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DIGITAL SIMULATION OF FLEXIBLE AIRCRAFT RESPONSE TO SYMMETRICAL AND ASYMMETRICAL RUNWAY ROUGHNESS

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Structural Mechanics Division

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A method has been developed for determining the dynamic response of a flexible aircraft to runway roughness during takeoff or constant speed taxi. The equations that formulate the mathematical model have been programmed for a CDC 6600 digital computer and uses a Calcomp plotter for part of the program output. Three sets of runway elevation data are input to provide a forcing function at each landing gear. Three runway profiles measured at Washington National Airport, runway 36, were used to represent a typical commercial

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asymmetric profile. Three lines of profile were analytically generated to represent traversing a 1-cos dip at a 45 degree angle of approach.

Several aircraft have been simulated with this program, each during a takeoff and a constant speed taxi. The data used to simulate the airplanes (McDonnell Douglas C-9A, Boeing 727-100, and an AMST) and the runway profile data used, are included in the appendix of this paper.

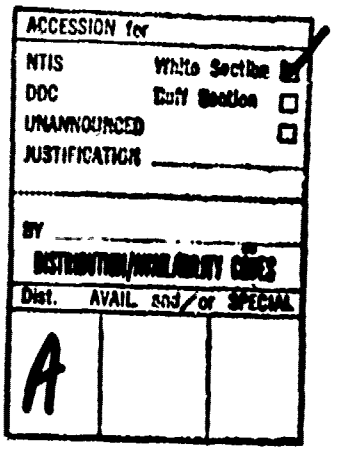
Comparison of simulated results to limited experimental data was good. Peak vertical acceleration levels at the pilot's station were within 14%.

The effect of the asymmetry of a profile on pilot's station vertical acceleration was significant providing the asymmetry of the profile was significant.

FOREWORD

This report was prepared by A. G Gerardi, Aerospace Engineer in the Loads and Response Prediction Group of the Structural Mechanics Division of the Air Force Flight Dynamics Laboratory at Wright-Patterson Air Force Base, Ohio. The work described herein is a part of the Air Force Systems Command exploratory development program to predict aircraft dynamic loads during ground operations. The work was directed under Project 1367, "Structural Integrity for Military Aerospace Vehicles," Task 136701, "Structural Flight Loads Data."

This report covers work done in the period from September 1975 to August 1976.



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INTRODUCTION

A common problem that can occur during takeoff and taxiing operations of aircraft is high acceleration levels caused by a rough runway. Due to these accelerations, runways must be evaluated with respect to roughness in order to ensure timely pavement maintenance to control aircraft structural loads and fatigue. Also, rough runways adversely affect the ability of the crew members by reducing instrument readability and crew comfort. Figure 1 shows the current criterion (Reference 1) used to set maximum allowable vertical acceleration levels from a human comfort standpoint. Reference 2 addressed the runway roughness problem at considerable length and contains the development of a mathematical model and subsequent computer program called "TAXI" to simulate the dynamic response of military aircraft to runway roughness on a symmetrical runway. For a symmetric runway, only one runway profile is required. Normally this is sufficient for representing a paved runway. With the advent of the AMST (Advanced Medium STOL Transport) and is some cases with conventional airplanes operating off of semiprepared or very rough paved surfaces, the rolling motion of an aircraft became significant. This rolling motion was the result of operating the aircraft on an asymmetric runway. Therefore, in order to properly simulate this response it became necessary to include the runway profile encountered by each landing gear.

1. PURPOSE OF THIS STUDY

The purpose of this study is to develop a computer program, capable of simulating an aircraft during constant speed taxi or takeoff from runways that are asymmetrical.

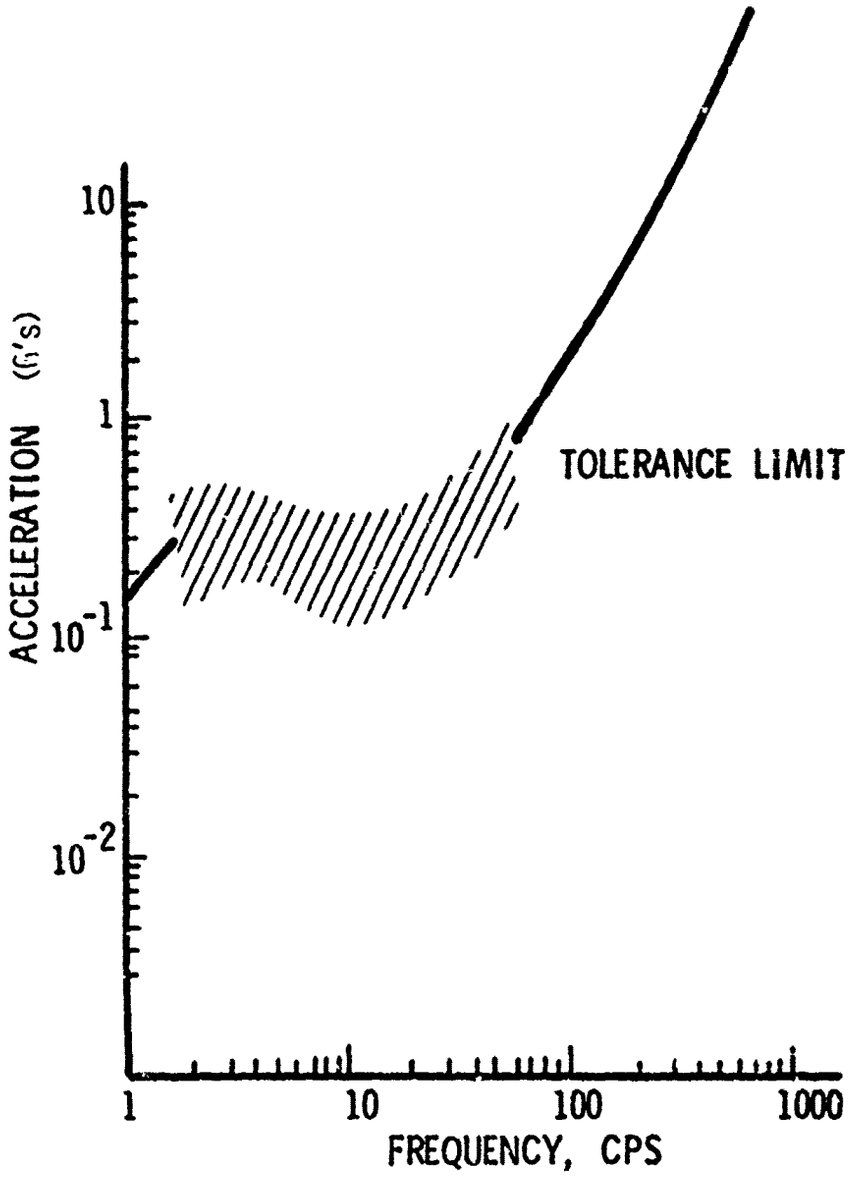


Figure 1. Accepted Military Human Tolerance Vertical Vibration Criterion

SECTION II
MATHEMATICAL MODEL

The airplane/runway mathematical model used for this study was the basic mathematical model developed in Reference 2. A detailed description of the components that make up this general model, as well as the assumptions made are shown in Reference 2. This report presents, in summary form, the landing gear strut and tire representation, the airplane rigid body and flexible body representation, the runway profile representation, the equations of motion, and the solution technique.

1. GENERAL AIRPLANE/RUNWAY MODEL

The general model represents an asymmetrical body with a nose gear and a right and left main landing gear. Each landing gear strut is assumed to have point contact with the profile and it is assumed that each landing gear traverses a different profile. Aerodynamic lift and drag are modeled, and thrust is applied at the aircraft's center of gravity.

The airplane is free to roll, pitch, plunge, and translate horizontally down the runway and each landing gear unsprung mass is free to translate vertically. To these rigid body degrees of freedom, up to 30 flexible modes of vibration are included. This airplane motion is controlled by the landing gear strut forces, lift, drag, thrust, and the resisting parameters of aircraft mass and inertia.

The landing gear struts are nonlinear, single acting oleo pneumatic energy absorbing devices (Figure 2) and are represented in the model as the sum of the three forces; pneumatic, hydraulic, and strut bearing friction forces. The pneumatic force, which is the largest of the three is represented by the equation:

$$F_A = \frac{PV}{\frac{V}{A} - S} \qquad (1)$$

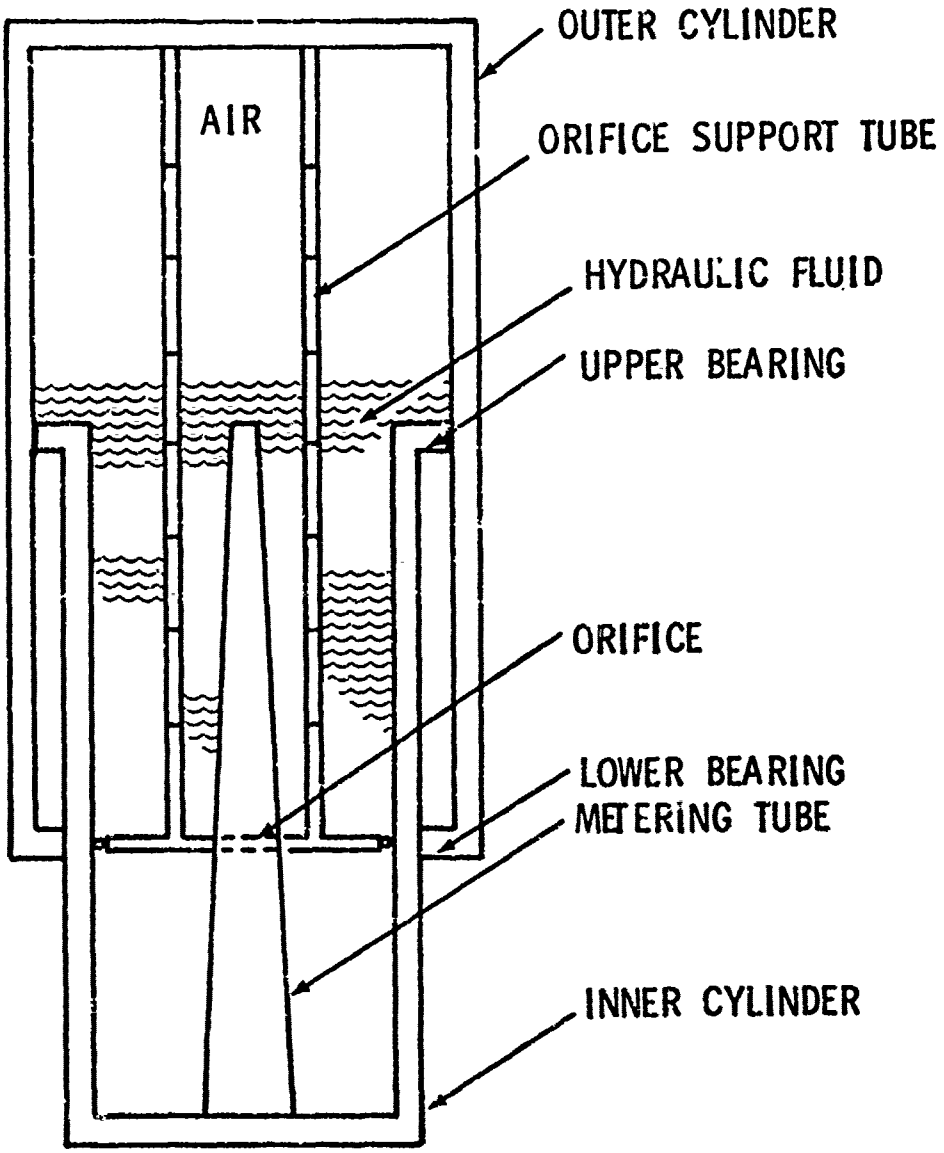


Figure 2. Typical Single Acting Oleo Pneumatic Landing Gear Strut

where:

P = fully extended strut pressure
V = fully extended strut volume
A = pneumatic piston area
S = strut stroke

The damping force is given by the equation:

$$F_h = \frac{\rho_h A_h^3 \dot{S}|\dot{S}|}{2 (C_d A_o)^2} \quad (2)$$

where:

ρ_h = density of the hydraulic fluid
A_h = the hydraulic piston area
A_o = effective orifice area (constant orifice minus metering pin area)
C_d = orifice coefficient (use 0.9)
$\dot{S}$ = strut piston velocity

The third strut force is the strut bearing friction force and is neglected in the model because the force is small for symmetrically loaded struts. (See Reference 2).

The tire force is represented by the linear equation:

$$F_T = k T_D \quad (3)$$

where:

T_D = tire deflection
k = linear tire spring constant

The runway elevation data is input into the model in two foot increments. The profile is made continuous by fitting the following

polynominal through the three elevation data points and the slope at the end of the previous profile segment:

$$y(x) = a_1 + a_2x + a_3x^2 + a_4x^3 \qquad (4)$$

where:

$a_{1,2,3,4}$ = coefficients derived from the elevation and slope data

This is done for each of the three lines of runway profile data.

2. RIGID BODY EQUATIONS OF MOTION

The differential equations of motion for the mathematical model were derived by application of the Lagrange equations (See Appendix A). The general form of these equations is shown below and corresponds to the notation shown in Figure A-1 in Appendix A.

$$\ddot{Z} = (F_{s1_*} + F_{s2} + F_{s3} + L - W)/M_{cg} \quad \text{[c.g., vertical acceleration]} \quad (5)$$

$$\ddot{Z}_1 = (F_{t1} - F_{s1} - W_1)/M_1 \quad \text{[unsprung mass vertical acceleration]} \quad (6)$$

$$\ddot{Z}_2 = (F_{t2} - F_{s2} - W_2)/M_2 \quad \text{[unsprung mass vertical acceleration]} \quad (7)$$

$$\ddot{Z}_3 = (F_{t3} - F_{s3} - W_3)/M_3 \quad \text{[unsprung mass vertical acceleration]} \quad (8)$$

$$\ddot{\theta} = (F_{s1}A + F_{s2}B + F_{TD}e_1 - F_{s3}C)/I_{yy} \quad \text{[pitching acceleration]} \quad (9)$$

$$\ddot{\phi} = (F_{s3} - F_{s2})C/I_{xx} \quad \text{[rolling acceleration]} \quad (10)$$

$$\ddot{X} = (F_T - F_{TD} - F_{AD})/(M_{cg}) \quad \text{[horizontal translation acceleration]} \quad (11)$$

where:

F_{s1}, F_{s2}, F_{s3} = total landing gear strut forces

F_{t1}, F_{t2}, F_{t3} = tire forces

M_{cg}, W, I_{yy}, I_{xx} = aircraft mass, weight, and pitching and roll inertias

*The subscript 1, 2 and 3 corresponds to the nose, right main and left main landing gears respectively.

W_1, W_2, W_3 = upsprung landing gear weights

A, B, C, ε_1 = moment arms

L, F_T, F_{TD}, F_{AD} = lift, thrust, and tire and aerodynamic drag forces
[F_T and F_{AD} act through the center of gravity]

3. FLEXIBILITY EQUATIONS OF MOTION

$$M_i\ddot{q}_i = \xi_{i1}F_{s1} + \xi_{i2}F_{s2} + \xi_{i3}F_{s3} - 2\zeta_i\omega_i\dot{q}_i - \omega_i^2 M_i q_i \text{ for the ith mode}$$

where:

M_i = the generalized mass

ξ_{i1}, ξ_{i2}, ξ_{i3} = modal deflections at gear location 1, 2 and 3

ω_i = modal frequency

ζ = damping factor

$q_i = \dot{q}_i, \ddot{q}_i$ = generalized coordinates and their time derivatives.

The sign convention is as follows:

Z = Vertical Displacement	+ up
θ = Pitch	+ nose down
ϕ = Roll	+ roll right
q = Deflection Due to Bending	+ up
X = Horizontal Translation	+ forward

4. SOLUTION TECHNIQUE

The technique used for solving the coupled nonlinear differential equations of motion that describe the simulated aircraft is a three-term Taylor series. For example, the equation:

$$\ddot{x} = -c\dot{x} - kx \tag{12}$$

The three term Taylor series representations can be written as

$$X_{(I+1)} = X_{(I)} + \dot{X}_{(I)}(\Delta t) + \ddot{X}_{(I)}\frac{(\Delta t)^2}{2} \tag{13}$$

where: $I = 1 \rightarrow N$

The values for $\ddot{x}$, $\dot{x}$ and x from the previous step are substituted into Equation 13 and a new value for x is obtained. Differentiating Equation 13 we obtain for the velocity $\dot{x}$, the expression:

$$\dot{x}_{(I+1)} = \dot{x}_{(I)} + \ddot{x}_{(I)} \, (\Delta t) \tag{14}$$

The values for $\dot{x}$ and $\ddot{x}$ are then substituted into Equation 14 and a new value of $\dot{x}$ is found. This entire process is repeated with the new values of x and $\dot{x}$ to obtain the next point in the solution.

SECTION III
COMPUTER PROGRAM

The computer program, TAX2, which computes the dynamic response of a flexible aircraft to an asymmetrical runway profile, consists of one basic program and several subroutines. A complete listing of the program is contained in Appendix B. Table 1 contains a description of the aircraft input data and Figure 3 shows the source deck setup for use on the CDC 6600 computer at Wright-Patterson AFB, Ohio.

1. OUTPUT FORMAT

The results of the calculations are presented as both a printed output and a time history plot. The printed output lists the value of fifteen parameters each 0.01 second. A sample of this listed output is shown in Table 2. The fifteen parameters listed in the heading are:

XMAINL	-	Left Main landing gear strut deflection (inches)
XMAINR	-	Right Main landing gear strut deflection (inches)
XNOSE	-	Nose gear strut deflection (inches)
ZPML	-	Left Main landing gear runway elevation (inches)
ZPMR	-	Right Main landing gear runway elevation (inches)
ZPN	-	Nose landing gear runway elevation (inches)
BETADD	-	Rolling acceleration ($\ddot{\phi}$) (rad/sec^2)
THETADD	-	Pitching acceleration ($\ddot{\Theta}$) (rad/sec^2)
BETA	-	Roll angle (ϕ) (rad)
THETA	-	Pitch angle (Θ) (rad)
SPEED	-	Aircraft velocity (ft/sec)
DISTANCE	-	Distance traveled down the runway (feet)
TIME	-	Real time (seconds)
CGACC	-	Center of Gravity Vertical Acceleration (g's)
PSA	-	Pilot's Station Vertical Acceleration (g's)

Figure 4 shows a photographic reduction of a typical Calcomp-plotted time history. This figure depicts a Boeing 727-100 taxiing at 50 fps over a 1-cos bump at a 45° angle of approach. The plotted output includes titles showing the airplane simulated, its gross weight,

TABLE 1

DESCRIPTION OF INPUT AIRCRAFT DATA

Section 1 (cards 1-5) - General Airplane Data

Card Column	Format	Variable Name	Data for McDonnell-Douglas C-9A	Definition
Card 1				
1-80	8A10	PLANE	McDonnell-Douglas C-9A	Airplane Being Simulated and Gross Weight
Card 2				
1-10	F10.1	W	108000.	Vehicle Weight (lbs)
11-20	F10.1	A	51.6	Distance Main Gear to CG (in)
21-30	F10.1	B	589.4	Distance Nose Gear to CG (in)
31-40	F10.1	MMI	20800000.	Pitch Moment of Inertia (lb in sec^2)
41-52	F12.0	WS	96.	Wing Station of Main Gear (in)
53-64	F12.0	MMIR	8000000.	Roll Moment of Inertia (lb in sec^2)
Card 3				
1-10	F10.2	PSARM	607.0	Distance of Pilot Station to CG (in)
11-20	F10.2	TAILRM	318.5	Distance of Tail Station to CG (in)
Card 4				
1-10	F10.2	SPEED	50.	Initial Velocity of Airplane (ft/sec)
11-20	F10.2	THRUST	29000.	Total Airplane Thrust (lbs)
21-30	F10.2	TAKEOFF	285.5	Airplane Rotation Speed (ft/sec)

TABLE 1 (Continued)

Card Column	Format	Variable Name	Data for McDonnell-Douglas C-9A	Definition
Card 5				
1-10	F10.4	CL	1.1	Lift Coefficient
11-20	F10.4	AREA	1000.7	Wing Area (ft^2)
21-30	F10.4	CD	.1	Drag Coefficient
Section 2 (cards 6-11) - Main and Nose Gear				
Card 6				
1-10	F10.2	WM	957.16	Unsprung Weight of Each Main Gear (lbs)
11-20	F10.2	WN	153.43	Unsprung Weight of Nose Gear (lbs)
21-30	F10.2	SXM	2.	Number of Main Gear Struts
31-40	F10.2	SXN	1.	Number of Nose Gear Struts
Card 7				
1-10	F10.5	AHN	6.745	Hydraulic Piston Area Nose (in^2)
11-20	F10.5	AAN	8.2958	Pneumatic Piston Area Nose (in^2)
21-30	F10.5	AHM	16.5	Hydraulic Piston Area Main (in^2)
31-40	F10.5	AAM	21.648	Pneumatic Piston Area Main (in^2)
Card 8				
1-10	F10.5	PAOH	120.	Nose Strut Preload Pressure (lbs/in^2)
11-20	F10.5	PAOM	220.	Main Strut Preload Pressure (lbs/in^2)

TABLE 1 (Continued)

Card Column	Format	Variable Name	Data for McDonnell-Douglas C-9A	Definition
21-30	F10.5	VON	126.2	Fully Extended Nose Strut Air Volume (in^3)
31-40	F10.5	VOM	366.0	Fully Extended Main Strut Air Volume (in^3)
41-50	F10.5	OAM	.543	Orifice Area Main (in^2)
51-60	F10.5	OAN	.442	Orifice Area Nose (in^2)
Card 9				
1-10	F10.3	SLM	85.5	Distance from Axle to CG Waterline Main Gear Strut Unloaded (in)
11-20	F10.3	SLN	87.3	Distance from Axle to CG Waterline Nose Gear Strut Unloaded (in)
Card 10				
1-10	F10.1	TSM	23428.6	Main Tire Spring Constant Per Strut (lbs/in)
11-20	F10.1	TSN	8632.5	Nose Tire Spring Constant Per Strut (lbs/in)
Card 11				
1-10	F10.5	DX	.001	Integration Step Size
Card 12				
1-5	I5	IFPLOT	0	0-Plot; 1-No Plot
6-10	I5	IFLIST	0	0-List; 1-No List
Section 3 (cards 13-16) - Metering Pin Description				
Card 13				
1-5	I5	NSCN	5	Number of Slope Changes Nose Gear

TABLE 1 (Continued)

Card Column	Format	Variable Name	Data for McDonnell-Douglas C-9A	Definition
* Card 14A, 14B,....				
1-10	F10.3	STROKN (I)	*	Stroke Corresponding to Metering Pin Diameter, Nose Gear
11-20	F10.3	PINDN (I)	*	Metering Pin Diameter, Nose Gear (in)
Card 15				
1-5	I5	NSCM	*	Number of Slope Changes Main Gear
* Card 16A, 16B,....				
1-10	F10.3	STROKM (I)	*	Stroke Corresponding to Metering Pin Diameter, Nose Gear
11-20	F10.3	PINDM (I)	*	Metering Pin Diameter, Main Gear (in)
Section 4 (cards 17-19) - Flexibility Data				
Card 17				
1-5	I5	NFM	7	Number of Symmetrical Flexible Modes
6-10	I5	NAFM	7	Number of Asymmetrical Modes
** Card 18A, 18B,....				
1-10	F10.3	SIMAIN (I)	**	Mode Shape Deflection Main Gear
11-20	F10.3	SINOSE (I)	**	Mode Shape Deflection Nose Gear
21-30	F10.3	SICG (I)	**	Mode Shape Deflection CG
31-40	F10.3	SITAIL (I)	**	Mode Shape Deflection Tail Station

TABLE 1 (Continued)

Card Column	Format	Variable Name	Data for McDonnell-Douglas C-9A	Definition
41-50	F10.3	SIPS	**	Mode Shape Deflection Pilot Station
** Card 19A, 19B,....				
1-15	F15.2	GM (I)	**	Generalized Mass (lbs sec^2/in)
16-25	F10.3	OMEGA (I)	**	Modal Frequency (rad/sec)
** Card 20A, 20B,....				
1-10	F10.3	SILEFT (I)	**	Deflection for Left Main Gear
11-20	F10.3	SIRIGHT (I)	**	Deflection for Right Main Gear
** Card 21A, 21AB,....				
1-15	F15.3	GMA (I)	**	Asymmetrical Generalized Mass (lbs sec^2/in)
16-25	F10.4	OMEGAA (I)	**	Asymmetrical Modal Frequency (rad/sec)

* One card is required for each stroke-metering pin combination read into the program.

