are more suited to control optimization problems. There are many fine direct methods, among them are the method of Hook and Jeeves {4} and the method of Rosenbrock {9}. T. Lange-Nielsen {6} has modified Rosenbrock's



method and used it to develop an optimization algorithim using CSMP^{*}. Details of Rosenbrock's method and Lange'Nielsen's modifications can be found in reference [6].

€

C

When using a numerical optimization routine one must be careful to insure that the results are correct. In optimization the objective is to minimize a performance index while a system goes from one state to another. For a performance index such as the integral squared error (ISE) an analytical check can be made of the results by using tables {7} that express ISE in terms of known system quantities.

Continuous Systems Modeling Program. An IBM analog simulation that uses digital methods. (see reference {5}) 2

contribution of a business to develop the set

بعاهدته فتعادره المرهالي

ź

1 T

If a full of a loose of the loose of the loose of a loose of the loose

المحادي والأخرارية الأر

「ないないないないないないないないないないないないないないないないない」 ちょうい ふんしゅうちょう いちょう ちょう ちょう ちょうちょう ちょうちょう ちょうちょう

This is not to say that the system can be easily optimized by analytical methods if ISE is used. Another way to help guarantee that results are correct is to be familiar enough with the problem that is being optimized that you have some idea of what your results should be. It is for this reason that the material in chapters two, three and four is presented.

Care must be taken when synthesizing > mathematical model. An inaccurate model can cause all efforts to have been in vain, and the results will be useless. Automatic control problems include the dynamics of mechanical components as well as the characteristics of electrical and hydraulic components. Sight-line stabilization is a problem that requires some modeling in all three of these areas as well as a thorough understanding of kinematics, and of course control theory.

The problem of sight-line stabilization will be examined in chapters two, three and four; and detailed mathematical model will be developed in chapter four. Sometimes concessions have to be made to factors over which there is no control. Computation time on a computer is one such factor. It is for this reason that a simplified version of the detailed model is used in the actual numerical optimization. This simplified model is developed in chapter five.

ور دروم و امر الله المؤلماتي الدور و مدا المو مدا الدور

3

e di segnati di Madel SAN kali anta sino in ndra Zi Usino na di 2

Chapter 2

4

reaspear i na saahharanga sanchiyahinga dahasi in kangadang k

SIGHT-LINE STABILIZATION

The concept behind sight-line stabilization is a simple one. Consider a sight-line unit vector, \bar{e}_s , (see fig. 2) directed from a point, 0, to a point, P, with its base fixed at 0. Point P is fixed in inertial space, and 0 is fixed to a base, B, as shown in fig. 2. The control variables are the traverse angle, T, and the elevation angle, E, defined as in fig. 2. The problem is to keep \bar{e}_s oriented from 0 to P while the hull undergoes general pitch, roll, and yaw motion about the z, x, and y axes respectively. The notation will be to use p to denote pitch angle, r to denote roll angle, and q to denote yaw angle; with superscript dot denoting the familiar derivative with respect to time (\dot{p} , \dot{r} , and \dot{e} are shown in fig. 2).

€

It is now desireable to derive an expression for T and E in terms of the known quantities. In the future it will be found that it is useful to do this in terms of the x-y-z reference frame previously defined. The sight-line unit vector, \tilde{e}_s , can be written in terms of the x, y and z axis unit vectors; \tilde{i} , \tilde{j} , \tilde{k} respectively.

 $\overline{e}_{i} = \cos(E)\cos(T) \cdot \overline{i} + \sin(E) \cdot \overline{j} + \cos(E)\sin(\Gamma) \cdot \overline{k}$ (1)

The derivative of $\overline{e_s}$ in the inerti "reference frame can be found by applying a general rule from vector calculus.



C

rear to transition was the every say that to be an orthogonal that the second of the second

蹇



5

1. * 1.*** "4. edi edite - 1.

۴,

134.00

й в . -

azun malu

$$\frac{I}{dt}\left(\bar{e}_{s}\right) = \frac{B}{dt}\left(\bar{e}_{s}\right) + \bar{\omega} \times \bar{e}_{s}$$
(2)

The superscript I denotes the inertial reference frame, the superscript B denotes the base reference frame, and $\tilde{\omega}$ is the general rotation vector for the base given by equation (3).

$$\vec{\omega} = \dot{\mathbf{r}} \, \vec{\mathbf{i}} + \dot{\mathbf{q}} \, \vec{\mathbf{j}} + \dot{\mathbf{p}} \, \vec{\mathbf{k}} \tag{3}$$

By expanding the expressions on the right of equation (2) equations (4) and (5) are obtained.

$$\vec{\omega} \times \vec{e}_{s} = \{ \dot{c} \cdot \cos(E) \sin(T) - \dot{p} \cdot \sin(E) \} \cdot \vec{i} + \{ \dot{p} \cdot \cos(E) \cos(T) - \dot{f} \cdot \cos(E) \sin(T) \} \cdot \vec{j} + \{ r \cdot \sin(E) - \dot{q} \cdot \cos(E) \cos(T) \} \cdot \vec{k}$$
(4)

$$\frac{B_{d}}{dt} (\tilde{e}_{s}) = \{ -\tilde{T} \cdot \cos(E)\sin(T) - \dot{E} \cdot \sin(E)\cos(T) \} \cdot \tilde{I} + \\
\{ \dot{E} \cdot \cos(E) \} \cdot \tilde{J} + \\
\{ \dot{T} \cdot \cos(E)\cos(T) - \dot{E} \cdot \sin(E)\sin(T) \} \cdot \tilde{k}$$
(5)

The stabilization requirement is given by equation (6):

C

Ś

ż

. .

and the second second

A.

14 - X-

$$\frac{1}{dt}\left(\bar{e}_{g}\right)=0$$
(6)

6

-

÷

a three a set of the market the set of

بواحيا الا

Equation (2) therefore reduces to equation (7):

C

$$0 = \frac{B_{d}}{dt} (\bar{e}_{s}) + \bar{\omega} x \bar{e}_{s}$$
(7)

7

ŝ,

By substituting equations (4) and (5) into equation (7) and noting that for a vector quantity to be zero each component must be zero, the following set of three scalar equations from the \tilde{i} , \tilde{j} and \tilde{k} components respectively are obtained.

$$0 = -\vec{E} \cdot \cos(T)\sin(E) - \vec{T} \cdot \sin(T)\cos(E) - \dot{p} \cdot \sin(E) + \dot{q} \cdot \sin(T)\cos(E)$$
(8)

$$0 = \dot{E} \cdot \cos(E) + \dot{p} \cdot \cos(T) \cos(E) - \dot{r} \cdot \sin(T) \cos(E)$$
(9)

$$0 = -\dot{E} \cdot \sin(T) \sin(E) + \dot{T} \cdot \cos(T) \cos(E) + \dot{T} \cdot \sin(E) - \dot{q} \cdot \cos(T) \cos(E)$$
(10)

By solving equation (9) the expression for $\dot{\mathbf{E}}$ is obtained.

$$\dot{\mathbf{E}} = \dot{\mathbf{r}} \cdot \sin(\mathbf{T}) - \dot{\mathbf{p}} \cdot \cos(\mathbf{T})$$
(11)

Substituting equation (11) into either equation (8) or equation (10) gives the expression for \dot{T} , equation (12):

$$T = \dot{q} - \tan(E)\{\dot{r} \cdot \cos(T) + \dot{p} \cdot \sin(T)\}$$
(12)

Equations (11) and (12) are the governing equations of motion. Note that T and E are measured with respect to the base.

Now that the equations of motion for T and E are known it must be determined how T and E are to be controlled. Associated with the traverse axis there is an inertia, $J_{T}^{}$, and with the elevation axis an inertia, J_{EE} . These are represented in fig. 3. J_T rotates with respect to the base around the previously defined y axis, and is thus measured with respect to the y axis. Define a new set of coordinates x_T , y_T , z_T , that are fixed to J_T such that y_T and z_{T} rotate with J_{T} . J_{EE} is confined to rotate about the z_{T} axis, and is thus measured with respect to the z_{T} axis. It is easy to see that part of J_{EE} will be included in J_T . This component is denoted by J_{ET} . J_{ET} is not fixed, but is a function of E. The movement of J_T through an angle T is accomplished by a motor, M_T , mounted on J_{η} parallel to the y axis as shown in fig. 3b. The torque is transferred through a gear ratio of N_{T} . Similarly J_{E} is driven by a motor, M_{E} , mounted on J_{T} parallel to the z_{T} axis with an associated gear ratio N_F.

C

÷

It is desireable to return to the governing equations of motion and examine the significance of their terms more carefully. They are repeated below for convenience.

$$\dot{\mathbf{E}} = \dot{\mathbf{r}} \cdot \sin(\mathbf{T}) - \dot{\mathbf{p}} \cdot \cos(\mathbf{T})$$
(11)

8

a dan sanaka si da kasa sana



Ł

C

£

.









• •



9

ાં હાટુ ભારતીવીવાર જે પશ્ચિત અન્યત્વક હેલ્લ અદીવે વિભયંત

$$\dot{T} = \dot{q} - \tan(E) \{ \dot{r} \cdot \cos(T) + \dot{p} \cdot \sin(T) \}$$

The pitch and roll velocity vectors can be resolved through the traverse angle T to form two new vectors, $\dot{\mathbf{r}} \cdot \cos(T) + \dot{\mathbf{p}} \cdot \sin(T)$ and $\dot{\mathbf{p}} \cdot \cos(\mathbf{T}) - \dot{\mathbf{r}} \cdot \sin(\mathbf{T})$, which together with the original yaw vector, q, form equivalent components of hull motion (see fig. 4). It is easy to see that $\overline{i \cdot \cos(T)}$; $\dot{p} \cdot \sin(T)$ is in the previously defined x_{T} direction, and $\dot{p} \cdot \cos(T) - \dot{r} \cdot \sin(T)$ is in the previously defined z_{r} direction. One of the stabilization requirerents is to drive \dot{E} about the z_{T} axis such that \bar{e}_{s} remains oriented in inertial space. From equation (11) it is seen that E is simply the negative of the new equivalent vector, $\dot{\mathbf{p}} \cdot \cos(\mathbf{T}) - \dot{\mathbf{r}} \cdot \sin(\mathbf{T})$. Since this is always oriented parallel to the elevation drive axis there is no need to accelerate J_p inertially, but the only requirement is that E compensate for the hull motion. Torque is required only to accelerate motor and gear inertia and overcome friction. The traverse axis can be analyzed in a similar manner. The first term in equation (12) is q. This is always oriented parallel to the traverse drive axis and thus requires no torque to accelerate J_{π} inertially. But the second term in equation (12), $tan(E){\hat{r} \cdot cos(T) - \hat{p} \cdot sin(T)}$, is oriented at a right angle to the traverse drive axis. This is the component of hull motion which requires torque to accelerate J_{T} inertially. It is extremely important that these torque requirements in terms of hull motion be clearly understood. For if they are not, one could end up designing a control system that would have the

C

10

and the state of the second second of the second

(12)





C

ſ

Equivalent Base Motion Vectors

function of moving the hull with respect to the sight-line vector. Let us now proceed to the considerations of the actual control system. المحاطا الكركيني والعاصر

CHAPTER 3

SYSTEM CONCEPTS

The traverse axis only will be considered from here on. This can be done because the two axes are operated independently. All the assumptions and conclusions that follow can be easily extended to the elevation axis.

Focause of space limitation and the extremely large traverse inertia, the size of the motor that can be used to drive the traverse inertia is very small, in a maximum torque output sense, in comparison to the size of the traverse inertia. This causes the system to be sluggish when compared to the high speed servo mechanisms that are familiar to control engineers. This inherent sluggishness is the biggest obstacle that must be overcome.

