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LOAD FACTORS FOR KICK STAGE

by

J. A. Staley and A. F. Leondis

prepared for

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GENERAL DYNAMICS
CONVAIR DIVISION

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FINAL REPORT

LOAD FACTORS FOR KICK STAGE

by

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prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

February 28, 1967

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Technical Management
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San Diego, California

SUMMARY

The fundamental concept of the cryogenic Kick Stage vehicle requires an efficient solution to the thermodynamic problem of storage of liquids in space and the structural problem of withstanding the loads encountered.

It is the object of this report to evaluate the loads expected for the Kick Stage when boosted by the Atlas/Centaur launch vehicle. The Kick Stage structure studied consists of two alternate truss designs: one with two ten-foot diameter rings and the other with three. Other variations in truss members and payload weights have also been studied.

Maximum acceleration loads were found to exist and may be a designing factor for at least one part of the Kick Stage at the following times:

(a) Launch
(b) During flight, (Mach-one to Max q period)
(c) Maximum booster acceleration (Atlas)
(d) Centaur main engine cutoff and
(e) Kick Stage main engine cutoff.

Other conditions studied included Atlas thrust buildup, and Centaur and Kick Stage Main Engine Starts.

Truss loads were summarized separately to take advantage of phasing of the loads of different masses and thereby reduce the truss loads and weight. The maximum tensile load in the main truss is only about half the sum of the peak loads if phasing were neglected. This analysis also takes into account a predicted environmental vibration response which is taken as uncorrelated with dynamic responses beyond the nominal static loads. This environmental factor increases the difference in the truss loads noted above.

Clearance necessary between the payload and the nose fairing was found to be 1.64 inches plus local deformation of payload equipment. The clearance between the nose fairing and the forward ring is recommended to be 0.90 inch. These clearances are based upon the 2-ring truss design. The 3-ring design was found to be less favorable.

Some analysis was made using a beryllium aluminum alloy cruciform beam (which supports the Kick Stage engine and liquid oxygen tanks). This work indicates that significant advantages may be obtained with such a beam.

The analysis of Centaur and Kick Stage main engine cutoff transients indicates that the liquid propellants will become unsettled at that time. The energy stored in the elastic vehicle, when released at engine cutoff, causes this problem.

Additional analysis is also recommended to parallel any future development of Kick Stage.

LOAD FACTORS FOR KICK STAGE

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J. A. Staley and A. F. Leondis

ABSTRACT

An 8,800-pound cryogenic Kick Stage, considered as a third stage for the Atlas-Centaur rocket combination, is analyzed to determine the load factors developed during launch and flight until the last Kick Stage main engine cutoff. The load factors are intended to provide an accurate basis for design of the basic Kick Stage structure (not small components). Required clearance inside the cone cylinder nose fairing is also considered.

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1

INTRODUCTION

1.1 LONG RANGE OBJECTIVES

One of the building blocks considered for the support of future space exploration plans is the cryogenic Kick Stage. The Kick Stage has a two-fold purpose. The first is to extend present launch vehicle capabilities to support unmanned space programs. This is really a simple matter of economics, in that for many of the planned unmanned programs the use of Kick Stage will shift launch vehicle requirements to that of a less expensive vehicle (including Kick Stage). The second purpose of Kick Stage is to develop one of the propulsion technologies required for future manned space vehicles. Kick Stage development will advance operational cryogenic space vehicle systems required for high energy, long coast and manned missions to the planets.

The vehicle described in this report, Atlas SLV-3C/Centaur/Kick Stage (oxygen-hydrogen), would be capable of placing approximately 2,200 pounds in a synchronous equatorial earth orbit, 2,750 pounds to Mars or a 110-pound solar probe to 0.28 astronomical unit from the Sun.

1.2 INITIAL HARDWARE AND GROUND TESTING

The Kick Stage as currently envisioned requires a lightweight structure optimized for thermodynamic insulation during extended interplanetary coast periods. If development of Kick Stage is pursued, the initial hardware will be used for ground testing at LeRC in order to determine and study the major problem areas associated with this type of vehicle. In order to obtain realistic dynamic and static load tests of the primary structure, it is planned to simulate the operational flight weight structure as closely as possible. Therefore, the preliminary structural design of the Kick Stage must be based upon an accurate assessment of the critical load conditions before and during flight, giving due consideration to the dynamic loads developed and transmitted within the integrated Atlas/Centaur/Kick Stage vehicle. This report is intended to serve as the assessment of critical loads for several variations of Kick Stage structure and payloads as described in this section.

1.3 LAUNCH VEHICLE AND FLIGHT SEQUENCE

The Atlas/Centaur/Kick Stage vehicle is a three or three and one-half stage vehicle. The first stage, which is the Atlas, is a liquid oxygen-kerosene type booster with three large engines. Two of these engines called the "booster package" are jettisoned after two to three minutes of flight. The remaining single large engine and the entire Atlas propellant tank continues to operate for a few additional minutes until propellant depletion. The Atlas portion of flight is thus made in two phases, the booster phase and the

sustainer phase and is sometimes called a stage and a half. Figure 1-1 shows in a diagramatic sketch the probable sequence of events during flight. After booster jettison the insulation panels from the Centaur liquid hydrogen tank are dropped, followed by the two halves of the nose fairing. After jettison of the sustainer tank, the Centaur main engines start and may or may not be restarted depending on mission requirements. After Centaur burn-out and staging, the Kick Stage main engine start takes place, followed by cut-offs and restarts as necessary. Payload separation from Kick Stage is not shown in the sketch and for some missions may not take place if the mass and thermal shielding of the empty vehicle is beneficial. A more accurate sketch of the entire launch configuration vehicle is shown in Figure 1-2.

The Centaur model used is based upon the AC-12 Centaur with propellant levels adjusted to 5 percent for first main engine cutoff and second main engine start.

The Atlas vehicle used is the SLV-3C as proposed in TCP 8446R2 "SLV-3A/ SLV-3C Airborne Changes", dated March 14, 1966. Propellant levels have been adjusted to provide a thrust/weight ratio of 1.20 at launch. The Atlas launcher used in this study is quite similar to the one used for AC-9. Slight changes may be made in holddown pressure and auxiliary support systems which should have little or no effect on the launch vehicle. See Section 5 for details concerning launcher "Back Pressure".

1.4 KICK STAGE DESCRIPTION

The Kick Stage as treated in this report is an 8,800-pound vehicle excluding payload. It has a single RL10A-3-3 engine for use with liquid hydrogen and liquid oxygen. It has a nominal 10 foot diameter and may carry payloads of 300 to 3,000 pounds (only these extreme payload weights have been studied.) The principle components of the Kick Stage (shown schematically in Figure 1-3) are a 9 foot oblate spheroid LH_2 tank supported by a thin conical shell; a cruciform beam that supports the RL10A-3-3 engine; four spherical LO_2 tanks supported by the aft ring and the cruciform beam, and a primary space truss structure consisting of struts and rings which tie the various components together. Two variations of the truss (see Figures 1-4 and 1-5) have been considered. Other details of the aft ring and cruciform beam are shown in Figures 1-6 and 1-7.

The cone-cylinder nose fairing encloses both the payload and the Kick Stage down to the aft ring. The stiffness of the nose fairing was taken to be equal to that of the Surveyor nose fairing.

The Kick Stage to Centaur adapter was taken to have the following properties: $EI = 360 \times 10^9$ lb-in.^{2} and $KAG = 38 \times 10^6$ lb.

The many variations of the Kick Stage structure and payload weights are summarized in Table 1-1. There are basically only 9 different configurations. These employ a modulus of 10^7 psi for the truss and 10.3×10^6 psi for the cruciform beam. Nine

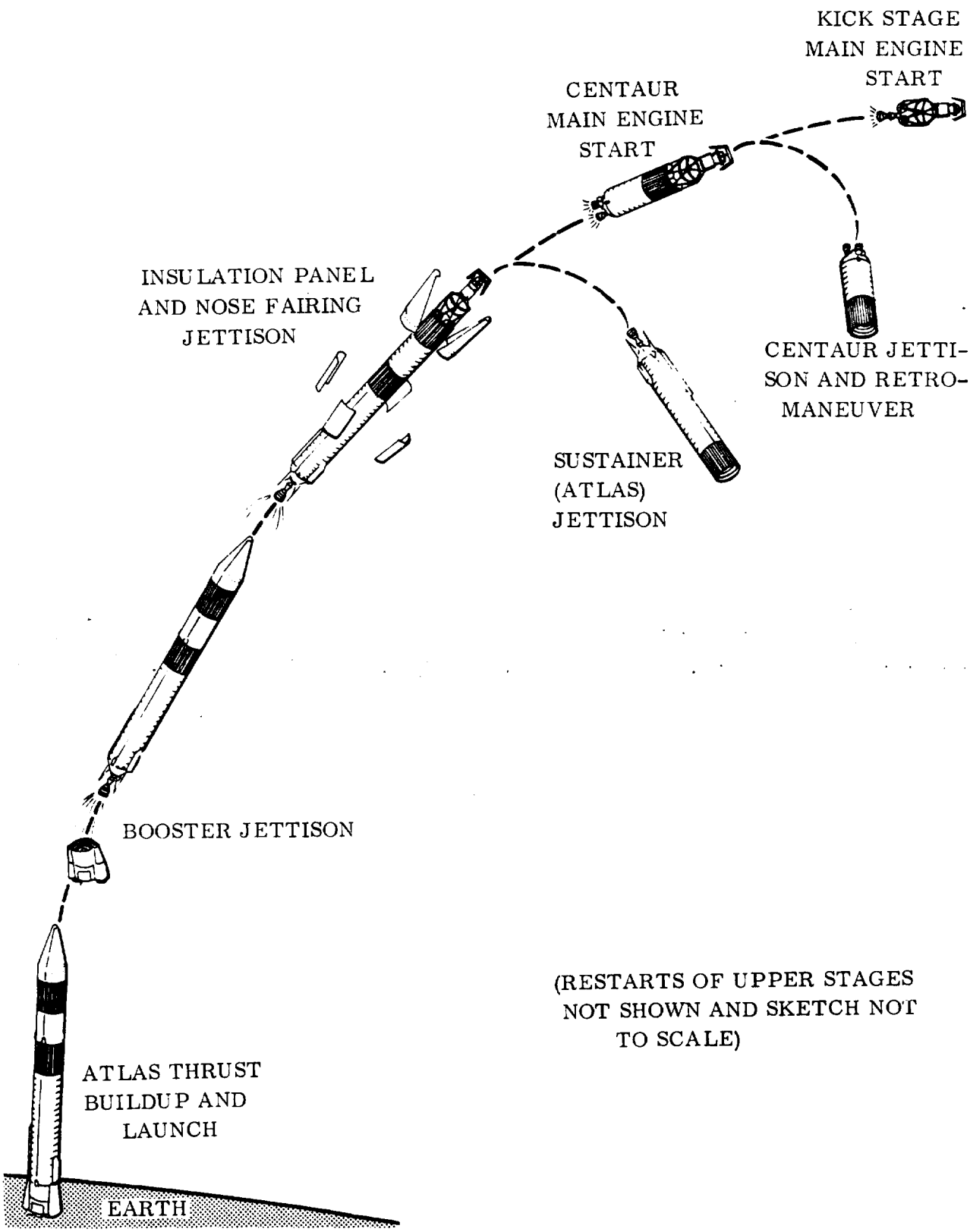


Figure 1-1. Flight Sequence for Atlas/Centaur/Kick Stage

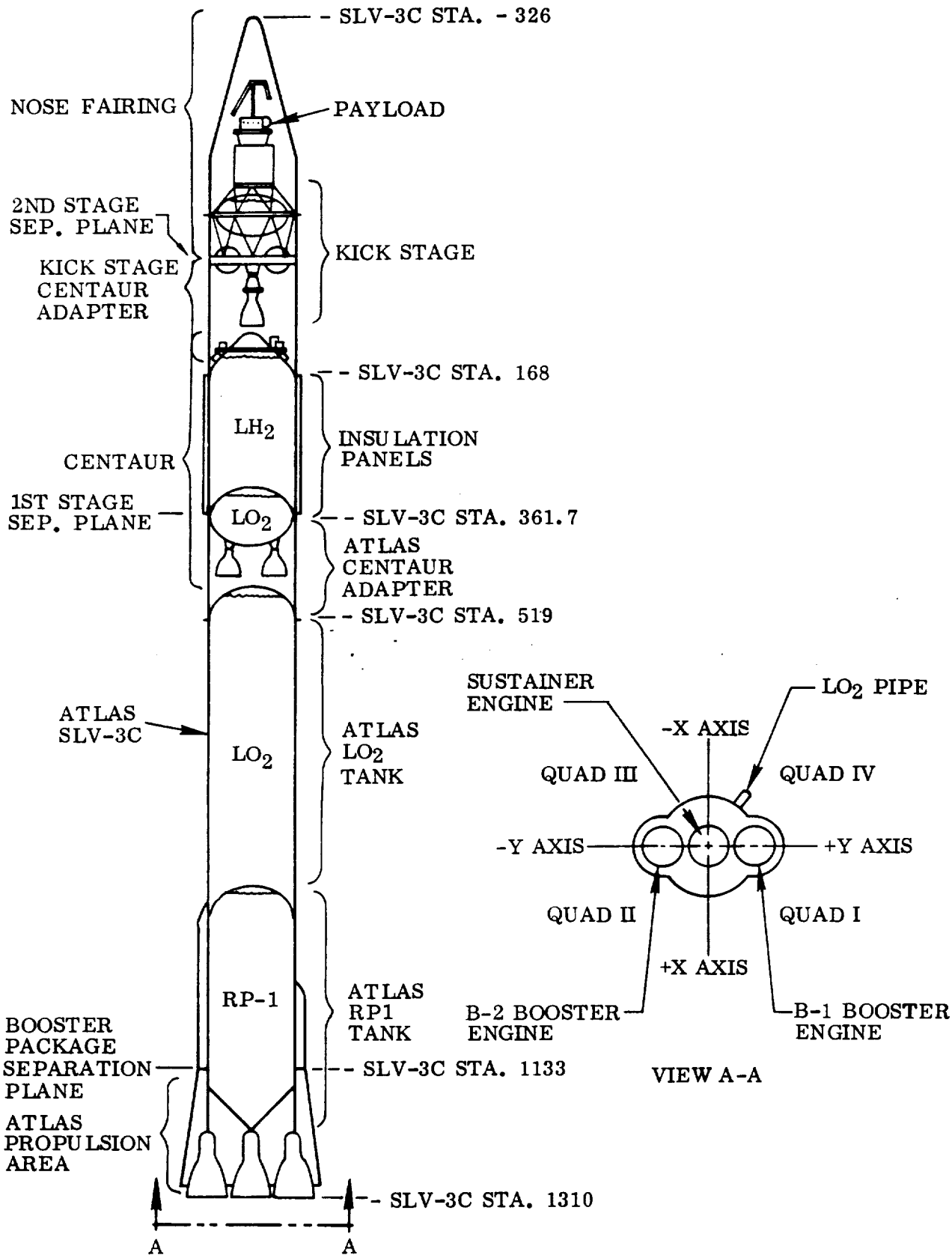


Figure 1-2. Atlas/Centaur/Kick Stage Launch Configuration

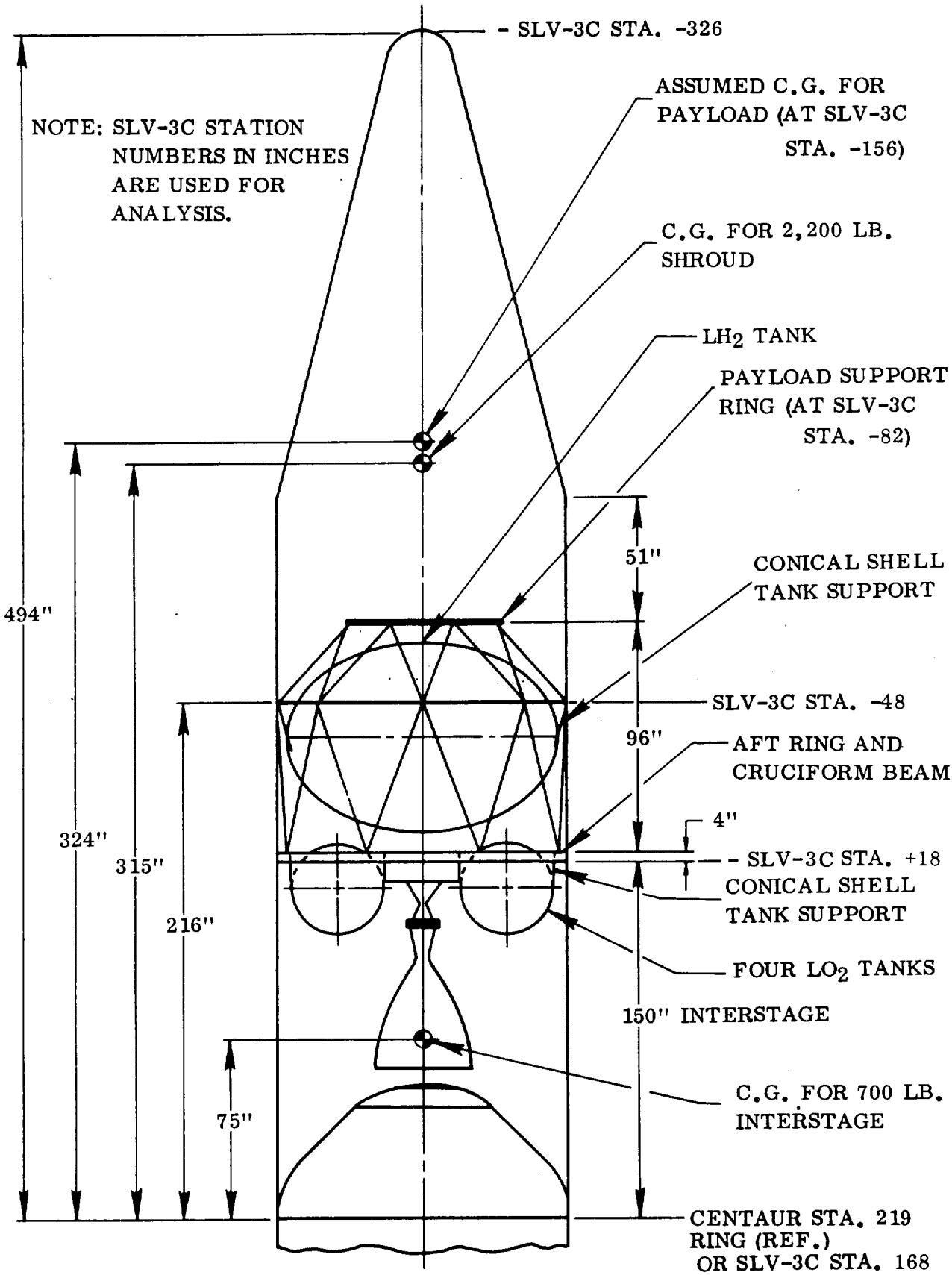


Figure 1-3. Cryogenic Kick Stage Configuration for Use With Centaur

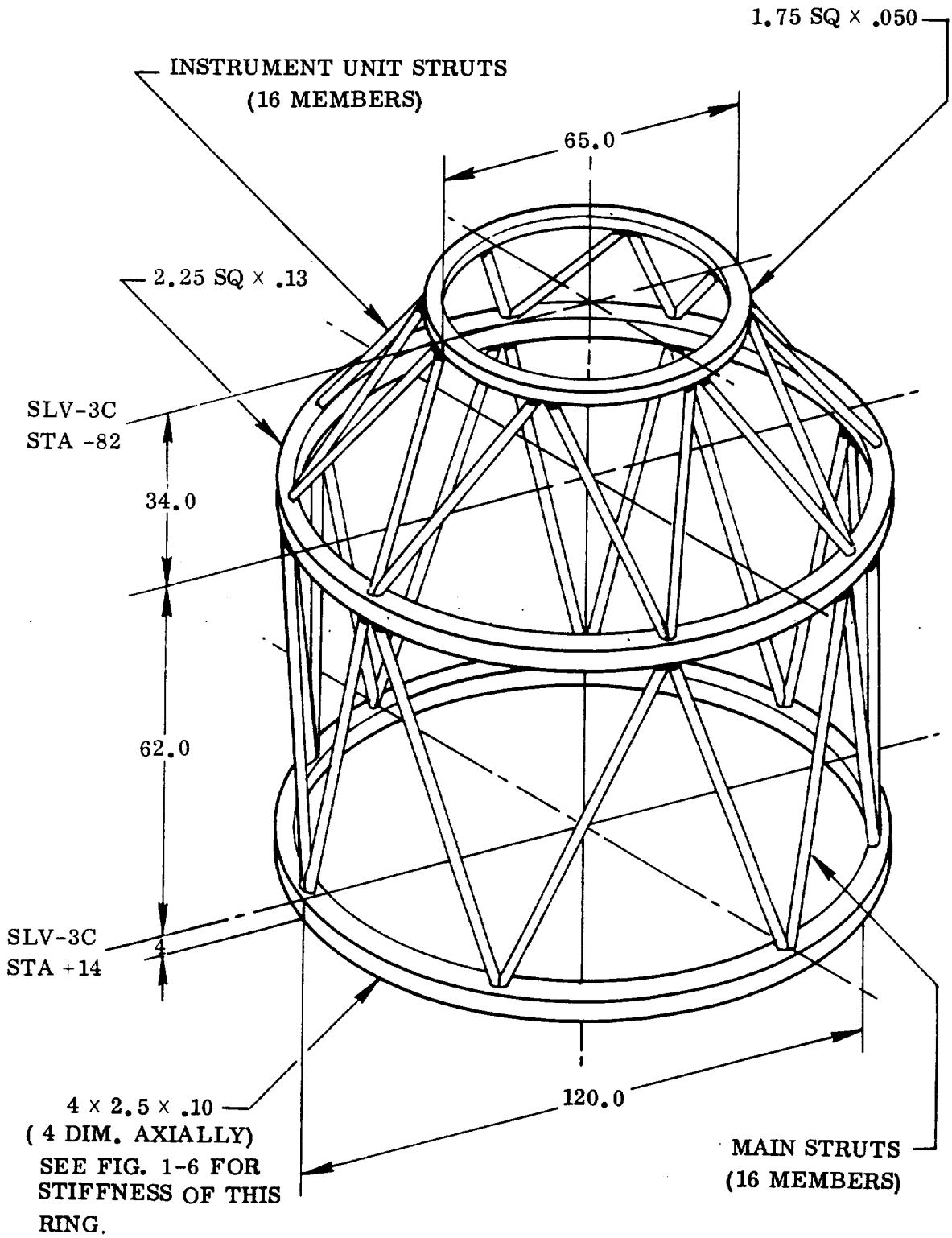


Figure 1-4. Two Ring Design

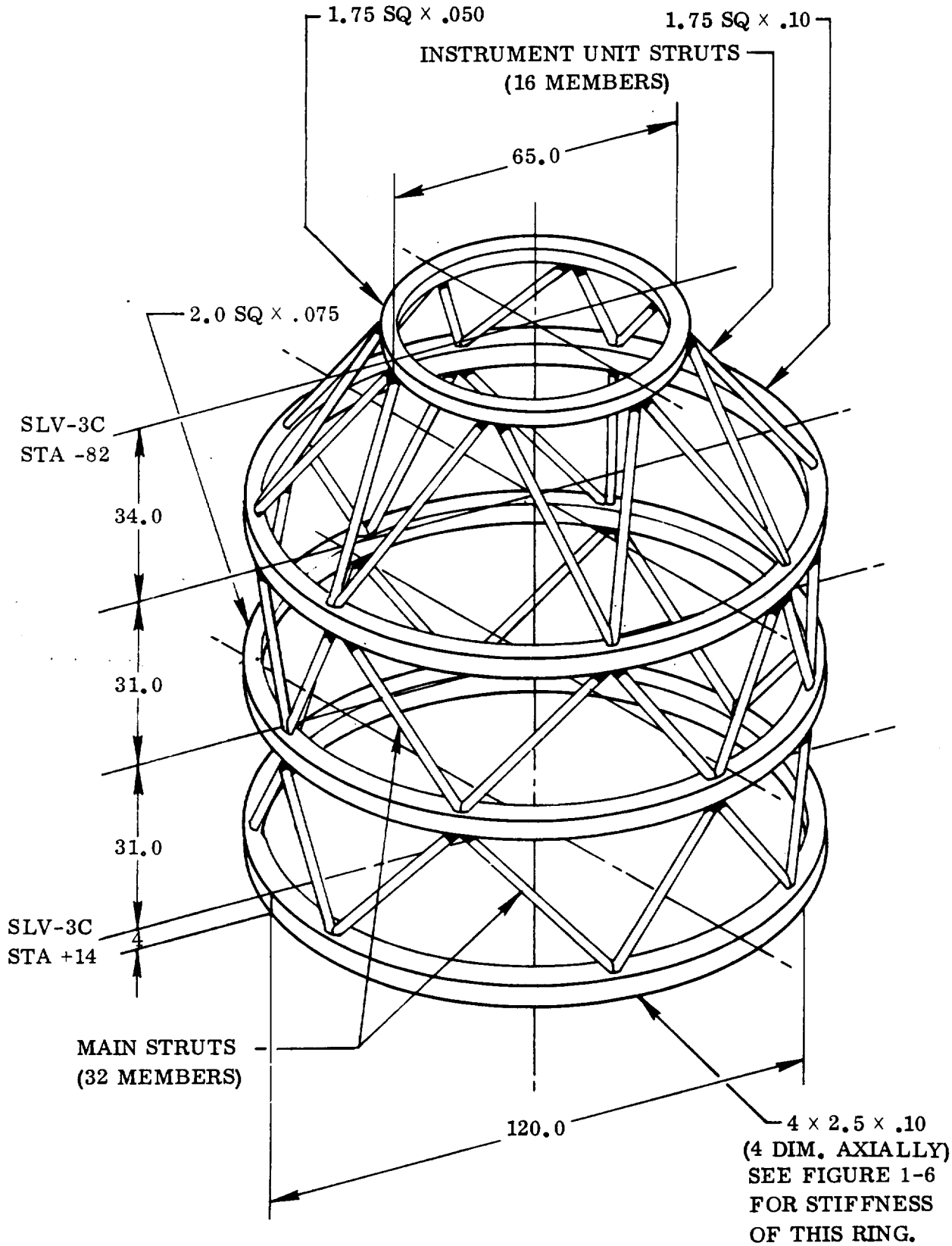
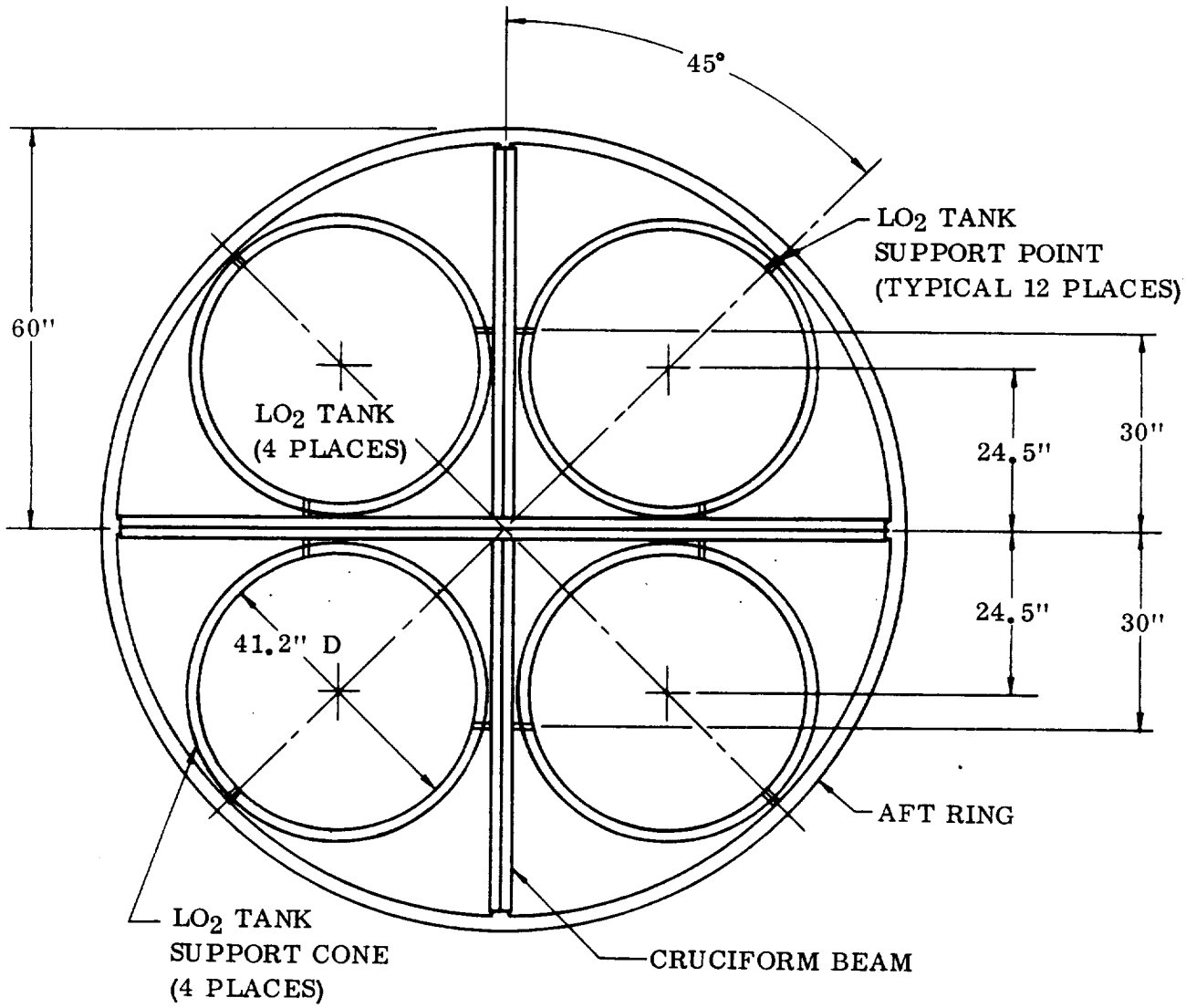


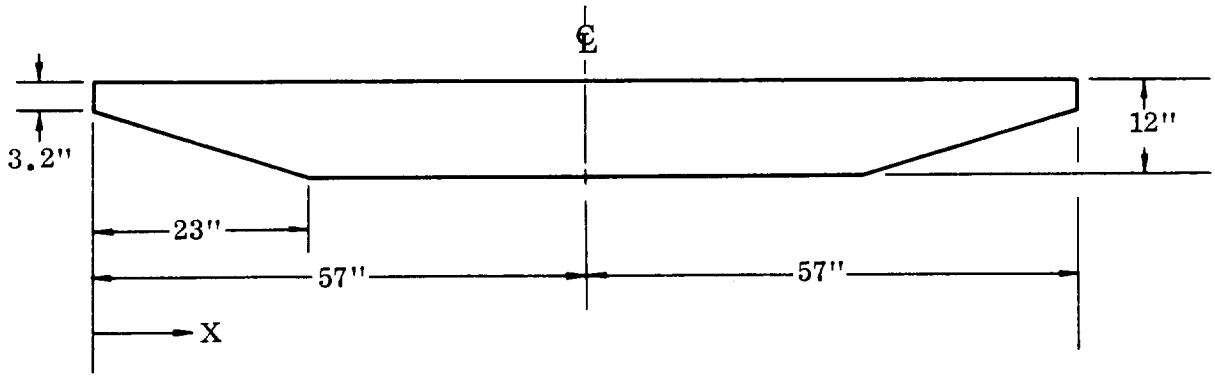
Figure 1-5. Three Ring Design



AFT RING BENDING STIFFNESS - $(EI)_R = 4.6 \times 10^7$ LB-IN.^{2}

AFT RING SHEAR STIFFNESS - $(JG)_R = 1.3 \times 10^7$ LB-IN.^{2}

Figure 1-6. Aft Ring - Cruciform Beam Assembly



BEAM CHARACTERISTICS

$E = 10.3 \times 10^6$ PSI $\qquad$ $G = 3.9 \times 10^6$ PSI

X Inch	$EI \times 10^{-6}$ lb-in.^{2}	$KAG \times 10^{-6}$ lb
0	41.0	1.00
2	62.0	1.24
4	86.0	1.48
6	116.0	1.72
8	149.0	1.96
10	188.0	2.21
15	304.0	2.81
20	446.0	3.42
23	538.0	3.74
|	|	|
57	538.0	3.74

Figure 1-7. Cruciform Beam

TABLE 1-1. STRUT CONFIGURATION AND PAYLOAD WEIGHT ASSOCIATED WITH EACH OF THE LONGITUDINAL AND LATERAL MODEL CASES

Case Number*	Instrument Unit Strut Dimensions (Inches)	Main Strut Dimensions (Inches)	Strut Configuration (Figure Number)	Payload Weight (lbs)
1	1.75 OD × 0.06 Wall	2.25 OD × 0.08 Wall	Two Rings (1-4)	3000
2	1.75 OD × 0.09 Wall	2.25 OD × 0.12 Wall	Two Rings (1-4)	3000
3	1.75 OD x 0.03 Wall	2.25 OD × 0.04 Wall	Two Rings (1-4)	3000
4	1.75 OD × 0.06 Wall	2.25 OD × 0.08 Wall	Two Rings (1-4)	300
5	1.75 OD × 0.09 Wall	2.25 OD x 0.12 Wall	Two Rings (1-4)	300
6	1.75 OD × 0.03 Wall	2.25 OD × 0.04 Wall	Two Rings (1-4)	300
7	1.75 OD × 0.06 Wall	1.5 OD × 0.05 Wall	Three Rings (1-5)	3000
8	1.75 OD × 0.09 Wall	1.5 OD × 0.075 Wall	Three Rings (1-5)	3000
9	1.75 OD × 0.03 Wall	1.5 OD × 0.025 Wall	Three Rings (1-5)	3000

NOTE:
*Nine other cases are also used in the gust analysis. These are identified by adding the letter "S" (for stiff) after the case number shown above and are changed only by increasing the modulus of elasticity to 30×10^6 psi (beryllium-aluminum alloy).

more were created by changing the properties of the truss and cruciform beam members to a modulus of 30×10^6 psi. All of these cases were used in the gust analysis and in addition two more that were formed by connecting the Kick Stage forward ring to the nose fairing. A list of mathematical models, used in the various studies decribed by this report, is presented in Table 1-2. As shown later in Section 7, the most critical time for gusts and related loads was found to be 72 seconds, for that reason most of the gust models were evaluated at that time.

The four added models (45A, 46A, 46B, and 46C) shown in the table were considered to be important to show changes in load factors resulting from changes in stiffness and/or payload weight.

Kick Stage weights and C.G. locations for various propellant levels are presented in Table 1-3.

TABLE 1-2. TABLE OF MODELS

Math Model No.	Longitudinal	Lateral	Kick Stage Case No.*	Kick Stage Propellant Level	Centaur Propellant Level	Atlas Propellant Level	Remarks
1	X		1	Full	Full	Full	Model for Atlas thrust buildup analysis. Launcher included in Model.
2	X		1	Full	Full	Full	Models 2-7 for launch analysis
3		X	1	Full	Full	Full	
4	X		4	Full	Full	Full	
5		X	4	Full	Full	Full	
6	X		7	Full	Full	Full	
7		X	7	Full	Full	Full	
8		X	1	Full	Full	t = 56	Models 8-31 for gust and static aeroelastic analysis
9		X	1	Full	Full	t = 64	
10		X	1	Full	Full	t = 72	
11		X	1	Full	Full	t = 80	
12		X	2	Full	Full	t = 72	
13		X	3	Full	Full	t = 72	Models 8-11
14		X	4	Full	Full	t = 72	and 20-23 for
15		X	5	Full	Full	t = 72	selection of
16		X	6	Full	Full	t = 72	most critical
17		X	7	Full	Full	t = 72	time of flight.
18		X	8	Full	Full	t = 72	Most critical
19		X	9	Full	Full	t = 72	time was found
20		X	1S	Full	Full	t = 56	to be 72 sec.
21		X	1S	Full	Full	t = 64	Other Kick
22		X	1S	Full	Full	t = 72	Stage Models
23		X	1S	Full	Full	t = 80	were analyzed
24		X	2S	Full	Full	t = 72	at same most
25		X	3S	Full	Full	t = 72	critical time.
26		X	4S	Full	Full	t = 72	
27		X	5S	Full	Full	t = 72	S indicates E =
28		X	6S	Full	Full	t = 72	30×10^6 lbs/sq.in.

TABLE 1-2. TABLE OF MODELS (CONTINUED)

Math Model No.	Longitudinal	Lateral	Kick Stage Case No.*	Kick Stage Propellant Level	Centaur Propellant Level	Atlas Propellant Level	Remarks
29		X	7S	Full	Full	t=72	
30		X	8S	Full	Full	t=72	
31		X	9S	Full	Full	t=72	
32		X	1	Full	Full	t=72	Special additional case.
33		X	7	Full	Full	t=72	
34	X		1	Full	5%	Jett.	Models 34-37 for Centaur 2nd MES and 1st MECO analysis. Atlas has been jettisoned here.
35		X	1	Full	5%	Jett.	
36	X		4	Full	5%	Jett.	
37	X		7	Full	5%	Jett.	
38	X		1	Full	Empty	Jett.	Models 38-41 for Centaur 2nd MECO analysis.
39		X	1	Full	Empty	Jett.	
40	X		4	Full	Empty	Jett.	
41	X		7	Full	Empty	Jett.	
42	X		1	Full	Jett.	Jett.	Models 42-44 for Kick Stage 1st MES analysis. Centaur has been jettisoned here
43	X		4	Full	Jett.	Jett.	
44	X		7	Full	Jett.	Jett.	
45	X		1	1/3	Jett.	Jett.	Model 45 for Kick Stage 2nd MES. 45A for Kick Stage 1st MECO.
45A	X		4	1/3	Jett.	Jett.	
46	X		1	Empty	Jett.	Jett.	Model 46 for Kick Stage 2nd MECO.
46A	X		4	Empty	Jett.	Jett.	
46B	X		4M**	Empty	Jett.	Jett.	
46C	X		1M**	Empty	Jett.	Jett.	

NOTE: * Kick Stage case numbers are referenced to Table 1-1.
** Kick Stage case numbers 4M and 1M are modified to include a 60 cps payload primitive frequency and a beryllium-alluminum cruciform beam, respectively.

TABLE 1-3. WEIGHTS AND C. G. LOCATIONS FOR MODEL MASSES

		Kick Stage					
		Full Load		1/3 Full Load		Empty	
	Item	Wt. (lb)	C.G.* (in.)	Wt. (lb)	C.G.* (in.)	Wt. (lb)	C.G.* (in.)
1	Payload	3000/300	324	3000/300	324	3000/300	324
2	Payload Ring & Equip.	436	250	436	250	436	250
3	Fwd. Ring & Equip.	174	216	174	216	174	216
4	LH_2 & Structure	1390	202	610	187	220	201
5	LO_2 & Structure	6130	142	2250	132	290	142
6	Engine & Structure	380	106	380	106	380	106
7	Aft Ring & Beam	290	148	290	148	290	148

NOTE:
*Distance forward of Centaur 219 Ring. Changes in weight between the various Kick Stage cases have been neglected except for the weights shown in the table.

1.5 IMPORTANT DESIGN CONDITIONS

Based upon previous experience with Atlas and Atlas/Centaur vehicles, it was expected that the important load conditions for Kick Stage would be:

a. Launcher release transients

b. Gust loads during the time of flight near Mach 1 and maximum aerodynamic pressure

c. Maximum booster acceleration

4. Centaur last main engine cutoff.

In addition to these recognized load conditions, the Kick Stage main engine start and cutoff transients required evaluation.

Other conditions which were considered important enough to warrant investigation were Atlas thrust buildup and some miscellaneous Centaur start and cutoff transients. A special study of environmental vibration has also been made (Section 11) to permit inclusion of loads due to this source.

Although all important load conditions are believed to be included, for the design of the basic Kick Stage structure, it should be recognized that other studies are necessary for proper integration of electronic components, nose fairings, thermal insulation, pre-launch air conditioning systems, etc. During the course of this study it was noted that the most favorable arrangement of cruciform beam and nose fairings would be with the nose fairing hinge points at the ends of one member of the beam. This arrangement would permit the large compressive radial load from the nose fairings to be supported in a very efficient manner. Another detail of future interest is the shaped charge shock developed near the aft ring of the Kick Stage truss by the shaped charge used to cutoff the nose fairing. Equipment items mounted within approximately a foot of this ring may see extremely high shocks (perhaps 2,000 to 3,000 g's for less than one millisecond). The intensity of the shock is considerably less only 3 to 4 feet away.