** One card is required for each flexible mode.

Note: A summary of all the data used in this study is shown in Appendix C.

TABLE 1 (Concluded)

Runway Profile Magnetic Tape

The runway profile is read into the program from a magnetic tape or permanent file. The format for this is shown below:

Column	Format	Variable Name	Definition
Read 1			
1-80	8A10	SITE**	Runway Profile and Direction
Read 2			
1-6	I6	NPTSS**	Number of Runway Elevation Points
* Read 3, 4,....N+2			
1-70	10F7.3	ELEVL**	Runway Profile Data
		ELEV	
		ELEVR	

* One read required for every ten runway profile elevation points.

** The process is repeated for each of the three profiles.

Note: All of the runway profile data used in this study is listed in Appendix D.

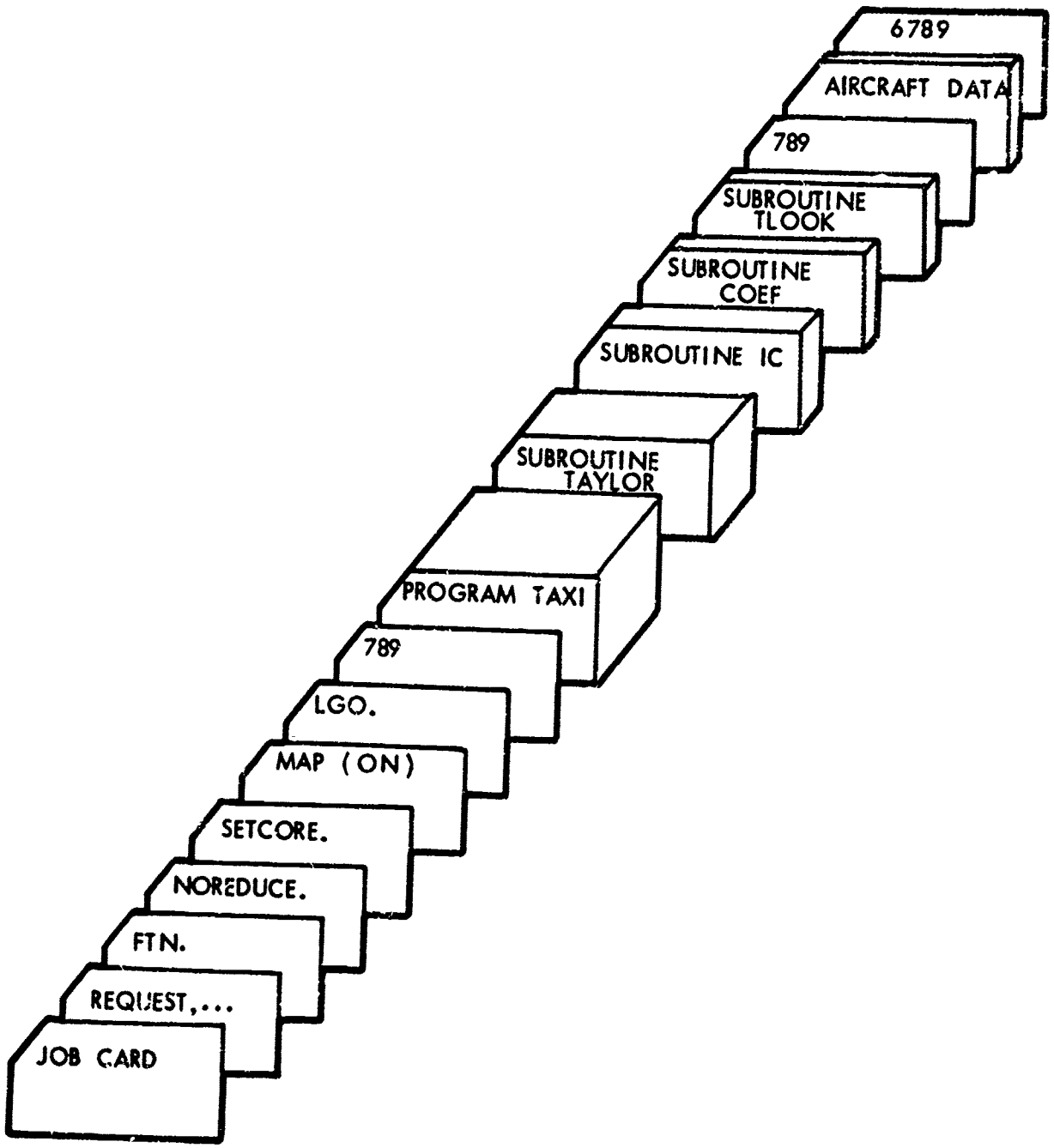
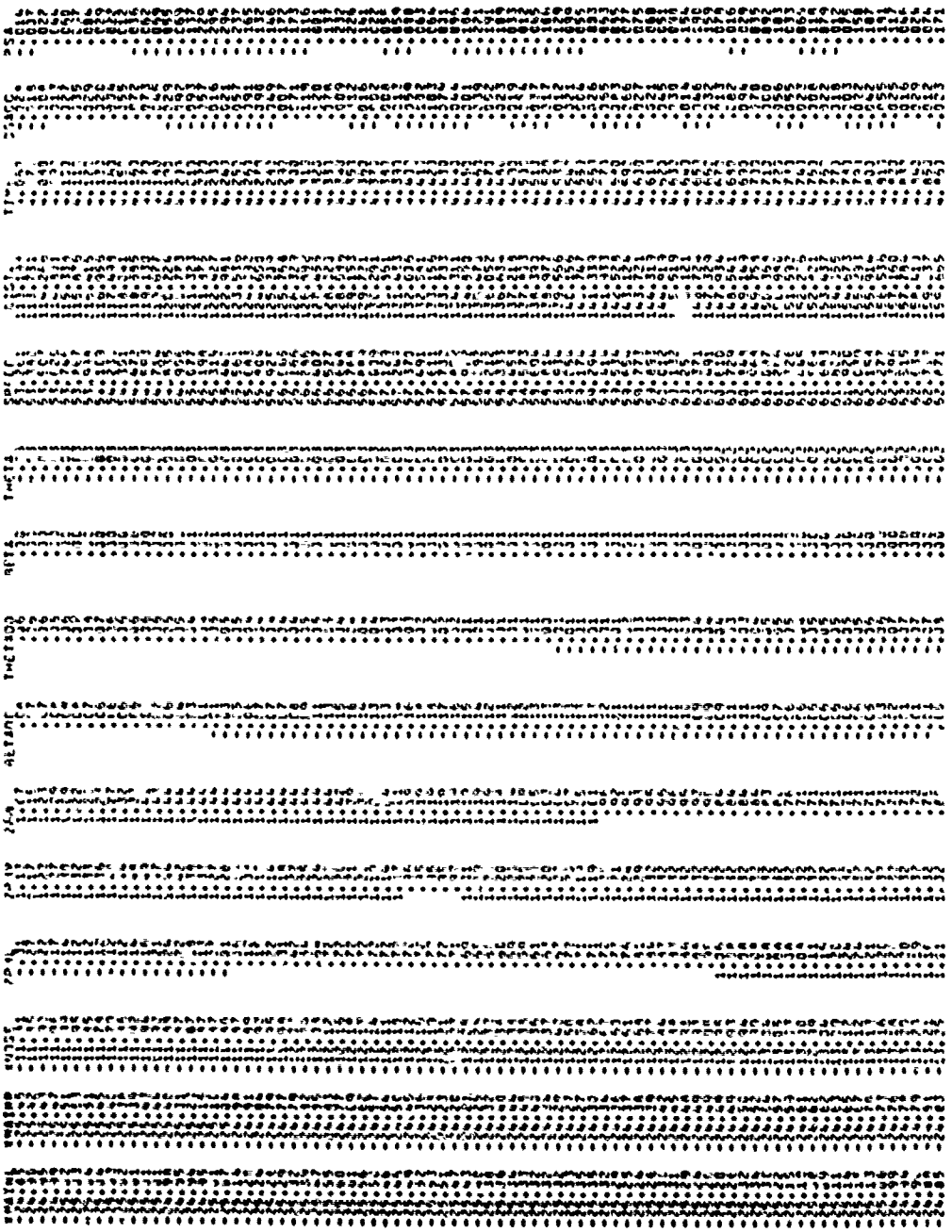


Figure 3. Source Deck Setup

TABLE 2

TYPICAL COMPUTER OUTPUT LISTING



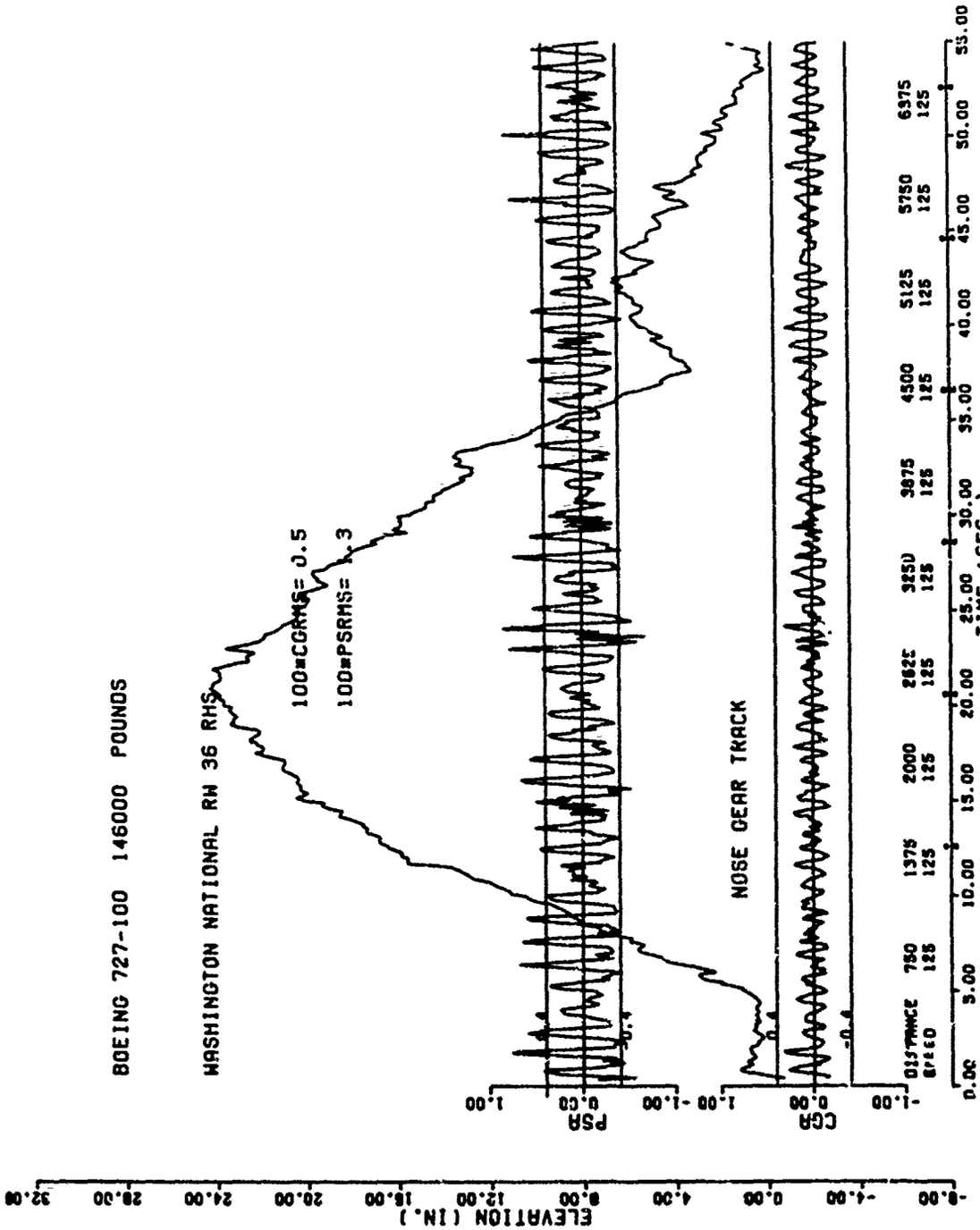


Figure 4. Typical Calcomp Plotted Output

the runway number and its location. The abscissa is the time axis annotated every second. At every time annotation the current value of aircraft speed, in feet per second, and the current aircraft position on the runway, in feet, are printed out. Runway markers (1,000-foot markers) are also plotted on the time scale to aid in aircraft positioning. The plot titled "Nose Gear Track" is a time history of the runway profile as it is encountered by the aircraft's nose gear. The actual runway profile is preceded by 100 feet of smooth surface to allow any starting transients to damp out prior to encountering the actual profile. There are two aircraft acceleration time histories that are of particular interest. One is the vertical acceleration at the pilot's station (PSA), the other is the vertical acceleration at the aircraft's center of gravity (CGA). Each time history is banded by the human tolerance criterion of $\pm$0.4 g. In order to minimize the amount of computer central memory required to store the acceleration time histories, the higher frequency components were effectively filtered out by limiting the sampling interval. All of the acceleration peaks, however, are shown on the plot. It should be noted that the pilot station acceleration time history is not always within the band of accepted human tolerance criteria. Thus, the plot is very useful in that it provides a graphical record of the level of acceleration, and it shows which bumps in the runway profile caused the high acceleration response.

SECTION IV
DISCUSSION OF SIMULATIONS

Table 3 contains a summary of the simulations made in this study. Three different airplanes were simulated: the Boeing 727-100, the McDonnell Douglas C-9A, and an AMST configuration. Each airplane was simulated traversing two profiles: Washington National Runway 36, and a 1-cos dip. Simulations were made using mathematical models with and without a roll degree of freedom, i.e. one or three profiles, and with and without flexible wings so that comparisons of the responses could be made.

Figures 5 and 6 show the plotted results of a Boeing 727-100 traversing the Washington National runway profile without a roll degree of freedom and with a roll degree of freedom respectively. Both runs were made at a constant speed of 125 feet per second, because this speed produced higher levels of vertical acceleration for this airplane. Comparison of these two figures shows a significant increase in the vertical acceleration at the pilot's station (P.S.) while the aircraft is at different locations on the runway. For example, at T=46 sec. P.S. acceleration levels more than doubled when three lines of profile were used. This is attributed to the fact that the profiles seen by the main landing gear were rougher in the latter case. Figure 7 shows the Power Spectral Density (PSD) levels of each line of survey for the Washington National runway. A PSD is a measure of the relative roughness of a runway versus frequency. It can be seen that the PSD level is different for each line of survey which accounts for the change in the aircraft's dynamic response. Figures 8 and 9 show the 727-100 traversing a 1-cos dip headon and at a 45° angle respectively. In this case the speed was 50 fps which "tunes" the natural pitching frequency (1 cps) of the 727-100 to this 1-cos dip. Hitting the 1-cos dip at an angle caused an increase in the peak P.S. and C.G. acceleration levels.

In was necessary to try to simulate different aircraft with the computer program in an effort to check the program's versatility.

TABLE 3

SUMMARY OF SIMULATIONS

Run #	Airplane	Profile	Speed	Remarks
1	727-100	Washington National (C)	125 fps	No Roll DOF*, Rigid Wings
2	727-100	Washington National (L,C,R)	125 fps	With Roll DOF, Rigid Wings
3	727-100	(1-cos) (C)	50 fps	No Roll DOF, Rigid Wings
4	727-100	(1-cos) (L,C,R)	50 fps	With Roll DOF, Rigid Wings
5	C-9A	(1-cos) (L,C,R)	50 fps	With Roll DOF, Rigid Wings
6	AMST	(1-cos) (L,C,R)	50 fps	With Roll DOF, Rigid Wings
7	727-100	Washington National (L,C,R)	Takeoff	With Roll DOF, Rigid Wings
8	AMST	Washington National (L,C,R)	Takeoff	With Roll DOF, Rigid Wings
9	C-9A	Washington National (L,C,R)	Takeoff	With Roll DOF, Rigid Wings
10	C-9A	(1-cos) (L,C,R)	50 fps	With Roll DOF, Flexible Wings
11	C-9A	Washington National (L,C,R)	Takeoff	With Roll DOF, Flexible Wings

* Degree of Freedom

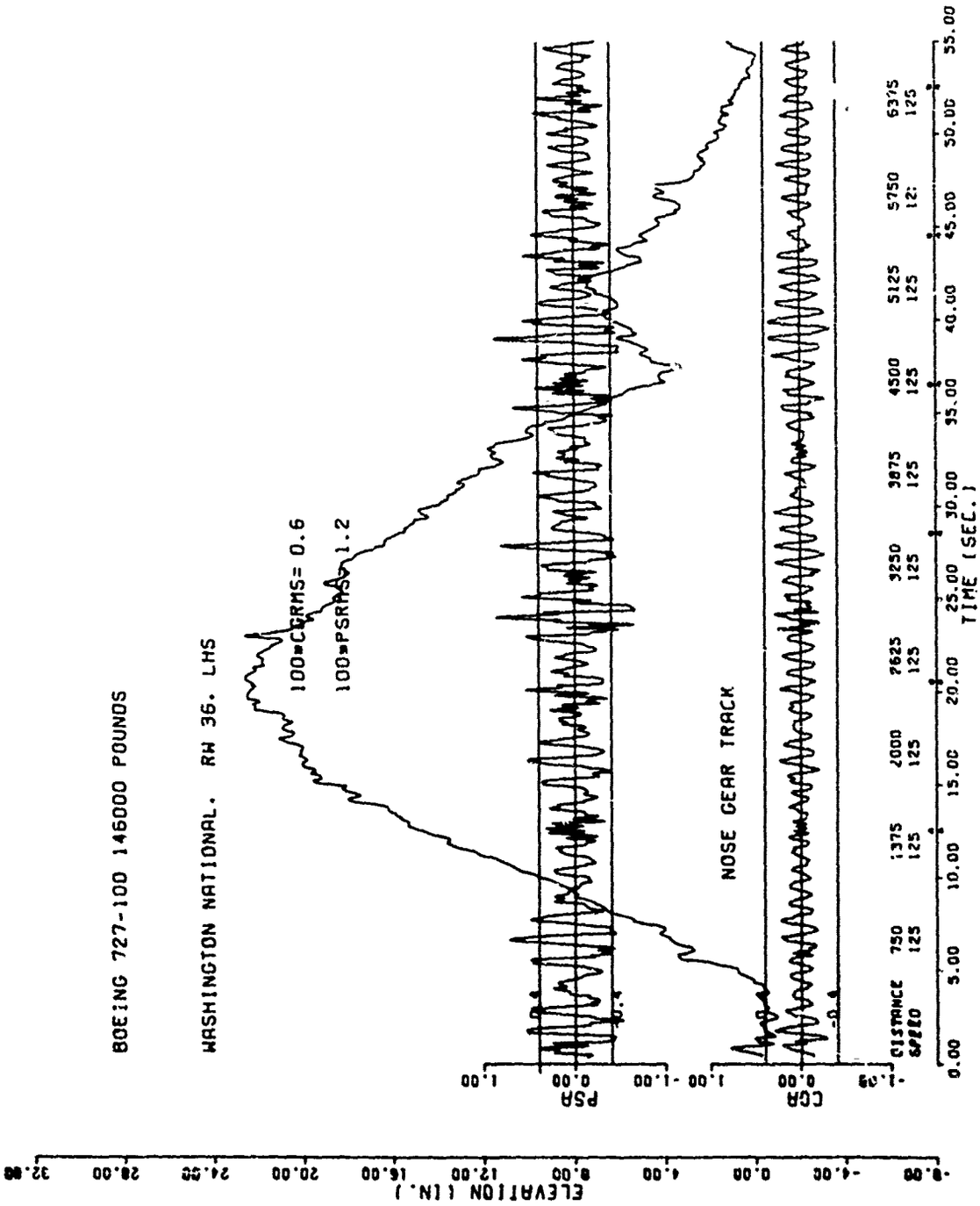


Figure 5. Boeing 727-100 Constant Speed Taxi Simulation over the Washington National Profile Without a Roll Degree of Freedom