C

The Quarter

ž

There are two basic approaches to sight-line stabilization. One method is the familiar matching of an output to a command input. The other method matches the output of an auxilliary high speed sight servo to the command input, and then uses the output of the sight servo as the input to the sight-line stabilization system. The reason for this will be explained later.

The familiar matching of input to output is known as the disturbed method. In this method the traverse component of the sightline is fixed to the traverse inertia, J_{T} (see fig. 5).







ſ

The main control system consists of the traverse load inertia, the traverse drive motor, the other related components and the necessary dynamic relationships. Because the main control system is inherently sluggish there is a tendency for the operator to apply manual correction to help speed up the system. This can have a very negative effect on the overall performance of the system.

The second method of sight-line stabilization is the directedline method. In this method the sight-line is fixed to an auxiliary sight inertia which is very small when compared to J_T . Because the sight inertia is small it can be driven at relatively high speeds. The command input is applied to this high speed sight servo and matched to its output. The output of the sight servo is then used as the input to the main control system, and the output of the main 13

·

÷,

control system is matched to the output of the sight servo (see fig. 6).

Figure 6





C

24 12 A A

1

1.1

This has the effect of matching the command input to the main control system utput, but it does so in two stages. Because the command input is matched to the output of a relatively high speed system, the tendency to apply manual correction is eliminated.

There is no conclusive evidence as to which of the two previously discussed methods is more effective, although the bulk of the work that has been done is on the directed method. The attention here will be focused on the disturbed method because it is the simpler of the two methods, and yet it still includes all the basic considerations of the dynamics necessary for a sight-line

1991 1. MAG 1

كلانك تعأطه للحلفط وال

いいで、このである、この、このではないであるのであるのであるのである。 こうごう ちゅうしょう あん ある ある ある ないない うち

12.2

אנו אינטענין אינטענעראין אינטערער אינערטער אינעריפאראיראייאינעראיאייגעער אייראייריי אין אין איין אין איין איי

1

stabilization system. The simplicity also cuts down on the computation time that is required for the numerical optimization which will be used later on.

٠.

C

うちろう シート・ファイト ちゃうちゃう ちんちょうちょうかい かっかい かいかいかい いってい アイト たいかいかい しょうない かいしょう たいかい かいしょう ちょうかい ちょうかい

C

CHAPTER 4

DESIGN

For a system that is to be optimized, the system need not be designed to meet certain performance specifications (i.e. rise time, overshoot, settling time, bandwidth) as is the usual case. This is possible because when the system is optimized all the parameters will be adjusted to satisfy the given performance index. This performance index may include the classic time response characteristics or may be completely void of ther. Whatever the case, the time response will be shaped during the optimization along with the frequency response. The objective will therefore be to design a system that is a reasonable starting point for the optimization routine. A reasonable system for a starting point can defined as a system that does not have anything critically wrong with it, such as being unstable. The root locus method of synthesis lends itself very well to the design of a system with such loose specifications, and is therefore what will be used. It causes very little difficulty to keep an approximate range for a bandwidth in mind when using the root locus technique. The objective will be to design the system for the optimization starting point to have a bandwidth of approximately 300 radiana per second. This value was obtained as a typical one from the literature, however it is by no means a value that should be used for all stabilization systems.

C

1

£

us should we should be the the state of the second s

5

a and the second states of the second states of the second s

A hydraulic motor is used to drive the traverse inertia because rore torque can be obtained from a hydraulic motor than can be obtained from an electric motor of the same physical size A partial block diagram of a typical constant displacement piston t_{ff} by draulic motor and its control value is shown in fig 7. A list of the variables and a set of numerical values (where applicable) is given in table 1.

Figure 7



.

and an and the second second

いたいがいかいたい かめいい かんしゅうかん かわか かわい どうない かえいぼう スプレンテム・ハイ・ション・ション・ション・ション・シーム かんしゅうそうしょう

11.

ž,



and the second second second second second second second second second second second second second second second

-

- -

A. Belli

1.00

Table 1

List of Motor Variables

KP - servo valve gain 15,000 psi/ma K₆ - pressure feedback gain .002 ma/psi GV - serve value transfer function $1/\{s^2/1200^2 + 1.4 \cdot s/1200 \div 1\}$ G_6 - pressure feedback compensation $s/\{(s/20 + 1) \cdot (s/.5 + 1)\}$ $0.016 \text{ in}^3/\text{rad}$ DM - motor displacement CP - valve orfice damping coefficient 6,200 lb/sec/in⁵ β - bulk modulus of fluid 300,000 psi V_{p} - effective volume of fluid under compression 1 in³ θ_{ma} - actual motor angle in radians $\tau_{\rm m}$ - motor torque in in-lbs P_L - pressure applied to metor in psi C_2 - compressibility flow in in³/sec Q_D - displacement flow through motor in i.3/sec Q_L - total load flow through metering orfice in in³/sec i - input current to servo value in ma V_c - motor and value configuration input current in ma

€

an in a stard of the start of the start of the start with the start of

CP is actually a nonlinear term which depends on the flow rate, Q_L . The value given for CP is for the small signal region. The value input current will saturate at some value, typically 10 ms. The maximum supply pressure also has a limiting value with 3,000 psi being representative for the type of system being considered. The pressure saturation will be the limiting factor in the performance of the system. The maximum pressure of 3,000 psi and the motor displacement of .016 in³/rad combine to prowide a maximum torque or 48 in-1b (=3,000 psi x .016 in³) which will be very small for the size of load inertia being dealt with. A detailed development of a block diagram similar to fig. 7 can be found in reference {8}.

T

(

ſ

To complete the block diagram of fig. 7 it must be determined in what menner the torque, r_m , drives the load. Consider the expanded partial view of fig. 3b in fig. 3. The definitions of the variables shown in fig. ξ are given in table 2. ، مەر، مەر بەرىغى ئەرەلارغىغىغىر تارىغەر بىغىر ، مەر، ، مەر مەر، مەر بەرەلىغىنى ئەر ئەرەلىغى بەرەلىغى مەر، مەر



3

20

er den karren au Kontesten un siste

ر ما داد بلاس الم الم ما المانية .

ž

ł -

marchine

-

·* +;

1. いたんのかい さんなん ないないない ひょうろうかん いっている たいちょう からんにかめ おかんごろう テレー

I

Ē

Table 2

Definitions of Drive Variables

- previously defined base yaw angle 4 - radius of J_T ring gear R - radius of M_T pinion geer r" - inertial sight-line traverse angle φ θ_m ' - motor angle needed to compensate for q () m - component of motor angle that is required to inertially drive sight-line through angle $(\phi-q)$ 0 - original pinion center 0^{t} - pinion center position due to q input 0" - final inertial pinion center

C

A second s

*

าส เกรียนเสียงสมุทรร และกร ระชาตรรรษรรัฐสมุลเลสู

the set of the set of

When the base undergoes a yaw angle of q the moior must accelerate the motor and gear inertias through an angle of θ_m ', and overcome friction to keep \bar{e}_g oriented along the x axis as is required for sight-line stabilization. Geometrically this means that points A and A' must remain coincident. The two variables, q and θ_m ', are related by equation (13).

$$\mathcal{R} \cdot q = r^{\mathbf{r}} \cdot \theta_{\mathbf{m}}^{\mathbf{r}} \tag{13}$$

When it is required to move the sight-line from its initial orientation, \bar{e}_s , to another one, \bar{e}_s ', the motor must accelerate

 J_T as well as the motor and gear inertias. J_T must traverse an angle ϕ while the pinion turns through an angle θ_m , ϕ and θ_m are related by equation (14). For this case points A and B coincide.

$$\mathbf{r}^{\mathbf{t}} \boldsymbol{\theta}_{\mathbf{r}} = (\mathbf{R} - \mathbf{r}^{\mathbf{t}}) \boldsymbol{\cdot} \boldsymbol{\phi} \tag{14}$$

When both q and ϕ occur simultane-susly J_T need only be driven inertially through an angle that is the difference between ϕ and q. Roll without ellip conditions require that the arc length from point C to point D be the same as the arc length from point E to point B', where B and B' are coincident initially. This relationship can be expressed by equation (15).

$$\mathbf{R}^*(\mathbf{\phi} - \mathbf{q}) = \mathbf{r}^*(\mathbf{\phi} + \mathbf{\theta}_m) \tag{15}$$

Equation (15) can be rewritten in the form of equation (16).

€

CALLA SAL

ようちょう 書

the second rates

ŝ

C

$$\mathbf{r}^{\mathbf{t}}\boldsymbol{\theta}_{\mathbf{n}} = (\mathbf{R} - \mathbf{r}^{\mathbf{t}}) \cdot \boldsymbol{\phi} - \mathbf{R} \cdot \mathbf{q}$$
(16)

It is worth noting that equation (16) becomes equation (14) when there is no q input. The gear ratio, N, is defined by equation (17).

$$\mathbf{x} = \mathbf{R}/\mathbf{r}^{*} \tag{17}$$

Using this relationship equation (16) can be rewritten as:

22

Beneric Dudienter all

1.1.

بالايك مماقا المحظراتك البرأطيع يتوالحا تالعهما

$$\theta_{\rm m} = (N-1) \cdot \dot{\phi} - N \cdot q = N \cdot \{ (N-1) \cdot \phi / N - q \}$$
(18)

23

Associated with the motor shaft is a compliance, KL. If friction is neglected, the motor torque serves to accelerate the motor and gear inertia, J_m , and twist the shaft. The angle of twist is the difference between the actual motor shaft angle, θ_{ma} , and the angle that is predicted by equation (18). The motor torque is given by the following expression.

$$\tau_{\rm m} = J_{\rm m} \cdot s^2 \cdot \theta_{\rm ma} + KL \cdot \{\theta_{\rm ma} - N \cdot (\{N-1\} \cdot \phi/N - q)\}$$
(19)

By using the relationship in equation (19) and the block diagram in fig. 7, the block diagram of fig. 9 can be obtained. Typical values of the quantities introduced in fig. 9 are given in table 3 below.

Ę

and the second second

and a subsection of a description

€

Table 3

Load Variables

KL - motor shaft compliance	600 in-1b/rad
J - motor and gear inertia	0.00158 in-1b-sec ²
J _T - traverse load inertia	1.44(10 ⁴) in-lb-sec ²
N – gear ratio	1000
AR - motor shaft twist apole	

The compressibility flow, Q_C, is very small in comparison to the displacement flow through the motor, and can for all practical purposes be neglected.

Assuming q equal to zero, the transfer function from V_{C} to ϕ can be readily found following a series of block diagram manipulations (see fig. 10), and is given by equation (20).

Figure 9

Motor and Load

C








C

re of recursions

۲ **۳**۳ مار

taldered Minetanes 1

لى المحمد بالمحافظة والمحافة المارية المراجع المراجع

ř.