1.6 REPORT ORGANIZATION

In the preparation of this report it was felt that the reader would most frequently be interested in the tabulated loads and clearance data. Because of this, the Total Loads and Recommendations Section was made the second section of the report. It is hoped that this will prove to be more convenient than placing it last. Other sections containing detail data follow Section 2 as outlined in the Table of Contents on page vii.

2

TOTAL LOADS AND RECOMMENDATIONS

This section is intended to present the final results of the Kick Stage load and clearance study. Loads and clearances are presented in this section for the many possible variations of the Kick Stage structure discussed in Section 1. The reader is encouraged to read the text of this section to understand the meaning of the loads presented.

2.1 FORMAT OF LOAD TABULATION

The main results of this study are presented in Table 2-1. Details peculiar to the loads and clearances for each load event or condition considered are found in later sections of this report.

The conditions listed in the left hand column of Table 2-1 are abbreviations for significant dynamic loading conditions which occur from Atlas Thrust Buildup (TBU) to Kick Stage Second Main Engine Cutoff (KMECO2) and are arranged in flight sequence. The definitions of the abbreviations used in the "condition" column are given in Table 2-2. The case numbers refer to Tables 1-1 and 1-2 while the MM (Math Model) numbers refer to Table 1-2.

Inertia loads for seven lumped masses of the Kicked Stage, axial and lateral loads in the Kick Stage truss, and clearance loss between the Kick Stage and Nose Fairing are presented in Table 2-1 for each significant event.

Lateral and longitudinal static, dynamic, and environmental components are given for each load or clearance loss. These are combined to give a resultant, or total load (positive and/or negative).

It should be pointed out that some results are presented for several Kick Stage cases not originally required under this study. Variations in Kick Stage properties were considered which might reduce loads at Kick Stage MECO. These results are presented toward the end of Table 2-1 and are discussed below.

Accelerations are taken positive when acting forward and are quoted as "Design Limit values," not ultimate.

2.2 INERTIA LOADS

Inertia loads shown in Table 2-1 were taken from later sections of this report and were combined and tabulated here.

TABLE 2-1. TOTAL DESIGN LIMIT ACCELERATIONS, TRUSS LOADS AND CLEARANCES

Condition	Type Load	Payload (g's)		Payload Ring (g's)		Forward Ring (g's)		Hydrogen (g's)		LO_2 (g's)		Engine (g's)		Aft Ring (g's)		Truss Loads at Sta. +14			Clearance Loss	
		Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Bending Moment (10^6 in.-lb)	Shear (10^3 lb)	Axial Force (10^3 lb)	P/L to N/F (in.)	Fwd Ring to N/F (in.)
Atlas	Static	1.00	0.02	1.00	0.02	1.00	0.02	1.00	0.02	1.00	0.02	1.00	0.02	1.00	0.02	0.013	0.10	+5.0	0.02	0.01
TBu	Dyn +	+0.52	±0.8*	+0.46	±0.8*	+0.41	±0.8*	+0.41	±0.8*	+0.51	±0.8*	+0.65	±0.8*	+0.40	±0.8*	±0.50*	±4.0*	-2.41	±0.75*	±0.19*
Case 1	Dyn -	-0.70	—	-0.60	—	-0.53	—	-0.53	—	-0.79	—	-1.09	—	-0.51	—	—	—	-4.21	—	—
MM 1	Env	0.74	0.74	1.93	1.93	3.1	3.1	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	2.85	2.85	0.04	0.02
3K P/L	Total +	1.00 +0.90	0.02 ±1.09*	1.00 +1.96	0.02 ±2.09*	1.00 +3.13	0.02 ±3.20*	1.00 +1.16	0.02 ±1.34*	1.00 +0.72	0.02 ±0.95*	1.00 +2.20	0.02 ±2.25*	1.00 +2.43	0.02 ±2.53*	0.01 ±0.51*	0.10 ±4.81*	5.0 +4.19	±0.77*	±0.20*
	Total -	1.00 -1.02	—	1.00 -2.02	—	1.00 -3.14	—	1.00 -1.20	—	1.00 -0.94	—	1.00 -2.37	—	1.00 -2.45	—	—	—	5.0 -5.76	—	—
Launch	Static	1.20	0	1.20	0	1.20	0	1.20	0	1.20	0	1.20	0	1.20	0	0	0	6.00	0	0
Case 1	Dyn +	+0.99	±1.72	+0.88	±0.61	+0.78	±0.45	+0.78	±0.40	+1.04	±0.37	+1.34	±0.44	+0.75	±0.36	±0.94	±6.05	+4.6	±0.48	±0.095
MM 2,3	Env	0.74	0.74	1.93	1.93	3.1	3.1	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	2.85	2.85	0.04	0.020
3K P/L	Total +	1.2 +1.24	±1.87	1.2 +2.12	±2.03	1.2 +3.20	±3.13	1.2 +1.33	±1.15	1.2 +1.16	±0.83	1.2 +2.50	±2.14	1.2 +2.52	±2.43	±0.95	±6.69	6.0 +5.41	±0.48	±0.097
Launch	Static	1.20	0	1.20	0	1.20	0	1.20	0	1.20	0	1.20	0	1.20	0	0	0	2.76	0	0
Case 4	Dyn +	+0.83	±1.55	+0.71	±1.01	+0.69	±0.82	+0.70	±0.74	+1.03	±0.52	+1.38	±0.44	+0.69	±0.53	±0.19	±2.07	±1.64	±0.24	±0.099
MM 4,5	Env	2.32	2.32	1.93	1.93	3.1	3.1	1.08	1.08	0.51	0.51	2.1	2.1	2.4	2.4	0.15	1.93	1.93	0.11	0.020
300 P/L	Total +	1.2 +2.46	±2.79	1.2 +2.06	±2.18	1.2 +3.18	±3.21	1.2 +1.29	±1.31	1.2 +1.15	±0.73	1.2 +2.51	±2.15	1.2 +2.50	±2.46	±0.24	±2.83	2.76 +2.44	±0.26	±0.10
Launch	Static	1.20	0	1.20	0	1.20	0	1.20	0	1.20	0	1.20	0	1.20	0	0	0	6.0	0	0
Case 7	Dyn +	+1.15	±2.38	+1.01	±0.61	+0.82	±0.58	+0.83	±0.54	+0.95	±0.46	+1.20	±0.58	+0.69	±0.46	±1.22	±7.30	+5.1	±1.13	±0.190
MM 6,7	Env	0.74	0.74	1.93	1.93	3.1	3.1	1.08	1.08	0.51	0.51	2.1	2.1	2.4	2.4	0.15	2.85	2.85	0.04	0.020
3K P/L	Total +	1.20 +1.37	±2.49	1.20 +2.18	2.02	1.20 +3.21	±3.15	1.20 +1.36	±1.21	1.20 +1.08	±0.70	1.20 +2.42	+2.18	1.20 +2.50	±2.44	±1.23	±7.84	6.0 +5.85	±1.13	±0.19
Launch	Static	1.20	0	1.20	0	1.20	0	1.20	0	1.20	0	1.20	0	1.20	0	0	0	6.0	0	0
with B.P.	Dyn +	+0.33	±0.38	+0.29	±0.16	+0.27	±0.12	+0.27	±0.11	+0.35	±0.08	+0.44	±0.09	+0.27	±0.08	±0.22	±1.40	+1.5	0.12	0.034
Case 1	Env	0.74	0.74	1.93	1.93	3.1	3.1	1.08	1.08	0.51	0.51	2.1	2.1	2.4	2.4	0.15	2.85	2.85	0.04	0.020
MM 2,3	Total +	1.20 +0.81	±0.83	1.20 +1.95	±1.94	1.20 +3.11	±3.10	1.20 +1.11	±1.09	1.20 +0.62	±0.52	1.20 +2.14	±2.10	1.20 +2.42	±2.40	±0.27	±3.18	6.0 +3.22	±0.13	±0.03
3K P/L																				
Flight	Static	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	0.14	1.11	9.50	1.10	0.46
Case 1	Dyn	0	1.14	0	0.30	0	0.28	0	0.27	0	0.25	0	0.22	0	0.26	0.56	3.78	0	0.49	0.14
MM 10	Env	0.74	0.74	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	2.85	2.85	0.23	0.22
3K P/L	Total	1.9 ±0.74	0.23 ±1.36	1.90 ±1.93	0.23 ±1.95	1.90 ±3.10	0.23 ±3.11	1.90 ±1.08	0.23 ±1.11	1.90 ±0.51	0.23 ±0.57	1.90 ±2.10	0.23 ±2.11	1.90 ±2.40	0.23 ±2.41	0.14 ±0.58	1.11 ±4.73	9.50 ±2.85	1.10 ±0.54	0.46 ±0.26
Flight	Static	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	0.14	1.11	9.50	1.09	0.45
Case 2	Dyn	0	1.16	0	0.30	0	0.28	0	0.27	0	0.23	0	0.20	0	0.24	0.61	3.91	0	0.48	0.14
MM 12	Env	0.74	0.74	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	2.85	2.85	0.23	0.22
3K P/L	Total	1.90 ±0.74	0.23 ±1.38	1.90 ±1.93	0.23 ±1.95	1.90 ±3.10	0.23 ±3.11	1.90 ±1.08	0.23 ±1.11	1.90 ±0.51	0.23 ±0.56	1.90 ±2.10	0.23 ±2.11	1.90 ±2.40	0.23 ±2.41	0.14 ±0.63	1.11 ±4.84	9.50 ±2.85	1.09 ±0.53	0.45 ±0.26
Flight	Static	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	0.14	1.11	9.50	1.13	0.48
Case 3	Dyn	0	1.05	0	0.29	0	0.27	0	0.26	0	0.27	0	0.24	0	0.28	0.55	3.56	0	0.53	0.17
MM 13	Env	0.74	0.74	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	2.85	2.85	0.23	0.22
3K P/L	Total	1.90 ±0.74	0.23 ±1.28	1.90 ±1.93	0.23 ±1.95	1.90 ±3.10	0.23 ±3.11	1.90 ±1.08	0.23 ±1.11	1.90 ±0.51	0.23 ±0.58	1.90 ±2.10	0.23 ±2.11	1.90 ±2.40	0.23 ±2.42	0.14 ±0.57	1.11 ±4.56	9.50 ±2.85	1.13 ±0.58	0.48 ±0.28
Flight	Static	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	0.04	0.50	4.37	1.05	0.46
Case 4	Dyn	0	1.05	0	0.73	0	0.67	0	0.64	0	0.47	0	0.45	0	0.48	0.14	1.73	0	0.34	0.13
MM 14	Env	2.32	2.32	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	1.93	1.93	0.25	0.22
300 P/L	Total	1.90 ±2.32	0.25 ±2.54	1.90 ±1.93	0.25 ±2.06	1.90 ±3.10	0.25 ±3.17	1.90 ±1.08	0.25 ±1.25	1.90 ±0.51	0.25 ±0.69	1.90 ±2.10	0.25 ±2.15	1.90 ±2.40	0.25 ±2.45	0.04 ±0.21	0.50 ±2.59	4.37 ±1.93	1.05 ±0.42	0.46 ±0.26

TABLE 2-1. TOTAL DESIGN LIMIT ACCELERATIONS, TRUSS LOADS AND CLEARANCES (CONTINUED)

Condition	Type Load	Payload (g's)		Payload Ring (g's)		Forward Ring (g's)		Hydrogen (g's)		LO_2 (g's)		Engine (g's)		Aft Ring (g's)		Truss Loads			Clearance Loss	
		Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Bending Moment (10^6 in.-lb)	Shear (10^3 lb)	Axial Force (10^3 lb)	P/L to N/F (in.)	Fwd Ring to N/F (in.)
Flight	Static	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	0.04	0.50	4.37	1.04	0.45
Case 5	Dyn	0	0.98	0	0.70	0	0.64	0	0.62	0	0.48	0	0.46	0	0.49	0.13	1.66	0	0.32	0.13
MM 15	Env	2.32	2.32	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	1.93	1.93	0.25	0.22
300 P/L	Total	1.90 ±2.32	0.25 ±2.52	1.90 ±1.93	0.25 ±2.05	1.90 ±3.10	0.25 ±3.16	1.90 ±1.08	0.25 ±1.24	1.90 ±0.51	0.25 ±0.70	1.90 ±2.10	0.25 ±2.15	1.90 ±2.40	0.25 ±2.45	0.04 ±0.20	0.50 ±2.54	4.37 ±1.93	1.04 ±0.41	0.45 ±0.26
Flight	Static	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	0.04	0.50	4.37	1.07	0.47
Case 6	Dyn	0	1.25	0	0.86	0	0.78	0	0.75	0	0.43	0	0.41	0	0.45	0.16	2.02	0	0.38	0.15
MM 16	Env	2.32	2.32	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	1.93	1.93	0.25	0.22
300 P/L	Total	1.90 ±2.32	0.25 ±2.64	1.90 ±1.93	0.25 ±2.11	1.90 ±3.10	0.25 ±3.20	1.90 ±1.08	0.25 ±1.32	1.90 ±0.51	0.25 ±0.67	1.90 ±2.10	0.25 ±2.14	1.90 ±2.40	0.25 ±2.44	0.04 ±0.22	0.50 ±2.79	4.37 ±1.93	1.07 ±0.45	0.47 ±0.27
Flight	Static	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	0.14	1.11	9.50	1.15	0.47
Case 7	Dyn	0	0.93	0	0.29	0	0.30	0	0.30	0	0.28	0	0.24	0	0.29	0.48	2.95	0	0.58	0.14
MM 17	Env	0.74	0.74	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	2.85	2.85	0.23	0.22
3K P/L	Total	1.90 ±0.74	0.23 ±1.19	1.90 ±1.93	0.23 ±1.95	1.90 ±3.10	0.23 ±3.11	1.90 ±1.08	0.23 ±1.12	1.90 ±0.51	0.23 ±0.58	1.90 ±2.10	0.23 ±2.11	1.90 ±2.40	0.23 ±2.42	0.14 ±0.50	1.11 ±4.10	9.50 ±2.85	1.15 ±0.62	0.47 ±0.26
Flight	Static	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	0.14	1.11	9.50	1.14	0.46
Case 8	Dyn	0	0.96	0	0.29	0	0.30	0	0.30	0	0.27	0	0.24	0	0.28	0.50	3.09	0	0.55	0.13
MM 18	Env	0.74	0.74	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	2.85	2.85	0.23	0.22
3K P/L	Total	1.90 ±0.74	0.23 ±1.23	1.90 ±1.93	0.23 ±1.95	1.90 ±3.10	0.23 ±3.11	1.90 ±1.08	0.23 ±1.12	1.90 ±0.51	0.23 ±0.58	1.90 ±2.10	0.23 ±2.11	1.90 ±2.40	0.23 ±2.42	0.14 ±0.52	1.11 ±4.20	9.50 ±2.85	1.14 ±0.60	0.46 ±0.26
Flight	Static	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	0.14	1.11	9.50	1.21	0.48
Case 9	Dyn	0	0.82	0	0.28	0	0.30	0	0.30	0	0.29	0	0.25	0	0.30	0.42	2.63	0	0.68	0.16
MM 19	Env	0.74	0.74	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	2.85	2.85	0.23	0.22
3K P/L	Total	1.90 ±0.74	0.23 ±1.10	1.90 ±1.93	0.23 ±1.95	1.90 ±3.10	0.23 ±3.11	1.90 ±1.08	0.23 ±1.12	1.90 ±0.51	0.23 ±0.59	1.90 ±2.10	0.23 ±2.11	1.90 ±2.40	0.23 ±2.42	0.14 ±0.45	1.11 ±3.88	9.50 ±2.85	1.21 ±0.72	0.48 ±0.27
Flight	Static	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	0.14	1.11	9.50	1.06	0.45
Case 1s	Dyn	0	0.87	0	0.44	0	0.38	0	0.37	0	0.26	0	0.24	0	0.27	0.49	3.57	0	0.41	0.15
MM 22	Env	0.74	0.74	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	2.85	2.85	0.23	0.22
3K P/L	Total	1.90 ±0.74	0.23 ±1.14	1.90 ±1.93	0.23 ±1.98	1.90 ±3.10	0.23 ±3.12	1.90 ±1.08	0.23 ±1.14	1.90 ±0.51	0.23 ±0.57	1.90 ±2.10	0.23 ±2.11	1.90 ±2.40	0.23 ±2.41	0.14 ±0.51	1.11 ±4.57	9.50 ±2.85	1.06 ±0.47	0.45 ±0.27
Flight	Static	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	0.14	1.11	9.50	1.05	0.45
Case 2s	Dyn	0	0.82	0	0.44	0	0.39	0	0.37	0	0.28	0	0.26	0	0.29	0.47	3.43	0	0.39	0.14
MM 24	Env	0.74	0.74	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	2.85	2.85	0.23	0.22
3K P/L	Total	1.90 ±0.74	0.23 ±1.10	1.90 ±1.93	0.23 ±1.98	1.90 ±3.10	0.23 ±3.12	1.90 ±1.08	0.23 ±1.14	1.90 ±0.51	0.23 ±0.58	1.90 ±2.10	0.23 ±2.12	1.90 ±2.40	0.23 ±2.42	0.14 ±0.49	1.11 ±4.46	9.50 ±2.85	1.05 ±0.45	0.45 ±0.26
Flight	Static	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	0.14	1.11	9.50	1.07	0.45
Case 3s	Dyn	0	0.99	0	0.43	0	0.38	0	0.36	0	0.23	0	0.21	0	0.23	0.55	3.90	0	0.44	0.16
MM 25	Env	0.74	0.74	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	2.85	2.85	0.23	0.22
3K P/L	Total	1.90 ±0.74	0.23 ±1.24	1.90 ±1.93	0.23 ±1.98	1.90 ±3.10	0.23 ±3.12	1.90 ±1.08	0.23 ±1.14	1.90 ±0.51	0.23 ±0.56	1.90 ±2.10	0.23 ±2.11	1.90 ±2.40	0.23 ±2.41	0.14 ±0.57	1.11 ±4.83	9.50 ±2.85	1.07 ±0.50	0.45 ±0.27
Flight	Static	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	0.04	0.50	4.37	1.04	0.45
Case 4s	Dyn	0	0.88	0	0.66	0	0.61	0	0.60	0	0.48	0	0.45	0	0.50	0.12	1.58	0	0.32	0.13
MM 26	Env	2.32	2.32	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	1.93	1.93	0.25	0.22
300 P/L	Total	1.90 ±2.32	0.25 ±2.48	1.90 ±1.93	0.25 ±2.04	1.90 ±3.10	0.25 ±3.16	1.90 ±1.08	0.25 ±1.24	1.90 ±0.51	0.25 ±0.70	1.90 ±2.10	0.25 ±2.15	1.90 ±2.40	0.25 ±2.45	0.04 ±0.19	0.50 ±2.49	4.37 ±1.93	1.04 ±0.41	0.46 ±0.26

TABLE 2-1. TOTAL DESIGN LIMIT ACCELERATIONS, TRUSS LOADS AND CLEARANCES (CONTINUED)

Condition	Type Load	Payload (g's)		Payload Ring (g's)		Forward Ring (g's)		Hydrogen (g's)		LO_2 (g's)		Engine (g's)		Aft Ring (g's)		Truss Loads			Clearance Loss	
		Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Bending Moment (10^6 in.-lb)	Shear (10^3 lb)	Axial Force (10^3 lb)	P/L to N/F (in.)	Fwd Ring to N/F (in.)
Flight	Static	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	0.04	0.50	4.37	1.03	0.45
Case 5a	Dyn	0	0.86	0	0.65	0	0.60	0	0.58	0	0.49	0	0.45	0	0.50	0.12	1.56	0	0.32	0.12
MM27	Env	2.32	2.32	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	1.93	1.93	0.25	0.22
300 P/L	Total	1.90 ±2.32	0.25 ±2.47	1.90 ±1.93	0.25 ±2.04	1.90 ±3.10	0.25 ±3.16	1.90 ±1.08	0.25 ±1.22	1.90 ±0.51	0.25 ±0.71	1.90 ±2.10	0.25 ±2.15	1.90 ±2.40	0.25 ±2.45	0.04 ±0.19	0.50 ±2.48	4.37 ±1.93	1.03 ±0.41	0.45 ±0.25
Flight	Static	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	1.90	0.25	0.04	0.50	4.37	1.05	0.45
Case 6a	Dyn	0	0.92	0	0.69	0	0.64	0	0.62	0	0.48	0	0.44	0	0.49	0.12	1.64	0	0.33	0.13
MM 28	Env	2.32	2.32	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	1.93	1.93	0.25	0.22
300 P/L	Total	1.90 ±2.32	0.25 ±2.50	1.90 ±1.93	0.25 ±2.05	1.90 ±3.10	0.25 ±3.16	1.90 ±1.08	0.25 ±1.24	1.90 ±0.51	0.25 ±0.70	1.90 ±2.10	0.25 ±2.15	1.90 ±2.40	0.25 ±2.45	0.04 ±0.19	0.50 ±2.53	4.37 ±1.93	1.05 ±0.41	0.45 ±0.26
Flight	Static	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	0.14	1.11	9.50	1.00	0.45
Case 7a	Dyn	0	1.13	0	0.37	0	0.28	0	0.27	0	0.22	0	0.19	0	0.23	0.61	4.00	0	0.46	0.15
MM 29	Env	0.74	0.74	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	2.85	2.85	0.23	0.22
3K P/L	Total	1.90 ±0.74	0.23 ±1.35	1.90 ±1.93	0.23 ±1.96	1.90 ±3.10	0.23 ±3.11	1.90 ±1.08	0.23 ±1.11	1.90 ±0.51	0.23 ±0.56	1.90 ±2.10	0.23 ±2.11	1.90 ±2.40	0.23 ±2.41	0.14 ±0.63	1.11 ±4.91	9.50 ±2.85	1.08 ±0.52	0.45 ±0.27
Flight	Static	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	0.14	1.11	9.50	1.07	0.45
Case 8a	Dyn	0	1.08	0	0.40	0	0.29	0	0.27	0	0.22	0	0.19	0	0.23	0.59	3.94	0	0.45	0.14
MM 30	Env	0.74	0.74	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	2.85	2.85	0.23	0.22
3K P/L	Total	1.90 ±0.74	0.23 ±1.31	1.90 ±1.93	0.23 ±1.97	1.90 ±3.10	0.23 ±3.11	1.90 ±1.08	0.23 ±1.11	1.90 ±0.51	0.23 ±0.56	1.90 ±2.10	0.23 ±2.11	1.90 ±2.40	0.23 ±2.41	0.14 ±0.61	1.11 ±4.86	9.50 ±2.85	1.07 ±0.51	0.45 ±0.26
Flight	Static	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	0.14	1.11	9.50	1.00	0.45
Case 9a	Dyn	0	1.15	0	0.30	0	0.27	0	0.27	0	0.24	0	0.21	0	0.25	0.60	3.89	0	0.46	0.15
MM 31	Env	0.74	0.74	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	2.85	2.85	0.23	0.22
3K P/L	Total	1.90 ±0.74	0.23 ±1.37	1.90 ±1.93	0.23 ±1.95	1.90 ±3.10	0.23 ±3.11	1.90 ±1.08	0.23 ±1.11	1.90 ±0.51	0.23 ±0.56	1.90 ±2.10	0.23 ±2.11	1.90 ±2.40	0.23 ±2.41	0.14 ±0.63	1.11 ±4.82	9.50 ±2.85	1.09 ±0.53	0.45 ±0.27
Flight	Static	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	0.48	8.87	9.50	0.655	0.00
Case 1	Dyn	0	0.96	0	0.32	0	0.30	0	0.29	0	0.24	0	0.23	0	0.25	0.40	9.02	0	0.28	0.04
MM 32	Env	0.74	0.74	1.93	1.93	3.10	5.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.05	1.00	2.85	0.23	0
3K P/L	Total	1.90 ±0.74	0.23 ±1.31	1.90 ±1.93	0.23 ±1.96	1.90 ±3.10	0.23 ±5.11	1.90 ±1.08	0.23 ±1.12	1.90 ±0.51	0.23 ±0.56	1.90 ±2.10	0.23 ±2.11	1.90 ±2.40	0.23 ±2.41	0.48 ±0.40	8.87 ±9.08	9.50 ±2.85	0.655 ±0.36	0.00 ±0.04
Flight	Static	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	1.90	0.23	0.46	8.62	9.50	0.65	0.00
Case 7	Dyn	0	0.82	0	0.31	0	0.32	0	0.32	0	0.26	0	0.24	0	0.28	0.31	8.74	0	0.38	0.04
MM 33	Env	0.74	0.74	1.93	1.93	3.10	5.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.05	1.00	2.85	0.23	0
3K P/L	Total	1.90 ±0.74	0.23 ±1.10	1.90 ±1.93	0.23 ±1.95	1.90 ±3.10	0.23 ±5.11	1.90 ±1.08	0.23 ±1.13	1.90 ±0.51	0.23 ±0.57	1.90 ±2.10	0.23 ±2.11	1.90 ±2.40	0.23 ±2.42	0.46 ±0.31	8.62 ±8.80	9.50 ±2.85	0.65 ±0.44	0.00 ±0.04
Max	Static	5.8	0.1	5.8	0.1	5.8	0.1	5.8	0.1	5.8	0.1	5.8	0.1	5.8	0.1	0.08	0.50	29.0	0.06	0.02
Boost	Dyn	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Accel	Env	0.37	0.37	0.96	0.96	1.53	1.53	0.54	0.54	0.26	0.26	1.03	1.03	1.18	1.18	0.08	1.43	1.43	0.06	0.01
3K P/L	Total	5.8 ±0.37	0.1 ±0.37	5.8 ±0.96	0.1 ±0.96	5.8 ±1.53	0.1 ±1.53	5.8 ±0.54	0.1 ±0.54	5.8 ±0.26	0.1 ±0.26	5.8 ±1.18	0.1 ±1.18	5.8 ±1.03	0.1 ±1.03	0.08 ±0.08	0.50 ±1.43	29.0 ±1.43	0.06 ±0.06	0.02 ±0.01

TABLE 2-1. TOTAL DESIGN LIMIT ACCELERATIONS, TRUSS LOADS AND CLEARANCES (CONTINUED)

Condition	Type Load	Payload (g's)		Payload Ring (g's)		Forward Ring (g's)		Hydrogen (g's)		LO_2 (g's)		Engine (g's)		Aft Ring (g's)		Truss Loads			Clearance Loss	
		Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Bending Moment (10^6 in.-lb)	Shear (10^3 lb)	Axial Force (10^3 lb)	P/L to N/F (in.)	Fwd Ring to N/F (in.)
CMECO 1	Static	1.67/0	0	1.67/0	0	1.67/0	0	1.67/0	0	1.67/0	0	1.67/0	0	1.67/0	0	0	0	8.35/0		
Case 1	Dyn +	+0.42	±0.30*	+0.06	±0.36*	+0.18	±0.32*	+0.53	±0.32*	+0.05	±0.20*	+1.06	±0.35*	+0.09	±0.20*	±0.16*	±1.02*	+0.26	Nose Fairing	
MM 34	Dyn-	-2.60	—	-0.95	—	-1.23	—	-1.65	—	-1.14	—	-4.34	—	-1.06	—	—	—	-6.24	Jettisoned	
3K P/L	Env	0.74	0.74	1.93	1.93	3.1	3.1	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	2.85	-2.85		
	Total +	1.67 +0.85	±0.80*	1.67 +1.93	±1.96*	1.67 +3.1	±3.12*	1.67 +1.20	±1.13*	1.67 +0.51	±0.55*	1.67 +2.35	±2.13*	1.67 +2.40	±2.41*	±0.22*	±3.03*	8.35 +2.86		
	Total -	0 -2.70	—	0 -2.15	—	0 -3.30	—	0 -1.97	—	0 -1.25	—	0 -4.82	—	0 -2.62	—	—	—	0 -6.86		
CMECO 1	Static	1.96/0	0	1.96/0	0	1.96/0	0	1.96/0	0	1.96/0	0	1.96/0	0	1.96/0	0	0	0	4.51/0		
Case 4	Dyn +	+3.35	±0.30*	+0.45	±0.36*	+0.40	±0.32*	+0.50	±0.32*	+0.07	±0.20*	+0.94	±0.35*	+0.07	±0.20*	±0.16*	±1.02*	+0.133		
MM 36	Dyn -	-5.62	—	-1.98	—	-1.52	—	-1.86	—	-1.51	—	-5.24	—	-1.13	—	—	—	-3.99		
300 P/L	Env	2.32	2.32	1.93	1.93	3.1	3.1	1.08	1.08	0.51	0.51	2.4	2.4	2.1	2.1	0.15	1.93	1.93		
	Total +	1.96 +4.07	±2.34*	1.96 +1.98	±1.96*	1.96 +3.12	±3.12*	1.96 +1.19	±1.13*	1.96 +0.51	±0.55*	1.96 +2.58	±2.42*	1.96 +2.10	±2.11*	±0.22*	±2.18*	4.51 +1.93		
	Total -	0 -6.06	—	0 -2.76	—	0 -3.45	—	0 -2.15	—	0 -1.59	—	0 -5.76	—	0 -2.39	—	—	—	0 -4.43		
CMES 2	Static	0/1.67	0	0/1.67	0	0/1.67	0	0/1.67	0	0/1.67	0	0/1.67	0	0/1.67	0	0	0	0/8.35		
Case 1	Dyn +	+0.36	±0.05	+0.27	±0.05	+0.24	±0.04	+0.25	±0.04	+0.25	±0.04	+0.39	±0.06	+0.24	±0.04	±0.03	±0.16	+1.35		
MM 34, 35	Dyn -	0	—	0	—	0	—	0	—	0	—	0	—	0	—	—	—	0		
3K P/L	Env	0.74	0.74	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	2.85	2.85		
	Total +	1.67 +0.82	±0.74	1.67 +1.95	±1.93	1.67 +3.11	±3.10	1.67 +1.11	±1.08	1.67 +0.57	±0.51	1.67 +2.14	±2.10	1.67 +2.41	±2.40	±0.15	±2.85	8.35 +3.15		
	Total -	0 -0.74	—	0 -1.93	—	0 -3.10	—	0 -1.08	—	0 -0.51	—	0 -2.10	—	0 -2.40	—	—	—	0 -2.85		
CMES 2	Static	0/1.96	0	0/1.96	0	0/1.96	0	0/1.96	0	0/1.96	0	0/1.96	0	0/1.96	0	0	0	0/4.51		
Case 4	Dyn +	+0.76	±0.05*	+0.67	±0.05*	+0.62	±0.04*	+0.66	±0.04*	+0.61	±0.04*	+0.85	±0.06*	+0.60	±0.04*	±0.03*	±0.16*	+0.37		
MM 36	Dyn -	0	—	0	—	0	—	0	—	0	—	0	—	0	—	—	—	0		
300 P/L	Env	2.32	2.32	1.93	1.93	3.1	3.1	1.08	1.08	0.51	0.51	2.4	2.4	2.1	2.1	0.15	1.93	1.93		
	Total +	1.96 +2.44	±2.32*	1.96 +2.04	±1.93*	1.96+3.16	±3.1*	1.96 +1.27	±1.08*	1.96 +0.80	±0.51*	1.96 +2.55	±2.4*	1.96 +2.18	±2.1*	±0.15*	±1.94*	4.51 +1.96		
	Total -	0 -2.32	—	0 -1.93	—	0 -3.10	—	0 -1.08	—	0 -0.51	—	0 -2.4	—	0 -2.1	—	—	—	0 -1.93		
CMES 2	Static	0/1.67	0	0/1.67	0	0/1.67	0	0/1.67	0	0/1.67	0	0/1.67	0	0/1.67	0	0	0	0/8.35		
Case 7	Dyn +	+0.31	±0.05*	+0.27	±0.05*	+0.31	±0.04*	+0.35	±0.04*	+0.28	±0.04*	+0.46	±0.06*	+0.25	±0.04*	±0.03*	±0.16*	+1.10		
MM 37	Dyn -	0	—	0	—	0	—	0	—	0	—	0	—	0	—	—	—	0		
3K P/L	Env	0.74	0.74	1.93	1.93	3.1	3.1	1.08	1.08	0.51	0.51	2.4	2.4	2.1	2.1	0.15	2.85	2.85		
	Total +	1.67 +0.80	±0.74*	1.67 +1.95	±1.93*	1.67 +3.12	±3.1*	1.67 +1.14	±1.08*	1.67 +0.58	±0.51*	1.67 +2.56	±2.4*	1.67 +2.11	±2.1*	±0.15*	±2.85*	8.35 +3.05		
	Total -	0 +0.74	—	0 -1.93	—	0 -3.1	—	0 -1.08	—	0 -0.51	—	0 -2.4	—	0 -2.1	—	—	—	0 -2.85		
CMECO 2	Static	1.82/0	0	1.82/0	0	1.82/0	0	1.82/0	0	1.82/0	0	1.82/0	0	1.82/0	0	0	0	9.10/0		
Case 1	Dyn +	+0.45	±0.30	+0.12	±0.36	+0.95	±0.32	+1.59	±0.32	+0.12	±0.20	+1.38	±0.35	+0.71	±0.20	±0.16	±1.02	+0.32		
MM 38, 39	Dyn -	-2.77	—	-1.16	—	-1.50	—	-1.94	—	-1.08	—	-5.18	—	-1.30	—	—	—	-5.66		
3K P/L	Env	0.74	0.74	1.93	1.93	3.10	3.10	1.08	1.08	0.51	0.51	2.10	2.10	2.40	2.40	0.15	2.85	2.85		
	Total +	1.82 +0.87	±0.80	1.82 +1.93	±1.96	1.82 +3.10	±3.12	1.82 +2.51	±1.13	1.82 +0.51	±0.55	1.82 +2.51	±2.13	1.82 +2.50	±2.41	±0.22	±3.03	9.10 +2.87	Nose Fairing	
	Total -	0 -2.87	—	0 -2.25	—	0 -3.44	—	0 -2.22	—	0 -1.19	—	0 -5.59	—	0 -2.73	—	—	—	0 -6.34	Jettisoned	

TABLE 2-1. TOTAL DESIGN LIMIT ACCELERATIONS, TRUSS LOADS AND CLEARANCES (CONTINUED)

Condition	Type Load	Payload (g's)		Payload Ring (g's)		Forward Ring (g's)		Hydrogen (g's)		LO_2 (g's)		Engine (g's)		Aft Ring (g's)		Truss Loads			Clearance Loss	
		Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Bending Moment (10^6 in.-lb)	Shear (10^3 lb)	Axial Force (10^3 lb)	P/L to N/F (in.)	Fwd Ring to N/F (in.)
CMECO 2	Static	2.18/0	0	2.18/0	0	2.18/0	0	2.18/0	0	2.18/0	0	2.18/0	0	2.18/0	0	0	0	5.02/0	Nose Fairing	
Case 4	Dyn +	+5.59	±0.30*	+0.83	±0.36*	+0.46	±0.32*	+0.98	±0.32*	+0.18	±0.20*	+1.44	±0.35*	+0.16	±0.20*	±0.16*	±1.02*	+1.0	Jettisoned	
MM 40	Dyn -	-7.72	—	-2.46	—	-1.68	—	-2.04	—	-1.43	—	-5.60	—	-1.29	—	—	—	-5.87		
300 P/L	Env	2.32	2.32	1.93	1.93	3.1	3.1	1.08	1.08	0.51	0.51	2.4	2.4	2.10	2.10	0.15	1.93	1.93		
	Total +	2.18 +6.05	±2.34*	2.18 +2.10	±1.96*	2.18 +3.14	±3.12*	2.18 +1.46	±1.13*	2.18 +0.54	±0.55*	2.18 +2.80	±2.42*	2.18 +2.10	±2.11*	±0.22*	±2.18	5.02 +2.17		
	Total -	0 -8.06	—	0 -3.12	—	0 -3.53	—	0 -2.31	—	0 -1.52	—	0 -6.10	—	0 -2.46	—	—	—	0 -6.18		
CMECO 2	Static	1.82/0	0	1.82/0	0	1.82/0	0	1.82/0	0	1.82/0	0	1.82/0	0	1.82/0	0	0	0	9.10/0		
Case 7	Dyn +	+0.12	±0.30*	+0.12	±0.36*	+1.06	±0.32*	+1.67	±0.32*	+0.12	±0.20*	+2.69	±0.35*	+0.12	±0.20*	±0.16*	±1.02*	+0.09		
MM 41	Dyn -	-2.03	—	-0.90	—	-1.95	—	-2.25	—	-1.39	—	-4.35	—	-1.81	—	—	—	-4.44		
3K P/L	Env	0.74	0.74	1.93	1.93	3.1	3.1	1.08	1.08	0.51	0.51	2.4	2.4	2.1	2.1	0.15	2.85	2.85		
	Total +	1.82 +0.75	±0.80*	1.82 +1.93	±1.96*	1.82 +3.28	±3.16*	1.82 +1.99	±1.13*	1.82 +0.52	±0.55*	1.82 +3.61	±2.43*	1.82 +2.10	±2.11*	0 ±0.22*	0 ±3.03*	9.10 +2.85		
	Total -	0 -2.16	—	0 -2.13	—	0 -3.66	—	0 -2.50	—	0 -1.48	—	0 -4.97	—	0 -2.77	—	—	—	0 -5.28		
KMES 1	Static	0/1.27	0	0/1.27	0	0/1.27	0	0/1.27	0	0/1.27	0	0/1.27	0	0/1.27	0	0	0	0/6.35		
Case 1	Dyn +	+0.41	±0.10*	+0.36	±0.10*	+0.34	±0.10*	+0.39	±0.10*	+0.30	±0.10*	+0.54	±0.10*	+0.28	±0.10*	±0.05*	±0.33*	+1.49		
MM 42	Dyn -	-0	—	-0	—	-0	—	-0.11	—	-0	—	-0	—	-0.11	—	—	—	-0		
3K P/L	Env	0.58	0.58	1.52	1.52	2.40	2.40	0.85	0.85	0.41	0.41	3.00	3.00	1.87	1.87	0.15	2.25	2.25		
	Total +	1.27 +0.71	±0.58*	1.27 +1.56	±1.52*	1.27 +2.42	±2.40*	1.27 +0.94	±0.86*	1.27 +0.51	±0.42*	1.27 +3.05	±3.00*	1.27 +1.87	±1.87*	±0.16*	±2.27*	6.35 +8.16		
	Total -	0 -0.58	—	0 -1.52	—	0 -2.40	—	0 -0.85	—	0 -0.41	—	0 -3.0	—	0 -1.87	—	—	—	0 -2.25		
KMES 1	Static	0/1.65	0	0/1.65	0	0/1.65	0	0/1.65	0	0/1.65	0	0/1.65	0	0/1.65	0	0	0	0/3.80		
Case 4	Dyn +	+1.15	±0.1*	+0.47	±0.1*	+0.42	±0.1*	+0.53	±0.1*	+0.29	±0.1*	+0.63	±0.1*	+0.36	±0.1*	±0.05*	±0.33*	+1.21		
MM 43	Dyn -	-0.07	—	-0.05	—	-0	—	-0.05	—	-0	—	-0.37	—	-0	—	—	—	-0		
300 P/L	Env	1.84	1.84	1.52	1.52	2.4	2.4	0.85	0.85	0.41	0.41	3.0	3.0	1.87	1.87	0.13	1.53	1.53		
	Total +	1.65 +2.15	±1.84*	1.65 +1.59	±1.52*	1.65 +2.44	±2.4*	1.65 +1.00	±0.86*	1.65 +0.50	±0.42*	1.65 +3.07	±3.0*	1.65 +1.90	±1.87*	0 ±0.14*	0 ±1.56*	3.80 +1.95		
	Total -	0 -1.84	—	0 -1.52	—	0 -0	—	0 -0.85	—	0 -0.41	—	0 -3.02	—	0 -1.87	—	—	—	0 -1.53		
KMES 1	Static	0/1.27	0	0/1.27	0	0/1.27	0	0/1.27	0	0/1.27	—	0/1.27	—	0/1.27	—	0	0	0/6.35		
Case 7	Dyn +	+0.67	±0.1*	+0.51	±0.1*	+0.51	±0.1*	+0.62	±0.1*	+0.42	±0.1*	+1.22	±0.1*	+0.35	±0.1*	±0.05*	±0.33*	+2.29		
MM 44	Dyn -	0	—	-0	—	-0.04	—	-0.10	—	-0	—	-0.32	—	-0	—	—	—	-0		
3K P/L	Env	0.58	0.58	1.52	1.52	2.4	2.4	0.85	0.85	0.41	0.41	3.0	3.0	1.87	1.87	0.15	2.25	2.25		
	Total +	1.27 +0.89	±0.59*	1.27 +1.60	±1.52*	1.27 +2.45	±2.4*	1.27 +1.05	±0.86*	1.27 +0.59	±0.42*	1.27 +3.24	±3.0*	1.27 +1.90	±1.87*	±0.16*	±2.27*	6.35 +3.21		
	Total -	0 -0.58	—	0 -1.52	—	0 -2.4	—	0 -0.86	—	0 -0.41	—	0 -3.02	—	0 -1.87	—	—	—	0 -2.25		
KMECO 1	Static	2.10/0	0	2.10/0	0	2.10/0	0	2.10/0	0	2.10/0	0	2.10/0	0	2.10/0	0	0	0	8.86/0		
Case 1	Dyn +	+0.29	±0.15*	+0.37	±0.15*	+1.43	±0.15*	+1.71	±0.15*	+0.55	±0.15*	+3.91	±0.15*	+1.47	±0.15*	±0.01*	±0.08*	+0.36		
MM 45	Dyn -	-3.30	—	-1.65	—	-2.79	—	-3.03	—	-2.31	—	-7.86	—	-2.49	—	—	—	-6.37		
3K P/L	Env	0.58	0.58	1.52	1.52	2.4	2.4	1.29	1.29	0.67	0.67	3.0	3.0	1.87	1.87	0.15	2.22	2.22		
	Total +	2.10 +0.65	±0.60*	2.10 +1.56	±1.53*	2.10 +2.79	±2.40*	2.10 +2.14	±1.30*	2.10 +0.87	±0.69*	2.10 +4.93	±3.0*	2.10 +2.38	±1.88*	±0.15*	±2.22*	8.86 +2.25	Nose Fairing	
	Total -	0 -3.35	—	0 -2.24	—	0 -3.68	—	0 -3.29	—	0 -2.41	—	0 -8.41	—	0 -3.11	—	—	—	0 -6.75	Jettisoned	

