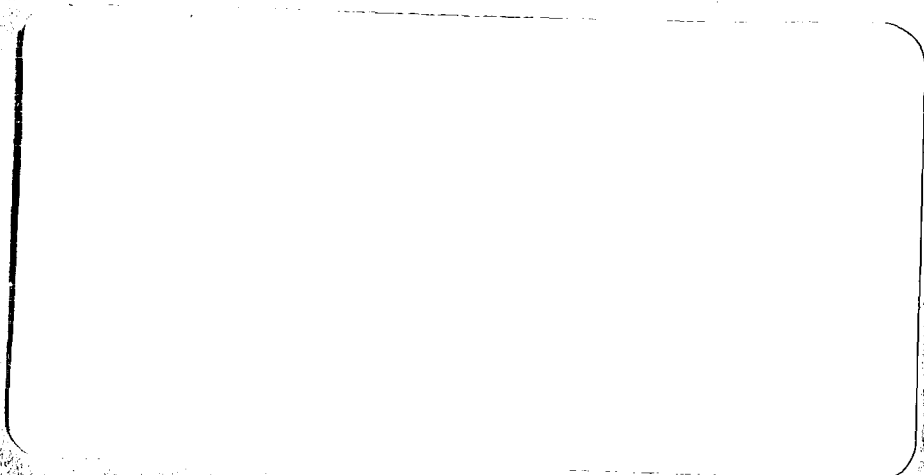


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(NASA-CR-124259) COMPUTER PROGRAM FOR THE LOAD AND TRAJECTORY ANALYSIS OF TWO
 DOF BODIES CONNECTED BY AN ELASTIC
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USERS MANUAL

COMPUTER PROGRAM FOR THE LOAD AND
TRAJECTORY ANALYSIS OF TWO 3 D.O.F. BODIES
CONNECTED BY AN ELASTIC TETHER
(Ref. NASA Contract NAS8-29144)

By
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And
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February 5, 1973

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ABSTRACT

This report contains the derivation of the differential equations of motion of a 3 D.O.F. body joined to a 3 D.O.F. body by an elastic tether. The tether is represented by a spring and dashpot in parallel. A computer program which integrates the equations of motion is also described. Although the derivation of the equations of motion are for a general system, the computer program is written for defining loads in large boosters recovered by parachutes.

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NOMENCLATURE

The following is a list of the variables used in the computer program with a brief description of each. The notation is displayed in two forms, 1) as it appears in the computer program, and 2) as used throughout the discussion of this report. Some of the variables used in the report are defined when they are introduced, and are therefore not included in the nomenclature.

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<u>FORTTRAN</u>	<u>STANDARD</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
A	A	Length of tether in X direction from decelerator confluence point to forebody confluence point	m
AA(6,4)		Dummy variable used to express incremental velocities in the numerical integration computation	N /S or rad/sec
AALP (16)		An array of eight variables representing angle-of-attack of the forebody	rad
AALPP (16)		An array of eight variables representing angle-of-attack of the decelerator	rad
AAM(8)		An array of eight variables representing Mach number of the forebody	
AAMP (8)		An array of eight variables representing Mach number of the decelerator	
ABAR	\bar{A}	Distance along longitudinal axis of the forebody from the intersection of the body axes to the tether confluence point, positive toward the nose	m
AD	A	Time derivative of A	m /sec
ALP	α	Angle-of-attack of forebody	rad
ALPDEG	α	Angle-of-attack of forebody	deg
ALPP	α_{ρ}	Angle-of-attack of decelerator	rad
ALPPDE	α_{ρ}	Angle-of-attack of decelerator	deg

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<u>FORTTRAN</u>	<u>STANDARD</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
ALPPSL		The ratio of two angle-of-attack differences used in interpolation of aerodynamic coefficients of the decelerator.	
ALPSL		The ratio of two angle-of-attack differences used in interpolation of aerodynamic coefficients of the forebody.	
AM		Mach number of forebody	
AMP		Mach number of decelerator	
AMPSL		The ratio of two Mach number differences used in interpolation of aerodynamics coefficients of the decelerator	
AMSL		The ratio of two Mach number differences used in interpolation of aerodynamics coefficients of the forebody	
APBAR	\bar{A}_p	Projection along longitudinal axis of decelerator from a line between the intersection of body axes and the tether confluence point, positive toward the nose	m
AREAI		Alphameric input-AREA SEQUENCE OF INFLATION	
ATMOS		Alphameric input defining atmosphere	
AOBAR		Projection along longitudinal axis of the forebody from a line between the intersection of the body axes and the bridle confluence point, positive toward the nose	m

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<u>FORTTRAN</u>	<u>STANDARD</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
ALBAR	\bar{A}_1	Distance along longitudinal axis of the forebody from the intersection of the body axes to the No. one bridle attach point, positive toward the nose	m
A2BAR	\bar{A}_2	Distance along longitudinal axis of the forebody from the intersection of the body axes to the No. two bridle attach point, positive toward the nose	m
B	B	Length of tether in Z direction from decelerator confluence point to forebody confluence point	m
BBAR	\bar{B}	Projection along lateral axis of forebody from a line between the intersection of the body axes and the tether confluence point, positive up	m
BD	\dot{B}	Time derivative of B	m/sec
BET1	β_1	Positive angle defined in Figure 6	rad
BET1DE	β_1	Positive angle defined in Figure 6	deg
BET2	β_1	Positive angle defined in Figure 6	rad
BET2DE	β_2	Positive angle defined in Figure 6	deg
BPBAR	\bar{B}_P	Projection along lateral axis of decelerator from a line between the intersection of the body axes and the tether confluence point, positive up	m
BOBAR		Projection along lateral axis of the forebody from a line between the intersection of the body axes and the bridle confluence point, positive up	m

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<u>FORTTRAN</u>	<u>STANDARD</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
B1BAR	\bar{B}_1	Distance along lateral axis of the forebody from the intersection of the body axes to the No. one bridle attach point, positive up	m
B2BAR	\bar{B}_2	Distance along lateral axis of the forebody from the intersection of the body axes to the No. two bridle attach point, positive up	m
C	C	Damping coefficient of tether	N sec/m
CA	C_A	Axial coefficient of forebody	
CAAP		Drag area of decelerator	m ²
CAP	C_{AP}	Axial coefficient of decelerator	
CCA(8, 16)		An array of eight by 16 variables representing axial force coefficients of the forebody corresponding to AAM(8) and AALP (16)	
CCAP(8, 16)		An array of eight by 16 variables representing axial force coefficients of the decelerator corresponding to AAMP(8) and AALPP(16)	
CCM(8, 16)		An array of eight by 16 variables representing moment coefficient of the forebody corresponding to AAM(8) and AALP (16)	
CCMP(8, 16)		An array of eight by 16 variables representing moment coefficients of the decelerator corresponding to AAMP(8) and AALPP(16)	

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<u>FORTTRAN</u>	<u>STANDARD</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
CCMQ(8,16)		An array of eight by 16 variables representing damping moment coefficients of the forebody corresponding to AAM(8) and AALP (16)	rad ⁻¹
CCMQP(8,16)		An array of eight by 16 variables representing damping moment coefficients of the decelerator corresponding to AAMP(8) and AALPP(16)	rad ⁻¹
CCN(8,16)		An array of eight by 16 variables representing normal force coefficients of the forebody corresponding to AAM(8) and AALP(16)	
CCNP(8,16)		An array of eight by 16 variables representing normal force coefficients of the decelerator corresponding to AAMP(8) and AALPP(16)	
CHI	X	tan ⁻¹ A/B	rad
CHID	X	dx/dt	rad/sec
CHIDDE	X	dx/dt	deg/sec
CHIDEG	X	tan ⁻¹ A/B	deg
CM	C _m	Moment coefficient of forebody	
CMP	C _{mp}	Moment coefficient of decelerator	
CMQ	C _{mq}	Damping moment coefficient of forebody	rad ⁻¹
CMQP	C _{mqp}	Damping moment coefficient of decelerator	rad ⁻¹
CN	C _N	Normal force coefficient of forebody	

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<u>FORTTRAN</u>	<u>STANDARD</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
CNP	C_{Np}	Normal force coefficient of decelerator	
CONF		Dummy number used to test for the initial configuration of the system	
CONST		Dummy number used to test for completion of trajectory	
CTHE	$\cos \theta$	$\cos \theta$	
CTHEP	$\cos \theta_p$	$\cos \theta_p$	
D	d	Aerodynamics reference length for forebody	m
DADTHE	$\frac{dA}{d\theta}$	$\frac{dA}{d\theta}$	m/rad
DADTHP	$\frac{dA}{d\theta_p}$	$\frac{dA}{d\theta_p}$	m/rad
DAMP		$C \cdot L_T$	m
DBDTHE	$\frac{dB}{d\theta}$	$\frac{dB}{d\theta}$	m/rad
DBDTHP	$\frac{dB}{d\theta_p}$	$\frac{dB}{d\theta_p}$	m/rad
DCG		Distance between the reference center of the forebody and the C.g. of the decelerator	m
DD(3,3)		Coefficients of the second derivatives in the equations of motion of the forebody	kg or kg- m ²
DL	DL	Distance between the two bridle connection points on the forebody	m
DLP	DLP	Distance between the two suspension line connection points on the decelerator	m

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<u>FORTTRAN</u>	<u>STANDARD</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
DLS1	DLS ₁	Change in length of first suspension line due to tension in the elastic system	m
DLS2	DLS ₂	Change in length of second suspension line due to tension in the elastic system	m
DL1	DL ₁	Change in length of the first bridle line of the forebody due to tension in the elastic system	m
DL2	DL ₂	Change in length of the second bridle line of the forebody due to tension in the elastic system	m
DP	d _p	Aerodynamic reference length of the decelerator (same as Ref. dia. D ₀)	m
DT	Δt	Integration time increment	sec
DTI		Length of inflation time	sec
DTP		Number which controls the number of integrations between data output	
DTPC		Control variable in printout routine	
DTP1	DTP1	Input constant which controls the number of integrations between data output when DT = DT1	sec
DTP2	DTP2	Input constant which controls the number of integrations between data output when DT = DT2	sec
DTVC		Time increment to close thrust valve of reaction control system on forebody	sec

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<u>FORTTRAN</u>	<u>STANDARD</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
DT1	DT1	First integration time increment	sec
DT2	DT2	Second integration time increment	sec
DYPR	q	Dynamic pressure acting on forebody	N/m ²
DYPRP	q _p	Dynamic pressure acting on decelerator	N/m ²
EE(3)		Variables representing the forces or torque acting on the forebody, shown in the equations of motion	N or m ^{-N}
EPS		A small positive constant used to check for redundant or inconsistent equations in CROUT subroutine	
EPSP1	ε _{p1}	Positive angle defined in Figure 6	rad
EPSP1D	ε _{p1}	Positive angle defined in Figure 6	deg
EPSP2	ε _{p2}	Positive angle defined in Figure 6	rad
EPSP2D	ε _{p2}	Positive angle defined in Figure 6	deg
EPS1	ε ₁	Positive angle defined in Figure 6	rad
EPS1DE	ε ₁	Positive angle defined in Figure 6	deg
EPS2	ε ₂	Positive angle defined in Figure 6	rad
EPS2DE	ε ₂	Positive angle defined in Figure 6	deg
ETA1	η ₁	Positive angle defined in Figure 6	rad
ETA1DE	η ₁	Positive angle defined in Figure 6	deg
ETA2	η ₂	Positive angle defined in Figure 6	rad

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<u>FORTTRAN</u>	<u>STANDARD</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
ETA2DE		Positive angle defined in Figure 6	deg
FF(3)		Variables representing the accelerations of the decelerator	m/sec ² or rad/sec ²
G	g	Acceleration of gravity of Z	N/sec ²
GAM	γ	Flight path angle of forebody	rad
GAMDEG	γ	Flight path angle of forebody	deg
GAMP	γ_p	Flight path angle of decelerator	rad
GAMPDE	γ_p	Flight path angle of decelerator	deg
GR		Acceleration of gravity at sea level	m/sec ²
HHH		Altitude below which trajectory is ended	m
I		Dummy variable used in DO loops	
IERSW		Control number used to check for inconsistent or redundant equations in CROUT subroutine	
III		Control variable used in the iteration section of SUBR	
IIYP(16)		An array of sixteen variables representing the pitch moment of inertia of the decelerator corresponding to TTI(16)	kg-m ²
IY	I_y	Pitch moment of inertia of forebody	kg-m ²
IYP	I_{yp}	Pitch moment of inertia of decelerator	kg-m ²
J		Dummy variable used in DO loops	
JJ		Dummy variable used to control output	
JJJ		Dummy variable used to control output	

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<u>FORTTRAN</u>	<u>STANDARD</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
K	K	Spring constant of elastic system	N/m
KBL	KBL	Longitudinal spring constant of bridle	N/m
KBT	KBT	Transverse spring constant of bridle	N/m
KH1	KH1	Spring constant of one bridle line (LH1)	N/m
KH2	KH2	Spring constant of second bridle line (LH2)	N/m
KKS (8)	KKS (8)	Spring constant array of dimension 8	N/m
KPHI	$K\phi$	Spring constant of bridle at a pull-off angle ϕ	N/m
KS	KS	Spring constant of both decelerator suspension lines	N/m
KSPKH1	KSPKH1	Spring constant of elastic system when bridle line 2 is slack	N/m
KSPKH2	KSPKH2	Spring constant of elastic system when bridle line 1 is slack	N/m
LAM	λ	Angular displacement of forebody's confluence point using the intersection of the forebody's body axes and the longitudinal axis as a reference	rad
LAMDEG	λ	Angular displacement of forebody's confluence point using the intersection of the forebody's body axes and the longitudinal axis as a reference	deg
LAMO	λ_0	Positive angle defined in Figure 6	rad
LAMODE	λ_0	Positive angle defined in Figure 6	deg
LAMOP	λ_{0p}	Positive angle defined in Figure 6	rad
LAMOPD	λ_{0p}	Positive angle defined in Figure 6	deg

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<u>FORTTRAN</u>	<u>STANDARD</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
LAM1	λ_1	Positive angle defined in Figure 6	rad
LAMI1DE	λ_1	Positive angle defined in Figure 6	deg
LAM2	λ_2	Positive angle defined in Figure 6	rad
LAM2DE	λ_2	Positive angle defined in Figure 6	deg
LH1	LH1	Length of first bridle line	m
LH2	LH2	Length of second bridle line	m
LS1	LS1	Length of first suspension line	m
LS2	LS2	Length of second suspension line	m
LT	L_T	Length of riser line	m
LTD	\dot{L}_T	$\frac{dL_T}{dt}$	m/sec
LTR		Length of riser line if bridle is not slack	m
LT0	L_{T0}	Unstretched length of riser line	m
L0	L_0	Distance from intersection of forebody's body axes to bridle confluence point	m
LOP	L_{0p}	Distance from c.g. of decelerator to confluence point of suspension lines	m
L1	L_1	Distance from intersection of forebody's body axis to the negative bridle attach point	m
L2	L	Distance from intersection of forebody's body axes to the positive bridle attach point	m
M	m	Mass of forebody	kg

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<u>FORTTRAN</u>	<u>STANDARD</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
MA		Added mass of decelerator at T	kg
MMA(16)		An array of 16 variables representing added mass of the decelerator corresponding to TTI(16)	kg
MP	m_p	Mass of decelerator at T	kg
MU	μ	Pull-off angle of riser from suspension lines	rad
MUD	$\dot{\mu}$	$\frac{d\mu}{dt}$	rad/sec
MUDEG	μ	Pull-off angle of riser from suspension lines	deg
MUDDEG	$\dot{\mu}$	$\frac{d\mu}{dt}$	deg/sec
NA		Axial g load on forebody (earth g's)	
NAP		Axial g load on decelerator (earth g's)	
NN		Normal g load on forebody (earth g's)	
NNP		Normal g load on decelerator (earth g's)	
NU	ν	Positive angle defined in Figure 6	rad
NUDEG	ν	Positive angle defined in Figure 6	deg
NUP	ν_p	Positive angle defined in Figure 6	rad
NUPDEG	ν_p	Positive angle defined in Figure 6	deg
PHI	ϕ	Pull-off angle of riser from forebody's confluence point	rad
PHIB		Pull-off angle of riser from forebody's confluence point used in iteration section of SUBR	rad

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<u>FORTTRAN</u>	<u>STANDARD</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
PHID	$\dot{\phi}$	$\frac{d\phi}{dt}$	rad/sec
PHIDDE	$\dot{\phi}$	$\frac{d\phi}{dt}$	deg/sec
PHIDEG	ϕ	Pull-off angle of riser from forebody's confluence point	deg
PHI1	ϕ_1	Maximum pull-off angle before bridle line 2 goes slack	rad
PHI1DE	ϕ_1	Maximum pull-off angle before bridle line 2 goes slack	deg
PHI2	ϕ_2	Maximum pull-off angle before bridle line 1 goes slack	rad
PHI2DE	ϕ_2	Maximum pull-off angle before bridle line 1 goes slack	deg
POINT(5)		An array used to transfer data points from the program to a tape	
QTHE	Q_θ	Generalized force on θ equation	m-N
QTHEP	$Q_{\theta p}$	Generalized force on θ_p equation	m-N
QX	Q_x	Generalized force on X equation	N
QXP	Q_{xp}	Generalized force on X_p equation	N
QZ	Q_z	Generalized force on Z equation	N
QZP	Q_{zp}	Generalized force on Z_p equation	N
R		Radius of planet	m
RHO	ρ	Atmospheric density at Z	kg/m ³

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<u>FORTTRAN</u>	<u>STANDARD</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
S	S	Aerodynamic reference area of forebody	m ²
SIG1	σ_1	Positive angle defined in Figure 6	rad
SIG1DE	σ_1	Positive angle defined in Figure 6	deg
SIG2	σ_2	Positive angle defined in Figure 6	rad
SIG2DE	σ_2	Positive angle defined in Figure 6	deg
SP	S_p	Reference area of decelerator (S_o)	m ²
SPI		Reference area of decelerator during inflation	m ²
SSPI(16)		An array of sixteen variables representing reference area of decelerator corresponding to TTI(16)	m ²
STHE	$\sin \theta$	$\sin \theta$	
STHEP	$\sin \theta_p$	$\sin \theta_p$	
T	t	Flight time	sec
TC		Time at which thrust valve on reaction control system is closed	sec
TDTC		Time at which DT and DTP change value from DT1 → DT2 and DTP1 → DTP2	sec
TENS		Tension in riser line	N
THE	θ	Pitch angle of forebody	rad
THED	$\dot{\theta}$	$\frac{d\theta}{dt}$	rad/sec
THEDDD	$\ddot{\theta}$	$\frac{d^2\theta}{dt^2}$	deg/sec ²
THEDDE	$\dot{\theta}$	$\frac{d\theta}{dt}$	deg/sec

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<u>FORTTRAN</u>	<u>STANDARD</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
THEDEG	θ	Pitch angle of forebody	deg
THEDL		Forebody's pitching rate at which reaction control thruster begins to turn off	rad/sec
THEDU		Forebody's pitching rate at which reaction control thruster is turned on	rad/sec
THED2	$\dot{\theta}^2$	$(\frac{d\theta}{dt})^2$	rad ² /sec ²
THEP	θ_p	Pitch angle of decelerator	rad
THEPD	$\dot{\theta}_p$	$\frac{d\theta_p}{dt}$	rad/sec
THPDDD	$\ddot{\theta}_p$	$\frac{d^2\theta_p}{dt^2}$	deg/sec ²
THPDDE	$\dot{\theta}_p$	$\frac{d\theta_p}{dt}$	deg/sec
THPDEG	θ_p	Pitch angle of decelerator	deg
TI		Time at which decelerator inflation begins (=0.0)	sec
TIMEI		Alphameric input - TIME SEQUENCE OF INFLATION	
TISL		Ratio of two time differences used to calculate inflation characteristics of decelerator	
TOR		Maximum value of torque on the forebody produced by the reaction control system	m-N

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<u>FORTRAN</u>	<u>STANDARD</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
TORQ		Value of torque on forebody produced by reaction control system at T	m-N
TSL		Ratio of time differences used in the interpolation of gust velocity	
TTENS (8)		Tension array associated with KKS (8)	N
TTG (8)		An array of eight variables representing time used in gust interpolation	sec
TTI (16)		An array of 16 variables representing time used in the inflation interpolation	sec
TTT		Time at which trajectory is ended	sec
V	V	Total inertial velocity of forebody	m/sec
VD		Total inertial acceleration of forebody	m/sec ²
VG	V _g	Gust velocity	m/sec
VP	V _p	Total inertial velocity of decelerator	m/sec
VPD		Total inertial acceleration of decelerator	m /sec ²
VS		Speed of sound at Z	m/sec
VVG (8)		An array of eight variables representing gust velocity corresponding to TTG (8)	m/sec
X	X	Horizontal displacement of forebody along the <u>X</u> inertial coordinate	m

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<u>FORTTRAN</u>	<u>STANDARD</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
ZBAR	\bar{Z}	Lateral displacement of the c.g. of the forebody from the intersection of the body axes, positive up	m
XD	\dot{X}	$\frac{dX}{dt}$	m/sec
XDD	\ddot{X}	$\frac{d^2X}{dt^2}$	m/sec ²
XP	X_p	Horizontal displacement of decelerator along the X inertial coordinate	m
XPD	\dot{X}_p	$\frac{dX_p}{dt}$	m/sec
XPDD	\ddot{X}_p	$\frac{d^2X_p}{dt^2}$	m/sec ²
Z	Z	Vertical displacement of forebody along the Z inertial coordinate	m
XBAR	\bar{X}	Longitudinal displacement of the c.g. of the forebody from the intersection of the body axes, positive toward the nose	m
ZD	\dot{Z}	$\frac{dZ}{dt}$	m/sec
ZDD	\ddot{Z}	$\frac{d^2Z}{dt^2}$	m/sec ²
ZP	Z_p	Vertical displacement of decelerator along the Z inertial coordinate	m
ZPD	\dot{Z}_p	$\frac{dZ_p}{dt}$	m/sec
ZPDD	\ddot{Z}_p	$\frac{d^2Z_p}{dt^2}$	m/sec ²
ZSL		Ratio of altitude differences used in the interpolation of RHO and VS	

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SECTION I - INTRODUCTION

The objective of this report is to present a computer simulation of the dynamics of two bodies (coupled by an elastic tether) in a plane. This is a simplification of a more general problem (see Ref 5). Both bodies have two translation degrees of freedom and one rotational degree of freedom each; the tether is considered massless and its only function is to apply a constraint to the two bodies such that they remain in the vicinity of each other. A situation in which this simulation would be of use is in a deceleration and stabilization study of a re-entry vehicle by a parachute system. The re-entry vehicle (hereafter denoted as the forebody) is assumed to have arbitrary mass and shape characteristics, but the decelerator is considered to be symmetric. Also included in the report is a listing and explanation of the computer program used to integrate the equations of motion.