Q

C



$$\frac{\Phi}{V_{c}} = \frac{KP \cdot GV \cdot DM \cdot KI \cdot N \cdot KL}{\left(1 + KP \cdot GV \cdot K_{6} \cdot G_{6}\right) \cdot (J_{T} \cdot s^{2} + N \cdot \{N-1\} \cdot KL - KL^{2} \cdot N \cdot \{N-1\} \cdot KI) + DM^{2} \cdot KI \cdot CP \cdot s \cdot (J_{T} \cdot s^{2} + N \cdot \{N-1\} \cdot KL)}$$
(20)

where:

. U-1-1-1

. . . .

an addition in the second second second second by the second in the second second second second second second s

€

$$KI = \frac{1/KL}{J_{\rm IL} \cdot s^2/KL + 1}.$$
 (21)

By substituting the appropriate numerical values which were given previously, the transfer function of equation (22) is obtained.

$$\frac{1}{2} = \frac{9.12 \cdot (10^{12}) \cdot (s+20) \cdot (s+.5)}{\left(s \cdot (s+.54) \cdot (s+4.37) \cdot (s+1284.58) \cdot (s^2+2\{.21\}370s+370^2\} \cdot (s^2+2\cdot\{.52\} \cdot 1200 \cdot s+1200^2)\right)}$$
(22)

The last term in the denominator of equation (22) will have a flat frequency response cut to approximately 1200 rad/sec , and its time response is very fast when compared to the other terms. For all pratical purposes it can be normalized and set equal to unity since it will have little effect on either the frequency response or the time response. Dividing the numerator and denominator of equation (22) by 1200^2 and assuming that the dynamic effects of $(s^2/1200^2 + 2\cdot\{.52\}\cdot s/1200 + 1)$ are negligible, equation (22) can be simplified to equation (23).

$$\frac{\phi}{v_{c}} = \frac{\vdots .34 \cdot (10^{6}) \cdot (s+20) \cdot (s+.5)}{s \cdot (s+.54) \cdot (s+4.37) \cdot (s+1284.58) \cdot (s^{2}+2\{.21\}370s+370^{2})}$$
(23)

Consider the transfer function of the servo valve.

$$GV = \frac{1}{s^2/1200^2 + 2 \cdot (.7) \cdot s/1200 + 1}$$
(24)

This resembles very closely the term that has just been neglected. If GV is set equal to unity when substituting the numerical values into equation (20), the following revised transfer function for ϕ/V_c is obtained.

$$\frac{\phi}{V_{a}} = \frac{6.34 \cdot (10^{6}) \cdot (s+2^{6}) \cdot (s+.5)}{s \cdot (s+.55) \cdot (s+4.37) \cdot (s+1060.5) \cdot (s^{2}+2\{.31\}406s+406^{2})}$$
(25)

This is in very good agreement with equation (23), and therefore GV will be assumed to be unity. There is no way to readily eliminate the term 1/(s + 1060.5) in equation (25) by a block diagram alteration. It must therefore be tolerated.

(

a star it with a start of a

i ha i

£

Since ϕ is defined to be the inertial component of traverse motion it should be zero for a yaw, q, input which is the noninertial component of traverse motion. This is the same as requiring that $\Delta \theta$ be zero for a q input (see fig. 9). Assuming that ϕ does equal zero, and setting V_c equal to zero yields the simplified block diagram in fig. 11 for q inputs only. The validity of assuming that ϕ and V_c equal zero will be seen later on. G_q and ž

ويتوجع فيقالما ولام الألفان المواد والمتلفان والمسافلا والمعالم والمعالي والمحافظ

q_c will be determined.

Figure 11

Reduced Block Diagram for q Input Only



The requirement that $\Delta \theta$ equal zero implies that:

$$\vartheta_{\mathbf{m},\mathbf{a}} = -\mathbf{N}^*\mathbf{q} \tag{26}$$

Assuming that $q_c = 0$ the transfer function from - KL-N q to θ_{ma} is given by (27).

$$\frac{\theta_{ma}}{-KL\cdot N\cdot q} = \frac{1/KL\cdot (1 + KP\cdot K_{6}\cdot G_{6})}{(J_{m}\cdot s^{2}/KL + 1)\cdot (1 + KP\cdot K_{6}\cdot C_{6}) + CP\cdot DM^{2}\cdot s/KL}$$
(27)

「おうちょう」で、ころのないで、ころ、ころ、ころ、 ちょうちゅうほう

and the second second second second second second second second second second second second second second second

C

an addition of the and the and the second state of the second states and

Equation (27) can be rewritten as equation: (28).

K

(

C-

÷.

$$\frac{\theta_{\text{ma}}}{-N \cdot q} = T_1 = \frac{(1 + KP \cdot K_6 \cdot G_6)}{(J_m \cdot s^2/KL + 1) \cdot (1 + KP \cdot K_6 \cdot G_6) + CP \cdot DM^2 \cdot s/KL}$$
(28)

Assuming that -KL·N·q is zero, the transfer function from $q_c \cdot G_q$ to θ_{ma} is given by (29).

$$\frac{{}^{\mathrm{g}}\mathrm{ma}}{\mathrm{q}_{\mathrm{c}} \cdot \mathrm{G}_{\mathrm{q}}} = \mathrm{T}_{2} = \frac{\mathrm{KP} \cdot \mathrm{DM}/\mathrm{KL}}{(\mathrm{J}_{\mathrm{m}} \cdot \mathrm{s}^{2}/\mathrm{KL} + 1) \cdot (1 + \mathrm{KP} \cdot \mathrm{K}_{\mathrm{6}} \cdot \mathrm{G}_{\mathrm{6}}) + \mathrm{CP} \cdot \mathrm{DM}^{2} \cdot \mathrm{s}/\mathrm{KL}}$$
(29)

By letting $q_c = -N \cdot q$, it is seen that for θ_{RA} to be equal to $-N \cdot q$ ail that need be required is that:

$$T_1 + T_2 \cdot G_q = 1$$
 (30)

Substituting equations (28) and (29) into (30) yields the expression for G_q .

$$G_{q} = \frac{-J_{m} \cdot s^{2} \cdot (1 + KP \cdot K_{6} \cdot G_{6}) - CP \cdot DM^{2} \cdot s}{KP \cdot DM}$$
(31)

Substituting the appropriate numerical values into (31) yields equation (32).

nner versetas se estad nee setadore intereste sur terrar en entre en entre setadore se en entre estadore estad Anneres e entre alterna traducer da anner e de terrar productiva entre traducer en terrar entre estadore en en

$$G_{q} = \frac{-60 \cdot s^{2} \cdot (s/.031 + 1) \cdot (s/320.5 + 1)}{(s/20 + 1) \cdot (s/.5 + 1)}$$
(32)

Thus if an input, - N·q, is applied through a transfer function, G₂, and the output is applied to the stabilization system as shown in fig. 11: there will be no motion of ϕ for a yaw input.

The design of the hardware to provide a transfer function for \mathbb{C}_q is a difficult if not impossible task. The best that can be hoped for is a good approximation, but it is not the purpose of this writing to design hardware. The purpose is to show the necessary mathematical relationships for sight-line stabilization.

Yaw inputs have a negligible effect on the performance of a sight-line stabilization system when compared to the inertial inputs. Therefore further efforts will be concentrated on the inertial inputs only.

(

1.00

and the second second second second second second second second second second second second second second second

「「「「「「「「「」」」」」」」

4

Consider again fig. 9 with the two q inputs and the compressibility term removed, and GV set equal to unity. It is repeated below as fig. 12 for convenience. The transfer function for fig. 12 was given by equation (25) which is also repeated below as equation (33).

$$\frac{\phi}{V_{c}} = \frac{6.34 \cdot (10^{5}) \cdot (s + 20) \cdot (s + .5)}{s(s + .55)(s + 4.37)(s + 1060.5)(s^{2} + 2\{.31\}406 \cdot s + 406^{2})} (33)$$

at here some some some som at some som at some for the source of the sou



Mctor and Load for Inertial Inputs Only



Velocity feedback will be seen to enhance the performance and stability of the system for reasons that will become obvious later. By placing a velocity loop around ϕ/V_c and adding series compensation, the block diagram of fig. 13 is obtained. Since ϕ is an inertial angle its time derivative must be measured by a rate gyroscope. The general form for the transfer function of a rate gyro is given by equation (34).

$$T_{RG} = \frac{K \cdot s}{s^2 / \omega^2 + 2\zeta s / \omega + 1}$$
 (34)

ŝ

AUNTROLOGIC STATES STATES

1947 - 1949.

.

.

,

100 H M

÷

.

:

als also see the second and the second second second second sectors about the second second second second secon







There are a number of rate gyros available that have a natural frequency much larger than 300 rad/sec. For a rate gyro of this type, the output will be approximately proportional to the rate only.

Similarly for a position gyro with the same restrictions on natural frequency, its transfer function can be approximated by a simple gain.

$$T_{PG} = \frac{K}{s^2/\omega^2 + 2\zeta s/\omega + 1} = K ma/rad$$
(36)

It must now be determined what KV and G_{VC} should be. A pole zero plot for equation (33) is given in fig. 14. The scale has been exyanded in the region mean the origin in order that the smaller terms

€

والإلا فالأرار المعالم المالة والمحال معالم والمالي والمالي والمالي

1 m. 19 mail 1

£

can be shown.

C

. 46. 5 . 1.

Ť

1 . 21. 2 . 10 . 14. 14

Figure 14





Somewhat arbitrarily it will be assumed that KV is unity. It should be remembered that this is only a starting value for optimization. It is easy to see from fig. 14 that the five poles and zeroes near the origin will dominate the time response. When plotting the root locus for fig. 13 the velocity feedback will cancel out the pole at the origin, and the pole at 0.55 can be assumed to cancel with the zero at 0.5. It is reasonable to assume that G_{VC} contain a term (s + 4.37)/(s + 20) for cancellation. If this and a gain were all that were included in G_{VC} , then the root locus would tend 山子 财计性性支援

14.44.

ALC VALUE

ş

to the right half plane, and there would be little room for the bandwidth of the system to be increased without lowering the damping ratio of the complex pole pair. By introducing two lead networks of the form (s + 150)/(s + 2000) the root locus will take the form of fig. 15.

(

C

ĩ

Ę







For a compensator gain, VK, of 800, ϕ/V_v will be given by equation (37).

$$\frac{\phi}{\nabla} = \frac{5.2 \cdot (10^9) \cdot (s + 150)^2}{\left(s \cdot (s + 3453) \cdot (s + 181 + j \cdot 238) \cdot (s + 181 - j \cdot 238) \cdot (s + 749 + j \cdot 1439) \cdot (s + 749 - j \cdot 1439)}$$
(37)

. ;;

35

Therefore it is reasonable to let:

$$G_{VC} = 800 \cdot \frac{(s + 4.37) \cdot (s + 150)^2}{(s + 20) \cdot (s + 2000)^2}$$
(38)

A: a starting value.

The next step is to determine the series compensation for the $po + i \circ n l cop$ (see fig. 16).

Figure 16

Position Loop



(

. . . .

.

•

7

£

A pole zero plot of equation (37) is given in fig. 17.

1

i.

સંદર્ભકાર કાર્યો પ્રત્યો પ્રત્યો હતા હતા છે.

.

 $\mathcal{A} \in \mathcal{A}$



Pole Zero Flot of ¢/V_v



The first thing to note is that the two zeros at 150 are too small if the frequency response is to be flat out to approximately 300 rad/sec. Also a closed loop pole will fall someplace between 0 and 150. Therefore the two zeroes must be increased in magnitude to help draw the root locus to the left. After some trial and error, 700 was chosen to be a suitable value for the zeroes. Thus G_{PC} will contain two lag networks of the form (s \pm 700)/(s \pm 150). If these two lag networks and a gain, PK, were all that were contained in G_{PC} , the root locus of fig. 16 would tend to the right half plane from the smaller complex pole pair, and there would be little room for the damping ratio to decrease during optimization, if desired. This can be averted by introducing a lead network such as ($\epsilon \pm$ 700)/ (s \pm 3J00) into G_{PC} . A root locus for the position loop with the previously discussed compensation is given in fig. 18. For a position compensator gain, PK, of 1200, ϕ/R will be given by equation (39).

€_

2011 AL 1V

C

$$\frac{e}{R} = \frac{6.23 \cdot (10^{12}) \cdot (s + 700)^3}{\begin{cases} (s + 297) \cdot (s + 145 + j \cdot 540) \cdot (s + 145 - j \cdot 540) \cdot \\ (s + 3303 + j \cdot 584) \cdot (s + 3303 - j \cdot 584) \cdot \\ (s + 559 + j \cdot 1314) \cdot (s + 559 - j \cdot 1314) \end{cases}$$
(39)

Therefore it can be assumed that a reasonable starting value of G_{pC} is given by equation (40).

$$G_{PC} = \frac{(s \div 700)^3}{(s \div 150)^2 \cdot (s \div 3000)}$$
 (46)

37

HALL A STATE

Figure 18

38

and a contraction. Name of a contract a contract



Root Locus of Position Loop

1

C

hartonation arrenter algebra its are retricted to the structure the second

÷.