TABLE 2-1. TOTAL DESIGN LIMIT ACCELERATIONS, TRUSS LOADS AND CLEARANCES (CONTINUED)

Condition	Type Load	Payload (g's)		Payload Ring (g's)		Forward Ring (g's)		Hydrogen (g's)		LO_2 (g's)		Engine (g's)		Aft Ring (g's)		Truss Loads			Clearance Loss	
		Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Longt'l.	Lat'l.	Bending Moment (10^6 in.-lb)	Shear (10^3 lb)	Axial Force (10^3 lb)	P/L to N/F (in.)	Fwd Ring to N/F (in.)
KMECO 1	Static	3.38/0	0	3.38/0	0	3.38/0	0	3.38/0	0	3.38/0	0	3.38/0	0	3.38/0	0	0	0	5.14/0	Nose Fairing	
Case 4	Dyn +	+5.14	±0.15*	+0.46	±0.15*	+0.42	±0.15*	+0.74	±0.15*	+0.13	±0.15*	+4.32	±0.15*	+0.31	±0.15*	±0.01*	±0.08*	+0.41	Jettisoned	
MM 45A	Dyn -	-7.49	—	-4.15	—	-3.35	—	-3.69	—	-1.17	—	-6.10	—	-2.49	—	—	—	-4.45		
300 P/L	Env	1.84	1.84	1.52	1.52	2.4	2.4	1.29	1.29	0.67	0.67	3.0	3.0	1.87	1.87	0.11	1.24	1.24		
	Total +	3.38 +5.46	±1.85*	3.38 +1.59	±1.53*	3.38 +2.44	±2.40*	3.38 +1.49	±1.30*	3.38 +0.68	±0.69*	3.38 +5.26	±3.0*	3.38 +1.89	±1.88*	±0.11*	±1.24*	5.14 +1.31		
	Total -	0 -7.71	—	0 -4.42	—	0 -4.12	—	0 -3.91	—	0 -1.35	—	0 -6.80	—	0 -3.11	—	—	—	0 -4.62		
KMES 2	Static	0/2.10	0	0/2.10	0	0/2.10	0	0/2.10	0	0/2.10	0	0/2.10	0	0/2.10	0	0	0	0/8.86		
Case 1	Dyn +	+0.55	±0.1*	+0.46	±0.1*	+0.48	±0.1*	+0.53	±0.1*	+0.57	±0.1*	+0.59	±0.1*	+0.55	±0.1*	±0.05*	±0.33*	+1.85		
MM 45	Dyn -	-0	—	-0	—	-0	—	-0	—	-0	—	-0.05	—	-0	—	—	—	-0		
3K P/L	Env	0.58	0.58	1.52	1.52	2.40	2.40	1.29	1.29	0.67	0.67	3.0	3.0	1.87	1.87	0.15	2.22	2.22		
	Total +	2.10 +0.80	±0.59*	2.10 +1.59	±1.52*	2.10 +2.45	±2.40*	2.10 +1.39	±1.29*	2.10 +0.88	±0.68*	2.10 +3.06	±3.00*	2.10 +1.95	±1.87*	±0.16*	±2.24*	8.86 +2.89		
	Total -	0 -0.58	—	0 -1.52	—	0 -2.40	—	0 -1.29	—	0 -0.67	—	0 -3.0	—	0 -1.87	—	—	—	0 -2.22		
KMECO 2	Static	3.13/0	0	3.13/0	—	3.13/0	—	3.13/0	—	3.13/0	—	3.13/0	—	3.13/0	—	0	0	11.99/0		
Case 1	Dyn +	+0.13	±0.15*	+0.13	±0.15*	+2.13	±0.15*	+2.38	±0.15*	+4.13	±0.15*	+7.18	±0.15*	+2.96	±0.15*	±0.01*	±0.08*	+0.50		
MM 46	Dyn -	-3.18	—	-1.85	—	-3.56	—	-3.67	—	-5.57	—	-12.38	—	-4.07	—	—	—	-6.28		
3K P/L	Env	0.58	0.58	1.52	1.52	2.4	2.4	2.1	2.1	1.87	1.87	3.0	3.0	1.87	1.87	0.13	1.46	1.46		
	Total +	3.13 +0.60	±0.60*	3.13 +1.52	±1.53*	3.13 +3.21	±2.40*	3.13 +2.48	±2.10*	3.13 +4.53	±1.88*	3.13 +7.78	±3.0*	3.13 +3.50	±1.88*	±0.13*	±1.46*	11.99 +1.54		
	Total -	0 -3.23	—	0 -2.39	—	0 -4.29	—	0 -4.23	—	0 -5.88	—	0 -12.74	—	0 -4.54	—	—	—	0 -6.45		
KMECO 2	Static	7.18/0	0	7.18/0	0	7.18/0	0	7.18/0	0	7.18/0	0	7.18/0	0	7.18/0	0	0	0	8.12/0		
Case 4	Dyn +	+2.81	±0.15*	+0.28	±0.15*	+0.28	±0.15*	+0.28	±0.15*	+0.28	±0.15*	+3.48	±0.15*	+0.28	±0.15*	±0.01*	±0.08*	+0.36		
MM 46A	Dyn -	-8.97	—	-4.15	—	-3.87	—	-3.93	—	-2.02	—	-8.31	—	-3.43	—	—	—	-3.48		
300 P/L	Env	1.84	1.84	1.52	1.52	2.4	2.4	2.10	2.10	1.87	1.87	3.0	3.0	1.87	1.87	0.09	1.06	1.06		
	Total +	7.18 +3.36	±1.85*	7.18 +1.54	±1.53*	7.18 +2.42	±2.4*	7.18 +2.12	±2.10*	7.18 +1.89	±1.88*	7.18 +4.59	±3.0*	7.18 +1.89	±1.88*	±0.09*	±1.06*	8.12 +1.12		
	Total -	0 -9.16	—	0 -4.42	—	0 -4.55	—	0 -4.46	—	0 -2.75	—	0 -8.84	—	0 -3.91	—	—	—	0 -3.64		
KMECO 2	Static	7.18/0	0	7.18/0	0	7.18/0	0	7.18/0	0	7.18/0	0	7.18/0	0	7.18/0	0	0	0	8.12/0		
Case 4	Dyn +	+0.28	±0.15*	+0.28	±0.15*	+0.28	±0.15*	+0.28	±0.15*	+0.28	±0.15*	+4.63	±0.15*	+0.28	±0.15*	±0.01*	±0.08*	+0.33		
MM 46B	Dyn -	-5.47	—	-3.81	—	-1.85	—	-1.94	—	-2.25	—	-10.02	—	-1.16	—	—	—	-3.78		
300 P/L	Env	1.84	1.84	1.52	1.52	2.4	2.4	2.1	2.1	1.87	1.87	3.0	3.0	1.87	1.87	0.09	1.06	1.06		
(Stiff	Total +	7.18 +1.86	±1.85*	7.18 +1.54	±1.53*	7.18 +2.42	±2.40*	7.18 +2.12	±2.10*	7.18 +1.89	±1.88*	7.18 +5.52	±3.0*	7.18 +1.89	±1.88*	±0.09*	±1.06*	8.12 +1.11		
P/L)	Total -	0 -5.78	—	0 -4.10	—	0 -3.03	—	0 -2.86	—	0 -2.93	—	0 -10.46	—	0 -2.20	—	—	—	0 -3.93		
KMECO 2	Static	3.13/0	0	3.13/0	0	3.13/0	0	3.13/0	0	3.13/0	0	3.13/0	0	3.13/0	0	0	0	11.99/0		
Case 1	Dyn +	+0.13	±0.15*	+0.13	±0.15*	+1.54	±0.15*	+1.53	±0.15*	+1.88	±0.15*	+2.79	±0.15*	+1.96	±0.15*	±0.01*	±0.08*	+0.50		
MM 46C	Dyn -	-2.12	—	-1.85	—	-3.54	—	-3.82	—	-4.33	—	-6.56	—	-3.79	—	—	—	-3.18		
3K P/L	Env	0.58	0.58	1.52	1.52	2.4	2.4	2.1	2.1	1.87	1.87	3.0	3.0	1.87	1.87	0.13	1.46	1.46		
(Stiff	Total +	3.13 +0.59	±0.60*	3.13 +1.53	±1.53*	3.13 +2.85	±2.40*	3.13 +2.60	±2.10*	3.13 +2.65	±1.88*	3.13 +4.10	±3.0*	3.13 +2.71	±1.88*	±0.13*	±1.46*	11.99 +1.54	Nose Fairing	
Beam)	Total -	0 -2.20	—	0 -2.40	—	0 -4.28	—	0 -4.36	—	0 -4.72	—	0 -6.56	—	0 -4.23	—	—	—	0 -3.50	Jettisoned	

TABLE 2-2. DEFINITIONS OF TERMS IN TABLE 2-1.

Term	Definition
Atlas TBU	Atlas thrust buildup; missile held down by launcher
Launch	Release of missile from launcher
Flight	Flight through Mach 1 and maximum aerodynamic pressure
Maximum Booster Acceleration	Maximum booster acceleration, just prior to booster engine cutoff (also MBA)
CMECO1	First Centaur main engine cutoff
CMES2	Second Centaur main engine start
CMECO2	Second Centaur main engine cutoff
KMES1	First Kick Stage main engine start
KMECO1	First Kick Stage main engine cutoff
KMES2	Second Kick Stage main engine start
KMECO2	Second Kick Stage main engine cutoff
STATIC	Constant or slowly varying (initial and final values are separated by a / mark)
DYN+	Maximum positive dynamic load
DYN-	Maximum negative dynamic load
ENV	Environmental load (understood to be ±)
TOTAL+	Maximum total positive load
TOTAL-	Maximum total negative load
Longt'l	Longitudinal direction, parallel to centerline
Lat'l	Lateral direction, normal to centerline
3k P/L	Indicates analysis includes 3,000 lb payload
300 P/L	Indicates analysis includes 300 lb payload

NOTE:

* Indicates "best guess" data.

B. P. Indicates with back pressure for one launch analysis (see Section 6 for details.

All lateral loads are symmetrical so where ± signs are omitted with lateral loads they are understood to exist.

Truss Loads are evaluated at SLV-3C station + 14 inches (just in front of the aft ring).

Positive axial truss loads are compression.

Longitudinal accelerations are plus forward.

Payload clearance loss does not include deflection of components of the payload.

In order to understand the method of combining loads, it is first necessary to understand the methods of caclulating the various loads and the probabilities of occurrence of the loads. In general, there are two separate types of responses occurring together at the same time: one due to a given thrust transient or other design load condition that can be analyzed by classical methods and the other "Environmental Vibration", caused by higher frequency random noise, boundary-layer turbulence, and others, that, for want of better methods, is handled empirically (see Section 11). Both of these types of responses include at least some random loads. For example the thrust rise curve used in the analysis of the second Centaur Main Engine Start (CMES2) is much more severe than average or typical data. The object in selecting this worst case curve is of course, to provide enough strength in the structure so that mission failures will not occur. It should be clear, therefore, that the loads determined as a result of this analysis are partly random. The random part is taken, for simplicity, as the load in excess of the nominal (or average) acceleration at that time.

For example, consider the last condition shown on page 2-5 of Table 2-1. The nominal (average or mean) acceleration prior to MECO is 1.82 g's and after MECO is zero. These loads are called "Static+" and "Static-" respectively. The analysis of this MECO condition, however, indicated that the most positive acceleration was 2.27 g's on the payload mass and also a minimum of -2.77 g's (see Figure 9-13). Then the positive random load (called Dyn+) is 2.27 -1.82 or +0.45 g's. The negative random (Dyn-) load is -2.77 -0 or -2.77 g's.

The Environmental Vibration (Env) load is assumed to be all random (with respect to amplitude probability) and taken to be 0.74 g'2 (see Table 11-1). The Env loads are understood to be plus or minus.

It has been found that simple addition of these various loads leads to unreasonably conservative (too high) totals, so that it is preferred to use the Root-Sum-Square (RSS) method to combine the random parts which are then added to the Static as shown below:

$$\text{Total} + = (\text{STATIC} +) + \left[(\text{DYN} +)^2 + (\text{ENV})^2\right]^{\frac{1}{2}}$$

$$\text{Total} - = (\text{STATIC} -) - \left[(\text{DYN} -)^2 + \text{ENV})^2\right]^{\frac{1}{2}}$$

It should be noted that many special cases exist where the loads presented are somewhat different from the example given above. In the case of the Atlas TBU, the vehicle is held by the launcher so that only one Static load is shown (1.00 g). In many cases the greatest negative analytical load is equal to the Static- value so that Dyn- equals zero. For example see the Centaur second Main Engine Start (CMES 2) conditions on page 2-5.

In addition to the loads acting in the direction of primary interest there may be significant loads acting at right angles in a secondary direction. For instance, at Atlas thrust buildup, longitudinal loads can be determined using a longitudinal model and thrust buildup curves for the Atlas engines. However, lateral response is also known

to be produced by Atlas thrust buildup. In some cases, best guess data for such secondary response has been supplied on the basis of Atlas/Centaur flight experience. These data have been included in Table 2-1 for a guide only, and are identified by an asterisk (*) wherever they appear.

Lateral loads are treated in the same manner, but within the scope of this study, are symmetrical so that plus and minus lateral loads are equal in magnitude.

A total load envelope may be formed by considering a combination of the various loads specified for a given mass. The loads specified may, in general, have static and random (random loads are TOTAL less STATIC) terms in each direction (forward, aft, and lateral). The envelope is formed as shown in Figure 2-1.

The corners of the load envelope are shown as elliptical. If the random loads are uncorrelated, it is believed that the elliptical corner is best in order to approximate a bivariate statistical distribution. However, to save time, the corners are frequently made square (more conservative) if the item under analysis is not critical.

A detailed examination has been made of the various accelerations in Table 2-1 and a short summary has been made in Table 2-3 for Cases 1, 4, and 7. The most critical values for the two ring truss have been underlined.

The payload mass can be seen to generate a maximum forward acceleration at MBA and a maximum separation plane tension at Kick Stage first MECO. The payload maximum lateral load would be 1.87 g's at launch unless the 3-ring design is used, in which case the required load is 2.49 g's. In Table 2-3 the loads shown for the Case 4 payload are one-tenth of the accelerations shown in Table 2-1 because the load is the product of acceleration and weight. The last launch entry in Table 2-1 shows the reduction of payload lateral response to less than half by means of using the launcher "back pressure". Back pressure is discussed in Section 6.

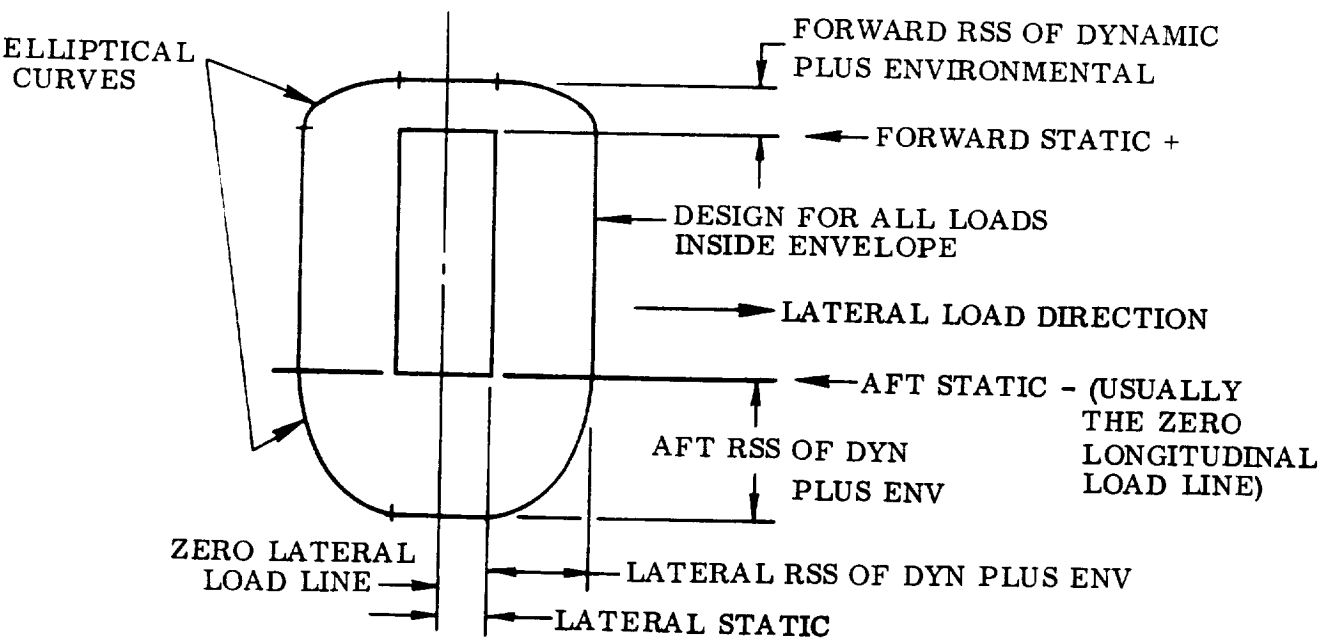


Figure 2-1. Total Load Envelope

TABLE 2-3. TOTAL LOAD SUMMARY (FOR PAYLOAD, LH_2 AND LO_2 MASSES)

	Gravities (Based on maximum weight of each mass)								
	Payload			LH_2			LO_2		
	+Longt'l	-Longt'l	Lat'l	+Longt'l	-Longt'l	Lat'l	+Longt'l	-Longt'l	Lat'l
CASE 1									
Atlas TBU	1.9	-0.02	1.11*	2.16	-0.2	1.36*	1.72	+0.06	0.97*
Launch	2.44	-	1.87	2.53	-	1.15	2.36	-	0.63
Flight	2.63	-	1.59	2.98	-	1.34	2.41	-	0.80
MBA	6.17	-	0.47	6.34	-	0.64	6.06	-	0.36
CMECO1	2.52	-2.7	0.80*	2.87	-1.97	1.13*	2.18	-1.25	0.55*
CMES2	2.49	-0.74	0.74	2.78	-1.08	1.08	2.24	-0.51	0.51
CMECO2	2.69	-2.87	0.80	4.33	-2.22	1.13	2.33	-1.19	0.55
KMES1	1.98	-0.58	0.59*	2.21	-0.85	0.86*	1.78	-0.41	0.42*
KMECO1 †	2.75	-3.35	0.60*	1.86	-1.41	0.57*	1.09	-0.89	0.25*
KMES2 †	2.90	-0.58	0.59*	1.53	-0.58	0.58*	1.31	-0.30	0.30*
KMECO2 ‡	3.73	-3.23	0.60*	0.89	-0.67	0.33*	0.36	-0.28	0.09*
CASE 4 ★									
Launch	0.37	-	0.28	2.49	-	1.31	2.35	-	0.73
Flight	0.42	-	0.28	2.98	-	1.50	2.41	-	0.94
CMECO1	0.60	-0.61	0.23*	3.15	-2.15	1.13*	2.47	-1.59	0.55*
CMES2	0.44	-0.23	0.23*	3.23	-1.08	1.08*	2.76	-0.51	0.51*
CMECO2	0.82	-0.81	0.23*	3.64	-2.31	1.13*	2.72	-1.52	0.55*
KMES1	0.38	-0.18	0.18*	2.65	-0.85	0.86*	2.15	-0.41	0.42*
KMECO1 †	0.88	-0.77	0.19*	2.14	-1.72	0.57*	1.49	-0.50	0.25*
KMECO2 ‡	1.05	-0.92	0.19*	1.47	-0.71	0.33*	0.43	-0.13	0.09*
CASE 7									
Launch	2.57	-	2.49#	2.56	-	1.21	2.28	-	0.70
Flight	2.64	-	1.42	2.98	-	1.35	2.41	-	0.81
CMES2	2.47	-0.74	0.74*	2.81	-1.08	1.08*	2.25	-0.51	0.51*
CMECO2	2.57	-2.16	0.80*	2.57	-2.50#	1.13*	2.34	-1.48	0.55*
KMES1	2.16	-0.58	0.59*	2.32	-0.86	0.86*	1.86	-0.41	0.42*

NOTES:

* "best guess", underlined numbers are most critical for 2-ring truss.

† Corrected to equiv. load on max. wt. LH_2 acc × 610/1390, LO_2 acc × 2250/6130.

‡ Corrected to equiv. load LH_2 acc × 220/1390, LO_2 acc × 290/6130.

★ Case 4 payload acc × 300/3000 to make equiv. loads.

\# If 3-ring truss is used (case 7) these values become more critical.

These loads are taken to be positive when accelerating forward, and negative when accelerating backwards.

The Liquid Hydrogen (LH_2) tank load can be seen to be maximum of +6.34g's (accelerating forward) at MBA while the greatest negative load is -2.31g's at Centaur second MECO with the 300-pound payload (Case 4). As discussed more fully in Section 9, this -2.31g's was determined with a Mathematical Model (MM) that does not permit the liquid to leave its settled position at the bottom of the tank and therefore, cannot be considered entirely valid. It is, however, considered conservative to design the structure for such a load. This and the problem of Kick Stage Main Engine Start (MES) with possible-unsettled propellants may require additional study. The maximum lateral load on the LH_2 mass occurs in the Mach 1 to Max q flight time with the small payload (Case 4).

Liquid Oxygen (LO_2) mass loads are similar to the LH_2 loads in the forward and lateral directions. The worst reversed acceleration on the LO_2 is at Centaur first MECO, 1.59 g's (Case 4). Only slightly less is the load at Centaur second MECO (1.52 g's) and this may also be expected to unsettle the LO_2 for Kick Stage start. The negative LO_2 loads for the heavy payloads are somewhat better with the smallest load occurring with the 2-ring truss design. It should be kept in mind that the loads in Table 2-3 have been reduced in proportion to weight reduction for Kick Stage propellant masses and also for the lightweight payload. In the case of the lateral load on the LO_2 mass it should be noted that the largest load in Table 2-3 is at the top, for Atlas TBU, but this load is a "best guess" and very conservative. Since the flight load for Case 4 was only slightly smaller, it was decided to use the more reliable (analytical) value as most critical.

Acceleration loads on the engine are worst at Kick Stage second MECO. The maximum negative acceleration of 12.7 g's in Case 1 (see Table 2-1) is considered to be far from critical since the gimbal and supporting structure are designed for engine thrust which is much greater. The positive acceleration load of 11.77 g's in Case 4 may be critical in gimbal tension. The "best guess" 3 g lateral load on the engine is only useful in conjunction with other loads such as actuator loads, plumbing loads, etc. These other loads on the engine may be important also in the longitudinal direction.

The other masses, in general, are similar to those mentioned except that they may require design to almost 10 g's forward acceleration based on the Case 4, light payload, maximum Kick Stage acceleration.

Accelerations are taken positive when acting forward and are quoted as "Design Limit" values, not ultimate.

LO_2 mass loads and accelerations in this section are based on the group of 4 bottles acting as a whole. It may be advisable to increase the strength of the individual bottles by using the higher environmental vibration load for single bottles, as stated in Section 11.

To explore the possible benefits to be obtained by increasing stiffness of the Kick Stage/Payload structure, two additional MM were analyzed. The first of these, MM 46B, shown next to last on the last page of Table 2-1, has a 300-pound payload with a very stiff payload structure. The longitudinal frequency of the cantilevered payload is 60 cps in this case. The model was analyzed at Kick Stage second MECO and shows a considerable reduction in payload, forward ring, and LH_2 mass response.

The second model (46C) with a beryllium-aluminum cruciform beam is shown last in the table. This model has a 3000-pound payload and shows a sizeable reduction in both payload and engine responses.

2.3 TRUSS LOADS

Truss loads in the form of lateral shears, moments and axial loads at Station 14 are included because of their possible importance in the design of the Kick Stage truss.

The general method of combining static, dynamic, and environmental components to get totals is the same as for inertia loads. The reason for including the truss loads in addition to the accelerations of the various masses is so that when all masses are not moving in phase, the reduced loads in the truss would be available. It should be clear that these truss loads should be the same or less than the equivalent of the individual mass accelerations.

A summary of the truss loads is shown in Table 2-4. It may be seen that for each type of load, the Case 7 loads are the same or higher than Case 1. The Case 4 truss loads are non-critical.

The situation regarding MM 32 and 33, with the forward ring tied to the nose fairing at Station -48 (in SLV-3C) indicates that while the bending moments in the truss are not higher than required for launch, the shear load is much higher. The Case 1 shear load is 17.95×10^3 lb and the Case 7 shear load is 17.42×10^3 lb. (See the third page of Table 2-1). It seems that the nose fairing deflects far enough to apply considerable load to the truss. If the truss loads above are not acceptable there are two alternatives remaining: (1) replace the tie with a flexible link to result in reduced truss loads or (2) test the nose fairing after fabrication to see if it might be stiffer than predicted. Otherwise, it seems, the nose fairing tie should be discarded. Positive axial loads are taken as compression.

2.4 CLEARANCE

The method of combining static, dynamic, and environmental clearance losses is the same as for inertia loads. No factor of safety is included in these numbers;

TABLE 2-4. TOTAL TRUSS LOADS AND CLEARANCE SUMMARY

	Truss Loads				Clearance Loss	
	Bending Moment 10^6 in.-lb	Shear 10^3 lb	Axial Load+ 10^3 lb	Axial Load- 10^3 lb	Payload in.	Fwd. Ring in.
CASE 1						
Atlas TBU	0.52*	5.01*	9.19	-0.76	0.77*	0.20
Launch	0.95	6.69	11.41	-	0.48	0.10
Flight	0.72	5.84	12.35	-	1.64	0.72
MBA	0.16	1.93	30.43	-	0.14	0.03
CMECO1	0.22*	3.03*	11.21	-6.86	-	-
CMES2	0.15	2.85	11.50	-2.85	-	-
CMECO2	0.22	3.03	11.97	-6.34	-	-
KMES1	0.16*	2.27*	14.51	-2.25	-	-
KMECO1	0.15*	2.22*	11.11	-6.75	-	-
KMES2	0.16*	2.24*	11.75	-2.22	-	-
KMECO2	0.13*	1.46*	13.53	-6.45	-	-
CASE 4						
Launch	0.24	2.83	5.20	-	0.26	0.10
Flight	0.25	3.09	6.30	-	1.47	0.72
CMECO1	0.22*	2.18*	6.44	-4.43	-	-
CMES2	0.15*	1.94*	6.47	-1.93	-	-
CMECO2	0.22*	2.18*	7.19	-6.18	-	-
KMES1	0.14*	1.56*	5.75	-1.53	-	-
KMECO1	0.11*	1.24*	6.45	-4.62	-	-
KMECO2	0.09*	1.06*	9.24	-3.64	-	-
CASE 7						
Launch	1.23#	7.84#	11.85	-	1.13	0.19
Flight	0.64	5.21	12.35	-	1.77#	0.73#
CMES2	0.15*	2.85*	11.40	-2.85	-	-
CMECO2	0.22*	3.03*	11.95	-5.28	-	-
KMES1	0.16*	2.27*	9.56	-2.25	-	-

Underlined numbers are most critical for 2-ring truss.

* = "best guess"

If 3-ring truss is used (case 7) these values become more critical

they represent the clearance loss due to expected dynamic loads, with the exception that the environmental vibration terms include a factor of conservatism of 1.5.

It appears in the analysis that the great bulk of the loss of clearance is due to deflection of the nose fairing. In view of this, it seems reasonable that there is only 0.21 inches difference between Case 3 (most soft 2-ring with 3000-pound payload) and Case 2S (stiffest 2-ring) with an average value of about 1.6 inches. The loss of clearance is somewhat less with the 300-pound payload and larger with the 3-ring design. Some values are shown for the basic cases in Table 2-4 and the remainder of the data is in Table 2-1 at the end of this section.

It should be noted that loss of clearance of the payload as used in this report does not include elastic deflection of parts of the payload.

2.5 RECOMMENDATIONS

The following items are presented in summary of the more important results obtained.

1. The 2-ring truss is recommended over the 3-ring design because of lower loads and clearance loss in many cases.

2. The wall thickness of the truss tubes and the modulus of elasticity for the tubes seems to make small differences in loads and clearances so that these should be picked to optimize margins, weights and costs.

3. The stiffer beryllium-aluminum criciform beam shows promise and should be evaluated at the critical load conditions to judge its value.

4. Forward ring to nose fairing clearance should be 0.90 inches (1.25 F.O.S. $\times$ 0.72) on the radius or 1.80 inches on the diameter, assuming that Cases 1 and 4 will be selected for the design.

5. The connection between the forward ring and the nose fairing should be considered only if the nose fairing can be shown to be stiffer than assumed or if a soft spring can be considered to be feasible for connecting the two.

6. The truss loads presented should be used in preference to methods using peak, in phase accelerations. This may result in considerable saving of weight.

7. The problems related to unsettling the liquid propellants should be considered in greater depth. The work done in this study has established that the energy stored in the elastic vehicle when released at Centaur and Kick Stage MECO is sufficient to cause considerable disturbance in the liquids.

8. This is a preliminary analysis. It is recommended that, in the course of development of Kick Stage, additional analyses be performed along the lines of the work presented here and beyond.

3

INFLUENCE COEFFICIENTS AND MATHEMATICAL MODELS

This section covers the analysis of the influence coefficients of the Kick Stage structure and the incorporation of these coefficients, as well as weight and geometric data, to construct the Mathematical Models (MM) which are a fundamental tool throughout this report. The modes based on these data for the various SLV-3C/Centaur/Kick Stage configurations are presented in Section 4.

3.1 KICK STAGE INFLUENCE COEFFICIENTS

The analysis of Kick Stage included determining influence coefficients for the primary space truss structure, cruciform beam, and the oblate spheriod LH_2 tank and its supporting conical shell. The associated lateral and longitudinal stiffnesses were determined from the influence coefficients.

3.1.1 SPACE TRUSS. The longitudinal model influence coefficients for the truss configurations were determined by methods compatible with the discussion below on lateral influence coefficients, but have been treated more simply as the average deflection per unit longitudinal load because these longitudinal loads are uniformly distributed about the rings. There are only two longitudinal truss configurations required (see Table 1-2). The truss was analyzed by a computer program (GDC Program 3231) based on the displacement (stiffness) method presented in Reference 3-1 and 3-2. The resulting stiffnesses are:

a. Case 1 $K_{equip\ support}$ (K_{23}) = 1.7972×10^5 lb/in.
K_{truss} (K_{37} or K_T) = 9.5662×10^5 lb/in.

b. Case 7 $K_{equip\ support} = 1.0511 \times 10^5$ lb/in. $K_{truss} = 2.0553 \times 10^5$ lb/in.

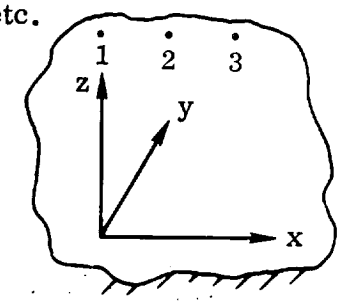
(See Section 1 for description of Kick Stage Cases.)

The lateral model influence coefficients were calculated from the point by point influence coefficient data obtained from the same computer program. In this method the circular rings were approximated by 16 equal straight segments, and the lateral moment, M_1, and shear, P_1, were applied at eight nodes of the payload ring for all cases, and also at eight nodes of the forward ring, M_2 and P_2, for cases 1 and 7. The moment distribution was taken linear with respect to distance from the neutral axis and the shear distribution was taken to be sinusoidal about the circumference with only the strut joints carrying the applied load. The data that resulted from the computer program (3231) was in the form of deflections and rotations of 32 points (16 on each ring), a total of 192 numbers for any given load. It was necessary because of computer size

limitations to reduce this number of degrees of freedom so that the eigen-value problem for the entire launch vehicle (the whole MM) could be solved. The method, discussed in detail below, equates the total load and elastic energy of the complete truss model to a simpler (fewer degree of freedom) model. The General Theory, presented first, is more broad in application and results in an influence coefficient matrix for a rigid body mounted on an elastic support intended to represent the original field of n general and arbitrary points. The Special Theory (Section 3.1.1.2) is limited in application to the problem of reducing the data for the whole truss to a 4×4 influence coefficient matrix for lateral translations and rotations of 2 rigid but elastically coupled rings.

3.1.1.1 General Co-ordinate Transformation Theory. The matrix transformation is a method for determining the generalized influence coefficients of n points on an elastic body.

Let $\underset{3n \times 1}{\{P\}}$ be a load vector which may be partitioned into 3 parts; first, n terms for x direction loads, second, n terms for the y direction, etc.



Let $\underset{3n \times 1}{\{\Delta\}}$ be a displacement vector similar to $\{P\}$ such that

$$\{\Delta\} = \underset{3n \times 3n}{[\delta]} \{P\}$$

where $[\delta]$ is the point by point influence coefficient matrix.

Let $\underset{6 \times 1}{\{\bar{P}\}}$

be a generalized load vector consisting of the sum of forces in the x, y, and z directions and the total moments acting about these axes.

Let $\underset{6 \times 1}{\{\bar{\Delta}\}}$ be a generalized displacement vector similar to $\{P\}$ such that

$$\{\bar{\Delta}\} = \underset{6 \times 6}{[\bar{\delta}]} \{\bar{P}\}$$

where $[\bar{\delta}]$ is the generalized influence coefficient matrix.

Since the energy stored in the elastic body is the same for the application of both loads $\{P\}$ and $\{\bar{P}\}$, then

$$\text{Energy} = 1/2 \{\bar{P}\}' \{\bar{\Delta}\} = 1/2 \{\bar{P}\}' [\bar{\delta}] \{\bar{P}\} = 1/2 \{P\}' [\delta] \{P\}.$$

From equilibrium considerations there also exists a transformation

$$\underset{3n \times 6}{[T]}$$

such that

$$\{P\} = [T] \{\bar{P}\}$$

where the columns of $[T]$ are the loads on the n points for unit loads in the generalized coordinates. Also

$$\{P\}' = \{\bar{P}\}'[T]'$$

$$\{\bar{P}\}'[\bar{\delta}]\{\bar{P}\} = \{\bar{P}\}'[T]'[\delta]\{P\}$$

$$\{\bar{P}\}'[\bar{\delta}]\{\bar{P}\} = \{\bar{P}\}'[T]'[\delta][T]\{\bar{P}\}$$

$$[\bar{\delta}] = [T]'[\delta][T]$$

3.1.1.2 Special Co-ordinate Transformation Theory. For this case of the lateral deflections of the truss (due to shear load and bending moment) it was possible to modify the general theory and thereby produce a method that was much more efficient and concise. For this special theory, four external loads were applied to the truss, shear and moment at the payload ring and also at the forward ring.