REF: ENGINEERING PROCEDURE S-017

SECTION II - EQUATIONS OF MOTION1. General

The system is defined as two rigid bodies joined by an elastic tether and free to move in a given plane. Both the forebody and the decelerator have 3 D.O.F. In general the forebody may have an off center c.g., but the decelerator is considered to be symmetric and homogeneous. The elastic tether is simulated by a spring and dashpot in parallel and is attached to the forebody by means of a bridle; the tether is attached to the decelerator at the confluence point of the suspension lines or at the apex of a BALLUTE.

The motion is referenced to a Cartesian coordinate system fixed on a flat, non-rotating planet. Coordinate system XZ is an inertial coordinate system (Figure 1); X_1Z_1 and X_BZ_B are body axes for the forebody and decelerator respectively. XZ and X_BZ_B are fixed to the forebody and decelerator respectively at one point and always remain parallel to the inertial XZ axes. In general, axes XZ and X_1Z_1 intersect at the same point but not at the center of gravity of the forebody. Therefore, X_1Z_1 are not principal axes in general. However, X_BZ_B are principal axes. \vec{r}_1 is the vector distance from the intersection of the body axes (longitudinal and lateral axes of the forebody) to the confluence point of the forebody. Because of the harness configuration, this confluence point changes location discretely or continuously during a simulation. This problem will be

discussed in Section III-2. \vec{r}_2 is the vector distance from the intersection of the body axis of the decelerator (c.g. location) to the confluence point of the decelerator.

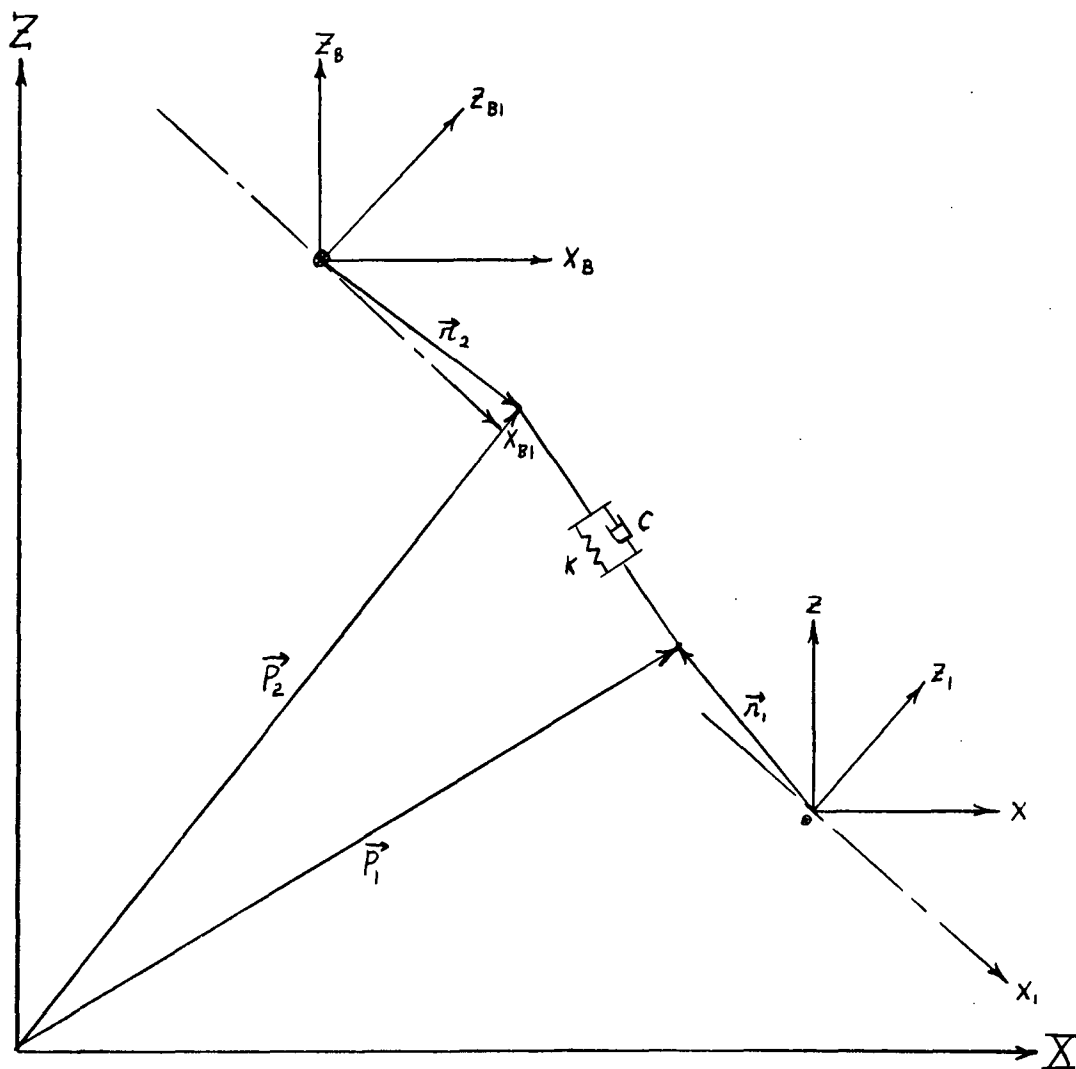


FIGURE 1 - COORDINATE SYSTEM

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2. Kinetic Energy

Consider an arbitrary body rotating and translating in a plane (Figure 2). Axes \bar{X}, \bar{Z} are inertial axes; axes X_1, Z_1 are orthogonal axes fixed to the body and intersect at point 0. Angular velocity, $\dot{\theta}$, has only one component perpendicular to the plane of motion. Linear velocity \vec{V}_0 has components V_{0X_1} and V_{0Z_1} along the instantaneous directions of the X_1, Z_1 axes respectively. m is located at the center of mass of the body with position \bar{X}, \bar{Z} relative to the X_1, Z_1 axes (\bar{X} and \bar{Z} are considered constant in this problem). \vec{u} is the velocity of the center of mass with respect to the X_1, Z_1 axes and it has components u_{X_1}, u_{Z_1} . \vec{r} is the vector from 0 to m .

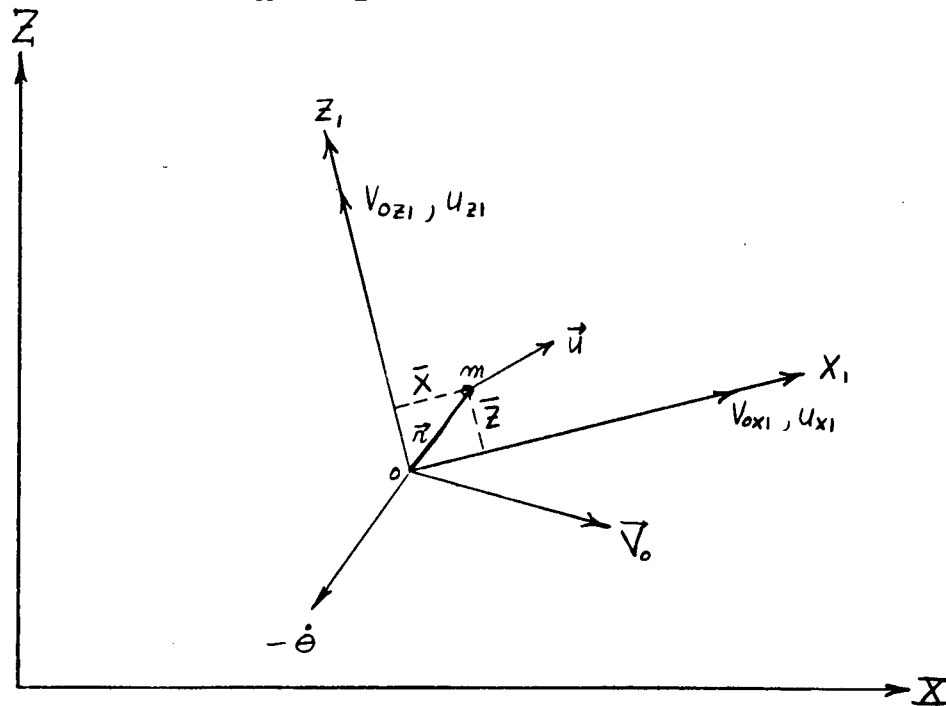


FIGURE 2 - RIGID BODY WITH 3 D. O. F.

REF: ENGINEERING PROCEDURE S-017

The velocity \vec{u} can be expressed as follows:

$$\vec{u} = \vec{\omega} \times \vec{r} = (-\dot{\theta} \vec{j}) \times (\bar{X} \vec{i} + \bar{Z} \vec{k}) \quad (1)$$

It follows immediately from equation (1):

$$\left. \begin{aligned} u_{x_1} &= -\dot{\theta} \bar{Z} \\ u_{z_1} &= +\dot{\theta} \bar{X} \end{aligned} \right\} \quad (2)$$

If the point o has instantaneous velocity components V_{0x_1} and V_{0z_1} along X_1 and Z_1 (\vec{V}_0 represents a linear velocity of the body as a whole), the inertial velocity along X_1, Z_1 are:

$$\left. \begin{aligned} V_{x_1} &= V_{0x_1} + u_{x_1} = V_{0x_1} - \dot{\theta} \bar{Z} \\ V_{z_1} &= V_{0z_1} + u_{z_1} = V_{0z_1} + \dot{\theta} \bar{X} \end{aligned} \right\} \quad (3)$$

The kinetic energy is:

$$T = \frac{1}{2} m (V_{x_1}^2 + V_{z_1}^2) \quad (4)$$

Expanding equation (4):

$$\begin{aligned} T &= \frac{1}{2} m [V_{0x_1}^2 + V_{0z_1}^2] + \frac{1}{2} m [\dot{\theta}^2 (\bar{Z}^2 + \bar{X}^2)] \\ &\quad + m [-V_{0x_1} \dot{\theta} \bar{Z} + V_{0z_1} \dot{\theta} \bar{X}] \end{aligned} \quad (5)$$

or

$$T = \frac{1}{2} m V_0^2 + \frac{1}{2} I_Y \dot{\theta}^2 + m (-V_{0x_1} \bar{Z} + V_{0z_1} \bar{X}) \dot{\theta} \quad (6)$$

Equation (6) applies to both the forebody and the decelerator. However, in the case of the decelerator \bar{X} and \bar{Z} are zero. Therefore, for the decelerator:

$$T_p = \frac{1}{2} m_p V_{0p}^2 + \frac{1}{2} I_{yp} \dot{\theta}_p^2 \quad (7)$$

Velocities V_{0x1} and V_{0z1} must now be transformed from the body axes coordinate system to the inertial coordinate system. Figure 3 shows the relationship.

$$V_{0x1} = \dot{X} \cos \theta + \dot{Z} \sin \theta \quad (8)$$

$$V_{0z1} = -\dot{X} \sin \theta + \dot{Z} \cos \theta \quad (9)$$

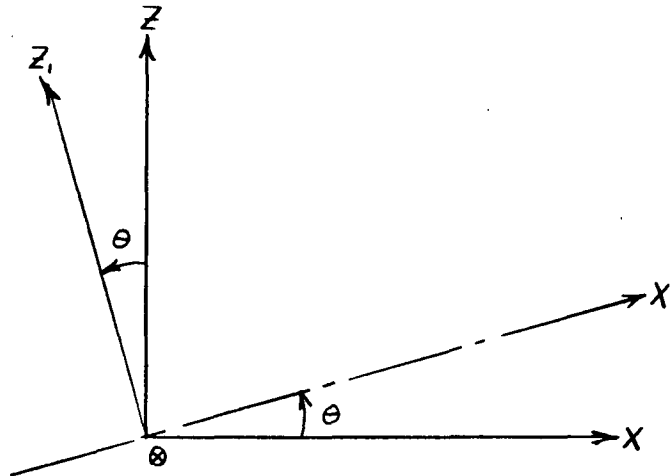


FIGURE 3 - TRANSFORMATION ANGLE

The total kinetic energy of the system is:

$$T_T = \frac{1}{2} m (\dot{X}^2 + \dot{Z}^2) + \frac{1}{2} m_p (\dot{X}_p^2 + \dot{Z}_p^2) + \frac{1}{2} I_Y \dot{\theta}^2 + \frac{1}{2} I_{yp} \dot{\theta}_p^2 + m \dot{\theta} [-\dot{X}(\bar{Z} \cos \theta + \bar{X} \sin \theta) - \dot{Z}(\bar{Z} \sin \theta - \bar{X} \cos \theta)] \quad (10)$$

3. Potential Energy

The potential energy in the system is due to the weight of the two bodies and to the elasticity in the tether.

$$V_T = mg[Z + \bar{X} \sin \theta + \bar{Z} \cos \theta] + m_p g z_p + \frac{1}{2} K(L_T - L_{T_0})^2 \quad (11)$$

L_{T_0} is the unstretched length of the tether and L_T is the stretched length of the tether given by the geometry of the system. Referring to Figure 1:

$$L_T = |\vec{P}_2 - \vec{P}_1| \quad (12)$$

\vec{P}_1 and \vec{P}_2 are vectors from the inertial coordinate system to the confluence points of the forebody and decelerator respectively. For the decelerator:

$$\vec{P}_2 = X_p \vec{i} + z_p \vec{k} + \vec{r}_2 \quad (13)$$

$$\vec{r}_2 = \bar{A}_p \vec{i}_{p1} + \bar{B}_p \vec{k}_{p1} \quad (14)$$

$$\vec{i}_{p1} = \vec{i} \cos \theta_p + \vec{k} \sin \theta_p \quad (15)$$

$$\vec{k}_{p1} = -\vec{i} \sin \theta_p + \vec{k} \cos \theta_p \quad (16)$$

$$\vec{P}_2 = \vec{i}(X_p + \bar{A}_p \cos \theta_p - \bar{B}_p \sin \theta_p) + \vec{k}(z_p + \bar{A}_p \sin \theta_p + \bar{B}_p \cos \theta_p) \quad (17)$$

For the forebody:

$$\vec{P}_1 = x \vec{i} + z \vec{k} + \vec{r}_1 \quad (18)$$

$$\vec{r}_1 = \bar{A} \vec{i}_1 + \bar{B} \vec{k}_1 \quad (19)$$

$$\vec{i}_1 = \vec{i} \cos \theta + \vec{k} \sin \theta \quad (20)$$

$$\vec{k}_1 = -\vec{i} \sin \theta + \vec{k} \cos \theta \quad (21)$$

$$\vec{P}_1 = \vec{i}(x + \bar{A} \cos \theta - \bar{B} \sin \theta) + \vec{k}(z + \bar{A} \sin \theta + \bar{B} \cos \theta) \quad (22)$$

$$L_T = (L_T \cdot L_T)^{\frac{1}{2}} \quad (23)$$

$$L_T = [(X_p + \bar{A}_p \cos \theta_p - \bar{B}_p \sin \theta_p - x - \bar{A} \cos \theta + \bar{B} \sin \theta)^2 + (Z_p + \bar{A}_p \sin \theta_p + \bar{B}_p \cos \theta_p - z - \bar{A} \sin \theta - \bar{B} \cos \theta)^2]^{\frac{1}{2}} \quad (24)$$

Define the variables A and B such that:

$$L_T = [A^2 + B^2]^{\frac{1}{2}} \quad (25)$$

The constraint equation is:

$$\bar{g} = [A^2 + B^2]^{\frac{1}{2}} - L_T = 0 \quad (26)$$

Derivatives of A and B with respect to the coordinates are:

$$\left. \begin{aligned} \frac{\delta A}{\delta X} &= -1 & \frac{\delta B}{\delta Z} &= -1 \\ \frac{\delta A}{\delta X_p} &= 1 & \frac{\delta B}{\delta Z_p} &= 1 \end{aligned} \right\} \quad (27)$$

$$\frac{\delta A}{\delta Z} = \frac{\delta A}{\delta Z_p} = \frac{\delta B}{\delta X} = \frac{\delta B}{\delta X_p} = 0 \quad (28)$$

$$\frac{\delta A}{\delta \theta} = \bar{A} \sin \theta + \bar{B} \cos \theta \quad (29)$$

$$\frac{\delta A}{\delta \theta_p} = -\bar{A}_p \sin \theta_p - \bar{B}_p \cos \theta_p \quad (30)$$

$$\frac{\delta B}{\delta \theta} = -\bar{A} \cos \theta + \bar{B} \sin \theta \quad (31)$$

$$\frac{\delta B}{\delta \theta_p} = \bar{A}_p \cos \theta_p - \bar{B}_p \sin \theta_p \quad (32)$$

4. Rayleigh's Dissipation Function (See Ref 1 and 2)

Frictional forces which are proportional to the velocity may be derived in terms of a function defined as

$$\mathcal{J} = \frac{1}{2} \sum_{i=1}^n C_i \dot{q}_i^2 \quad (33)$$

where the summation is over all the degree of freedom. For this problem, Raleigh damping is considered only in the tether.

$$\mathcal{J} = \frac{1}{2} C \dot{L}_T^2 \quad (34)$$

5. Lagrange's Equation

Lagrange's equation for non-conservative forces, holonomic, scleronomic constraint, and Rayleigh's dissipation function can be written

$$\frac{d}{dt} \left(\frac{\delta L}{\delta \dot{q}_i} \right) - \frac{\delta L}{\delta q_i} - \lambda \frac{\delta \bar{g}}{\delta q_i} + \frac{\delta \mathcal{F}}{\delta \dot{q}_i} = Q_i \text{ (See Ref 1 \& 2)} \quad (35)$$

In equation (35), the term $\lambda \frac{\delta \bar{g}}{\delta q_i}$ expresses the generalized force exerted by the tether on the "i"th degree of freedom. The term $\frac{\delta \mathcal{F}}{\delta \dot{q}_i}$ is the damping in the spring and Q_i is the non-conservative aerodynamic and reaction control forces.

The Lagrangian (L) is equal to the total kinetic energy of the system minus the total potential energy of the system.

$$L = T_T - V_T \quad (36)$$

Substituting equation (10) and (11) into equation (36), the Lagrangian can be written as a function of the generalized coordinates, $(X, Z, \theta, X_p, Z_p, \theta_p)$.

$$\begin{aligned} L = & \frac{1}{2} m (\dot{X}^2 + \dot{Z}^2) + \frac{1}{2} m_p (\dot{X}_p^2 + \dot{Z}_p^2) + \frac{1}{2} I_Y \dot{\theta}^2 + \frac{1}{2} I_{Yp} \dot{\theta}_p^2 \\ & + m \dot{\theta} [-\dot{X}(\bar{Z} \cos \theta + \bar{X} \sin \theta) - \dot{Z}(\bar{Z} \sin \theta - \bar{X} \cos \theta)] \\ & - mg[Z + \bar{X} \sin \theta + \bar{Z} \cos \theta] - m_p g Z_p - \frac{1}{2} K(L_T - L_{T0})^2 \end{aligned} \quad (37)$$

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Now operate on equation (37) with equation (35).

X equation

$$\frac{\delta L}{\delta \dot{X}} = m \dot{X} - m \dot{\theta} (\bar{Z} \cos \theta + \bar{X} \sin \theta) \quad (38)$$

$$\begin{aligned} \frac{d}{dt} \left(\frac{\delta L}{\delta \dot{X}} \right) &= m \ddot{X} - m \ddot{\theta} (\bar{Z} \cos \theta + \bar{X} \sin \theta) \\ &\quad - m \dot{\theta}^2 (-\bar{Z} \sin \theta + \bar{X} \cos \theta) \end{aligned} \quad (39)$$

$$\frac{\delta L}{\delta X} = 0 \quad (40)$$

$$\frac{\delta \bar{q}}{\delta X} = [A \frac{\delta A}{\delta X} + B \frac{\delta B}{\delta X}] / L_T = - \frac{A}{L_T} \quad (41)$$

$$\frac{\delta \mathcal{F}}{\delta \dot{X}} = 0 \quad (42)$$

Z equation

$$\frac{\delta L}{\delta \dot{Z}} = m \dot{Z} - m \dot{\theta} (\bar{Z} \sin \theta - \bar{X} \cos \theta) \quad (43)$$

$$\begin{aligned} \frac{d}{dt} \left(\frac{\delta L}{\delta \dot{Z}} \right) &= m \ddot{Z} - m \ddot{\theta} (\bar{Z} \sin \theta - \bar{X} \cos \theta) \\ &\quad - m \dot{\theta}^2 (\bar{Z} \cos \theta + \bar{X} \sin \theta) \end{aligned} \quad (44)$$

$$\frac{\delta L}{\delta Z} = - mg \quad (45)$$

$$\frac{\delta \bar{g}}{\delta Z} = [A \frac{\delta A}{\delta Z} + B \frac{\delta B}{\delta Z}] / L_T = \frac{B}{L_T} \quad (46)$$

$$\frac{\delta \mathcal{I}}{\delta \dot{Z}} = 0 \quad (47)$$

X_p Equation

$$\frac{\delta L}{\delta \dot{X}_p} = m_p \dot{X}_p \quad (48)$$

$$\frac{d}{dt} \left(\frac{\delta L}{\delta \dot{X}_p} \right) = m_p \ddot{X}_p \quad (49)$$

$$\frac{\delta L}{\delta X_p} = 0 \quad (50)$$

$$\frac{\delta \bar{g}}{\delta X_p} = [A \frac{\delta B}{\delta X_p} + B \frac{\delta B}{\delta X_p}] / L_T = \frac{A}{L_T} \quad (51)$$

$$\frac{\delta \mathcal{I}}{\delta \dot{X}_p} = 0 \quad (52)$$

Z_p Equation

$$\frac{\delta L}{\delta \dot{Z}_p} = m_p \dot{Z}_p \quad (53)$$

$$\frac{d}{dt} \left(\frac{\delta L}{\delta \dot{Z}_p} \right) = m_p \ddot{Z}_p \quad (54)$$



$$\frac{\delta L}{\delta \dot{Z}_p} = -m_p g \quad (55)$$

$$\frac{\delta \bar{g}}{\delta \dot{Z}_p} = [A \frac{\delta A}{\delta \dot{Z}_p} + B \frac{\delta B}{\delta \dot{Z}_p}] / L_T = \frac{B}{L_T} \quad (56)$$

$$\frac{\delta \mathcal{F}}{\delta \dot{Z}_p} = 0 \quad (57)$$

θ Equation

$$\frac{\delta L}{\delta \dot{\theta}} = I_Y \dot{\theta} - m[\dot{X}(\bar{Z} \cos \theta + \bar{X} \sin \theta) + \dot{Z}(\bar{Z} \sin \theta - \bar{X} \cos \theta)] \quad (58)$$

$$\begin{aligned} \frac{d}{dt} \left(\frac{\delta L}{\delta \dot{\theta}} \right) &= I_Y \ddot{\theta} - m[\ddot{X}(\bar{Z} \cos \theta + \bar{X} \sin \theta) \\ &+ \dot{Z}(\bar{Z} \sin \theta - \bar{X} \cos \theta)] + \dot{X}\dot{\theta}(-\bar{Z} \sin \theta + \bar{X} \cos \theta) \\ &+ \dot{Z}\dot{\theta}(\bar{Z} \cos \theta + \bar{X} \sin \theta)] \end{aligned} \quad (59)$$