Surger - Street

The transfer function ϕ/R satisfies the 300 rad/sec bandwidth requirement, and the smallest damping ratio present is the 0.26 associated with the complex pair (s + 145 + j.540).(s + 145 - j. 540). Although a damping ratio of 0.26 gives approximately 45% overshoot the system will have nowhere near this amount of overshoot due to the pressure saturation previously discussed, nor will the system be anywhere near as fast as the denominator of equation (39) might indicate. The whole sight-line stabilization system is shown in fig. 19. It includes inertial inputs, R, as well as the noninertial input q. This is not the final system, but only a starting point for the optimization.

It can be seen that for a q input only, R will be equal to zero. ϕ depends only on what is between it and the input to the system, in this case the only input is q. Since G_q was designed to cause ϕ to be zero for q inputs, there will be no position feedback from ϕ . Therefore V_c will equal zero, and it is seen that the assumptions made earlier in regard to V_c and q, when designing G_q, were valid.

(

the second states

Although a strict linear analysis was used throughout this chapter, and there was no non-linear check on the stability of the system due to the pressure saturation; it is belived that there will be no problem with stability. This is because of the limiting value on the torque of the system.

and face as the second program is a second as the second

\$

ž

.

t

Ŀ

Figure 19

-





.

40

;

;

....

· · ·

.

.

÷

ţ

ì

CHAPTER 5

SIMPLIFIED VERSION

Numerical computation time can be a prohibitive factor when optimizing a system, as is the case for the system of chapter 4. It is the objective of this chapter to develop a simplified model that will reduce the amount of computation time required for optimization.

An examination of fig. 19 reveals an undamped second order term in the expression for the motor load. This expression is siven below.

$$\frac{1/\text{KL}}{J_{\text{L}} \cdot \text{s}^2/\text{KL} + 1}$$
(41)

Multiplying the numerator and denominator of this expression by KL/J_m , and substituting the numerical values given yields (42).

C

1.05.0

•

÷.

$$\frac{632.9}{s^2 + 616.2^2}$$
(42)

The numerical optimization routine that will be used later requires that the differential equations of the system be integrated repeatedly. When numerically integrating an expression with a natural frequency as high as the one in (42) a large amount of compute time is required because the integration interval has to be "the reduct of the work should a first should be shown that a first and the

10001 411

adar to state of the second second second second second second second second second second second second second

ł,

40.1

en glytti i sig pådastad i rengenes abb må da i lated er de te

للأشينية تبدر سيتناقب الاصراري

42

made very small in order to achieve reasonable accuracy. For all practical purposes the term $J_m \cdot s^2/KL$ can be assumed to be negligible, and expression (41) can be approximated by 1/KL. This alleviates the need to integrate expression (41), however there are other expressions that also must be dealt with in order to reduce computation time for the whole system.

Again referring to fig. 19 if the loop containing the terms N, N-1 and N-KL/ $(J_T \cdot s^2)$ is collapsed, the following expression can be readily obtained:

$$\frac{N \cdot KL/J_{T}}{s^{2} + N \cdot (N-1) \cdot KL/J_{T}}$$
(43)

By substituting the appropriate numerical values into (43), expression (44) is obtained.

$$\frac{41.66}{s^2 + 209^2}$$
(44)

This term also requires a very small integration interval in order to achieve reasonable accuracy.

Expression (43) arises out of the dynamical considerations for motor shaft compliance. If it is assumed that the motor shaft is rigid, then it is easy to see that:

(45)

$$=\frac{\theta_{m}}{N-1}$$

C

Service Strengt

Weather & I take market

Neglecting friction, the motor morque serves to accelerate the motor and gear inertia through the angle θ_{n} , and the traverse inertia (divided by the gear ratio) through an angle ϕ . This relation is expressed in equation (46).

$$\tau_{\rm m} = J_{\rm m} \cdot s^2 \cdot \theta_{\rm m} + J_{\rm T} \cdot s^2 \cdot \phi/N \tag{46}$$

If equation (45) is substituted into equation (46), and N-1 is assumed to be approximated by N, equation (47) is obtained.

C

and a second a second and a second se

いろうみ うちがい

Ś

$$I_{\underline{m}} = (J_{\underline{m}} \in J_{\underline{T}}/N^2) \cdot s^2 \cdot \theta_{\underline{m}}$$
(47)

Combining equation (47) with the block diagram in fig. 7 and neglecting compressibility flow and GV as was done earlier, the block diagram in fig. 20 is obtained where:

$$J_{I} = J_{T} / N + J_{m} \cdot N$$
(48)

By using the block diagram in fig. 20 and substituting in the proper numerical values, the expression for ϕ/V_c is obtained.

$$\frac{\phi}{V_{a}} = \frac{15.02 \cdot (s + 20) \cdot (s + .5)}{s(s + .53) \cdot (s + 4.38) \cdot (s + 414.90)}$$
(49)

Figure 20

Simplified Version of Motor Load Relation



Following the same procedure as was used for the development of the model in chapter 4, the next step is to add velocity feedback. This is represented in fig. 21.

:

A. 11.

-

Ż

In Marty.

in a complete station of the second state of t

C

Figure 21

Velocicy Feedback



44

يد المالية المراجع المالية المراجع المراية في المالية في المالية المراجع المالية المراجع المالية المراجع

and and set of a build of a build of the set

NV: ..

Service States

Let K_v be unity, and let G_v be used for the cancellation of the smaller terms in equation (49). G_v is then expressed as (50).

$$G_{v} = \frac{VK \cdot (8 + .55) \cdot (8 + 4.38)}{(5 + .5) \cdot (5 + 20)}$$
(50)

VR is a variable gain to be determined. The pole at .55 and the zero at .5 were assumed not to cancel because the pole at .55 was found to be somewhat sensitive to changes in the other parameters when some preliminary programs of the system were run. By using equation (50) the transfer function for $\phi/V_{\rm p}$ is found to be:

€

£

$$\frac{\Phi}{V_{v}} = \frac{VK \cdot 15.02}{s(s + 414.90 + VK \cdot 15.02)}$$
(51)

Consider $\phi/V_{\rm w}$ with position feedback as is shown in fig. 22.

Figure 22

Position Feedback



Let C_v be simply a gain, PK. Then the transfer function for fig.22 is given by equation (52).

Ŧ

È

the can wain

and a second second and water and a share of the second second second second second second second second second

È

$$\frac{\phi}{R} = \frac{PK \cdot VK \cdot 15.02}{s^2 + (414.90 + VK \cdot 15.02) \cdot s + PK \cdot VF \cdot 15.02}$$
(52)

The expression 414.9 + VK-15.02 will correspond to the $2\zeta\omega$ term of a quadratic. Remembering that a bandwidth of approximately 300 is desired, ω can be chosen so as to satisfy this requirement. Let ω be 315, also let ζ be unity for an initial value. By substituting these values in equation (52), VK is found to be 14.32 and PK is found to be 461.29.

Fig 23 is then the final simplified configuration for a system to be used as a starting point for optimization. This system is for inertial inputs only, i.e. K is the inertial component only. The yaw inputs, q, were ignored altogether because in this simplified version they are trivial.

કરી, સંવિધાયા કોસ્ટ્રોસ્ટ્રેસ્ટ્રેસ્ટ્રિસ્ટ્રિસ્ટ્રિસ્ટ્રિસ્ટ્રિસ્ટ્રિસ્ટ્રિસ્ટ્રિસ્ટ્રિસ્ટ્રિસ્ટ્રિસ્ટ્રિસ્ટ્ર

Figure 23

-

it to an are stad on the

and the family of the state of the state of the second state of the st

; ,

1111

C

Ċ

Final Simplified Version of Figure 19



47

8

The set of the state

•

÷

A reasonable question to ask is: How good is the approximation of the detailed model that is given by the simplified hodel in chapter 5? The answer to this question can be found by running the model of chapter 4 with 3 very large number inserted for KL. This approximates the case of a rigid motor shaft. However if equation (43) is considered it can be seen that as KL is increased so is the natural frequency of the undamped second order term, and this causes the computation time for the solution of the system equations to go up. An attempt was made to run the system with a very large value for KL(10^8), but the amount of computation time required for this was prohibitive. However, the simplified system is thought to give a good approximation to the detailed version because the transient response of the simplified system (see appendix A and Fig. 26) is on the order of the transient responses erocuntered in the literature.

(

T

CHAPTER 6

OPTIMIZATION

The term optimization is an abstract one to say the least. There are many different definitions of optimization. Basically to optimize a system means to minimize a performance index (cost index) while the system goes from one state to another. This performance index is a function of the parameters of the system. The system parameters include all the physical variables of the system (gains, compensator values, inertias, etc.); and, in the strictest sense, the input. The input will not be assumed to be a parameter here. This corresponds to an input over which there is no control, a case that is not uncommon in the control system area.

ĺ

There are many forms for the performance index. Integral forms are a very popular type. Among the integral forms is the integral squared error (ISE). If a system goes from one state at time t_1 to another state at time t_2 , then the ISE is given by equation (53), where R is the input to the system and C is the output of the system.

ISE =
$$\int_{t_1}^{t_2} (R-C)^2 dt$$
 (53)

With the use of Parceval's theorem $\{7\}$ and tables $\{7\}$, the ISE can be computed with some ease when $c_1 = 0$ and $t_2 = \infty$. This is not to 49

يرتبعهم المحمدين ومعاد والمناكم والمحافظ ووودا المحادث المحاد والمعالمين والمعالم والمعالي

ANALY AND NORTHER OF A

÷,

.

view of the table advector

which a

say that a minimum ISE is easily obtained analytically.

Numerical optimization routines have gained in popularity because of the difficulty in applying analytical techniques in optimization. The key to a numerical technique is the method used to vary the system parameters in the search for the optimum solution. There are two classes of search techniques: indirect search and direct search. All indirect search methods employ the use of the gradient of the performance surface in one manner or another. Highly oscillatory or even discontinous performance surfaces are very common in the control system area. This highly oscillatory nature can cause a gradient to be calculated incorrectly, thus affecting the optimization. For this reason direct search methods are more suited to optimal control problems.

There are many fine direct search techniques. Among them are the methods of Hook and Jeeves {4} and the method of Rosenbrock {9}. Lange-Nielsen {6} has modified Rosenbrock's method and used it to develop an optimization program. A detailed description of Rosenbrock's method and Lange-Nielsen's modifications can be found in reference [6]. A step by step implementation of Lange-Nielsen's program can also be found in reference [6].

ŧ

Ę

Lange-Nielsen's program will be used to optimize the sight-line stabilization system of chapter 5 using ISE as the performance index. In Lange-Nielsen's program the system parameters are perturbed using the modified version of Roscnbrock's method, and after each pertubation the system differential equations are solved using CSMP {5}. 50

and an historic mighting

117 Mar.

marcina).

The performance index is calculated, and the procedure is repeated until convergence is essured. The reader is referred to reference [10] for a verification of the accuracy of Lange-Nielsen's program.

ŧ.

Before the actual optimization can take place, the parameters that are to be varied must be decided upon. The procedure that will be used here will be one of elimination of inappropriate parameters.

Consider figure 23. Let the zeroes of the compensator be known as ZL1 and ZL2, and let the poles be known as PL1 and PL2. Also let the poles of G_6 be called Pl and P2. All the system parameters can now be listed in table 4.