The node by node load vector $\underset{48\times 4}{\{P\}}$ is a matrix which may be partitioned into 4 columns of 48 elements (numbers) each. These four columns represent the external applied loads: shear at payload ring, $\bar{P}_1$; moment at payload ring, $\bar{M}_1$; shear at forward ring, $\bar{P}_2$; and moment at forward ring, $\bar{M}_2$, respectively. Further, the 48 elements of each column consist of 16 loads, one at each of 16 nodes, on the truss in the x direction, 16 loads in the y direction, and 16 in the z direction. Most of these loads are zeros. The node by node displacement vector $\underset{48\times 4}{\{\Delta\}}$ is a matrix giving the displacements of the nodes in a manner similar to vector $\{P\}$. Then the node by node influence coefficient matrix $\underset{48\times 48}{[\delta]}$ is defined by the relation:

$$\underset{48\times 4}{\{\Delta\}} = \underset{48\times 48}{[\delta]}\ \underset{48\times 4}{\{P\}}\ .$$

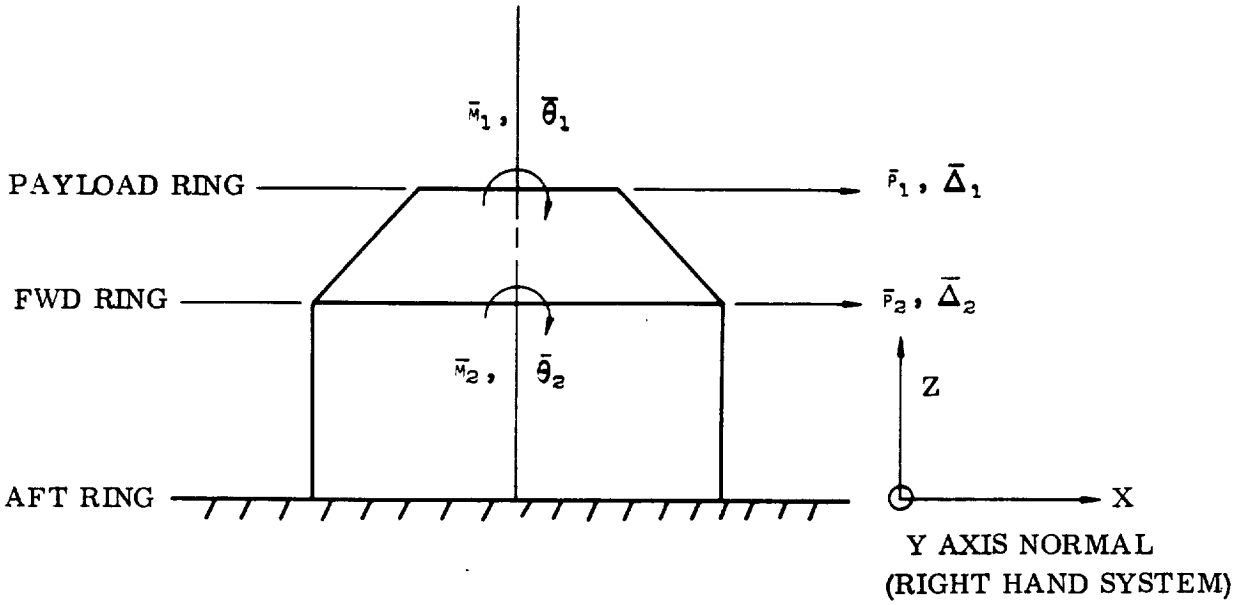
It follows, for the generalized co-ordinates, that:

$$\underset{4\times n}{\{\bar{\Delta}\}} = \underset{4\times 4}{[\bar{\delta}]} \times \underset{4\times n}{\{\bar{P}\}},$$

where the generalized displacement $\{\bar{\Delta}\}$ consists of n columns (for n load applications) of 4 elements each. These elements of each column are the displacements of the payload ring, as a whole, which is in the x direction, $\bar{\Delta}_1$; the rotation of the payload ring about the y axis, $\bar{\theta}_1$; the displacement of the forward ring, in the x direction, $\bar{\Delta}_2$; and the rotation of the forward ring about the y axis, $\bar{\theta}_2$. The generalized influence coefficient elements are shown in the sketch accompanying Table 3-1. The derivation of the generalized influence coefficient matrix is the same for this special theory as for the general theory above, except that each term has a different meaning.

$$\underset{4\times 4}{[\bar{\delta}]} = \underset{4\times 48}{[T]'}\ \underset{48\times 48}{[\delta]}\ \underset{48\times 4}{[T]}$$

TABLE 3-1. LATERAL INFLUENCE COEFFICIENTS FOR KICK STAGE TRUSS (INCLUDING RING FLEXIBILITIES)



$$\begin{vmatrix} \bar{\Delta}_1 \\ \bar{\theta}_1 \\ \bar{\Delta}_2 \\ \bar{\theta}_2 \end{vmatrix} = \begin{vmatrix} \bar{\delta}_{1P1} & \bar{\delta}_{1M1} & \bar{\delta}_{1P2} & \bar{\delta}_{1M2} \\ \bar{\theta}_{1P1} & \bar{\theta}_{1M1} & \bar{\theta}_{1P2} & \bar{\theta}_{1M2} \\ \bar{\delta}_{2P1} & \bar{\delta}_{2M1} & \bar{\delta}_{2P2} & \bar{\delta}_{2M2} \\ \bar{\theta}_{2P1} & \bar{\theta}_{2M1} & \bar{\theta}_{2P2} & \bar{\theta}_{2M2} \end{vmatrix} \times \begin{vmatrix} \bar{P}_1 \\ \bar{M}_1 \\ \bar{P}_2 \\ \bar{M}_2 \end{vmatrix} = [\bar{\delta}] \times |\bar{P}|$$

TABLE 3-1. LATERAL INFLUENCE COEFFICIENTS FOR KICK STAGE TRUSS (INCLUDING RING FLEXIBILITIES) (CONTINUED)

COEFFICIENT	Case 1, 4	Case 2, 5	Case 3, 6	Case 7	Case 8	Case 9
$\bar{\delta}_{1P1}$ (in./lb)	2.342×10^{-5}	1.656×10^{-5}	4.403×10^{-5}	3.471×10^{-5}	2.594×10^{-5}	6.109×10^{-5}
$\bar{\theta}_{1M1}$ (rad./in. - lb)	1.189×10^{-8}	9.660×10^{-9}	1.861×10^{-8}	1.695×10^{-8}	1.427×10^{-8}	2.502×10^{-8}
$\bar{\delta}_{2P2}$ (in./lb)	1.228×10^{-5}	——— *	———	1.401×10^{-5}	———	———
$\bar{\theta}_{2M2}$ (rad./in. - lb)	4.970×10^{-10}	——— *	———	2.352×10^{-9}	———	———
$\bar{\theta}_{1P1}$ (rad./lb)	-6.394×10^{-8}	-2.409×10^{-8}	-1.838×10^{-7}	1.628×10^{-7}	1.735×10^{-7}	1.305×10^{-7}
$\bar{\delta}_{1M1}$ (in./in. - lb)	-6.393×10^{-8}	-2.409×10^{-8}	-1.838×10^{-7}	1.628×10^{-7}	1.735×10^{-7}	1.305×10^{-7}
$\bar{\delta}_{2P1}$ (in./lb)	1.280×10^{-5}	8.691×10^{-6}	2.513×10^{-5}	1.638×10^{-5}	1.135×10^{-5}	3.150×10^{-5}
$\bar{\delta}_{1M2}$ (in./lb)	1.280×10^{-5}	———	———	1.638×10^{-5}	———	———
$\bar{\theta}_{2P1}$ (rad./lb)	3.624×10^{-8}	2.610×10^{-8}	6.671×10^{-8}	1.708×10^{-7}	1.316×10^{-7}	2.888×10^{-7}
$\bar{\delta}_{1M2}$ (in./in. - lb)	3.624×10^{-8}	———	———	1.708×10^{-7}	———	———
$\bar{\delta}_{2M1}$ (in./in. - lb)	1.506×10^{-8}	1.023×10^{-8}	2.958×10^{-8}	6.970×10^{-8}	5.098×10^{-8}	1.260×10^{-7}
$\bar{\theta}_{1P2}$ (rad./lb)	1.506×10^{-8}	———	———	6.970×10^{-8}	———	———
$\bar{\theta}_{2M1}$ (rad./in. - lb)	6.227×10^{-10}	4.667×10^{-10}	1.092×10^{-9}	2.973×10^{-9}	2.370×10^{-9}	4.788×10^{-9}
$\bar{\theta}_{1M2}$ (rad./in. - lb)	6.228×10^{-10}	———	———	2.974×10^{-9}	———	———
$\bar{\theta}_{2P2}$ (rad./lb)	1.506×10^{-8}	———	———	6.971×10^{-8}	———	———
$\bar{\delta}_{2M2}$ (in./in. - lb)	1.506×10^{-8}	———	———	6.971×10^{-8}	———	———

* Calculations were not made for P_2, M_2 loads for Cases 2, 5, 3, 6, 8 and 9.

The transformation matrix [T] is defined by the relation:

$$\underset{48\times n}{\{P\}} = \underset{48\times 4}{[T]} \; \underset{4\times n}{\{\bar{P}\}}.$$

It can be seen that each column of [T] is a load configuration for unit generalized load. The value of each term of the [T] matrix is shown in Table 3-2 as an aid in understanding the method.

The computer solution results in node by node deflections for each external unit generalized load applied one at a time. These computer results are the elements of the matrix product $\underset{48\times 48}{[\delta]} \; \underset{48\times 4}{[T]}$.

Premultiplying by $[T]'$ gives

$$\underset{4\times 4}{[\bar{\delta}]}$$

which is the generalized influence coefficient matrix for the truss. The matrix equation and the values of the elements obtained are shown in Table 3-1.

3.1.2 CRUCIFORM BEAM AND AFT RING. The influence coefficients for the longitudinal model for the cruciform beam and the aft ring were calculated (using the program based on Reference 3-1 and 3-2) for two cases: first, with the Kick Stage adapter attached, so that the aft ring was considered rigid; and second, without the Kick Stage adapter, so that the aft ring was considered flexible. The stiffness of the criciform beam was considered to be independent of the aft ring. These influence coefficients are summarized in Table 3-3.

3.1.3 LIQUID HYDROGEN (LH_2) TANK AND CONICAL SUPPORT. An assumption was made that the LH_2 tank flexibility can be included by scaling the properties of the Centaur Liquid Oxygen (LO_2) tank. This procedure results in the LH_2 tank flexibility in the longitudinal direction being about ten times more flexible than the supporting conical adapter between the tank and the forward ring.

The theory of thin-walled tanks indicates that the stiffness effective in supporting the liquid mass is dependent only on the product of the modulus of elasticity times the skin thickness. The size of the tank, if the shape is constant, does not matter. The Centaur tank was considered to have a spring constant of 1.32×10^6 lb/in. and an Et of 0.54×10^6 ($E = 27 \times 10^6$ and $t = 0.020$ in.). Since the Kick Stage LH_2 tank has an Et of 0.35×10^6 ($E = 10^7$, $t = 0.035$ in., aluminum) its longitudinal stiffness was determined to be 0.857×10^6 lb/in. The stiffness of the conical support was determined to 12.31×10^6 lb/in.

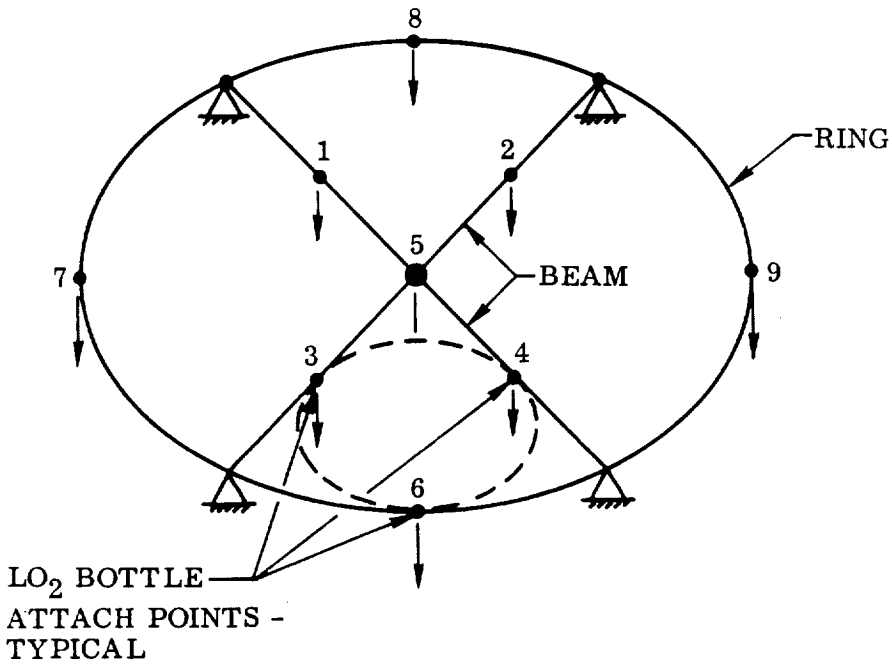
TABLE 3-2. TRANSFORMATION MATRIX ELEMENTS FOR SPECIAL THEORY

$$[T] = \begin{bmatrix} T_{1,1} & T_{1,2} & T_{1,3} & T_{1,4} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ T_{48,1} & \cdot & \cdot & T_{48,4} \end{bmatrix}$$

			$T_{9,3}$	=	+.0366
			$T_{10,3}$	=	+.2134
			$T_{11,3}$	=	+.2134
			$T_{12,3}$	=	+.0366
			$T_{13,3}$	=	+.0366
			$T_{14,3}$	=	+.2134
$T_{2,1}$	=	+.125	$T_{15,3}$	=	+.2134
$T_{3,1}$	=	+.25	$T_{16,3}$	=	+.0366
$T_{4,1}$	=	+.125	$T_{25,3}$	=	-.0884
$T_{6,1}$	=	+.125	$T_{26,3}$	=	-.0884
$T_{7,1}$	=	+.25	$T_{27,3}$	=	+.0884
$T_{8,1}$	=	+.125	$T_{28,3}$	=	+.0884
$T_{18,1}$	=	-.125	$T_{29,3}$	=	-.0884
$T_{20,1}$	=	+.125	$T_{30,3}$	=	-.0884
$T_{22,1}$	=	-.125	$T_{31,3}$	=	+.0884
$T_{24,1}$	=	+.125	$T_{32,3}$	=	+.0884
			$T_{41,4}$	=	-.003850
			$T_{42,4}$	=	-.001595
$T_{33,2}$	=	-.00769	$T_{43,4}$	=	+.001595
$T_{34,2}$	=	-.00544	$T_{44,4}$	=	+.003850
$T_{36,2}$	=	+.00544	$T_{45,4}$	=	+.003850
$T_{37,2}$	=	+.00769	$T_{46,4}$	=	+.001595
$T_{38,2}$	=	+.00544	$T_{47,4}$	=	-.001595
$T_{40,2}$	=	-.00544	$T_{48,4}$	=	-.003850

All other elements are zero.

TABLE 3-3. CRUCIFORM BEAM AND AFT RING INFLUENCE COEFFICIENTS



CRUCIFORM BEAM INFLUENCE COEFFICIENTS ($E = 10.3 \times 10^6$)

$$\delta_{11} = 2.6527 \times 10^{-5} \quad \text{in./lb}$$

$$\delta_{12} = \delta_{13} = 1.5319 \times 10^{-5} \quad \text{in./lb}$$

$$\delta_{14} = 1.2911 \times 10^{-5} \quad \text{in./lb}$$

$$\delta_{15} = 2.3165 \times 10^{-5} \quad \text{in./lb}$$

$$\delta_{56} = 3.5029 \times 10^{-5} \quad \text{in./lb}$$

AFT RING INFLUENCE COEFFICIENTS

$$\delta_{88} = 4.551 \times 10^{-4} \quad \text{in./lb}$$

$$\delta_{87} = \delta_{89} = -2.491 \times 10^{-4} \quad \text{in./lb}$$

$$\delta_{98} = 1.765 \times 10^{-4} \quad \text{in./lb}$$

3.2 MATHEMATICAL MODELS

The MM used in this analysis were developed from current SLV-3C/Centaur weight and stiffness data. Kick Stage weights were obtained from Table 1-3 and stiffnesses were calculated from influence coefficient data. With this data the longitudinal and lateral models, Figures 3-1 and 3-2, were constructed. A description of each of the MM is contained in Table 1-2.

3.2.1 LONGITUDINAL MODEL. The spring between nodes 1 and 2, Table 3-4, was designed for a 20 cps primitive payload frequency. (a primitive frequency is the frequency for a part of a system when the part is clamped at its base, in this case clamped at node 2). The 2-3 spring was calculated from Section 3.1.1. Spring 3-4 was calculated from

$$K_{3-4} = \frac{K_{LH}\ K_C}{K_{LH} + K_C}$$

where

$$K_C = AE/L$$

the stiffness of the conical support, and K_{LH} is the stiffness calculated as outlined in Section 3.1.3. The flexibility matrix (of springs connecting the rest of the Kick Stage) was determined from the following equations:

$$K_{35} = \frac{(3/2)\,K_T\,K_{B1}\,(K_{B2} + 2\,K_{B3})}{\text{(Denominator)}}$$

$$K_{36} = -\frac{K_T\,K_{B1}\,K_{B2}}{\text{(Denominator)}}$$

$$K_{37} = \frac{2K_R\,K_T\,(K_{B1} + K_{B2} + 2K_{B3}) - 2\,K_T\,K_{B1}\,K_{B3}}{\text{(Denominator)}} + \frac{1}{2}K_T$$

$$K_{56} = \frac{3\,K_{B1}\,K_{B2}\,(K_T + 2\,K_R)}{\text{(Denominator)}}$$

$$K_{57} = \frac{3\,K_{B1}\,(K_R\,K_{B2} + 6\,K_R\,K_{B3} + K_{B2}\,K_T)}{\text{(Denominator)}}$$

$$K_{67} = \frac{4\,K_{B2}K_{B3}\,(2\,K_R + K_T) + 2\,K_{B1}\,K_{B2}\,(K_{B3} - K_R)}{\text{(Denominator)}}$$

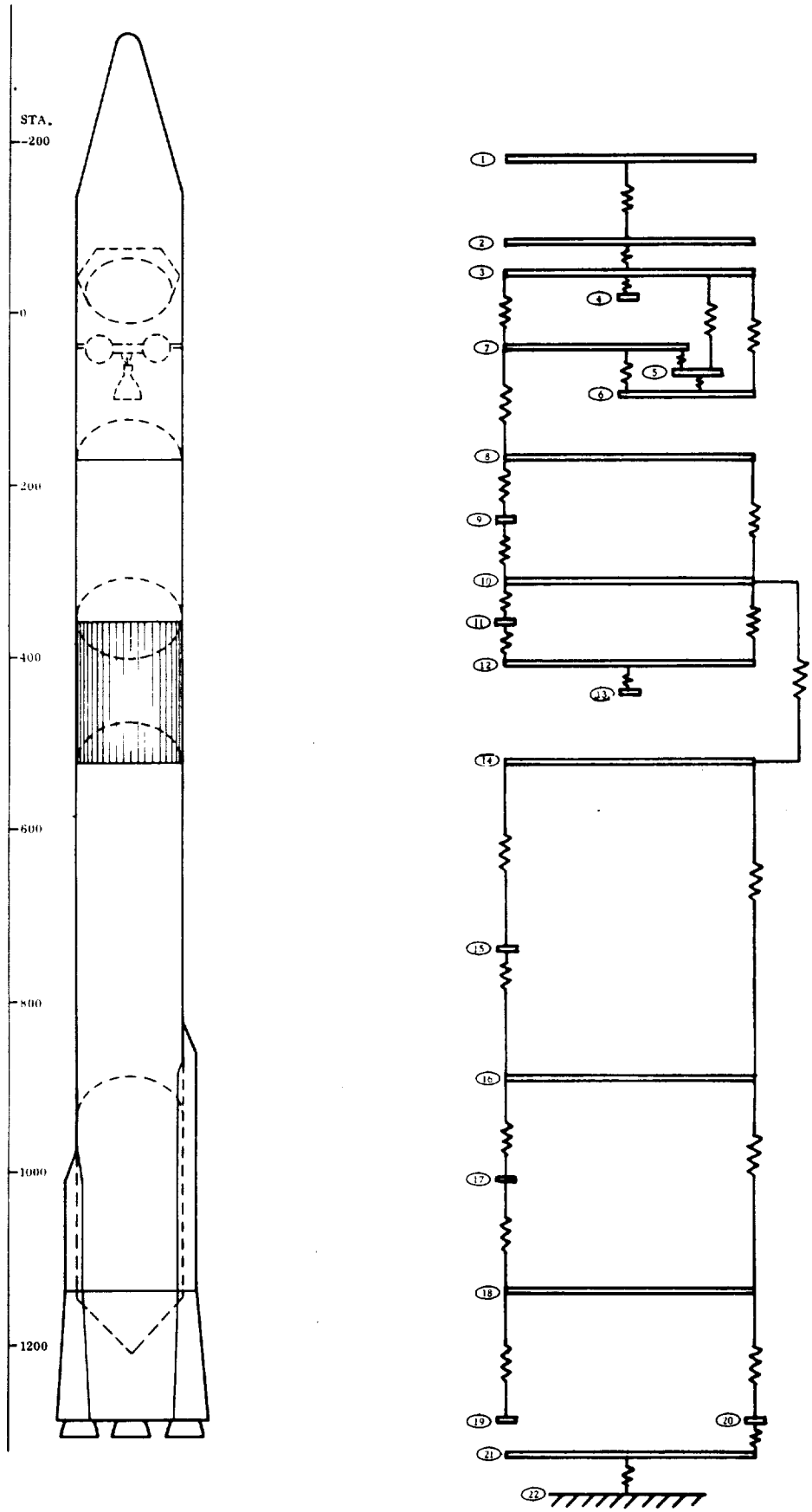


Figure 3-1. Longitudinal Model

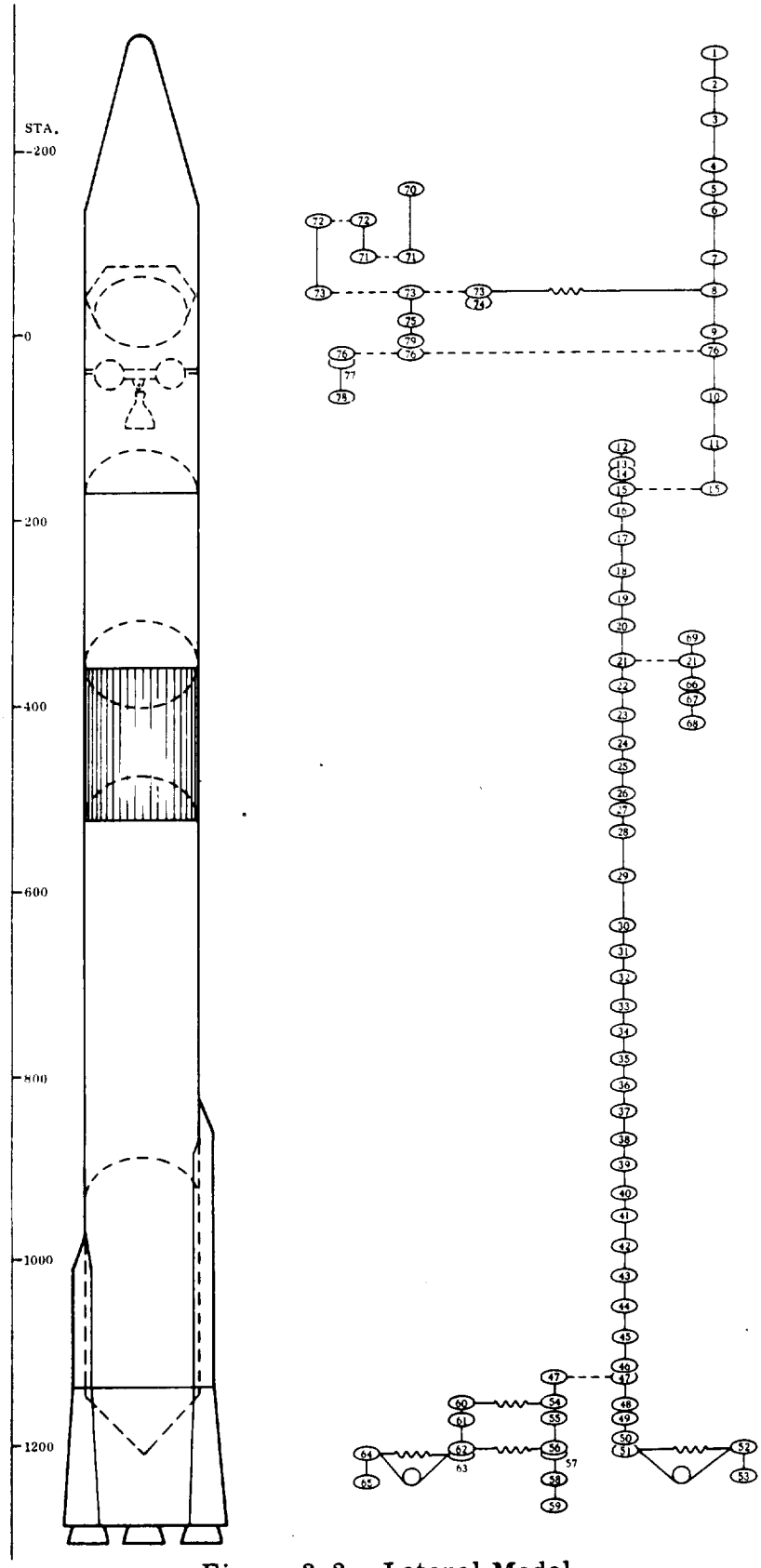


Figure 3-2. Lateral Model

TABLE 3-4. SPRING CONSTANTS FOR LONGITUDINAL MODELS

Connecting Nodes	Model 1 / Millions of (lbs/in.)	2	4	6	34 34A	36 36A	37	38	40	41	42	43	44	45	46	45A 46A	46B	46C
1-2	0.123	0.123	0.0123	0.123	0.123	0.0123	0.123	0.123	0.0123	0.123	0.123	0.0123	0.123	0.123	0.123	0.0123	0.123	0.123
2-3	0.180	0.180	0.180	0.105	0.180	0.180	0.105	0.180	0.180	0.105	0.180	0.180	0.105	0.180	→	→	→	→
3-4	0.801	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
3-5	Not Used	→	→	→	→	→	→	→	→	→	0.148	0.148	0.100	0.148	→	→	→	0.360
3-6	Not Used	→	→	→	→	→	→	→	→	→	-0.0653	→	-0.0442	-0.0653	→	→	→	-0.159
3-7	0.957	→	→	0.206	0.957	0.957	0.206	0.957	0.957	0.206	0.458	0.458	0.0889	0.458	→	→	→	0.408
5-6	0.451	→	→	→	→	→	→	→	→	→	0.208	0.208	0.171	0.208	→	→	→	0.506
5-7	0.572	→	→	→	→	→	→	→	→	→	0.212	0.212	0.182	0.212	→	→	→	0.514
6-7	-0.224	→	→	→	→	→	→	→	→	→	-0.0350	→	-0.0315	-0.0350	→	→	→	-0.0714
7-8	0.500	→	→	→	→	→	→	→	→	→	Jett.	→	→	→	→	→	→	→
8-9	0.159	→	→	→	→	→	→	→	→	→	Jett.	→	→	→	→	→	→	→
8-10	0.639	→	→	→	→	→	→	→	→	→	Jett.	→	→	→	→	→	→	→
9-10	0.374	→	→	→	→	→	→	→	→	→	Jett.	→	→	→	→	→	→	→
10-11	8.906	→	→	→	→	→	→	→	→	→	Jett.	→	→	→	→	→	→	→
10-12	-0.328	→	→	→	→	→	→	→	→	→	Jett.	→	→	→	→	→	→	→
10-14	1.44	→	→	→	Jett.	→	→	→	→	→	→	→	→	→	→	→	→	→
11-12	0.614	→	→	→	→	→	→	→	→	→	Jett.	→	→	→	→	→	→	→
12-13	20.0	→	→	→	→	→	→	→	→	→	Jett.	→	→	→	→	→	→	→
14-15	0.0802	→	→	→	Jett.	→	→	→	→	→	→	→	→	→	→	→	→	→
14-16	0.417	→	→	→	Jett.	→	→	→	→	→	→	→	→	→	→	→	→	→
15-16	0.187	→	→	→	Jett.	→	→	→	→	→	→	→	→	→	→	→	→	→
16-17	0.321	→	→	→	Jett.	→	→	→	→	→	→	→	→	→	→	→	→	→
16-18	1.40	→	→	→	Jett.	→	→	→	→	→	→	→	→	→	→	→	→	→
17-18	0.826	→	→	→	Jett.	→	→	→	→	→	→	→	→	→	→	→	→	→
18-19	0.788	→	→	→	Jett.	→	→	→	→	→	→	→	→	→	→	→	→	→
18-20	1.50	→	→	→	Jett.	→	→	→	→	→	→	→	→	→	→	→	→	→
20-21	0.625	Jett.	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
21-22	31.08	Jett.	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→

where

$$\text{Denominator} = 4(K_R + K_T)(K_{81} + K_{82} + 2K_{83}) + K_{81}(K_{82} + 2K_{83})$$

$$K_{81} = 4/(\delta_{11} + \delta_{12} + \delta_{13} + \delta_{14} - 4\delta_{15})$$

$$K_{82} = 1/(\delta_{55} - \delta_{15})$$

$$K_{83} = 1/2\delta_{15}$$

$$K_R = 4/(\delta_{66} + \delta_{67} + \delta_{68} + \delta_{69})$$

K_T from Section 3.1.1

Current SLV-3C/Centaur stiffnesses were used in all the remaining springs of Table 3-4.

The weights lumped at nodes 1 through 6, Table 3-5 of the longitudinal model are prescribed in Table 1-3. Node 7 includes 290 pounds of aft ring and beam, 2200 pounds of nose fairing, and 1/2 of the Kick Stage adaptor. Existing Centaur weights were adjusted at Node 8 to account for configuration differences, and 1/2 of the Kick Stage adaptor was lumped at this node. The insulation panels, 1200 pounds, were lumped at nodes 8 and 10, and the SLV-3C/Centaur interstage adaptor, 1133 pounds, was lumped at nodes 10 and 14. The LH_2 (250 pound) and LO_2 (1254 pound) for models 34, 36, and 37 were lumped at nodes 10 and 12, respectively. Node 18 includes 11,400 pounds of RP1 and node 20 includes 3590 pounds of launcher. SLV-3C propellants for models 1, 2, 4, and 6 were off-loaded in order to give a liftoff thrust-to-weight ratio of 1.2 based on 390,328 pounds of thrust. The remaining weights of Table 3-5 were obtained from current SLV-3C/Centaur data.

3.2.2 LATERAL MODEL. The payload support structure lateral stiffness between nodes 70 and 71, Table 3-6, was based on a 20 cps cantilevered response. The stiffness, $K = m\omega^2$, is also given by

$$K = \frac{P}{\delta} = 1/\left[\frac{\ell^3}{3EI} - \frac{\ell}{KAG}\right]$$

Assume the bending flexibility, $\ell^3/3EI$, equals the shear flexibility ℓ/KAG, then

$$EI = 2\omega^2 m \ell^3/3$$

$$KAG = 2\omega^2 m \ell$$

The lateral stiffness of the truss was based on the beam system of Figure 3-3. This beam model was chosen because it satisfied the negative coupling requirements that exist between the payload ring and the forward ring. The term "negative coupling" is used to mean that the rotation at the end of the truss due to shear load is opposite to

that found in simple beam theory. (See terms δ_{1M_1} and θ_{1P_1} in Table 3-1.) It is necessary to use a beam system to represent the truss because of input requirements for the computer program used. The cantilevered influence coefficients of the forward bay are given by

$$\begin{Bmatrix} \delta_1 \\ \theta_1 \end{Bmatrix} = \begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix} \begin{Bmatrix} \overline{P_1} \\ \overline{M_1} \end{Bmatrix} = \begin{bmatrix} \left(\frac{\ell^3}{12EI_1} + \frac{\ell^3}{24EI_2} + \frac{3\ell}{2KAG}\right) & -\frac{\ell^2}{8EI_2} \\ -\frac{\ell^2}{8EI_2} & \left(\frac{\ell}{EI_1} + \frac{\ell}{2EI_2}\right) \end{bmatrix} \begin{Bmatrix} \overline{P_1} \\ \overline{M_1} \end{Bmatrix}$$

Because $C_{12} = C_{21}$ we can say C_{11}, C_{12}, and C_{22} represent three structural properties of the forward bay. The three chosen were EI_1, EI_2, and KAG. Similarly for the aft bay

$$\begin{Bmatrix} \delta_2 \\ \theta_2 \end{Bmatrix} = \begin{bmatrix} \overline{C_{11}} & \overline{C_{12}} \\ \overline{C_{21}} & \overline{C_{22}} \end{bmatrix} \begin{Bmatrix} \overline{P_2} \\ \overline{M_2} \end{Bmatrix} = \begin{bmatrix} \left(\frac{7}{24}\frac{\overline{\ell}^3}{\overline{EI_1}} + \frac{1}{24}\frac{\overline{\ell}^3}{\overline{EI_2}} + \frac{\overline{\ell}}{\overline{KAG}}\right) & \left(\frac{3\overline{\ell}^2}{8\overline{EI_1}} + \frac{\overline{\ell}^2}{8\overline{EI_2}}\right) \\ \left(\frac{3\overline{\ell}^2}{8\overline{EI_1}} + \frac{\overline{\ell}^2}{8\overline{EI_2}}\right) & \left(\frac{\overline{\ell}}{2\overline{EI_1}} + \frac{\overline{\ell}}{2\overline{EI_2}}\right) \end{bmatrix} \begin{Bmatrix} \overline{P_2} \\ \overline{M_2} \end{Bmatrix}$$

Again the three structural properties represented by the influence coefficient matrix were chosen as $\overline{EI_1}$, $\overline{EI_2}$, and $\overline{KAG}$. The deflections and rotations (Figure 3-3) of the overall beam model of the truss are given by

$$\overline{\Delta_2} = (\overline{P_1} + \overline{P_2})\,\overline{C_{11}} + \left(\overline{M_1} + \overline{M_2} + \frac{\overline{P_1}\,\ell}{2}\right)\overline{C_{12}}$$

$$\overline{\theta_2} = (\overline{P_1} + \overline{P_2})\,\overline{C_{21}} + \left(\overline{M_2} + \frac{\overline{P_1}\,\ell}{2} + \overline{M_1}\right)\overline{C_{22}}$$

$$\overline{\Delta_1} = \overline{\Delta_2} + \frac{\ell}{2}\overline{\theta_2} + \overline{P_1}\,C_{11} + \overline{M_1}\,C_{12}$$

$$\overline{\theta_1} = \overline{\theta_2} + \overline{P_1}\,C_{21} + \overline{M_1}\,C_{22}$$

written in matrix form

$$\begin{Bmatrix} \overline{\Delta_1} \\ \overline{\theta_1} \\ \overline{\Delta_2} \\ \overline{\theta_2} \end{Bmatrix} = \begin{bmatrix} \left(\overline{C_{11}} + \ell\,\overline{C_{12}} + \frac{\ell^2}{4}\overline{C_{22}} + C_{11}\right) & \left(\frac{\ell}{2}\overline{C_{22}} + \overline{C_{12}} + C_{12}\right) & \left(\overline{C_{11}} + \frac{\ell}{2}\overline{C_{21}}\right) & \left(\overline{C_{12}} + \frac{\ell}{2}\overline{C_{22}}\right) \\ \left(\overline{C_{21}} + \frac{\ell}{2}\overline{C_{22}} + C_{21}\right) & (\overline{C_{22}} + C_{22}) & \overline{C_{21}} & \overline{C_{22}} \\ \left(\overline{C_{11}} + \frac{\ell}{2}\overline{C_{12}}\right) & \overline{C_{12}} & \overline{C_{11}} & \overline{C_{12}} \\ \left(\overline{C_{21}} + \frac{\ell}{2}\overline{C_{22}}\right) & \overline{C_{22}} & \overline{C_{21}} & \overline{C_{22}} \end{bmatrix} \begin{Bmatrix} \overline{P_1} \\ \overline{M_1} \\ \overline{P_2} \\ \overline{M_2} \end{Bmatrix}$$

It should be noted that the above matrix has only six independent variables (the lengths are considered fixed by the geometry) and that these six variables are determinable

from only the two left rows of the matrix. This means that it is sufficient to evaluate the chosen beam model by considering the deformations of the truss caused only by loads at the payload ring. This has been done. In order to evaluate the errors due to this simplified approach, Cases 1 and 7 were analyzed for loads applied to the forward ring also as shown in Table 3-1.

Errors in the beam representation of the truss were determined by term by term comparisons of the above matrix and the one shown on Page 3-4. The two left rows are exact because they were set equal to determine the beam properties. The upper-right (4 × 4) quarter must also be exact because of symmetry. The lower-right (4×4) quarter matrix has been found by comparison to be equal (to at least four significant figures) except for the $\bar{\theta}_{2M_2}$ term. This value from Table 3-1 is 4.970×10^{-10} (for Case 1) and is 6.227×10^{-10} ($\overline{C}_{22}$) for the beam model. This discrepancy was not considered important enough to justify the complication of bringing the two terms into agreement (and the risk of exceeding the computer program capacity). The following relations are helpful in determining the beam properties in the mathematical models and are the same as in Figure 3-3. $EI_1 = EI_{72-73}$, $EI_2 = EI_{72-71}$, $KAG = KAG_{72-73} = KAG_{72-71}$, $\overline{EI}_1 = EI_{75-79}$, $\overline{EI}_2 = EI_{73-75}$, and $\overline{KAG} = KAG_{75-79} = KAG_{73-75}$.

The lateral bending stiffness between nodes 73 and 74 (the LH_2 tank support cone) was calculated from

$$EI = \frac{\pi}{4} R^4 E$$

where R is the radius of the conical support and $E = 16 \times 10^6$ psi. The shear stiffness of the cone was estimated since it is no doubt quite stiff by comparison to the other parts of the model.

The lateral stiffness of the Kick Stage adaptor, nodes 79-76, 76-10, 10-11, and 11-15 were specified by LeRC as noted in Section 1. Kick Stage adaptor stiffness was used between nodes 79 and 76 because of the aft ring which occupies most of that distance.

This yielded a relatively stiff model between the nodes and also lumped the weight of the aft ring and beam at the correct station number.

The lateral bending stiffness between nodes 76 and 77 accounted for rotary inertia of the LO_2 bottles attached to the cruciform beam. The LO_2 bottles are located a distance r from the centerline of the missile. The antisymmetric, second, bending mode of the cruciform beam has a natural frequency of 46.1 cps, as determined by a computer solution. For a rotary vibrating mass it follows that:

$$\omega^2 = \frac{K_\theta}{I_\theta}$$

where

$$K_\theta = \frac{EI}{\ell} \quad \text{and } I_\theta = 2mr^2$$

therefore

$$EI_{76-77} = 2mr^2 \ell \omega^2$$

where ℓ is the distance between nodes 76 and 77 and m is an effective mass of 357 pounds. The shear stiffness was calculated such that the deflection due to shear was 1/10 that due to bending, and by doing so, this may compensate for local flexibility of the bottles and their supports. This yields the following expression:

$$KAG_{76-77} = \frac{30\,EI}{\ell^2}$$

The engine stiffness properties, node 77-78, were taken to be one half of the current Centaur engine values since the Centaur analysis includes the stiffness of two engines.

The lateral bending and shear stiffnesses of the nose fairing were taken to be equal to the stiffnesses of the current Surveyor nose fairing.

The stiffness of the translational spring between nodes 73 and 8 (the forward ring to nose fairing tie for models 32 and 33 only) was designed such that the relative motion of these two nodes was small.

The remaining lateral bending and shear stiffnesses were the same as current SLV-3C/Centaur stiffnesses. The lateral stiffness properties for all configurations considered are summarized in Table 3-6. Where two values of EI or KAG appear for one connecting node, the first value is a beginning stiffness and the second value is an ending stiffness for a beam of non-uniform stiffness. Where only one value appears, then the stiffness is constant over the length of the beam element.

The weight distribution for the lateral models are summarized in Table 3-7. The Kick Stage weights are lumped at nodes 70 through 79 and are the same weights as those used for the longitudinal model.

The SLV-3C propellants were off-loaded such that a thrust-to-weight ratio of 1.2 existed for models 3, 5, and 7.

The weight distribution in models 3, 5, and 7 include slosh weight, where slosh weight is that portion of vehicle propellants which can be considered to slosh. For lateral models 8 through 33 slosh weight is not included in the weight distribution.

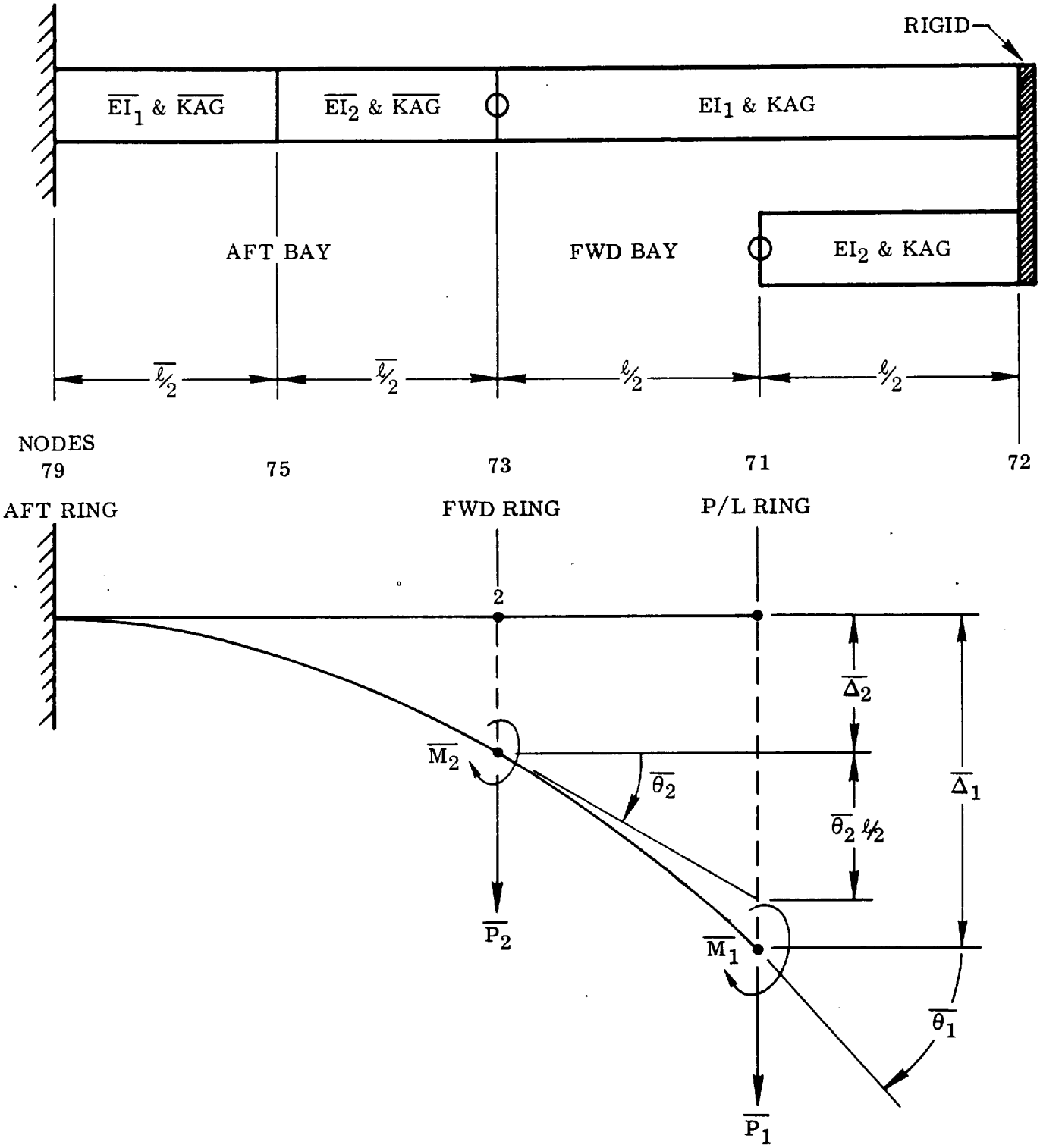


Figure 3-3. Truss Model

TABLE 3-5. WEIGHTS FOR LONGITUDINAL MODELS

Node	Item	Model 1 / Weight (lbs)	2	4	6	34 34A	36 36A	37
1	Payload	3,000	3,000	300	3,000	3,000	300	3,000
2	P/L Ring & Equip	436						
3	Fwd. Ring & Equip	174						
4	LH_2 & Structure	1,390						
5	LO_2 & Structure	6,130						
6	Engine & Structure	380						
7	Aft Ring & Beam	2,840				640		
8	Fwd. Bulkhead, Centaur	1,790				1,290		
9	LH_2 Centaur	5,005				0		
10	Centaur Tank	2,085				1,269		
11	LO_2 Centaur	25,082				0		
12	Aft Bulkhead, Centaur	1,273				2,527		
13	Centaur Engines	754						
14	Fwd. Bulkhead, Atlas	2,182				Jett.		
15	LO_2, Atlas	179,517		181,366	179,517	Jett.		
16	Atlas Tank	1,873				Jett.		
17	RP-1 Atlas	69,223		70,074	69,223	Jett.		
18	Aft Bulkhead, Atlas	14,712				Jett.		
19	Sustainer Engine	1,255				Jett.		
20	Booster Engines	10,600	7,010			Jett.		
21	Launcher	44,000	Jett.					
22	Launcher Pad	0	Jett.					
Total Model Weight (lbs)		373,701	326,111	326,111	326,111	17,990	15,290	17,990

TABLE 3-5. WEIGHTS FOR LONGITUDINAL MODELS (CONTINUED)

Node	Model 38 / Weight (lbs)	40	41	42	43	44	45	46	45A	46A	46B	46C
1	3,000	300	3,000	3,000	300	3,000	3,000	3,000	300	300	300	3,000
2	436	→	→	→	→	→	→	→	→	→	→	→
3	174	→	→	→	→	→	→	→	→	→	→	→
4	1,390	→	→	→	→	→	610	220	610	220	→	→
5	6,130	→	→	→	→	→	2,250	290	2,250	290	→	→
6	380	→	→	→	→	→	→	→	→	→	→	→
7	640	→	→	290	→	→	→	→	→	→	→	→
8	1,290	→	→	Jett.	→	→	→	→	→	→	→	→
9	0	→	→	Jett.	→	→	→	→	→	→	→	→
10	1,019	→	→	Jett.	→	→	→	→	→	→	→	→
11	0	→	→	Jett.	→	→	→	→	→	→	→	→
12	1,273	→	→	Jett.	→	→	→	→	→	→	→	→
13	754	→	→	Jett.	→	→	→	→	→	→	→	→
*	16,486	13,786	16,486	11,800	9,100	11,800	7,140	4,790	4,440	2,090	2,090	4,790

* Total Model Weight, lbs.