$$\begin{aligned} \frac{\delta L}{\delta \theta} &= -m\dot{\theta}[\dot{X}(-\bar{Z} \sin \theta + \bar{X} \cos \theta) + \dot{Z}(\bar{Z} \cos \theta + \bar{X} \sin \theta)] \\ &- mg[\bar{X} \cos \theta - \bar{Z} \sin \theta] \end{aligned} \quad (60)$$

$$\frac{\delta \bar{g}}{\delta \theta} = [A \frac{\delta A}{\delta \theta} + B \frac{\delta B}{\delta \theta}] / L_T \quad (61)$$

$$\frac{\delta \mathcal{F}}{\delta \theta} = 0 \quad (62)$$

θ_B Equation

$$\frac{\delta L}{\delta \dot{\theta}_P} = I_{YP} \dot{\theta}_P \quad (63)$$

$$\frac{d}{dt} \left(\frac{\delta L}{\delta \dot{\theta}_P} \right) = I_{YP} \ddot{\theta}_P \quad (64)$$

$$\frac{\delta L}{\delta \theta_P} = 0 \quad (65)$$

$$\frac{\delta \bar{g}}{\delta \theta_P} = \left[A \frac{\delta A}{\delta \theta_P} + B \frac{\delta B}{\delta \theta_P} \right] / L_T \quad (66)$$

$$\frac{\delta \mathcal{I}}{\delta \dot{\theta}_P} = 0 \quad (67)$$

 L_T Equation

$$\frac{d}{dt} \left(\frac{\delta L}{\delta \dot{L}_T} \right) = 0 \quad (68)$$

$$\frac{\delta L}{\delta L_T} = -K (L_T - L_{T0}) \quad (69)$$

$$\frac{\delta \bar{g}}{\delta L_T} = -1 \quad (70)$$

$$\frac{\delta \mathcal{I}}{\delta \dot{L}_T} = C L_T \quad (71)$$

If equations (68) to (71) are substituted into equation (35), the resulting equation is:

$$K(L_T - L_{T0}) + \lambda + C \dot{L}_T = 0 \quad (72)$$

$$\lambda = -[K(L_T - L_{T0}) + C \dot{L}_T] \quad (73)$$

The variable λ can now be substituted into equation (35) when writing out the differential equations of motion. \dot{L}_T is found by differentiating equation (25)

$$\dot{L}_T = \frac{d}{dt} [A^2 + B^2]^{1/2} = \frac{A \dot{A} + B \dot{B}}{L_T} \quad (74)$$

$$A = x_p + \bar{A}_p \cos \theta_p - \bar{B}_p \sin \theta_p - x - \bar{A} \cos \theta + \bar{B} \sin \theta \quad (75)$$

$$\begin{aligned} \dot{A} = & \dot{x}_p - \bar{A}_p \dot{\theta}_p \sin \theta_p - \bar{B}_p \dot{\theta}_p \cos \theta_p - \dot{x} \\ & + \bar{A} \dot{\theta} \sin \theta + \bar{B} \dot{\theta} \cos \theta \end{aligned} \quad (76)$$

$$B = z_p + \bar{A}_p \sin \theta_p + \bar{B}_p \cos \theta_p - z - \bar{A} \sin \theta - \bar{B} \cos \theta \quad (77)$$

$$\begin{aligned} \dot{B} = & \dot{z}_p + \bar{A}_p \dot{\theta}_p \cos \theta_p - \bar{B}_p \dot{\theta}_p \sin \theta_p - \dot{z} - \bar{A} \dot{\theta} \cos \theta \\ & + \bar{B} \dot{\theta} \sin \theta \end{aligned} \quad (78)$$

Hence λ can be expressed as a function of the generalized coordinates and their time derivative. The six equations of motion are now expressed as follows:

1) X Equation:

$$m\ddot{X} - m(\bar{Z} \cos \theta + \bar{X} \sin \theta)\ddot{\theta} = m(-\bar{Z} \sin \theta + \bar{X} \cos \theta)\dot{\theta}^2 + [K(L_T - L_{T0}) + C \dot{L}_T] \left[\frac{A}{L_T} \right] + Q_X \quad (79)$$

2) Z Equation:

$$m\ddot{Z} - m(\bar{Z} \sin \theta - \bar{X} \cos \theta)\dot{\theta} = m(\bar{Z} \cos \theta + \bar{X} \sin \theta)\dot{\theta}^2 - mg + [K(L_T - L_{T0}) + C \dot{L}_T] \left[\frac{B}{L_T} \right] + Q_Z \quad (80)$$

3) X_p Equation

$$m_p \ddot{X}_p = -[K(L_T - L_{T0}) + C \dot{L}_T] \left[\frac{A}{L_T} \right] + Q_{xp} \quad (81)$$

4) Z_p Equation

$$m_p \ddot{Z}_p = -m_p g - [K(L_T - L_{T0}) + C \dot{L}_T] \left[\frac{B}{L_T} \right] + Q_{zp} \quad (82)$$

5) θ Equation:

$$I_y \ddot{\theta} - m(\bar{Z} \cos \theta + \bar{X} \sin \theta)\ddot{X} - m(\bar{Z} \sin \theta - \bar{X} \cos \theta)\ddot{Z} = -mg[\bar{X} \cos \theta - \bar{Z} \sin \theta] - [K(L_T - L_{T0}) + C \dot{L}_T] \left[A \frac{\delta A}{\delta \theta} + B \frac{\delta B}{\delta \theta} \right] / L_T + Q_\theta \quad (83)$$

6) θ_p Equation

$$I_{yp} \ddot{\theta}_p = -[K(L_T - L_{T0}) + C \dot{L}_T] \left[A \frac{\delta A}{\delta \theta_p} + B \frac{\delta B}{\delta \theta_p} \right] / L_T + Q_{\theta p} \quad (84)$$

6. Non-Conservative Generalized Forces

a) Forebody Aerodynamics:

The aerodynamics of the forebody are given with respect to the body axes as shown in Figure 4.

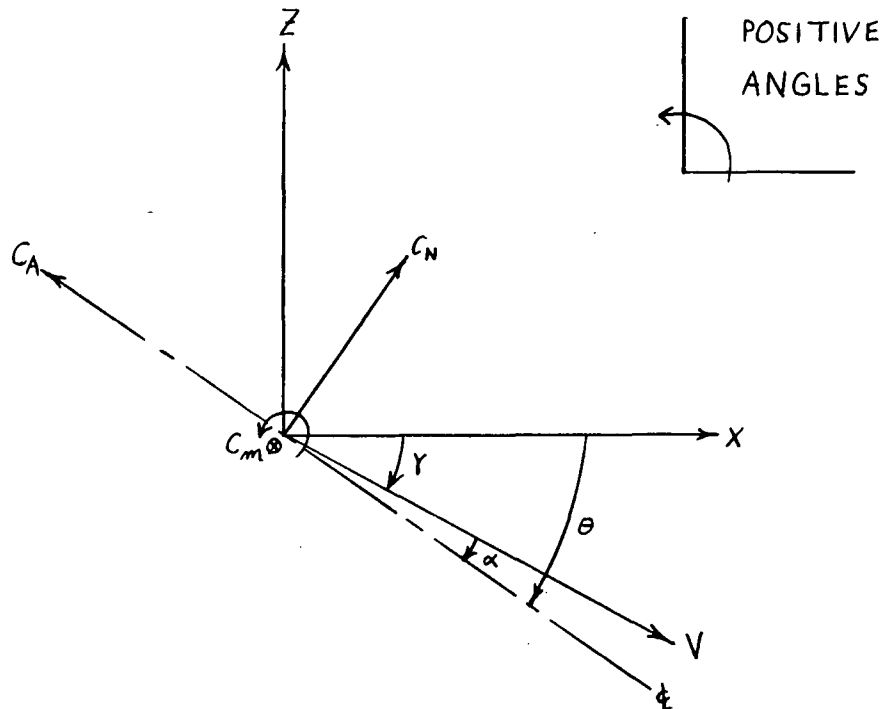


FIGURE 4 - AERODYNAMICS OF FOREBODY

$$Q_x = -qS(C_A \cos \theta + C_N \sin \theta) \quad (85)$$

$$Q_z = qS(C_N \cos \theta - C_A \sin \theta) \quad (86)$$

The generalized force Q_θ is given later in equation (90).

b) Decelerator Aerodynamics:

The aerodynamics of the decelerator are given with respect to the body axes (Figure 5).

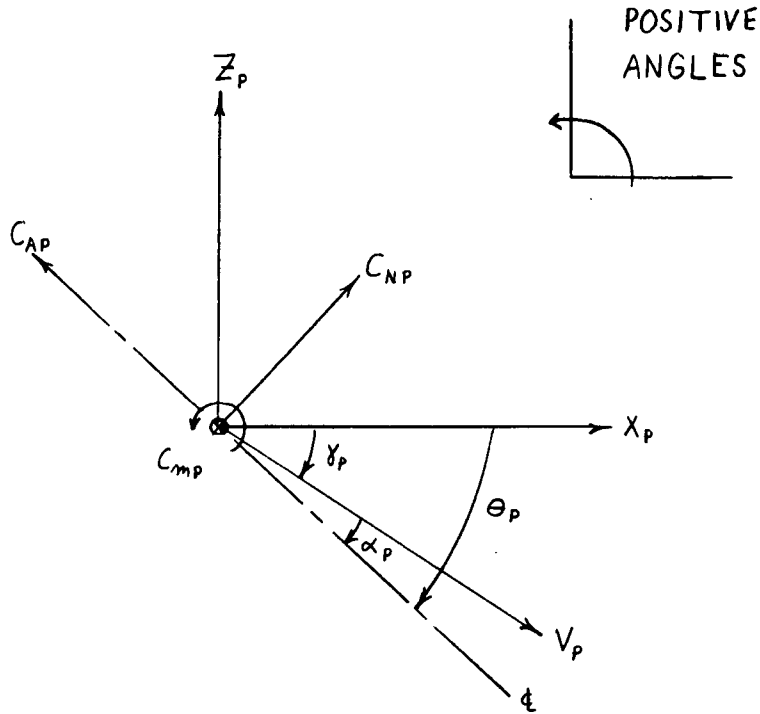


FIGURE 5 - AERODYNAMICS OF DECELERATOR

$$Q_{xp} = -q_p S_p (C_{AP} \cos \theta_p + C_{NP} \sin \theta_p) \quad (87)$$

$$Q_{zp} = q_p S_p (C_{NP} \cos \theta_p - C_{AP} \sin \theta_p) \quad (88)$$

$$Q_{\theta p} = q_p S_p d_p [C_{mp} + C_{m\dot{\theta}p} \left(\frac{\dot{\theta}_p d_p}{V_p} \right)] \quad (89)$$

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c) Reaction Control System:

A reaction control system may be used to stabilize the forebody's pitching motions. This is accomplished by checking the pitching rate of the forebody. If the absolute value of the rate is above a given upper value, a restoring torque (TORQ) is applied to the forebody. This restoring torque is maintained until a given lower value of pitching rate is reached. The torque is then decreased to zero over a finite time increment (DTVC). The generalized force Q_{θ} is now written as:

$$Q_{\theta} = q S d [C_m + C_{m\dot{\theta}} \left(\frac{\dot{\theta} d}{V}\right)] + \text{TORQ} \quad (90)$$

7. Solution of Equations of Motion

Because the center of mass of the forebody is not located at the intersection of the longitudinal and vertical axes (point 0, Figure 2), the equation of motion of the forebody are coupled in the second derivatives. These equations ((79), (80), (83)) have the following form:

$$\left. \begin{aligned} D_{11} \ddot{X} + D_{12} \ddot{Z} + D_{13} \ddot{\theta} &= E_1 \\ D_{21} \ddot{X} + D_{22} \ddot{Z} + D_{23} \ddot{\theta} &= E_2 \\ D_{31} \ddot{X} + D_{32} \ddot{Z} + D_{33} \ddot{\theta} &= E_3 \end{aligned} \right\} \quad (91)$$

Before numerically integrating equation (91), they are separated using Crout reduction (Refer to Ref 3). The final form will be:

$$\ddot{q}_i = f_i(X, Z, \theta, X_p, Z_p, \theta_p, \dot{X}, \dot{Z}, \dot{\theta}, \dot{X}_p, \dot{Z}_p, \dot{\theta}_p, t) \quad (92)$$

$i = 1, 2, 3$

The equations of motion for the decelerator are not coupled in the second derivative and can be written in the form:

$$\left. \begin{aligned} \ddot{X}_p &= F_1 \\ \ddot{Z}_p &= F_2 \\ \ddot{\theta}_p &= F_3 \end{aligned} \right\} \quad (93)$$

The six second order differential equations of motion, (92) and (93), can now be numerically integrated using 4th order Runge-Kutta. (Re Ref. 4).

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SECTION IIIAPPLICATION OF THE EQUATIONS OF MOTION TO THE ANALYSIS
OF A ROCKET BOOSTER RECOVERED BY A PARACHUTE

(Ref. Figure 6)

1. General

The mathematical model defined up to this point applies to a general system. Except for the tether line, the entire system is rigid. In actual application the structure between either body reference point and the appropriate tether end is not rigid. In other words there is an elastic structure between the end of the tether and the referenced body. The tether is attached to the forebody by an elastic bridle, and to the aft body by the elastic suspension lines of a parachute. An effective system spring constant must be used to adequately account for the effect the suspension lines and bridle have on the system spring constant.

The bridle consists of two lines (LH1, LH2) attached to points (1 and 2) located on the forebody. The other ends of lines LH1 and LH2 attach to the tether. An important fact to remember is that the lines can't carry a compressive load and one bridle line will go slack if the tether tension load is directed in such a direction as to lie outside σ_1 or σ_2 . Therefore, when the tether tension load is directed along one of the bridle lines or outside σ_1 or σ_2 , the opposite line goes slack and the tether and the line become one longer tether connecting the aft body to the forebody at point 1 or 2 depending upon which bridle line is carrying the load. The suspension lines in the

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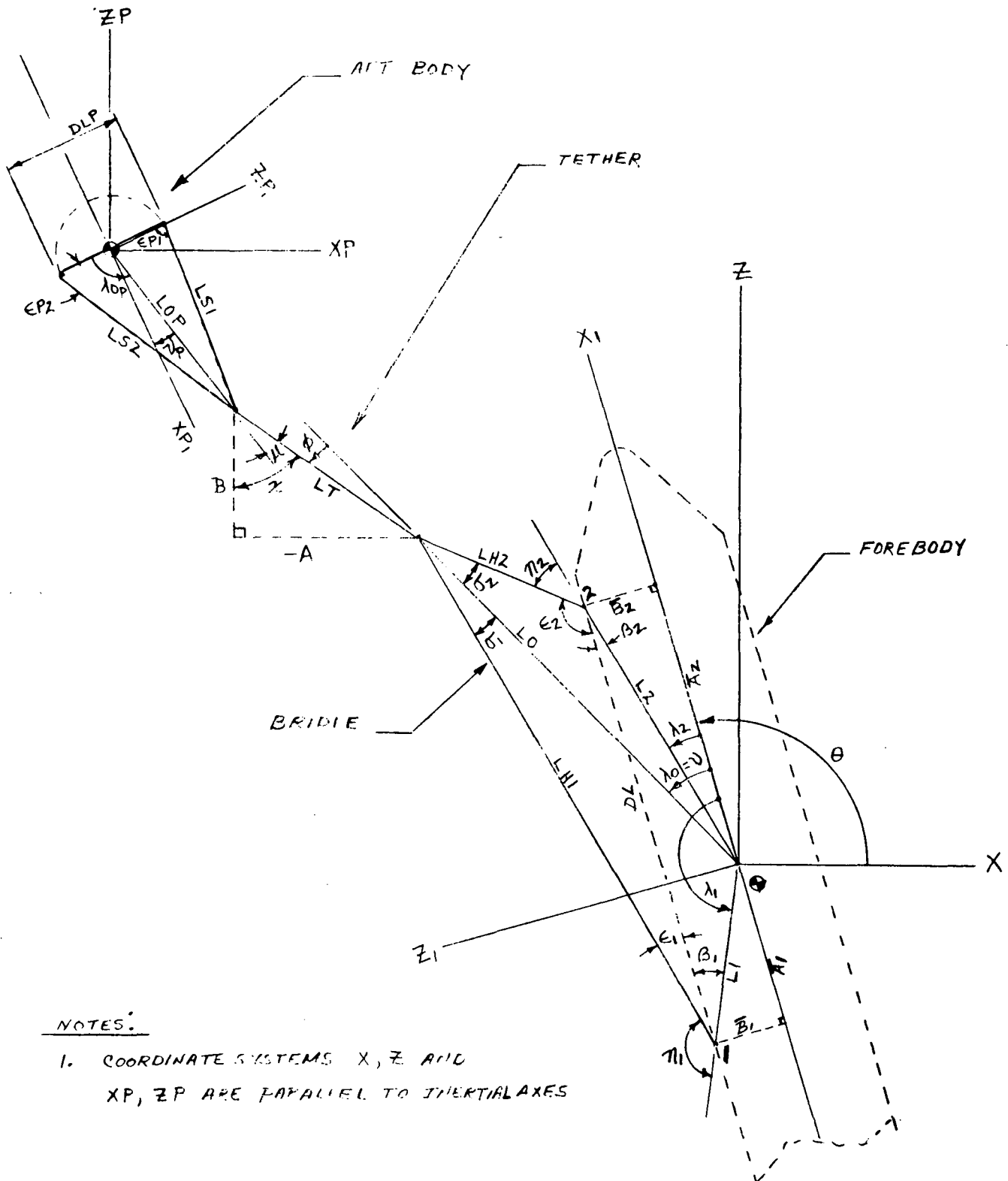
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parachute (aft body) are resolved into two lines (LS1 and LS2). Each line has a spring constant (KS) which is used together with the bridle spring constant ($K\phi$, see Equation 133) in calculating an effective system spring constant (K) for the dynamic two body system. It should be noted here that the computer program from which this program has been adapted was written for the Viking program. This system had a very short rigid tether, the elastic effects of which were included in the parachute suspension line spring constant (KS). Therefore, one half the tether spring constant should be added in series with one of the parachute suspension line spring constants, and the resultant spring constant is the spring constant KS used in this computer program.

The parachute shown in Figure 9 can be made elastic or rigid by removing or adding the "C" in the comment column of the card CALL SUSPEN in the subroutine, SUBR. It has been found that a rigid parachute representation results in a much faster running program, with little change in tether tension when compared to a system with an elastic parachute. Therefore, this program calls for the rigid parachute simulation; and if desired it can be made elastic as discussed above.

SYSTEM GEOMETRY

FIG. 6



NOTES:

1. COORDINATE SYSTEMS X, Z AND X_P, Z_P ARE PARALLEL TO INERTIAL AXES

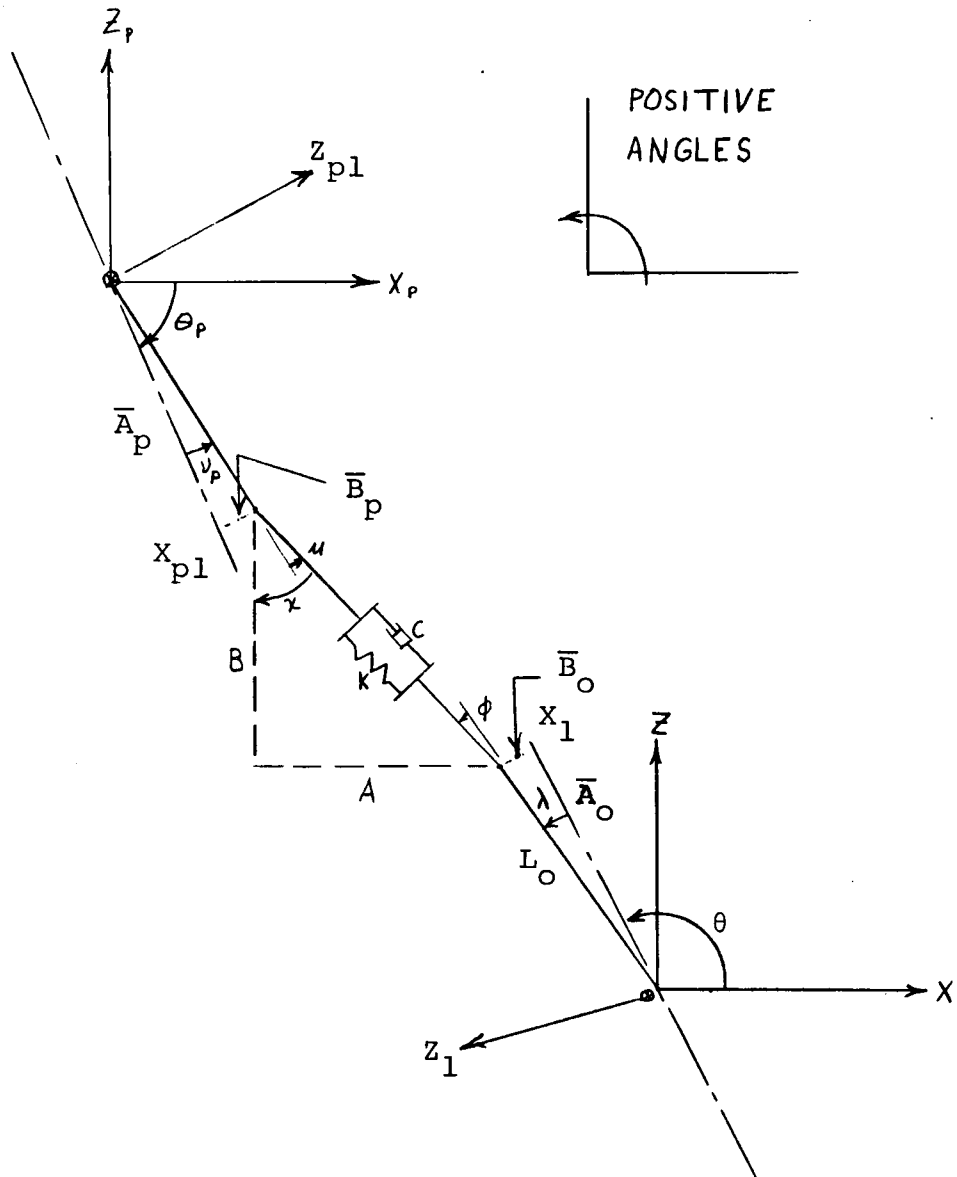


FIGURE 7 - SCHEMATIC OF 2 BODY SYSTEM

From Figure 7, the following relationships exist:

$$\chi = \tan^{-1} \frac{A}{B} \tag{94}$$

$$\mu = -\frac{\pi}{2} - \theta_p - \nu_p - \chi \tag{95}$$

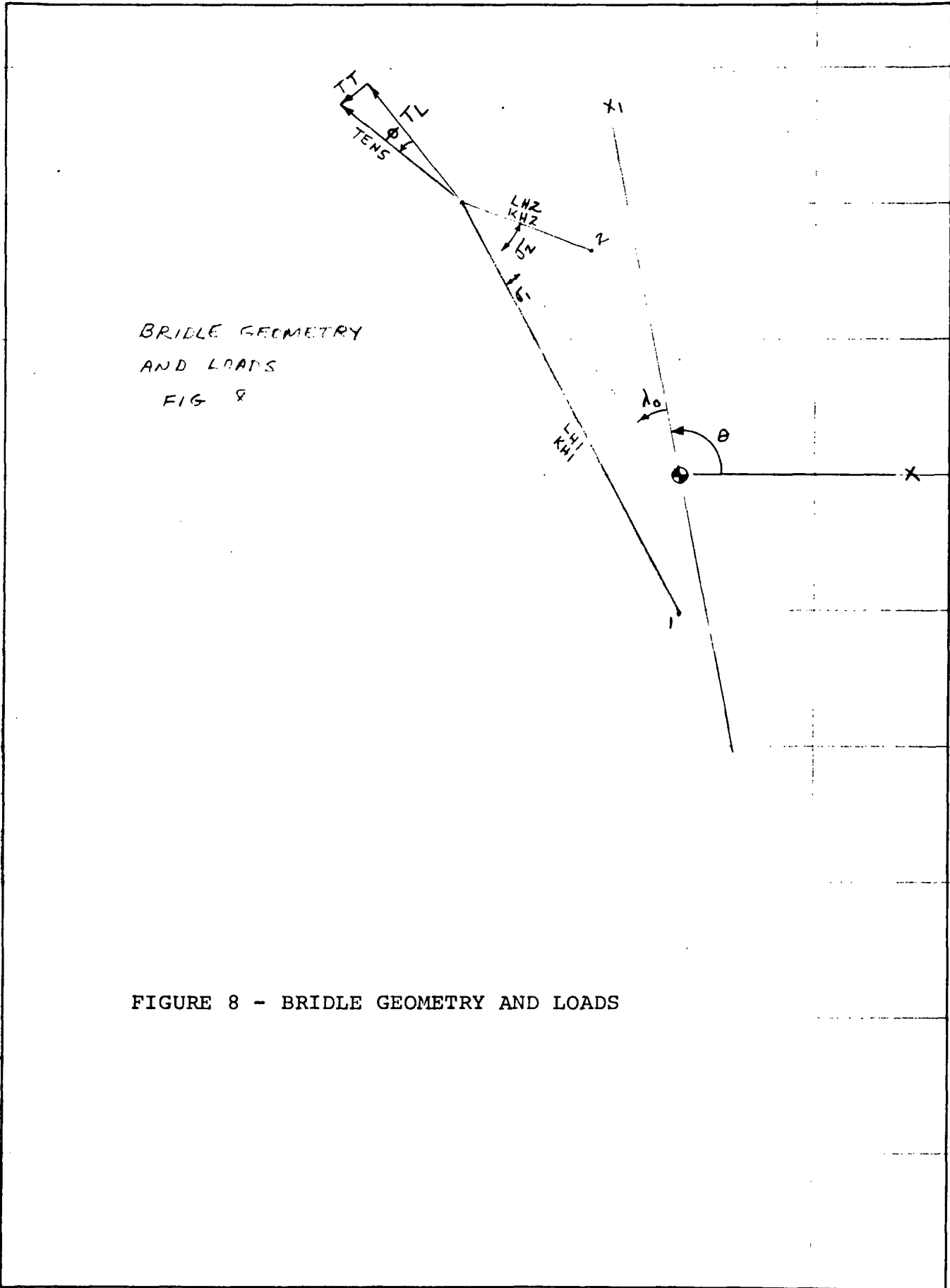
$$\phi = -\theta - \lambda + \frac{\pi}{2} - \chi \tag{96}$$

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BRIDLE GEOMETRY
AND LOADS
FIG 8

FIGURE 8 - BRIDLE GEOMETRY AND LOADS

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2. Bridle Geometry

At any given time the bridle schematic will be as shown in Figure 6. The complete geometry of the system, shown in Figure 6 can be defined by inputting six variables. These variables are LH1, LH2, \bar{A}_1 , \bar{A}_2 , \bar{B}_1 , \bar{B}_2 . LH1, and LH2 are always positive and represent the lengths of the two bridle lines of the bridle. \bar{A}_1 and \bar{A}_2 are positive towards the nose of the vehicle. They represent the distance to the location of the bridle attach points along the centerline. \bar{B}_1 and \bar{B}_2 represent distances to the bridle attach points along the lateral axis of the vehicle. With these six values the geometry of Figure 6 is defined through the following equations:

$$L_1 = \sqrt{\bar{A}_1^2 + \bar{B}_1^2} \quad (97)$$

$$L_2 = \sqrt{\bar{A}_2^2 + \bar{B}_2^2} \quad (98)$$

$$DL = \sqrt{(\bar{B}_2 - \bar{B}_1)^2 + (\bar{A}_2 - \bar{A}_1)^2} \quad (99)$$

$$\beta_1 = \cos^{-1} [(L_1^2 + DL^2 - L_2^2) / (2 * L_1 * DL)] \quad (100)$$

$$\beta_2 = \cos^{-1} [(L_2^2 + DL^2 - L_1^2)/(2*L_2*DL)] \quad (101)$$

$$\epsilon_1 = \cos^{-1} [(LH1^2 + DL^2 - LH2^2)/(2*LH1*DL)] \quad (102)$$

$$\epsilon_2 = \cos^{-1} [(LH2^2 + DL^2 - LH1^2)/(2*LH2*DL)] \quad (103)$$

$$\eta_1 = \pi - \beta_1 - \epsilon_1 \quad (104)$$

$$\eta_2 = \pi - \beta_2 - \epsilon_2 \quad (105)$$

$$L_0 = [L_1^2 + LH1^2 - 2*LH1*L_1*\cos(\beta_1 + \epsilon_1)]^{1/2} \quad (106)$$

$$\lambda_2 = \tan^{-1}(\bar{B}_2/\bar{A}_2) \quad (107)$$

$$\lambda_1 = \tan^{-1}(\bar{B}_1/\bar{A}_1) \quad (108)$$

$$\lambda_0 = \lambda_2 + \cos^{-1} [(L_2^2 + L_0^2 - LH2^2)/(2*L_2*L_0)] \quad (109)$$

$$\sigma_1 = \pi - \beta_1 - \epsilon_1 - (\lambda_1 - \lambda_0) \quad (110)$$

$$\sigma_2 = \pi - \beta_2 - \epsilon_2 - (\lambda_0 - \lambda_2) \quad (111)$$

$$\nu = \lambda_0 \quad (112)$$

$$\bar{A}_0 = L_0 * \cos \nu \quad (113)$$

$$\bar{B}_0 = L_0 * \sin \nu \quad (114)$$

Equations (97) to (114) are used to find the point which the tension is acting through. If ϕ is greater than σ_1 , the confluence point of the forebody is located at (\bar{A}_1, \bar{B}_1) ; if ϕ is less than σ_2 , the confluence point is at (\bar{A}_2, \bar{B}_2) . Otherwise the confluence point is at (\bar{A}_0, \bar{B}_0) . However, (\bar{A}_0, \bar{B}_0) is a variable depending on LH1 and LH2 which depend on the tension and the angle ϕ . The following method is used to find LH1 and LH2 when each leg of the bridle is under tension. Figure 8 shows a schematic of the forebody bridle.

The tension loads in lines LH1 and LH2 are given by Equations 115 and 116.

$$T_1 = \text{TENS} \left[\frac{-\sin\phi \cos\sigma_2}{\sin(\sigma_1 + \sigma_2)} + \frac{\cos\phi \sin\sigma_2}{\sin(\sigma_1 + \sigma_2)} \right] \quad (115)$$

$$T_2 = \text{TENS} \left[\frac{\sin\phi \cos\sigma_1}{\sin(\sigma_1 + \sigma_2)} + \frac{\cos\phi \sin\sigma_1}{\sin(\sigma_1 + \sigma_2)} \right] \quad (116)$$

The change in lengths of bridle lines LH1 and LH2 from unstrained length is given by Equations 117 and 118.

$$DL = T_1/KH1 \quad (117)$$

$$DL = T_2/KH2 \quad (118)$$

The bridle spring constants, KBT and KBL in the directions of forces TT and TL are given by Equations 119 and 120.

$$KBT = \left[\left\{ \frac{\cos \sigma_2}{\sin(\sigma_1 + \sigma_2)} \right\}^2 \cdot \frac{1}{KH1} + \left\{ \frac{\cos \sigma_1}{\sin(\sigma_1 + \sigma_2)} \right\}^2 \cdot \frac{1}{KH2} \right]^{-1} \quad (119)$$

$$KBL = \left[\left\{ \frac{\sin \sigma_2}{\sin(\sigma_1 + \sigma_2)} \right\}^2 \cdot \frac{1}{KH1} + \left\{ \frac{\sin \sigma_1}{\sin(\sigma_1 + \sigma_2)} \right\}^2 \cdot \frac{1}{KH2} \right]^{-1} \quad (120)$$

Now using equations 117 and 118

$$LH1 = LH1 + DL_1 \quad (121)$$

$$LH2 = LH2 + DL_2 \quad (122)$$

If the value of LH1 and LH2 are now used in equations (97) to (114) the confluence point will be translated and \bar{A}_0 and \bar{B}_0 will be used to give new values of A, B, ϕ , μ , etc. Now the process is repeated. This is done until $\phi_i - \phi_{i-1} \leq .5$ degree. If the iteration does not converge for $i \leq 10$, the program will write out "ITERATION DOES NOT CONVERGE" and will continue on. It has been observed that during some computer runs the iteration did not converge but continued on to the next step without any noticeable effect to the results. Usually, if the iteration does not converge, a smaller Δt is needed. This of course cost more time on the computer.

3. Parachute Suspension Geometry

A typical parachute has many suspension lines. To include the effect of each line separately is no small task. Consequently, the suspension system is assumed to be two lines as shown in Figure 9.

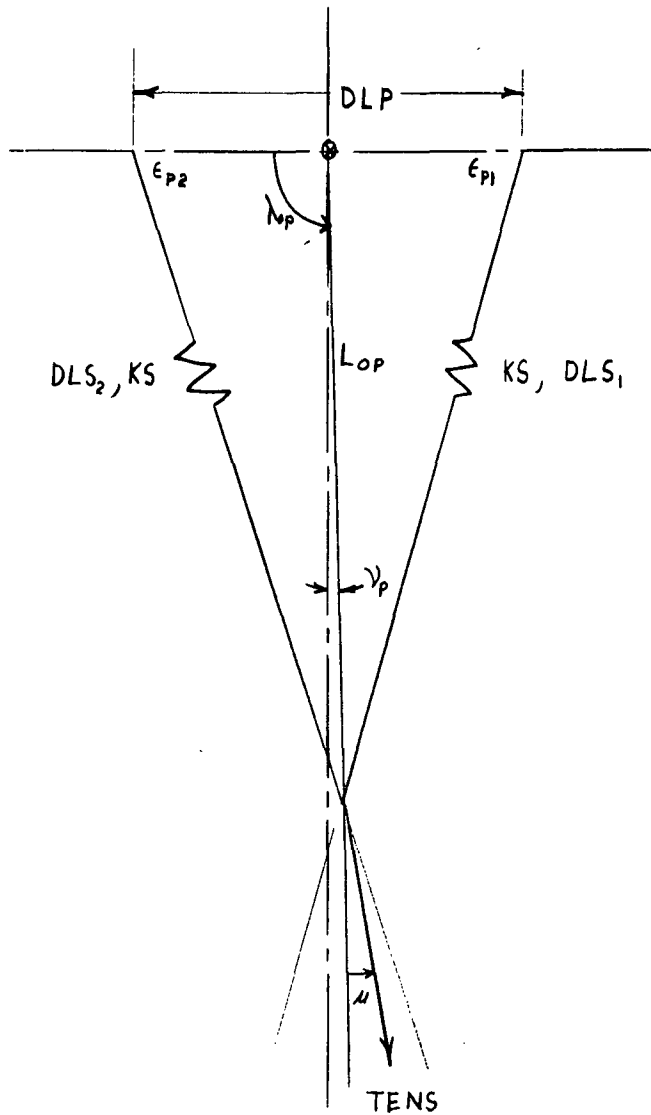


FIGURE 9 - PARACHUTE GEOMETRY

Since the parachute is symmetric, three quantities will define its geometry (DLP, LS1, LS2). The following equations result from this input:

$$\epsilon_{p1} = \cos^{-1} [(DLP^2 + LS1^2 - LS2^2)/2*DLP*LS1] \quad (123)$$

$$\epsilon_{p2} = \cos^{-1} [(DLP^2 + LS2^2 - LS1^2)/2*DLP*LS2] \quad (124)$$

$$L_{0p} = [(\frac{DLP}{2})^2 + LS1^2 - DLP*LS1*\cos \epsilon_{p1}]^{\frac{1}{2}} \quad (125)$$

$$\nu_p = \cos^{-1} [((\frac{DLP}{2})^2 + L_{0p}^2 - LS2^2)/(DLP*L_{0p})] - \frac{\pi}{2} \quad (126)$$

$$\bar{A}_p = L_{0p} \cos \nu_p \quad (127)$$

$$\bar{B}_p = L_{0p} \sin \nu_p \quad (128)$$

Like the bridle confluence point the suspension lines confluence point can also translate. Summing forces in two orthogonal directions, and assuming the system to be in equilibrium, yields

$$TENS*\cos(\mu + \nu_p) = DLS_1*KS \sin \epsilon_{p1} + DLS_2*KS \sin \epsilon_{p2} \quad (129)$$

$$TENS*\sin(\mu + \nu_p) = -DLS_1*KS \cos \epsilon_{p1} + DLS_2*KS \cos \epsilon_{p2} \quad (130)$$

Expressing (127) and 128) in matrix form, inverting and solving for DLS_1 and DLS_2 gives:

$$\text{TENS} \begin{Bmatrix} \cos(\mu + v_p) \\ \sin(\mu + v_p) \end{Bmatrix} = \text{KS} \begin{bmatrix} \sin \epsilon_{p1} & \sin \epsilon_{p2} \\ -\cos \epsilon_{p1} & \cos \epsilon_{p2} \end{bmatrix} \begin{Bmatrix} DLS_1 \\ DLS_2 \end{Bmatrix} \quad (131)$$

$$\begin{Bmatrix} DLS_1 \\ DLS_2 \end{Bmatrix} = \frac{\text{TENS}}{\text{KS} \cdot \sin(\epsilon_{p1} + \epsilon_{p2})} \begin{bmatrix} \cos \epsilon_{p2} & -\sin \epsilon_{p2} \\ \cos \epsilon_{p1} & \sin \epsilon_{p1} \end{bmatrix} \begin{Bmatrix} \cos(\mu + v_p) \\ \sin(\mu + v_p) \end{Bmatrix} \quad (132)$$

Using equation (130) LS_1 and LS_2 are calculated.

$$LS_1 = LS_1 + DLS_1 \quad (133)$$

$$LS_2 = LS_2 + DLS_2 \quad (134)$$

If these values are used in equations (123) to (128) the confluence point will be translated as shown in Figure 9, and new values of \bar{A}_p and \bar{B}_p will be used in the equation of motion. Unlike the bridle it is assumed that neither side of the suspension lines will become slack. This motion of the suspension line confluence point is also included in the iteration process mentioned at the end of the preceding Section III-2.

It is possible to allow each suspension line to stretch independently, thereby providing a better simulation. To allow the parachute to change geometry under load, remove the "C" from the comment column of the card CALL SUSPEN in the subroutine SUBR. This allows entry to SUSPEN and provides for stretch in the suspension lines.

4. Spring Constant of Elastic System

When both bridle lines are in tension, the spring constant for the bridle is given by:

$$K\phi = \frac{KBL * KBT}{[KBT * \cos^2 \phi + KBL * \sin^2 \phi]} \quad (\text{Ref Pg 28}) \quad (135)$$

Then the spring constant for the complete system is

$$K = \frac{2 * KS * K\phi}{2 * KS + K\phi} \quad (\text{Ref Pg 22}) \quad (136)$$

If one bridle line goes slack the spring constant becomes either:

$$K = KSPKH1 = \frac{2 * KS * KH1}{2 * KS + KH1} \quad (137)$$

or

$$K = KSPKH2 = \frac{2 * KS * KH2}{2 * KS + KH2} \quad (138)$$

SECTION IV - COMPUTER PROGRAM

1. Inputs

The format for all numeric inputs is 8F10.0. There are a couple alphameric inputs which use 20A4. The following is a list of all inputs used to make a computer run in the order read in.

ATMOS	- Alphameric discription of atmosphere, 1 card	
TIMEI	- Alphameric statement, TIME SEQUENCE OF INFLATION, 1 card	
AREAI	- Alphameric statement, AREA SEQUENCE OF INFLATION, 1 card	
TTI	- An array of 16 variables representing time inflation sequence, 2 cards	sec
SSPI	- An array of 16 variables representing reference area of decelerator, S_o , corresponding to TTI, 2 cards	m ²
MMA	- An array of 16 variables representing added mass associated with the decel- erator corresponding to TTI, 2 cards	kg
IIYP	- An array of 16 variables representing pitch moment of inertia of the decel- erator corresponding to TTI, 2 cards	kg-m ²
TTG	- An array of eight variables repre- senting time for gust sequence, 1 card	sec
VVG	- An array of eight variables repre- senting gust velocities corresponding to TTG, 1 card	m/sec

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- AAM - An array of eight variables representing Mach number of the forebody, 1 card
- AAMP - An array of eight variables representing Mach number of the decelerator, 1 card
- AALPE - An array of eight variables representing angle-of-attack of the forebody, 1 card deg
- AALPPE - An array of eight variables representing angle-of-attack of the decelerator, 1 card deg
- CCA - An array of eight by eight variables representing axial force coefficients of the forebody, 8 cards
- CCN - An array of eight by eight variables representing normal force coefficients of the forebody, 8 cards
- CCM - An array of eight by eight variables representing pitch moment coefficients of the forebody, 8 cards
- CCMQ - An array of eight by eight variables representing pitch damping coefficient of the forebody, 8 cards rad⁻¹
- CCAP - An array of eight by eight variables representing axial force coefficient of the decelerator, 8 cards
- CCNP - An array of eight by eight variables representing normal force coefficients of the decelerator, 8 cards
- CCMP - An array of eight by eight variables representing pitch moment coefficients of the decelerator, 8 cards

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CCMQP	- An array of eight by eight variables representing pitch damping coefficients of the decelerator, 8 cards	rad ⁻¹
TTENS	- An array of 8 elements representing force in spring KS	N
KKS	- An array of 8 elements representing the spring constant, KS	N/m
X	- Initial range of forebody	m
Z	- Initial altitude of forebody	m
THE	- Initial pitch angle of forebody	deg
THED	- Initial pitching velocity of forebody	deg/sec
V	- Initial velocity of forebody	
GAM	- Initial flight path angle of forebody	deg
HHH	- Altitude below which trajectory ends	m
THEP	- Initial pitch angle of decelerator	deg
GAMP	- Initial flight path angle of decelerator	deg
VP	- Initial velocity of decelerator	m/sec
THEPD	- Initial pitching velocity of decelerator	deg/sec
TOR	- Maximum value of torque from the reaction control system	m-N
THEDU	- Forebody's pitching rate at which the reaction control thruster is turned on giving a torque of TOR	deg/sec
THEDL	- Forebody's pitching rate at which the reaction control thruster begins to turn off	deg/sec

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DTVC	-	Length of time for reaction control thruster valve to close	sec
APBAR	-	Distance from c.g. of decelerator to confluence point of the decelerator suspension lines	m
XBAR	-	Lateral c.g. off-set of forebody positive up	m
ZBAR	-	Longitudinal c.g. off-set of forebody, positive towards nose	m
S	-	Aerodynamic reference area of forebody	m ²
D	-	Aerodynamic reference length of forebody	m
M	-	Mass of forebody	kg
IY	-	Pitch moment of inertia of forebody	kg-m ²
LTR	-	Length of riser line	m
C	-	Damping coefficient of elastic system	N $\frac{\text{sec}}{\text{m}}$
DP	-	Aerodynamic reference length of decelerator (same as Ref. dia. D _o)	m
MP	-	Mass of decelerator	kg
IYP	-	Moment of inertia of decelerator fully inflated	kg-m ²
DTI	-	Inflation time	sec
T	-	Initial time	sec
TI	-	Time inflation begins	sec
DT1	-	First integration time increment	sec
DT2	-	Second integration time increment	sec
DTP1	-	Number of integrations between printout when DT = DT1	

DTP2	-	Number of integrations between print-out when DT=DT2	
TDTC	-	Time at which DT1 → DT2 and DTP1 → DTP2	sec
TTT	-	Time at which trajectory is ended	sec
LH1	-	Length of first bridle line (see Figure 7)	m
LH2	-	Length of second bridle line (see Figure 7)	m
A1BAR	-	Distance along longitudinal axis of the forebody from the intersection of the body axes to the negative harness attach point, positive toward the nose (see Figure 7)	m
A2BAR	-	Distance along longitudinal axis of the forebody from the intersection of the body axes to the positive harness attach point, positive toward the nose (see Figure 7)	m
B1BAR	-	Distance along lateral axis of the forebody from the intersection of the body axes to the negative harness attach point, positive up (see Figure 7)	m
B2BAR	-	Distance along lateral axis of the forebody from the intersection of the body axes to the positive harness attach point, positive up (See Figure 7)	m
LS1	-	Length of first suspension line	m

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LS2	-	Length of second suspension line	m
DLP	-	Distance between the two suspension line connection points on the decelerator	m
KH1	-	Spring constant of bridle line LH1	N/m
KH2	-	Spring constant of bridle line LH2	N/m
HEADER	-	Title card for plot	
CONT	-	Condition card for digital program	

2. Output

At predetermined intervals (see inputs eee, fff), the following data is outputted. Each term is defined in the nomenclature.

1st row: T, X, XD, XDD, VD, GAMDEG, AM, TENS, PHIDEG,
QX, CA, CAP

2nd row: TORQ, Z, ZD, ZDD, VPD, GAMPDE, AMP, DAMP, PHIDDE,
QZ, CN, CNP

3rd row: M, THEDEG, THEDDE, THEDDD, NA, ALPDEG, DYPR, LT0,
MUDEG, QTHE, CM, CMP

4th row: MP, XP, XPD, XPDD, NN, ALPPDE, DYPRP, LT, MUDDEG,
QXP, CMQ, CMQP

5th row: IY, ZP, ZPD, ZPDD, NAP, V, DP, LTD, CHIDEG, QZP,
K, CAAP

6th row: IYP, THPDEG, THPDDE, THPDDD, NNP, VP, RHO, DCG,
CHIDDE, QTHEP, C, SPI

7th row: LAMDEG, A, B, PHILDE, PHI2DE, ABAR, BBAR, NUPDEG,
APBAR, BPBAR, LOP, VG

When a simulation reaches TTT or HHH, the computer will write out "RUN ENDED BY CONSTRAINTS." It will then attempt to read in more data cards to initialize for another run. If the first card read in contains a "1." in the first two columns, the program will CALL EXIT. Otherwise it will read in data starting from input (y) and proceeding to input (www).