Table 4

List of System Parameters

PK	PL2	DM
VK	KP	CP
21.1	K6	N
ZI.2	P1	J _T
PL1	P2	J

It is intuitively obvious that J_m and J_T will tend to their lower limits, and DM will tend to its upper limit. If the expression for J_L is considered, it can be seen that N will tend to a very large number in order to minimize J_L . It can therefore be assumed that the behavior of these four parameters during optimization is known, and that the values given have already been extended to their How we have the second of the second

a side and the state of the second state of the second second second second second second second second second

limits. CP is a small signal value for a nonlinear term, and therefore to use it as a parameter would have little meaning. Pl and P2 are part of the pressure feedback transfer function, G_6 . It is not always possible to order hardware that has the exact physical characteristics that are wanted. This may be the case with Pl and P2, therefore they will also be deleted as parameters. PL1 and PL2 are see to cancel Pl and P2 directly, and since Pl and P2 are deleted as parameters, PL1 and PL2 will also be deleted. KP and Kg are part of the servo valve pressure feedback configuration. But since they are gains it will be assumed that they can be altered without much trouble. Some preliminary runs of the program have shown that KV remains approximately equal to unity. KV will therefore be left fixed at one. There are no foreseen reasons for not using the remaining variables, therefore the variables to be used in the optimization are KP, PK, VK, K₆, ZLl and ZL2. In order that the compensator be fut in proper form for CSMP, VK must be modified as follows:

€

$$VK = 14.32 \cdot PL1 \cdot PL2/ZL1/ZL2$$
 (54)

The parameters are listed below in table 5 along with their starting numerical values for convenience.

Everything is now ready for the actual optimization, which is done with the use of the optimization program developed by T. Lange-Nielsen [10]as previously mentioned. The optimal parameters 52

and the state of the second second second

contraction of the second

53

are listed below in table 6 for several magnitudes of step inputs along with the percent overshoot of the system and the optimal value of ISE. The step magnitudes are representative of those encountered in pratice. The changes in percent overshoot are due to the non-linearity. A sensitivity check of the system with the 0.1 step is given in table 7.

Tiple 5

Initial Values of Farameters Used in Optimization

KP =	15000 psi/na	к ₆	*	0.002 ma/psi
PK =	461.29	ZL1	n	0.55
VK =	3.43	ZL2	54	4.36

C

Table 6

Optimal Parameters

Step Magnitude	0.05	0.10	0.15	0.20
KP	29231.1	22468.1	13355.1	29170.8
K ₆	.0018154	.0025239	.0006002	.0033426
PK	540.687	463.931	435.085	400.212
VK	3.60303	4.14173	2.93995	2.97975
ZL1	.548911	.512743	.497890	.547466
ZL2	9.05973	6.06801	5,74567	4.39803
P.O.	28.2	5.87	5,63	
ISE	2.4763E-4	1.3941E-3	3.8416E-3	8.01J.5E-3

Parameter	7 Perturbation	ISE	P.0.
	+10	1 3945E-3	7.41
	-10	1.39412-3	5.59
	+20	1.3945E-3	7.48
	-20	1.3945E-3	4.22
	+10	1.3941R-3	5.59
P	-10	1.3945E-3	7.48
` 6	÷20	1.3946E-3	4.05
•	-20	1.3945E-3	7.48
<u></u>	+10	1.3945E-3	7.48
Þv	-10	1.3948E-3	3.73
PK -	+20	1.3945 E-3	7.48
	20	1.3948E-3	3.73
VK -	+10	1.3945E-3	7.48
	-10	1.3945 <u>E</u> -3	4.14
	+20 ,	1.3 ⁻ 45E-3	7.48
	-20	1.3948E-3	3.73
ZL1 -	+10	1.4043E~3	13.24
	-10	1.4041E-3	
	+20	1.4285E-3	19.15
	~20	1.4314E-3	

Sensitivity Check

C

ş

1

٠.

Ē

the company is to be a new a list areas with the

اجر

:

÷

1

. '

Table 7

(Continued)

Parameter	% Perturbation	ISE	P.0.
ZL?	+10	1.3950E-3	7.48
	-10	1.3951E-3	3.73
	+20	1.3957E-3	7.48
	-20	1.3959E-3	3.73

8

C

2

:

V 1 10 1 1.

i,

£

The frequency response of the system that had the 0.1 step as the system input is found in figures 24 and 25, and the transient response of the same system is found in figure 26 and appendix A. A discussion of all the results obtained in this chapter and the conclusions that can be drawn from these results is found in chapter 7.

ŝ

and the second of the second term on the states when we see

AND AN PUR



56

こうしょう ちょうかい かんかい ひょうかい ちょうぶん ゆ

•••

1

1.1.1

is a called an encoderate and a share to a second a second

£



7

1. Me 1.

÷

4 61

C

57

11、 and a strate a second with a strategy and a strategy an

ڊ •

. . . .

* * * *

A Low and Low and A



CHAPTER 7

DISCUSSION AND CONCLUSIONS

The performance of the system follows an expected trend when compared to the trend of the inputs. It can be seen from table 6 that as the magnitude of the step input decreases, the system overshoot increases. At the magnitude of the step decreases there is less torque required to drive the system; hence there is less saturation of the load pressure, and the system behaves more like a linear system.

E

to an it was surfa

--- Ileri

The important question is: Which set of parameter values should be used for the final system? Since the physical inputs to the system will be of a random nature (pitch, roll and yaw), there will be a wide range of inputs to the system. The system will obviously not be able to perform in an optimal senner for all the inputs. One approach to determine the best set of parameters might be to use each step as the input to each optimal system and compare the results.

A consideration of the sensitivity check in table 7, and an overall view of the parameters in table 6 may serve just as well. If the change in the percent overshoot from the optimum value (\sim ptimum value is 5.87 %) is considered, then the system is somewhat insensitive to all the parameters except for ZLL. An examination of the values for ZLL given in table 6 shows that the smallest value 59

1. - COMP - 1- 10 - 10

40 CP

.

۶

Sec. 1 6 40.

for ZLI is approximately 91 % of the largest value. If a value somewhere in between is chosen, the performance of the system for any of the inputs will not be affected greatly.

FF, K_6 and 21.2 all have wide variations in their parameter values as can be seen from table 6, however an examination of table 7 shows that these three parameters are all very insensitive with respect to the change in percent overshoot. PK and VK do not vary a great deal; nor are they very sensitive.

Considering the data in chapter 5, the final decision on the parameter values must be made only after considering all the available facts. Facts such as linearity of elements (amplifier gains, compensator poles, etc.), and the actual shape of the input distribution. Ideally, if the actual system input were available, the optimal parameters could be found. However the actual system input is not always available as is the case here. Therefore the optimal parameters of chapter 6 can only be used as one factor in the final choice for the final system.

£

The frequency response plots of figures 24 and 25 reveal that the 300 rad/sec bandwidth requirement has been satisfied for the optimal system with the 0.1 step input. They also reveal that there is no problem with stability as is sometimes encountered in systems with non-linear elements. The transient response in appendix A & Fig. 26 proves the dominance of the pressure saturation over the system performance as was expected. One final conclusion can be drawn by noting the small gmount of overshoot for the systems with the three l_rgest
í

€

inputs, and concluding that for systems with strict limitations on available drive torque the overshoot tends to be small.

Appendis A

System Cutput

A list of the print-plotted variables and their definitions are given in table 8.

Table 8

Output Variables

PHI	-	system output
X900	-	torque
ISE	-	integral squared error

C



ŧ

(

£

INIMUM	Ĩ	÷	+	+	+	+	+	•	+	+ 1	+ 1	ţ	+	+ I I	†	+ = = = = = = = = = = = = = = = = = = =	+	+	+	+	• • • • • • •	+	+	
Σ	IHd	0.0	3.7547E-05	1°5019E-04	3.3792E-U4	6 C075E-u4	9°3867E-04	1,3517E-03	1. 8398E-U3	2 4033E-03	3,0413E-03	3° 75476-03	4.5432E-03	5.,4067E-03	6., 3454E-03	7,35926-03	8°4480E-U3	9.6120E-03	1.0851E-U2	1.2165E-02	1.35546-02	Lu 5019E-02	1-6558E-02	
	►-	0.0	5. 0000E-03	1°0000E-02	1.50005-02	2~0000E02	2°50002-02	3, COODE-02	3. 5000E-02	4,0000E-02	4. 5000E-02	5,0000E-02	5. 5000E-02	6,0UC0E-02	6. 5000E-02	7¢0000E-02	7.5000E-02	8,0000E-02	8. 5000E-02	9.00C0E-02	9° 5000E-C2	1°0000E-01	1.0500E-01	

•



63

11 1 13

.

*

· · •

• • • •

.

و بيغافيه فيسابغ ويعافر و

مو د مامید کور د اود. ا

.

--

1 -----+============== + ! ! ! ! ! ! ! ! ! ! ! ! ! ! ! ! 1 1 5.1402E-02 5.4196E-02 7.6229E-02 7.8301E-02 1,8173E-02 1,98625-02 2°1627E-02 2.3467E-02 2,5382E-02 2.07372E-02 209437E-02 3.1577E-02 3,3792E-U2 3-6083E-02 3,8448E-02 4.0889E-U2 4,34046-02 4 .5995E-02 4.8661E-U2 5 + 6945E-02 5,96186-02 6,2216E-02 6.4739E-02 6.7187E-V2 6.9560E-02 7 1858E-U2 7.4081E-02 8°0299E-u2 8-2221E-U2 2.3000E-01 2.3500E-01 2.4000E-01 1.2500E-01 1.3000E-01 1.3500E-01 1.4000E-01 1,5000E-01 1.5500E-01 1. 6500E-01 1.7500E-01 1.8000E-01 1.8500E-01 2.0000E-01 2.2500E-01 2.2500E-01 1.1000E-01 1.1500E-01 1.2000E-01 1.4500E-01 1.6000E-01 1-7000E-U1 1, 9000E-01 1.9500E-01 2.0500E-01 2.1000E-01 2.1500E-01 2,4500E-01 5000E-01 S.

(

€

64

٠.

ç

7

2

ě

i

ł



C

C

	X	WOW IN	IHd	VERSUS T	MAXIMUM
۴	0•) DH1	-			1.0587E-01 I
2.5500E-01	8,40685-02				•
2.6000E-01	8.5840E-Ú2			+ ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ;	
2°6500E-01	8.7538E-U2			+	
2.7000E-01	8.91596-02				
2.7500E-01	9, C7U6E-02				
2,8000E-01	9.2178E-U2			***************	+
2,8500E-01	9.35754-02			*******************	+
2.9000E-01	9°4897E-02				+
2.9500E-01	9°6143E-02				+
3.0000E-01	9°7314E-02				+
3.05006-01	9,8411E-02				+ = = =
3.1000E-01	9,9432E-U2			******************	+
3,1500E-01	1.0038E-01				+
3.2000E-01	1-0125E-V1				+
3. 25COE-01	1.0205E-U1				+=====
3.3000E-01	1, C277E-01				+ = = = = = =
3+3500E-01	1.0341E-U1				+
3.4000E-C1	1.0398E-u1				+
3.45U0E-01	1.0448E-01				+
3, 5000E-01	1,C490E-01				+ = = = = = = = = =
3.5500E-01	1, 0524E-01				+
3.6000E-01	1.0551E-C1			***********************	* = = = = = =

· * * * * * * * * * * * * * * * * * * *	· 두 안 한부터 한 바람자 21 년 또 독 부 후 주 등 한 것 두 두 한 것 31 등 것 것 것 같 것 수 있 한 것 것 수 있 는 것 수 있 는 것 수 있 수 있 수 있 수 있 수 있 수 있 수 있 수 있 수 있 수	***************************************	***************************************		·호수···································	· faite contract to the set of th	. 2 4 1 2 4 5 4 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8	**?\$~!~*********************************	. 속 또 는 옷은 후수 유명 유용 등 등 등 등 등 등 후 두 옷 중 속 등 후 속 후 속 후 후 후 후 후 후 후 후 후 후 후 후 후 후		÷ # * * * * * * * * * * * * * * * * * *		+	÷==+++++++++++++++++++++++++++++++++++	÷\$	÷ = = = = = = = = = = = = = = = = = = =	÷\$************************************	, , , , , , , , , , , , , , , , , , , 	◆ 4 9 3 4 5 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8	·~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~				.	.	***************************************		***************************************
1,0571E-01	1.0583E-01	1,0587E-01	1.0584E-C1	1-05746-01	1.0556E-L1	1°0530E-01	1°0497E-01	1,0457E-01	1.04096-01	1,0353E-01	1,0290E-01	2,0222E-01	1,0160E-01	1,0105E-U1	1.0057E-01	1.0017E-01	9.9848E-U2	9.9598E-U2	9° 94245- U2	9., 9324E-U2	9a 9300E-C2	9°9351E-C2	9,9476E-U2	9 9677E-C2	9,9953E-02	1,0020E-01	1,00386-01	1,Cr48E-C1
3.6500E-01	3. 7000E- 01	3.7500E-01	3.8000E-01	3. 8500E-01	3. 9000E-01	3.9500E-01	4.0000E-01	4.050UE-01	4.1000E-01	4.1500E-01	4.2000E-01	4.2500E-01	4.3000E-01	4.3500E-01	4.4000E-01	4.4500E-01	4. 5000E-01	4.5500E-01	4.6001E-01	4.6500E-01	4. 7000E-01	4.75006-01	4. 8000E-C1	4.8500E-01	4-, 9000EC1	4.9500E-CI	5.0000E-01	5. 0500E-01

C

(

.