TABLE 3-6. STIFFNESSES FOR LATERAL MODELS (BENDING STIFFNESS)

Connecting Nodes	Element	Model 3 / EI (billions of lb-in.^{2})	5	7	8, 9 10, 11	12	13	14	15	16	17	18	19
70-71	B	33.6	3.36	33.6	33.6	33.6	33.6	3.36	3.36	3.36	33.6	33.6	33.6
72-71	B	5.77	5.77	72.3	5.77	11.5	2.31	5.77	11.5	2.31	72.3	-13.8	3.65
8-73	TS*	Not Used											
72-73	B	12.6	12.6	5.03	12.6	10.9	81.8	12.6	10.9	81.8	5.03	4.73	6.23
73-74	B	271.4											
73-75	B	69.2	69.2	14.0	69.2	83.8	45.4	69.2	83.8	45.4	14.0	16.2	9.94
75-79	B	177.7	177.7	40.7	177.7	320.8	75.9	177.7	320.8	75.9	40.7	67.4	18.6
79-76	B	360.0											
76-77	B	0.790											
77-78	B	282.5											
	B	31.4											

Connecting Nodes	Element	Model 20, 21 22, 23 / EI (billions of lb-in.^{2})	24	25	26	27	28	29	30	31	32	33	35, 39
70-71	B	33.6	33.6	33.6	3.36	3.36	3.36	33.6	33.6	33.6	33.6	33.6	33.6
72-	B	17.3	34.6	6.92	17.3	34.6	6.92	216.8	-41.3	11.0	5.77	72.3	5.77
8-73	TS*	Not Used									0.10	0.10	Jett.
72-73	B	37.9	32.7	245.2	37.9	32.7	245.2	15.1	14.2	18.7	12.6	5.03	12.6
73-74	B	271.4											
73-75	B	207.5	251.3	136.1	207.5	251.3	136.1	42.1	48.7	29.8	69.2	14.0	69.2
75-79	B	533.0	962.3	227.7	533.0	962.3	227.7	122.1	202.3	55.7	177.7	40.7	177.7
79-76	B	360.0											
76-77	B	2.30									.790		
77-78	B	282.5											
	B	31.4											

TABLE 3-6. STIFFNESSES FOR LATERAL MODELS (SHEAR STIFFNESS) (CONTINUED)

Connecting Nodes	Element	Model 3 / KAG (millions of lbs)	5	7	8,9 10,11	12	13	14	15	16	17	18	19
70-71	B	18.4	1.84	18.4	18.4	18.4	18.4	1.84	1.84	1.84	18.4	18.4	18.4
72-71	B	20.2	20.2	14.3	20.2	29.7	9.59	20.2	29.7	9.59	14.3	18.5	8.52
72-73	B	20.2	20.2	14.3	20.2	29.7	9.59	20.2	29.7	9.59	14.3	18.5	8.52
73-74	B	41,544.0											
73-75	B	5.28	5.28	5.35	5.28	7.74	2.70	5.28	7.74	2.70	5.35	7.78	2.76
75-79	B	5.28	5.28	5.35	5.28	7.74	2.70	5.28	7.74	2.70	5.35	7.78	2.76
79-76	B	38.0											
76-77	B	658.2											
77-78	B	107.0											
	B	10.7											

Connecting Nodes	Element	Model 20,21 22,23 / KAG (millions of lbs)	24	25	26	27	28	29	30	31	32	33	35, 39
70-71	B	18.4	18.4	18.4	1.84	1.84	1.84	18.4	18.4	18.4	18.4	18.4	18.4
72-71	B	60.6	89.0	28.8	60.6	89.0	28.8	42.9	55.4	25.6	20.2	14.3	20.2
72-73	B	60.6	89.0	28.8	60.6	89.0	28.8	42.9	55.4	25.6	20.2	14.3	20.2
73-74	B	41,544.0											
73-75	B	15.8	23.2	8.09	15.8	23.2	8.09	16.0	23.4	8.28	5.28	5.35	5.28
75-79	B	15.8	23.2	8.09	15.8	23.2	8.09	16.0	23.4	8.28	5.28	5.35	5.28
79-76	B	38.0											
76-77	B	1,915.2									658.2		
77-78	B	107.0											
	B	10.7											

TABLE 3-6. STIFFNESSES FOR LATERAL MODELS (BENDING AND SHEAR STIFFNESS) (SHEET 1 OF 2) (CONTINUED)

Connecting Nodes	Element	EI 10^9 of lb-in.^{2} Models 35 & 39	EI 10^9 of lb-in.^{2} All Other Models	KAG millions of lbs Models 35 & 39	KAG millions of lbs All Other Models
1-2	B	Jett.	5.0	Jett.	0.3
			10.0		0.5
2-3			10.0		0.5
			30.0		0.7
3-4			30.0		0.7
			75.0		1.5
4-5			75 0		1.5
			100.5		2.0
5-6			100.5		2.0
			140.0		2.5
6-7			140.0		2.5
7-8			140.0		2.5
8-9			140.0		2.5
9-76		Jett.	140.0	Jett.	2.5
76-10		360.0	360.0	38.0	38.0
10-11		360.0	360.0	38.0	38.0
11-15		360.0	360.0	38.0	38.0
12-13		45.0	45.0	10.5	10.5
		167.0	167.0	19.0	19.0
13-14		70.0	70.0	19.0	19.0
		110.0	110.0	20.5	20.5
14-15		110.0	110.0	20.5	20.5
		255.0	255.0	22.7	22.7
15-16		255.0	255.0	28.9	28.9
16-17		255.0	255.0	28.9	28.9
17-18		255.0	255.0	28.9	28.9
18-19		255.0	255.0	28.9	28.9
19-20		255.0	255.0	28.9	28.9
20-21	B	255.0	255.0	28.9	28.9

Connecting Nodes	Element	EI 10^9 of lb-in.^{2} Models 35 & 39	EI 10^9 of lb-in.^{2} All Other Models	KAG millions of lbs Models 35 & 39	KAG millions of lbs All Other Models
69-21	B	140.0	140.0	22.6	22.6
		255.0	255.0	29.0	29.0
21-66		320.0	320.0	37.5	37.5
		105.0	105.0	30.0	30.0
66-67		105.0	105.0	30.0	30.0
		182.0	182.0	15.0	15.0
67-68		565.0	565.0	214.0	214.0
		62.8	62.8	21.4	21.4
21-22		Jett.	435.0	Jett.	45.5
22-23			435.0		45.5
23-24			435.0		45.5
24-25			435.0		45.5
25-26			435.0		45.5
26-27			435.0		45.5
27-28			311.5		35.3
28-29			311.5		35.3
29-30			311.5		35.3
30-31			311.5		35.3
31-32			311.5		35.3
			329.8		37.3
32-33			329.8		37.3
			348.1		39.4
33-34			348.1		39.4
34-35			348.1		39.4
35-36			348.1		39.4
			366.4		41.5
36-37			366.4		41.5
	B	Jett.	403.1	Jett.	45.6

TABLE 3-6. STIFFNESSES FOR LATERAL MODELS (BENDING AND SHEAR STIFFNESS) (SHEET 2 OF 2) (CONTINUED)

Connecting Nodes	Element	EI 10^9 of lb-in.^{2} Models 35 & 39	EI 10^9 of lb-in.^{2} All Other Models	KAG millions of lbs Models 35 & 39	KAG millions of lbs All Other Models
37-38	B	Jett.	403.1	Jett.	45.6
			439.7		49.8
38-39			439.7		49.8
			476.4		53.9
39-40			476.4		53.9
			513.0		58.1
40-41			513.0		58.1
			549.7		62.2
41-42			549.7		62.2
42-43			549.7		62.2
43-44			549.7		64.3
			550.0		64.3
44-45			586.3		66.4
			586.3		66.4
45-46			604.6		68.4
46-47			696.2		78.8
47-48			460.0		70.5
			270.0		45.0
48-49			390.0		63.0
			650.0		25.0
49-50			650.0		25.0
			150.0		10.0
50-51	B	Jett.	150.0	Jett.	10.0

Connecting Nodes	Element	EI 10^9 of lb-in.^{2} Models 35 & 39	EI 10^9 of lb-in.^{2} All Other Models	KAG millions of lbs Models 35 & 39	KAG millions of lbs All Other Models
51-52	RS*	Jett.	0.012	Jett.	Not Used
51-52	TS*		0.92		Not Used
52-53	B		2000.0		1000.0
47-54			870.0		118.0
			869.0		118.0
54-55			870.0		118.0
			880.0		125.0
55-56			880.0		125.0
			900.0		139.0
56-57			338.0		13.0
			337.0		18.0
57-58			337.0		18.0
			334.0		18.0
58-59			334.0		18.0
	B		330.0		18.0
54-60	TS*		0.00012		Not Used
56-62	TS*		0.00015		Not Used
60-61	B		1000.0		500.0
61-62	B		1000.0		500.0
62-63	B		1000.0		500.0
63-64	TS*		10.0		Not Used
63-64	RS*		0.0855		Not Used
64-65	B	Jett.	1000.0	Jett.	500.0

NOTE:

* TS stands for translational spring, billions of lb/in., and RS stands for rotational spring, billions of in.-lb/rad. Where two entries appear for one element, these are initial and final values for a non-uniform element.

TABLE 3-7. WEIGHT DISTRIBUTION FOR LATERAL MODELS

Node	Station (in.)	Model 3 / Weight (lbs.)	5	7	8, 20	9, 21	10, 22	11, 23	12, 13, 17 18, 19, 24 25, 29, 30, 31, 32, 33	14, 15, 16 26, 27, 28	35	39
1	-300.49	193.0									Jett.	Jett.
2	-270.49	149.0									Jett.	Jett.
3	-230.49	174.0									Jett.	Jett.
4	-180.49	184.0									Jett.	Jett.
5	-156.0	127.0									Jett.	Jett.
6	-133.0	244.0									Jett.	Jett.
7	-82.0	335.0									Jett.	Jett.
8	-48.0	323.0									Jett.	Jett.
9	-1.0	302.0									Jett.	Jett.
76	20.0	632.0									464.0	464.0
10	68.0	175.0										
11	118.0	175.0										
15	168.0	1,036.0									256.0	256.0
70	-156.0	3,000.0	300.0	3,000.0						300.0	3,000.0	3,000.0
71	-82.0	436.0										
72	-116.0	0										
73	-48.0	174.0										
74	-34.0	1,390.0										
75	-17.0	0										
79	14.0	0										
77	26.0	6,130.0										
78	62.0	380.0										
12	122.0	758.0										
13	141.0	288.0									210.0	210.0
14	149.0	521.0			369.0						206.0	206.0
16	199.0	1,112.0									103.0	103.0
17	229.0	1,164.0									103.0	103.0
18	264.0	1,119.0									65.0	65.0
19	294.0	1,043.0									76.0	76.0
20	324.0	928.0									406.0	200.0
21	361.0	11,269.0									437.0	392.0
69	337.0	8,335.0			5,177.0						236.0	236.0
66	387.0	6,155.0									901.0	315.0
67	402.5	1,096.0										427.0
68	426.7	813.0										
22	387.0	208.0									Jett.	Jett.
23	419.0	173.0									Jett.	Jett.
24	449.0	214.0									Jett.	Jett.
25	474.0	274.0			306.0						Jett.	Jett.
26	504.0	187.0	321.0	187.0	207.0						Jett.	Jett.
27	519.0	7,400.0	9,115.0	7,400.0	163.0						Jett.	Jett.
28	543.23	16,533.0			119.0						Jett.	Jett.

TABLE 3-7. WEIGHT DISTRIBUTION FOR LATERAL MODELS (CONTINUED)

Node	Station (in.)	Model 3 / Weight (lbs)	5	7	8, 20	9, 21	10, 22	11, 23	12, 13, 17, 18, 19, 24, 25, 29, 30, 31, 32, 33	14, 15, 16 26, 27, 28	35	39
29	591.73	23,291.0	23,291.0	23,291.0	159.0	159.0	159.0	159.0	159.0	159.0	Jett.	Jett.
30	644.58	18,840.0	→	→	134.0	→	→	→	→	→	↑	↑
31	673.69	13,390.0	→	→	4,337.0	228.0	96.0	→	→	→	↑	↑
32	702.90	13,360.0	→	→	13,058.0	8,433.0	1,604.0	94.0	1,604.0	→	↑	↑
33	731.91	13,333.0	→	→	13,293.0	13,298.0	11,517.0	4,533.0	11,517.0	→	↑	↑
34	761.02	13,349.0	→	→	13,326.0	13,331.0	13,343.0	13,135.0	13,343.0	→	↑	↑
35	790.13	13,367.0	→	→	13,327.0	13,331.0	13,344.0	13,354.0	13,344.0	→	↑	↑
36	819.24	13,354.0	→	→	13,324.0	13,329.0	13,341.0	13,351.0	13,341.0	→	↑	↑
37	848.35	13,360.0	→	→	13,325.0	13,329.0	13,341.0	13,351.0	13,341.0	→	↑	↑
38	877.46	13,122.0	→	→	13,085.0	13,089.0	13,101.0	13,111.0	13,101.0	→	↑	↑
39	906.57	6,097.0	6,948.0	6097.0	7,188.0	7,190.0	7,197.0	7,202.0	7,197.0	→	↑	↑
40	937.40	10,956.0	→	→	1,011.0	1,011.0	1,012.0	1,012.0	1,012.0	→	↑	↑
41	962.64	9,263.0	→	→	313.0	→	→	→	→	→	↑	↑
42	992.50	10,807.0	→	→	468.0	→	→	→	→	→	↑	↑
43	1,025.0	11,188.0	→	→	2,367.0	757.0	502.0	→	→	→	↑	↑
44	1,057.0	11,227.0	→	→	10,431.0	8,066.0	4,377.0	1,718.0	4377.0	→	↑	↑
45	1,090.0	11,278.0	→	→	11,382.0	11,396.0	11,311.0	9,969.0	11,311.0	→	↑	↑
46	1,122.5	7,491.0	→	→	7,575.0	7,584.0	7,617.0	7,646.0	7,617.0	→	↑	↑
47	1,133.0	6,653.0	→	→	6,534.0	6,541.0	6,569.0	6,594.0	6,569.0	→	↑	↑
48	1,160.54	5,424.0	→	→	5,467.0	5,473.0	5,497.0	5,518.0	5,497.0	→	↑	↑
49	1,175.7	2,046.0	→	→	2,064.0	2,066.0	2,075.0	2,082.0	2,075.0	→	↑	↑
50	1,198.0	655.0	→	→	661.0	662.0	664.0	666.0	664.0	→	↑	↑
51	1,210.0	306.0	→	→	→	→	→	→	→	→	↑	↑
52	1,210.0	0	→	→	→	→	→	→	→	→	↑	↑
53	1,240.0	1,024.0	→	→	→	→	→	→	→	→	↑	↑
54	1,160.0	310.0	→	→	→	→	→	→	→	→	↑	↑
55	1,176.0	877.0	→	→	→	→	→	→	→	→	↑	↑
56	1,206.0	1,400.0	→	→	→	→	→	→	→	→	↑	↑
57	1,212.0	1,243.0	→	→	→	→	→	→	→	→	↑	↑
58	1,242.0	820.0	→	→	→	→	→	→	→	→	↑	↑
59	1,267.0	599.0	→	→	→	→	→	→	→	→	↑	↑
60	1,160.0	0	→	→	→	→	→	→	→	→	↑	↑
61	1,176.0	200.0	→	→	→	→	→	→	→	→	↑	↑
62	1,206.0	0	→	→	→	→	→	→	→	→	↑	↑
63	1,212.0	0	→	→	→	→	→	→	→	→	↑	↑
64	1,212.0	0	→	→	→	→	→	→	→	→	↑	↑
65	1,242.0	1,857.0	→	→	→	→	→	→	→	→	Jett.	Jett.
Total Weight (lbs)		325,633.0	325,633.0	325,633.0	209,702.0	197,064.0	184,457.0	171,883.0	184,456.0	181,756.0	17,991.0	16,485.0

4

VIBRATION MODES

This section presents a discussion of the method used to obtain modal data for the longitudinal and lateral models described in Sections 1 and 3. Modal data is presented for selected models based on mass and stiffness data of Section 3.

4.1 METHOD OF SOLUTION

Natural modes, frequencies, and generalized masses were determined by a digital computer program, Reference 4-1, which uses the weight and flexibility data contained in a mathematical model as well as a coding method to indicate which springs and masses are connected. The same program is used for both longitudinal and lateral modes. The program computes the natural vibrational modes and frequencies for a one-dimensional system consisting of beams, translational springs, and rotational springs. The effect of shear stiffness as well as bending stiffness is included. The structure for which modes are desired must be represented as a group of lumped masses and/or mass inertias connected by beams and/or springs. The program can solve either a free-free case (every point is free to translate and rotate) or a fixed case (at least one point cannot translate and/or rotate). Axial loading of the beam can be included, but only if the stiffness (cross-sectional area) of each beam element is constant. The program is of an intermediate nature; that is, data are collected and arranged for input, modes obtained as output, and the modes used as input to structural load programs and to stability analysis programs. This program is not directly connected to other programs. However, many special printed and punched outputs are available for use as input directly into other programs.

In matrix form, the set of differential equations describing an undamped free vibration system are

$$\left[M\right]\left\{\ddot{q}\right\} + \left[K\right]\left\{q\right\} = \left\{0\right\} \tag{4-1}$$

where

$[M]$ = mass matrix

$[K]$ = stiffness matrix

$\{\ddot{q}\}$ = generalized acceleration vector

$\{q\}$ = generalized displacement vector

Assuming simple harmonic motion of the form

$$\{q\} = \{\psi\} \cos \omega t$$

Equation 4-1 becomes

$$-\omega^2 \left[M \right] \left\{ \psi \right\} + \left[K \right] \left\{ \psi \right\} = \left\{ 0 \right\} \tag{4-2}$$

Making the substitutions $\lambda = 1/\omega^2$ and $[E] = [K]^{-1}$, Equation 4-2 becomes

$$\left[E \right] \left[M \right] \left\{ \psi \right\} = \lambda \left\{ \psi \right\} \tag{4-3}$$

Equation 4-3 is now solved for the eigenvalues λ and the eigenvectors $\{\psi\}$. In Equation 4-3

$[E]\ [M]$ is the dynamic matrix

$\omega = 1/\sqrt{\lambda}$ is the circular frequency

$\{\psi\}$ is a mode shape

It is easier to invert the mass matrix than the stiffness matrix. However, the highest frequency (lowest eigenvalue) would be obtained first. Thus it would be necessary to obtain all the eigenvalues in order to obtain the lowest frequency. For this reason, the more laborious route of inverting the stiffness matrix is used. Since the lowest frequencies are those usually desired, they can be obtained without obtaining all the eigenvalues.

The computer program also computes the generalized mass for a given mode:

$$M = \left\{ \psi \right\}^T \left[M \right] \left\{ \psi \right\}$$

This term is useful in computing structural response.

4.2 MODAL DATA

Selected modal data for all Centaur/Kick Stage longitudinal models are presented in Tables 4-1 and 4-2 for the first and second modes. These tables include the modal frequency, generalized mass, and modal displacements at significant Kick Stage masses and at the Centaur engine. Modes have in general been normalized to the largest modal amplitude.

Tables 4-3 through 4-38 present complete generalized mass, natural frequency, modal displacement, and modal slope data for the first 5 modes for math models 1, 2, 3, 10, 17, 32, 33, 34, 35, 42, 45, and 46.

In Tables 4-1 and 4-2, models 46B and 46C are for special variations on Kick Stage and payload stiffnesses. Model 46B has a 60 cps longitudinal payload natural frequency while all other longitudinal models had an uncoupled payload longitudinal natural frequency of 20 cps. Model 46C is a model with a cruciform beam having a modulus of elasticity of $E = 30 \times 10^6$; all other models were for Kick Stage cruciform beams with $E = 10.3 \times 10^6$ psi.

TABLE 4-1. SELECTED CENTAUR KICK STAGE MODAL DATA, FIRST MODE

Condition*	Payload Weight (lb)	Model	Genl'zd Mass $\frac{lb\text{-}sec^2}{in.}$	Frequency (cps)	Modal Amplitude, N. D.				
					Payload	Kick Stage LH_2	Kick Stage LO_2	Kick Stage Engine	Centaur Engines
CMES2	3000	34	7.90	13.7	-0.637	-0.124	0.451	1.000	-0.168
CMES2	300	36	6.32	14.8	-0.448	-0.181	0.405	1.000	-0.459
CMES2	3000	37	12.2	11.9	1.000	0.196	-0.434	-0.819	-0.110
CMECO2	3000	38	8.75	13.8	-0.732	-0.136	0.448	1.000	-0.129
CMECO2	300	40	5.90	15.8	-0.807	-0.263	0.368	1.000	-0.458
CMECO2	3000	41	12.6	11.9	1.000	0.194	-0.463	-0.875	-0.093
KMES1	3000	42	11.3	14.4	-0.933	-0.104	0.452	1.000	—
KMES1	300	43	0.970	18.4	1.000	0.0892	-0.0706	-2.32	—
KMES1	3000	44	13.5	11.9	-0.994	-0.197	0.511	1.000	—
KMECO1	3000	45	5.19	16.8	-0.558	0.120	0.538	1.000	—
KMECO1	300	45A	0.912	19.2	1.000	0.0098	-0.109	-0.243	—
KMECO2	3000	46	1.82	21.7	-0.248	0.239	0.556	1.000	—
KMECO2	300	46A	0.966	20.5	1.000	-0.112	-0.215	-0.357	—
KMECO2	300	46B	6.02	29.0	1.000	0.492	-0.529	-2.02	—
KMECO2	3000	46C	5.38	24.8	-0.477	0.726	1.000	1.32	—

NOTE:
*CMES2 = Centaur Second Main Engine Start
CMECO2 = Centaur Second Main Engine Cutoff
KMES2 = Kick Stage Second Main Engine Start
KMECO2 = Kick Stage Second Main Engine Cutoff

TABLE 4-2. SELECTED CENTAUR KICK STAGE MODAL DATA, SECOND MODE

Condition*	Payload Weight (lb)	Model	Genl'zd Mass $\frac{lb\text{-}sec^2}{in.}$	Frequency (cps)	Modal Amplitude, N. D.				
					Payload	Kick Stage LH_2	Kick Stage LO_2	Kick Stage Engine	Centaur Engines
CMES2	3000	34	19.96	16.4	-0.954	0.152	-0.289	-0.832	1.000
CMES2	300	36	0.853	19.1	1.000	0.0168	-0.0009	-0.0035	-0.0831
CMES2	3000	37	9.66	15.5	0.321	-0.115	0.379	1.000	-0.706
CMECO2	3000	38	14.5	18.2	-0.721	0.313	-0.272	-0.942	1.000
CMECO2	300	40	0.899	19.5	1.000	-0.0221	0.0182	0.0726	-0.119
CMECO2	3000	41	8.82	17.3	0.341	-0.233	0.318	1.000	-0.781
KMES1	3000	42	4.24	30.2	0.256	-0.777	0.0554	1.000	——
KMES1	300	43	4.86	25.6	1.000	-0.723	0.136	1.05	——
KMES1	3000	44	6.40	27.1	0.332	-1.04	0.0770	1.000	——
KMECO1	3000	45	2.60	35.7	0.174	-0.710	-0.0136	1.000	——
KMECO1	300	45A	7.18	29.6	-0.840	0.975	-0.214	-1.74	——
KMECO2	3000	46	3.46	40.5	0.209	-1.01	-0.243	1.000	——
KMECO2	300	46A	6.10	32.3	-0.626	0.879	-0.232	-1.891	——
KMECO2	300	46B	1.59	57.9	1.000	-0.600	-0.306	0.315	——
KMECO2	3000	46C	4.14	55.8	-0.133	1.000	-0.055	-1.38	——

NOTE:
*CMES2 = Centaur Second Main Engine Start
CMECO2 = Centaur Second Main Engine Cutoff
KMES2 = Kick Stage Second Main Engine Start
KMECO2 = Kick Stage Second Main Engine Cutoff

TABLE 4-3. LONGITUDINAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 1

Mode	1	2	3	4	5
Generalized Mass lb-sec^2/in.	568.54	78.934	47.786	8.5741	10.002
Natural Frequency (cps)	2.5983	6.2415	8.6354	12.843	14.224
Node No.	Deflection in./in.	Deflection in./in.	Deflection in./in.	Deflection in./in.	Deflection in./in.
1	6.8806-01*	7.9038-01	6.2385-01	-1.8039-02	1.0000+00
2	6.7647-01	7.1358-01	5.0781-01	-1.0616-02	4.9532-01
3	6.6741-01	6.5411-01	4.1898-01	-5.1013-03	1.2501-01
4	6.6821-01	6.5866-01	4.2460-01	-5.2551-03	1.2967-01
5	6.9061-01	8.1748-01	6.9460-01	4.8802-01	-1.8882-01
6	7.1668-01	1.0000-00	1.0000-00	1.0000-00	-4.3996-01
7	6.6495-01	6.3865-01	3.9700-01	-3.9208-03	5.1077-02
8	6.5142-01	5.5166-01	2.6702-01	-1.1504-01	-4.1554-02
9	6.4827-01	5.2579-01	2.1773-01	-1.9102-01	-1.0075-01
10	6.4095-01	4.8676-01	1.7455-01	-1.8020-01	-9.8023-02
11	6.4254-01	4.9387-01	1.7953-01	-1.9221-01	-1.0623-01
12	6.4754-01	5.1661-01	1.9582-01	-2.3397-01	-1.3553-01
13	6.4755-01	5.1668-01	1.9588-01	-2.3411-01	-1.3564-01
14	6.2540-01	4.0784-01	9.4419-02	-1.3986-01	-7.7198-02
15	1.0000-00	-1.7225-01	2.2358-02	5.1431-03	2.4560-03
16	4.9728-01	2.3822-01	-1.7245-01	-1.5984-02	-1.2184-02
17	4.4801-01	3.0246-01	-3.9070-01	4.1540.02	1.7347-02
18	4.0294-01	2.2650-01	-2.2599-01	5.2106-03	-1.2347-03
19	4.0338-01	2.2795-01	-2.2876-01	5.3544-03	-1.2767-03
20	2.8708-01	1.6410-01	-1.6684-01	4.0422-03	-9.7835-04
21	5.6641-03	3.2526-03	-3.3239-03	8.1587-05	-1.9854-05
22	0.	0.	0.	0.	0.

NOTE:
*6.8806-01 = 6.8806×10^{-1}

TABLE 4-4. LONGITUDINAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 2

Mode	1	2	3	4	5
Generalized Mass lb-sec^2/in.	300.96	33.870	8.5431	10.004	49.637
Natural Frequency (cps)	5.3321	7.9974	12.842	14.224	24.826
Node No.	Deflection in./in.	Deflection in./in.	Deflection in./in.	Deflection in./in.	Deflection in./in.
1	8.4278-01	6.7269-01	-1.7436-02	1.0000	4.8066-02
2	7.8301-01	5.6536-01	-1.0263-02	4.9532-01	-2.5832-02
3	7.3657-01	4.8293-01	-4.9338-03	1.2502-01	-7.2462-02
4	7.4031-01	4.8847-01	-5.0825-03	1.2967-01	-8.1362-02
5	8.6087-01	7.2785-01	4.8809-01	-1.8887-01	1.5301-02
6	1.0000-00	1.0000-00	1.0000-00	-4.4006-01	1.1410-01
7	7.2433-01	4.6222-01	-3.7929-03	5.1086-02	-7.2939-02
8	6.5605-01	3.4210-01	-1.1499-01	-4.1534-02	-6.5027-02
9	6.3725-01	2.9962-01	-1.9100-01	-1.0072-01	-1.1627-01
10	6.0446-01	2.5534-01	-1.8020-01	-9.7997-02	-3.9978-02
11	6.1086-01	2.6155-01	-1.9221-01	-1.0621-01	-5.4931-02
12	6.3122-01	2.8173-01	-2.3395-01	-1.3550-01	-1.3038-01
13	6.3129-01	2.8180-01	-2.3410-01	-1.3560-01	-1.3069.01
14	5.3698-01	1.7052-01	-1.3991-01	-7.7184-02	6.6492-02
15	-5.3682-01	4.8124-03	5.1610-03	2.4569-03	-7.6991-03
16	5.0227-01	-9.6586-02	-1.6208-02	-1.2207-02	4.2684-01
17	6.8315-01	-2.3211-01	3.9329-02	1.7790-02	-2.2395-01
18	5.8710-01	-1.5763-01	5.3641-03	-1.3779-03	7.0542-01
19	5.8983-01	-1.5929-01	5.5121-03	-1.4248-03	7.8414-01
20	5.9519-01	-1.6260-01	5.8231-03	-1.5254-03	1.0000-00

TABLE 4-5. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 3

Mode 1
Generalized Mass = 30.307 lb-sec^2/in.
Frequency = 1.5623 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	1.0000E 00	1.6243E-03	1.7853E-03
2	-270.5	9.4760E-01	1.6217E-03	1.7534E-03
3	-230.5	8.7724E-01	1.6155E-03	1.7620E-03
4	-180.5	7.9086E-01	1.6080E-03	1.7011E-03
5	-156.0	7.4930E-01	1.6044E-03	1.6893E-03
6	-133.0	7.1057E-01	1.6012E-03	1.6825E-03
7	-82.0	6.2454E-01	1.5922E-03	1.6926E-03
8	-48.0	5.6677E-01	1.5837E-03	1.7037E-03
9	-1.0	4.8662E-01	1.5677E-03	1.7043E-03
76	20.0	4.5077E-01	1.5589E-03	1.6138E-03
10	68.0	3.7405E-01	1.5285E-03	1.5821E-03
11	118.0	2.9602E-01	1.4830E-03	1.5369E-03
15	168.0	2.2060E-01	1.4232E-03	1.4684E-03
70	-156.0	7.8080E-01	2.0831E-03	2.1149E-03
71	-82.0	6.2548E-01	2.0354E-03	2.0352E-03
72	-116.0	6.8999E-01	1.8459E-03	1.8459E-03
73	-48.0	5.6884E-01	1.6131E-03	1.6797E-03
74	-34.0	5.4625E-01	1.6131E-03	1.6131E-03
75	-17.0	5.1414E-01	1.5790E-03	1.7464E-03
79	14.0	4.6027E-01	1.5609E-03	1.6563E-03
77	26.0	4.4151E-01	1.5327E-03	1.5320E-03
78	62.0	3.8637E-01	1.5325E-03	1.5291E-03
12	122.0	2.8627E-01	1.4236E-03	1.4288E-03
13	141.0	2.5915E-01	1.4236E-03	1.4269E-03
14	149.0	2.4774E-01	1.4234E-03	1.4278E-03
16	199.0	1.7506E-01	1.3600E-03	1.4376E-03
17	229.0	1.3292E-01	1.2908E-03	1.3699E-03
18	264.0	8.6514E-02	1.1998E-03	1.2800E-03
19	294.0	4.9383E-02	1.1130E-03	1.1938E-03
20	324.0	1.4966E-02	1.0179E-03	1.0991E-03
21	361.0	-2.3360E-02	9.8926E-04	9.2216E-04
69	337.0	-2.0216E-03	8.8925E-04	8.8907E-04
66	387.0	-4.6565E-02	8.8953E-04	8.9183E-04
67	402.5	-6.0377E-02	8.8961E-04	8.9075E-04
68	426.7	-8.1911E-02	8.8962E-04	8.9040E-04
22	397.0	-4.6982E-02	8.3177E-04	8.7948E-04
23	419.0	-7.3932E-02	7.5638E-04	8.0403E-04
24	449.0	-9.6933E-02	6.8107E-04	7.2863E-04
25	474.0	-1.1433E-01	6.1489E-04	6.6231E-04
26	504.0	-1.3295E-01	5.3139E-04	5.7865E-04
27	519.0	-1.4131E-01	4.8796E-04	5.3832E-04
28	543.2	-1.5321E-01	3.8697E-04	4.3152E-04
29	591.7	-1.6864E-01	1.7653E-04	1.9820E-04
30	644.6	-1.7216E-01	-5.9174E-05	-6.2899E-05
31	673.7	-1.6810E-01	-1.8895E-04	-2.1213E-04

TABLE 4-5. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 3 (CONTINUED)

Mode 1

Generalized Mass = 30.307 lb-sec^2/in.