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Before beginning each trajectory, a list of variables will be printed out which mostly define the initial geometry of the system. These variables are defined in the nomenclature.

1st row: LH1, LH2, A1BAR, A2BAR, B1BAR, B2BAR, L1, L2,
DL, L0, BET1DE, BET2DE

2nd row: EPS1DE, EPS2DE, ETA1DE, ETA2DE, SIG1DE, SIG2DE,
LAM1DE, LAM2DE, LAM0DE, NUDEG, A0BAR, B0BAR

3rd row: K, KSPKH1, KSPKH2, T1, DT1, THEDU, THEDL, TOR,
DTVC, LS1, LS2, DLP

4th row: LOP, LAMOPD, NUPDEG, APBAR, BPBAR, EPSP1D,
EPSP2D, DT, KH1, KH2

Also printed out is the atmosphere used; the area versus time inflation sequence; spring constant array, KKS(8), and its tension array, TTENS(8); and the aerodynamic coefficient arrays and their associated mach number and angle of attack arrays.

3. Fortran IV Program Description

A listing of the program may be found in Section IV-5.
A description of the main program and the subroutines follows:

a. Main Program

- 1) Read inputs
- 2) Initialize and define certain variables
- 3) Call BRIDLE so that the geometry of the system may be defined
- 4) Output data points on tape for later plotting if $T > TPLOT$
- 5) Check time and altitude constraints (inputs ee and hhh)
- 6) If constraint or output conditions are met, write output
- 7) Advance the six coordinates through one time increment (Δt) by use of Runge-Kutta numerical integration
- 8) Check for increase in DT and DTP (input ggg)

b. Subroutine SUBR

- 1) Calculate acceleration of gravity at Z
- 2) Calculate torque available from reaction control system
- 3) Calculate gust velocity as a function of time, and density and speed of sound as a function of altitude
- 4) Calculate total inertial velocity, Mach number, and dynamic pressure of the forebody and decelerator

- 5) Calculate flight path angle and angle-of-attack
- 6) Call AERO to determine the aerodynamics of the system
- 7) Calculate bridle, riser, suspension lines geometry under tension and iterate until the geometry converges to one compatible to the tension in the elastic system. After the iteration has converged, the tension, damping, pull-off angles and rates will be determined.
- 8) Call MATRIX to determine the equation of motion of the forebody
- 9) Express equations of motion of decelerator

c) Subroutine AERO

- 1) Calculate the aerodynamic coefficients of the forebody and the decelerator as a function of Mach number and angle-of-attack
- 2) Calculate the generalized forces acting on the forebody
- 3) Calculate the reference area, apparent mass, pitch moment of inertia and total mass of decelerator
- 4) Calculate the aerodynamic coefficients of the decelerator (CNP, CMP, CMQP) during inflation, assumed a linear increase
- 5) Calculate the generalized forces acting on the decelerator

d) Subroutine MATRIX

- 1) Define the matrices DD(i,j) and EE(i)
- 2) Call CROUT so that the equations of motion of the forebody are separated into a form suitable for integration



e) Subroutine BRIDLE

- 1) Calculate the geometry of the bridle, bridle attach points and intersection of the body axes of the forebody
- 2) Call SUSPEN so that the geometry of the decelerator and suspension lines can be defined.
- 3) Write out pertinent information about the geometry of the system
- 4) Define the initial position of the decelerator with respect to the forebody

f) Subroutine SUSPEN

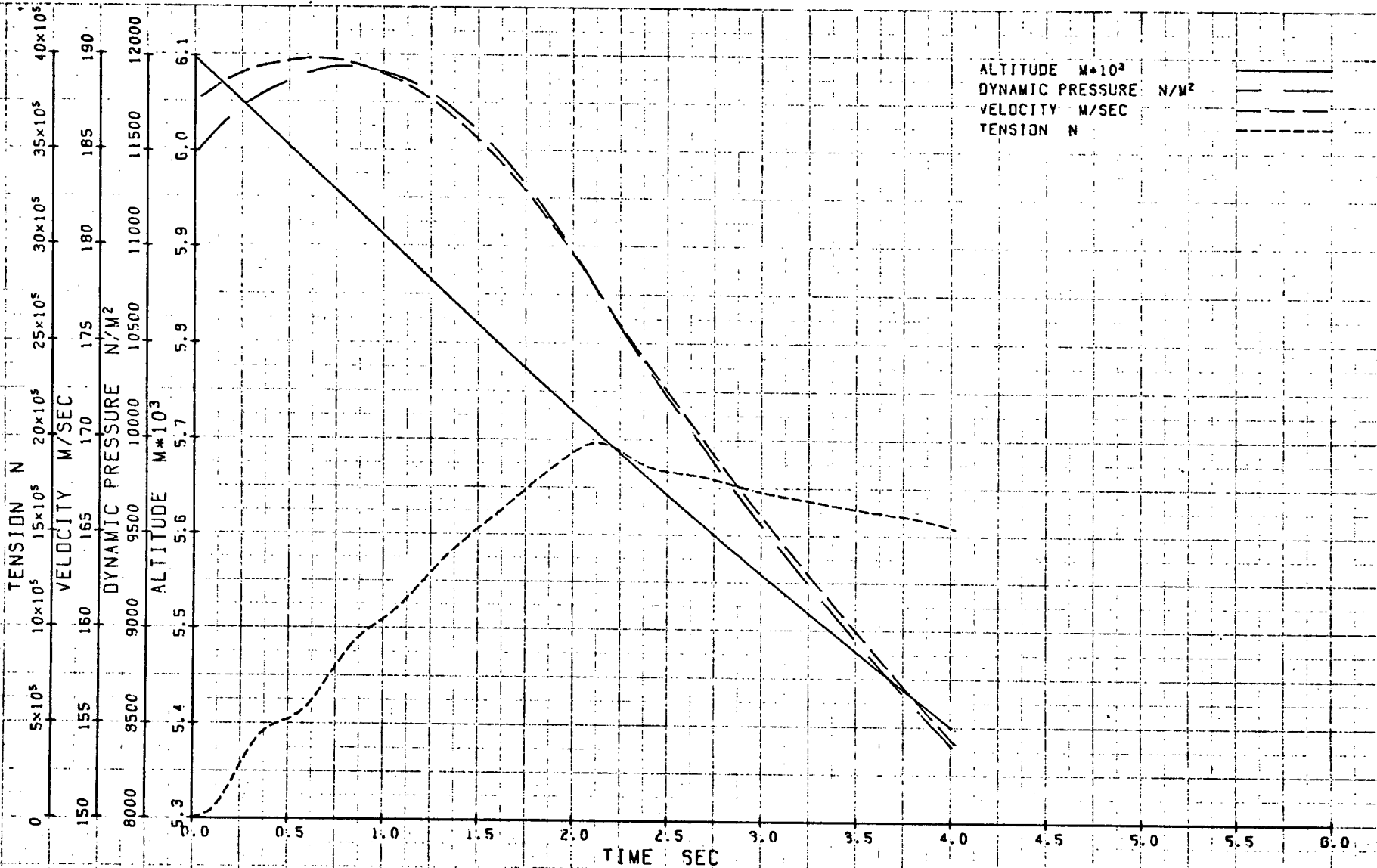
- 1) Calculate the geometry of the decelerator and suspension lines
- 2) Calculate the position of the decelerator if the suspension lines are allowed to stretch

g) Subroutine CROUT

- 1) Decouple the equations of motion of the forebody. Equations (91) will be reduced to the form (92)

4. Sample Computer Run

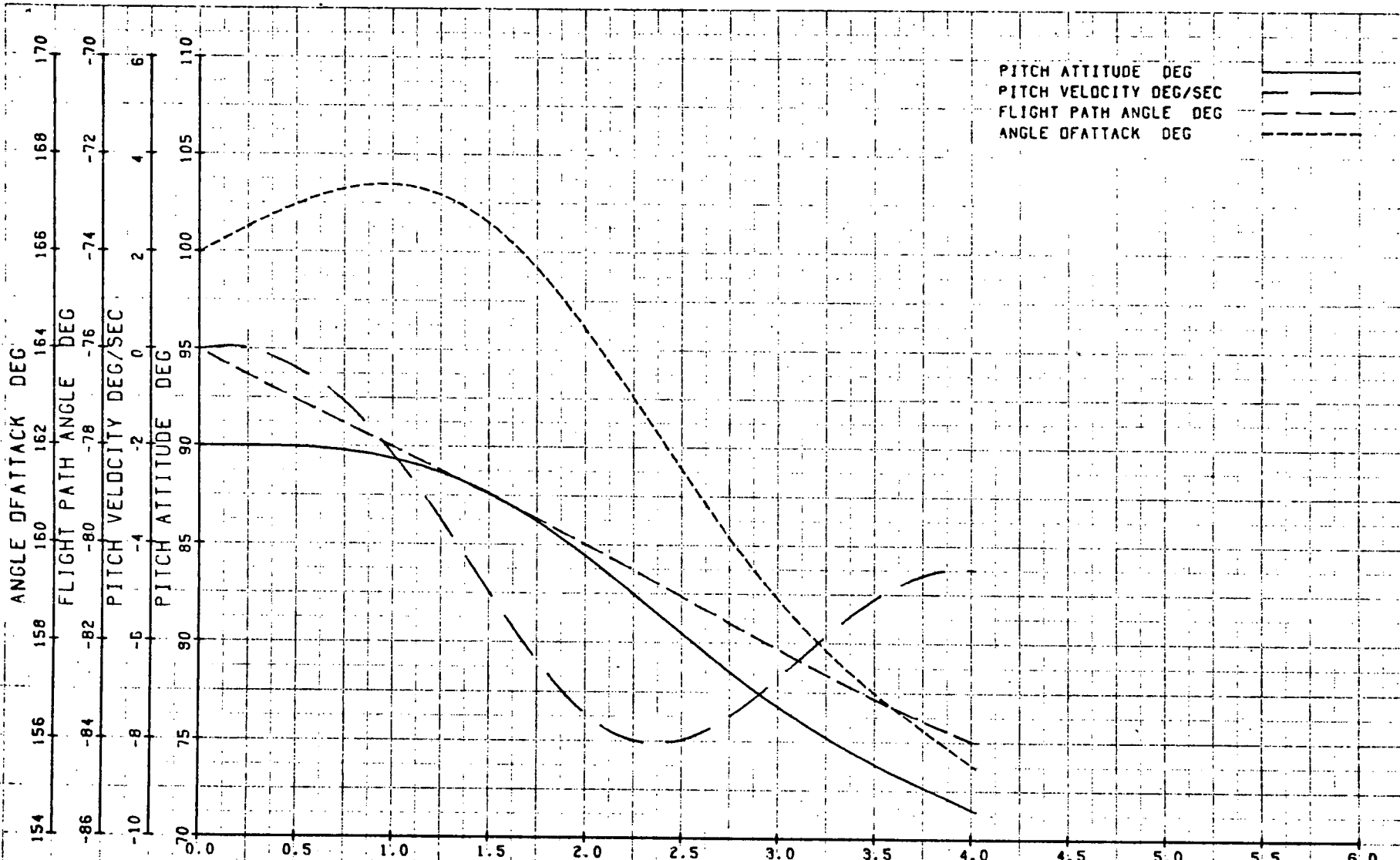
Figure 10 shows Calcomp plots of 8 program output variables versus time for a sample computer run. Immediately following this figure is a list of the input data used to make this run and several pages of output.



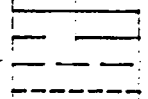
TIME SEC

FIGURE 10

MAIN PAR. DEPLOY THROUGH 1ST STAGE OF REEFING, ALT=6096M, VEL=187.5M/S, GAM=-76 DEG



PITCH ATTITUDE DEG
 PITCH VELOCITY DEG/SEC
 FLIGHT PATH ANGLE DEG
 ANGLE OFATTACK DEG



TIME SEC
 FIGURE 10a

MAIN PAR. DEPLOY THROUGH 1ST STAGE OF REEFING, ALT=6096M, VEL=187.5M/S, GAM=-76 DEG

STANDARD EARTH ATMOSPHERE

MAIN PARACHUTE INFLATION TIME, TTI(16)						
MAIN PARACHUTE DRAG AREA, SSPI(16)						
0.0	2.	10.	14.	30.	39.	1000.
0.0						
2.7871	371.612	371.612	1114.836	1114.836	3307.347	3307.347
0.0						
146.	876.	876.	2919.	2919.	8756.	8756.
0.0						
566732.76	566732.76	566732.76	566732.76	566732.76	566732.76	566732.76
0.0						
0.0	1000.					
0.0						

SPACE SHUTTLE BOOSTER, MAIN PARACHUTE DEPLOYMENT THROUGH 1ST STAGE OF REEFING

INITIAL VALUES, ENGINEERING UNITS ARE METRIC (METERS, NEWTON, SEC)

LH1	LH2	A1BAR	A2BAR	B1BAR	B2BAR	L1	L2	DL	LO	BET1	BET2
EPS1	EPS2	ETA1	ETA2	SIG1	SIG2	LAM1	LAM2	LAM3	VU	A0BAR	B0BAR
KSPKB	KSPKH1	KSPKH2	T-INF	DT-INF	THEDU	THEDL	TORQUE	DT-VALVE	LS1	LS2	DLP
LOP	LAMOP	NUP	APBAR	BPBAR	EPS1P	EPS2P	DT	KH1	KH2		
36.576	6.096	-12.192	24.384	1.981	1.981	12.352	24.464	36.576	25.198	9.230	4.645
9.560	85.220	161.210	90.135	9.084	76.135	170.770	4.645	18.645	18.645	23.876	8.056
556571.	547271.	761421.	0.0	2.000	9.000	8.000	0.0	0.010	69.799	69.799	30.480
68.115	90.000	0.000	68.115	0.000	77.388	77.388	0.025	1459390.	5837561.		

SHUTTLE ROCKET MOTOR STANDARD EARTH ATMOSPHERE

MAIN PARACHUTE INFLATION TIME, ITI(16)

0.0	2.000	10.000	14.000	30.000	38.000	1000.000	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

MAIN PARACHUTE DRAG AREA, SSPI(16)

2.787	371.612	371.612	1114.836	1114.836	3307.347	3307.347	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SPRING CONSTANT ARRAY, KKS(8)

437817.1	437817.1	0.0	0.0	0.0	0.0	0.0	0.0
----------	----------	-----	-----	-----	-----	-----	-----

SPRING CONSTANT TENSION ARRAY, ITENS(8)

0.044482216.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
---------------	-----	-----	-----	-----	-----	-----	-----

AERODYNAMIC PARAMETERS

FORBODY ANGLE OF ATTACK ARRAY, AALP(16) DEGREES

0.0	45.000	80.000	90.000	110.000	135.000	180.000	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

MACH NUMBER ARRAY, AAM(8)

0.0	10.000	0.0	0.0	0.0	0.0	0.0	0.0
-----	--------	-----	-----	-----	-----	-----	-----

FORBODY AXIAL COEF. ARRAY, CCA(8,16)

4.8500	2.3000	-0.6800	-1.0000	-1.2000	-1.1000	-0.5500	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.8500	2.3000	-0.6800	-1.0000	-1.2000	-1.1000	-0.5500	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

FORBODY NORMAL COEF. ARRAY, CCN(8,16)

0.0	8.5000	16.5000	17.0000	15.8000	10.0000	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	8.5000	16.5000	17.0000	15.8000	10.0000	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TIME	RANGE	HORVEL	HORACC	TOTACC	GAMMA	MACH NO	TENSION	PHI	QX	CA	CAP
TORQUE	ALTITUDE	VERTVEL	VERTACC	TOTACCP	GAMMAP	MACH NOP	DAMPING	PHID	QZ	CN	CNP
MASS	THETA	THEVEL	THEACC	AX-G	ALPHA	DY-PR	LTO	MU	QTHE	C4	C4P
MASSP	RANGE P	HORVELP	HORACCP	NOR-G	ALPHAP	DY-PRP	LT	MUD	QXP	CMQ	CMQP
IY	ALTITUDEP	VERTVELP	VERTACCP	AX-SP	VELOCITY	DP	LTD	CHI	QZP	K	CAAP
IYP	THETAP	THEVELP	THEACCP	NOR-SP	VELOCITYP	DENSITY	DCG	CHID	QTHEP	C	SP
LAMDA	A	B	PHI1	PHI2	ABAR	BBAR	NUP	APBAR	BPBAR	LOP	GUST VEL
0.0	0.0	45.3	-4.9	9.9	-76.0	0.6	3485.7	-4.6	-441099.	-0.72111	0.50000
0.0	6096.0	-181.9	-8.6	4.4	-76.0	0.6	0.0	0.0	102249.	3.1111	-0.0000
90482.20	90.00	0.0	0.52	-0.88	166.00	11474.61	15.24	0.02	227216.	0.4044	-0.0000
2408.055	-28.22	45.35	-1.26	0.50	-0.00	11474.61	15.25	0.0	-3868.	-0.0	-0.1000
24404760.	6200.8	-181.9	-4.2	0.4	187.5	46.0	0.0	-14.0	15515.	557480.	1.4
566732.76	-76.00	0.0	0.00	-0.23	187.45	0.65310	00	108.50	0.0	-0.	875.63
18.64	-3.69	14.79	9.08	76.10	23.88	8.06	0.00	68.12	0.00	68.12	0.0
0.050	2.3	45.1	-4.9	9.8	-76.1	0.6	9380.1	-4.7	-439923.	-0.71983	0.50000
0.0	6086.9	-182.3	-8.5	15.5	-76.0	0.6	589.1	-0.9	102548.	3.0879	0.0002
90482.20	90.00	0.03	0.48	-0.87	166.10	11530.15	15.24	-0.02	226609.	0.4014	0.0000
2426.305	-25.96	45.16	-5.86	0.50	0.03	11447.79	15.26	-0.90	-16628.	-0.0	-0.1000
24404760.	6191.7	-181.6	14.3	-1.6	187.8	46.0	0.7	-14.0	66697.	557486.	6.0
566732.76	-76.00	-0.00	-0.02	-0.23	187.14	0.65380	00	108.51	0.90	46.	875.63
18.64	-3.69	14.80	9.08	76.08	23.88	8.06	0.00	68.12	0.00	68.12	0.0
0.100	4.5	44.9	-5.0	9.6	-76.2	0.6	36912.1	-4.7	-438669.	-0.71855	0.50000
0.0	6077.8	-182.7	-8.2	24.6	-76.1	0.6	1827.9	-1.8	102837.	3.0645	0.0005
90482.20	90.00	0.05	0.34	-0.84	166.21	11584.94	15.24	-0.08	225962.	0.3984	0.0000
2444.555	-23.71	44.80	-8.09	0.50	0.07	11329.45	15.31	-1.75	-29092.	-0.0	-0.1000
24404760.	6182.6	-180.6	23.3	-2.5	188.2	46.0	2.1	-13.9	116708.	557505.	10.6
566732.76	-76.00	-0.01	-0.34	-0.23	186.07	0.65440	00	108.53	1.76	189.	875.63
18.63	-3.69	14.86	9.07	75.92	23.90	8.06	0.00	68.12	0.00	68.12	0.0
0.150	6.7	44.6	-5.1	9.1	-76.3	0.6	95587.2	-4.8	-437277.	-0.71726	0.50000
0.0	6068.6	-183.1	-7.6	20.5	-76.1	0.6	3171.1	-2.4	103094.	3.0411	0.0007
90492.20	90.01	0.06	0.04	-0.77	166.32	11637.03	15.24	-0.16	225242.	0.3953	0.0000
2462.805	-21.48	44.40	-7.15	0.52	0.10	11194.32	15.41	-2.33	-41227.	-0.0	-0.1000
24404760.	6173.6	-179.5	19.2	-2.1	188.5	46.0	3.6	-13.8	155424.	557530.	15.2
566732.76	-76.00	-0.05	-1.82	-0.23	184.87	0.65510	00	108.72	2.38	689.	875.63
18.61	-3.69	14.96	9.06	75.58	23.94	8.06	0.00	68.12	0.00	68.12	0.0
0.200	9.0	44.3	-5.3	8.5	-76.4	0.6	180936.9	-4.8	-435693.	-0.71597	0.50000
0.0	6059.5	-183.5	-6.7	6.2	-76.1	0.6	4058.3	-2.5	103308.	3.0177	0.0009
90482.20	90.01	0.05	-0.40	-0.68	166.42	11684.38	15.24	-0.24	224423.	0.3923	0.0000
2481.055	-19.27	44.11	-3.77	0.54	0.13	11117.72	15.56	-2.19	-53321.	-0.0	-0.1000
24404760.	6164.7	-178.8	4.9	-0.6	188.8	46.0	4.6	-13.7	214073.	557554.	19.8
566732.76	-76.01	-0.21	-5.17	-0.25	184.14	0.65580	00	108.93	2.40	2468.	875.63
18.58	-3.70	15.12	9.04	75.07	24.00	8.07	0.00	68.12	0.00	68.12	0.0
0.250	11.2	44.1	-5.5	7.9	-76.5	0.6	277830.2	-4.9	-433903.	-0.71471	0.50000
0.0	6050.3	-183.8	-5.6	12.7	-76.2	0.6	4157.8	-1.6	103476.	2.9947	0.0011
90482.20	90.01	0.02	-0.90	-0.57	166.52	11725.62	15.24	-0.29	223500.	0.3893	0.0000
2499.305	-17.07	44.01	0.37	0.56	0.16	11143.47	15.74	-0.97	-65781.	-0.0	-0.1000
24404760.	6155.7	-178.9	-12.7	1.3	189.0	46.0	4.7	-13.7	264482.	557565.	24.4
566732.76	-76.03	-0.57	-9.07	-0.28	184.26	0.65640	00	109.17	1.54	7007.	875.63
18.55	-3.72	15.29	9.01	74.49	24.06	8.07	0.00	68.12	0.00	68.12	0.0