14 N

ŝ

ł

C

£

PAGE 3

.

the sector between the sector of the sector

67

0

Reproduced from best available copy. "

- Minte

. . .

수요요 또 또 또 또 또 또 또 또 또 또 또 또 또 또 또 또 또 또	┿┇╒╻╻╻╻╻╻╻╻╻╻╻╻╻╻╻╻╻╻╻╻╻	┿╂╤⋧╄⋴⋧⋿⋧⋳⋩⋳⋧⋿⋧⋸⋩⋵⋩⋵⋩⋵⋩⋩⋩⋩⋩⋩⋧⋧⋧⋳⋩⋬⋧⋬⋧⋧⋧⋧⋧⋧⋧⋧⋧	· · · · · · · · · · · · · · · · · · ·	÷ ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ;	÷		+ # # # # # # # # # # # # # # # # # # #	◆\$************************************	÷ * * * * * * * * * * * * * * * * * * *	÷*************************************	÷*************************************	÷;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;	÷ • • • • • • • • • • • • • • • • • • •	÷ 2 5 5 2 5 2 5 2 5 6 6 6 6 8 9 9 9 9 9 7 8 6 8 9 7 8 5 8 5 8 5 8 5 8 5 8 5 8 5 8 5 8 5 8	÷÷************************************	÷\$	· · · · · · · · · · · · · · · · · · ·	÷=====================================	÷\$	÷;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;	÷===:;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;	÷\$	◆ \$	÷ 6 9 4 4 4 5 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6	÷22434242424242424244444444444444444444	◆ ■ 1 = = = = = = = = = = = = = = = = = =	┿┰╒╸┵╉ ╄╊ ┇╪┺┺┇╋┇╋┇╋╘┲╛┺┇┾╋╴┇╾┇┺╘┇┆┇┇┇┇╋┇┇╋┇┇	÷*************************************
1,00256-01	1,0026E-01	1°00256-01	1.0024E-01	1,00256-01	L,0024E-01	1,0024E-01	1.0023E-01	1,00246-01	1. C023E-01	1.0022E-U1	1,00226-01	1,00226-01	1.0021E-01	1., C022E-u1	1,0021E-01	1,0021E-01	1,0021E-01	1,0021E-01	1.0021E-01	1+ CO21E-C1	1, CO2CE-01	1,0020E-U1	1,002UE-U1	1,0020E-01	1:0019E-u1	1.00186-01	1:0019E-U1	1°6019E-01
6- 2000E-01	6. 2500E-01	6. 3000E-01	6, 350UE-01	6.40C0E-01	5°4500E-01	6. 5000E-01	6.55U0E-01	6.6000E-01	6.6500E-CI	6. 7000E-01	6.7500E-01	6. 8000E-01	6, 8500E-01	و° 30006-01	6.950CE-01	7-00006-01	7.0500E-01	7.ª 1000E-C1	7°1500E+01	7.2000E-01	7.2500E-01	7,3000E-01	7.3500E-01	7.4000E-C1	7.4500E-01	7.5000E-01	7.5500E-01	7° 60008-01

C

(

PAGE 4

£_____

2

MAXIMUM 1.05875-01		+	+	+	+ = = =	+	+1::	+ = = =	+ ! !	+ 1	+ = + = =	+	+ 1 7 8	+ = = =	+	+ 1 1	+	+	+ = = =	+	+ /	+ 1 1 1	****
VERSUS T		********************				a a a a a a a a a a a a a a a a a a a					* • * * * * * * * * * * * * * * * * * *		******************	******************	*********************		*******************	******************	********************	*****************		********************	**************************
IHd WOM									******************						***************								,
NIW 0-0	IHd	1,00186-01	1,00198-01	1,0018E-U1 -	1.00186-01	1.0J18E-01 -	1. CO18E-01 -	1,00176-01	1,0018E-01	1 00186-01	1-0018E-C1	1.0017E-01 -	1,0017E-01 -	1,0017é-01 -	1, CO16E-C1 -	1,0017E-C1 -	1,00176-01 -	1,0017E-01 -	1°0106-01	1.0016E-C1 -	1.0016E-01 -	1,0016E-Úì -	1,0016F-01 -
	1 -	7.6500E-C1	7.70006-01	7.7500E-01	7.8000E-01	7, 8500E-01	7° 9000E-01	7°9500E-01	8.0000E-01	8°0500E-01	8.1000E-01	8.1500E-01	8. 2000E-01	8. 25-JUEC1	8.3000E-01	8.3530E-01	Br 4000E-01	8.4500E-01	8° 500CE-01	8. 550CE-01	8., 6070E-01	8°6500E-01	8.7000E-01

69

ۍ چ

;

ž

こうちょう こうちょうかんしょう ゆうぶ

. . .

1,00,17E-01 1.6016E-01 1.0016E-01 1.0016E-01 1.0016E-01	1,0016E-01 1,0015E-01 1,0016E-01 1,0015E-01 1,0015E-01 1,0015E-01	1,00156-01 1,00156-01 1,00156-01 1,00156-01	1,0014E-01 1,0014E-01 1,0013E-01 1,0014E-01 1,0014E-01	1,00156-01 1,00146-01 1,00146-01 1,00146-01 1,00146-01 1,00146-01
8.7500E-01 8.8000E-01 8.9500E-01 8.9500E-01 8.9500E-01	9,0000E-01 9,0500E-01 9,1000E-01 9,1500E-01 9,2500E-01	9- 3000E-01 9- 3500E-01 9- 4500E-01 9- 4500E-01	9. 5500E-01 9. 6000E-01 9. 6500E-01 9. 7030E-01 9. 7500E-01	9.8000E-01 9.8500E-01 9.9000E-01 9.9500E-01 1.0000E 01

C

PAGE

-

1

k

MAXIMUM 3.0000F 03							+ 8 \$ 8 8 8 8 8 8 8 8 8 8 8 8	+ = = = = = = = = = = = = = = =	***********	+ = = = = = = = = = = = = = = = = = = =	*****	+ = = = = = = = = = = = = = = = = = = =		+		*************				+ = = + = = = = = = = = = = = =	***********	**********	
VERSUS T													***										
006X							50005555555555555555555555555555555555			,		5 6 8 8 8 1 9 8 1 9 8							*****		******		
INIMUN Codde 03						8 6 8 3 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8		8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8	8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8				8 1 8 5 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8	8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8			5 5 7 5 7 5 5 7 5 5 7 5 5 7 5 5 7 5 5 7 5 5 7 5 5 7 5 5 7 5 5 7 5 5 7 5 5 7 5 5 7 5 5 7 5			9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1		****	
E 9 M I		0 3	03	c) C)	03	n C	603	C B	60	63	CJ	03	Ū3	63	C3	03	C C	03	60	e:)	60	C3	
	006 X	3,0000E	3, 0000E	3°0000€	3°000E	3° 000CE	3,0000E	3, 000CE	3°0000E	3,0000E	32000E	3, CUOOE	300008	3, 3000E	3. 0000E	3°000E	3-0000E	3~ CC00E	3,0000	3° 0000E	3.000CE	3°0000E	
	<u>ــ</u>	0°C	5. 00C0E-03	1.0000E-02	1. 5000E-02	2,0000E-C2	2.500E-02	3°0000E-02	3.5000E-02	4.0000E-02	4.5000E-02	5. COCOE-02	5°5000E-C2	6.000E-02	6. 5000E-U2	7.0000E-02	7°5000E-02	8. 0C00E-02	8,5000E-02	9.0000E-02	9.5000E-02	1,0000E-C1	

	72
	,
00000000000000000000000000000000000000	
$\begin{array}{c} \mathbf{u} \in $	



C

73

v

1 1 1 1 ł 1 1 1 111 Ì 1 111 1131 1111 111 ł ł 111 İ ł t I 03 0 0 0 0 0 0 **6** 3 00000 с ы ы 3 63 69 EG GG 63 Ċ3 c3 03 03 G 03 ŋ ŝ 5 -3°0000E -3,000CE -3.0000É -3°000E -3,0000E -3,000dE -3, COOOE 3.0000E 3,000CE 3.0000E 3.0000E 3,0000E 3. COUGE 3.0002E 3,000UE 3,0000E 3. 600GE 3. 000GE -3.0000E -3°0900E -3°00'0E -3,0000E -3.0000E -3,0000È -3,0000E -3, COOCE 3,0000E 3°0000E -3,0000É 3.8000E-01 3.8500E-01 4.05C0E-01 3.7000E-01 3. 7500E-01 3.9500E-01 4-0000E-01 4. 1000E-01 4.1530E-01 8000E-01 0000E-01 3. 900UE-01 +• 2000E-01 4 = 25:00E-01 4,3000E-01 4.3500E-01 4°4500E-01 4~5500E-01 7500E-01 85005-01 9000E-01 9500E-01 5.0500E-01 4~4000E-01 4 5000E-01 4~6000E-C1 4 c 6 5 C C E - C 1 4°7000E-01 3. 6500E-01 + ۍ جو я Ф 9 • 5.0

Ľ

ľ

7

C

C

PAGE 3

		X	WOW INI	006X	VERSUS	T MAX	MUMI
		m I	0000E (3			3,000	0E 03
-	C06 X		I				
5.1000E-01	-3,0000E	60	+				
5.1500E-01	-1.7515E	60					
5.2030E-01	3• 0000E	ŝ					+
5.250GE-01	1.4181E	C3				+ - + - + - + - + - + - + - + - + - + -	
5°3000E-01	-3,18496	62		+			
5.3590E-U1	2,7886E	02			+ 1 8 8		
5.400UE-C1	1。2834E	03) 			+ • • •	
5.4500E-01	-5.8900E	02		+			
5.5000E-01	9°1605E	02				+	
5.5500E-01	-1.5188E	60	+				
5.6000E-01	-7ª 3749E	10			ţ		
5.6500E-01	-2,8056E	02		+			
5.7000E-01	-1°3561E	0 9	+				
5.7500E-C1	4 ° 2463E	02			+		
5. 8000E-01	-1,0272E	02		1 	۰ ۲		
5, 8500E-01	-8,1606E	02	jêrk pristri	+			
5.9000E-01	9° 2852E	02				+ -	
5. 9500E-01	-1-4724E	53					
6.0000E-01	6,2152E	61		1 1 1 1 1 1 1 1	+		
6.05005-G1	6,3 1 52E	02					
6•1000E-01	-1,918CE	() ()			+		
6.1500E-01	-9° 8040E	Û2	****	+			