Frequency = 1.5623 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	-1.5986E-01*	-3.1332E-04	-3.4988E-04
33	731.9	-1.4787E-01	-4.2677E-04	-4.7443E-04
34	761.0	-1.3231E-01	-5.3301E-04	-5.9351E-04
35	790.1	-1.1342E-01	-6.3354E-04	-7.0380E-04
36	819.2	-9.1496E-02	-7.2416E-04	-7.9947E-04
37	848.3	-6.7063E-02	-8.0151E-04	-8.7576E-04
38	877.5	-4.0635E-02	-8.6529E-04	-9.3695E-04
39	906.6	-1.2620E-02	-9.1737E-04	-9.8493E-04
40	937.4	1.8383E-02	-9.6163E-04	-1.0241E-03
41	952.6	4.4544E-02	-9.9052E-04	-1.0476E-03
42	992.5	7.6228E-02	-1.0182E-03	-1.0728E-03
43	1025.0	1.1145E-01	-1.0421E-03	-1.0918E-03
44	1057.0	1.4657E-01	-1.0597E-03	-1.1023E-03
45	1090.0	1.8303E-01	-1.0717E-03	-1.1061E-03
46	1122.5	2.1897E-01	-1.0791E-03	-1.1045E-03
47	1133.0	2.3053E-01	-1.0805E-03	-1.0923E-03
48	1160.5	2.6063E-01	-1.0821E-03	-1.0918E-03
49	1175.7	2.7714E-01	-1.0824E-03	-1.0917E-03
50	1198.0	3.0151E-01	-1.0828E-03	-1.0965E-03
51	1210.0	3.1464E-01	-1.0831E-03	-1.0944E-03
52	1210.0	3.1464E-01	-1.3342E-03	-1.3343E-03
53	1240.0	3.5467E-01	-1.3343E-03	-1.3343E-03
54	1160.0	2.5986E-01	-1.0820E-03	-1.0877E-03
55	1176.0	2.7727E-01	-1.0826E-03	-1.0883E-03
56	1206.0	3.0992E-01	-1.0831E-03	-1.0943E-03
57	1212.0	3.1651E-01	-1.0832E-03	-1.0931E-03
58	1242.0	3.4922E-01	-1.0835E-03	-1.0886E-03
59	1267.0	3.7639E-01	-1.0836E-03	-1.0867E-03
60	1160.0	2.5852E-01	-1.1686E-03	-1.1683E-03
61	1176.0	2.7721E-01	-1.1686E-03	-1.1683E-03
62	1206.0	3.1226E-01	-1.1688E-03	-1.1688E-03
63	1212.0	3.1928E-01	-1.1688E-03	-1.1692E-03
64	1212.0	3.1928E-01	-1.2474E-03	-1.2478E-03
65	1242.0	3.5671E-01	-1.2476E-03	-1.2479E-03

*1.5986E-01 = 1.5986×10^{-1}

**Includes bending and shear slope

TABLE 4-6. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 3

Mode 2
Generalized Mass = 31.268 lb-sec^2/in.
Frequency = 3.8254 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	1.0000E 00	2.3838E-03	3.3547E-03
2	-270.5	9.0630E-01	2.3738E-03	3.1547E-03
3	-230.5	7.7901E-01	2.3370E-03	3.1839E-03
4	-180.5	6.3021E-01	2.2932E-03	2.8138E-03
5	-156.0	5.6207E-01	2.2726E-03	2.7332E-03
6	-133.0	5.0001E-01	2.2543E-03	2.6807E-03
7	-82.0	3.6260E-01	2.2047E-03	2.7040E-03
8	-48.0	2.7017E-01	2.1589E-03	2.7207E-03
9	-1.0	1.4292E-01	2.0764E-03	2.6773E-03
76	20.0	8.6885E-02	2.0319E-03	2.2559E-03
10	68.0	-1.5482E-02	1.8826E-03	2.0545E-03
11	118.0	-1.1339E-01	1.6827E-03	1.8541E-03
15	168.0	-2.0014E-01	1.4375E-03	1.5565E-03
70	-156.0	7.5440E-01	5.0722E-03	5.2563E-03
71	-82.0	3.7225E-01	4.7962E-03	4.7984E-03
72	-116.0	5.0822E-01	3.6828E-03	3.6828E-03
73	-48.0	2.8389E-01	2.3346E-03	2.6617E-03
74	-34.0	2.5121E-01	2.3344E-03	2.3344E-03
75	-17.0	1.8953E-01	2.1409E-03	2.9424E-03
79	14.0	9.9777E-02	2.0426E-03	2.4990E-03
77	26.0	7.4764E-02	2.0159E-03	2.0154E-03
78	62.0	2.1921E-03	2.0159E-03	2.0158E-03
12	122.0	-1.3466E-01	1.4361E-03	1.4215E-03
13	141.0	-1.6175E-01	1.4363E-03	1.4264E-03
14	149.0	-1.7315E-01	1.4366E-03	1.4225E-03
16	199.0	-2.4723E-01	1.1935E-03	1.3882E-03
17	229.0	-2.8487E-01	9.3725E-04	1.1162E-03
18	264.0	-3.1807E-01	6.1526E-04	7.7644E-04
19	294.0	-3.3672E-01	3.2138E-04	4.6426E-04
20	324.0	-3.4578E-01	1.2928E-05	1.3841E-04
21	361.0	-3.4329E-01	-3.8500E-04	-4.2701E-04
69	337.0	-3.5678E-01	-3.9102E-04	-5.8814E-04
66	387.0	-3.3653E-01	-3.7598E-04	-2.9312E-04
67	402.5	-3.3139E-01	-3.7406E-04	-3.4194E-04
68	426.7	-3.2245E-01	-3.7372E-04	-3.5539E-04
22	387.0	-3.2493E-01	-5.4552E-04	-7.8598E-04
23	419.0	-2.9689E-01	-7.1974E-04	-9.6215E-04
24	449.0	-2.6584E-01	-8.5949E-04	-1.1037E-03
25	474.0	-2.3696E-01	-9.5839E-04	-1.2046E-03
26	504.0	-1.9927E-01	-1.0558E-03	-1.3037E-03
27	519.0	-1.7940E-01	-1.0958E-03	-1.4086E-03
28	543.2	-1.4280E-01	-1.1668E-03	-1.5941E-03
29	591.7	-6.1242E-02	-1.2204E-03	-1.7281E-03
30	644.6	2.9903E-02	-1.1246E-03	-1.6506E-03
31	673.7	7.5914E-02	-1.0003E-03	-1.4927E-03

TABLE 4-6. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 3 (CONTINUED)

Mode 2
Generalized Mass = 31.268 lb-sec^2/in.
Frequency = 3.8254 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	1.1614E-01*	-8.3326E-04	-1.2469E-03
33	731.9	1.4834E-01	-6.3779E-04	-9.6261E-04
34	761.0	1.7210E-01	-4.1561E-04	-6.5921E-04
35	790.1	1.8649E-01	-1.7007E-04	-3.2226E-04
36	819.2	1.9069E-01	8.4778E-05	3.1544E-05
37	848.3	1.8485E-01	3.2645E-04	3.6034E-04
38	877.5	1.7004E-01	5.4402E-04	6.4579E-04
39	906.6	1.4758E-01	7.3483E-04	8.7223E-04
40	937.4	1.1773E-01	9.0807E-04	1.0639E-03
41	962.6	8.9048E-02	1.0282E-03	1.1991E-03
42	992.5	5.1092E-02	1.1494E-03	1.3369E-03
43	1025.0	5.5711E-03	1.2599E-03	1.4515E-03
44	1057.0	-4.2237E-02	1.3458E-03	1.5268E-03
45	1090.0	-9.3418E-02	1.4074E-03	1.5659E-03
46	1122.5	-1.4455E-01	1.4474E-03	1.5719E-03
47	1133.0	-1.6089E-01	1.4555E-03	1.5155E-03
48	1160.5	-2.0270E-01	1.4646E-03	1.5141E-03
49	1175.7	-2.2552E-01	1.4665E-03	1.5184E-03
50	1198.0	-2.5955E-01	1.4690E-03	1.5515E-03
51	1210.0	-2.7802E-01	1.4711E-03	1.5408E-03
52	1210.0	-2.7802E-01	3.2738E-03	3.2744E-03
53	1240.0	-3.7626E-01	3.2740E-03	3.2746E-03
54	1160.0	-2.0108E-01	1.4643E-03	1.4980E-03
55	1176.0	-2.2515E-01	1.4680E-03	1.5034E-03
56	1206.0	-2.7022E-01	1.4715E-03	1.5347E-03
57	1212.0	-2.7954E-01	1.4720E-03	1.5267E-03
58	1242.0	-3.2494E-01	1.4737E-03	1.5029E-03
59	1267.0	-3.6224E-01	1.4740E-03	1.4921E-03
60	1160.0	-1.9025E-01	2.0987E-03	2.0961E-03
61	1176.0	-2.2378E-01	2.0989E-03	2.0962E-03
62	1206.0	-2.8668E-01	2.1001E-03	2.0998E-03
63	1212.0	-2.9930E-01	2.1005E-03	2.1027E-03
64	1212.0	-2.9930E-01	2.7451E-03	2.7472E-03
65	1242.0	-3.8173E-01	2.7462E-03	2.7484E-03

*1.1614E-01 = 1.1614×10^{-1}

**Includes bending and shear slope

TABLE 4-7. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 3

Mode 3
Generalized Mass = 36.820 lb-sec^2/in.
Frequency = 6.3506 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	-2.8338E-02	9.2116E-04	8.4566E-04
2	-270.5	-5.4311E-02	9.2241E-04	8.4375E-04
3	-230.5	-8.7505E-02	9.2592E-04	8.0108E-04
4	-180.5	-1.2828E-01	9.3146E-04	8.1982E-04
5	-156.0	-1.4808E-01	9.3466E-04	8.0720E-04
6	-133.0	-1.6660E-01	9.3801E-04	7.8693E-04
7	-82.0	-2.0529E-01	9.4992E-04	7.0851E-04
8	-48.0	-2.2767E-01	9.6379E-04	6.0497E-04
9	-1.0	-2.5393E-01	9.9549E-04	5.1272E-04
76	20.0	-2.6357E-01	1.0155E-03	9.8052E-04
10	68.0	-3.0903E-01	7.2795E-04	7.9879E-04
11	118.0	-3.4095E-01	4.1010E-04	4.7477E-04
15	168.0	-3.5622E-01	7.5189E-05	4.4547E-05
70	-156.0	1.0000E 00	1.2148E-02	1.2821E-02
71	-82.0	7.6118E-02	1.1140E-02	1.1167E-02
72	-116.0	3.5631E-01	6.9976E-03	6.9976E-03
73	-48.0	-2.0096E-02	2.0727E-03	3.0499E-03
74	-34.0	-4.9115E-02	2.0728E-03	2.0728E-03
75	-17.0	-1.4582E-01	1.3849E-03	3.6976E-03
79	14.0	-2.5544E-01	1.0511E-03	2.3681E-03
77	26.0	-2.7081E-01	1.3197E-03	1.3276E-03
78	62.0	-3.1979E-01	1.3215E-03	1.3682E-03
12	122.0	-3.5718E-01	6.5278E-05	-4.1031E-05
13	141.0	-3.5695E-01	6.6983E-05	-2.9026E-06
14	149.0	-3.5688E-01	6.9415E-05	-2.4399E-05
16	199.0	-3.5247E-01	-2.1283E-04	-2.9252E-04
17	229.0	-3.3877E-01	-4.8334E-04	-6.1913E-04
18	264.0	-3.1084E-01	-7.8116E-04	-9.6988E-04
19	294.0	-2.7742E-01	-1.0158E-03	-1.2500E-03
20	324.0	-2.3608E-01	-1.2265E-03	-1.4970E-03
21	361.0	-1.7587E-01	-1.4482E-03	-1.7106E-03
59	337.0	-2.1779E-01	-1.4583E-03	-1.7899E-03
66	387.0	-1.4177E-01	-1.4392E-03	-1.3516E-03
67	402.5	-1.2007E-01	-1.4377E-03	-1.4093E-03
68	426.7	-8.5369E-02	-1.4374E-03	-1.4240E-03
22	387.0	-1.2117E-01	-1.5057E-03	-2.1301E-03
23	419.0	-5.2632E-02	-1.5158E-03	-2.1417E-03
24	449.0	1.1009E-02	-1.4644E-03	-2.0906E-03
25	474.0	6.2259E-02	-1.3765E-03	-2.0019E-03
26	504.0	1.2005E-01	-1.2171E-03	-1.8407E-03
27	519.0	1.4690E-01	-1.1153E-03	-1.7648E-03
28	543.2	1.8715E-01	-8.4682E-04	-1.3422E-03
29	591.7	2.2867E-01	-2.2253E-04	-2.2528E-04
30	644.6	2.0578E-01	4.5454E-04	9.9021E-04
31	673.7	1.6567E-01	7.6402E-04	1.6563E-03

TABLE 4-7. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 3 (CONTINUED)

Mode 3

Generalized Mass = 36.820 lb-sec^2/in.

Frequency = 6.3506 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	1.1089E-01*	9.8263E-04	2.0299E-03
33	731.9	4.8668E-02	1.0907E-03	2.1944E-03
34	761.0	-1.6457E-02	1.0901E-03	2.2163E-03
35	790.1	-7.9317E-02	9.8152E-04	2.0402E-03
36	819.2	-1.3352E-01	7.7447E-04	1.6381E-03
37	848.3	-1.7373E-01	5.0335E-04	1.1029E-03
38	877.5	-1.9780E-01	2.0063E-04	5.4651E-04
39	906.6	-2.0578E-01	-1.0987E-04	6.2095E-05
40	937.4	-2.0109E-01	-4.3158E-04	-3.9473E-04
41	962.6	-1.8600E-01	-6.8032E-04	-7.7609E-04
42	992.5	-1.5698E-01	-9.5527E-04	-1.1644E-03
43	1025.0	-1.1275E-01	-1.2303E-03	-1.5319E-03
44	1057.0	-5.8708E-02	-1.4652E-03	-1.8181E-03
45	1090.0	4.9647E-03	-1.6501E-03	-2.0110E-03
46	1122.5	7.2375E-02	-1.7839E-03	-2.1001E-03
47	1133.0	9.4192E-02	-1.8138E-03	-1.9772E-03
48	1160.5	1.4862E-01	-1.8457E-03	-1.9777E-03
49	1175.7	1.7851E-01	-1.8538E-03	-2.0234E-03
50	1198.0	2.2471E-01	-1.8559E-03	-2.1841E-03
51	1210.0	2.5062E-01	-1.8769E-03	-2.1647E-03
52	1210.0	2.5062E-01	-1.1933E-02	-1.1936E-02
53	1240.0	6.0872E-01	-1.1935E-02	-1.1937E-02
54	1160.0	1.4621E-01	-1.8503E-03	-1.9845E-03
55	1176.0	1.7866E-01	-1.8661E-03	-2.0284E-03
56	1206.0	2.3944E-01	-1.8796E-03	-2.0759E-03
57	1212.0	2.5199E-01	-1.8812E-03	-2.0251E-03
58	1242.0	3.1175E-01	-1.8858E-03	-1.9645E-03
59	1267.0	3.6014E-01	-1.8866E-03	-1.9361E-03
60	1160.0	6.5100E-02	-6.0295E-03	-6.0100E-03
61	1176.0	1.6127E-01	-6.0307E-03	-6.0111E-03
62	1206.0	3.4171E-01	-6.0398E-03	-6.0354E-03
63	1212.0	3.7802E-01	-6.0424E-03	-6.0534E-03
64	1212.0	3.7802E-01	-1.0933E-02	-1.0944E-02
65	1242.0	7.0650E-01	-1.0943E-02	-1.0954E-02

*1.1089E-01 = 1.1089×10^{-1}

**Includes bending and shear slope

TABLE 4-8. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 3

Mode 4
Generalized Mass = 2.7318 lb-sec^2/in.
Frequency = 7.0577 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	1.0000E 00	1.5126E-03	4.7968E-03
2	-270.5	8.7973E-01	1.4582E-03	4.0961E-03
3	-230.5	7.1266E-01	1.3337E-03	4.1455E-03
4	-180.5	5.4092E-01	1.1869E-03	2.8786E-03
5	-156.0	4.7336E-01	1.1188E-03	2.5909E-03
6	-133.0	4.1654E-01	1.0586E-03	2.4013E-03
7	-82.0	2.9260E-01	8.9771E-04	2.4440E-03
8	-48.0	2.0851E-01	7.5107E-04	2.4659E-03
9	-1.0	9.5254E-02	4.8969E-04	2.3024E-03
76	20.0	4.7730E-02	3.4994E-04	7.8677E-04
10	68.0	2.9614E-02	3.3115E-04	3.6762E-04
11	118.0	1.1901E-02	3.0215E-04	3.3911E-04
15	168.0	-4.1336E-03	2.6340E-04	2.9277E-04
70	-156.0	-3.1952E-01	-4.0462E-03	-4.3115E-03
71	-82.0	-1.0277E-02	-3.6482E-03	-3.6596E-03
72	-116.0	-9.5435E-02	-2.0103E-03	-2.0103E-03
73	-48.0	1.8608E-03	-6.6817E-05	-4.5635E-04
74	-34.0	2.7963E-03	-6.6821E-05	-6.6821E-05
75	-17.0	2.8612E-02	2.0400E-04	-7.2188E-04
79	14.0	4.9015E-02	3.3584E-04	-1.9139E-04
77	26.0	4.5836E-02	2.9714E-04	2.9569E-04
78	62.0	3.5203E-02	2.9689E-04	2.9052E-04
12	122.0	8.0787E-03	2.6364E-04	2.6661E-04
13	141.0	3.0285E-03	2.6359E-04	2.6535E-04
14	140.0	9.0556E-04	2.6353E-04	2.6532E-04
16	199.0	-1.3205E-02	2.2231E-04	2.7035E-04
17	229.0	-2.0618E-02	1.7757E-04	2.2220E-04
18	264.0	-2.7324E-02	1.1963E-04	1.5946E-04
19	294.0	-3.1225E-02	6.5551E-05	9.9811E-05
20	324.0	-3.3278E-02	7.9743E-06	3.6644E-05
21	361.0	-3.3158E-02	-6.7024E-05	-8.7048E-05
69	337.0	-3.6238E-02	-6.9105E-05	-1.3725E-04
66	387.0	-3.2478E-02	-6.4093E-05	-3.7050E-05
67	402.5	-3.1707E-02	-6.3475E-05	-5.3112E-05
68	426.7	-3.0208E-02	-6.3369E-05	-5.7523E-05
22	387.0	-2.8733E-02	-9.5935E-05	-1.8446E-04
23	419.0	-2.2362E-02	-1.2292E-04	-2.1200E-04
24	449.0	-1.5725E-02	-1.3956E-04	-2.2904E-04
25	474.0	-9.8896E-03	-1.4698E-04	-2.3681E-04
26	504.0	-2.7421E-03	-1.4815E-04	-2.3815E-04
27	519.0	8.1375E-04	-1.4555E-04	-2.4824E-04
28	543.2	7.0044E-03	-1.3347E-04	-2.4045E-04
29	591.7	1.7276E-02	-8.8499E-05	-1.5803E-04
30	644.6	2.2305E-02	-1.8796E-05	-2.8885E-05
31	673.7	2.1662E-02	2.2146E-05	6.3383E-05

TABLE 4-8. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 3 (CONTINUED)

Mode 4
Generalized Mass = 2.7318 lb-sec^2/in.
Frequency = 7.0577 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.0	1.8703E-02*	5.8228E-05	1.3403E-04
33	731.9	1.3978E-02	8.5093E-05	1.8512E-04
34	761.0	7.9704E-03	1.0172E-04	2.2069E-04
35	790.1	1.2404E-03	1.0694E-04	2.3379E-04
36	819.2	-5.4253E-03	9.9931E-05	2.1692E-04
37	848.3	-1.1228E-02	8.2760E-05	1.7669E-04
38	877.5	-1.5681E-02	5.8443E-05	1.2635E-04
39	906.6	-1.8577E-02	2.9802E-05	7.7406E-05
40	937.4	-2.0249E-02	-3.0697E-06	2.6430E-05
41	962.6	-2.0306E-02	-3.0493E-05	-1.9745E-05
42	992.5	-1.9005E-02	-6.2792E-05	-6.8158E-05
43	1025.0	-1.5951E-02	-9.7291E-05	-1.1792E-04
44	1057.0	-1.1446E-02	-1.2880E-04	-1.6077E-04
45	1090.0	-5.5403E-03	-1.5543E-04	-1.9369E-04
46	1122.5	1.1644E-03	-1.7632E-04	-2.1343E-04
47	1133.0	3.4014E-03	-1.8130E-04	-2.0161E-04
48	1160.5	3.8687E-03	-1.8568E-04	-2.0005E-04
49	1175.7	1.1920E-02	-1.8592E-04	-2.0890E-04
50	1199.0	1.6770E-02	-1.8888E-04	-2.3481E-04
51	1210.0	1.9565E-02	-1.9074E-04	-2.3387E-04
52	1210.0	1.9566E-02	-1.9132E-03	-1.9136E-03
53	1240.0	7.6978E-02	-1.9134E-03	-1.9138E-03
54	1160.0	8.7872E-03	-1.8822E-04	-2.1309E-04
55	1176.0	1.2371E-02	-1.9126E-04	-2.2422E-04
56	1206.0	1.9087E-02	-1.9370E-04	-2.2135E-04
57	1212.0	2.0381E-02	-1.9387E-04	-2.0896E-04
58	1242.0	2.6551E-02	-1.9436E-04	-2.0279E-04
59	1267.0	3.1545E-02	-1.9445E-04	-1.9980E-04
60	1160.0	-1.1529E-02	-1.1941E-03	-1.1892E-03
61	1176.0	7.5003E-03	-1.1944E-03	-1.1895E-03
62	1206.0	4.3214E-02	-1.1967E-03	-1.1954E-03
63	1212.0	5.0410E-02	-1.1973E-03	-1.1996E-03
64	1212.0	5.0410E-02	-2.4272E-03	-2.4296E-03
65	1242.0	1.2334E-01	-2.4299E-03	-2.4322E-03

*1.8703E-02 = 1.8703 × 10^{-2}
**Includes bending and shear slope

TABLE 4-9. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 3

Mode 5
Generalized Mass = 19.247 lb-sec^2/in.
Frequency = 7.7004 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	-7.3077E-01	-1.3115E-03	-4.1685E-03
2	-270.5	-6.2627E-01	-1.2642E-03	-3.5439E-03
3	-230.5	-4.8211E-01	-1.1564E-03	-3.5519E-03
4	-190.5	-3.3552E-01	-1.0305E-03	-2.4427E-03
5	-156.0	-2.7850E-01	-9.7261E-04	-2.1790E-03
6	-133.0	-2.3086E-01	-9.2184E-04	-1.9983E-03
7	-82.0	-1.2864E-01	-7.8830E-04	-1.9855E-03
8	-48.0	-6.1315E-02	-6.6865E-04	-1.9421E-03
9	-1.0	2.6388E-02	-4.5984E-04	-1.7477E-03
76	20.0	5.1751E-02	-3.5007E-04	-6.6932E-04
10	68.0	7.6126E-02	-2.4377E-04	-2.4521E-04
11	118.0	8.5556E-02	-1.3268E-04	-1.3186E-04
15	168.0	8.9316E-02	-2.1804E-05	8.5935E-06
70	-156.0	-1.2280E-02	-5.5256E-04	-5.6470E-04
71	-82.0	2.9058E-02	-5.3435E-04	-5.3680E-04
72	-116.0	1.2627E-02	-4.5161E-04	-4.5161E-04
73	-48.0	4.1110E-02	-3.6269E-04	-3.4694E-04
74	-34.0	4.6189E-02	-3.6283E-04	-2.6284E-04
75	-17.0	5.0496E-02	-3.5259E-04	-2.9806E-04
79	14.0	5.9695E-02	-3.5021E-04	-3.1916E-04
77	26.0	6.4263E-02	-4.5985E-04	-4.6268E-04
78	62.0	8.0992E-02	-4.6055E-04	-4.7799E-04
12	122.0	8.9948E-02	-1.8136E-05	2.1224E-05
13	141.0	8.9750E-02	-1.8767E-05	7.1018E-06
14	140.0	8.9673E-02	-1.9668E-05	1.5041E-05
16	199.0	8.6975E-02	6.8724E-05	1.3046E-04
17	229.0	8.1520E-02	1.4995E-04	2.3178E-04
18	264.0	7.1550E-02	2.3406E-04	3.3424E-04
19	294.0	6.0326E-02	2.9516E-04	4.1034E-04
20	324.0	4.7047E-02	3.4451E-04	4.7087E-04
21	361.0	2.8596E-02	3.8755E-04	4.7927E-04
69	337.0	3.9822E-02	3.9028E-04	4.7943E-04
66	387.0	1.9179E-02	3.8608E-04	3.7057E-04
67	402.5	1.3273E-02	3.8593E-04	3.8230E-04
68	426.7	3.9394E-03	3.8592E-04	3.8501E-04
22	387.0	1.3521E-02	3.9296E-04	5.8161E-04
23	419.0	-4.9638E-03	3.8130E-04	5.7007E-04
24	449.0	-2.1669E-02	3.5200E-04	5.4041E-04
25	474.0	-3.4723E-02	3.1403E-04	5.0150E-04
26	504.0	-4.8867E-02	2.5230E-04	4.3853E-04
27	519.0	-5.5160E-02	2.1486E-04	3.9235E-04
28	543.2	-6.3342E-02	1.1983E-04	1.9911E-04
29	591.7	-6.3767E-02	-8.0220E-05	-2.1878E-04
30	644.6	-4.0474E-02	-2.5455E-04	-5.8647E-04
31	673.7	-2.0618E-02	-3.0832E-04	-7.2958E-04

TABLE 4-9. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 3 (CONTINUED)

Mode 5

Generalized Mass = 19.247 lb-sec^2/in.

Frequency = 7.7004 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	1.3156E-03*	-3.2149E-04	-7.4039E-04
33	731.9	2.2133E-02	-2.9489E-04	-6.6770E-04
34	761.0	4.0090E-02	-2.3305E-04	-5.4195E-04
35	790.1	5.3398E-02	-1.4160E-04	-3.5455E-04
36	819.2	6.0449E-02	-3.2983E-05	-1.2423E-04
37	848.3	6.0695E-02	7.6300E-05	1.0091E-04
38	877.5	5.4928E-02	1.7388E-04	2.8970E-04
39	906.6	4.4099E-02	2.5303E-04	4.1552E-04
40	937.4	3.0020E-02	3.1425E-04	4.9634E-04
41	962.6	1.6783E-02	3.4694E-04	5.4053E-04
42	992.5	7.9490E-05	3.6615E-04	5.5736E-04
43	1025.0	-1.8391E-02	3.6398E-04	5.5227E-04
44	1057.0	-3.5313E-02	3.3950E-04	4.9394E-04
45	1090.0	-5.0276E-02	2.9745E-04	4.0392E-04
46	1122.5	-6.1689E-02	2.4469E-04	3.0100E-04
47	1133.0	-6.4522E-02	2.2835E-04	2.5679E-04
48	1160.5	-7.5909E-02	2.8031E-04	4.3342E-04
49	1175.7	-8.2715E-02	2.9560E-04	5.3834E-04
50	1198.0	-9.7102E-02	3.2062E-04	8.5685E-04
51	1210.0	-1.0730E-01	3.4495E-04	8.6189E-04
52	1210.0	-1.0731E-01	2.3111E-02	2.3116E-02
53	1240.0	-8.0084E-01	2.3114E-02	2.3119E-02
54	1160.0	-6.7851E-02	1.7299E-04	-2.0313E-05
55	1176.0	-6.5587E-02	1.4794E-04	-1.4595E-04
56	1206.0	-6.1369E-02	1.3024E-04	3.8399E-05
57	1212.0	-6.2468E-02	1.3073E-04	1.7677E-04
58	1242.0	-6.7403E-02	1.3209E-04	1.5575E-04
59	1267.0	-7.1068E-02	1.3234E-04	1.4668E-04
60	1160.0	-2.9599E-01	-1.0727E-02	-1.0672E-02
61	1176.0	-1.2522E-01	-1.0730E-02	-1.0675E-02
62	1206.0	1.9536E-01	-1.0755E-02	-1.0739E-02
63	1212.0	2.6005E-01	-1.0763E-02	-1.0785E-02
64	1212.0	2.6006E-01	-2.4626E-02	-2.4649E-02
65	1242.0	1.0000E 00	-2.4657E-02	-2.4679E-02

*1.3156E-03 = 1.3156×10^{-3}

**Includes bending and shear slope

TABLE 4-10. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 10

Mode 1

Generalized Mass = 30.81 lb-sec^2/in.

Frequency = 1.8910 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	1.0000E 00	1.8554E-03	2.0911E-03
2	-270.5	9.3896E-01	1.8514E-03	2.0440E-03
3	-230.5	8.5638E-01	1.8424E-03	2.0554E-03
4	-180.5	7.5564E-01	1.8315E-03	1.9660E-03
5	-156.0	7.0865E-01	1.8253E-03	1.9481E-03
6	-133.0	6.6403E-01	1.8216E-03	1.9375E-03
7	-82.0	5.6491E-01	1.8087E-03	1.9503E-03
8	-48.0	4.9833E-01	1.7964E-03	1.9637E-03
9	-1.0	4.0599E-01	1.7738E-03	1.9618E-03
76	20.0	3.6473E-01	1.7614E-03	1.8355E-03
10	68.0	2.7781E-01	1.7193E-03	1.7865E-03
11	118.0	1.8984E-01	1.6576E-03	1.7272E-03
15	168.0	1.0540E-01	1.5775E-03	1.6340E-03
70	-156.0	7.5281E-01	2.5019E-03	2.5467E-03
71	-82.0	5.6601E-01	2.4345E-03	2.4343E-03
72	-116.0	6.4216E-01	2.1662E-03	2.1662E-03
73	-48.0	5.0106E-01	1.8374E-03	1.9289E-03
74	-34.0	4.7533E-01	1.8374E-03	1.8374E-03
75	-17.0	4.3769E-01	1.7894E-03	2.0185E-03
79	14.0	3.7549E-01	1.7641E-03	1.8946E-03
77	26.0	3.5428E-01	1.7312E-03	1.7304E-03
78	62.0	2.9199E-01	1.7311E-03	1.7273E-03
12	122.0	1.7814E-01	1.5779E-03	1.5826E-03
13	141.0	1.4809E-01	1.5778E-03	1.5808E-03
14	149.0	1.3544E-01	1.5777E-03	1.5813E-03
16	199.0	5.4789E-02	1.4937E-03	1.5901E-03
17	229.0	8.4147E-03	1.4027E-03	1.4995E-03
18	264.0	-4.2032E-02	1.2839E-03	1.3806E-03
19	294.0	-8.1778E-02	1.1715E-03	1.2673E-03
20	324.0	-1.1797E-01	1.0493E-03	1.1438E-03
21	361.0	-1.5728E-01	8.8528E-04	9.1709E-04
69	337.0	-1.3628E-01	8.8493E-04	8.7350E-04
66	387.0	-1.8074E-01	8.8657E-04	8.9809E-04
67	402.5	-1.9459E-01	8.8688E-04	8.9177E-04
68	426.7	-2.1607E-01	8.8693E-04	8.8993E-04
22	387.0	-1.8008E-01	8.1304E-04	8.4052E-04
23	419.0	-2.0551E-01	7.2146E-04	7.4865E-04
24	449.0	-2.2665E-01	6.3295E-04	6.5981E-04
25	474.0	-2.4220E-01	5.5727E-04	5.8363E-04
26	504.0	-2.5831E-01	4.6418E-04	4.9002E-04
27	519.0	-2.6630E-01	4.1671E-04	4.4585E-04
28	543.2	-2.7487E-01	3.0788E-04	3.4034E-04
29	591.7	-2.8596E-01	8.3549E-05	1.1561E-04
30	644.6	-2.8539E-01	-1.7061E-04	-1.3898E-04
31	673.7	-2.7925E-01	-3.1488E-04	-2.8359E-04

TABLE 4-10. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 10 (CONTINUED)

Mode 1

Generalized Mass = 30.81 lb-sec^2/in.

Frequency = 1.8910 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	-2.6882E-01*	-4.5847E-04	-4.3115E-04
33	731.9	-2.5423E-01	-5.9590E-04	-5.8562E-04
34	761.0	-2.3482E-01	-7.3115E-04	-7.4900E-04
35	790.1	-2.1064E-01	-8.6467E-04	-9.1057E-04
36	819.2	-1.8123E-01	-9.8967E-04	-1.0568E-03
37	848.3	-1.4932E-01	-1.0997E-03	-1.1784E-03
38	877.5	-1.1350E-01	-1.1929E-03	-1.2779E-03
39	906.6	-7.5073E-02	-1.2709E-03	-1.3562E-03
40	937.4	-3.2222E-02	-1.3387E-03	-1.4197E-03
41	968.3	1.1362E-03	-1.3841E-03	-1.4598E-03
42	999.3	3.8415E-02	-1.4296E-03	-1.5046E-03
43	1028.0	7.7989E-02	-1.4691E-03	-1.5433E-03
44	1057.0	1.4785E-01	-1.4998E-03	-1.5697E-03
45	1090.0	1.9992E-01	-1.5211E-03	-1.5811E-03
46	1122.5	2.5131E-01	-1.5344E-03	-1.5794E-03
47	1133.0	2.6783E-01	-1.5370E-03	-1.5580E-03
48	1160.5	3.1077E-01	-1.5399E-03	-1.5574E-03
49	1175.7	3.3432E-01	-1.5405E-03	-1.5575E-03
50	1198.0	3.6909E-01	-1.5412E-03	-1.5665E-03
51	1210.0	3.8783E-01	-1.5418E-03	-1.5626E-03
52	1210.0	3.8783E-01	-2.0158E-03	-2.0159E-03
53	1240.0	4.4931E-01	-2.0158E-03	-2.0160E-03
54	1160.0	3.0961E-01	-1.5397E-03	-1.5502E-03
55	1176.0	3.3444E-01	-1.5403E-03	-1.5514E-03
56	1206.0	3.8097E-01	-1.5419E-03	-1.5523E-03
57	1212.0	3.9038E-01	-1.5421E-03	-1.5601E-03
58	1242.0	4.3705E-01	-1.5426E-03	-1.5520E-03
59	1257.0	4.7576E-01	-1.5427E-03	-1.5435E-03
60	1160.0	3.0703E-01	-1.7039E-03	-1.7029E-03
61	1176.0	3.3427E-01	-1.7036E-03	-1.7029E-03
62	1206.0	3.8536E-01	-1.7039E-03	-1.7038E-03
63	1212.0	3.9559E-01	-1.7039E-03	-1.7046E-03
64	1212.0	3.9559E-01	-1.8564E-03	-1.8571E-03
65	1242.0	4.5131E-01	-1.8567E-03	-1.8573E-03

*-2.6882E-1 = -2.6882×10^{-1}

**Includes bending and shear slope

TABLE 4-11. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 10

Mode 2
Generalized Mass = 26.252 lb-sec^2/in.
Frequency = 4.113 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	1.0000E 00	2.4874E-03	3.6028E-03
2	-270.5	8.9994E-01	2.4689E-03	3.3700E-03
3	-230.5	7.6391E-01	2.4264E-03	3.3998E-03
4	-180.5	6.0594E-01	2.3759E-03	2.9711E-03
5	-156.0	5.3411E-01	2.3523E-03	2.8763E-03
6	-133.0	4.6889E-01	2.3313E-03	2.8136E-03
7	-82.0	3.2472E-01	2.2747E-03	2.8343E-03
8	-48.0	2.2792E-01	2.2227E-03	2.8454E-03
9	-1.0	9.5079E-02	2.1295E-03	2.7876E-03
76	20.0	3.5846E-02	2.0795E-03	2.3224E-03
10	68.0	-6.7595E-02	1.9104E-03	2.0875E-03
11	118.0	-1.6660E-01	1.5885E-03	1.8646E-03
15	168.0	-2.5328E-01	1.4202E-03	1.5372E-03
70	-156.0	7.6317E-01	5.6358E-03	5.8510E-03
71	-82.0	3.3815E-01	5.3130E-03	5.3163E-03
72	-116.0	4.8713E-01	4.0081E-03	4.0081E-03
73	-48.0	2.4526E-01	2.4315E-03	2.8043E-03
74	-34.0	2.1122E-01	2.4313E-03	2.4313E-03
75	-17.0	1.4500E-01	2.2057E-03	3.1156E-03
79	14.0	5.0118E-02	2.0919E-03	2.6100E-03
77	26.0	2.4364E-02	2.0835E-03	2.0835E-03
78	62.0	-5.0675E-02	2.0837E-03	2.0868E-03
12	122.0	-1.8893E-01	1.4190E-03	1.3944E-03
13	141.0	-2.1555E-01	1.4184E-03	1.4025E-03
14	149.0	-2.2675E-01	1.4189E-03	1.3981E-03
16	199.0	-2.9940E-01	1.1563E-03	1.3440E-03
17	229.0	-3.3535E-01	8.8152E-04	1.0476E-03
18	264.0	-3.6568E-01	5.3961E-04	5.8174E-04
19	294.0	-3.8117E-01	2.3073E-04	3.4872E-04
20	324.0	-3.8649E-01	-9.0179E-05	5.1816E-06
21	361.0	-3.7875E-01	-4.9921E-04	-5.4901E-04
59	337.0	-3.9411E-01	-5.0398E-04	-6.6032E-04
66	387.0	-3.6990E-01	-4.8778E-04	-3.8269E-04
67	402.5	-3.6321E-01	-4.8535E-04	-4.4475E-04
68	426.7	-3.5161E-01	-4.8493E-04	-4.6183E-04
22	397.0	-3.5581E-01	-6.6455E-04	-9.6465E-04
23	419.0	-3.2202E-01	-8.3891E-04	-1.1415E-03
24	449.0	-2.8567E-01	-9.7293E-04	-1.2777E-03
25	474.0	-2.5253E-01	-1.0627E-03	-1.3701E-03
26	504.0	-2.1009E-01	-1.1439E-03	-1.4536E-03
27	519.0	-1.8804E-01	-1.1736E-03	-1.5300E-03
28	543.3	-1.4925E-01	-1.2180E-03	-1.6217E-03
29	591.7	-6.9896E-02	-1.2292E-03	-1.6327E-03
30	644.6	1.4035E-02	-1.1182E-03	-1.5219E-03
31	672.7	5.6746E-02	-1.0025E-03	-1.4060E-03

TABLE 4-11. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 10 (CONTINUED)

Mode 2
Generalized Mass = 26.252 lb-sec^2/in.
Frequency = 4.113 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	9.5354E-02*	-8.5206E-04	-1.2296E-03
33	731.9	1.2813E-01	-6.7563E-04	-9.9752E-04
34	761.0	1.5333E-01	-4.7236E-04	-7.1688E-04
35	790.1	1.6964E-01	-2.4558E-04	-3.9515E-04
36	819.2	1.7617E-01	-9.3598E-05	-5.4815E-05
37	848.7	1.7303E-01	2.1430E-04	2.6132E-04
38	877.5	1.6129E-01	4.1423E-04	5.3421E-04
39	906.5	1.4227E-01	5.8713E-04	7.4821E-04
40	937.4	1.1545E-01	7.4042E-04	9.0700E-04
41	968.6	9.2310E-02	8.4436E-04	1.0019E-03
42	992.5	6.0738E-02	9.4844E-04	1.1058E-03
43	1025.0	2.3208E-02	1.0436E-03	1.1999E-03
44	1057.0	-1.6362E-02	1.1187E-03	1.2692E-03
45	1090.0	-5.9086E-02	1.1733E-03	1.3058E-03
46	1122.5	-1.0193E-01	1.2093E-03	1.3183E-03
47	1133.0	-1.1564E-01	1.2167E-03	1.2698E-03
48	1160.5	-1.5068E-01	1.2243E-03	1.2690E-03
49	1175.7	-1.6981E-01	1.2267E-03	1.2757E-03
50	1198.0	-1.9837E-01	1.2290E-03	1.3047E-03
51	1210.0	-2.1390E-01	1.2310E-03	1.2953E-03
52	1210.0	-2.1391E-01	2.9454E-03	2.9460E-03
53	1240.0	-3.0229E-01	2.9453E-03	2.9462E-03
54	1160.0	-1.4930E-01	1.2245E-03	1.2555E-03
55	1174.0	-1.6943E-01	1.2282E-03	1.2610E-03
56	1206.0	-2.0729E-01	1.2314E-03	1.2886E-03
57	1212.0	-2.1512E-01	1.2319E-03	1.2811E-03
58	1242.0	-2.5319E-01	1.2334E-03	1.2598E-03
59	1257.0	-2.8444E-01	1.2337E-03	1.2501E-03
60	1160.0	-1.3872E-01	1.8341E-03	1.8315E-03
61	1174.0	-1.6803E-01	1.8342E-03	1.8316E-03
62	1206.0	-2.2299E-01	1.8354E-03	1.8351E-03
63	1212.0	-2.3401E-01	1.8358E-03	1.8378E-03
64	1212.0	-2.3401E-01	2.4659E-03	2.4679E-03
65	1242.0	-3.0807E-01	2.4671E-03	2.4690E-03

*9.5354E-2 = 9.5354 × 10^{-2}
**Includes bending and shear slope

TABLE 4-12. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 10

Mode 3
Generalized Mass = 3.1490 lb-sec^2/in.
Frequency = 6.966 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	1.0000E 00	1.4193E-03	4.6186E-03
2	-270.5	8.3447E-01	1.3663E-03	3.9395E-03
3	-230.5	7.2234E-01	1.2449E-03	3.3958E-03
4	-180.5	5.5946E-01	1.1015E-03	2.7635E-03
5	-156.0	4.9358E-01	1.0348E-03	2.4865E-03
6	-133.0	4.3907E-01	9.7578E-04	2.3059E-03
7	-82.0	3.1979E-01	8.1752E-04	2.3605E-03
8	-48.0	2.3828E-01	6.7274E-04	2.3985E-03
9	-1.0	1.2777E-01	4.1352E-04	2.2540E-03
75	20.0	8.1070E-02	2.7443E-04	7.1053E-04
10	68.0	6.5857E-02	2.9072E-04	3.2516E-04
11	113.0	4.9321E-02	2.9879E-04	3.3454E-04
15	168.0	3.2559E-02	2.9742E-04	3.3538E-04
70	-156.0	-4.2466E-01	-5.4170E-03	-5.7606E-03
71	-82.0	-1.1082E-02	-4.9018E-03	-4.9166E-03
72	-116.0	-1.2741E-01	-2.7806E-03	-2.7806E-03
73	-48.0	1.0625E-02	-2.6430E-04	-7.6297E-04
74	-34.0	1.4326E-02	-2.6433E-04	-2.6433E-04
75	-17.0	5.0254E-02	8.6114E-05	-1.0959E-03
79	14.0	8.1677E-02	2.5625E-04	-4.1683E-04
77	26.0	7.9795E-02	1.7804E-04	1.7544E-04
78	62.0	7.3515E-02	1.7752E-04	1.8456E-04
12	122.0	4.6881E-02	2.9892E-04	3.1571E-04
13	141.0	4.0970E-02	2.9865E-04	3.0947E-04
14	149.0	3.8487E-02	2.9827E-04	3.1144E-04
16	199.0	2.1493E-02	2.8720E-04	3.5335E-04
17	229.0	1.1064E-02	2.7048E-04	3.3976E-04
18	264.0	-3.9577E-04	2.4195E-04	3.1234E-04
19	294.0	-9.2937E-03	2.0976E-04	2.7927E-04
20	324.0	-1.7081E-02	1.7047E-04	2.3779E-04
21	361.0	-2.4789E-02	1.1258E-04	1.2510E-04
69	337.0	-2.2644E-02	1.1180E-04	8.6031E-05
66	387.0	-2.8656E-02	1.1534E-04	1.4001E-04
67	402.5	-3.0676E-02	1.1599E-04	1.2637E-04
68	426.7	-3.3524E-02	1.1610E-04	1.2242E-04
22	387.0	-2.6660E-02	8.6121E-05	5.8574E-05
23	419.0	-2.8039E-02	5.6229E-05	2.8115E-05
24	449.0	-2.8488E-02	3.0939E-05	2.2283E-06
25	474.0	-2.8294E-02	1.1927E-05	-1.7589E-05
26	504.0	-2.7441E-02	-8.3368E-06	-3.8636E-05
27	519.0	-2.6788E-02	-1.7403E-05	-5.2770E-05
28	543.2	-2.5167E-02	-3.5710E-05	-7.6046E-05
29	591.7	-2.0732E-02	-6.4289E-05	-1.0507E-04
30	644.6	-1.4613E-02	-8.3068E-05	-1.2422E-04
31	673.7	-1.0914E-02	-8.7862E-05	-1.2922E-04

TABLE 4-12. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 10 (CONTINUED)

Mode 3

Generalized Mass = 3.1490 lb-sec^2/in.