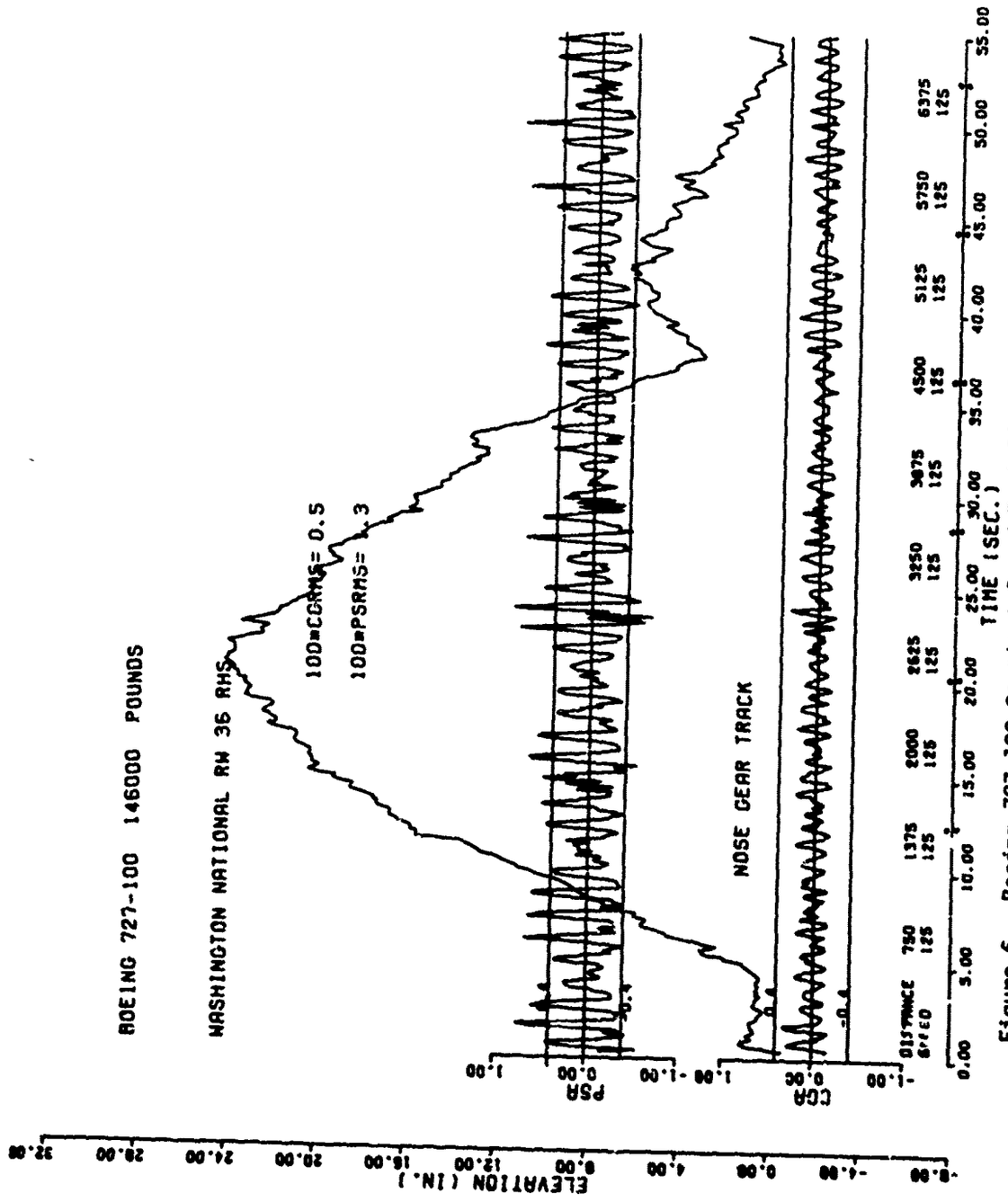


Figure 6. Boeing 727-100 Constant Speed Taxi Simulation over the Washington National Profile With a Roll Degree of Freedom

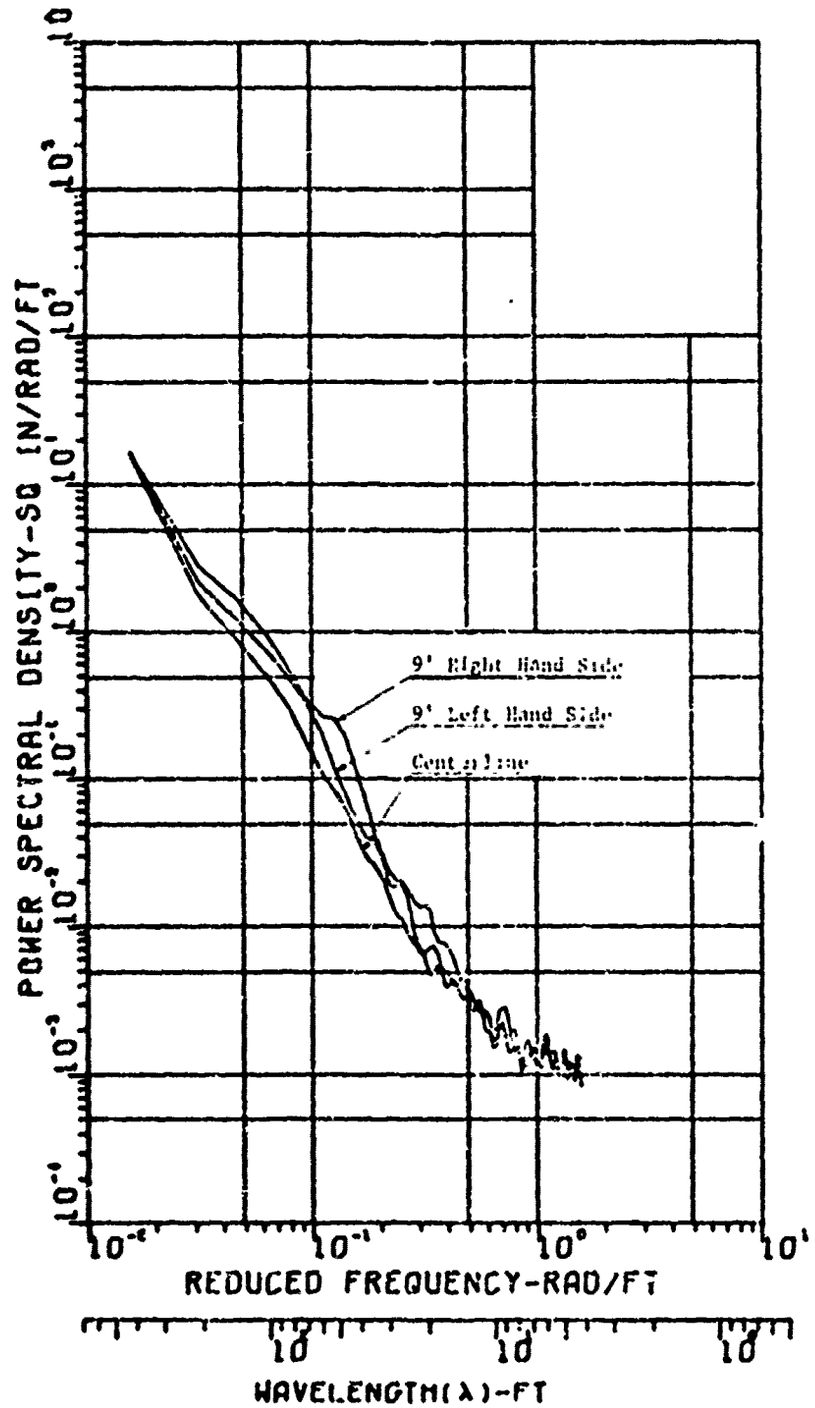


Figure 7. PSD of Washington National Airport Runway 36

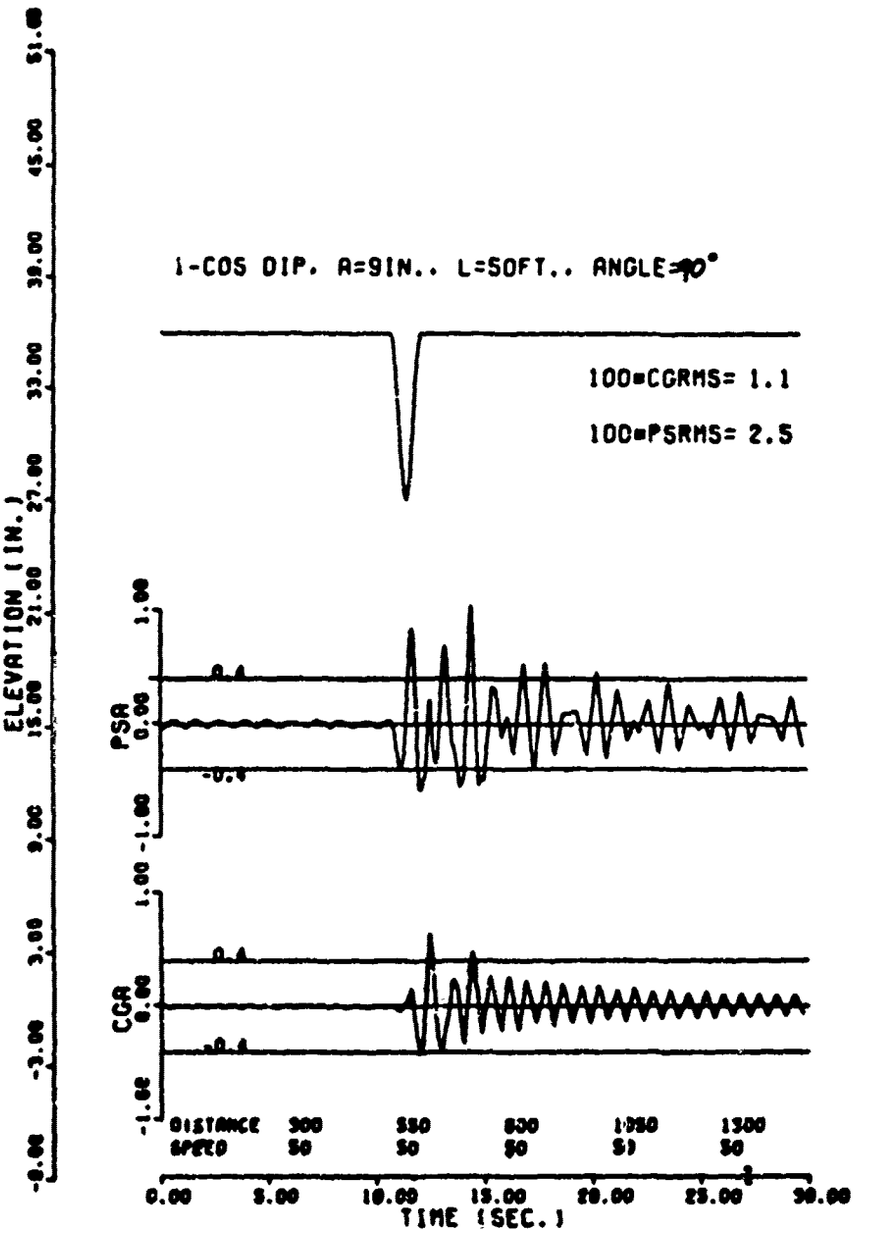


Figure 8. Boeing 727-100 Traversing a (1-cos) dip head-on.

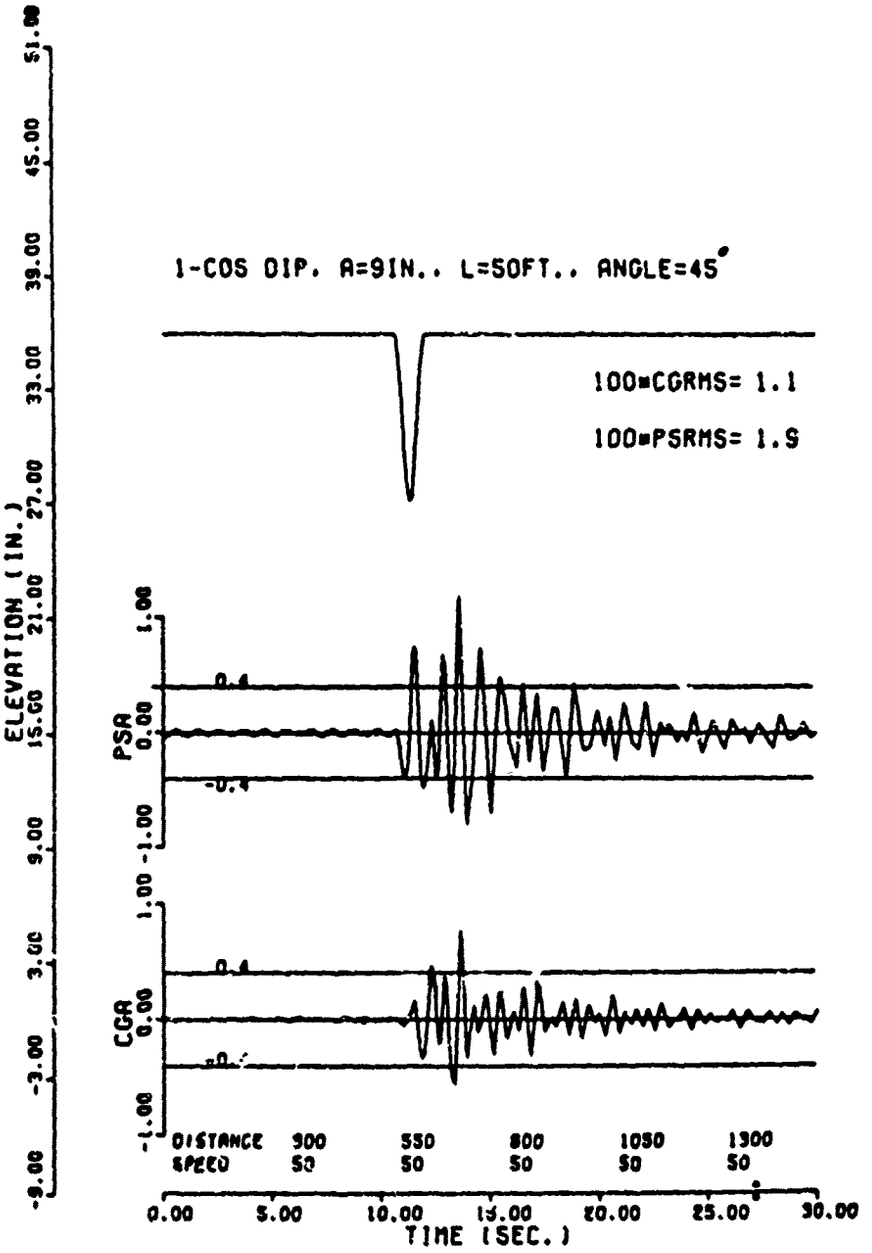


Figure 9. Boeing 727-100 Traversing a (1-cos) dip at a 45° angle

Figures 10 and 11 show the plotted results of the C-9A and AMST respectively hitting the 1-cos dip at a 45° angle at a constant speed of 50 fps. While the C-9A had a relatively high response, the AMST, which is designed to operate off of rough fields, "absorbed" the dip to a large degree. This indicates that the computer program is calculating relative responses which are at least intuitively correct.

Up to this point only constant speed simulations have been discussed. Figures 12, 13 and 14 show the plotted results of the Boeing 727-100, AMST and the C-9A respectively taking off from the Washington National runway profile. Takeoff simulations are made by starting at a near zero forward velocity and accelerating at a constant thrust until rotation speed is reached, then the simulation is terminated. Again it can be seen that the AMST (which is designed for rough field operation) had a very low dynamic response, even though this runway is relatively rough. Figure 15 shows the plotted PSD's of Washington National Runway 36 and of two typically smooth runways, one at Portland Oregon and one at Dulles International. The Washington National Runway is significantly rougher.

Experimental data was available for comparison with the 727-100 takeoff simulation. Figure 16 shows the actual time history plots of vertical acceleration measured on a 727-100 taking off at 120,000 pounds gross weight from Washington National Runway 36 on December 11, 1972. Some parameters of the test aircraft were unknown such as strut and tire pressures and actual inertias. So exact simulation was not possible. However, Table 4 shows that comparison of several peak values of vertical accelerations at the P.S. were within 15 percent. The comparisons of C.G. vertical accelerations were not as good. In the simulation the acceleration levels were lower. It appears that main gear strut pressures on the actual airplane were lower than that simulated. This difference would cause the higher response in the plunge mode.