4 i 1 + ! + İ + | } | | | | | 1 İ İ 1 + | | + | | İ 1 1 1 1 1 1 1 Ì 1 +5111111 ----İ İ + | { | | | | | | 1 1 ł I 1 1 1 1 # 1 1 111 ŧ I 1 ŧ I 111 1 Ċ 1 с 9 0 0 3 e o o EJ 03 02 200 03 C3 3 50 61 02 02 25 52 Č2 000 25 -1 N 0 0 C 2 3 **1**, ŝ $\dot{\mathbf{O}}$ 1,3834E -2,65965 -1, 1075E 1.C634E -1=2702E 1,1248E -9°4176E 1.4573E -8°0895E 4° J359E 8: 2392E 8° 347CE 1.726CE 5,4073E -1 3125E -1,1117E 1.0079È 5.7832E -3,986GE -2:4605E -6,83355 1.7925E 6.0195E -3, 5072E -7.5666€ -2°C390É -1.0849E -8°2762E 4,3462E 6.2500E-01 6-5000E-01 6.3000E-01 6.3500E-01 6.4000E-01 6.4530E-01 6.5530E-01 6.6000E-01 6.6500E-01 6. 7000E-01 6. 8000E-01 6. 9000E-01 7, 0500E-01 7.2000E-01 7-40COE-31 7.5500E-01 6. 2000E-01 6.7530E-01 6e 8500E-01 6.9500E-01 7- 6003E-91 7.01000E-01 7.1500E-01 7-2500E-01 7-3000E-01 7. 3500E-01 7,4500E-01 7.5000E-01 7° 6000 E-01

(

Ð

in the second se

(

-

PAGE 4

"

MAXIMUM 3.00005.23		I																					
VERSUS T		* * * * * * *		+	+	+		+	+	+		+	+		***********	+ ; ; ; ; ; ;	+	+ = 5		+ = = = = = = = = = = = = = = = = = = =	+	+ = = = =	+
X 90C			+						# # # # # #		+		5	+ 1	* * * * * * * * * * * * * * * * * * * *				+				
[NIMUM 1030F 23		re so i se se se se so s													8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8								
1 1 1 1 1 1 1 1 1 1 1 1 1 1)	02	C 2	C1	20	60	C3	02	02	22	C V	C 2	02	02 0	C3	20	Ĉ2	01	02	25	02	C2	S N
	C:06 X	5,1816E	-4,8637E	-4.81945	1,5051E	1.0032E	-1,3259Ē	4°2096E	4°7346E	8,1546E	-3°8168E	1,1310E	7°9718E	-7 . 9556E	1,6710E	4 ° 5564E	6°9409E	4°C418E	-6"Ĉ248E	3±1686E	5°5742È	2°9157U	9,9625E
	-	7.65002-01	7° 7000E-01	7.7500E-01	7. 8000E-01	7.8500E-01	7c 9000E-01	7.9500E-01	8.0000E-U1	8-0530E-01	8°1000E-01	8°1500E-01	8° 2000E-01	8. 2500E-01	8.3000E-01	8, 3500E-01	8° 4030E-01	8.45J0E-C1	8° 5000E-01	8.550CE-01	8•6000E-01	8° 6500E-01	8. 7000E-01

+ + | | | + 1 1 ŧ l + = : ŧ + | + | | | | 1 ł + ! ! ! ! ! ! ! ! ۱ +====== | i + 1 + :; +121 İ + 1 1 1 1 1 1 1 1 1 1 1 Ì I 56848888 E 7 8 1 8 I İ I I í 1 1 + | + | | | Ì + | 161 + | | 1 1 1 1 1 1 I i 1 1 1 ł I İ 1 İ ********** 1 l 1 1 ŧ İ 1 1 1 1 1 1 1 ì 111 Ì 1 1 111 1111 ł 1 ļ 1 1 1 l ł t 1 G 60 ĉ 60 02 60 ŝ 02 02 05 63 02 5 25 02 02 5 5 2 05 25 5 <u></u> 25 Ç 63 20 5 -1,2906E 5.C564E 3 º 9824E 1,0370E 1,1424E -9.1107È 1.1258E 1.6488E -1.2655E 5. 6377E -9,1504E -1,07126 1.5461E 1,4294E 6,1709E 4 : 6746E -4,1917E -4,7942E -7,8686E 2.7342E 3.867GE 8° 6203E -7.3671E 1,5967E 2.4961E -1,0128E 8.7500E-01 8.8000E-01 8.9500E-01 8.9500E-01 8.9000E-01 9.7000E-01 9.7500E-01 8.9500E-01 9-0000E-01 9.0500E-01 9.1000E-01 9. 1500E-01 9,2000E-01 1,0000E 00 9-2500E-01 9°3500E-01 9°3000E-01 9.4000E-01 9°4500E-01 9.5000E-C1 9-5500E-01 9.60C0E-01 9e 6500E-01 9.8000E-01 9° 8500E-01 9.9500E-01 9° 9000E-01



Ŧ

(

1 1 i 1511 + | | | | | | | | | ----+ *** + +:+ + 8 - 9 8 8 8 8 8 8 8 8 8 8 8 8 +20065880568 1 *** } | | | 111 111 111 **** Ì 0 5 1 1 1 1171 ł 1 1 9.7399E-04 1.0068E-03 1.0382E-03 L.C682E-03 1.1239E-03 1.1495E-03 1-1737E-03 1°2175E-C3 1.3512E-03 1c3636E-03 3766E-C3 1.C968E-03 L 1963E-03 1,2372E-C3 1.2554E-U3 1.2721E-C3 L.2874E-03 1,3013E-C3 1,3138E-03 1.3249E-03 1:3348E-L3 1.3435E-03 L°3578E-C3 5729E-C3 1,3822E-U3 3861E-C3 L, 3686E-03 Le 3796E-ù3 L. 3844E-03 د 1.7500E-01 1.8000E-01 1.1.500E-01 1.2000E-01 1.2500E-01 1.3000E-01 1.3500E-01 1.4000E-01 1.4500E-01 1.5500E-01 1-6000E-01 L-6500E-01 1. 7000E-01 ., 8500E-01 1.9000E-01 1º95036-01 2-3000E-01 1.1000E-01 1.5000E-01 2 0000 E-01 2.0500E-01 2. 1000E-01 2. 1500E-01 2.2000E-01 2,25C0E-01 2.4000°-01 2s 45005 -01 2.50001-01 2.3500E-01