Frequency = 6.966 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	-7.1498E-03*	-8.8681E-05	-1.2858E-04
33	731.9	-3.4631E-03	-8.5739E-05	-1.2677E-04
34	761.0	2.1135E-04	-7.8920E-05	-1.2230E-04
35	790.1	3.5169E-03	-6.7942E-05	-1.0807E-04
36	819.2	5.4395E-03	-5.3331E-05	-8.3387E-05
37	848.3	8.4477E-03	-3.7013E-05	-5.3540E-05
38	877.5	9.5746E-03	-2.0589E-05	-2.3865E-05
39	906.6	9.8526E-03	-5.1708E-06	8.4647E-07
40	937.4	9.5174E-03	9.3383E-06	1.8369E-05
41	968.3	8.0178E-03	1.9697E-05	2.8624E-05
42	992.5	7.3332E-03	3.0705E-05	3.9890E-05
43	1025.0	5.4314E-03	4.1631E-05	5.0938E-05
44	1057.0	4.6249E-03	5.1285E-05	6.1175E-05
45	1090.0	2.4479E-03	5.9434E-05	7.0783E-05
46	1123.5	1.1438E-05	6.5869E-05	7.7263E-05
47	1133.0	-7.0955E-04	6.7404E-05	7.3740E-05
48	1160.5	-2.4072E-03	6.8800E-05	7.3395E-05
49	1175.7	-3.9260E-03	6.9195E-05	7.6251E-05
50	1198.0	-5.6875E-03	6.9817E-05	8.4499E-05
51	1210.0	-6.6939E-03	7.0406E-05	8.4150E-05
52	1210.0	-6.6941E-03	6.1466E-04	6.1479E-04
53	1240.0	-7.5139E-03	6.1473E-04	6.1486E-04
54	1160.0	-2.7715E-03	6.9514E-05	7.7098E-05
55	1176.0	-4.0569E-03	7.0442E-05	8.0405E-05
56	1206.0	-6.4658E-03	7.1191E-05	7.9985E-05
57	1212.0	-6.9372E-03	7.1249E-05	7.6338E-05
58	1242.0	-9.1947E-03	7.1416E-05	7.4276E-05
59	1267.0	-1.1036E-02	7.1646E-05	7.3267E-05
60	1160.0	3.2524E-03	3.6877E-04	3.6733E-04
61	1176.0	-3.6253E-03	3.6885E-04	3.6742E-04
62	1206.0	-1.3656E-02	3.6954E-04	3.6916E-04
63	1212.0	-1.5978E-02	3.6973E-04	3.7044E-04
64	1212.0	-1.5878E-02	7.3416E-04	7.3486E-04
65	1242.0	-3.7937E-02	7.3494E-04	7.3564E-04

*-7.1498E-03 = -7.1498×10^{-3}

**Includes bending and shear slope

TABLE 4-13. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 10

Mode 4
Generalized Mass = 14.381 lb-sec^2/in.
Frequency = 7.5955 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	3.2164E-01	5.6514E-04	1.7886E-03
2	-270.5	2.7679E-01	5.4487E-04	1.5221E-03
3	-230.5	2.1484E-01	4.9867E-04	1.5279E-03
4	-180.5	1.5172E-01	4.4465E-04	1.0534E-03
5	-156.0	1.2711E-01	4.1976E-04	9.4129E-04
6	-133.0	1.0652E-01	3.9791E-04	8.5491E-04
7	-82.0	6.2211E-02	3.4030E-04	8.6262E-04
8	-48.0	3.2894E-02	2.8854E-04	8.4800E-04
9	-1.0	-5.5100E-03	1.9791E-04	7.6794E-04
76	20.0	-2.1102E-02	1.5014E-04	2.9208E-04
10	68.0	-2.7554E-02	1.0761E-04	1.1267E-04
11	118.0	-3.2034E-02	6.1997E-05	6.6253E-05
15	168.0	-3.4161E-02	1.5264E-05	8.3514E-06
70	-156.0	-5.0872E-03	6.9436E-05	6.4542E-05
71	-82.0	-1.0044E-02	7.6774E-05	7.7194E-05
72	-116.0	-4.7031E-03	1.0443E-04	1.0443E-04
73	-48.0	-1.4393E-02	1.4027E-04	1.2139E-04
74	-24.0	-1.6357E-02	1.4032E-04	-1.4032E-04
75	-17.0	-1.7243E-02	1.4601E-04	9.5112E-05
79	14.0	-2.0245E-02	1.4970E-04	1.2072E-04
77	26.0	-2.2143E-02	1.8764E-04	1.8860E-04
78	62.0	-2.8959E-02	1.8789E-04	1.9395E-04
12	122.0	-3.4032E-02	1.3940E-05	-5.5010E-07
13	141.0	-3.4038E-02	1.4172E-05	4.6427E-06
14	149.0	-3.4128E-02	1.4504E-05	2.4502E-06
16	199.0	-3.3645E-02	-2.4216E-05	-4.0071E-05
17	229.0	-3.1775E-02	-6.0784E-05	-8.4232E-05
18	264.0	-2.7931E-02	-1.0039E-04	-1.3081E-04
19	294.0	-2.3503E-02	-1.3100E-04	-1.6712E-04
20	324.0	-1.8001E-02	-1.5702E-04	-1.9825E-04
21	361.0	-1.0073E-02	-1.8545E-04	-2.1252E-04
69	337.0	-1.4961E-02	-1.8606E-04	-2.0630E-04
66	387.0	-5.4138E-03	-1.8517E-04	-1.8165E-04
67	402.5	-2.5487E-03	-1.8519E-04	-1.8497E-04
68	436.7	1.9356E-03	-1.8519E-04	-1.8563E-04
22	387.0	-2.6890E-03	-1.9312E-04	-2.4910E-04
23	419.0	4.3640E-03	-1.9712E-04	-2.5311E-04
24	449.0	1.1944E-02	-1.9543E-04	-2.5120E-04
25	474.0	1.8159E-02	-1.9001E-04	-2.4526E-04
26	504.0	2.5350E-02	-1.7874E-04	-2.3328E-04
27	519.0	2.8739E-02	-1.7117E-04	-2.3287E-04
28	543.2	3.4370E-02	-1.5037E-04	-2.1921E-04
29	591.7	4.3716E-02	-9.5006E-05	-1.6292E-04
30	644.6	5.0252E-02	-1.4103E-05	-8.0876E-05
31	673.7	5.1825E-02	3.9495E-05	-2.6300E-05

TABLE 4-13. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 10 (CONTINUED)

Mode 4

Generalized Mass = 14.381 lb-sec^2/in.

Frequency = 7.5955 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.3	5.1681E-02*	9.7889E-05	4.2687E-05
33	731.0	4.9348E-02	1.5789E-04	1.5437E-04
34	761.0	4.2748E-02	2.1685E-04	2.9861E-04
35	790.1	3.2038E-02	2.6797E-04	4.2419E-04
36	819.2	1.8363E-02	3.0209E-04	4.9804E-04
37	848.3	3.3964E-02	3.1595E-04	5.1286E-04
38	877.5	-1.1334E-02	3.1053E-04	4.8493E-04
39	906.5	-2.4729E-02	2.8946E-04	4.3257E-04
40	937.4	-3.7103E-02	2.5439E-04	3.7632E-04
41	962.6	-4.6006E-02	2.1820E-04	3.2955E-04
42	992.5	-5.5090E-02	1.6642E-04	2.7586E-04
43	1025.0	-6.2921E-02	9.7508E-05	2.0253E-04
44	1057.0	-6.8048E-02	1.7194E-05	1.0417E-04
45	1090.0	-6.9568E-02	-7.0794E-05	-3.3656E-05
46	1122.5	-6.5900E-02	-1.5920E-04	-1.7601E-04
47	1133.0	-6.3723E-02	-1.8381E-04	-2.0187E-04
48	1160.5	-6.1158E-02	-1.6509E-04	-9.2864E-05
49	1175.7	-5.9669E-02	-1.6015E-04	-6.9363E-05
50	1198.0	-5.8763E-02	-1.5242E-04	2.6509E-05
51	1210.0	-5.8938E-02	-1.4506E-04	2.2354E-05
52	1210.0	-5.8990E-02	6.6791E-03	6.6806E-03
53	1240.0	-2.5942E-01	6.6800E-03	6.6815E-03
54	1160.0	-5.5723E-02	-2.3952E-04	-4.3459E-04
55	1176.0	-4.6916E-02	-2.8463E-04	-5.5464E-04
56	1206.0	-3.0337E-02	-2.8283E-04	-3.9938E-04
57	1212.0	-2.8780E-02	-2.8271E-04	-2.6856E-04
58	1242.0	-2.0550E-02	-2.8241E-04	-2.7698E-04
59	1267.0	-1.3557E-02	-2.8236E-04	-2.7970E-04
60	1160.0	-2.7341E-01	-1.0687E-02	-1.0634E-02
61	1176.0	-1.0324E-01	-1.0690E-02	-1.0638E-02
62	1206.0	2.1621E-01	-1.0714E-02	-1.0699E-02
63	1212.0	2.8065E-01	-1.0721E-02	-1.0743E-02
64	1212.0	2.8065E-01	-2.3941E-02	-2.3963E-02
65	1242.0	1.0000E 00	-2.3970E-02	-2.3992E-02

*5.1681E-02 = 5.1681 × 10^{-2}

**Includes bending and shear slope

TABLE 4-14. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 10

Mode 5
Generalized Mass = 5.5460 lb-sec^2/in.
Frequency = 8.0290 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	1.3684E-01	3.3859E-04	1.1327E-03
2	-270.5	1.5857E-01	3.2543E-04	9.5758E-04
3	-230.5	1.1964E-01	2.9552E-04	9.5624E-04
4	-180.5	8.0457E-02	2.6072E-04	6.4733E-04
5	-156.0	6.5408E-02	2.4476E-04	5.7281E-04
6	-133.0	5.2927E-02	2.3081E-04	5.2126E-04
7	-82.0	2.6342E-02	1.9432E-04	5.1346E-04
8	-48.0	9.0222E-03	1.6181E-04	4.9644E-04
9	-1.0	-1.3220E-02	1.0549E-04	4.3869E-04
76	20.0	-2.2017E-02	7.6045E-05	1.5813E-04
10	68.0	-2.4673E-02	4.2539E-05	3.8287E-05
11	118.0	-2.5718E-02	8.7392E-06	3.7217E-06
15	168.0	-2.5067E-02	-2.3737E-05	-3.6308E-05
70	-156.0	1.5600E-02	3.5457E-04	3.7134E-04
71	-82.0	-1.1259E-02	3.2943E-04	3.3098E-04
72	-116.0	-2.4969E-03	2.2255E-04	2.2255E-04
73	-48.0	-1.4957E-02	9.9745E-05	1.1104E-04
74	-34.0	-1.6354E-02	9.9800E-05	9.9804E-05
75	-17.0	-1.3429E-02	8.3596E-05	1.0381E-04
79	14.0	-2.1542E-02	7.6733E-05	8.8241E-05
77	26.0	-2.2627E-02	1.1686E-04	1.1792E-04
78	62.0	-2.5897E-02	1.1711E-04	1.2341E-04
12	122.0	-2.6658E-02	-2.4890E-05	-3.7373E-05
13	141.0	-2.6010E-02	-2.4687E-05	-3.2993E-05
14	149.0	-2.5740E-02	-2.4397E-05	-3.4824E-05
16	199.0	-2.3262E-02	-4.9316E-05	-7.3779E-05
17	229.0	-2.0620E-02	-7.1537E-05	-1.0169E-04
18	254.0	-1.6566E-02	-9.3549E-05	-1.2855E-04
19	294.0	-1.2412E-02	-1.0857E-04	-1.4716E-04
20	324.0	-7.7753E-03	-1.1965E-04	-1.6054E-04
21	361.0	-1.6396E-03	-1.2756E-04	-1.4778E-04
69	337.0	-4.8596E-03	-1.2778E-04	-1.3513E-04
66	387.0	1.7890E-03	-1.2801E-04	-1.3138E-04
67	402.5	3.8211E-03	-1.2817E-04	-1.3042E-04
68	426.7	6.9340E-03	-1.2820E-04	-1.2994E-04
22	387.0	2.4602E-03	-1.2787E-04	-1.5763E-04
23	419.0	7.4714E-03	-1.2535E-04	-1.5499E-04
24	449.0	1.2047E-02	-1.2012E-04	-1.4947E-04
25	474.0	1.5702E-02	-1.1364E-04	-1.4246E-04
26	504.0	1.9818E-02	-1.0339E-04	-1.3156E-04
27	519.0	2.1742E-02	-9.7263E-05	-1.2885E-04
28	542.2	2.4758E-02	-8.1532E-05	-1.1657E-04
29	591.7	2.9513E-02	-4.3068E-05	-7.7390E-05
30	644.6	3.2245E-02	9.2425E-06	-2.4238E-05
31	673.7	3.2461E-02	4.2591E-05	9.8041E-06

TABLE 4-14. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 10 (CONTINUED)

Mode 5

Generalized Mass = 5.5460 lb-sec^2/in.

Frequency = 8.0290 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	3.1622E-02*	7.8164E-05	5.1949E-05
33	731.9	2.9448E-02	1.1403E-04	1.2182E-04
34	761.0	2.4569E-02	1.4852E-04	2.1193E-04
35	790.1	1.7159E-02	1.7651E-04	2.8673E-04
36	819.2	8.0819E-03	1.9344E-04	3.2494E-04
37	848.3	-1.5274E-02	1.9725E-04	3.2309E-04
38	877.5	-1.0638E-02	1.8915E-04	2.9394E-04
39	906.6	-1.8585E-02	1.7203E-04	2.5205E-04
40	937.4	-2.5554E-02	1.4719E-04	2.1243E-04
41	962.6	-3.0527E-02	1.2319E-04	1.8020E-04
42	992.5	-3.5575E-02	9.0239E-05	1.4726E-04
43	1025.0	-3.9680E-02	4.7770E-05	1.0257E-04
44	1057.0	-4.2143E-02	-5.4953E-07	4.2313E-05
45	1090.0	-4.2366E-02	-5.2351E-05	-4.3055E-05
46	1122.5	-3.9374E-02	-1.0290E-04	-1.2880E-04
47	1133.0	-3.7828E-02	-1.1661E-04	-1.5199E-04
48	1160.5	-3.1304E-02	-1.7753E-04	-2.8563E-04
49	1175.7	-2.6106E-02	-1.9777E-04	-4.5840E-04
50	1198.0	-1.2260E-02	-2.3276E-04	-9.0489E-04
51	1210.0	-1.1530E-03	-2.6777E-04	-9.4259E-04
52	1210.0	-1.1457E-03	-3.3362E-02	-3.3369E-02
53	1240.0	1.0000E 00	-3.3367E-02	-3.3373E-02
54	1160.0	-3.4805E-02	-1.1770E-04	-1.1965E-04
55	1176.0	-3.2776E-02	-1.1833E-04	-1.2765E-04
56	1206.0	-2.3932E-02	-1.1857E-04	-1.0550E-04
57	1212.0	-2.8400E-02	-1.1839E-04	-9.9431E-05
58	1242.0	-2.5232E-02	-1.1789E-04	-1.0919E-04
59	1267.0	-2.2409E-02	-1.1731E-04	-1.1289E-04
60	1150.0	-4.8204E-02	-7.0912E-04	-7.0591E-04
61	1176.0	-3.6908E-02	-7.0933E-04	-7.0615E-04
62	1206.0	-1.5703E-02	-7.1080E-04	-7.0967E-04
63	1212.0	-1.1432E-02	-7.1123E-04	-7.1208E-04
64	1212.0	-1.1432E-02	-1.5278E-03	-1.5287E-03
65	1242.0	3.4457E-02	-1.5297E-03	-1.5306E-03

*3.1622E-02 = 3.1622 × 10^{-2}

**Includes bending and shear slope

TABLE 4-15. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 17

Mode 1
Generalized Mass = 32.343 lb-sec^2/in.
Frequency = 1.8755 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	1.0000E 00	1.8708E-03	2.1027E-03
2	-270.5	9.3859E-01	1.8670E-03	2.0564E-03
3	-230.5	8.5602E-01	1.8581E-03	2.0675E-03
4	-180.5	7.5513E-01	1.8473E-03	1.9796E-03
5	-156.0	7.0680E-01	1.8422E-03	1.9620E-03
6	-133.0	6.6186E-01	1.8376E-03	1.9515E-03
7	-82.0	5.6204E-01	1.8249E-03	1.9640E-03
8	-48.0	4.9500E-01	1.8129E-03	1.9771E-03
9	-1.0	4.0203E-01	1.7907E-03	1.9751E-03
76	20.0	3.6050E-01	1.7784E-03	1.8523E-03
10	68.0	2.7275E-01	1.7348E-03	1.8050E-03
11	118.0	1.8400E-01	1.6712E-03	1.7418E-03
15	168.0	9.8885E-02	1.5889E-03	1.6460E-03
70	-156.0	8.2591E-01	3.1427E-03	3.1912E-03
71	-82.0	5.9156E-01	3.0701E-03	3.0599E-03
72	-116.0	6.9316E-01	3.0469E-03	3.0469E-03
73	-48.0	5.0647E-01	2.1557E-03	2.2586E-03
74	-34.0	4.7629E-01	2.1556E-03	2.1556E-03
75	-17.0	4.3595E-01	1.8998E-03	2.1396E-03
79	14.0	3.7138E-01	1.7814E-03	1.9181E-03
77	26.0	3.4994E-01	1.7492E-03	1.7484E-03
78	62.0	2.8700E-01	1.7491E-03	1.7454E-03
12	122.0	1.7214E-01	1.5893E-03	1.5938E-03
13	141.0	1.4188E-01	1.5893E-03	1.5921E-03
14	149.0	1.2915E-01	1.5892E-03	1.5926E-03
16	199.0	4.7923E-02	1.5032E-03	1.6005E-03
17	229.0	1.2694E-03	1.4100E-03	1.5077E-03
18	264.0	-4.9419E-02	1.2888E-03	1.3862E-03
19	294.0	-8.9299E-02	1.1741E-03	1.2706E-03
20	324.0	-1.2556E-01	1.0496E-03	1.1448E-03
21	361.0	-1.6484E-01	8.8273E-04	9.1453E-04
69	337.0	-1.4391E-01	8.8237E-04	8.7050E-04
66	387.0	-1.8825E-01	8.8406E-04	8.9584E-04
67	402.5	-2.0206E-01	8.8437E-04	8.8936E-04
68	426.7	-2.2348E-01	8.8442E-04	8.8748E-04
22	387.0	-1.8755E-01	8.0929E-04	8.3617E-04
23	419.0	-2.1282E-01	7.1629E-04	7.4287E-04
24	449.0	-2.3376E-01	6.2652E-04	6.5275E-04
25	474.0	-2.4912E-01	5.4982E-04	5.7555E-04
26	504.0	-2.6497E-01	4.5556E-04	4.8078E-04
27	519.0	-2.7182E-01	4.0754E-04	4.3595E-04
28	543.2	-2.8113E-01	2.9748E-04	3.2913E-04
29	591.7	-2.9153E-01	7.0882E-05	1.0212E-04
30	644.6	-2.9028E-01	-1.8551E-04	-1.5470E-04
31	673.7	-2.8366E-01	-3.3090E-04	-3.0043E-04

TABLE 4-15. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 17 (CONTINUED)

Mode 1

Generalized Mass = 32.343 lb-sec^2/in.

Frequency = 1.8755 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	-2.7273E-01*	-4.7549E-04	-4.4895E-04
33	731.9	-2.5761E-01	-6.1381E-04	-6.0421E-04
34	761.0	-2.3764E-01	-7.4984E-04	-7.6827E-04
35	790.1	-2.1290E-01	-8.8410E-04	-9.3055E-04
36	819.2	-1.8361E-01	-1.0092E-03	-1.0768E-03
37	848.3	-1.5042E-01	-1.1192E-03	-1.1982E-03
38	877.5	-1.1402E-01	-1.2124E-03	-1.2975E-03
39	906.6	-7.5026E-02	-1.2903E-03	-1.3757E-03
40	937.4	-3.1575E-02	-1.3581E-03	-1.4392E-03
41	962.6	5.2734E-03	-1.4035E-03	-1.4792E-03
42	992.5	5.0132E-02	-1.4483E-03	-1.5240E-03
43	1025.0	1.0033E-01	-1.4885E-03	-1.5627E-03
44	1057.0	1.5081E-01	-1.5191E-03	-1.5890E-03
45	1090.0	2.0353E-01	-1.5404E-03	-1.6004E-03
46	1122.5	2.5554E-01	-1.5537E-03	-1.5986E-03
47	1133.0	2.7226E-01	-1.5563E-03	-1.5773E-03
48	1160.5	3.1573E-01	-1.5592E-03	-1.5767E-03
49	1175.7	3.3958E-01	-1.5598E-03	-1.5768E-03
50	1198.0	3.7477E-01	-1.5605E-03	-1.5858E-03
51	1210.0	3.9375E-01	-1.5610E-03	-1.5818E-03
52	1210.0	3.9375E-01	-2.0338E-03	-2.0339E-03
53	1240.0	4.5477E-01	-2.0338E-03	-2.0340E-03
54	1160.0	3.1457E-01	-1.5590E-03	-1.5694E-03
55	1176.0	3.3970E-01	-1.5601E-03	-1.5706E-03
56	1206.0	3.8681E-01	-1.5612E-03	-1.5816E-03
57	1212.0	3.9634E-01	-1.5613E-03	-1.5793E-03
58	1242.0	4.4358E-01	-1.5619E-03	-1.5713E-03
59	1267.0	4.8277E-01	-1.5620E-03	-1.5678E-03
60	1160.0	3.1199E-01	-1.7223E-03	-1.7217E-03
61	1176.0	3.3954E-01	-1.7224E-03	-1.7217E-03
62	1206.0	3.9119E-01	-1.7227E-03	-1.7227E-03
63	1212.0	4.0153E-01	-1.7228E-03	-1.7234E-03
64	1212.0	4.0153E-01	-1.8748E-03	-1.8754E-03
65	1242.0	4.5780E-01	-1.8750E-03	-1.8756E-03

*-2.7273E-01 = -2.7273×10^{-1}

**Includes bending and shear slope

TABLE 4-16. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 17

Mode 2
Generalized Mass = 26.120 lb-sec^2/in.
Frequency = 3.9359 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	6.1229E-01	1.8260E-03	2.4514E-03
2	-270.5	5.4325E-01	1.8157E-03	2.3191E-03
3	-230.5	4.4984E-01	1.7919E-03	2.3316E-03
4	-180.5	3.4002E-01	1.7638E-03	2.0900E-03
5	-156.0	2.8932E-01	1.7508E-03	2.0347E-03
6	-133.0	2.4313E-01	1.7392E-03	1.9969E-03
7	-82.0	1.4106E-01	1.7083E-03	1.9998E-03
8	-48.0	7.3016E-02	1.6803E-03	1.9942E-03
9	-1.0	-1.9949E-02	1.6308E-03	1.9503E-03
76	20.0	-6.0594E-02	1.6046E-03	1.7536E-03
10	68.0	-1.4056E-01	1.4455E-03	1.5832E-03
11	118.0	-2.1481E-01	1.2442E-03	1.3806E-03
15	168.0	-2.7802E-01	1.0069E-03	1.0920E-03
70	-156.0	1.0000E 00	8.7913E-03	9.0497E-03
71	-82.0	3.3988E-01	8.4040E-03	8.3587E-03
72	-116.0	6.1139E-01	8.2784E-03	8.2784E-03
73	-48.0	1.6032E-01	3.5263E-03	3.9717E-03
74	-34.0	1.1096E-01	3.5262E-03	3.5262E-03
75	-17.0	4.0028E-02	2.2003E-03	3.1873E-03
79	14.0	-5.0090E-02	1.6190E-03	2.1819E-03
77	26.0	-7.0362E-02	1.6433E-03	1.6443E-03
78	62.0	-1.2959E-01	1.6436E-03	1.6509E-03
12	122.0	-2.3278E-01	1.0045E-03	9.7787E-04
13	141.0	-2.5150E-01	1.0049E-03	9.8718E-04
14	149.0	-2.5938E-01	1.0055E-03	9.8260E-04
16	199.0	-3.1018E-01	7.7806E-04	9.1220E-04
17	229.0	-3.3376E-01	5.4263E-04	6.5668E-04
18	264.0	-3.5135E-01	2.5337E-04	3.4600E-04
19	294.0	-3.5756E-01	-4.8876E-06	6.5740E-05
20	324.0	-3.5529E-01	-2.7046E-04	-2.1808E-04
21	361.0	-3.4071E-01	-6.0521E-04	-6.5751E-04
69	337.0	-3.5804E-01	-6.0919E-04	-7.3925E-04
66	387.0	-3.2831E-01	-5.9600E-04	-5.1102E-04
67	402.5	-3.1977E-01	-5.9406E-04	-5.6151E-04
68	426.7	-3.0552E-01	-5.9373E-04	-5.7534E-04
22	387.0	-3.1639E-01	-7.3892E-04	-1.0020E-03
23	419.0	-2.8199E-01	-8.7794E-04	-1.1430E-03
24	449.0	-2.4604E-01	-9.8248E-04	-1.2493E-03
25	474.0	-2.1390E-01	-1.0504E-03	-1.3193E-03
26	504.0	-1.7335E-01	-1.1087E-03	-1.3794E-03
27	519.0	-1.5249E-01	-1.1284E-03	-1.4396E-03
28	543.2	-1.1629E-01	-1.1537E-03	-1.5053E-03
29	591.7	-4.3355E-02	-1.1343E-03	-1.4864E-03
30	644.6	3.2312E-02	-1.0064E-03	-1.3586E-03
31	673.7	7.0228E-02	-8.8847E-04	-1.2403E-03

TABLE 4-16. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 17 (CONTINUED)

Mode 2
Generalized Mass = 26.120 lb-sec^2/in.
Frequency = 3.9359 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	1.0406E-01*	-7.4064E-04	-1.0693E-03
33	731.9	1.3232E-01	-5.7119E-04	-8.4857E-04
34	761.0	1.5339E-01	-3.7898E-04	-5.8456E-04
35	790.1	1.6616E-01	-1.6707E-04	-2.8654E-04
36	819.2	1.6995E-01	5.1720E-05	2.4228E-05
37	848.3	1.6496E-01	2.5754E-04	3.1014E-04
38	877.5	1.5220E-01	4.4066E-04	5.5566E-04
39	906.6	1.3291E-01	5.9856E-04	7.4807E-04
40	937.4	1.0738E-01	7.3830E-04	8.9166E-04
41	962.6	8.3736E-02	8.3294E-04	9.7780E-04
42	992.5	5.3080E-02	9.2757E-04	1.0731E-03
43	1025.0	1.6744E-02	1.0139E-03	1.1575E-03
44	1057.0	-2.1354E-02	1.0818E-03	1.2198E-03
45	1090.0	-6.2354E-02	1.1310E-03	1.2555E-03
46	1122.5	-1.0339E-01	1.1632E-03	1.2621E-03
47	1133.0	-1.1651E-01	1.1698E-03	1.2178E-03
48	1160.5	-1.5011E-01	1.1772E-03	1.2170E-03
49	1175.7	-1.6846E-01	1.1788E-03	1.2208E-03
50	1198.0	-1.9582E-01	1.1808E-03	1.2480E-03
51	1210.0	-2.1069E-01	1.1825E-03	1.2394E-03
52	1210.0	-2.1069E-01	2.6750E-03	2.6754E-03
53	1240.0	-2.9095E-01	2.6751E-03	2.6756E-03
54	1160.0	-1.4882E-01	1.1770E-03	1.2044E-03
55	1176.0	-1.6817E-01	1.1801E-03	1.2091E-03
56	1206.0	-2.0442E-01	1.1829E-03	1.2341E-03
57	1212.0	-2.1192E-01	1.1834E-03	1.2276E-03
58	1242.0	-2.4842E-01	1.1847E-03	1.2084E-03
59	1267.0	-2.7841E-01	1.1850E-03	1.1997E-03
60	1160.0	-1.3972E-01	1.7055E-03	1.7033E-03
61	1176.0	-1.6697E-01	1.7056E-03	1.7034E-03
62	1206.0	-2.1809E-01	1.7067E-03	1.7064E-03
63	1212.0	-2.2834E-01	1.7070E-03	1.7088E-03
64	1212.0	-2.2834E-01	2.2485E-03	2.2503E-03
65	1242.0	-2.9586E-01	2.2495E-03	2.2513E-03

*1.0406E-01 = 1.0406 x 10^{-1}
**Includes bending and shear slope

TABLE 4-17. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 17

Mode 3
Generalized Mass = 4.7611 lb-sec^2/in.
Frequency = 5.7668 cps

Node No.	Station No.	Deflection	Total** Slope rad./in.	Bending Slope rad./in.
1	-300.5	1.0000E 00	1.5579E-03	3.7606E-03
2	-270.5	9.0296E-01	1.5315E-03	3.3045E-03
3	-230.5	7.6831E-01	1.4480E-03	3.3656E-03
4	-180.5	6.2368E-01	1.3485E-03	2.5251E-03
5	-156.0	5.6361E-01	1.3020E-03	2.3428E-03
6	-133.0	5.1153E-01	1.2505E-03	2.2269E-03
7	-82.0	3.9628E-01	1.1481E-03	2.2899E-03
8	-48.0	3.1704E-01	1.0442E-03	2.3460E-03
9	-1.0	2.0772E-01	8.5591E-04	2.2700E-03
76	20.0	1.6020E-01	7.5396E-04	1.1105E-03
10	68.0	1.1969E-01	7.6117E-04	8.4690E-04
11	118.0	7.7568E-02	7.4650E-04	8.3378E-04
15	168.0	3.6695E-02	7.0880E-04	7.8593E-04
70	-156.0	-4.8053E-01	-6.5827E-03	-6.8492E-03
71	-82.0	1.6458E-02	-6.1832E-03	-6.1457E-03
72	-116.0	-1.7970E-01	-6.0515E-03	-6.0515E-03
73	-48.0	1.1374E-01	-1.1492E-03	-1.5244E-03
74	-34.0	1.2983E-01	-1.1494E-03	-1.1495E-03
75	-17.0	1.5377E-01	1.8266E-04	-6.0146E-04
79	14.0	1.6403E-01	7.4047E-04	2.9323E-04
77	26.0	1.5617E-01	6.2858E-04	6.2517E-04
78	62.0	1.3370E-01	5.2793E-04	6.1179E-04
12	122.0	6.9939E-02	7.1031E-04	7.2748E-04
13	141.0	5.6206E-02	7.1004E-04	7.2097E-04
14	149.0	5.0432E-02	7.0965E-04	7.2267E-04
16	199.0	1.1444E-02	6.5721E-04	7.8832E-04
17	229.0	-1.1309E-02	5.9370E-04	7.2478E-04
18	264.0	-3.5110E-02	5.0271E-04	6.3071E-04
19	294.0	-5.2612E-02	4.1055E-04	5.3301E-04
20	324.0	-6.6966E-02	3.0591E-04	4.2148E-04
21	361.0	-7.9792E-02	1.6066E-04	1.7321E-04
69	337.0	-7.7236E-02	1.5882E-04	9.8592E-05
66	387.0	-8.5891E-02	1.6615E-04	2.1574E-04
67	402.5	-8.8900E-02	1.6739E-04	1.8761E-04
68	426.7	-9.3028E-02	1.6761E-04	1.7963E-04
22	387.0	-8.1094E-02	9.7354E-05	1.8250E-05
23	419.0	-8.0511E-02	2.7120E-05	-5.3135E-05
24	449.0	-7.8012E-02	-3.0918E-05	-1.1232E-04
25	474.0	-7.4646E-02	-7.3434E-05	-1.5631E-04
26	504.0	-6.9253E-02	-1.1729E-04	-2.0156E-04
27	519.0	-6.6077E-02	-1.3626E-04	-2.3391E-04
28	543.2	-5.9636E-02	-1.7311E-04	-2.8396E-04
29	591.7	-4.4476E-02	-2.2473E-04	-3.3626E-04
30	644.6	-2.5938E-02	-2.4717E-04	-3.5921E-04
31	673.7	-1.5490E-02	-2.4442E-04	-3.5669E-04

TABLE 4-17. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 17 (CONTINUED)

Mode 3
Generalized Mass = 4.7611 lb-sec^2/in.
Frequency = 5.7668 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	-5.3303E-03*	-2.3126E-04	-3.3777E-04
33	731.9	4.0947E-03	-2.0899E-04	-3.0824E-04
34	761.0	1.2575E-02	-1.7770E-04	-2.6766E-04
35	790.1	1.9594E-02	-1.3777E-04	-2.0917E-04
36	819.2	2.4646E-02	-9.1669E-05	-1.3525E-04
37	848.3	2.7464E-02	-4.4851E-05	-5.8551E-05
38	877.5	2.8121E-02	-8.3118E-07	1.1723E-05
39	906.6	2.6856E-02	3.8522E-05	6.7829E-05
40	937.4	2.4051E-02	7.4148E-05	1.0773E-04
41	962.6	2.1025E-02	9.8705E-05	1.3090E-04
42	992.5	1.6729E-02	1.2376E-04	1.5635E-04
43	1025.0	1.1247E-02	1.4730E-04	1.7972E-04
44	1057.0	5.1887E-03	1.6662E-04	1.9874E-04
45	1090.0	-1.6280E-03	1.8147E-04	2.1273E-04
46	1122.5	-8.6907E-03	1.9193E-04	2.1882E-04
47	1133.0	-1.0965E-02	1.9422E-04	2.0795E-04
48	1160.5	-1.6699E-02	1.9671E-04	2.0801E-04
49	1175.7	-1.9838E-02	1.9732E-04	2.1096E-04
50	1198.0	-2.4615E-02	1.9818E-04	2.2251E-04
51	1210.0	-2.7257E-02	1.9895E-04	2.2050E-04
52	1210.0	-2.7257E-02	8.9406E-04	8.9425E-04
53	1240.0	-5.4086E-02	8.9414E-04	8.9433E-04
54	1160.0	-1.6448E-02	1.9590E-04	2.0686E-04
55	1176.0	-1.9802E-02	1.9806E-04	2.0958E-04
56	1206.0	-2.6083E-02	1.9907E-04	2.1525E-04
57	1212.0	-2.7391E-02	1.9921E-04	2.1204E-04
58	1242.0	-3.3663E-02	1.9962E-04	2.0662E-04
59	1267.0	-3.8764E-02	1.9970E-04	2.0408E-04
60	1160.0	-1.1397E-02	4.6487E-04	4.6366E-04
61	1176.0	-1.8816E-02	4.6495E-04	4.6372E-04
62	1206.0	-3.2734E-02	4.6552E-04	4.6528E-04
63	1212.0	-3.5532E-02	4.6568E-04	4.6644E-04
64	1212.0	-3.5532E-02	7.6917E-04	7.6991E-04
65	1242.0	-5.8639E-02	7.6978E-04	7.7052E-04

*-5.3303E-03 = -5.3303 x 10^{-3}
**Includes bending and shear slope

TABLE 4-18. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 17

Mode 4
Generalized Mass = 14.368 lb-sec^2/in.
Frequency = 7.5955 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	3.0777E-01	5.4552E-04	1.7162E-03
2	-270.5	2.6471E-01	5.2612E-04	1.4611E-03
3	-230.5	2.0525E-01	4.8192E-04	1.4663E-03
4	-180.5	1.4464E-01	4.3025E-04	1.0122E-03
5	-156.0	1.2099E-01	4.0544E-04	9.0483E-04
6	-133.0	1.0119E-01	3.8555E-04	8.3157E-04
7	-82.0	5.8599E-02	3.3048E-04	8.2886E-04
8	-48.0	3.0440E-02	2.8103E-04	8.1418E-04
9	-1.0	-6.4220E-03	1.9448E-04	7.3695E-04
76	20.0	-2.1379E-02	1.4889E-04	2.8442E-04
10	68.0	-2.7777E-02	1.0647E-04	1.1161E-04
11	118.0	-3.2206E-02	6.0971E-05	6.5289E-05
15	168.0	-3.4287E-02	1.4327E-05	7.4179E-06
70	-156.0	-6.0570E-04	1.2367E-04	1.2309E-04
71	-82.0	-9.7360E-03	1.2455E-04	1.2551E-04
72	-116.0	-5.4132E-03	1.2463E-04	1.2463E-04
73	-48.0	-1.3896E-02	1.3535E-04	1.2300E-04
74	-34.0	-1.5792E-02	1.3540E-04	1.3540E-04
75	-17.0	-1.7092E-02	1.4202E-04	1.0746E-04
79	14.0	-2.0515E-02	1.4868E-04	1.2897E-04
77	26.0	-2.2413E-02	1.8677E-04	1.8774E-04
78	62.0	-2.9199E-02	1.8702E-04	1.9314E-04
12	122.0	-3.4206E-02	1.2997E-05	-1.5653E-06
13	141.0	-3.4252E-02	1.3231E-05	3.6535E-06
14	149.0	-3.4273E-02	1.3564E-05	1.4523E-06
16	199.0	-3.3744E-02	-2.5075E-05	-4.0934E-05
17	229.0	-3.1849E-02	-6.1567E-05	-8.5040E-05
18	264.0	-2.8037E-02	-1.0108E-04	-1.3154E-04
19	294.0	-2.3529E-02	-1.3161E-04	-1.6777E-04
20	324.0	-1.8008E-02	-1.5845E-04	-1.9882E-04
21	361.0	-1.0061E-02	-1.8585E-04	-2.1294E-04
69	337.0	-1.4959E-02	-1.8647E-04	-2.0671E-04
66	387.0	-5.3904E-03	-1.8558E-04	-1.8209E-04
67	402.5	-2.5187E-03	-1.8560E-04	-1.8539E-04
68	426.7	1.9757E-03	-1.8561E-04	-1.8605E-04
22	387.0	-3.6676E-03	-1.9347E-04	-2.4945E-04
23	419.0	4.3953E-03	-1.9742E-04	-2.5339E-04
24	449.0	1.1983E-02	-1.9567E-04	-2.5143E-04
25	474.0	1.8203E-02	-1.9020E-04	-2.4543E-04
26	504.0	2.5398E-02	-1.7888E-04	-2.3341E-04
27	519.0	2.8839E-02	-1.7129E-04	-2.3296E-04
28	543.2	3.4422E-02	-1.5043E-04	-2.1924E-04
29	591.7	4.3767E-02	-9.4958E-05	-1.6285E-04
30	644.6	5.0295E-02	-1.3946E-05	-8.0689E-05
31	672.7	5.1862E-02	3.9708E-05	-2.6057E-05

TABLE 4-18. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 17 (CONTINUED)

Mode 4
Generalized Mass = 14.368 lb-sec^2/in.
Frequency = 7.5955 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	5.1710E-02*	9.8154E-05	4.2984E-05
33	731.9	4.9368E-02	1.5820E-04	1.5473E-04
34	761.0	4.2756E-02	2.1720E-04	2.9904E-04
35	790.1	3.2034E-02	2.6835E-04	4.2467E-04
36	819.2	1.8345E-02	3.0239E-04	4.9843E-04
37	848.3	3.3692E-03	3.1617E-04	5.1311E-04
38	877.5	-1.1366E-02	3.1067E-04	4.8506E-04
39	906.6	-2.4764E-02	2.8952E-04	4.3258E-04
40	937.4	-3.7136E-02	2.5439E-04	3.7626E-04
41	962.6	-4.6037E-02	2.1815E-04	3.2944E-04
42	992.5	-5.5108E-02	1.6631E-04	2.7570E-04
43	1025.0	-6.2943E-02	9.7359E-05	2.0232E-04
44	1057.0	-6.8062E-02	1.7006E-05	1.0392E-04
45	1090.0	-6.9573E-02	-7.1014E-05	-3.3936E-05
46	1122.5	-6.5896E-02	-1.5944E-04	-1.7631E-04
47	1133.0	-6.3716E-02	-1.8406E-04	-2.0215E-04
48	1160.5	-6.1142E-02	-1.6536E-04	-9.3181E-05
49	1175.7	-5.9648E-02	-1.6042E-04	-6.9724E-05
50	1198.0	-5.8733E-02	-1.527[illegible]E-04	2.6023E-05
51	1210.0	-5.8953E-02	-1.4535E-04	2.1865E-05
52	1210.0	-5.8955E-02	6.6705E-03	6.6721E-03
53	1240.0	-2.5913E-01	6.6714E-03	6.6729E-03
54	1160.0	-5.5709E-02	-2.3977E-04	-4.3484E-04
55	1176.0	-4.6898E-02	-2.6488E-04	-5.5489E-04
56	1206.0	-3.0312E-02	-2.8308E-04	-4.0015E-04
57	1212.0	-2.8753E-02	-2.8296E-04	-2.6893E-04
58	1242.0	-2.0515E-02	-2.8266E-04	-2.7724E-04
59	1267.0	-1.3516E-02	-2.8261E-04	-2.7996E-04
60	1160.0	-2.7339E-01	-1.0687E-02	-1.0634E-02
61	1176.0	-1.0322E-01	-1.0690E-02	-1.0638E-02
62	1206.0	2.1623E-01	-1.0714E-02	-1.0699E-02
63	1212.0	2.8066E-01	-1.0721E-02	-1.0743E-02
64	1212.0	2.8067E-01	-2.3941E-02	-2.3962E-02
65	1242.0	1.0000E 00	-2.3970E-02	-2.3991E-02

*5.1710E-02 = 5.1710 x 10^{-2}
**Includes bending and shear slope

TABLE 4-19. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 17

Mode 5
Generalized Mass = 5.5635 lb-sec^2/in.
Frequency = 8.0282 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	2.2841E-01	3.9910E-04	1.3698E-03
2	-270.5	1.9431E-01	3.8302E-04	1.1561E-03
3	-230.5	1.4728E-01	3.4644E-04	1.1555E-03
4	-180.5	1.0005E-01	3.0386E-04	7.7815E-04
5	-156.0	8.1967E-02	2.8431E-04	6.8752E-04
6	-133.0	6.6998E-02	2.6721E-04	6.2509E-04
7	-82.0	3.5085E-02	2.2241E-04	6.1738E-04
8	-48.0	1.4223E-02	1.8243E-04	5.9895E-04
9	-1.0	-1.2646E-02	1.1297E-04	5.3052E-04
76	20.0	-2.3304E-02	7.6587E-05	1.7799E-04
10	68.0	-2.5855E-02	4.1139E-05	3.5137E-05
11	118.0	-2.6701E-02	5.7694E-06	-1.0309E-06
15	168.0	-2.5782E-02	-2.7806E-05	-4.2032E-05
70	-156.0	6.9964E-03	2.7106E-04	2.7858E-04
71	-82.0	-1.3340E-02	2.5978E-04	2.6004E-04
72	-116.0	-4.8184E-03	2.5577E-04	2.5577E-04
73	-48.0	-1.8504E-02	1.1743E-04	1.1295E-04
74	-34.0	-2.0149E-02	1.1750E-04	1.1751E-04
75	-17.0	-2.0992E-02	8.5244E-05	6.4784E-05
79	14.0	-2.2862E-02	7.6739E-05	6.5069E-05
77	26.0	-2.3926E-02	1.1963E-04	1.2075E-04
78	62.0	-2.8299E-02	1.1990E-04	1.2652E-04
12	122.0	-2.7577E-02	-2.8999E-05	-4.2115E-05
13	141.0	-2.6845E-02	-2.8788E-05	-3.7376E-05
14	149.0	-2.6539E-02	-2.8489E-05	-3.9261E-05
16	199.0	-2.3754E-02	-5.3951E-05	-8.1287E-05
17	229.0	-2.0880E-02	-7.6424E-05	-1.0954E-04
18	264.0	-1.6551E-02	-9.8345E-05	-1.3635E-04
19	294.0	-1.2168E-02	-1.1295E-04	-1.5451E-04
20	324.0	-7.3224E-03	-1.2332E-04	-1.6710E-04
21	361.0	-9.6701E-04	-1.2995E-04	-1.5080E-04
69	337.0	-4.2236E-03	-1.3014E-04	-1.3653E-04
66	387.0	2.5574E-03	-1.3050E-04	-1.3474E-04
67	402.5	4.6358E-03	-1.3068E-04	-1.3329E-04
68	426.7	7.8109E-03	-1.3072E-04	-1.3267E-04
22	387.0	3.1686E-03	-1.2961E-04	-1.5867E-04
23	419.0	8.2011E-03	-1.2637E-04	-1.5529E-04
24	449.0	1.2776E-02	-1.2053E-04	-1.4914E-04
25	474.0	1.6416E-02	-1.1359E-04	-1.4164E-04
26	504.0	2.0500E-02	-1.0286E-04	-1.3023E-04
27	519.0	2.2402E-02	-9.6520E-05	-1.2718E-04
28	543.2	2.5380E-02	-8.0365E-05	-1.1434E-04
29	591.7	3.0000E-02	-4.1265E-05	-7.4511E-05
30	644.6	3.2568E-02	1.1412E-05	-2.0981E-05
31	673.7	3.2688E-02	4.4816E-05	1.3122E-05

TABLE 4-19. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 17 (CONTINUED)

Mode 5

Generalized Mass = 5.5635 lb-sec^2/in.