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C GOODYEAR AEROSPACE PROGRAM ZK886
C ASSESSMENT OF LOADS RESULTING FROM PARACHUTE DECELERATION SYSTEM
C CONVERTED FOR MSFC UNDER NASA CONTRACT VAS8-29144
IMPLICIT REAL*8(A-H,O-Z)
REAL TM(302),YA(302),YB(302),YC(302),YD(302),YE(302),YF(302),
1 YG(302),YH(302),HEADER(14)
DOUBLE PRECISION LAM1DE,LAM2DE,LAMUDE,NUDEG,LAMOPD,KS,
1KSPKH2,LTR,MJ,MUD,LH1,LH2,L1,L2,L0,LAM1,LAM2,LAM0,NU
2,MUDEG,MUDEG,NAP,NNP,LAM,LAMDEG,LS1,LS2,LJP,LAMOP,NJP,NJPDEG
3,M,MP,IY,IYP,LT,LTD,LTO,NA,NN,K,KSPKH1
4,MMA(16),MA,IYYP(16),KBL,KBT,KH1,KH2,KPH1,KKS(8)
DIMENSION ATMOS(20),TIMEI(20),AREAI(20)
COMMON T,DT,X,Z,XP,ZP,THEP,THEP,XD,ZD,XPZ,ZPD,THEP,THEP,GAM,GAMP,
1ALP,ALPP,AM,AMP,DYPR,DYPRP,RHO,S,SP,D,DP,M,MP,IY,IYP,LT,LTD,LTO,
2DCG,C,K,CA,CN,CM,CMQ,CCA(8,16),CCN(8,16),CCM(8,16),CCMQ(8,16),CAP,
3CNP,CMP,CMQP,CCAP(8,16),CCNP(8,16),CCMP(8,16),CCMQP(8,16),V,VP,GR,
4R,AA(6,4),DD(3,3),EE(3),FF(3),GX,QZ,QXP,QZP,QTHE,QTHEP,APBAR,XBAR,
5ZBAR,AA4(8),AAMP(8),AALPE(16),AALPPE(16),IIN,IOUT,
6DADTHE,DBDTHE,DADTHP,DBDTHP,ABAR,BBAR,A,B,CHI,CHID,MU,MUD,PHI,SP,I,
7PHID,PHI1,PHI2,BE11,3ET2,EPS1,EPS2,KSPKH1,KSPKH2,LTR,DL,
8SIG1,SIG2,ETA1,ETA2,TENS,DAMP,STHE,CTHE,STHEP,CTHEP,LH1,LH2,
9A1BAR,A2BAR,B1BAR,B2BAR,B3BAR,B3BAR,LC,L1,L2,LAM0,LAM1,LAM2,NU,G
COMMON TOR,THEOU,THEOL,DTVC,TJRO,BRID,LAM,TI,CONF,DTI,COAB
1,TTI(16),SSPI(16),LS1,LS2,LJP,LAMOP,NUP,BPBAR,EPSP1,EPSP2,DLP,KS
2,MMA,MA,TTG(8),VVG(8),VG,IYYP,KBL,KBT,KH1,KH2,TTENS(8),KKS,
3CUNT(20),AALP(16),AALPP(16)
1 FORMAT(3F10.0)
2 FORMAT(20A4)
50 FORMAT(1H1,9X,'TIME',6X,'RANGE',5X,'HORVEL',4X,'HORACC',4X,
1'TOTACC',4X,'GAMMA',5X,'MACH NO',3X,'TENSION',3X,'PHI',7X,'QX',
28X,'CA',8X,'CAP'/10X,'TORQUE',4X,'ALTITUDE',2X,'VERTVEL',3X,
3'VERTACC',3X,'TOTACCP',3X,'GAMMAP',4X,'MACH NUP',2X,'DAMPING',
43X,'PHID',6X,'QZ',8X,'CN',8X,'CNP'/10X,'MASS',6X,'THETA',5X,
5'THEVFL',4X,'THEACC',4X,'AX-G',6X,'ALPHA',5X,'DY-PR',5X,'LTD',
67X,'MU',8X,'QTHE',6X,'CM',8X,'CMP'/10X,'MASSP',5X,'RANGEP',4X,
7'HORVELP',3X,'HORACCP',3X,'NOR-G',5X,'ALPHAP',4X,'DY-PRP',4X,
8'LT',9X,'MUD',7X,'QXP',7X,'CMQ',7X,'CMQP'/10X,'IY',8X,'ALTITUDEP',
91X,'VERTVELP',2X,'VERTACCP',2X,'AX-GP',5X,'VELOCITY',2X,'OP',
18X,'LTD',7X,'CHI',7X,'QZP',7X,'K',9X,'CAAP'/10X,'IYP',7X,'THETAP',
24X,'THEVELP',3X,'THEACCP',3X,'NOR-GP',4X,'VELOCITYP',1X,'DENSITY'
3,3X,'DCG',7X,'CHID',6X,'QTHEP',5X,'C',9X,'SP'/10X,'LAMDA',5X,
4'A',9X,'B',9X,'PHI1',6X,'PHI2',6X,'ABAR',6X,'BBAR',6X,'NUP',7X,
5'APBAR',5X,'BPBAR',5X,'LJP',7X,'GUST VEL'///)
51 FORMAT(8X,F8.3,1X,8(F9.1,1X),F9.0,2X,2(F8.5,2X)/
18X,9(F8.1,2X),F9.0,1X,2(F8.4,2X)/
28X,F8.2,2X,8(F8.2,2X),F10.0, 2(F8.4,2X)/
38X,F9.3,2X,8(F8.2,2X),F9.0,1X,2(F8.4,2X)/
47X,F9.0,2X,8(F8.1,2X),F9.0,1X,F9.0,1X,F8.1/
58X,6(F9.2,1X),E10.4,2(F8.2,2X),F9.0,1X,2(F9.2,2X)/
68X,12(F8.2,2X)/)
52 FORMAT(///20X,'RUN ENDED BY CONSTRAINT'///)
53 FORMAT(/10X,8F10.3/10X,8F10.3/)
55 FORMAT(/10X,'SHUTTLE ROCKET MOTOR',5X,20A4)
56 FORMAT(/10X,20A4)

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58 FORMAT(1H ,10X,'SPRING CONSTANT ARRAY, <KS(8)'//)
59 FORMAT(1H ,10X,8(F10.1)//)
60 FORMAT(1H ,10X,'SPRING CONSTANT TENSION APRAY, ITENS(9)'//)
61 FORMAT(13A6,A2)

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IIN=5
IOUT=6
READ(IIN,2) ATMOS
READ(IIN,2) TIMEI
READ(IIN,2) AREA1
READ(IIN,1) TTI,SSPI,MMA,IYYP
READ(IIN,1) TTG,VVG
READ(IIN,1) AAM,AAMP,AALPE,AALPPE
DO 20 I=1,16
AALP(I)=AALPE(I)/57.2958
20 AALPP(I)=AALPPE(I)/57.2958
READ(IIN,1)((CCA(I,J),J=1,16),I=1,8)
READ(IIN,1)((CCN(I,J),J=1,16),I=1,8)
READ(IIN,1)((CCM(I,J),J=1,16),I=1,8)
READ(IIN,1)((CCM2(I,J),J=1,16),I=1,8)
READ(IIN,1)((CCAP(I,J),J=1,16),I=1,8)
READ(IIN,1)((CCNP(I,J),J=1,16),I=1,8)
READ(IIN,1)((CCMP(I,J),J=1,16),I=1,8)
READ(IIN,1)((CCMP2(I,J),J=1,16),I=1,8)
READ(IIN,1) TTENS,KKS
105 READ(IIN,1) X,Z,THE,THED,V,GAM,HHH
IF(X.F0.1.) GO TO 900
READ(IIN,1) THEP,GAMP,VP,THEPD
READ(IIN,1) TOR,THEDJ,THEDL,DTVC
READ(IIN,1) APBAR,XBAR,ZBAR
READ(IIN,1) S,D,M,IY,LTR,C
READ(IIN,1) DP,MP,IYP,DTI,TI
READ(IIN,1) T,DT1,DT2,DTP1,DTP2,TDIC,TTI
READ(IIN,1) LH1,LH2,A1BAR,A2BAR,B1BAR,B2BAR
READ(IIN,1) LS1,LS2,DLP,KH1,KH2
READ(IIN,61) HEADER
READ(IIN,2) CONT
THE=THE/57.2958
GAM=GAM/57.2958
THED=THED/57.2958
THEP=THEP/57.2958
THEPD=THEPD/57.2958
GAMP=GAMP/57.2958
XD=V*DCOS(GAM)
ZD=V*DSIN(GAM)
XPD=VP*DCOS(GAMP)
ZPD=VP*DSIN(GAMP)
R= 6378377.
GR= 9.8054160
C GR=32.17
C R=20926435.
DT=DT1
DTP=DTP1
LTO=LTR
TENS=0.

```

```

MA=0.
CONF=0.
L=0
CALL BRIDLE
WRITE(IOUT,55) ATMOS
WRITE(IOUT,56) TIMEI
WRITE(IOUT,53) TTI
WRITE(IOUT,56) AREA1
WRITE(IOUT,53) SSP1
WRITE(IOUT,58)
WRITE(IOUT,59)(KKS(I),I=1,8)
WRITE(IOUT,60)
WRITE(IOUT,59)(TTENS(I),I=1,8)
17 FORMAT(1H1,10X,'AFRODYNAMIC PARAMETERS'//)
18 FORMAT(10X,'FORBODY ANGLE OF ATTACK ARRAY, AALP(16) DEGREES'//)
16 FORMAT(1X,8F8.3//)
3 FORMAT(2(1X,8F8.3//))
4 FORMAT(1H ,10X,'MACH NUMBER ARRAY, AAM(8)'//)
5 FORMAT(1H ,10X,'FORBODY AXIAL COEF. ARRAY, CCA(8,16)'//)
6 FORMAT(16(1X,8(F3.4//))
7 FORMAT(1H ,10X,'FORBODY NORMAL COEF. ARRAY, CCN(8,16)'//)
8 FORMAT(1H1,10X,'FORBODY PITCH MOM COEF. ARRAY, CCM(8,16)'//)
9 FORMAT(1H ,10X,'FORBODY PITCH DAMPING COEF. ARRAY, CCMQ(8,16)'//)
10 FORMAT(1H1,10X,'AFTBODY ANGLE OF ATTACK ARRAY, AALPP(16) DEGREE'//)
11 FORMAT(1H ,10X,'AFTBODY MACH NUMBER ARRAY,AAMP(8)'//)
12 FORMAT(1H ,10X,'AFTBODY AXIAL COEF. ARRAY, CCAP(8,16)'//)
13 FORMAT(1H ,10X,'AFTBODY NORMAL COEF. ARRAY, CCNP(8,16)'//)
14 FORMAT(1H1,10X,'AFTBODY PITCH MOM COEF. ARRAY,CCMP(8,16)'//)
15 FORMAT(1H ,10X,'AFTBODY PITCH DAMPING COEF. ARRAY, CCMQP(8,16)'//)
WRITE(IOUT,17)
WRITE(IOUT,18)
WRITE(IOUT,3)(AALPE(J),J=1,16)
WRITE(IOUT,4)
WRITE(IOUT,16)(AAM(J),J=1,8)
WRITE(IOUT,5)
WRITE(IOUT,6)((CCA(I,J),J=1,16),I=1,8)
WRITE(IOUT,7)
WRITE(IOUT,6)((CCN(I,J),J=1,16),I=1,8)
WRITE(IOUT,8)
WRITE(IOUT,6)((CCM(I,J),J=1,16),I=1,8)
WRITE(IOUT,9)
WRITE(IOUT,6)((CCMQ(I,J),J=1,16),I=1,8)
WRITE(IOUT,10)
WRITE(IOUT,3)(AALPPE(J),J=1,16)
WRITE(IOUT,11)
WRITE(IOUT,16)(AAMP(J),J=1,8)
WRITE(IOUT,12)
WRITE(IOUT,6)((CCAP(I,J),J=1,16),I=1,8)
WRITE(IOUT,13)
WRITE(IOUT,6)((CCNP(I,J),J=1,16),I=1,8)
WRITE(IOUT,14)
WRITE(IOUT,6)((CCMP(I,J),J=1,16),I=1,8)
WRITE(IOUT,15)
WRITE(IOUT,6)((CCMQP(I,J),J=1,16),I=1,8)

```

```

19 TORQ=0.
THEDU=THEDJ/57.2958
THEDL=THEDL/57.2958
DTPC=0.
CONST=-1.
JJJ=1
JJ=1
WRITE(IOUT,50)
99 IF(Z.LT.HHH) CONST=0.
IF(T.GT.TTT) CONST=0.
IF(JJ.EQ.1) GO TO 101
DTPC=DTPC+1.
IF(DTPC.LT.DTP) GO TO 102
JJJ=JJJ+1
DTPC=0.
IF(JJJ.LE.6) GO TO 101
WRITE(IOUT,50)
JJJ=1
101 CALL SUBR
THPDDE=THEPD*57.2958
THEDDE=THED*57.2958
ALPDDE=ALPD*57.2958
PHIDDE=PHI*57.2958
GAMDEG=GAM*57.2958
THEDEG=THE*57.2958
THPDDE=THEP*57.2958
GAMPDE=GAMP*57.2958
ALPPDE=ALPP*57.2958
PHIDDE=PHID*57.2958
MUDEG=MU*57.2958
MUDDEG=MJD*57.2958
CHIDDE=CHI*57.2958
LAMDDE=LAM*57.2958
NUDEG=NU*57.2958
NUPDEG=NUP*57.2958
PHI1DE=PHI1*57.2958
PHI2DE=PHI2*57.2958
DCG=DSQRT((X-XP)**2+(Z-ZP)**2)
XDD=EE(1)
ZDD=EE(2)
THEDDD=EE(3)*57.2958
XPDD=FF(1)
ZPDD=FF(2)
NAP=(XPDD*CTHEP+ZPDD*STHEP)/GR
NNP=(ZPDD*CTHEP-XPDD*STHEP)/GR
NA=(XDD*CTHE+ZDD*STHE)/GR
NN=(ZDD*CTHE-XDD*STHE)/GR
THPDD=FF(3)*57.2958
CAAP=CAP*SPI
VD=DSQRT(XDD**2+ZDD**2)
VPD=DSQRT(XPDD**2+ZPDD**2)
WRITE(IOUT,51) T,X,XD,XDD,VD,GAMDEG,AM,TENS,PHIDEG,QX,CA,CAP,TORQ,
IZ,ZD,ZDD,VPD,GAMPDE,AMP,DAMP,PHIDDE,QZ,CN,CNP,M,THEDEG,THEDDE,

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2THEDDO,NA,ALPDEG,DYPR,LTJ,MUDEG,QTHE,CM,CMP,MP,XP,XPD,XPDD,NN,
3ALPPDE,DYPRP,LT,MUDEG,QXP,CMQ,CMQP,IY,ZP,ZPD,ZPDD,NAP,V,DP,LTJ,
4CHIDEG,QZP,K,CAAP,IYP,THPDEG,THPDE,THPDD,NNP,VP,RHD,DCG,CHIDF,
5QTHFP,C,SPI,LAMDEG,A,B,PHILDE,PHIZDE,APAR,BBAR,NUPJEG,APBAR,BPBAR,
6LOP,VG
L=L+1
TM(L)=T
YA(L)=Z
YB(L)=DYPR
YC(L)=V
YD(L)=TENS
YE(L)=THEDEG
YF(L)=THEDDE
YG(L)=GAMDEG
YH(L)=ALPDEG
JJ=2
102 IF(CONST)103,104,200
200 CONTINUE
CALL PLTRAJ(TM,YA,YB,YC,YD,L,10,1,4,2,5,HEADER)
CALL PLTRAJ(TM,YF,YG,YH,L,10,7,11,6,8,HEADER)
GO TO 105
104 WRITE(IJUT,52)
CONST=1.
GO TO 101
103 DO 74 J=1,4
CALL SUBR
DO 75 I=1,3
75 AA(I,J)=EE(I)*DT
DO 76 I=4,5
76 AA(I,J)=FF(I-3)*DT
GO TO (71,72,73,74),J
71 X=X+XD*DT/2.
Z=Z+ZD*DT/2.
THE=THE+THED*DT/2.
XP=XP+XPD*DT/2.
ZP=ZP+ZPD*DT/2.
THEP=THEP+THEPD*DT/2.
XD=XD+AA(1,1)/2.
ZD=ZD+AA(2,1)/2.
THED=THED+AA(3,1)/2.
XPD=XPD+AA(4,1)/2.
ZPD=ZPD+AA(5,1)/2.
THEPD=THEPD+AA(6,1)/2.
T=T+DT/2.
GO TO 74
72 X=X+AA(1,1)*DT/4.
Z=Z+AA(2,1)*DT/4.
THE=THE+AA(3,1)*DT/4.
XP=XP+AA(4,1)*DT/4.
ZP=ZP+AA(5,1)*DT/4.
THEP=THEP+AA(6,1)*DT/4.
XD=XD-AA(1,1)/2.+AA(1,2)/2.
ZD=ZD-AA(2,1)/2.+AA(2,2)/2.
THED=THED-AA(3,1)/2.+AA(3,2)/2.

```


XPD=XPD-AA(4,1)/2.+AA(4,2)/2.
ZPD=ZPD-AA(5,1)/2.+AA(5,2)/2.
THEPD=THEPD-AA(6,1)/2.+AA(6,2)/2.

GO TO 74

73 X=X+DT*(XD/2.-AA(1,1)/4.+AA(1,2)/4.)
Z=Z+DT*(ZD/2.-AA(2,1)/4.+AA(2,2)/4.)
THE=THE+DT*(THE0/2.-AA(3,1)/4.+AA(3,2)/4.)
XP=XP+DT*(XPD/2.-AA(4,1)/4.+AA(4,2)/4.)
ZP=ZP+DT*(ZPD/2.-AA(5,1)/4.+AA(5,2)/4.)
THEP=THEP+DT*(THEPD/2.-AA(6,1)/4.+AA(6,2)/4.)
XD=XD-AA(1,2)/2.+AA(1,3)
ZD=ZD-AA(2,2)/2.+AA(2,3)
THE0=THE0-AA(3,2)/2.+AA(3,3)
XPD=XPD-AA(4,2)/2.+AA(4,3)
ZPD=ZPD-AA(5,2)/2.+AA(5,3)
THEPD=THEPD-AA(6,2)/2.+AA(6,3)
T=T+DT/2.

74 CONTINUE

XD=XD-AA(1,3)
ZD=ZD-AA(2,3)
THE0=THE0-AA(3,3)
XPD=XPD-AA(4,3)
ZPD=ZPD-AA(5,3)
THEPD=THEPD-AA(6,3)
X=X-DT*(XD+AA(1,2)/2.)
Z=Z-DT*(ZD+AA(2,2)/2.)
THE=THE-DT*(THE0+AA(3,2)/2.)
XP=X-DT*(XPD+AA(4,2)/2.)
ZP=ZP-DT*(ZPD+AA(5,2)/2.)
THEP=THEP-DT*(THEPD+AA(6,2)/2.)
X=X+XD*DT+(AA(1,1)+AA(1,2)+AA(1,3))*DT/6.
Z=Z+ZD*DT+(AA(2,1)+AA(2,2)+AA(2,3))*DT/6.
THE=THE+THE0*DT+(AA(3,1)+AA(3,2)+AA(3,3))*DT/6.
XP=XP+XPD*DT+(AA(4,1)+AA(4,2)+AA(4,3))*DT/6.
ZP=ZP+ZPD*DT+(AA(5,1)+AA(5,2)+AA(5,3))*DT/6.
THEP=THEP+THEPD*DT+(AA(6,1)+AA(6,2)+AA(6,3))*DT/6.
XD=XD+(AA(1,1)+2.*(AA(1,2)+AA(1,3))+AA(1,4))/6.
ZD=ZD+(AA(2,1)+2.*(AA(2,2)+AA(2,3))+AA(2,4))/6.
THE0=THE0+(AA(3,1)+2.*(AA(3,2)+AA(3,3))+AA(3,4))/6.
XPD=XPD+(AA(4,1)+2.*(AA(4,2)+AA(4,3))+AA(4,4))/6.
ZPD=ZPD+(AA(5,1)+2.*(AA(5,2)+AA(5,3))+AA(5,4))/6.
THEPD=THEPD+(AA(6,1)+2.*(AA(6,2)+AA(6,3))+AA(6,4))/6.

IF(T.LE.TDTC) GO TO 99

DT=DT2

DTP=DTP2

GO TO 99

900 CONTINUE

CALL CALEND

STOP

END

SUBROUTINE SUBR

IMPLICIT REAL*8(A-H,O-Z)

DOUBLE PRECISION LAM1DE,LAM2DE,LAMODE,NUDES,LAMOPD,KS,
IKSPKH2,LTR,MU,MUD,LH1,LH2,L1,L2,LO,LAM1,LAM2,LAM0,NU

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2, MUDEG, MJDEG, NAP, NNP, LAM, LAMDEG, LS1, LS2, LOP, LAMOP, NUP, NUPDEG
3, M, MP, IY, IYP, LT, LTO, LTO, NA, NN, K, KSPKH1
4, MMA(16), MA, IIYP(16), KBL, KBT, KH1, KH2, KPFI, KKS(8)
COMMON T, DT, X, Z, XP, ZP, THE, THEP, XD, ZD, XPD, ZPD, THEO, THEPD, GAM, GAMP,
1ALP, ALPP, AM, ANP, DYPR, DYPRP, RHJ, S, SP, D, DP, M, MP, IY, IYP, LT, LTO, LTD,
2DCG, C, K, CA, CN, CM, CD, CCA(8,16), CCN(8,16), CCM(8,16), CCMQ(8,16), CAP,
3CNP, CMP, CMQP, CCAP(8,16), CCNP(8,16), CCMP(8,16), CCMP(8,16), CCMP(8,16), V, VP, GR,
4R, AA(6,4), DD(3,3), EE(3), FF(3), QX, QZ, QXP, QZP, QTHE, QTHER, APBAR, XBAR,
5ZBAR, AA1(8), AAMP(8), AALPE(16), AALPPE(16), IIN, IOUT,
6DADTHE, DRDTHE, DADTHP, DRDTHP, ABAR, BBAR, A, B, CHI, CHID, MJ, MJD, PHI, SPI,
7PHID, PHI1, PHI2, BET1, BET2, EPS1, EPS2, KSPKH1, KSPKH2, LTR, DL,
8SIG1, SIG2, ETA1, ETA2, TENS, DAMP, STHE, CTHE, STHEP, CTHEP, LH1, LH2,
9A1BAR, A2BAR, R1BAR, B2BAR, B0BAR, A0BAR, L0, L1, L2, LAM0, LAM1, LAM2, NU, G
COMMON TOR, THEDU, THEDL, DTVC, TORQ, BRID, LAM, TI, CONF, DTI, CDAB
1, TTI(16), SSPI(16), LS1, LS2, LOP, LAMOP, NUP, BPBAR, EPSP1, EPSP2, JLP, KS
2, MMA, MA, TT(8), VVG(8), VG, IIYP, KBL, KBT, KH1, KH2, TTENS(3), KKS,
3CONT(20), AALP(16), AALPP(16)
III=1
G=GR*(R/(Z+R))**2

```

C
C
C

REACTION CONTROL SYSTEM

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IF(TORQ.EQ.0.) GO TO 49
IF(THEO.GT.THEDL) GO TO 48
IF(THEO.LT.-THEDL) GO TO 47
IF(T-TC.GT.DTVC) GO TO 40
IF(THEO.GT.0.) TORQ=-TOR*(1.-(T-TC)/DTVC)
IF(THEO.LT.0.) TORQ=TOR*(1.-(T-TC)/DTVC)
GO TO 42
48 TORQ=-TOR
TC=T
GO TO 42
47 TORQ=TOR
TC=T
GO TO 42
49 IF(THEO.LT.THEDU.AND.THEO.GT.-THEDU) GO TO 40
IF(THEO.GT.THEDU) GO TO 41
TORQ=TOR
TC=0.
GO TO 42
41 TORQ=-TOR
TC=0.
GO TO 42
40 TORQ=0.
42 CONTINUE
TORQ=0.0
I=2
400 IF(T.LE.TTG(I)) GO TO 401
I=I+1
GO TO 400
401 TSL=(T-TTG(I-1))/(TTG(I)-TTG(I-1))
VG=VVG(I-1)+(VVG(I)-VVG(I-1))*TSL
CALL DENS(M,Z,PR,RHO,VS)
CALL DENS(Z,PR,RHO,VS)