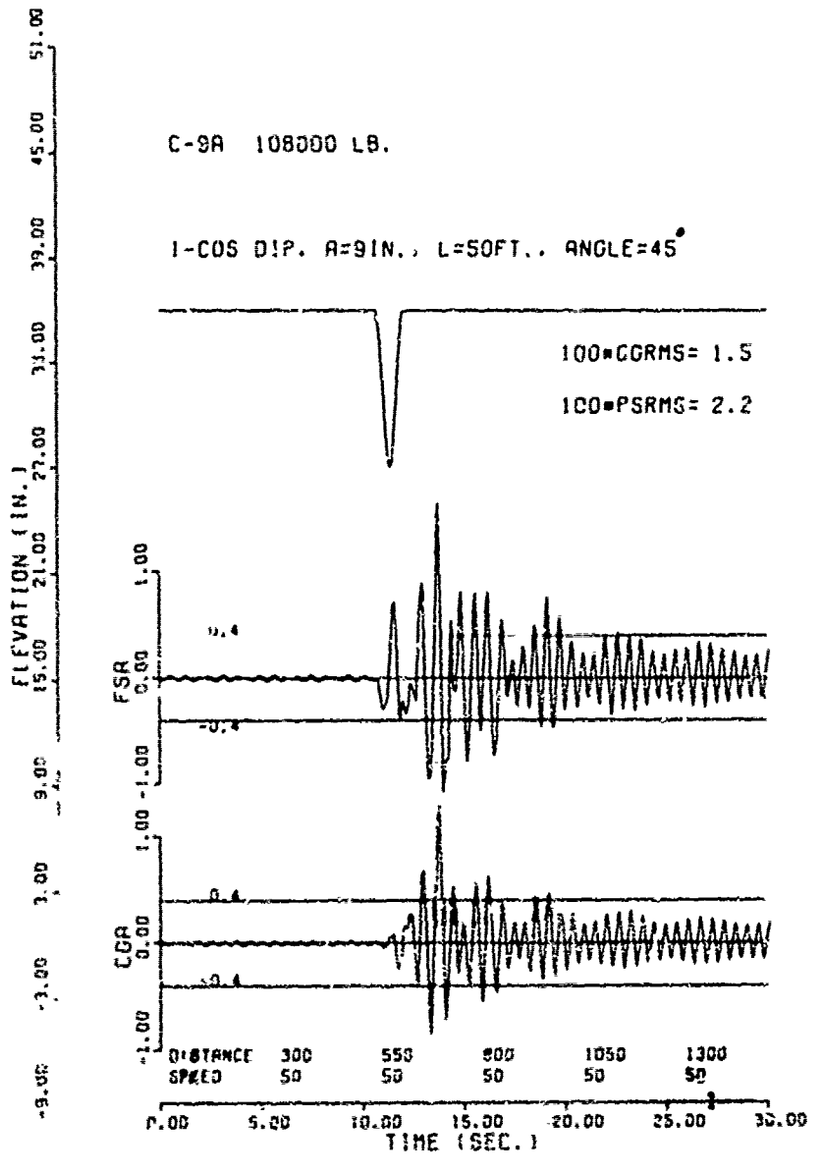


Figure 10. C-9A Traversing a (1-cos) dip at a 45° angle

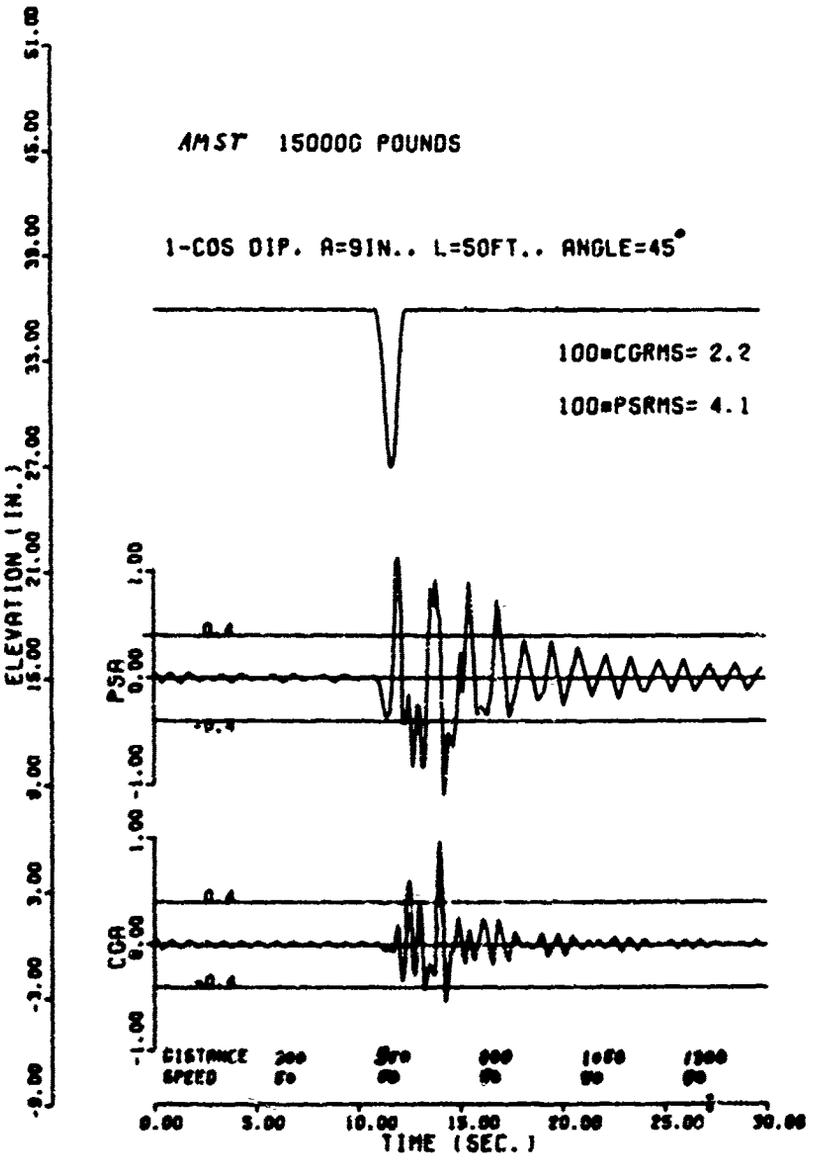


Figure 11. AMST Traversing a (1-cos) dip at a 45° angle

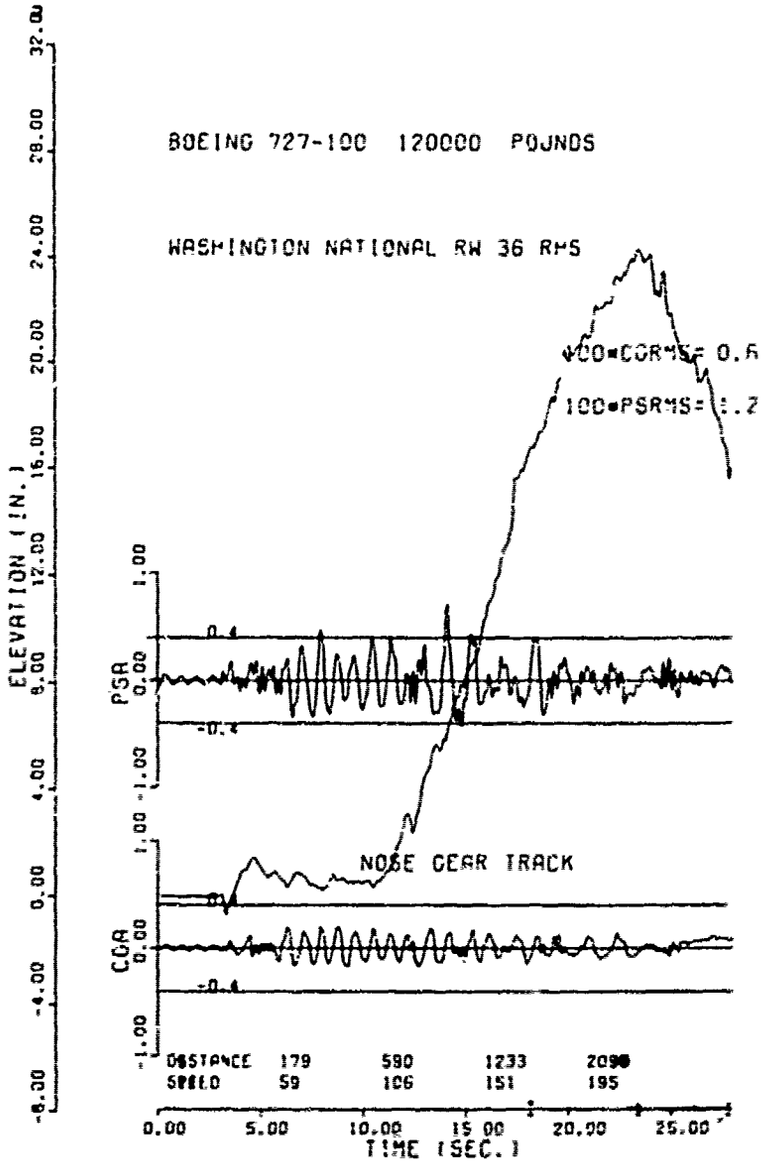


Figure 12. Boeing 727-100 Taking Off from Washington National Airport With the Roll Degree of Freedom Included

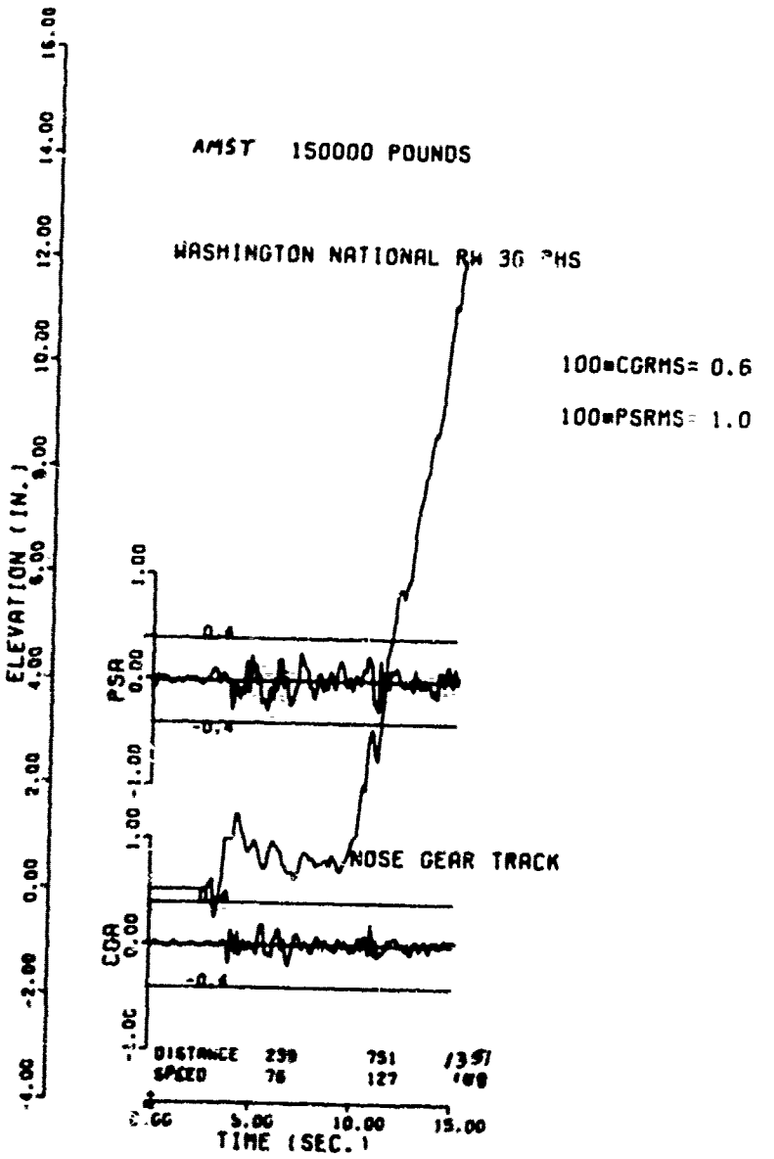


Figure 13. AMST Taking Off from Washington National Airport With the Roll Degree of Freedom Included

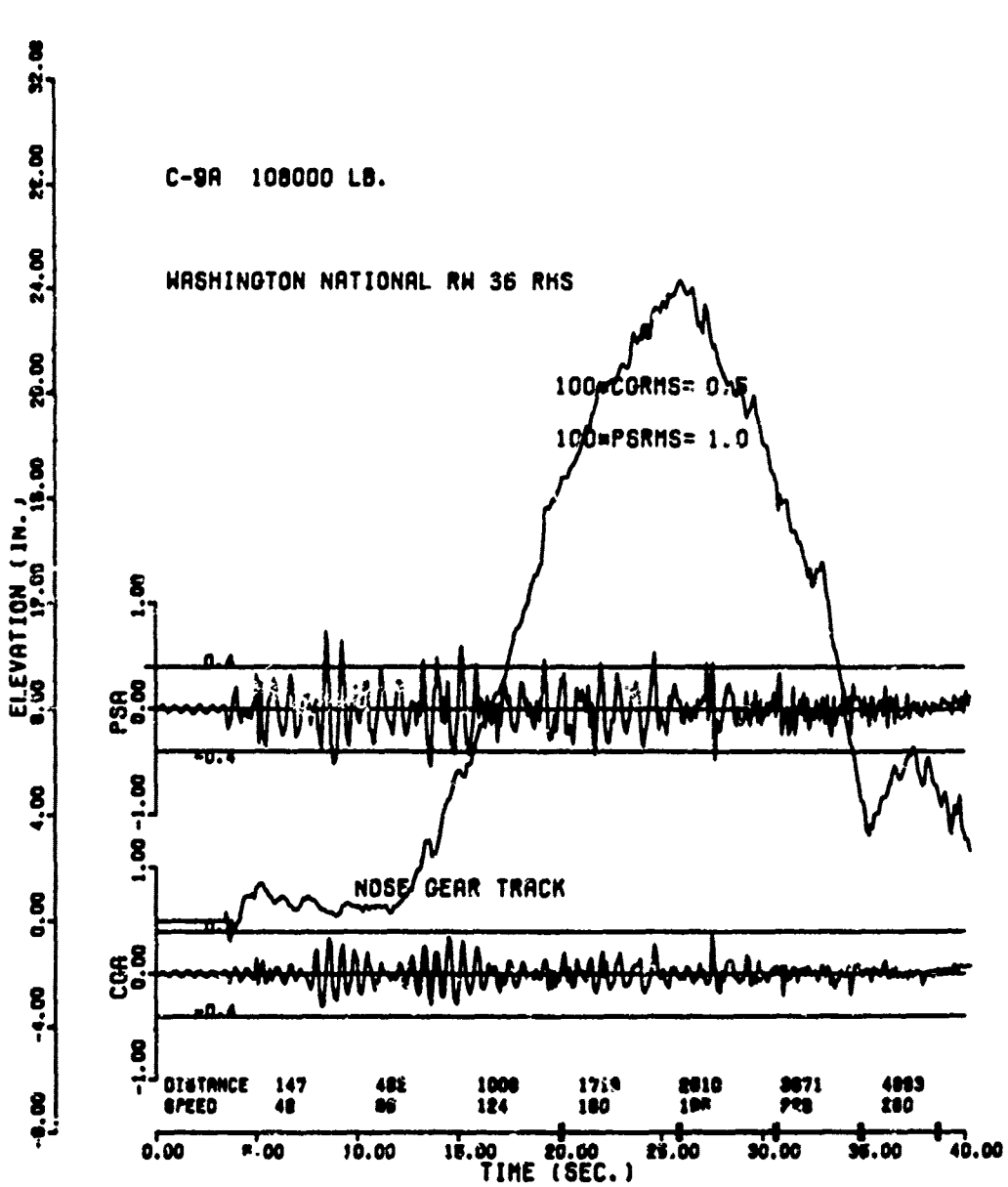


Figure 14. C-9A Taking Off from Washington National Airport With the Roll Degree of Freedom Included

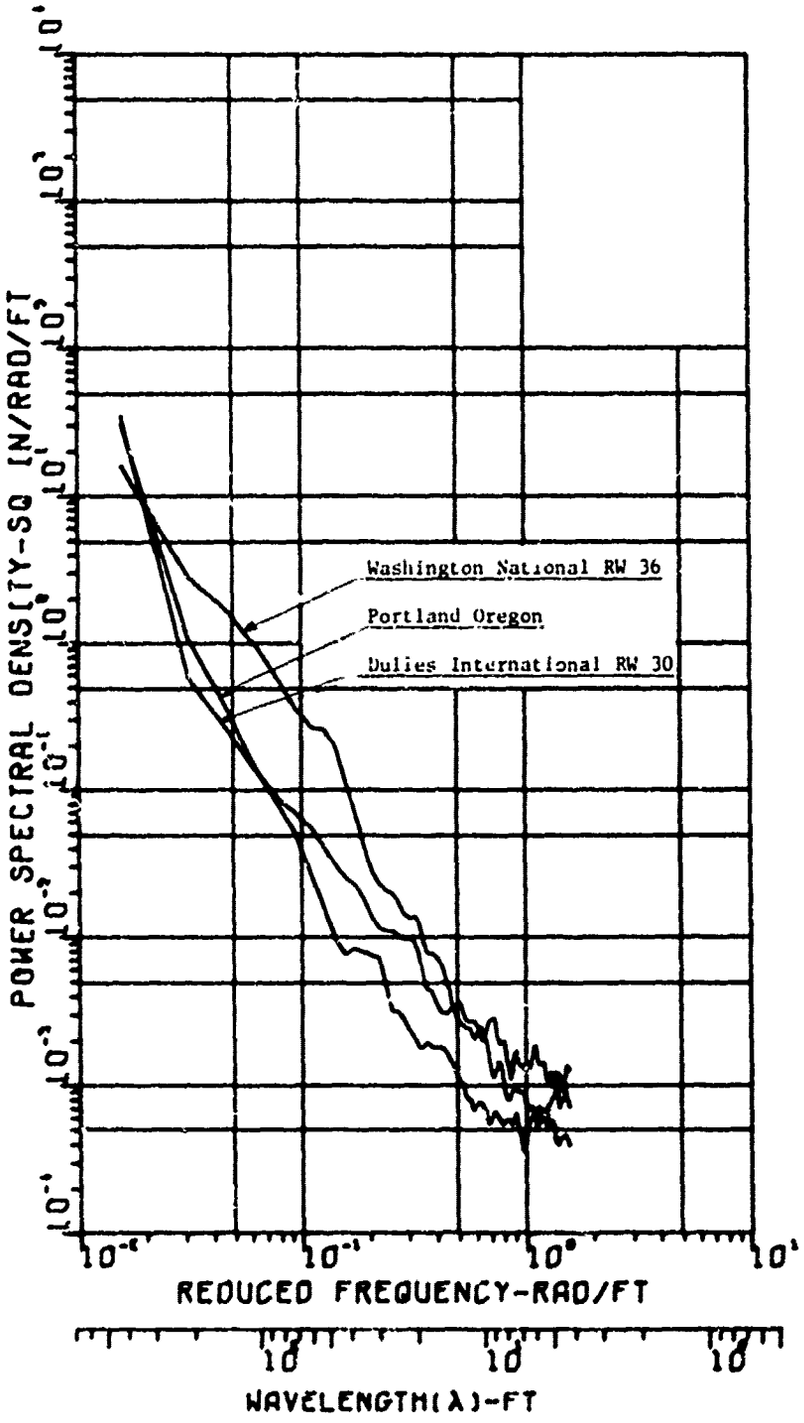


Figure 15. PSD of Washington National Runway 36 and two Typically Smooth Runways

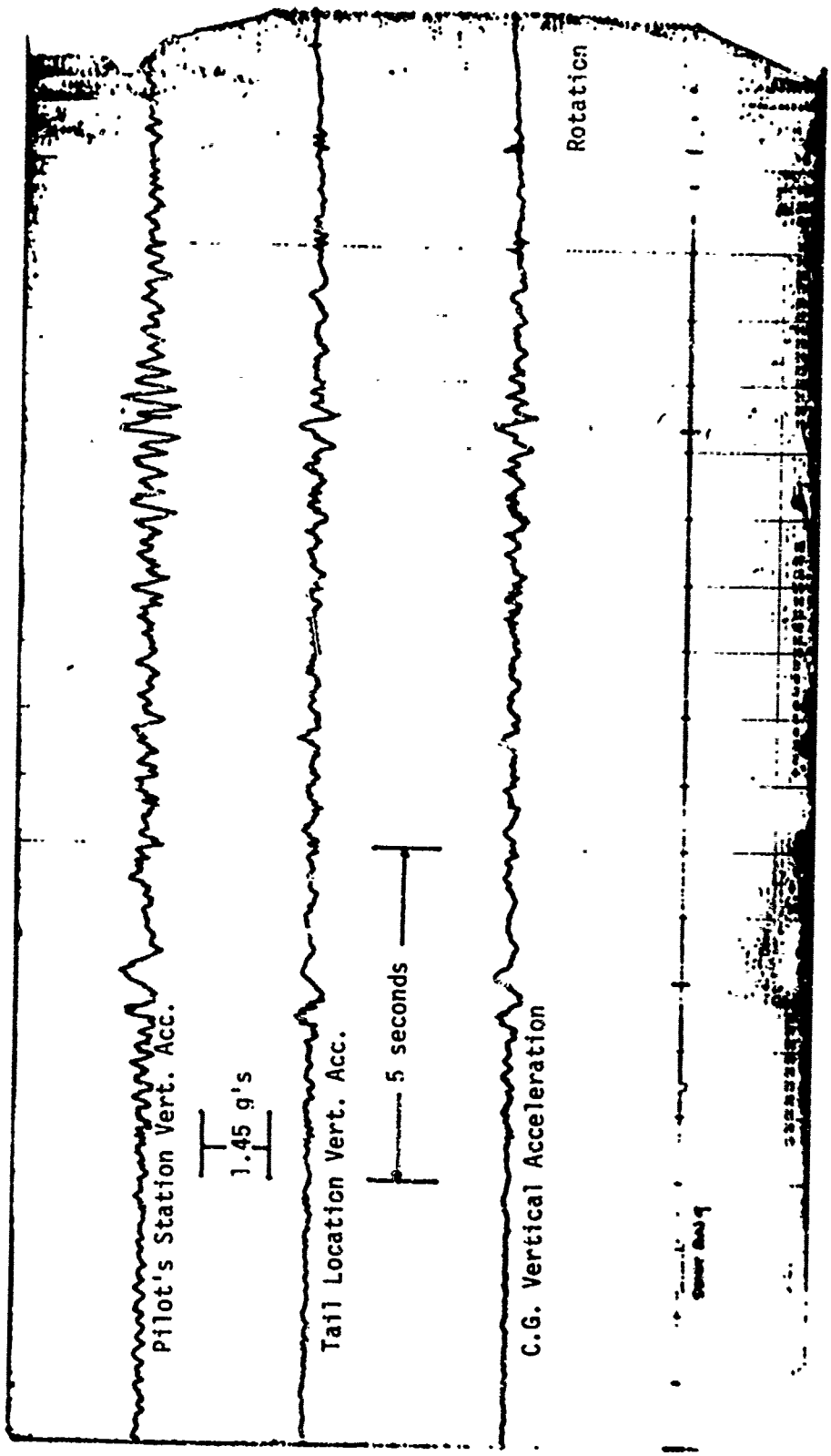


Figure 16. Measured Response of a Boeing 727-100 Takeoff at Washington National Airport Runway 36

TABLE 4

COMPARISONS OF SIMULATED AND EXPERIMENTAL DATA

	P.S. Vertical Acceleration		C.G. Vertical Acceleration	
Experimental Time (sec)	Exp (g's)	Sim (g's)	Exp (g's)	Sim (g's)
8.0	0.9425	0.90	0.55	0.35
16.3	1.305	1.12	0.80	0.40
20.5		TAKEOFF		

Note: All measurements are measured from peak to peak.

The remaining simulations made were with the inclusion of wing flexibility in the simulations. The purpose of including the wing flexibility was to see if there was a significant change in P.S. and C.G. vertical acceleration response when the wing was permitted to bend when acted on by a main landing gear strut force. These simulations were made on the C-9A only because this was the only aircraft for which wing flexibility data was available. Figure 17 shows the plotted results of C-9A with flexibile wings traversing the 1-cos dip at a 45° angle. This figure can be compared to Figure 10 which is the same simulation without flexible wings. By superimposing the two plots it was determined after T=17 seconds, small changes in vertical acceleration were appearing in both the P.S. and C.G. responses. Generally the higher accelerations occurred on the C-9A simulation with flexible wings. Also there was a phase lag. By the end of the run the rigid wing model lagged the flexible wing model by approximately one half of a cycle. Figure 18 shows the plotted response of the C-9A with flexible wings during a takeoff simulation from Washington National Runway 36. Figure 14 shows the same simulation without flexible wings. Superposition of the two plots shows little change, if any, in the airplane's response.