80

1.5000

J

f

 \sim

PAGE

-

£

Sec. 1

T 15500E-01 1.3394E-03 1.3394E-03 6500E-01 1.3387E-03 1.3394E-03 1.3394E-03 6500E-01 1.3387E-03 1.3394E-03 1.3394E-03 7000E-01 1.33934E-03 1.3391E-03 1.3394E-03 7000E-01 1.3391E-03 1.3391E-03 1.3391E-03 8500E-01 1.3391E-03 1.3391E-03 1.3391E-03 9500E-01 1.3391E-03 1.3391E-03 1.3391E-03 9500E-01 1.3391E-03 1.3391E-03 1.3391E-03 9500E-01 1.33917E-03 1.3391E-03 1.3391E-03 9500E-01 1.33917E-03 1.33917E-03 1.33917E-03 9500E-01 1.33917E-03 1.33917E-03 1.33917E-03 1500E-01 1.33917E-03 1.33917E-03 1.33917E-03 25000E-01 1.33917E-03 1.33917E-03 1.33917E-03 25000E-01 1.33917E-03 1.33917E-03 1.33917E-03 25000E-01 1.33917E-03 1.33917E-03 1.33917E-03 25000E-01 1.33917E-03 1.33917E-03 1.33917E-03 25000E-01 1.33917E-03 1.33917E		T	NIMUM	ISE	VERSUS T	MAXINUM
T ISE I \$500E-01 1.3887E-03			0			1°3941E-03
5500E-01 1.3876E-03 6000E-01 1.3887E-03 6000E-01 1.39086E-03 7500E-01 1.39086E-03 7500E-01 1.39086E-03 8500E-01 1.39086E-03 9500E-01 1.39146-03 1.39146-03 1.39146-03 9500E-01 1.39146-03 1.39146-03 1.39146-03 9500E-01 1.39146-03 1.39146-03 1.39146-03 9500E-01 1.39146-03 1.39146-03 1.39146-03 9500E-01 1.39146-03 1.39176-03 1.39176-03 1.5000E-01 1.39176-03 1.5000E-01 1.39176-03 1.5000E-01 1.39176-03 1.5000E-01 1.39176-03 1.5000E-01 1.39176-03 1.5000E-01 1.39176-03 1.5000E-01 1.39176-03 1.5000E-01 1.39176-03 1.5000E-01 1.39176-03 1.5000E-01 1.39176-03 1.5000E-01 1.39176-03 1.5000E-01 1.39176-03 1.5000E-01 1.39176-03	T	ISE	1			
6600E-01 1,3887E-03 7700E-01 1,3996E-03 7700E-01 1,3911E-03 7700E-01 1,3911E-03 8500E-01 1,3911E-03 9500E-01 1,3911E-03 9500E-01 1,3911E-03 9500E-01 1,3911E-03 9500E-01 1,3911E-03 9500E-01 1,3915E-03 9500E-01 1,3915E-03 9500E-01 1,3915E-03 9500E-01 1,3915E-03 9500E-01 1,3917E-03 10500E-01 1,3917E-03 10000E-01 1,3917E-03 10000E-01 1,3917E-03 10000E-01 1,3917E-03 10000E-01 1,3917E-03 10000E-01 1,3917E-03 10000E-01 1,3917E-03 10000E-01 1,3917E-03 10000E-01 1,3917E-03 10000E-01 1,3917E-03 10000E-01 1,3917E-03 10,3000E-01 1,3927E-03 10,3000E-01 1,3927E-03 10,3000E-01 1,3927E-03	10-30055 P	1.º 3876E-C3				
6500E-01 1,3996E-03 77000E-01 1,3914E-03 1,3914E-03 1,3914E-03 1,3914E-03 1,3914E-03 1,3914E-03 1,3914E-03 1,3914E-03 1,3914E-03 1,3914E-03 1,3914E-03 1,3914E-03 1,3914E-03 1,3914E-03 1,3915E-03 1,3914E-03 1,3915E-03 1,3917E-03 1,3917E-03 1,3917E-03 1,3917E-03 1,3917E-03 1,3917E-03 1,3917E-03 1,3917E-03 1,500E-01 1,3917E-03 1,500E-01 1,3917E-03 2,500E-01 1,3917E-03 2,500E-01 1,3917E-03 3,500E-01 1,3917E-03 1,500E-01 1,3917E-03 2,500E-01 1,3917E-03 2,500E-01 1,3917E-03 1,500E-01 1,3917E-03 2,500E-01 1,3917E-03 2,500E-01 1,3927E-03 1,3927E-03 1,3927E-03 1,3927E-03 1,3927E-03	2.6000E-01	1:3887E-ú3				+ ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ;
77006-01 1.39025-03 85006-01 1.39086-03 1.39116-03 1.39116-03 1.39116-03 1.39116-03 1.39116-03 1.39116-03 1.39116-03 1.39116-03 1.39116-03 1.39116-03 1.39116-03 1.39116-03 1.39116-03 1.39116-03 1.39116-03 1.39116-03 1.39116-03 1.39116-03 1.39116-03 1.39116-03 1.39116-03 1.39116-03 1.5006-01 1.39116-03 1.5006-01 1.39116-03 1.5006-01 1.39116-03 1.5006-01 1.39116-03 2.5006-01 1.39116-03 2.5006-01 1.39116-03 2.5006-01 1.39116-03 2.5006-01 1.39116-03 2.5006-01 1.39216-03 2.5006-01 1.39216-03 2.5006-01 1.39226-03 2.5006-01 1.39226-03 2.5006-01 1.39226-03	.• 6500E-01	1°3896E-ù3				÷;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
7500E-01 1,3908E-C3 88000E-01 1,3914E-C3 1,3914E-C3 1,39156-C3 1,39156-01 1,39156-C3 1,39156-03 1,39156-C3 1,39156-01 1,39156-C3 1,39176-01 1,39176-C3 1,39176-01 1,39176-C3 1,39176-01 1,39176-C3 1,5006-01 1,39176-C3 1,5006-01 1,39176-C3 1,5006-01 1,39176-C3 1,5006-01 1,39176-C3 1,5006-01 1,39176-C3 2,5006-01 1,39176-C3 2,55006-01 1,39176-C3 2,55006-01 1,39176-C3	: 7000E-01	1-3902E-U3				+ + + + + + + + + + + + + + + + + + + +
8000E=01 1,3911E-U3 0.8500E=01 1,3915E-C3 1.9900E=01 1,3915E-C3 1.9900E=01 1,3915E-C3 1.9900E=01 1,3915E-C3 1.9500E=01 1,3917E-C3 1.3917E-C3 1.3917E-C3 1.3920E-01 1.3927E-C3 1.4500E-01 1.3927E-C3 1.5500E-01 1.3927E-C3 1.5500E-01 1.3927E-C3 1.5500E-01 1.3927E-C3	10-3005-01	1.3908E-C3				+
0.8500E-01 1.3915E-03 1.9500E-01 1.3915E-03 1.9500E-01 1.3917E-05 1.3917E-05 1.3917E-05 1.3917E-05 1.3917E-05 1.3917E-05 1.3917E-05 1.3917E-05 1.3917E-05 1.3917E-05 1.3917E-05 1.3917E-05 1.3917E-05 1.3917E-05 1.3917E-05 1.3917E-03 1.3917E-03 1.1500E-01 1.3917E-03 1.2500E-01 1.3917E-03 1.2500E-01 1.3917E-03 1.2500E-01 1.3917E-03 2.2500E-01 1.3917E-03 2.2500E-01 1.3927E-03 2.5500E-01 1.3922E-03 2.5500E-01 1.3922E-03	2 8000E-01	1,3911E-U3				+
0.000E-01 1,39156-03 0.000E-01 1,39156-03 1,9500E-01 1,3917E-03 1,0500E-01 1,3917E-03 1,1500E-01 1,3917E-03 1,1500E-01 1,3917E-03 1,1500E-01 1,3917E-03 1,1500E-01 1,3917E-03 1,1500E-01 1,3917E-03 1,2500E-01 1,3917E-03 1,2500E-01 1,3917E-03 1,3917E-03 1,3917E-03 2,2500E-01 1,3917E-03 1,5500E-01 1,3927E-03 1,5500E-01 1,3927E-03	2•8500E-01	1°3914E-U3				+ = = = = = = = = = = =
R 9500E-01 1 3917E-03 I 0000E-01 1 3917E-03 I 0000E-01 1 3917E-03 I 1000E-01 1 3917E-03 I 1000E-01 1 3917E-03 I 1000E-01 1 3917E-03 I 1500E-01 1 3917E-03 I 2500E-01 1 3917E-03 I 2500E-01 1 3917E-03 I 2500E-01 1 3918E-03 I 3918E-03 1 1 I 3918E-03 1 1 I 3918E-03 1 1 I 3918E-03 1 1 I 3920E-01 1 3926E-03 I 4000E-01 1 39276E-03 I 5500E-01 1 39276E-03 I 5500E-01 1 39276E-03	10-3000E-01	1,39156-03			\$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$	*****
0.000E+C1 1. 3917E+C3 0.0500E+01 1. 3917E+C3 0.1500E+01 1. 3917E+C3 0.1500E+01 1. 3917E+C3 0.1500E+01 1. 3917E+C3 0.2500E+01 1. 3917E+C3 0.2500E+01 1. 3917E+C3 0.2500E+01 1. 3917E+C3 0.3500E+01 1. 3917E+C3 0.4000E+01 1. 3917E+C3 0.5500E+01 1. 3917E+C3 0.4000E+01 1. 3927E+C3 0.4000E+01 1. 3927E+C3 0.5500E+01 1. 3927E+C3 0.5500E+01 1. 3927E+C3	2+9500E-01	1,3916E-53	, , , , , , , , , , , , , , , , , , ,			+
0. 0500E-01 1. 3917E-03 0. 1000E-01 1. 3917E-03 0. 1500E-01 1. 3917E-03 1. 2500E-01 1. 3917E-03 1. 2500E-01 1. 3917E-03 1. 2500E-01 1. 3917E-03 1. 3917E-03	3.0C00E-C1	L. 3917E-C3				+ = = = = = = = = = = =
0. 1000E-01 1. 391 7E-03 0. 1500E-01 1. 391 7E-03 0. 2000E-01 1. 391 7E-03 0. 2500E-01 1. 391 7E-03 0. 2500E-01 1. 391 8E-03 0. 3500E-01 1. 391 8E-03 1. 391 9E-03	3. J500E-01	1,3917E-U3	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,			+ 2 2 2 2 2 2 2 2 2 2 2 4 4
0. 1500E-01 1. 3917E-C3 0. 2000E-01 1. 3917E-C3 0. 2500E-01 1. 3917E-C3 0. 2500E-01 1. 3918E-03 0. 3500E-01 1. 3918E-03 0. 4000E-01 1. 3919E-03 0. 4000E-01 1. 3926E-03 0. 5500E-01 1. 3926E-03 1. 3922E-03	1. LOCOE-C1	1e3917E-03				+
0.200E-01 1.3917E-03 0.2500E-01 1.3917E-03 0.300E-01 1.3918E-03 0.3500E-01 1.3918E-03 0.4000E-01 1.3919E-03 0.4000E-01 1.3926E-03 0.5500E-01 1.39226-03 0.5500E-01 1.39226-03 0.5500E-01 1.39226-03	1,1500E-01	L-3917E-C3	6 6 7 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8			* 2 8 8 8 8 8 8 8 8 8
0.2500E-01 1.3917E-03 0.3000E-01 1.3918E-03 0.3500E-01 1.3918E-03 0.4000E-01 1.3919E-03 0.4000E-01 1.3919E-03 0.4000E-01 1.3926E-03 0.5500E-01 1.3922E-03 0.5500E-01 1.3922E-03 0.5500E-01 1.3922E-03	1° 2000E-01	1,3917E-C3				+ 2 = 8 = 8 = 9 = 9 = 9
a3000E-01 1.3918E-03	122500E-01	1,3917E-C3				+
. 3500E-01 1,3918E-C3	1e 3000E-01	1:3918E-03				+ = = = = = = = = = = =
 4000E-01 1.3919E-03 4500E-01 1.3926E-03 5000E-01 1.3921E-03 5000E-01 1.3922E-03 5000E-01 3924E-03 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5000E-01 5	*3500E-01	1,3918E-C3				+
• 4500E-01 1 3925E-03	• 4000E-01	Lo3919E-03				+ = = = = = = = = = = = =
<pre>\$5000E=01 1,3921E=03 ===================================</pre>	• 4500E-01	1 3925E-43	* 8 8 4 8 9 8 8 9 8 8 9 8 8 9 8 8 9 8 8 9 8 8 9 8 8 9 8 8 9 8 8 9 8 8 9 8 8 9 8 8 9 8 9 8 9 8 9 8 9 8 9 8 9 8 9			+
<pre>*5500E=01 1.3922E=53</pre>	• 5000E-01	1, 3921E-03				* * * * * * * * * * * * *
• 6000E-01 1, 3924E-03	+ 5500E-01	L. 3922E-03				+ = = = = = = = = = = = = = =
	10-30009 °	L. 3924E-03				********

+============== 1111 **** + 111 1 1 Ì 1 ł ************ *********************** **** 111 1 1 1 1111 ----1 39819919888 1 Ì 1 ! l ł ł 111 1 2 1 5 1 1 İ İ 1 1 Ì 3925E-03 3927E-03 3929E-U3 3920E-U3 3932E-03 3934E-03 39356-03 3936E-03 3938E-03 3938E-03 3939E-C3 3940E-03 3940E-03 3940E-03 3940E-03 394CE-03 39406-03 3940E-03 1,3940E-U3 3940E-03 3940E-03 394CE-J3 3940E-03 3940E-J3 3940E-03 3940E-U3 3940E-U3 3940E-03 3940E-03 <u>_</u> -----_ ø * ••• • --۲. ہ ۔ 1 -3 ŝ 2 ., Å n . <u>.</u> 2 _____ ., 0 0 0 -3. 6500E-01 3. 7000E-01 3. 7500E-01 8000E-01 3.8500E-01 10-30006 9500E-01 4.0000E-01 4.0500E-01 4.1000E-01 4 • 1500E-01 4.2000E-01 4-2500E-01 4-3000E-01 4.3500E-01 4.4000E-01 4-4500E-01 4. 5000E-01 4. 6500E-01 4°5500E-C1 4-6000E-01 4. 7000E-01 4.7500E-C1 4° 8000E-01 4. 9500E-01 4 • 9000E-01 5.0000E-01 5.0500E-01 4. 8500E-01 3. , m ŝ

€

PAGE 3

1

S.

	Ŧ	[NI MUM	ISE	VERSUS T	MUMIXAM
	0.0				1.3941F-03
-	ISE	}			
5,1000E-01	1,3940E-03				• • • • • • • • • • • • • • • • • • • •
5.1500E-01	1°3940E-03				
5.2000E-01	1,3940E-U3				
5.2500E-U1	2.3340E-03			***************	
5e 30C0E-01	1,3940E-U3				+
5c 3500E-01	1,3941E-03	8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8			******
5.4000E-01	1°3941E-03				+
5.4500E-01	1°3941E-03				
5e 5000E-01	1.3941E-U3				
5.5500E-01	1.3941E-03				
5, 6000E-01	1,3941E-03				
5. 6500E-01	1.3941E-03				
5. 70CUE-U1	1a3941E-C3				
5. 7500E-01	1,3941E-03				
5- 8000E-01	1.3941E-03				
5.8500E~UI	1:3941E-C3				
5. 9000E-01	1,3941E-U3				
5.9530E-01	1.3941E-03				
6.C000E-01	1,3941E-03				
6. C500E-01	1,39416-03				*****
6, 1000E-01	1,3941E-03				+
6e1500E-01	I,3941E-03	****			

BIBLIOGRAPHY

- 1. Athans, M.; Falb, P. L., Optimal Control: An Introduction to the Theory and its Applications, New York: McGraw-Hill, 1966.
- 2. Dettman, John W., <u>Mathematical Methods in Physics and Engineering</u>, New York: McGraw-Hill, 1969.
- 3. Elgerd, Olle I., Controls Systems Theory, New York: McGraw-Hill, 1967.
- Hooke, R.; Jeeves, T. A., Direct Search Solution of Numerical and Statistical Problems, J. Assoc. Computer Machines, 8:212-229, 1961.
- 5. IBM, System/360 Continuous System Modeling Program, (360A-CX-16X), Users Manual, No. H20-0367-2.
- Lange-Nielsen, Truls and Lance, G. M., A Pattern Search Algorithm for Feedback Control System Parameter Optimization, Themis Report No. 32, AD726465.
- Neuton, G. C. Jr.; Gould, L. A.; Kaiser, James F., Analytical <u>Design of Linear Feudback Controls</u>, New York: John Wiley & Sons, Inc., 1957.
- 8. Philco-Ford Corp., Aeronutronic Div., Final Report: Concept Study of an Advanced Weapon Stabilization System for a Two-Man Cupola, Newport Beach, Calif., 1968.
- 9. Rosenbrock, H. H., An Automatic Method for Finding the Greatest or Least Value of a Function, Computer J., 3:175-184, 1960.
- Lange-Nielsen, Truls, Parameter Optimization of Feedback Control Systems Using Pattern Search, University of Iowa Ph.D. Thesis, 1970.

END