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C

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V=DSQRT(XD**2+ZD**2)
VP=DSQRT(XPD**2+ZPD**2)
AM=DSQRT((XD-VG)**2+ZD**2)/VS
AMP=DSQRT((XPD-VG)**2+ZPD**2)/VSP
DYPR=.5*RHO*((XD-VG)**2+ZD**2)
DYPRP=.5*RHO*((XPD-VG)**2+ZPD**2)
STHE=DSIN(THETHE)
CTHE=DCOS(THETHE)
STHEP=DSIN(THETHEP)
CTHEP=DCOS(THETHEP)
GAM=DATAN2(ZD,XD)
GAMP=DATAN2(ZPD,XPD)
ANG=DATAN2(ZD,(XD-VG))
IF(ANG.LT.0.0) ANG=ANG+5.2931854
201 THEA=6.293185+THE
ALP=THEA-ANG
IF(ALP.GT.3.1415927) ALP=ALP-6.283185
ANGP=DATAN2(ZPD,(XPD-VG))
IF(ANGP.LT.0.0) ANGP=ANGP+6.2931854
301 THEPA=6.283185+THEP
ALPP=THEPA-ANGP
IF(ALPP.GT.3.1415927) ALPP=ALPP-6.283185
700 CALL AERO

```

C

C BRIDLE, RISER, SUSPENSION GEOMETRY

C

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A=XP+APBAR*CTHEP-BPBAR*STHEP-X-ABAR*CTHE+BBAR*STHE
B=ZP+APBAR*STHEP+BPBAR*CTHEP-Z-ABAR*STHE-BBAR*CTHE
AD=XPD-APBAR*THEPD*STHEP-BPBAR*THEPD*CTHEP-X)+ABAR*THED*STHE+
1BBAR*THED*CTHE
BD=ZPD+APBAR*THEPD*CTHEP-BPBAR*THEPD*STHEP-ZD-ABAR*THED*CTHE+
1BBAR*THED*STHE
LT=DSQRT(A**2+B**2)
IF(LT.LT.LT0) GO TO 35
TENS=K*(LT-LT0)
GO TO 36
35 TENS=0.
36 CHI=DATAN(A/B)
MU=-1.5707963-THEP-NUP-CHI
PHI=1.5707963-THE-LAM-CHI
IF(B.LT.0.) MU=1.5707963-THEP-NUP-CHI
IF(B.LT.0.) PHI=4.7123889-THE-LAM-CHI
20 PHIB=PHI
I=2
600 IF(TENS.LE.TTENS(I)) GO TO 601
I=I+1
GO TO 600
601 TENS1=(TENS-TTENS(I-1))/(TTENS(I)-TTENS(I-1))
KS=KKS(I-1)+(KKS(I)-KKS(I-1))*TENS1
KSPKH1=(2.*KS*KH1)/(2.*KS+KH1)
KSPKH2=(2.*KS*KH2)/(2.*KS+KH2)
IF(PHI.GT.PHI2.OR.PHI.LT.-PHI1) GO TO 15
DL1=(TENS/(KH1*DSIN(SIG1+SIG2)))*(-DSIN(PHI)*DCOS(SIG2)
1+DCOS(PHI)*DSIN(SIG2))

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DL2= (TENS/(KH2*DSIN(SIG1+SIG2)))*(DSIN(PHI)*DCOS(SIG1)
1 +DCOS(PHI)*DSIN(SIG1))
LH1=LH1+DL1
LH2=LH2+DL2
CALL BRIDLE
LH1=LH1-DL1
LH2=LH2-DL2
BBAR=BJBAR
ABAR=AUBAR
PHI1=SIG1
PHI2=SIG2
KPHI=K9L*KBT/(KBT*(DCOS(PHI1)**2+KBL*(DSIN(PHI1)**2)
K=2.*KS*KPHI/(2.*KS+KPHI)
LTO=LTR
LAM=NU
GO TO 14
15 IF (PHI.LT.-PHI1) GO TO 16
ABAR=A2BAR
BBAR=B2BAR
LTO=LTR+LH2
K=KSPKH2
PHI2=ETA2
LAM=LAM2
IF (LAM.GT.3.1415927) LAM= LAM2-6.28318531
GO TO 14
16 ABAR=A1BAR
BBAR=B1BAR
LTO=LTR+LH1
K=KSPKH1
PHI1=ETA1
LAM=LAM1
14 DLS1=(TENS/(KS*DSIN(EPSP1+EPSP2)))*(DCOS(EPSP2)*DCOS(MU+VUP)-
DSIN(EPSP2)*DSIN(MU+NUP))
DLS2=(TENS/(KS*DSIN(EPSP1+EPSP2)))*(DCOS(EPSP1)*DCOS(MU+NUP)+
DSIN(EPSP1)*DSIN(MU+NUP))
LS1=LS1+DLS1
LS2=LS2+DLS2
C CALL SUSPEN
LS1=LS1-DLS1
LS2=LS2-DLS2
A=XP+APBAR*CTHEP-BPBAR*STHEP-X-ABAR*CTHE+BBAR*STHE
B=ZP+APBAR*STHEP+BPBAR*CTHEP-Z-ABAR*STHE-BBAR*CTHE
AD=XPD-APBAR*THEPD*STHEP-BPBAR*THEPD*CTHEP-XD+ABAR*THED*STHE+
BBAR*THED*CTHE
BD=ZPD+APBAR*THEPD*CTHEP-BPBAR*THEPD*STHEP-ZD-ABAR*THED*CTHE+
BBAR*THED*STHE
LT=DSQRT(A**2+B**2)
LTD=(A*AD+B*BD)/LT
CHI=DATAN(A/B)
MU=-1.5707963-THEP-NUP-CHI
PHI=1.5707963-THE-LAM-CHI
IF (B.LT.0.) MU=1.5707963-THEP-NUP-CHI
IF (B.LT.0.) PHI=4.7123889-THE-LAM-CHI
CHID=(B*AD-A*BD)/(LT**2)

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MUD=-THEPD-CHID
PHID=-THED-CHID
IF(LT,LT,LTO) GO TO 30
TENS=K*(LT-LTO)
DAMP=C*LTD
GO TO 31
30 TENS=0.
DAMP=0.
31 III=III+1
IF(III.GT.10) WRITE(ICUT,50)
IF(III.GT.10) GO TO 19
50 FORMAT(20X,'ITERATION DOES NOT CONVERGE')
IF(DABS(PHI-PHID).GT..0083) GO TO 20
19 DADTHE=ABAR*STHE+BBAR*CTHE
DBDTHE=-ABAR*CTHE+BBAR*STHE
DADTHP=-APBAR*STHEP-BPBAR*CTHEP
DBDTHP=APBAR*CTHEP-BPBAR*STHEP
CALL MATRIX
FF(1)=-((TENS+DAMP)*A/LT+QXP)/MP
FF(2)=-((TENS+DAMP)*B/LT+QZP)/MP-G*((MP-MA)/MP)
FF(3)=-((TENS+DAMP)*(A*DADTHP+B*DBDTHP)/LT+QTHEP)/IYP
RETURN
END
SUBROUTINE AFRD
IMPLICIT REAL*8(A-H,O-Z)
DOUBLE PRECISION LAMIDE,LAM2DE,LAMODE,NUDEG,LAMOPD,KS,
1KSPKH2,LTR,MJ,MUD,LH1,LH2,LL,L2,LO,LAM1,LAM2,LAMO,NU
2,MUDEG,MUDEG,NAP,NNP,LAM,LAMDEG,LS1,LS2,LJP,LAMOP,NJP,NUPDEG
3,M,MP,IY,IYP,LT,LTD,LTO,NA,NN,K,KSPKH1
4,MMA(16),MA,IYP(16),KBL,KBT,KH1,KH2,KPHI,KKS(8)
COMMON T,DT,X,Z,XP,ZP,THE,THEP,XU,ZD,XPD,ZPD,THED,THEPD,GAM,GAMP,
1ALP,ALPP,AM,AMP,DYPR,DYPRD,RHD,S,SP,D,DP,M,MP,IY,IYP,LT,LTD,LTO,
2DCG,C,K,CA,CN,CM,CNQ,CCA(8,16),CCN(8,16),CCM(8,16),CCMJ(8,16),CAP,
3CNP,CMP,CMOP,CCAP(8,16),CCNP(8,16),CCMP(8,16),CCMOP(8,16),V,VP,GR,
4R,AA(6,4),DD(3,3),EE(3),FF(3),QX,QZ,QXP,QZP,QTHE,QTHEP,APBAR,XBAR,
5ZBAR,AA4(8),AA4P(8),AALPE(16),AALPPE(16),IIN,IQJT,
6DADTHE,DBDTHE,DADTHP,DBDTHP,ABAR,BBAR,A,B,CHI,CHID,MU,MUD,PHI,SPI,
7PHID,PHI1,PHI2,BET1,BET2,EPS1,EPS2,KSPKH1,KSPKH2,LTR,DL,
8SIG1,SIG2,ETA1,ETA2,TENS,DAMP,STHE,CTHE,STHEP,CTHEP,LH1,LH2,
9A1BAR,A2BAR,B1BAR,B2BAR,BOBAR,AQBAR,LO,LL,L2,LAMO,LAM1,LAM2,NU,G
COMMON TOR,THEDU,THEDL,DTVC,TORQ,BRID,LAM,TI,CONF,DTI,CDAB
1,TTI(16),SSPI(16),LS1,LS2,DLP,LAMOP,NUP,BPBAR,EPS1,EPS2,DLP,KS
2,MMA,MA,TTG(8),VVG(8),VG,IYP,KBL,KBT,KH1,KH2,TTENS(8),KKS,
3CONT(20),AALP(16),AALPP(16)
I=2
500 IF(AM.LE.AAM(I)) GO TO 501
I=I+1
GO TO 500
501 AMSL=(AM-AAM(I-1))/(AAM(I)-AAM(I-1))
J=2
600 IF(DABS(ALP).LE.AALP(J)) GO TO 601
J=J+1
GO TO 600
601 ALPSL=(DABS(ALP)-AALP(J-1))/(AALP(J)-AALP(J-1))

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```

CA=(CCA(I,J-1)-CCA(I-1,J-1))*AMSL+CCA(I-1,J-1)+((CCA(I,J)-
ICCA(I-1,J))*AMSL+CCA(I-1,J)-((CCA(I,J-1)-CCA(I-1,J-1))*AMSL+
2CCA(I-1,J-1))*ALPSL
CN=(CCN(I,J-1)-CCN(I-1,J-1))*AMSL+CCN(I-1,J-1)+((CCN(I,J)-
ICCN(I-1,J))*AMSL+CCN(I-1,J)-((CCN(I,J-1)-CCN(I-1,J-1))*AMSL+
2CCN(I-1,J-1))*ALPSL
CM=(CCM(I,J-1)-CCM(I-1,J-1))*AMSL+CCM(I-1,J-1)+((CCM(I,J)-
ICCM(I-1,J))*AMSL+CCM(I-1,J)-((CCM(I,J-1)-CCM(I-1,J-1))*AMSL+
2CCM(I-1,J-1))*ALPSL

CMQ=(CCMQ(I,J-1)-CCMQ(I-1,J-1))*AMSL+CCMQ(I-1,J-1)+((CCMQ(I,J)-
ICCMQ(I-1,J))*AMSL+CCMQ(I-1,J)-((CCMQ(I,J-1)-CCMQ(I-1,J-1))*AMSL+
2CCMQ(I-1,J-1))*ALPSL
IF(ALP.LT.O.) CN=-CN
IF(ALP.LT.O.) CM=-CM
I=2
700 IF(AMP.LE.AAMP(I)) GO TO 701
I=I+1
GO TO 700
701 AMPSL=(AMP-AAMP(I-1))/(AAMP(I)-AAMP(I-1))
J=2
800 IF(DABS(ALPP).LE.AALPP(J)) GO TO 801
J=J+1
GO TO 800
801 ALPPSL=(DABS(ALPP)-AALPP(J-1))/(AALPP(J)-AALPP(J-1))
CAP=(CCAP(I,J-1)-CCAP(I-1,J-1))*AMPSL+CCAP(I-1,J-1)+((CCAP(I,J)-
ICCAP(I-1,J))*AMPSL+CCAP(I-1,J)-((CCAP(I,J-1)-CCAP(I-1,J-1))*AMPSL+
2CCAP(I-1,J-1))*ALPPSL
CNP=(CCNP(I,J-1)-CCNP(I-1,J-1))*AMPSL+CCNP(I-1,J-1)+((CCNP(I,J)-
ICCNP(I-1,J))*AMPSL+CCNP(I-1,J)-((CCNP(I,J-1)-CCNP(I-1,J-1))*AMPSL+
2CCNP(I-1,J-1))*ALPPSL
CMP=(CCMP(I,J-1)-CCMP(I-1,J-1))*AMPSL+CCMP(I-1,J-1)+((CCMP(I,J)-
ICCMP(I-1,J))*AMPSL+CCMP(I-1,J)-((CCMP(I,J-1)-CCMP(I-1,J-1))*AMPSL+
2CCMP(I-1,J-1))*ALPPSL
CMP=CMP+APBAR*CNP/DP
CMQP=(CCMQP(I,J-1)-CCMQP(I-1,J-1))*AMPSL+CCMQP(I-1,J-1)+
1*((CCMQP(I,J)-CCMQP(I-1,J))*AMPSL+CCMQP(I-1,J)-((CCMQP(I,J-1)-
2CCMQP(I-1,J-1))*AMPSL+CCMQP(I-1,J-1))*ALPPSL
IF(ALPP.LT.O.) CNP=-CNP
IF(ALPP.LT.O.) CMP=-CMP
QX=-DYPR*S*(CA*CTHE+CN*STHE)
QZ=DYPR*S*(CN*CTHE-CA*STHE)
QTHE=DYPR*S*D*(CM+CMQ*THE*D/V)+TORQ
I=2
900 IF(T.LE.TTI(I)) GO TO 901
I=I+1
GO TO 900
901 TISL=(T-TTI(I-1))/(TTI(I)-TTI(I-1))
SPI=SSPI(I-1)+(SSPI(I)-SSPI(I-1))*TISL
MP=MP+MA
MA=MMA(I-1)+(MMA(I)-MMA(I-1))*TISL
IYP=IIYP(I-1)+(IIYP(I)-IIYP(I-1))*TISL
MP=MP+MA
C IF(T.LT.DTI) CNP=CNP*T/DTI

```

```

C IF(T,LT,DTI) CMP=CMPT/DTI
C IF(T,LT,DTI) CMQP=CMQP*/DTI
QXP=-DYPRP*(SPI*CAP*CTHEP+SP*CNP*STHEP)
QZP=DYPRP*(SPI*CNP*CTHEP-SPI*CAP*STHEP)
QTHEP=DYPRP*SPI*DP*(CMP+CMQP*THEPD*DP/VP)
RETURN
END
SUBROUTINE MATRIX
IMPLICIT REAL*8(A-H,O-Z)
DOUBLE PRECISION LAM1DE,LAM2DE,LAMODE,NUDEG,LAMOPD,KS,
IKSPKH2,LTR,MU,MUD,LH1,LH2,L1,L2,L0,LAM1,LAM2,LAMQ,NU
2,MUDEG,MJDEG,NAP,NNP,LAM,LAMDEG,LS1,LS2,LOP,LAMOP,NUP,NUPDEG
3,M,MP,IY,IYP,LT,LTD,LTO,NA,NN,K,KSPKH1
4,MMA(16),MA,IYYP(16),KBL,KBT,KH1,KH2,KPHI,KKS(9)
COMMON T,DT,X,Z,XP,ZP,THE,THEP,XD,ZD,XPD,ZPD,THED,THEPD,GAM,GAMP,
1ALP,ALPP,AM,AMP,DYPR,DYPRP,RHO,S,SP,D,DP,M,MP,IY,IYP,LT,LTD,LTO,
2DCG,C,K,CA,CN,CM,CQ,CCA(8,16),CCN(8,16),CCM(8,16),CCMQ(8,16),CAP,
3CNP,CMPT,CMQP,CCAP(8,16),CCNP(8,16),CCMP(8,16),CCMQP(8,16),V,VP,G,
4R,AA(6,4),DD(3,3),EE(3),FF(3),QX,QZ,QXP,QZP,QTHE,QTHEP,APBAR,XBAR,
5ZBAR,AA(8),AAMP(8),AALPE(16),AALPPE(16),IIN,IOUT,
6DADTHE,DBDTHE,DADTHP,DBDTHP,ABAR,BBAR,A,B,CHI,CHID,MJ,MUD,PHI,SPI,
7PHID,PHI1,PHI2,BET1,BET2,EPS1,EPS2,KSPK11,KSPK12,LTR,DL,
8SIG1,SIG2,ETA1,ETA2,TENS,DAMP,STHE,CTHE,STHEP,CTHEP,LH1,LH2,
9A1BAR,A2BAR,B1BAR,B2BAR,B0BAR,A0BAR,L0,L1,L2,LAM0,LAM1,LAM2,NU,G
COMMON TOR,THEDU,THEDL,DTVC,TURO,BRID,LAM,JI,CONF,DTI,COAB
1,TTI(16),SSPI(16),LS1,LS2,LOP,LAMOP,NUP,BPBAR,EPSP1,EPSP2,DLP,KS
2,MMA,MA,TTG(8),VVG(8),VG,IYYP,KBL,KBT,KH1,KH2,TTENS(3),KKS,
3CNT(20),AALP(16),AALPP(16)
DD(1,1)=M
UD(1,2)=0
DD(1,3)=-M*(ZBAR*CTHE+XBAR*STHE)
DD(2,1)=0
DD(2,2)=M
DD(2,3)=-M*(ZBAR*STHE-XBAR*CTHE)
DD(3,1)=DD(1,3)
DD(3,2)=DD(2,3)
DD(3,3)=IY
THED2=THED**2
FE(1)=DD(2,3)*THED2+(TENS+DAMP)*A/LT+QX
EE(2)=-DD(1,3)*THED2+(TENS+DAMP)*B/LT-M*G+QZ
EE(3)=-G*DD(2,3)-(TENS+DAMP)*(A*DADTHE+B*DBDTHE)/LT+QTHE
EPS=.1D-11
CALL CROUT(DD,EE,3,3,EPS,IERSW)
IF(IERSW.EQ.0) RETURN
WRITE(IOUT,50)
STOP
50 FORMAT(////20X,'INCONSISTENT EQUATIONS')
END
SUBROUTINE BRIDLE
IMPLICIT REAL*8(A-H,O-Z)
DOUBLE PRECISION LAM1DE,LAM2DE,LAMODE,NUDEG,LAMOPD,KS,
IKSPKH2,LTR,MU,MUD,LH1,LH2,L1,L2,L0,LAM1,LAM2,LAMQ,NU
2,MUDEG,MJDEG,NAP,NNP,LAM,LAMDEG,LS1,LS2,LOP,LAMOP,NUP,NUPDEG
3,M,MP,IY,IYP,LT,LTD,LTO,NA,NN,K,KSPKH1

```

```

4, MMA(16), MA, IYYP(16), KBL, KBT, KHL, KH2, KP4I, KKS(8)
COMMON T, DT, X, Z, XP, ZP, THE, THEP, XD, ZD, XPD, ZPD, THED, THEPD, GAM, GAMP,
1ALP, ALPP, AM, AMP, DYPR, DYPRP, RHO, S, SP, D, DP, M, MP, LY, LYP, LT, LTO, LTO,
2DCG, C, K, CA, CN, CM, CMU, CCA(8, 15), CCN(8, 16), CCM(8, 16), CCMQ(8, 16), CAP,
3CNP, CMP, CMQP, CCAP(8, 16), CCNP(8, 16), CCMP(8, 16), CCMQP(8, 16), V, VP, GR,
4R, AA(6, 4), DD(3, 3), EE(3), FF(3), XX, XZ, QXP, QZP, QTHE, QTHEP, APBAR, XBAR,
5ZBAR, AAM(8), AAMP(8), AALPE(16), AALPPE(16), IIN, IOU,
6DADTHE, D3DTHE, DADTHP, DRDTHP, ABAR, BBAR, A, B, CHI, CHID, MU, MUD, PHI, SPI,
7PHID, PHI1, PHI2, BET1, BET2, EPS1, EPS2, KSPKH1, KSPKH2, LTR, DL,
8SIG1, SIG2, ETA1, ETA2, TENS, DAMP, STHE, CTHE, STHEP, CTHEP, LH1, LH2,
9A1BAR, A2BAR, B1BAR, B2BAR, B3BAR, AOBAR, LO, L1, L2, LAMO, LAM1, LAM2, NU, G
COMMON TOR, THEDU, THEDL, DTVC, DTORQ, BRID, LAM, TI, C3NF, DTI, CDAB
1, TTI(16), SSPI(16), LS1, LS2, LOP, LAMOP, NUP, BPBAR, EPS1, EPS2, DLP, KS
2, MMA, MA, TIG(8), VVG(8), VV, IYYP, KBL, KBT, KHL, KH2, TTENS(8), KKS,
3CONT(20), AALP(16), AALPP(16)

```

```
53 FORMAT(1H1, 15X, 20A4//)
```

```
54 FORMAT(1H , 10X, 'INITIAL VALUES, ENGINEERING UNITS ARE METRIC (METERS, NEWTON, SEC)')

```

```
55 FORMAT(1H , /10X, 'LH1', 7X, 'LH2', 7X, 'A1BAR', 5X, 'A2BAR', 5X, 'B1BAR', 5X,
1'B2BAR', 5X, 'L1', 8X, 'L2', 8X, 'DL', 8X, 'LO', 8X, 'BET1', 6X, 'BET2', /10X,
2'EPS1', 6X, 'EPS2', 6X, 'ETA1', 6X, 'ETA2', 6X, 'SIG1', 5X, 'SIG2', 6X,
3'LAM1', 6X, 'LAM2', 6X, 'LAMO', 6X, 'NU', 8X, 'AOBAR', 5X, 'B3BAR', /10X,
4'KSPKB', 5X, 'KSPKH1', 4X, 'KSPKH2', 4X, 'T-INF', 5X, 'DT-INF', 4X,
5'THEDU', 5X, 'THEDL', 5X, 'TORQUE', 4X, 'DT-VALVE', 2X, 'LS1', 7X, 'LS2',
67X, 'DLP', /10X, 'LOP', 7X, 'LAMOP', 5X, 'NUP', 7X, 'APBAR', 5X, 'BPBAR', 5X,
7'EPS1P', 5X, 'EPS2P', 5X, 'DT', 8X, 'KH1', 7X, 'KH2'//)

```

```
56 FORMAT(8X, 12(F8.3, 2X) / 8X, 12(F8.3, 2X) / 8X, 3(F9.0, 1X) , 9(F8.3, 2X)
1/8X, 8(F8.3, 2X) , 4(F9.0, 1X) //)

```

C

C STATEMENT FUNCTION

DARCOS(DL) = DACOS(DL)