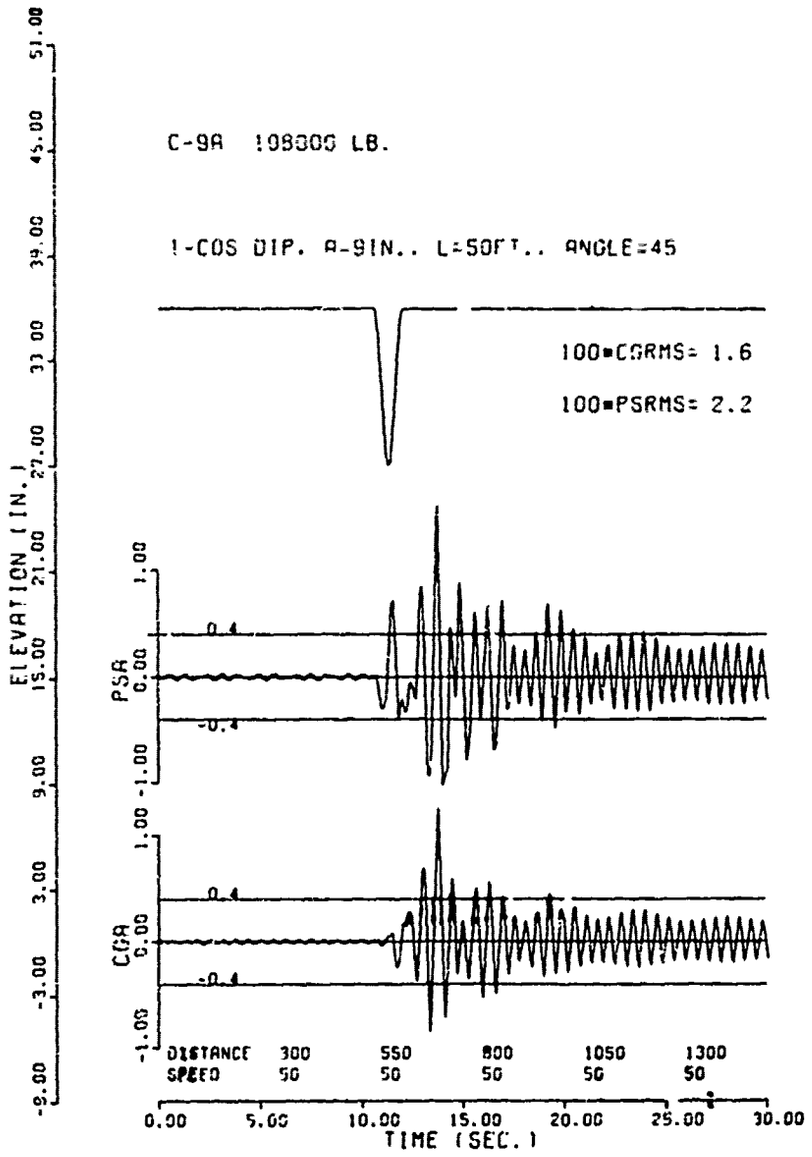


Figure 17. C-9A with Flexible Wings Taxiing over a (1-cos) dip at a 45° angle

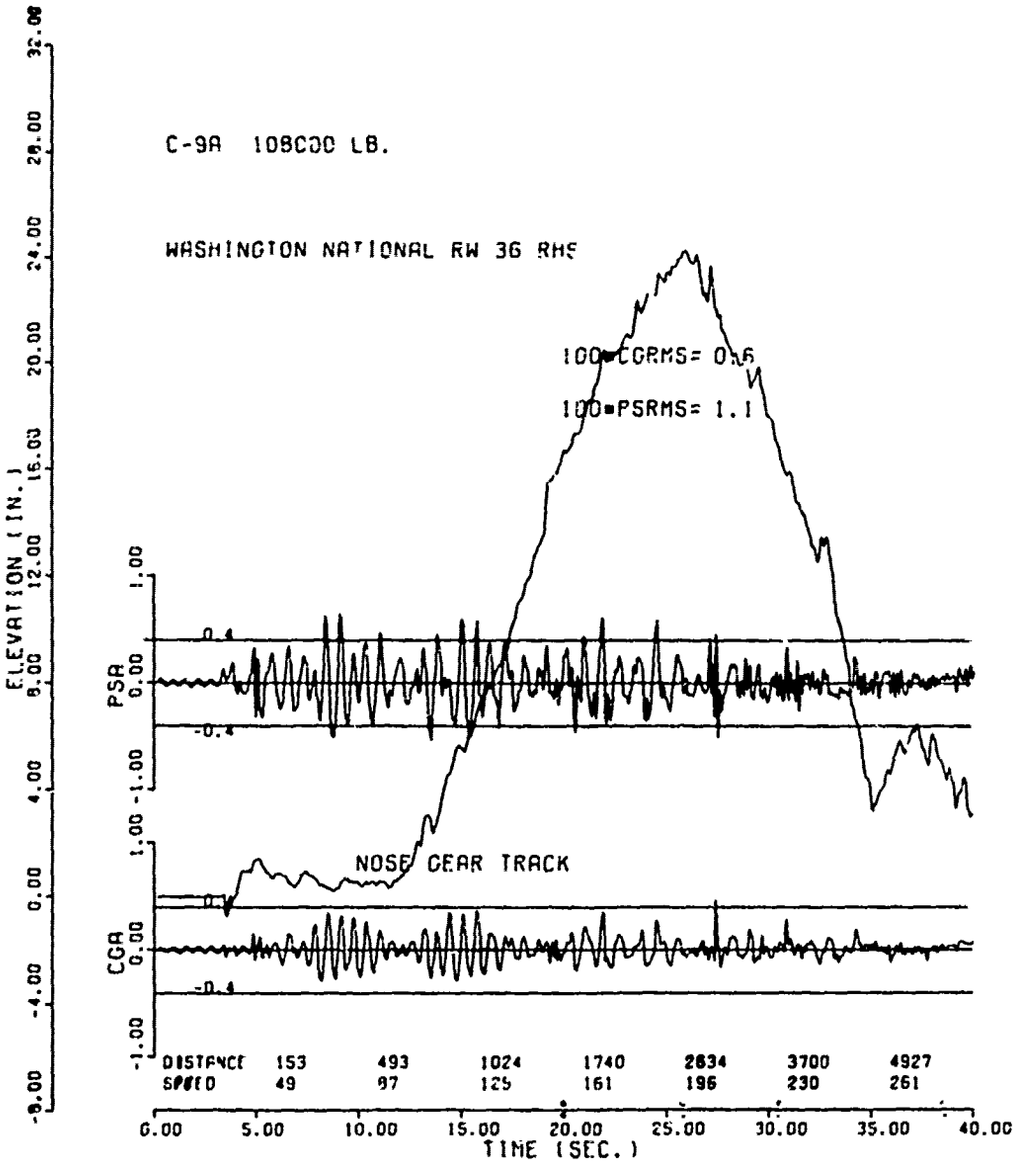


Figure 18. C-9A with Flexible Wings Taking Off from Washington National Runway 36

SECTION V
SUMMARY AND CONCLUSIONS

In summary, a mathematical model has been formulated and programmed for a digital computer and is capable of simulating most flexible aircraft traversing an unsymmetric runway profile during constant speed taxi or takeoff. Three different aircraft have been simulated and comparisons have been made with experimental data.

Based on the 11 simulations made, the following conclusions were drawn:

1. The roll degree of freedom has a significant effect on the pilot's station and center of gravity vertical acceleration levels if the runway profile is asymmetric. The degree is dependent upon how asymmetric the profile is.

2. The effect of wing flexibility on P.S. and C.G. vertical acceleration response is small enough to be neglected, at least for the airplane simulated (C-9A). However, with the addition of flexible wings, it now becomes an easy matter to expand the computer program to obtain vertical accelerations (and consequently shears and moments) at vital wing stations such as the wing root and engine and stores pylons. This would be a natural extension of the study.

3. Comparison of the simulated aircraft response with the limited amount of available test data was satisfactory. The roughest parts of the runway were identified and, as in the test, pilot station acceleration levels exceeded the $\pm$0.4g criterion. If exact strut and tire pressures, and inertia's were known for the test aircraft, the simulated C.G. response may have more closely matched the experimental data.

The simulated takeoff took an additional 5 seconds to reach rotation speed. It is assumed that the actual test aircraft weight was less than 120,000 pounds, because several runs were made without refueling the aircraft after each run. Therefore, some of the fuel had been burned off. The fact that the airplane was lighter than

that simulated would also contribute to the difference in C.G. response. Also, using a 15° flap setting changed the value of C_L and resulted in a shorter takeoff distance.

4. This computer program, "TAX2", appears to be a very efficient technique for locating the rough areas of an asymmetric runway. Using a CDC 6600 digital computer, a C-9A takeoff simulation required 70 seconds of central processor (CP) computer time, which is just 30 seconds over real time for this simulation. These numbers are typical for most simulations.

One of the advantages of a program of this type is that runway repairs can be simulated before the actual repair is made in order to determine the minimum amount of repair required. In addition, the effect of the proposed repair on other aircraft can be determined before the repair is made.

APPENDIX A
DEVELOPMENT OF EQUATIONS OF MOTION

Development of equations of motion using Lagrange equations. All symbols refer to Figure A-1.

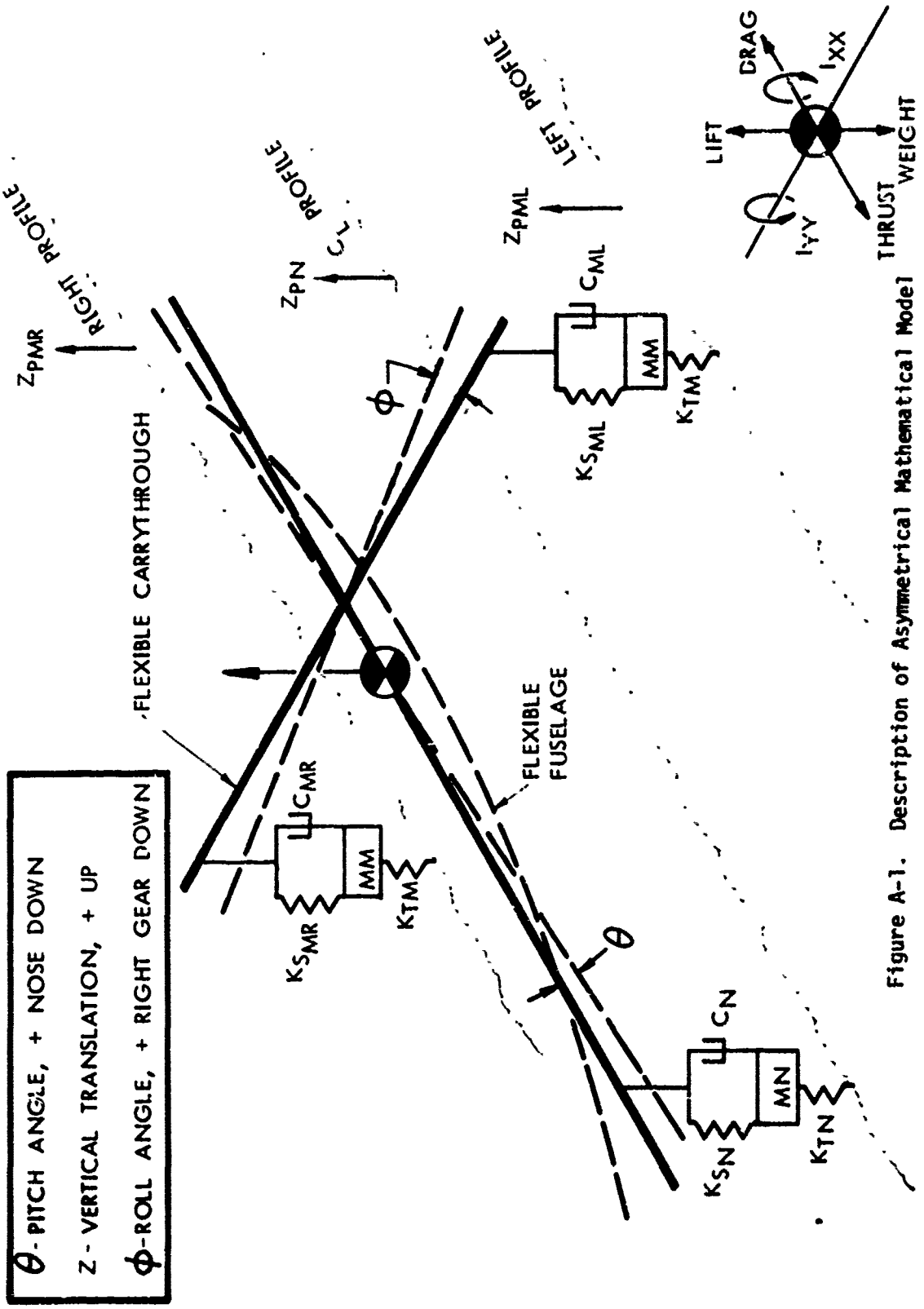


Figure A-1. Description of Asymmetrical Mathematical Model

Using Lagrange

$$\frac{d}{dt}\frac{\partial KE}{\partial \dot{q}_i} - \frac{\partial KE}{\partial q_i} + \frac{\partial PE}{\partial q_i} + \frac{\partial DE}{\partial \dot{q}_i} = 0$$

The Kinetic Energy is:

$$K.E. = \tfrac{1}{2}M_{cg}\dot{Z}^2 + \tfrac{1}{2}M_M\dot{Z}_{MR}^2 + \tfrac{1}{2}M_M\dot{Z}_{ML}^2 + \tfrac{1}{2}M_N\dot{Z}_N^2 + \tfrac{1}{2}I_{yy}\dot{\theta}^2 + \tfrac{1}{2}I_{xx}\dot{\phi}^2$$

The Potential Energy is:

$$P.E. = + W_M Z_{MR} + W_M Z_{ML} + W_N Z_N + WZ_{cg} - L\,Z_{cg} + \tfrac{1}{2}K_{SML}(Z_{cg} + A\theta - Z_{ML} - C\phi)^2 + \tfrac{1}{2}K_{TM}(Z_{ML} - Z_{PML})^2 + \tfrac{1}{2}K_{SMR}(Z_{cg} + A\theta - Z_{MR} + C\phi)^2 + \tfrac{1}{2}K_{TM}(Z_{MR} - Z_{PMR})^2 + \tfrac{1}{2}K_{SN}(Z_{cg} - B\theta - Z_N)^2 + \tfrac{1}{2}K_{TN}(Z_N - Z_{PN})^2$$

The Dissipative Energy is:

$$D.E. = + \tfrac{1}{2}C_{ML}(\dot{Z}_{cg} + A\dot{\theta} - \dot{Z}_{ML} - C\dot{\phi})^2 + \tfrac{1}{2}C_{MR}(\dot{Z}_{cg} + A\dot{\theta} - \dot{Z}_{MR} + C\dot{\phi})^2 + \tfrac{1}{2}C_N(\dot{Z}_{cg} - B\dot{\theta} - \dot{Z}_N)^2$$

Now Find $\frac{d}{dt}\frac{\partial KE}{\partial \dot{q}_i}$

$$\frac{d}{dt}\frac{\partial KE}{\partial \dot{Z}_{cg}} = M\ddot{Z}_{cg} \; ; \; \frac{d}{dt}\frac{\partial KE}{\partial \dot{Z}_N} = M_N\ddot{Z}_N$$

$$\frac{d}{dt}\frac{\partial KE}{\partial \dot{Z}_{MR}} = M_M\ddot{Z}_{MR} \; ; \; \frac{d}{dt}\frac{\partial KE}{\partial \dot{\theta}} = I_{yy}\ddot{\theta}$$

$$\frac{d}{dt}\frac{\partial KE}{\partial \dot{Z}_{ML}} = M_M\ddot{Z}_{ML} \; ; \; \frac{d}{dt}\frac{\partial KE}{\partial \dot{\phi}} = I_{xx}\ddot{\phi}$$

$$\frac{\partial KE}{\partial q_i} = 0$$

Now Find $\frac{\partial (P.E)}{\partial q_i}$

$$\frac{\partial (P.E)}{\partial Z_{cg}} = + K_{SML}(Z_{cg} + A\Theta - Z_{ML} - C\phi) + K_{SMR}(Z_{cg} + A\Theta - Z_{MR} + C\phi) + K_{SN}(Z_{cg} - B\Theta - Z_N) + W - L$$

$$\frac{\partial (P.E)}{\partial Z_{MR}} = + W_M - K_{SMR}(Z_{cg} + A\Theta - Z_{MR} + C\phi) + K_{TM}(Z_{MR} - Z_{PMR})$$

$$\frac{\partial (P.E)}{\partial Z_{ML}} = + W_M - K_{SML}(Z_{cg} + A\Theta - Z_{ML} - C\phi) + K_{TM}(Z_{ML} - Z_{PML})$$

$$\frac{\partial (P.E)}{\partial Z_N} = + W_N - K_{SN}(Z_{cg} - B\Theta - Z_N) + K_{TN}(Z_N - Z_{PN})$$

$$\frac{\partial (P.E)}{\partial \theta} = + K_{SML}A(Z_{cg} + A\Theta - Z_{ML} - C\phi) + K_{SMR}A(Z_{cg} + A\Theta - Z_{MR} + C\phi) - K_{SN}B(Z_{cg} - B\Theta - Z_N)$$

$$\frac{\partial (P.E)}{\partial \phi} = - K_{SML}C(Z_{cg} + A\Theta - Z_{ML} - C\phi) + K_{SMR}C(Z_{cg} + A\Theta - Z_{MR} + C\phi)$$

Now Find $\frac{\partial (D.E)}{\partial \dot{q}_i}$

$$\frac{\partial (D.E)}{\partial \dot{Z}_{MR}} = - C_{MR}(\dot{Z}_{cg} + A\dot{\Theta} - \dot{Z}_{MR} + C\dot{\phi})$$

$$\frac{\partial(D.E)}{\partial \dot{Z}_{ML}} = - C_{ML}(\dot{Z}_{cg} + A\dot{\Theta} - \dot{Z}_{ML} - C\dot{\phi})$$

$$\frac{\partial(D.E)}{\partial \dot{Z}_{N}} = - C_{N}(\dot{Z}_{cg} - B\dot{\Theta} - \dot{Z}_{N})$$

$$\frac{\partial(D.E)}{\partial \dot{Z}_{cg}} = + C_{MR}(\dot{Z}_{cg} + A\dot{\Theta} - \dot{Z}_{MR} + C\dot{\phi}) + C_{ML}(\dot{Z}_{cg} + A\dot{\Theta} - \dot{Z}_{ML} - C\dot{\phi}) - C_{N}(\dot{Z}_{cg} - B\dot{\Theta} - \dot{Z}_{N})$$

$$\frac{\partial(D.E)}{\partial \dot{\Theta}} = + C_{MR}A(\dot{Z}_{cg} + A\dot{\Theta} - \dot{Z}_{MR} + C\dot{\phi}) + C_{ML}A(\dot{Z}_{cg} + A\dot{\Theta} - \dot{Z}_{ML} - C\dot{\phi}) - C_{N}B(\dot{Z}_{cg} - B\dot{\Theta} - \dot{Z}_{N})$$

$$\frac{\partial(D.E)}{\partial \dot{\phi}} = + C_{MR}C(\dot{Z}_{cg} + A\dot{\Theta} - \dot{Z}_{MR} + C\dot{\phi}) - C_{ML}C(\dot{Z}_{cg} + A\dot{\Theta} - \dot{Z}_{MR} - C\dot{\phi})$$

Combine Terms

$$M\ddot{Z}_{cg} = - K_{SML}[Z_{cg} + A\Theta^{(X_{ML})} - Z_{ML} - C\phi] - K_{SMR}[Z_{cg} + A\Theta^{(X_{MR})} - Z_{MR} + C\phi] - K_{SN}[Z_{cg} - B\Theta^{(X_{N})} - Z_{N}] - W + L - C_{MR}[\dot{Z}_{cg} + A\dot{\Theta}^{(\dot{X}_{MR})} - \dot{Z}_{MR} + C\dot{\phi}] - C_{ML}[\dot{Z}_{cg} + A\dot{\Theta}^{(\dot{X}_{ML})} - \dot{Z}_{ML} - C\dot{\phi}] - C_{N}[\dot{Z}_{cg} - B\dot{\Theta}^{(\dot{X}_{N})} - \dot{Z}_{N}]$$

Rewriting we have

$$M\ddot{Z}_{cg} = [-K_{SML}(X_{ML}) - C_{ML}(\dot{X}_{ML})] + \qquad (1)$$

$$[-K_{SMR}(X_{MR}) - C_{MR}(\dot{X}_{MR})] +$$

$$[-K_{SN}(X_N) - C_N(\dot{X}_N)] - W + L$$

where the terms in the brackets are the left, right, and nose landing gear strut forces respectively.

Similarly

$$M_M\ddot{Z}_{ML} = K_{SML}(X_{ML}) + C_{ML}(\dot{X}_{ML}) - K_{TM}(Z_{ML} - Z_{PML}) - W_M \quad (2)$$

$$M_M\ddot{Z}_{MR} = K_{SMR}(X_{MR}) + C_{MR}(\dot{X}_{MR}) - K_{TM}(Z_{MR} - Z_{PMR}) - W_M \quad (3)$$

$$M_N\ddot{Z}_N = K_{SN}(X_N) + C_N(\dot{X}_N) - K_{TN}(Z_N - Z_{PN}) \quad (4)$$

$$I_{yy}\ddot{\Theta} = - K_{SML}A(X_{ML}) + C_{ML}A(\dot{X}_{ML}) + K_{SMR}A(X_{MR}) + C_{MR}A(\dot{X}_{MR}) - K_NB(X_N) + C_NB(X_N) \quad (5)$$

$$I_{xx}\ddot{\phi} = K_{SML}C(X_{ML}) + C_{ML}C(\dot{X}_{ML}) - K_{SMR}C(X_{MR}) - C_{MR}C(\dot{X}_{MR}) \quad (6)$$

The Forward Translation Equation of Motion is uncoupled and expressed as follows:

$$M\ddot{X} = T - D_a - D_t$$

where:

T = Thrust

D_a = Aerodynamic Drag

D_t = Tire Drag (Total)

The modal method will be used to express the aircraft's flexibility as follows:

$$M_i \ddot{q}_i = \xi_{ij} F_j - 2\zeta\omega_i M_i \dot{q}_i - \omega_i^2 M_i q_i$$

where i = the ith mode

F_j = the jth force input into the system (such as strut force)

M_i = the ith generalized mass

q_i = the generalized coordinate

ξ_{ij} = the modal deflection of the ith mode at fuselage station j for symmetric modes or wing station j for asymmetric modes.

ω_i = the ith mode natural frequency

ζ = Structural damping factor

By using this technique the displacements X'_{MR}, X'_{ML}, X'_N and their time derivatives reflect the motion of the bending fuselage and wings by adding the $\sum_{i=1}^{N} q_i \xi_{ij}$ (modal displacements) at the jth (required location).