C

```

L1=DSQRT(A1BAR**2+B1BAR**2)
L2=DSQRT(A2BAR**2+B2BAR**2)
DL=DSQRT((B2BAR-B1BAR)**2+(A2BAR-A1BAR)**2)
BET1=DARCOS((L1**2+DL**2-L2**2)/(2.*L1*DL))
BET2=DARCOS((L2**2+DL**2-L1**2)/(2.*L2*DL))
EPS1=DARCOS((LH1**2+DL**2-LH2**2)/(2.*LH1*DL))
EPS2=DARCOS((LH2**2+DL**2-LH1**2)/(2.*LH2*DL))
ETA1=3.1415927-BET1-EPS1
ETA2=3.1415927-BET2-EPS2
LO=DSQRT((L1**2+LH1**2-2.*LH1*L1*DCOS(BET1+EPS1)))
LAM1= DATAN2(B1BAR, A1BAR)
IF(LAM1.LT.0.0) LAM1=6.28318531+LAM1
LAM2= DATAN2(B2BAR, A2BAR)
IF(LAM2.LT.0.0) LAM2=6.28318531+LAM2
LAMO=LAM2+DARCOS((L2**2+LO**2-LH2**2)/(2.*L2*LO))
SIG1=3.1415927-BET1-EPS1-LAM1+LAMO
IF(LAMO.GE.3.14159270) SIG1=SIG1-6.28318531
SIG2=3.1415927-BET2-EPS2-LAM2+LAMO
IF(LAMO.GE.3.14159270) LAMO=LAMO-6.28318531
NU=LAMO
LAM=NU
AOBAR= LO*DCOS(NU)

```



```

BOBAR= LO*DSIN(NU)
PHI1=SIG1
PHI2=SIG2
IF(CONF.EQ.2.) RETURN
CALL SUSPEN
WRITE(IOUT,53) CONT
WRITE(IOUT,54)
WRITE(IOUT,55)
SS1S2= DSIN(SIG1+SIG2)
C2S12= DCOS(SIG2)/SS1S2
C1S12= DCOS(SIG1)/SS1S2
S2S12= DSIN(SIG2)/SS1S2
S1S12= DSIN(SIG1)/SS1S2
KBT= 1./((C2S12*C2S12/KH1)+(C1S12*C1S12/KH2))
KBL= 1./((S2S12*S2S12/KH1)+(S1S12*S1S12/KH2))
KSPKH1=(2.*KKS(1)*KH1)/(2.*KKS(1)+KH1)
KSPKH2=(2.*KKS(1)*KH2)/(2.*KKS(1)+KH2)
K= (2.*KKS(1)*KBL)/(2.*KKS(1)+KBL)
BET1DE=BET1*57.2958
BET2DE=BET2*57.2958
EPS1DE=EPS1*57.2958
EPS2DE=EPS2*57.2958
ETA1DE=ETA1*57.2958
ETA2DE=ETA2*57.2958
SIG1DE=SIG1*57.2958
SIG2DE=SIG2*57.2958
LAM1DE=LAM1*57.2958
LAM2DE=LAM2*57.2958
LAMODE=LAM0*57.2958
NUDEG=NU*57.2958
LAMOPD=LAMOP*57.2958
NUPDEG=NUP*57.2958
EPSP1D=EPSP1*57.2958
EPSP2D=EPSP2*57.2958
WRITE(IOUT,56) LH1,L2,A1BAR,A2BAR,B1BAR,B2BAR,L1,L2,DL,LO,BET1DE,
1BET2DE,EPSP1DE,EPSP2DE,ETA1DE,ETA2DE,SIG1DE,SIG2DE,LAM1DE,LAM2DE,
2LAMODE,NUDEG,A0BAR,B0BAR,K,KSPKH1,KSPKH2,TI,DTI,THEDU,THEDL,
3TUR,DTVC,LS1,LS2,OLP,LOP,LAMOPD,NUPDEG,APBAR,BPBAR,EPSP1D,EPSP2D
4,DT,KH1,KH2
ABAR=A0BAR
BBAR=B0BAR
XP=X+ABAR*DCOS(THET)-BBAR*DSIN(THET)-(APBAR+LTR+.01)*DCOS(THET)+BPBAR
1R*DSIN(THET)
ZP=Z+ABAR*DSIN(THET)+BBAR*DCOS(THET)-(APBAR+LTR+.01)*DSIN(THET)-BPBAR
1R*DCOS(THET)
CONF=2.
RETURN
END
SUBROUTINE SUSPEN
IMPLICIT REAL*8(A-H,O-Z)
DOUBLE PRECISION LAM1DE,LAM2DE,LAMODE,NUDEG,LAMOPD,KS,
1KSPKH2,LTR,MU,MUD,LH1,LH2,L1,L2,LO,LAM1,LAM2,LAMO,NU
2,MUDEG,MUDEG,NAP,NNP,LAM,LAMDEG,LS1,LS2,LOP,LAMOP,NUP,NUPDEG
3,M,MP,IY,IYP,LT,LTD,LTO,NA,NN,K,KSPKH1

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```

4, MMA(16), MA, IYYP(16), KBL, KBT, KHI, KH2, KPHI, KKS(8)
COMMON T, DT, X, Z, XP, ZP, THE, THEP, XD, ZD, XPD, ZPD, THED, THEPD, GAM, GAMP,
1ALP, ALPP, AM, AMP, DYPR, DYPRP, RHD, S, SP, D, DP, M, MP, IY, IYP, LT, LTO, LTD,
2DCG, C, K, CA, CN, CM, CMQ, CCA(8,16), CCN(8,16), CCM(8,16), CCMQ(8,16), CAP,
3CNP, CMP, CMJP, CCAP(8,16), CCNP(8,16), CCMP(8,16), CCMQP(8,16), V, VP, GR,
4R, AA(6,4), DU(3,3), FE(3), FE(3), XX, XZ, XXP, QZP, THE, THEP, APBAR, XBAR,
5ZBAR, AAM(8), AAMP(8), AALPE(16), AALPPE(16), IIN, IOUT,
6DADTHE, DBDTHE, DADTHP, DBDTHP, ABAR, BBAR, A, B, CHI, CHID, MU, MUD, PHI, SPI,
7PHID, PHIL, PHIZ, BET1, BET2, EPS1, EPS2, KSPKH1, <SPKH2, LTR, DL,
8SIG1, SIG2, ETA1, ETA2, TENS, JAMP, STHE, CTHE, STHEP, CTHEP, LH1, LH2,
9A1BAR, A2BAR, B1BAR, B2BAR, B3BAR, BOBAR, AOBAR, LO, L1, L2, LAMO, LAMI, LAM2, NU, G
COMMON TOR, THEOU, THEDL, OIVC, IQKQ, BKID, LAM, LI, CINF, DTI, CDAB
1, ITI(16), SSPI(16), LS1, LS2, LOP, LAMOP, NUP, BPBAR, EPSPI, EPSP2, DLP, KS
2, MMA, MA, TTG(8), VVG(8), VG, IYYP, KBL, KBT, KHI, KH2, TTENS(8), KKS,
3CONT(20), AALP(16), AALPP(16)

```

```

C
C STATEMENT FUNCTION
C DARCOS(DLP) = DARCOS(DLP)

```

```

C
EPSPI=DARCOS(((DLP**2+LS1**2-LS2**2)/(2.*DLP*LS1))
EPSP2=DARCOS((DLP**2+LS2**2-LS1**2)/(2.*DLP*LS2))
LOP=DSQRT((DLP/2.)**2+LS1**2-DLP*LS1*DCCOS(EPSPI))
LAMOP=DARCOS(((DLP/2.)**2+LOP**2-LS2**2)/(DLP*LOP))
NUP=LAMOP-1.5707963
APBAR=LOP*DCCOS(NUP)
BPBAR=LOP*DSIN(NUP)
IF(CINF.EQ.0.0) RETURN
XP=X+ABAR*CTHE-BBAR*STHE-APBAR*CTHEP+BPBAR*STHEP+(LTO+TENS/K)
1*DSIN(CHI)
ZP=Z+ABAR*STHE+BBAR*CTHE-APBAR*STHEP-BPBAR*CTHEP+(LTO+TENS/K)
1*DCCOS(CHI)
RETURN
END

```

```

SUBROUTINE CROUT( A, C, N, LD, EPS, IERSW)

```

```

C LINEAR ALGEBRAIC EQUATIONS - CROUT LS220 2
DOUBLE PRECISION A,C,SUM,EPS,ZERO
DIMENSION A(LD,1), C(1) LS220 3
ZERO = 0.000
C ZERO = 0. LS220 6
IERSW=0 LS220 7
IF(DABS(A(1,1)) - EPS)90,5,5
IF(ABS(A(1,1)) - EPS)90,5,5
C 5 IF(N-1)90,10,15 LS220 9
10 C(1) = C(1)/A(1,1) LS220 11
RETURN LS220 12
15 DO 20 I=2,N LS220 13
20 A(1,1)=A(1,I)/A(1,1) LS220 14
DO 65 I=2,N LS220 15
DO 65 J=2,N LS220 16
SUM = ZERO LS220 17
IF(J - 1) 30,30,25 LS220 18
25 JIN=I-1 LS220 19
GO TO 35 LS220 20
30 JIN = J-1 LS220 21

```

```

35 DO 40 K=1,JIN                                LS220 22
40 SUM =SUM+A(I,K)*A(K,J)                        LS220 23
   IF (J-1)45,45,55                              LS220 24
45 A(I,J) = A(I,J)-SUM                           LS220 25
   IF(J-1)65,50,90                                LS220 26
50 IF(DABS(A(I,1))-EPS)90,65,55
C 50 IF(ABS(A(I,1))-EPS)90,65,55                  LS220 28
55 IF(DABS(A(I,1)) - EPS)90,60,60
C 55 IF(ABS(A(I,1)) - EPS)90,50,60                LS220 30
60 A(I,J)=(A(I,J)-SUM)/A(I,1)                    LS220 31
65 CONTINUE                                       LS220 32
   C(I) = C(I) / A(I,1)                           LS220 33
   DO 75 I=2,N                                    LS220 34
   SUM = ZERO                                       LS220 35
   JIN =I-1                                         LS220 36
   DO 70 K=1,JIN                                    LS220 37
70 SUM=SUM+A(I,K)*C(K)                            LS220 38
   C(I)=(C(I)-SUM)/A(I,1)                          LS220 39
75 CONTINUE                                       LS220 40
   JIN =N-1                                         LS220 41
   DO 85 M=1,JIN                                    LS220 42
   SUM = ZERO                                       LS220 43
   L=JIN-M+1                                        LS220 44
   LL=L+1                                           LS220 45
   DO 80 K=LL,N                                     LS220 46
80 SUM = SUM +A(L,K)*C(K)                          LS220 47
85 C(L) = C(L) -SUM                                 LS220 48
   RETURN                                           LS220 49
90 IERSW=1                                          LS220 50
   RETURN                                           LS220 51
   END                                              LS220 52

```

SUBROUTINE PLTRAJ(X,Y1,Y2,Y3,Y4,N,IX,IY1,IY2,IY3,IY4,HDR)

```

C THIS SUBROUTINE PLOTS UP TO FOUR CURVES ON THE SAME X SCALE, EACH
C HAVING ITS OWN Y SCALE
C
C X THE X (HORIZONTAL) VALUES AT WHICH Y=F(X) IS COMPUTED
C Y1,Y2,Y3,Y4 THE Y (VERTICAL) COORDINATES AT EACH X
C N THE NUMBER OF POINTS IN EACH OF THE ARRAYS ABOVE
C IX THE CONTROL FOR X LABELLING (NOT=0)
C IY1,IY2,IY3,IY4 THE CONTROL FOR Y LABELLING (0=OMIT THIS & FOLLOWING)
C HDR THE HEADER IDENTIFICATION FOR THE CURVES)
C

```

```

DIMENSION X(1),Y1(1),Y2(1),Y3(1),Y4(1),HDR(1)
DIMENSION VMX(4),VM1(4),VM2(4),VM3(4),VM4(4),VMS(4,5),ID(27)
EQUIVALENCE (VMS(1,1),VM1(1)),(VMS(1,2),VM2(1)),(VMS(1,3),VM3(1)),
1 (VMS(1,4),VM4(1)),(VMS(1,5),VMX(1))

```

DIMENSION LABELS(4,12)

```

DATA LABELS / 'ALTITU','DE M*','ID**3 ','',
2 'VELOCI','TY M/','SEC ','',
3 'ACCELE','RATION',' M/SE','C**2 ','',
4 'DYNAMI','C PRES','SURE ','N/M**2',
5 'TENSIO','N N ','',
6 'FLIGHT',' PATH ','ANGLE ',' DEG ',
7 'PITCH ','ATTITU','DE DE','G ',

```

```

B      'ANGLE ', 'OF ATT', 'ACK D', 'EG  ',
9      'RANGE ', 'M      ', '      ',
A      'TIME  ', 'SEC   ', '      ',
B      'PITCH ', 'VELOCI', 'TY DE', 'G/SEC ',
C      'ANGLE ', 'OF ATT', 'ACK P ', ' DEG  '/

```

```
DIMENSION LTYPE(4)
```

```
DATA LTYPE / 0,1,2,5 /
```

```
DATA ID / 'USE 12', '3 INC', 'H GRID', 'PAPER', '20 GR', 'IDS PE',
```

```
2 'R INCH', 'USE ', 'BLACK ', 'LIQUID', 'INK IN', 'A 3 M', 'IL TIP',
```

```
3 'PEN. ', '      ', '      ', '      ', '      ', '      ', '      ',
```

```
4 '      ', '      ', '      ', '      ', '      ', '      ', '      '/
```

```
DATA XL,YL,HT / 12., 8., .105/
```

```
DATA DA2,DA3,DA4 / -.5, -1., -1.5/
```

```
DATA FG,FP/100J., .001/
```

```
DATA ITIME/0/
```

```
IF(IX.LE.0) GO TO 900
```

```
IF(ITIME)100,100,150
```

```
100 CALL CALID(ID)
```

```
HT2 = .5*HT
```

```
150 ITIME = ITIME + 1
```

```
C
```

```
CALL PLOT(0.,1.5,-3)
```

```
C
```

```
FIND MINIMUM, MAXIMUM OF ARRAYS
```

```
DO 190 I=1,5
```

```
VMS(2,I) = -.1E38
```

```
VMS(1,I) = +.1E38
```

```
190 CONTINUE
```

```
DO 200 I=1,N
```

```
IF( X(I).GT.VMX(2)) VMX(2) = X(I)
```

```
IF( X(I).LT.VMX(1)) VMX(1) = X(I)
```

```
IF(IY1.LE.0) GO TO 200
```

```
IF(Y1(I).GT.VM1(2)) VM1(2) = Y1(I)
```

```
IF(Y1(I).LT.VM1(1)) VM1(1) = Y1(I)
```

```
IF(IY2.LE.0) GO TO 200
```

```
IF(Y2(I).GT.VM2(2)) VM2(2) = Y2(I)
```

```
IF(Y2(I).LT.VM2(1)) VM2(1) = Y2(I)
```

```
IF(IY3.LE.0) GO TO 200
```

```
IF(Y3(I).GT.VM3(2)) VM3(2) = Y3(I)
```

```
IF(Y3(I).LT.VM3(1)) VM3(1) = Y3(I)
```

```
IF(IY4.LE.0) GO TO 200
```

```
IF(Y4(I).GT.VM4(2)) VM4(2) = Y4(I)
```

```
IF(Y4(I).LT.VM4(1)) VM4(1) = Y4(I)
```

```
200 CONTINUE
```

```
C
```

```
C
```

```
DO SCALING AND AXES
```

```
IF(IX - 1)400,310,320
```

```
310
```

```
VMX(1) = VMX(1)*FP
```

```
VMX(2) = VMX(2)*FP
```

```
320
```

```
CALL SCALE(VMX,XL,2,1)
```

```
CALL AXIS(0., 0., LABELS(1,IX) , -24, XL, 0., VMX(3), VMX(4))
```

```
IF(IX - 1)340,330,340
```

```
330
```

```
CONTINUE
```

```
VMX(3) = VMX(3)*FG
```

```
VMX(4) = VMX(4)*FG
```

340 CONTINUE

X(N+1) = VMX(3)

X(N+2) = VMX(4)

C

IF(IY1 - 1)400,351,352

351 VM1(1) = VM1(1)*FP

VM1(2) = VM1(2)*FP

352 CALL SCALE(VM1,YL,2,1)

CALL AXIS(0,0,LABELS(1,IY1),+24,YL,90.,VM1(3),VM1(4))

IF(IY1 - 1)354,353,354

353 CONTINUE

VM1(3) = VM1(3)*FG

VM1(4) = VM1(4)*FG

354 CONTINUE

Y1(N+1) = VM1(3)

Y1(N+2) = VM1(4)

C

IF(IY2 - 1)400,361,362

361 VM2(1) = VM2(1)*FP

VM2(2) = VM2(2)*FP

362 CALL SCALE(VM2,YL,2,1)

CALL AXIS(0A2,0,LABELS(1,IY2),+24,YL,90.,VM2(3),VM2(4))

IF(IY2 - 1)364,363,364

363 CONTINUE

VM2(3) = VM2(3)*FG

VM2(4) = VM2(4)*FG

364 CONTINUE

Y2(N+1) = VM2(3)

Y2(N+2) = VM2(4)

C

IF(IY3 - 1)400,371,372

371 VM3(1) = VM3(1)*FP

VM3(2) = VM3(2)*FP

372 CALL SCALE(VM3,YL,2,1)

CALL AXIS(0A3,0,LABELS(1,IY3),+24,YL,90.,VM3(3),VM3(4))

IF(IY3 - 1)374,373,374

373 CONTINUE

VM3(3) = VM3(3)*FG

VM3(4) = VM3(4)*FG

374 CONTINUE

Y3(N+1) = VM3(3)

Y3(N+2) = VM3(4)

C

IF(IY4 - 1)400,381,382

381 VM4(1) = VM4(1)*FP

VM4(2) = VM4(2)*FP

382 CALL SCALE(VM4,YL,2,1)

CALL AXIS(0A4,0,LABELS(1,IY4),+24,YL,90.,VM4(3),VM4(4))

IF(IY4 - 1)384,383,384

383 CONTINUE

VM4(3) = VM4(3)*FG

VM4(4) = VM4(4)*FG

384 CONTINUE

Y4(N+1) = VM4(3)

D.2

Y4(N+2) = VM4(4)

C

400 CONTINUE
CALL SYMBOL(1.0,-1.2,HT,HDR,0.,80)

C

C

DRAW LINES

J = N/24 + 1

IF(IY1)450,450,410

410 CONTINUE

CALL LINE(X,Y1,N,1,J,LTYPE(1))

IF(IY2)450,450,420

420 CONTINUE

CALL LINE(X,Y2,N,1,J,LTYPE(2))

IF(IY3)450,450,430

430 CONTINUE

CALL LINE(X,Y3,N,1,J,LTYPE(3))

IF(IY4)450,450,440

440 CONTINUE

CALL LINE(X,Y4,N,1,J,LTYPE(4))

450 CONTINUE

C

C

DRAW LABELLING

VX = XL - .5

T = VX - 2.7

VY = YL - HT-HT

IF(IY1)550,550,510

510 CONTINUE

CALL SYMBOL(T,VY,HT,LABELS(1,IY1),0.,24)

CALL SYMBOL(VX,VY+HT2,HT,LTYPE(1),0.,-1)

VY = VY - HT-HT

IF(IY2)550,550,520

520 CONTINUE

CALL SYMBOL(T,VY,HT,LABELS(1,IY2),0.,24)

CALL SYMBOL(VX,VY+HT2,HT,LTYPE(2),0.,-1)

VY = VY - HT-HT

IF(IY3)550,550,530

530 CONTINUE

CALL SYMBOL(T,VY,HT,LABELS(1,IY3),0.,24)

CALL SYMBOL(VX,VY+HT2,HT,LTYPE(3),0.,-1)

VY = VY - HT-HT

IF(IY4)550,550,540

540 CONTINUE

CALL SYMBOL(T,VY,HT,LABELS(1,IY4),0.,24)

CALL SYMBOL(VX,VY+HT2,HT,LTYPE(4),0.,-1)

550 CONTINUE

C

CALL PLOT(XL+4.,-1.5,-3)

900 CONTINUE

RETURN

END

SUBROUTINE DENSM(Z1, P, RHO, CS)

DOUBLE PRECISION Z1, P, RHO, CS

DIMENSION HB(22), PB(22), TB(22), A(22), B(22)

DATA HB/0.,36089.239,65616.798,104986.88,154199.48,170603.67,

```

1 200131.23,259186.35,291153.40,323002.75,354753.59,386406.39,
2 480781.04,512046.16,543215.48,605263.45,728243.91,939894.75,
3 1234619.4,1520799.4,1798726.4,2068776.5/
DATA PB/2116.217,472.67922,114.34505,18.128852,2.3162994,
1 1.2322512,.38032173,.021672818,.0034331482,.00062812953,
2 .00015359936,.000052668807,.000010571582,.0000077157071,
3 .0000058324672,.0000035196139,.00000145371,.39343987E-6,
4 .94176667E-7,.22884174E-7,.72058936E-8,.24891264E-8/
DATA TB/288.15,2*216.65,228.65,2*270.65,252.65,2*180.65,210.65,
1 260.65,350.65,960.65,1110.65,1210.65,1350.65,1550.65,1830.65,
2 2160.65,2420.65,2590.65,2700.65/
DATA A/-.68755356E-5,0.,.14068775E-5,.37325169E-5,0.,
1 -.22523554E-5,-.48256441E-5,0.,.52141408E-5,.74757236E-5,
2 .12120769E-4,.17628281E-4,.49941997E-5,.28386537E-5,
3 .18535746E-5,.12041172E-5,.85314774E-6,.6116347E-6,
4 .42048419E-6,.25268689E-6,2*.1572315E-6/
DATA B/5.255886,-.48063102E-4,-34.163232,-12.20117,-.38473567E-4,
1 17.081527,3.540804,-.57641135E-4,-11.055226,-6.6127901,
2 -3.2961763,-1.6390858,-2.1704464,-3.2456979,-4.6155949,
3 -6.4033868,-7.8733154,-9.3039039,-11.4627,-17.025198,
4 2*-25.562133/

```

C

```

Z = Z1*3.28084
H = 20855531.E0*Z/(20855531.E0 + Z)
DO 1 I = 2, 22
IF(H-HB(I))2,1,1
1 CONTINUE
I = 23
2 I = I - 1
DH = H - HB(I)
TEMP = 1. + A(I)*DH
T = TB(I)*TEMP
IF(A(I))3,6,3
6 TEMP = EXP(B(I)*DH)
GO TO 4
3 TEMP = TEMP**B(I)
4 P = PB(I)*TEMP*47.88025
RHO = .003483647*P/T
CS = 20.04679*SQRT(T)
RETURN
END

```

DATE February 5, 1973
REV DATE _____
REV DATE _____

GOODYEAR AEROSPACE
CORPORATION
AKRON 13, OHIO

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