For example;

Total Displacement $$X'_{MR} = X_{MR} + \sum_{i=1}^{N} q_i \xi_{iR} + \sum_{k=1}^{P} q_k \xi_{kR}$$

Total Velocity $$\dot{X}'_{MR} = \dot{X}_{MR} + \sum_{i=1}^{N} \dot{q}_i \xi_{iR} + \sum_{k=1}^{P} \dot{q}_k \xi_{kR}$$

where:

Term 1 = Displacements of the rigid body

Term 2 = Displacements due to the symmetric modes

Term 3 = Displacements due to the asymmetric modes

APPENDIX B
LISTING OF COMPUTER PROGRAM TAX2

BEST AVAILABLE COPY

```
PROGRAM TAX2        74/74    OPT=1                          FTN 4.5+R426        05/25/76  13.22.28        PAGE     1

      PROGRAM TAX2(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,PLOT,TAPE2,     TAX20010
     1TAPE3,TAPE4)                                                       TAX20020
C**********************************************************************TAX20030
C**********************************************************************TAX20040
C**********************************************************************TAX20050
C  THIS PROGRAM WILL PERFORM A SYMMETRIC                                 TAX20060
C  DYNAMIC TAXI ANALYSIS ON A FLEXIBLE                                   TAX20070
C  VEHICLE WITH ROLL TRAVERSING A GIVEN RIGID RUNWAY                     TAX20080
C  PROFILE.                                                              TAX20090
C**********************************************************************TAX20100
C**********************************************************************TAX20110
C**********************************************************************TAX20120
      COMMON/FLEX1/SIMAIN(15),SINOSE(15),SIPOS(15),SITAIL(15),SIPS(15)   TAX20130
      COMMON/FLEX2/NFM,SM(15),OMEGA(15),DM  AA(15),SMA(15)               TAX20140
      COMMON/FLEX3/Q(15),QD(15),QDD(15)                                  TAX20150
      COMMON/FLEX4/QA(15),QDA(15),QDDA(15),NAFM,SILEFT(15),SIRIGHT(15)   TAX20160
      DIMENSION SILEFT(15),SMA(15),OMEGAA(15),QDDA(15),QDA(15),QA(15)    TAX20170
      COMMON/X1/M,MM,WM,MCG,MN,MN,A,G,MMI ,MMI2                          TAX20180
      COMMON/X2/PADM,VOM,AAM,AHM,DAM                                     TAX20190
      COMMON/X3/PADN,VON,AAN,AHN,DAN                                     TAX20200
      COMMON/X4/SXM,SYN,SLM,SLN,TSM ,TSN                                 TAX20210
      COMMON/X5/CL,CD,AREA,THRUST                                        TAX20220
      COMMON/X6/Z,RFACTM,RFACTN,DX,NTRUN,SPEED                           TAX20230
      COMMON/X7/AM,BM,CM,DM,AN,BN,CN,DN,AMR,BMR,CMR,DMR                  TAX20240
      COMMON/X8/STROKM(20),PINDM(20),STROKN(20),PINDN(20),NSCM,NSCN      TAX20250
      COMMON/X9/FSM,FSN,FTM,FTN,XMAIN,XNOSE,VELM,VELN                    TAX20260
       COMMON/X99/FSML,FSMR,FTML,FTMR,XMAINL,XMAINR,VELML,VELMR,WS       TAX20270
      COMMON/X10/ZPM,ZPN,ZPML,ZPMR                                       TAX20280
      COMMON/20/CGML,SSML,ADML                                           TAX20290
      DIMENSION PLANE(8),SITE(4)                                         TAX20300
      DIMENSION ELEV(5000),ELEVL(5000),ELEVR(5000)                       TAX20310
      DIMENSION T(12), TD(12), TDD(12)                                   TAX20320
      DIMENSION YPL(6),YPM(6),             YPR(6)                        TAX20330
      DIMENSION CGACC(1900), TIME(1900), PSACC(1900), TIME1(1900)        TAX20340
      DIMENSION PROF(1800),RMARK(20)                                     TAX20350
      DIMENSION SSPLOT(300), STIME(300),DDPLOT(300)                      TAX20360
      REAL MCG,MM,MN,MMI,MMI2                                            TAX20370
      PSA=0.0                                                            TAX20380
      CGOUT=0.0                                                          TAX20390
      LOK=0                                                              TAX20400
      WOR=0.                                                             TAX20410
      X=0.                                                               TAX20420
      LLL = 1                                                            TAX20430
      LL = 0                                                             TAX20440
      STORE1 = 0.                                                        TAX20450
      STORE2 = 0.                                                        TAX20460
      STORE3 = 0.                                                        TAX20470
      STORE4 = 0.                                                        TAX20480
      NN = 0                                                             TAX20490
      II = 0                                                             TAX20500
      PP = 1.0                                                           TAX20510
      M = 1                                                              TAX20520
      ITT = 0                                                            TAX20530
C**********************************************************************TAX20540
C          READ AND PRINT INPUT DATA                                     TAX20550
C**********************************************************************TAX20560
C   W=VEHICLE WEIGHT AT CG (POUNDS)                                      TAX20570
```

```
C   A=DISTANCE MAIN GEAR TO CG (INCHES)                          TAX20580
C   B=DISTANCE NOSE GEAR TO CG (INCHES)                          TAX20590
C MMI=MASS MOMENT OF INERTIA (LB IN SEC SQ)                      TAX20600
C     WS  WING STATION OF MLG (INCHES)                           TAX20610
C      MMIR   MASS MOMENT OF INERTIA IN ROLL (LB IN SEC SQ)      TAX20620
C  PLANE= AIRPLANE BEING SIMULATED AND  GROSS WEIGHT             TAX20630
C  PSARM = DISTANCE OF PILOT STATION TO CG                       TAX20640
C      TAILRM = DISTANCE OF TAIL STATION TO CG                   TAX20650
C  TAKOFF= TAKE-OFF SPEED (FEET/SEC)                             TAX20660
C SPEED =INITIAL  VEL  OF  AIRPLANE                              TAX20670
C  THURST= TOTAL AIRPLANE THRUST                                 TAX20680
C  CL=LIFT COEFF.                                                TAX20690
C  AREA=WING AREA                                                TAX20700
C  CD=DRAG COEFF.                                                TAX20710
C  WM=WEIGHT OF MAIN GEAR  (EACH)                                TAX20720
C  WN=WEIGHT OF NOSE GEAR                                        TAX20730
C  SNM= NUMBER OF MAIN GEAR STRUTS                               TAX20740
C   SNN= NUMBER OF NOSE GEAR STRUTS                              TAX20750
C AHN  HYDRAULIC PISTON AREA NOSE SQ INCHES                      TAX20760
C AAN  PNEUMATIC PISTON AREA NOSE SQ INCHES                      TAX20770
C AHM  HYDRAULIC PISTON AREA MAIN SQ INCHES                      TAX20780
C AAM  PNEUMATIC PISTON AREA MAIN SQ INCHES                      TAX20790
C PAON NOSE STRUT PRELOAD PRESSURE  PSI                          TAX20800
C PAOM MAIN STRUT PRELOAD PRESSURE  PSI                          TAX20810
C VON  NOSE STRUT INITIAL VOLUME CU. IN.                         TAX20820
C VOM  MAIN STRUT INITIAL VOLUME CU. IN.                         TAX20830
C OAM  ORIFACE AREA MAIN                                         TAX20840
C OAN  ORIFACE AREA NOSE                                         TAX20850
C SLM=MAIN GEAR STRUT LENGTH UNLOADED INCHES                     TAX20860
C      DISTANCE FROM CL OF AXLE TO CG LINE                       TAX20870
C SLN=NOSE GEAR STRUT LENGTH UNLOADED INCHES                     TAX20880
C      DISTANCE FROM CL OF AXLE TO CG LINE                       TAX20890
C  TSM     MAIN TIRE SPRING CONSTANT PER STRUT                   TAX20900
C  TSN    NOSE TIRE SPRING CONSTANT PER STRUT                    TAX20910
C  DT=TIME STEP SIZE                                             TAX20920
C  READ METERING PIN DESCRIPTION STARTING AT ZERO STROKE         TAX20930
C  NSCN=# OF METERING PIN CHANGES NOSE GEAR                      TAX20940
C  NSCM=# OF METERING PIN CHANGES MAIN GEAR                      TAX20950
C  NFM = NUMBER OF FLEXIBLE MODES                                TAX20960
C  NAFM= NUMBER OF ASYMMETRIC MODES                              TAX20970
C  SIXXXX(I) = MODE SHAPE DEFLECTION (NON DIM.)                  TAX20980
C  GM(I) = GENERALIZED MASS (POUNDS-SEC SQ/IN)                   TAX20990
C  OMEGA (I) = MODAL FREQUENCIES (RAD/SEC)                       TAX21000
C  SILEFT(I)= LEFT GEAR MODE SHAPE DEFLECTION                    TAX21010
C  SIRIGHT(I)=RIGHT GEAR MODE SHAPE DEFLECTION                   TAX21020
C  GMA(I)= ASYM. MODE GEN. MASS                                  TAX21030
C  OMEGAA(I)= ASYM. MODE FREQ.                                   TAX21040
      READ (5,1) PLANE                                           TAX21050
 1    FORMAT(8A10)                                               TAX21060
      READ(5,5) W,A,B,MMI,WS,MMIR                                TAX21070
5     FORMAT(4F16.1,2F12.0)                                      TAX21080
      READ(5,10) PSARM,TAILRM                                    TAX21090
 10   FORMAT(2F10.2)                                             TAX21100
      READ(5,15) SPEED,THRUST,TAKOFF                             TAX21110
 15   FORMAT(3F10.3)                                             TAX21120
      READ(5,20) CL,AREA,CD                                      TAX21130
 20   FORMAT(3F10.4)                                             TAX21140
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      READ(5,25) WA,WN,SXM,SXN                                          TAX21150
      FORMAT(6F10.2)                                                    TAX21160
      READ(5,30) AMN,AAN,AMM,AAM                                        TAX21170
   30 FORMAT(4F10.5)                                                    TAX21180
      READ(5,35) PAON,PAOM,VON,VOM,OAN,OAM                              TAX21190
   35 FORMAT(6F10.9)                                                    TAX21200
      READ(5,40) SLM,SLN                                                TAX21210
   40 FORMAT(2F10.3)                                                    TAX21220
      READ(5,45) TSM ,TSN                                               TAX21230
   45 FORMAT(2F10.1)                                                    TAX21240
      READ(5,50)DX                                                      TAX21250
      READ(5,51)IFPLOT,IFLIST                                           TAX21260
   50 FORMAT(F10.3)                                                     TAX21270
      READ(5,51) NSCN                                                   TAX21280
   51 FORMAT(2I5)                                                       TAX21290
      READ(5,52) (STROKM(I),PINOM(I),I=1,NSCM)                          TAX21300
   52 FORMAT(2(F10.3))                                                  TAX21310
      READ(5,51)NSCN                                                    TAX21320
      READ(5,52) (STROKN(I),PINON(I),I=1,NSCN)                          TAX21330
      READ(5,51) NFN,NAFN                                               TAX21340
      READ(5,53) (SIWAIN(I),SINOSE(I),SIGG(I),SITAIL(I),SIPS(I)        TAX21350
     1,I=1,NFN)                                                         TAX21360
   53 FORMAT(5F10.7)                                                    TAX21370
      READ(5,54) (GN(I),OMEGA(I),I=1,NFN)                               TAX21380
   54 FORMAT(F15.3,F10.4)                                               TAX21390
      READ(5,52)(SILEFT(I),SIRIGHT(I),I=1,NAFN)                         TAX21400
      READ(5,54)(GMA(I),OMEGAA(I),I=1,NAFN)                             TAX21410
      WA=WA/386.                                                        TAX21420
      WN=WN/386.                                                        TAX21430
      WGGW/386.                                                         TAX21440
      TYPRUN = .01                                                      TAX21450
      IF(SPEED.GT.5.) TYPRUN = .02                                      TAX21460
      NTRUN=TYPRUN*100.                                                 TAX21470
      WRITE(6,59)                                                       TAX21480
   59 FORMAT(1H1,45X,40(1H*))                                           TAX21490
      WRITE(6,60)                                                       TAX21500
   60 FORMAT(44X,46H********** INPUT DATA **********)                   TAX21510
      WRITE(6,61)                                                       TAX21520
   61 FORMAT(///1X,41H********** GENERAL AIRCRAFT DATA **********)      TAX21530
      WRITE(6,62)PLANE                                                  TAX21540
   62 FORMAT(///,1X,8A10)                                               TAX21550
      WRITE(6,65) W,WN,WN,A,B, WS,WMI,WMIR                              TAX21560
   65 FORMAT(///,5X,*W=*,F10.1,5X,*WN=*,F10.2,5X,*WN=*,F10.2,5X,        TAX21570
     1*A=*,F10.3,5X,*B=*,F10.3,5X,*WS=*,F10.3,5X,*WMT=*,F12.0,///,5X,   TAX21580
     1*WMIR=*,F12.0)                                                    TAX21590
      WRITE(6,66) SXM,SXN,SLM,SLN,*SAR*,TAILR*                          TAX21600
   66 FORMAT(//,5X,*SXM=*,F9.1,5X,*SXN=*,F9.1,5X,*SLM=*,F9.1,5X,        TAX21610
     1*SLN=*,F8.1,5X,*PSAR*=*,F7.1,4X,*TAILR*=*,F7.1)                   TAX21620
      WRITE(6,70) AAN,AMM,PAOM,VOM,OAM,TSM                              TAX21630
   70 FORMAT(//,5X,*AAN=*,F9.2,5X,*AMM=*,F9.2,5X,*PAOM=*,F9.2,5X,       TAX21640
     1*VOM=*,F8.2,5X,*OAM=*,F9.2,5X,*TSM =*,F11.2)                      TAX21650
      WRITE(6,74) AAN,AMN,PAOM,VON,OAN,TSN                              TAX21660
   74 FORMAT(//,5X,*AAN=*,F8.2,5X,*AMN=*,F8.2,5X,*PAON=*,F9.2,4X,       TAX21670
     1*VON=*,F9.2,5X,*OAN=*,F9.2,5X,*TSN =*,F10.2)                      TAX21680
      WRITE(6,75) CL,CD,AREA,SPEED,THRUST,TAKOFF                        TAX21690
   75 FORMAT(//,5X,*CL=*,F9.3,5X,*CD=*,F9.3,5X,*AREA=*,F8.2,5X,         TAX21700
     1*SPEED=*,F7.1,4X,*THRUST=*,F7.0,5X,*TAKOFF=*,F10.2)               TAX21710
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      WRITE(6,76) (STROKN(I),PINON(I),I=1,NSCN)                          TAX21770
   76 FORMAT(///,3X,*STROKE NOSE   PIN DIAMETER   *//,2(3X,F19.3))       TAX21780
      WRITE(6,77) (STROKM(I),PINOM(I),I=1,NSCM)                          TAX21790
175   77 FORMAT(///,3X,*STROKE MAIN   PIN DIAMETER   *//,2(3X,F18.3))    TAX21800
      WRITE(6,88)                                                        TAX21810
   88 FORMAT(1H1,1X,*MODE  SIPS   SINOSE*,6X,* SIGS   SIMAIN  SITAIL     TAX21820
     1OMEGA  GEN. MASS*)                                                 TAX21830
      DO 45 I=1,NFN                                                      TAX21840
180   45 WRITE(6,90 )(I,SIPS(I),SINOSE(I),SIGS(I),SIMAIN(I),SITAIL(I),   TAX21850
     1OMEGA(I),GM(I))                                                    TAX21860
      WRITE(6,86)                                                        TAX21870
   86 FORMAT(///,*ASSYMETRICAL MODES*,/,1X,*MODE*,5X,*SIRIGHT*,5X,       TAX21880
     1*SILEFT*,5X,*OMEGAA*,5X,*GEN MASS*)                                TAX21890
      DO 88 I=1,NAFN                                                     TAX21900
185   WRITE(6,87)(I,SIRIGHT(I),SILEFT(I),OMEGAA(I),GMA(I))               TAX21910
   88 CONTINUE                                                           TAX21920
   87 FORMAT(1X,I5,3X,6(F10.3,1X))                                       TAX21930
   90  FORMAT(//,    2X,I2,6(F7.2,2X),F10.1)                             TAX21940
190   C ZMI =INITIAL MAIN GEAR POSITION INCHES                          TAX21950
      WRITE(6,95)                                                        TAX21960
   95 FORMAT(///,46X,43H********** INTIAL CONDITIONS **********)        TAX21970
      C ZNI =INITIAL NOSE GEAR POSITION INCHES                           TAX21980
      C ZCGI=INITIAL C.G. POSITION INCHES                                TAX21990
195   C THETAI=INITIAL PITCH ANGLE DEGREES                              TAX22000
      C   THE ABOVE PARAMETERS ARE CALCULATED IN SUBROUTINE IC           TAX22010
      CALL IC(  ZCGI,ZMI,ZNI,THETAI)                                     TAX22020
       ZMIL=ZMI                                                          TAX22030
       ZMIR=ZMI                                                          TAX22040
200   WRITE(6,185) ZMI,ZNI,THETAI,ZCGI                                  TAX22050
  185 FORMAT(///,5X,4HZMI=,F10.3,5X,4HZNI=,F10.3,5X,7HTHETAI=,F10.6,     TAX22060
     1X,5HZCGI=,F10.3,*DEYA=0.*)                                         TAX22070
      BETA=0.                                                            TAX22080
      REACTN=(ZNI TSN )*SXN                                              TAX22090
205   REACTM=(ZMI*TSM )*SXM                                             TAX22100
      WRITE(6,186) XMAIN,XNOSE,REACTN,REACTM                             TAX22110
  186 FORMAT (/,1X,*XMAIN=*,F8.3,3X,*XNOSE=*,F9.3,3X,*REACTN=*,F10.0,    TAX22120
     13X,*REACTM=*,F10.0)                                                TAX22130
      XMAINR=XMAIN                                                       TAX22140
210   ********************************************************************TAX22150
      C READ RUNWAY PROFILE DATA  ELEVL,ELEV,ELEVR                       TAX22160
      C   SITE= RUNWAY PROFILE AND DIRECTION                            TAX22170
      C  NPTSS=# OF RUNWAY ELEVATION DATA POINTS                         TAX22180
      WRITE (6,111)                                                      TAX22190
215   111 FORMAT(*1*)                                                   TAX22200
      DO 112 I=1,50                                                      TAX22210
       ELEVL(I)=0.                                                       TAX22220
       ELEVR(I)=0.                                                       TAX22230
  112 ELEV(I)=0.0                                                       TAX22240
220   READ(2,1) SITE                                                    TAX22250
      READ(3,1) SITE                                                     TAX22260
      READ(4,1) SITE                                                     TAX22270
      READ(2,116) NPTSS                                                  TAX22280
      READ(3,116) NPTSS                                                  TAX22290
225   READ(4,116) NPTSS                                                 TAX22300
      NPTSS=NPTSS+50                                                     TAX22310
  116 FORMAT(I4)                                                        TAX22320
      L0=51                                                              TAX22330
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      117  LSD = LD + 9                                                        TAX22290
           READ(2,110) (ELEVL(I),I=LD,LSD)                                     TAX22300
           READ(3,110) (ELEV(I),I=LD,LSD)                                      TAX22310
           READ(4,110) (ELEVR(I),I=LD,LSD)                                     TAX22320
      110  FORMAT(10F7.3)                                                      TAX22330
           M10=LD                                                              TAX22340
           IF(LSD.GE.NPTSS) GO TO 120                                          TAX22350
           LD=LD+10                                                            TAX22360
           GO TO 117                                                           TAX22370
      120  ELEV1=ELEV(S1)                                                      TAX22380
           ELEV2=ELEVL(S1)                                                     TAX22390
           ELEV3=ELEVR(S1)                                                     TAX22400
           DO 125 I=S1,M10                                                     TAX22410
           ELEVL(I) = (ELEVL(I)-ELEV2)*12.0                                    TAX22420
           ELEVR(I) = (ELEVR(I)-ELEV3)*12.0                                    TAX22430
      125  ELEV(I) = (ELEV(I)-ELEV1)*12.0                                      TAX22440
           DISTAN=0.                                                           TAX22450
           LSD=LSD-90                                                          TAX22460
           SLP=(LSD-S0)*2                                                      TAX22470
           SLP=ELEV(LSD)/SLP                                                   TAX22480
           DO 126 I=S1 ,M10                                                    TAX22490
           ELEV(I) =ELEV(I) -SLP*DISTAN                                        TAX22500
           ELEVR(I)=ELEVR(I)-SLP*DISTAN                                        TAX22510
           ELEVL(I)=ELEVL(I)-SLP*DISTAN                                        TAX22520
      126  DISTAN=DISTAN+2.                                                    TAX22530
           IVAL=(A+B)/24.                                                      TAX22540
           WRITE(6,130)                                                        TAX22550
      130  FORMAT(1H1,5X,*  RUNWAY PROFILE DATA NORMALIZED (SLOPE REMOVED)*    TAX22560
          150X,*FEET DOWN THE RUNWAY*)                                         TAX22570
           WRITE(6,1) SITE                                                     TAX22580
           LD1=1                                                               TAX22590
      135  LSD1 = LD1 + 9                                                      TAX22600
           LPRIN = LSD1 * 2                                                    TAX22610
           WRITE(6,140) (ELEV(I),I=LD1,LSD1),LPRIN                             TAX22620
      140  FORMAT(3X,10F10.5,10X,I0)                                           TAX22630
           LD1=LD1+10                                                          TAX22640
           IF(LD1.GE.M10) GO TO 145                                            TAX22650
           GO TO 135                                                           TAX22660
      145  WRITE(6,150) LD1                                                    TAX22670
      150  FORMAT(42H********** END RUNWAY DATA ********** LD1=,I5)            TAX22680
           DO 161 I=1,M10,10                                                   TAX22690
      161  WRITE(6,162) ELEVL(I), ELEV(I), ELEVR(I)                            TAX22700
      162  FORMAT (3(5X,F10.5))                                                TAX22710
           ENDRUN = NPTSS*2                                                    TAX22720
           NRN=(ENDRUN-100.)/1000.                                             TAX22730
           ON=(((ENDRUN-100.)-FLOAT(NRN*1000))/2.)+1100.                       TAX22740
           ENDRUN=ENDRUN-99.                                                   TAX22750
           T(2) =ZCGI                                                          TAX22760
           TD(2) = 0.                                                          TAX22770
           T(4) = ZNIL                                                         TAX22780
           T(5) = ZNIR                                                         TAX22790
            TD(5)=0.                                                           TAX22800
           TD(4) = 0.                                                          TAX22810
           T(6) = ZNI                                                          TAX22820
           TD(6) = 0.                                                          TAX22830
           T(8) = THETAI                                                       TAX22840
           TD(8) = 0.                                                          TAX22850
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                T(9)=BETA                                                       TAX22860
                  TD(9)=0.                                                      TAX22870
                T(10) = 0.                                                      TAX22880
                IF(IFLIST.EQ.8)  WRITE(6,155)                                   TAX22890
                TD(10) = SPEED                                                  TAX22898
290           155 FORMAT(1H1,*  YMAINL  XMAINR  XNOSE    ZPML      ZPMR    ZPN    *BETATAX22910
                   TDD    THETADD    BETA     THETA      SPEED     DIST.     TIME    CGACTAX22920
                   YC     PSA*)                                                TAX22930
                  QZ=0.                                                         TAX22940
295               ZPML=0.                                                       TAX22950
                  ZPMR=0.                                                       TAX22960
                  ZPN=0.                                                        TAX22970
                  ZLDOT=0.                                                      TAX22980
                  ZRDOT=0.                                                      TAX22990
300               ZNDOT=0.                                                      TAX23000
                  J=1                                                           TAX23010
                160 YPL(1) = ZLDOT                                              TAX23020
                  YPR(1) = ZRDOT                                                TAX23030
                  YPL(2)=ELEVL(J)                                               TAX23040
305               YPR(2)=ELEVR(J)                                               TAX23050
                  YPL(3)=ELEVL(J+1)                                             TAX23060
                  YPR(3)=ELEVR(J+1)                                             TAX23070
                  YPL(4)=ELEVL(J+2)                                             TAX23080
                  YPR(4)=ELEVR(J+2)                                             TAX23090
310               YPN(1)=ZNDOT                                                  TAX23100
                  YPN(2)=ELEV(IVAL)                                             TAX23110
                  YPN(3)=ELEV(IVAL+1)                                           TAX23120
                  YPN(4)=ELEV(IVAL+2)                                           TAX23130
                  Z=DZ                                                          TAX23140
315               CALL COEFF (YPN,AN,BN,CN,DN)                                  TAX23150
                  CALL COEFF (YPL,AL,BL,CL,DL)                                  TAX23160
                  CALL COEFF (YPR,AR,BR,CR,DR)                                  TAX23170
                  ZLDOT=DN                                                      TAX23180
                  ZRDOT=BNR                                                     TAX23190
320               ZNDOT=AN                                                      TAX23200
                  IF(N.GT.1) GO TO 245                                          TAX23210
                  N = N + 1                                                     TAX23220
                165 IF(IFLIST.NE.8)  GO TO 764                                  TAX23230
                  WRITE(3,170)YMAINL,XMAINR,XNOSE,ZPML,ZPMR,ZPN,TDD(9),TD(8),T(9), TAX23240
325               ZT(8),TD(10),T(10),X,CGOUT,PSA                                TAX23250
                C     WRITE(6,731) FSML,SSML,COML,VELML,BDY                     TAX23260
                C     WRITE(6,731) T(2),T(4),T(8),T(9)                          TAX23270
                C     WRITE(6,731) TD(2),TD(4),TD(8),TD(9)                      TAX23280
                  731 FORMAT(1X,6(9E,E15.8))                                    TAX23290
330               764 CONTINUE                                                  TAX23300
                  170 FORMAT(1X,6(2X,F6.2),4(2X,F7.2),3(2X,F8.3),2(2X,F6.3))    TAX23310
                  TIMEX=0.                                                      TAX23320
                ********************************************************************TAX23330
                  IF(IFPLOT.EQ.1) GO TO 230                                     TAX23340
335               IF(ABS(CGOUT ).LE.ABS(STORE2).AND.ABS(STORE2).GE.ABS(STORE1)) TAX23350
                  GO TO 180                                                     TAX23360
                 175  STORE1 = STORE2                                          TAX23370
                  STORE2 = CGOUT                                                TAX23380
                  GO TO 190                                                     TAX23390
340              180  IF(X-TIMEX(NN).GT..08) GO TO 185                         TAX23400
                  IF(ABS(STORE2).GT..00888) GO TO 165                           TAX23410
                  GO TO 175                                                     TAX23420
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        105  NN = NN + 1                                                       TAX23430
             CGACC(NN) = STORE2                                                TAX23440
             PROF(NN) = ZPM                                                    TAX23450
             TIME(NN) = X - 10. * DX                                           TAX23460
             IF(TIME(NN).LT.0.) TIME(NN) = .01                                 TAX23470
             STORE1 = STORE2                                                   TAX23480
             STORE2 = CGOUT                                                    TAX23490
        190  IF(ABS(PSA).LE.ABS(STORE4).AND.ABS(STORE4).GE.ABS(STORE3))        TAX23500
            1GO TO 205                                                         TAX23510
        200  STORE3 = STORE4                                                   TAX23520
             STORE4 = PSA                                                      TAX23530
             GO TO 215                                                         TAX23540
        205  IF(X-TIME1(LL).GT..08) GO TO 210                                  TAX23550
             IF(ABS(STORE4).GT..37) GO TO 210                                  TAX23560
             GO TO 200                                                         TAX23570
        210  LL = LL + 1                                                       TAX23580
             PSACC(LL) = STORE4                                                TAX23590
             TIME1(LL)=X - 10*DX                                               TAX23600
             IF(TIME1(LL).LE.0.) TIME1(LL) = .001                              TAX23610
             STORE3 = STORE4                                                   TAX23620
             STORE4 = PSA                                                      TAX23630
        215  IF(ABS(T(10)-RM).LT.5.0) GO TO 220                                TAX23640
             GO TO 225                                                         TAX23650
        220  II = II + 1                                                       TAX23660
             RMARK(II) = X/5.                                                  TAX23670
             RM = RM + 1000.                                                   TAX23680
             ITT = II                                                          TAX23690
        225  IF(ABS(X-PP).GT..0009) GO TO 230                                  TAX23700
             SSPLOT(LLL) = TD(10)                                              TAX23710
             STIME(LLL) = X/5.                                                 TAX23720
             DDPLOT(LLL) = T(10)                                               TAX23730
             LLL = LLL + 1                                                     TAX23740
             PP = PP + 5.0                                                     TAX23750
*************************************************************************TAX23760
        230  IF(HDR.LE.80.) GO TO 235                                          TAX23770
             HDR=0.                                                            TAX23780
             IF(IFLIST.EQ.0)  WRITE(6,155)                                     TAX23790
        235  HDR = HDR + 1.                                                    TAX23800
        240  X = X + DX                                                        TAX23810
             CALL TAYLOR(T,TD,TDD)                                             TAX23820
             IF(T(10).GE.ENDRUN) GO TO 259                                     TAX23830
             IF(X.GE.300.) GO TO 261                                           TAX23840
             TIMEX=TIMEX+DX                                                    TAX23850
              QDDCG=0.                                                         TAX23860
             QDDPS=0.                                                          TAX23870
             QDDTAL=0.                                                         TAX23880
             DO 241 I=1,NFN                                                    TAX23890
              QDDTAL=QDDTAL+QDD(I)*SITAIL(I)                                   TAX23900
             QDDCG=QDDCG+QDD(I)*SICG(I)                                        TAX23910
        241   QDDPS=QDDPS+QDD(I)*SIPS(I)                                       TAX23920
             TAILAC=(TDD(2)+TAILRM*TDD(8))/386. +QDDTAL/386.                   TAX23930
             PSA=(TDD(2)-PSARM*TDD(8))/386.      +QDDPS/386.                   TAX23940
             CGOUT=TDD(2)/386.    +QDDCG/386.                                  TAX23950
             IF(TD(10).GE.TAKOFF) GO TO 250                                    TAX23960
             IF(Z.LT.4.) GO TO 245                                             TAX23970
             DZ=Z-4.                                                           TAX23980
             J=J+2                                                             TAX23990
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                IVAL=IVAL+2                                                       TAX24000
                GO TO 160                                                         TAX24010
            245 CONTINUE                                                          TAX24020
C               IF(T(10).GT.600.0) GO TO 165                                      TAX24030
                IF(TIMEX.LT.TYRUN) GO TO 240                                      TAX24040
                GO TO 165                                                         TAX24050
            250 WRITE(6,255)                                                      TAX24060
            255 FORMAT(5X,* THE VEHICLE HAS TAKEN OFF*)                           TAX24070
            260 WRITE(6,262) EKORUN,T(10)                                         TAX24080
            262 FORMAT(3X,* END OF RUNWAY*,2F10.3)                                TAX24090
***************************************************************************TAX24100
            2C3 NGN = X                                                           TAX24110
                PSRMS=0.                                                          TAX24120
                CGRMS=0.                                                          TAX24130
                DO 261 I=1,NN                                                     TAX24140
            261 CGRMS=CGRMS+CGACC(I)**2                                           TAX24150
                DO 264 I=1,LL                                                     TAX24160
            264 PSRMS=PSRMS+PSACC(I)**2                                           TAX24170
                PSRMS=100.*SQRT(PSRMS)/FLOAT(LL)                                  TAX24180
                CGRMS=100.*SQRT(CGRMS)/FLOAT(NN)                                  TAX24190
                WRITE(6,268) PSRMS,CGRMS                                          TAX24200
            268  FORMAT(///,3X,*100 PSRMS=*,F10.3,10X,*100 CGRMS=*,F10.3)         TAX24210
                IF(IFPLOT.EQ.1) GO TO 295                                         TAX24220
                XLONG = FLOAT(NGN)/5.                                             TAX24230
                WRITE(6,265) NN,LL                                                TAX24240
            265 FORMAT(2I20)                                                      TAX24250
                IF(NN.LE.1000.OR.LL.LE.1000) GO TO 266                            TAX24260
                WRITE(6,267)                                                      TAX24270
            267 FORMAT(5X,*THE ARRAYS CGACC OR PSACC OR PROF HAVE EXCEEDED        TAX24280
               1 THEIR DIMENSIONED SIZE*)                                         TAX24290
            266 CONTINUE                                                          TAX24300
                CALL FACTOR (2.0)                                                 TAX24310
                CALL PLOT(0.0,-11.0,-3)                                           TAX24320
                CALL PLOT(3.,.7,-3)                                               TAX24330
                TIME(NN+1) = 0.0                                                  TAX24340
                TIME(NN+2) = 5.0                                                  TAX24350
                TIME1(LL+1)  =0.0                                                 TAX24360
                TIME1(LL+2) = 5.0                                                 TAX24370
                CGACC(NN+1) = -1.0                                                TAX24380
                CGACC(NN+2) = 1.0                                                 TAX24390
                PSACC(LL+1)= -1.0                                                 TAX24400
                PSACC(LL+2) = 1.0                                                 TAX24410
                CALL SCALE(PROF,10.,NN,1)                                         TAX24420
                PROF10 = PROF(NN+2) *10.                                          TAX24430
                IF(PROF10.GT.10.5) GO TO 275                                      TAX24440
                PROF(NN+2) = 6.0                                                  TAX24450
                IF(NPTSS.GE.1000) GO TO 270                                       TAX24460
                DO 269 I=1,NN                                                     TAX24470
            269 PROF(I)=PROF(I)+36.                                               TAX24480
            270 CALL AXIS(0.,0.,11HTIME (SEC.),-11,XLONG,0.0,TIME(NN+1),          TAX24490
               1TIME(NN+2))                                                       TAX24500
                IXLONG = XLONG                                                    TAX24510
                CALL PLOT (XLONG,1.1,0)                                           TAX24520
                CALL PLOT (0.,1.1,2)                                              TAX24530
                CALL SYMBOL (.1,.4,.105,8HDISTANCE,0.,8)                          TAX24540
                CALL SYMBOL (.1,.2,.105,5HSPEED,0.,5)                             TAX24550
                DO 275  I=1,IXLONG                                                TAX24560
```
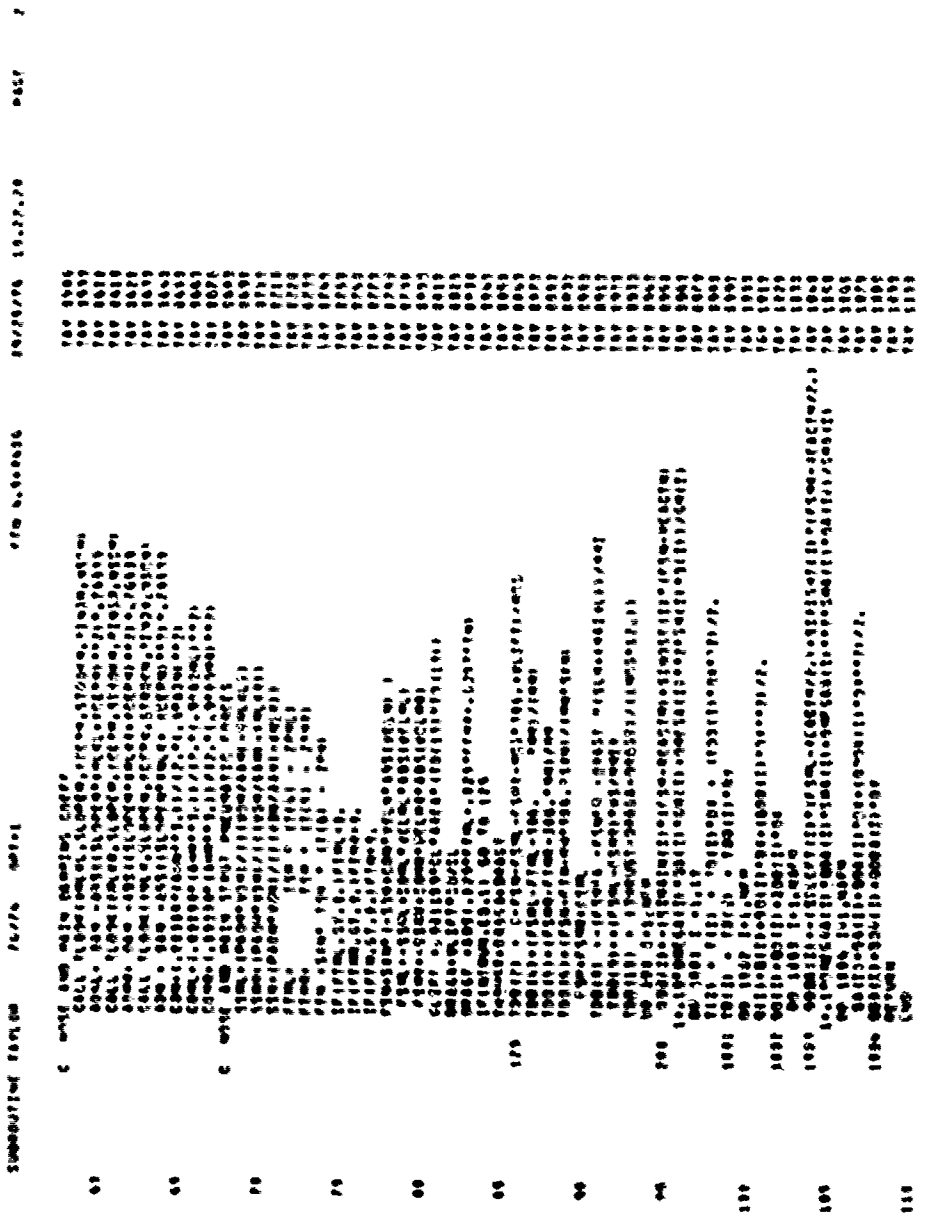

```
PROGRAM TAX2        74/74   OPT=1                    FTN 4.5+P436       05/25/76  10.27.20       PAGE    [illegible]

           CALL NUMBER(STIME(I),.2,.105,SSPLOT(I),0.0,-1)              TAX24570
     275   CALL NUMBER(STIME(I),.4,.105,DDPLOT(I),0.0,-1)              TAX24580
           CALL PLOT (XLONG,1.5,3)                                     TAX24590
           CALL PLOT (0.,1.5,2)                                        TAX24600
           DO 280 I=1,ITT                                              TAX24610
     280   CALL SYMBOL(XMARK(I),-.1,.065,14,5.0,1)                     TAX24620
           CALL PLOT (XLONG,1.9,3)                                     TAX24630
           CALL PLOT (0.,1.9,2)                                        TAX24640
           CALL SYMBOL(0.,9.,.14,PLANE,0.,40)                          TAX24650
           CALL SYMBOL(0.,8.,.14,SITE,0.,40)                           TAX24660
           CALL SYMBOL(4.,7.,.14,10HIDD*CGRMS=,0.,10)                  TAX24670
           CALL SYMBOL(4.,6.5,.14,10HIDD*PSRMS=,0.,10)                 TAX24680
           CALL NUMBER(5.5,7.,.14,CGRMS,0,1)                           TAX24690
           CALL NUMBER(5.5,6.5,.14,PSRMS,0,1)                          TAX24700
           XLONG2=XLONG/2.                                             TAX24710
           CALL SYMBOL(XLONG2,8.5,.14,11HAFFDL -FYS-,0.,11)            TAX24720
           CALL SYMBOL(XLONG2,7.5,.14,19HWPAFB OHIO,0.,19)             TAX24730
           CALL PLOT(0.,1.5,-3)                                        TAX24740
           CALL AXIS(0.,-1.,3HCGA,3,2.0,90.,CGACC(NN+1),CGACC(NN+2))   TAX24750
           CALL NUMBER(0.4,-.4,.105,-.4,90.0,1)                        TAX24760
           CALL NUMBER(0.5,.4,.105,0.4,90.0,1)                         TAX24770
           CALL PLOT(0.,-1.0,-3)                                       TAX24780
           CALL LINE(TIME,CGACC,NN,1,0,74)                             TAX24790
           CALL PLOT (XLONG,3.1,3)                                     TAX24800
           CALL PLOT (0.,3.1,2)                                        TAX24810
           CALL PLOT(0.,3.5,-3)                                        TAX24820
           CALL AXIS(0.,-1.,3HPSA,3,2.0,90.,PSACC(LL+1),PSACC(LL+2))   TAX24830
           CALL PLOT(0.,0.,3)                                          TAX24840
           CALL PLOT(XLONG,0.,2)                                       TAX24850
           CALL PLOT (XLONG,.4,3)                                      TAX24860
           CALL PLOT (-.1,.4,2)                                        TAX24870
           CALL NUMBER(0.5,.4,.105,0.4,90.0,1)                         TAX24880
           CALL NUMBER(0.4,-.5,.105,-.4,90.0,1)                        TAX24890
           CALL PLOT(0.,-1.0,-3)                                       TAX24900
           CALL LINE(TIME1,PSACC,LL,1,0,74)                            TAX24910
           CALL PLOT(0.,-3.0,-3)                                       TAX24920
           CALL AXIS(-1.0,0.,15HELEVATION (IN.),15,10.0,90.0,PROF(NN+1),  TAX24930
          1PROF(NN+2))                                                 TAX24940
           CALL PLOT(0.,0.,-3)                                         TAX24950
           XPROF=.25*ABS(PROF(NN+1))/PROF(NN+2)                        TAX24960
           CALL SYMBOL (2.,XPROF,.14,15HNOSE GEAR TRACK,0.,15)         TAX24970
           CALL LINE(TIME,PROF,NN,1,0,74)                              TAX24980
           XSTOP=XLONG+5.                                              TAX24990
           CALL PLOT (XSTOP,0.,-3)                                     TAX25000
           WRITE(6,290)                                                TAX25010
           CALL PLOTE                                                  TAX25020
     295   STOP                                                        TAX25030
     290   FORMAT(*5*)                                                 TAX25040
           END                                                         TAX25050
```



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```
SUBROUTINE IC        74/74    OPT=1                        FTN 4.[illegible]      [illegible]/76  [illegible]      PAGE    1

              SUBROUTINE IC( ZCGI,ZMI,ZNI,THETAI)                                   ICE 0010
              COMMON/FLEX1/SIMAIN(15),SINOSE(15),SIZ3(15),SITAIL(15),SIW5(15)     ICE 0020
              COMMON/FLEX2/NFM,GM(15),OMEGA(15)                                     ICE 0030
              COMMON/FLEX3/Q(15),QD(15),QDD(15)                                     ICE 0040
              COMMON/X1/W,WM,WN,MCG,MM,MN,A,B,MMI,MNI                               ICE 0050
              COMMON/X2/PAOM,VOM,AAM,AHM,RSM                                        ICE 0060
              COMMON/X3/PAON,VON,AAN,AHN,RSN                                        ICE 0070
              COMMON/X6/SXM,SYN,SLM,SLN,TSM ,TSN                                    ICE 0080
              COMMON/X9/FSM,FSN,FTM,FTN,XMAIN,XNOSE,VELM,VELN                       ICE 0090
               COMMON/X04/FSML,FSNO,FTML,FTNO,ZMAINL,XNOZNO,VELML,VELNO,MT          ICE 0100
*************************************************************************ICE 0110
C THIS PROGRAM WILL FIND THE INITIAL CONDITIONS FOR  TAXI                  ICE 0120
              REAL MCG,MM,MN,MMI,MNI                                                ICE 0130
C  FOR SYM MAIN AND SYM NOSE GEAR                                           ICE 0140
C  ZMI= MAIN GEAR TIRE DEFLECTION IN PERCENT                                ICE 0150
C  ZNI= NOSE GEAR TIRE DEFLECTION IS PERCENT DEFLECTION                     ICE 0160
C  ZCGI= CG DEFLECTION                                                      ICE 0170
C  THETAI= PITCH ANGLE                                                      ICE 0180
C  XMAIN=  MAIN LANDING GEAR STATIC STROKE                                  ICE 0190
C  XNOSE=  NOSE GEAR STATIC STROKE                                          ICE 0200
*************************************************************************ICE 0210
              RN=W/(1.+A/B)                                                         ICE 0220
              RM=W-RN                                                               ICE 0230
              RM=RM/SXM                                                             ICE 0240
              RN=RN/SYN                                                             ICE 0250
              ZMI=-RM/TSM                                                           ICE 0260
              ZNI=-RN/TSN                                                           ICE 0270
              RSM=RM-WM                                                             ICE 0280
              RSN=RN-WN                                                             ICE 0290
              XNOSE=+PAON*VON/RSN-VON/AAN                                           ICE 0300
              XMAIN=+PAOM*VOM/RSM-VOM/AAM                                           ICE 0310
              THETAI=-(XNOSE+ZNI-(XMAIN+ZMI))/(B+A)                                 ICE 0320
              ZCGI=XMAIN-A*THETAI+ZMI                                               ICE 0330
               DO 10 I=1,NFM                                                        ICE 0340
               QD(I)=0.                                                             ICE 0350
        10    Q(I)=0.                                                               ICE 0360
              RETURN                                                                ICE 0370
              END                                                                   ICE 0380
```

```
SUBROUTINE CO -        74/74   OPT=1                    FTN 4.5+R406      05/25/76  10.22.28       PAGE    1

          .OUTINE COEFF (Y,  A,B,C,D)                              COEF0010
          IENSION Y(4)                                             COEF0020
         A=Y(2)                                                    COEF0030
         B=Y(1)                                                    COEF0040
         C=(96.*Y(1)+56.*Y(2)-64.*Y(3)+8.*Y(4))/(-128.)            COEF0050
         D=(-16.*Y(1)-12.*Y(2)+15.*Y(3)-4.*Y(4))/(-128.)           COEF0060
         RETURN                                                    COEF0070
         END                                                       COEF0080
```

```
SUBROUTINE TLOOK       74/74   OPT=1                    FTN 4.5+R406      05/25/76  10.22.28       PAGE    1

          SUBROUTINE TLOOK (X,SLOPE,YCEPT,S,P,N)                     TL  0010
          DIMENSION S(30),P(30)                                      TL  0020
C                                                                    TL  0030
C         THIS IS A 2 DIMENSIONAL TABLE LOOK UP ROUTINE              TL  0040
C         WITH LINEAR INTERPOLATION                                  TL  0050
C                                                                    TL  0060
C      X  IS THE CURRENT VALUE OF STROKE                             TL  0070
C      SLOPE AND YCEPT ARE CALCULATED AND RETURNED                   TL  0080
C      S AND P  MAKE UP THE TABLE                                    TL  0090
C      N IS THE NUMBER OF VALUES IN THE TABLE                        TL  0100
          DO 1 I=1,N                                                 TL  0110
          IF (X.GE.S(I).AND.X.LT.S(I+1))GO TO 2                      TL  0120
    1      CONTINUE                                                  TL  0130
    2     SLOPE=(P(I+1)-P(I))/(S(I+1)-S(I)+.01)                      TL  0140
          YCEPT=P(I)-SLOPE*S(I)                                      TL  0150
          RETURN                                                     TL  0160
          END                                                        TL  0170
```

APPENDIX C
LISTING OF AIRPLANE DATA

- Boeing 727-100
- McDonnell Douglas C-9A
- AMST

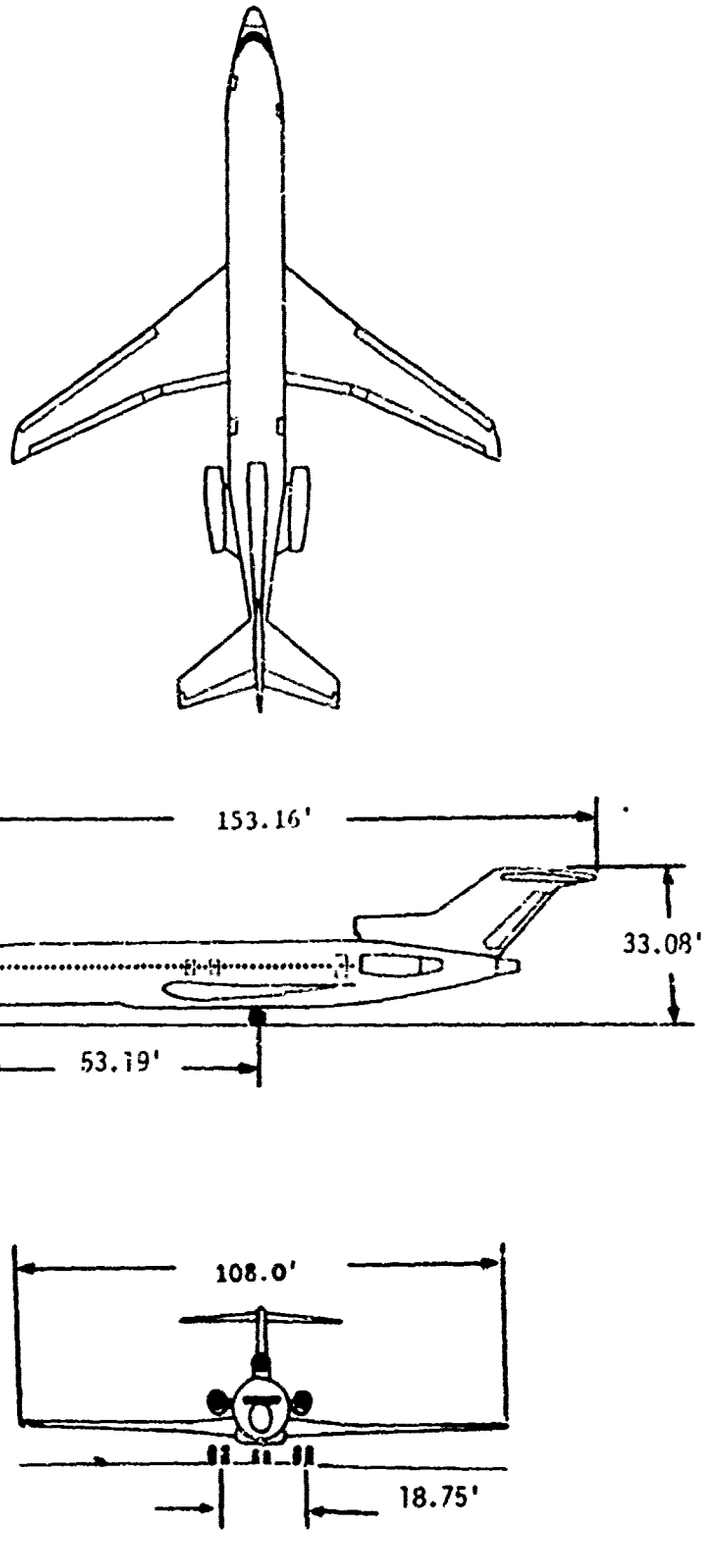

Figure C-1. Three View of Boeing 727-100

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MODE	SIPS	SINOSE	SICG	SIMAIN	SITAIL	OMEGA	GEN. MASS
1	-.23	-.23	-.32	-.03	-.04	14.08	6.0
2	.29	.22	[illegible]	-.29	-.06	22.97	7.0
3	-.17	-.14	.02	.00	-.04	38.35	2.7
4	-.23	-.15	.11	.09	.02	44.56	11.4
5	.32	.21	[illegible]	-.71	-.02	[illegible]	3.9
6	.21	.14	.25	.33	.09	59.66	5.0
7	-.15	[illegible]	[illegible]	-.34	.03	75.56	3.6
8	.33	.14	-.12	-.19	-.04	82.63	173.9
9	.80	.13	-.25	-.05	-.03	87.55	25.1
10	-.05	-.23	-.26	-.07	-.16	[illegible]	11.5

********* INITIAL CONDITIONS ************

ZMI= [illegible]   PHI= -1.479   THETAI= -.005752   ZCGI= -13.573

YMAIN= [illegible]   YNOSE= -5.425   [illegible]= -16147.   REACT[illegible]= -179851.

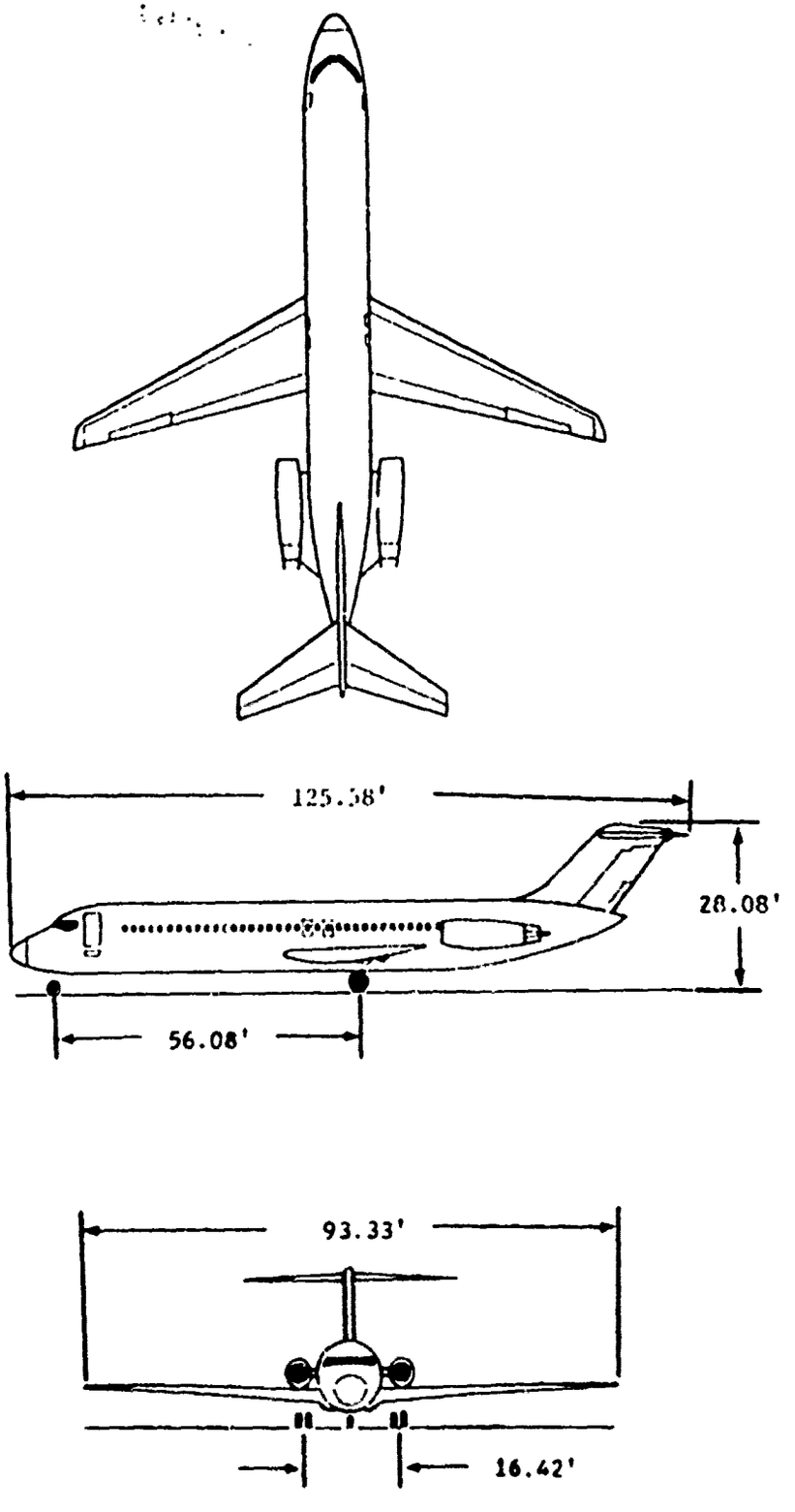

Figure C-2. Three View of McDonnell-Douglas C-9A

MODE	SIPS	SINOS	[illegible]	[illegible]	[illegible]	[illegible]	GEN. MASS
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

MODE	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]

********* INITIAL CONDITIONS ************

ZMI= [illegible] ZNI= [illegible] THETAI= [illegible] ZCGI= [illegible]

[illegible]

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```
**************** INPUT DATA ****************

********* GENERAL AIRCRAFT DATA *********

AWST   150933 POUNDS

W= 150000.0    WW= 3172.33    WV=   438.22    A=   53.650    D=   427.52.    WD=   113.333    WMI=   25950033.

WMSW=   15923330.

SWM=    2.0    SWN=     1.1    SLM=   18..5    SLN=  172.4    PSAPM=  934.2    TAILAM=  159.2

AAM=   70.89    AAMN=  59.41    PAOM=    93...    VCM= 1082.03    CAM=    2.72    TSM =  2.003.01

AAN=   23.75    ANN=   14.07    PAON=  147.33    VON=   79..00    CAN=    .5.    TSN =  1144...

CL=    2.650    CD=     .551    AREA= 1740.0.    SPEED=    2..    THRUST= 6.3...    TAKEOFF=    159.2

STROKE NOSE   PIN DIAMETER

     0.000        .475
     4.000        .355
     6.000        .583
    11.300        .620
    16.090        .755

STROKE MAIN   PIN DIAMETER

     0.000       1.300
     2.000       1.299
     5.300       1.200
     6.000       1.299
    10.000       1.493
    14.000       1.559
    19.000       1.463
    22.000       1.560
    25.000       1.700
    29.000       1..03
    99.3..       1.409
```

APPENDIX D
LISTING OF RUNWAY PROFILES

1. Figure D-1 - Washington National Runway 36-Left, Center, and Right hand profiles:
2. Profile data listing of the 1-cos dip used in these simulations: All three lines of profile were identical except that they occur at different times corresponding to the gear locations.

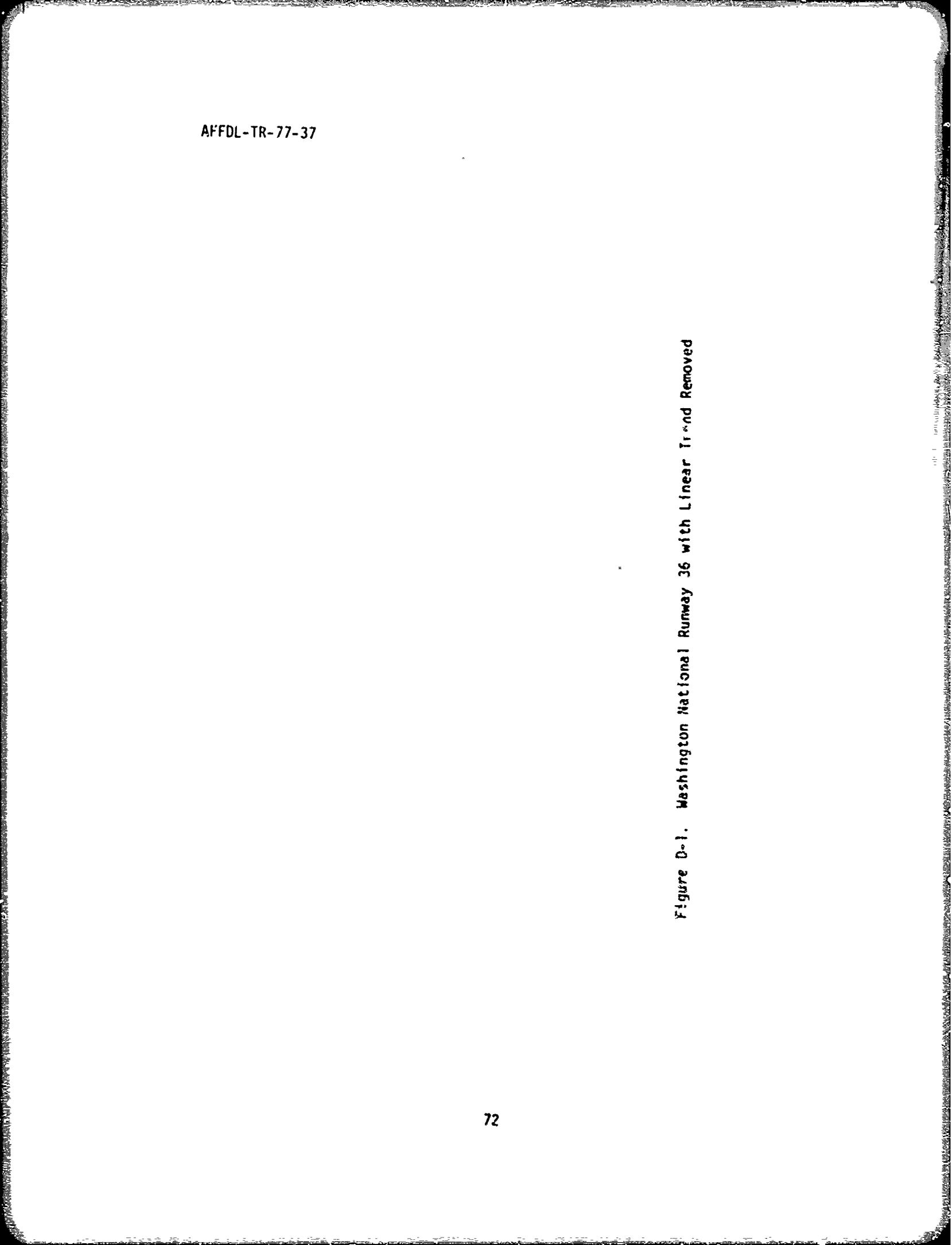
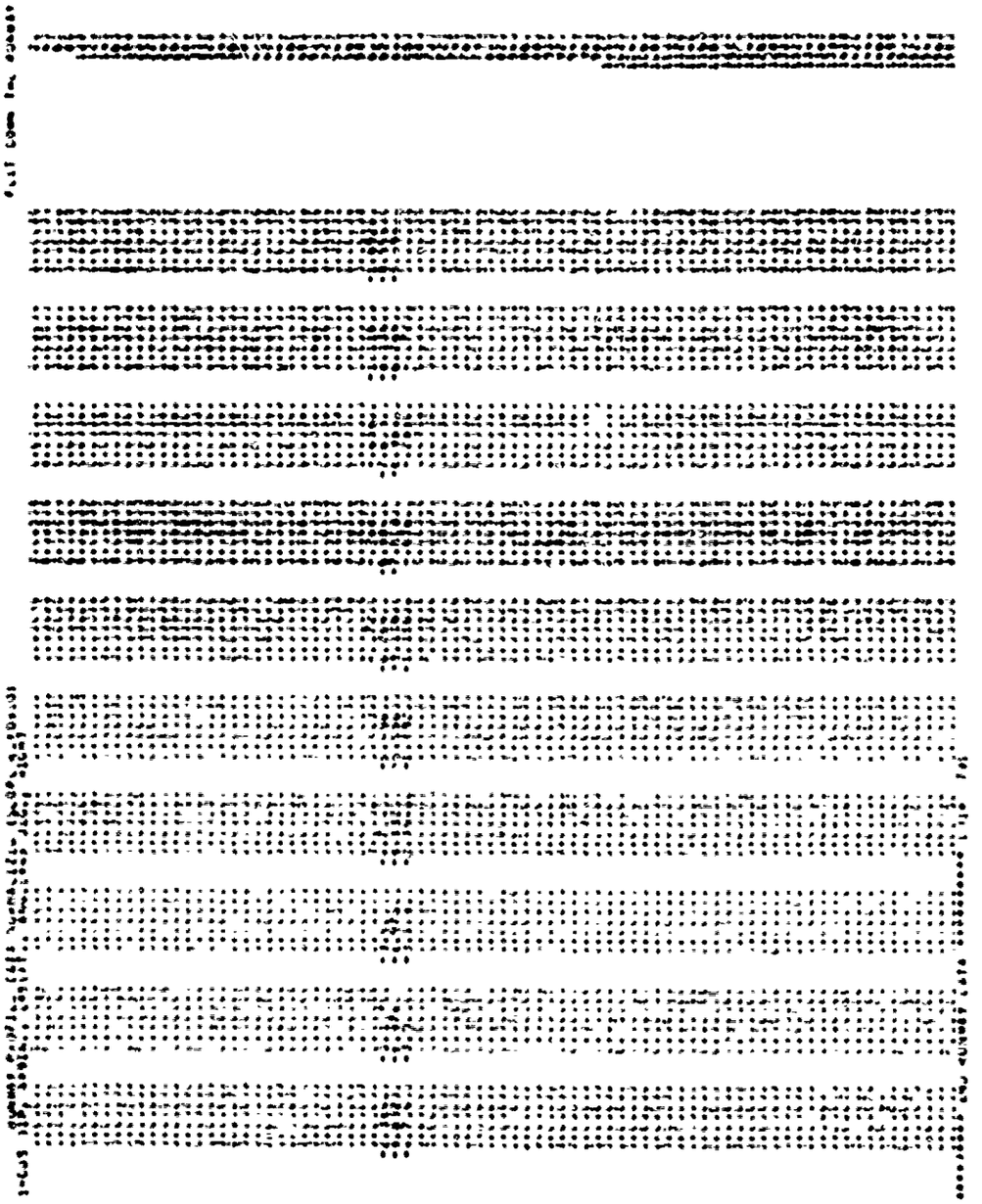


Figure D-1. Washington National Runway 36 with Linear Trend Removed



BIBLIOGRAPHY

Butterworth, C. K., and Boozer, D. E., Jr., C-141A Computer Code for Runway Roughness Studies, AFWL-TR-70-71, Air Force Weapons Laboratory, Kirtland AFB, New Mexico, August 1970.

Chance Vought Corporation, A Rational Method for Predicting Alighting Gear Dynamic Loads, ASD-TDR-62-555, Aeronautical Systems Division, Wright-Patterson AFB, Ohio, December 1963.

Cook, Robert F., Use of Discrete Runway Profile Elevation Data in Determining the Dynamic Response of Vehicles, TM-68-3-FDDS, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, May 1968.

Crenshaw, B. M., and Butterworth, C. K., Lockheed Georgia Company, Aircraft Landing Gear Dynamic Loads from Operation on Clay and Sandy Soil, AFFDL-TR-69-51, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, February 1971.

NACA TN 2477, Investigation of the Air-Compression Process During Drop Tests of an Oleo-Pneumatic Landing Gear, 1951.

Quade, Delmar A., The Boeing Company, Wichita Division, Location of Rough Areas of Runways for B-52 Aircraft, AFFDL-TR-67-175, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, March 1968.

REFERENCES

1. Goldman, D. E., and von Gierke, H. E., "Effects of Shock and Vibration on Man," Volume III, Chap. 44, Shock and Vibration Handbook (C. M. Harris and C. E. Crede, editors) McGraw Hill Book Co., New York, 1961.

2. Gerardi, A. G., Lohwasser, A. K., Computer Program for the Prediction of Aircraft Response to Runway Roughness, AFWL-TR-73-109, Volume I and II, Air Force Weapons Laboratory, Kirtland AFB, New Mexico, September 1973.

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