Frequency = 8.0282 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	3.1754E-02*	8.0341E-05	5.5178E-05
33	731.9	2.9488E-02	1.1606E-04	1.2490E-04
34	761.0	2.4521E-02	1.5011E-04	2.1474E-04
35	790.1	1.7046E-02	1.7796E-04	2.8902E-04
36	819.2	7.9034E-03	1.9443E-04	3.2639E-04
37	848.3	-1.7300E-03	1.9773E-04	3.2364E-04
38	877.5	-1.0849E-02	1.8917E-04	2.9366E-04
39	906.6	-1.8777E-02	1.7165E-04	2.5114E-04
40	937.4	-2.5811E-02	1.4648E-04	2.1114E-04
41	962.6	-3.0748E-02	1.2227E-04	1.8073E-04
42	992.5	-3.5649E-02	8.9129E-05	1.4620E-04
43	1025.0	-3.9698E-02	4.6519E-05	1.0077E-04
44	1057.0	-4.2103E-02	-1.8745E-06	4.0470E-05
45	1090.0	-4.2265E-02	-5.3686E-05	-4.4822E-05
46	1122.5	-3.9219E-02	-1.0419E-04	-1.3038E-04
47	1133.0	-3.7656E-02	-1.1788E-04	-1.5339E-04
48	1160.5	-3.1091E-02	-1.7881E-04	-2.8707E-04
49	1175.7	-2.5872E-02	-1.9904E-04	-4.5976E-04
50	1198.0	-1.1998E-02	-2.3403E-04	-9.0615E-04
51	1210.0	-8.7650E-04	-2.6903E-04	-9.4378E-04
52	1210.0	-8.6917E-04	-3.3353E-02	-3.3360E-02
53	1240.0	1.0000E 00	-3.3358E-02	-3.3364E-02
54	1160.0	-3.4600E-02	-1.1892E-04	-1.2071E-04
55	1176.0	-3.2556E-02	-1.1953E-04	-1.2856E-04
56	1206.0	-2.9686E-02	-1.1976E-04	-1.0675E-04
57	1212.0	-2.8144E-02	-1.1958E-04	-1.0084E-04
58	1242.0	-2.4936E-02	-1.1909E-04	-1.1050E-04
59	1267.0	-2.2081E-02	-1.1901E-04	-1.1416E-04
60	1160.0	-4.7722E-02	-6.9746E-04	-6.9431E-04
61	1176.0	-3.6612E-02	-6.9767E-04	-6.9456E-04
62	1206.0	-1.5756E-02	-6.9910E-04	-6.9799E-04
63	1212.0	-1.1555E-02	-6.9952E-04	-7.0035E-04
64	1212.0	-1.1555E-02	-1.4993E-03	-1.5001E-03
65	1242.0	3.3476E-02	-1.5011E-03	-1.5019E-03

*3.1754E-02 = 3.1754×10^{-2}

**Includes bending and shear slope

TABLE 4-20. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 32

Mode 1
Generalized Mass = 30.662 lb-sec^2/in.
Frequency = 1.8903 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	1.0000E 00	1.8524E-03	2.0880E-03
2	-270.5	9.3906E-01	1.8485E-03	2.0409E-03
3	-230.5	8.5710E-01	1.8394E-03	2.0523E-03
4	-180.5	7.5701E-01	1.8285E-03	1.9630E-03
5	-156.0	7.0909E-01	1.8233E-03	1.9451E-03
6	-133.0	6.6454E-01	1.8186E-03	1.9346E-03
7	-82.0	5.6558E-01	1.8057E-03	1.9473E-03
8	-48.0	4.9910E-01	1.7935E-03	1.9740E-03
9	-1.0	4.0565E-01	1.7704E-03	1.9849E-03
76	20.0	3.6391E-01	1.7573E-03	1.8376E-03
10	68.0	2.7720E-01	1.7154E-03	1.7845E-03
11	118.0	1.8943E-01	1.6538E-03	1.7233E-03
15	168.0	1.0517E-01	1.5739E-03	1.6303E-03
70	-156.0	7.5003E-01	2.4936E-03	2.5383E-03
71	-82.0	5.6386E-01	2.4266E-03	2.4263E-03
72	-116.0	6.3976E-01	2.1594E-03	2.1594E-03
73	-48.0	4.9910E-01	1.8321E-03	1.9191E-03
74	-34.0	4.7345E-01	1.8320E-03	1.8320E-03
75	-17.0	4.3630E-01	1.7847E-03	2.0006E-03
79	14.0	3.7465E-01	1.7600E-03	1.8830E-03
77	26.0	3.5349E-01	1.7273E-03	1.7265E-03
78	62.0	2.9134E-01	1.7272E-03	1.7234E-03
12	122.0	1.7775E-01	1.5743E-03	1.5790E-03
13	141.0	1.4777E-01	1.5742E-03	1.5772E-03
14	149.0	1.3515E-01	1.5741E-03	1.5777E-03
16	199.0	5.4682E-02	1.4903E-03	1.5865E-03
17	229.0	8.4124E-03	1.3995E-03	1.4961E-03
18	264.0	-4.1920E-02	1.2810E-03	1.3774E-03
19	294.0	-8.1576E-02	1.1688E-03	1.2644E-03
20	324.0	-1.1769E-01	1.0469E-03	1.1413E-03
21	361.0	-1.5691E-01	8.8329E-04	9.1504E-04
69	337.0	-1.3595E-01	8.8294E-04	8.7155E-04
66	387.0	-1.8031E-01	8.8458E-04	8.9607E-04
67	402.5	-1.9413E-01	8.8488E-04	8.8976E-04
68	426.7	-2.1556E-01	8.8494E-04	8.8793E-04
22	387.0	-1.7966E-01	8.1121E-04	8.3866E-04
23	419.0	-2.0504E-01	7.1984E-04	7.4700E-04
24	449.0	-2.2612E-01	6.3154E-04	6.5836E-04
25	474.0	-2.4164E-01	5.5602E-04	5.8235E-04
26	504.0	-2.5771E-01	4.6313E-04	4.8895E-04
27	519.0	-2.6469E-01	4.1577E-04	4.4487E-04
28	543.2	-2.7424E-01	3.0717E-04	3.3960E-04
29	591.7	-2.8531E-01	8.3322E-05	1.1535E-04
30	644.6	-2.8474E-01	-1.7031E-04	-1.3871E-04
31	673.7	-2.7860E-01	-3.1428E-04	-2.8302E-04

TABLE 4-20. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 32 (CONTINUED)

Mode 1
Generalized Mass = 30.662 lb-sec^2/in.
Frequency = 1.8903 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	-2.6820E-01*	-4.5757E-04	-4.3028E-04
33	731.9	-2.5364E-01	-5.9473E-04	-5.8442E-04
34	761.0	-2.3426E-01	-7.2970E-04	-7.4744E-04
35	790.1	-2.1014E-01	-8.6297E-04	-9.0871E-04
36	819.2	-1.8149E-01	-9.8758E-04	-1.0545E-03
37	848.3	-1.4895E-01	-1.0973E-03	-1.1758E-03
38	877.5	-1.1321E-01	-1.1902E-03	-1.2749E-03
39	906.6	-7.4876E-02	-1.2679E-03	-1.3539E-03
40	937.4	-3.2127E-02	-1.3355E-03	-1.4163E-03
41	962.6	4.1427E-03	-1.3808E-03	-1.4563E-03
42	992.5	4.8314E-02	-1.4255E-03	-1.5009E-03
43	1025.0	9.7766E-02	-1.4655E-03	-1.5395E-03
44	1057.0	1.4750E-01	-1.4961E-03	-1.5658E-03
45	1090.0	1.9945E-01	-1.5174E-03	-1.5771E-03
46	1122.5	2.5071E-01	-1.5306E-03	-1.5754E-03
47	1133.0	2.6718E-01	-1.5332E-03	-1.5542E-03
48	1160.5	3.1002E-01	-1.5361E-03	-1.5535E-03
49	1175.7	3.3351E-01	-1.5367E-03	-1.5537E-03
50	1198.0	3.6819E-01	-1.5374E-03	-1.5627E-03
51	1210.0	3.8689E-01	-1.5380E-03	-1.5587E-03
52	1210.0	3.8689E-01	-2.0105E-03	-2.0106E-03
53	1240.0	4.4722E-01	-2.0105E-03	-2.0107E-03
54	1160.0	3.0887E-01	-1.5359E-03	-1.5463E-03
55	1176.0	3.3363E-01	-1.5370E-03	-1.5475E-03
56	1206.0	3.8005E-01	-1.5381E-03	-1.5484E-03
57	1212.0	3.8944E-01	-1.5383E-03	-1.5462E-03
58	1242.0	4.3599E-01	-1.5388E-03	-1.5482E-03
59	1267.0	4.7460E-01	-1.5389E-03	-1.5447E-03
60	1160.0	3.0629E-01	-1.6992E-03	-1.6986E-03
61	1176.0	3.3347E-01	-1.6992E-03	-1.6986E-03
62	1206.0	3.8443E-01	-1.6995E-03	-1.6995E-03
63	1212.0	3.9463E-01	-1.6996E-03	-1.7003E-03
64	1212.0	3.9463E-01	-1.8517E-03	-1.8523E-03
65	1242.0	4.5020E-01	-1.8519E-03	-1.8525E-03

*-2.6820E-01 = -2.6820 x 10^{-1}
**Includes bending and shear slope

TABLE 4-21. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 32

Mode 2
Generalized Mass = 25.179 lb-sec^2/in.
Frequency = 4.1137 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	1.0000E 00	2.4549E-03	3.5707E-03
2	-270.5	9.0091E-01	2.4364E-03	3.3381E-03
3	-230.5	7.6614E-01	2.3939E-03	3.3685E-03
4	-180.5	6.0975E-01	2.3434E-03	2.9398E-03
5	-156.0	5.3867E-01	2.3197E-03	2.8452E-03
6	-133.0	4.7417E-01	2.2987E-03	2.7828E-03
7	-82.0	3.3154E-01	2.2419E-03	2.8046E-03
8	-48.0	2.3573E-01	2.1898E-03	2.8905E-03
9	-1.0	9.7344E-02	2.0933E-03	2.9037E-03
76	20.0	3.6701E-02	2.0399E-03	2.3166E-03
10	68.0	-6.5743E-02	1.8741E-03	2.0476E-03
11	118.0	-1.6286E-01	1.6565E-03	1.8291E-03
15	168.0	-2.4790E-01	1.3934E-03	1.5082E-03
70	-156.0	7.3986E-01	5.4829E-03	5.6917E-03
71	-82.0	3.2640E-01	5.1698E-03	5.1731E-03
72	-116.0	4.7146E-01	3.9042E-03	3.9042E-03
73	-48.0	2.3573E-01	2.3753E-03	2.7133E-03
74	-34.0	2.0248E-01	2.3751E-03	2.3751E-03
75	-17.0	1.4014E-01	2.1589E-03	2.9706E-03
79	14.0	4.9652E-02	2.0515E-03	2.5137E-03
77	26.0	2.4458E-02	2.0436E-03	2.0436E-03
78	62.0	-4.9141E-02	2.0437E-03	2.0467E-03
12	122.0	-1.8475E-01	1.3913E-03	1.3682E-03
13	141.0	-2.1087E-01	1.3917E-03	1.3761E-03
14	149.0	-2.2186E-01	1.3922E-03	1.3718E-03
16	199.0	-2.9315E-01	1.1348E-03	1.3188E-03
17	229.0	-3.2842E-01	8.6535E-04	1.0282E-03
18	264.0	-3.5820E-01	5.3014E-04	6.6951E-04
19	294.0	-3.7342E-01	2.2732E-04	3.4303E-04
20	324.0	-3.7866E-01	-8.7306E-05	6.2301E-06
21	361.0	-3.7113E-01	-4.8833E-04	-5.3711E-04
69	337.0	-3.8615E-01	-4.9301E-04	-6.4624E-04
66	387.0	-3.6247E-01	-4.7713E-04	-3.7411E-04
67	402.5	-3.5593E-01	-4.7474E-04	-4.3494E-04
68	426.7	-3.4458E-01	-4.7433E-04	-4.5168E-04
22	387.0	-3.4867E-01	-6.5044E-04	-9.4457E-04
23	419.0	-3.1558E-01	-8.2140E-04	-1.1179E-03
24	449.0	-2.7996E-01	-9.5283E-04	-1.2516E-03
25	474.0	-2.4751E-01	-1.0409E-03	-1.3422E-03
26	504.0	-2.0593E-01	-1.1205E-03	-1.4241E-03
27	519.0	-1.8433E-01	-1.1496E-03	-1.4990E-03
28	543.2	-1.4633E-01	-1.1941E-03	-1.5889E-03
29	591.7	-6.8569E-02	-1.2044E-03	-1.5999E-03
30	644.6	1.3678E-02	-1.0957E-03	-1.4914E-03
31	673.7	5.5535E-02	-9.8242E-04	-1.3779E-03

TABLE 4-21. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 32 (CONTINUED)

Mode 2
Generalized Mass = 25.179 lb-sec^2/in.
Frequency = 4.1137 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	9.3372E-02*	-8.3509E-04	-1.2051E-03
33	731.9	1.2550E-01	-6.6225E-04	-9.7775E-04
34	761.0	1.5020E-01	-4.6307E-04	-7.0279E-04
35	790.1	1.6619E-01	-2.4091E-04	-3.8753E-04
36	819.2	1.7260E-01	-9.4349E-06	-5.4041E-05
37	848.3	1.6953E-01	2.0974E-04	2.5577E-04
38	877.5	1.5804E-01	4.0566E-04	5.2321E-04
39	906.6	1.3940E-01	5.7510E-04	7.3294E-04
40	937.4	1.1412E-01	7.2532E-04	8.8856E-04
41	962.6	9.0452E-02	8.2718E-04	9.8155E-04
42	992.5	5.9579E-02	9.2918E-04	1.0843E-03
43	1025.0	2.2761E-02	1.0224E-03	1.1756E-03
44	1057.0	-1.6008E-02	1.0960E-03	1.2435E-03
45	1090.0	-5.7867E-02	1.1495E-03	1.2833E-03
46	1122.5	-9.9848E-02	1.1848E-03	1.2917E-03
47	1133.0	-1.1328E-01	1.1921E-03	1.2441E-03
48	1160.5	-1.4761E-01	1.2001E-03	1.2434E-03
49	1175.7	-1.6635E-01	1.2019E-03	1.2480E-03
50	1198.0	-1.9434E-01	1.2042E-03	1.2784E-03
51	1210.0	-2.0955E-01	1.2061E-03	1.2691E-03
52	1210.0	-2.0956E-01	2.8865E-03	2.8871E-03
53	1240.0	-2.9617E-01	2.8867E-03	2.8872E-03
54	1160.0	-1.4626E-01	1.2000E-03	1.2302E-03
55	1176.0	-1.6603E-01	1.2034E-03	1.2355E-03
56	1206.0	-2.0308E-01	1.2064E-03	1.2625E-03
57	1212.0	-2.1074E-01	1.2070E-03	1.2552E-03
58	1242.0	-2.4805E-01	1.2085E-03	1.2343E-03
59	1267.0	-2.7867E-01	1.2087E-03	1.2248E-03
60	1160.0	-1.3589E-01	1.7972E-03	1.7947E-03
61	1176.0	-1.6460E-01	1.7974E-03	1.7948E-03
62	1206.0	-2.1846E-01	1.7985E-03	1.7982E-03
63	1212.0	-2.2927E-01	1.7989E-03	1.8009E-03
64	1212.0	-2.2927E-01	2.4165E-03	2.4185E-03
65	1242.0	-3.0184E-01	2.4177E-03	2.4196E-03

*9.3372E-02 = 9.3372 x 10^{-2}
**Includes bending and shear slope

TABLE 4-22. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 32

Mode 3
Generalized Mass = 16.899 lb-sec^2/in.
Frequency = 7.5671 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	-6.4095E-01	-9.2438E-04	-3.3443E-03
2	-270.5	-5.5803E-01	-8.8428E-04	-2.8228E-03
3	-230.5	-4.4287E-01	-7.9271E-04	-2.8471E-03
4	-180.5	-3.2674E-01	-6.8519E-04	-1.9117E-03
5	-156.0	-2.8216E-01	-6.3545E-04	-1.6958E-03
6	-133.0	-2.4522E-01	-5.9163E-04	-1.5521E-03
7	-82.0	-1.6525E-01	-4.7516E-04	-1.5707E-03
8	-48.0	-1.1137E-01	-3.6958E-04	-5.7824E-04
9	-1.0	-1.3251E-01	-2.2173E-04	4.7442E-04
76	20.0	-1.4209E-01	-1.6477E-04	-2.2666E-07
10	68.0	-1.2920E-01	-2.5734E-04	-3.1555E-04
11	118.0	-1.1123E-01	-3.3869E-04	-4.0015E-04
15	168.0	-8.9452E-02	-4.0383E-04	-4.8146E-04
70	-156.0	4.7966E-01	7.3485E-03	7.8065E-03
71	-82.0	-8.1036E-02	6.6618E-03	6.6874E-03
72	-116.0	7.8450E-02	3.8105E-03	3.8105E-03
73	-48.0	-1.1132E-01	4.5642E-04	7.2921E-04
74	-34.0	-1.1771E-01	4.5676E-04	4.5679E-04
75	-17.0	-1.3170E-01	3.0427E-05	4.4210E-04
79	14.0	-1.4269E-01	-1.4714E-04	8.7277E-05
77	26.0	-1.4191E-01	4.6203E-05	5.1814E-05
78	62.0	-1.4387E-01	4.7402E-05	7.7318E-05
12	122.0	-1.0983E-01	-4.0802E-04	-4.5443E-04
13	141.0	-1.0143E-01	-4.0727E-04	-4.3742E-04
14	149.0	-9.7912E-02	-4.0621E-04	-4.4347E-04
16	199.0	-7.2214E-02	-4.4263E-04	-5.8241E-04
17	229.0	-5.4114E-02	-4.6570E-04	-6.1999E-04
18	264.0	-3.2004E-02	-4.7266E-04	-6.3696E-04
19	294.0	-1.2926E-02	-4.6050E-04	-6.2979E-04
20	324.0	5.6113E-03	-4.3107E-04	-6.0121E-04
21	361.0	2.6804E-02	-3.7089E-04	-4.2485E-04
69	337.0	1.8437E-02	-3.7013E-04	-3.4538E-04
66	387.0	3.7987E-02	-3.7558E-04	-4.1633E-04
67	402.5	4.4205E-02	-3.7676E-04	-3.9529E-04
68	426.7	5.3399E-02	-3.7698E-04	-3.8885E-04
22	387.0	3.6391E-02	-3.3713E-04	-3.5129E-04
23	419.0	4.6934E-02	-2.9422E-04	-3.0736E-04
24	449.0	5.5520E-02	-2.5270E-04	-2.6456E-04
25	474.0	6.1673E-02	-2.1724E-04	-2.2713E-04
26	504.0	6.7802E-02	-1.7386E-04	-1.8162E-04
27	519.0	7.0348E-02	-1.5188E-04	-1.5878E-04
28	543.2	7.3591E-02	-1.0188E-04	-1.0810E-04
29	591.7	7.6349E-02	-6.1083E-07	-5.0919E-06
30	644.6	7.3618E-02	1.1109E-04	1.0843E-04
31	673.7	6.9537E-02	1.7300E-04	1.7171E-04

TABLE 4-22. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 32 (CONTINUED)

Mode 3
Generalized Mass = 16.899 lb-sec^2/in.
Frequency = 7.5671 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	6.3613E-02*	2.3349E-04	2.4080E-04
33	731.9	5.5582E-02	2.8964E-04	3.5174E-04
34	761.0	4.3220E-02	3.3954E-04	4.9110E-04
35	790.1	2.7132E-02	3.7280E-04	5.9486E-04
36	819.2	9.0040E-03	3.8401E-04	6.2871E-04
37	848.3	-9.0796E-03	3.7215E-04	5.9453E-04
38	877.5	-2.5479E-02	3.4089E-04	5.1799E-04
39	906.6	-3.9174E-02	2.9578E-04	4.2580E-04
40	937.4	-5.0836E-02	2.3847E-04	3.4239E-04
41	962.6	-5.8680E-02	1.8672E-04	2.8043E-04
42	992.5	-6.6037E-02	1.1880E-04	2.1019E-04
43	1025.0	-7.1479E-02	3.4398E-05	1.2125E-04
44	1057.0	-7.3792E-02	-5.9012E-05	9.1746E-06
45	1090.0	-7.1975E-02	-1.5741E-04	-1.4041E-04
46	1122.5	-6.4688E-02	-2.5337E-04	-2.8909E-04
47	1133.0	-6.1335E-02	-2.7965E-04	-3.0876E-04
48	1160.5	-5.5569E-02	-2.6727E-04	-2.1223E-04
49	1175.7	-5.2224E-02	-2.6424E-04	-2.0308E-04
50	1198.0	-4.8024E-02	-2.5966E-04	-1.4782E-04
51	1210.0	-4.6165E-02	-2.5538E-04	-1.5288E-04
52	1210.0	-4.6166E-02	3.6920E-03	3.6929E-03
53	1240.0	-1.5696E-01	3.6925E-03	3.6934E-03
54	1160.0	-5.0688E-02	-3.3546E-04	-5.3111E-04
55	1176.0	-4.0361E-02	-3.6058E-04	-6.4954E-04
56	1206.0	-2.0935E-02	-3.7891E-04	-5.0288E-04
57	1212.0	-1.8726E-02	-3.7889E-04	-3.7353E-04
58	1242.0	-7.4069E-03	-3.7887E-04	-3.7829E-04
59	1267.0	2.0751E-03	-3.7888E-04	-3.7928E-04
60	1160.0	-2.6542E-01	-1.0656E-02	-1.0604E-02
61	1176.0	-9.5736E-02	-1.0659E-02	-1.0608E-02
62	1206.0	2.2280E-01	-1.0683E-02	-1.0668E-02
63	1212.0	2.8705E-01	-1.0690E-02	-1.0712E-02
64	1212.0	2.8705E-01	-2.3728E-02	-2.3750E-02
65	1242.0	1.0000E 00	-2.3757E-02	-2.3779E-02

*6.3613E-02 = 6.3613 × 10^{-2}
**Includes bending and shear slope

TABLE 4-23. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 32

Mode 4
Generalized Mass = 4.9776 lb-sec^2/in.
Frequency = 7.7260 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	1.0000E 00	1.5943E-03	5.5302E-03
2	-270.5	8.6243E-01	1.5291E-03	4.6745E-03
3	-230.5	6.7199E-01	1.3804E-03	4.6967E-03
4	-180.5	4.7985E-01	1.2065E-03	3.1716E-03
5	-156.0	4.0595E-01	1.1262E-03	2.8136E-03
6	-133.0	3.4462E-01	1.0558E-03	2.5714E-03
7	-82.0	2.1266E-01	8.6959E-04	2.5751E-03
8	-48.0	1.2490E-01	7.0190E-04	1.2493E-03
9	-1.0	1.3053E-01	4.5828E-04	-1.9116E-04
76	20.0	1.3459E-01	3.5795E-04	2.1534E-04
10	68.0	1.1230E-01	4.1593E-04	4.9351E-04
11	118.0	8.6447E-02	4.5626E-04	5.3664E-04
15	168.0	5.8986E-02	4.7538E-04	5.6000E-04
70	-156.0	-5.1188E-01	-7.9867E-03	-8.4962E-03
71	-82.0	9.7993E-02	-7.2227E-03	-7.2520E-03
72	-116.0	-7.3099E-02	-4.0477E-03	-4.0477E-03
73	-48.0	1.2483E-01	-3.1641E-04	-5.5582E-04
74	-34.0	1.2927E-01	-3.1681E-04	-3.1684E-04
75	-17.0	1.3574E-01	1.5018E-04	-1.1710E-04
79	14.0	1.3646E-01	3.3943E-04	1.8723E-04
77	26.0	1.3322E-01	1.5645E-04	1.5105E-04
78	62.0	1.2786E-01	1.5534E-04	1.2762E-04
12	122.0	8.2239E-02	4.7863E-04	5.1485E-04
13	141.0	7.2646E-02	4.7804E-04	5.0142E-04
14	149.0	6.8619E-02	4.7722E-04	5.0576E-04
16	199.0	3.9825E-02	4.7200E-04	6.1978E-04
17	229.0	2.1332E-02	4.5341E-04	6.0849E-04
18	264.0	6.0895E-04	4.1170E-04	5.6947E-04
19	294.0	-1.5720E-02	3.5851E-04	5.1463E-04
20	324.0	-3.0110E-02	2.8941E-04	4.4084E-04
21	361.0	-4.4413E-02	1.8294E-04	2.1147E-04
69	337.0	-4.1269E-02	1.8118E-04	1.2341E-04
66	387.0	-5.1254E-02	1.8899E-04	2.4310E-04
67	402.5	-5.4669E-02	1.9040E-04	2.1310E-04
68	426.7	-5.9366E-02	1.9065E-04	2.0441E-04
22	387.0	-4.6997E-02	1.3322E-04	7.4217E-05
23	419.0	-4.8447E-02	7.7755E-05	1.7533E-05
24	449.0	-4.8249E-02	3.1614E-05	-2.9862E-05
25	474.0	-4.7052E-02	-2.4208E-06	-6.5555E-05
26	504.0	-4.4510E-02	-3.7807E-05	-1.0253E-04
27	519.0	-4.2845E-02	-5.3222E-05	-1.2867E-04
28	543.2	-3.9105E-02	-8.3423E-05	-1.6938E-04
29	591.7	-2.9729E-02	-1.2669E-04	-2.1346E-04
30	644.6	-1.7754E-02	-1.4753E-04	-2.3491E-04
31	673.7	-1.0894E-02	-1.4723E-04	-2.3490E-04

TABLE 4-23. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 32 (CONTINUED)

Mode 4
Generalized Mass = 4.9776 lb-sec^2/in.
Frequency = 7.7260 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	-4.2070E-03*	-1.3875E-04	-2.2220E-04
33	731.9	1.9787E-03	-1.2303E-04	-2.0085E-04
34	761.0	7.4592E-03	-1.0019E-04	-1.6854E-04
35	790.1	1.1727E-02	-7.0790E-05	-1.1936E-04
36	819.2	1.4343E-02	-3.7493E-05	-5.8080E-05
37	848.3	1.5131E-02	-4.6678E-06	2.9226E-06
38	877.5	1.4242E-02	2.4621E-05	5.5409E-05
39	906.6	1.1979E-02	4.8741E-05	9.2606E-05
40	937.4	8.7154E-03	6.7965E-05	1.1369E-04
41	962.6	5.7252E-03	7.9079E-05	1.2228E-04
42	992.5	1.9311E-03	8.7739E-05	1.3107E-04
43	1025.0	-2.4168E-03	9.2196E-05	1.3482E-04
44	1057.0	-6.7092E-03	9.1525E-05	1.3137E-04
45	1090.0	-1.0902E-02	8.6120E-05	1.1790E-04
46	1122.5	-1.4399E-02	7.7195E-05	9.6957E-05
47	1133.0	-1.5339E-02	7.4174E-05	8.4880E-05
48	1160.5	-1.8795E-02	8.9145E-05	1.3178E-04
49	1175.7	-2.0873E-02	9.3597E-05	1.6312E-04
50	1198.0	-2.5215E-02	1.0092E-04	2.5639E-04
51	1210.0	-2.8274E-02	1.0806E-04	2.5842E-04
52	1210.0	-2.8276E-02	6.7960E-03	6.7975E-03
53	1240.0	-2.3222E-01	6.7969E-03	6.7984E-03
54	1160.0	-1.6703E-02	6.1448E-05	1.7072E-05
55	1176.0	-1.6524E-02	5.5684E-05	-1.2237E-05
56	1206.0	-1.6170E-02	5.1639E-05	3.2120E-05
57	1212.0	-1.6594E-02	5.1775E-05	6.4428E-05
58	1242.0	-1.8429E-02	5.2156E-05	5.8750E-05
59	1267.0	-1.9835E-02	5.2224E-05	5.6255E-05
60	1160.0	-6.9930E-02	-2.4782E-03	-2.4654E-03
61	1176.0	-3.0479E-02	-2.4790E-03	-2.4663E-03
62	1206.0	4.3586E-02	-2.4849E-03	-2.4812E-03
63	1212.0	5.8532E-02	-2.4867E-03	-2.4919E-03
64	1212.0	5.8532E-02	-5.7217E-03	-5.7269E-03
65	1242.0	2.3045E-01	-5.7288E-03	-5.7340E-03

*-4.2070E-03 = -4.2070×10^{-3}
**Includes bending and shear slope

TABLE 4-24. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 32

Mode 5
Generalized Mass = 5.7713 lb-sec^2/in.
Frequency = 8.0408 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	3.4531E-01	6.0373E-04	2.0758E-03
2	-270.5	2.9363E-01	5.7933E-04	1.7517E-03
3	-230.5	2.2238E-01	5.2388E-04	1.7504E-03
4	-180.5	1.5085E-01	4.5931E-04	1.1781E-03
5	-156.0	1.2348E-01	4.2967E-04	1.0406E-03
6	-133.0	1.0083E-01	4.0375E-04	9.4583E-04
7	-82.0	5.2547E-02	3.3585E-04	9.3381E-04
8	-48.0	2.0999E-02	2.7528E-04	5.5543E-04
9	-1.0	1.3082E-02	1.8388E-04	1.2818E-04
76	20.0	1.0702E-02	1.4378E-04	1.3691E-04
10	68.0	3.3571E-03	1.2924E-04	1.4548E-04
11	118.0	-3.4537E-03	1.0989E-04	1.2613E-04
15	168.0	-9.1848E-03	8.6264E-05	9.6497E-05
70	-156.0	-8.7401E-02	-1.3911E-03	-1.4853E-03
71	-82.0	1.9027E-02	-1.2498E-03	-1.2554E-03
72	-116.0	-9.6955E-03	-6.6194E-04	-6.6194E-04
73	-48.0	2.0982E-02	2.8135E-05	1.8304E-05
74	-34.0	2.0589E-02	2.8066E-05	2.8061E-05
75	-17.0	1.7163E-02	1.1044E-04	1.6402E-04
79	14.0	1.1601E-02	1.4095E-04	1.7146E-04
77	26.0	9.8920E-03	1.3078E-04	1.3041E-04
78	62.0	5.1960E-03	1.3074E-04	1.2952E-04
12	122.0	-5.3266E-03	8.6020E-05	8.3479E-05
13	141.0	-6.9259E-03	8.6061E-05	8.4310E-05
14	149.0	-7.5985E-03	8.6120E-05	8.3724E-05
16	199.0	-1.2033E-02	6.3015E-05	7.8570E-05
17	229.0	-1.3986E-02	3.8901E-05	5.1063E-05
18	264.0	-1.5193E-02	9.2178E-06	1.7574E-05
19	294.0	-1.5268E-02	-1.7164E-05	-1.2574E-05
20	324.0	-1.4434E-02	-4.4015E-05	-4.2778E-05
21	361.0	-1.2179E-02	-7.7282E-05	-8.8764E-05
69	337.0	-1.4508E-02	-7.7954E-05	-9.9950E-05
66	387.0	-1.0605E-02	-7.6141E-05	-6.5275E-05
67	402.5	-9.5054E-03	-7.5927E-05	-7.2158E-05
68	426.7	-7.6803E-03	-7.5892E-05	-7.3964E-05
22	387.0	-8.8839E-03	-8.9749E-05	-1.3284E-04
23	419.0	-4.4378E-03	-1.0091E-04	-1.4419E-04
24	449.0	-6.5494E-06	-1.0716E-04	-1.5050E-04
25	474.0	3.7879E-03	-1.0926E-04	-1.5251E-04
26	504.0	8.3525E-03	-1.0804E-04	-1.5108E-04
27	519.0	1.0602E-02	-1.0591E-04	-1.5490E-04
28	543.2	1.4416E-02	-9.8133E-05	-1.5304E-04
29	591.7	2.1246E-02	-7.1622E-05	-1.2605E-04
30	644.6	2.6768E-02	-2.6240E-05	-8.0019E-05
31	673.7	2.8630E-02	6.0298E-06	-4.7156E-05

TABLE 4-24. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 32 (CONTINUED)

Mode 5
Generalized Mass = 5.7713 lb-sec^2/in.
Frequency = 8.0408 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	2.9431E-02*	4.2452E-05	-3.3595E-06
33	731.9	2.8821E-02	8.0936E-05	6.9356E-05
34	761.0	2.5424E-02	1.1965E-04	1.6440E-04
35	790.1	1.9291E-02	1.5407E-04	2.4891E-04
36	819.2	1.1117E-02	1.7859E-04	3.0102E-04
37	848.3	1.9912E-03	1.9023E-04	3.1420E-04
38	877.5	-7.0713E-03	1.8948E-04	2.9874E-04
39	906.6	-1.5334E-02	1.7871E-04	2.6711E-04
40	937.4	-2.2986E-02	1.5925E-04	2.3372E-04
41	962.6	-2.8537E-02	1.3864E-04	2.0644E-04
42	992.5	-3.4257E-02	1.0873E-04	1.7521E-04
43	1025.0	-3.9293E-02	6.8564E-05	1.3211E-04
44	1057.0	-4.2720E-02	2.1472E-05	7.2661E-05
45	1090.0	-4.3941E-02	-3.0138E-05	-1.3851E-05
46	1122.5	-4.1855E-02	-8.1334E-05	-1.0251E-04
47	1133.0	-4.0570E-02	-9.5346E-05	-1.2877E-04
48	1160.5	-3.4725E-02	-1.5616E-04	-2.6170E-04
49	1175.7	-2.9873E-02	-1.7645E-04	-4.3572E-04
50	1198.0	-1.6513E-02	-2.1158E-04	-8.8387E-04
51	1210.0	-5.6451E-03	-2.4676E-04	-9.2268E-04
52	1210.0	-5.6377E-03	-3.3512E-02	-3.3519E-02
53	1240.0	1.0000E 00	-3.3516E-02	-3.3523E-02
54	1160.0	-3.8103E-02	-9.7210E-05	-1.0176E-04
55	1176.0	-3.6322E-02	-9.8210E-05	-1.1221E-04
56	1206.0	-3.2942E-02	-9.8674E-05	-8.4553E-05
57	1212.0	-3.2562E-02	-9.8451E-05	-7.5843E-05
58	1242.0	-3.0074E-02	-9.7841E-05	-8.7196E-05
59	1267.0	-2.7783E-02	-9.7738E-05	-9.1623E-05
60	1160.0	-5.5933E-02	-8.9481E-04	-8.9054E-04
61	1176.0	-4.1683E-02	-8.9509E-04	-8.9086E-04
62	1206.0	-1.4930E-02	-8.9705E-04	-8.9558E-04
63	1212.0	-9.5388E-03	-8.9762E-04	-8.9885E-04
64	1212.0	-9.5387E-03	-1.9841E-03	-1.9854E-03
65	1242.0	5.0061E-02	-1.9866E-03	-1.9879E-03

*2.9431E-02 = 2.9431×10^{-2}
**Includes bending and shear slope

TABLE 4-25. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 33

Mode 1
Generalized Mass = 31.670 lb-sec^2/in.
Frequency = 1.8755 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	1.0000E 00	1.8583E-03	2.0902E-03
2	-270.5	9.3896E-01	1.8544E-03	2.0439E-03
3	-230.5	8.5690E-01	1.8455E-03	2.0550E-03
4	-180.5	7.5663E-01	1.8348E-03	1.9671E-03
5	-156.0	7.0861E-01	1.8297E-03	1.9495E-03
6	-133.0	6.6395E-01	1.8251E-03	1.9391E-03
7	-82.0	5.6476E-01	1.8123E-03	1.9517E-03
8	-48.0	4.9814E-01	1.8003E-03	2.0172E-03
9	-1.0	4.0086E-01	1.7760E-03	2.0655E-03
76	20.0	3.5745E-01	1.7615E-03	1.8596E-03
10	68.0	2.7054E-01	1.7183E-03	1.7878E-03
11	118.0	1.8263E-01	1.6554E-03	1.7253E-03
15	168.0	9.8319E-02	1.5740E-03	1.6305E-03
70	-156.0	8.1156E-01	3.0837E-03	3.1313E-03
71	-82.0	5.8161E-01	3.0123E-03	3.0022E-03
72	-116.0	6.8129E-01	2.9895E-03	2.9895E-03
73	-48.0	4.9814E-01	2.1138E-03	2.1988E-03
74	-34.0	4.6855E-01	2.1138E-03	2.1138E-03
75	-17.0	4.3039E-01	1.8713E-03	2.0585E-03
79	14.0	3.6818E-01	1.7641E-03	1.8709E-03
77	26.0	3.4699E-01	1.7325E-03	1.7317E-03
78	62.0	2.8465E-01	1.7324E-03	1.7287E-03
12	122.0	1.7089E-01	1.5744E-03	1.5788E-03
13	141.0	1.4091E-01	1.5743E-03	1.5771E-03
14	149.0	1.2829E-01	1.5742E-03	1.5776E-03
16	199.0	4.7837E-02	1.4890E-03	1.5855E-03
17	229.0	1.6211E-03	1.3969E-03	1.4936E-03
18	264.0	-4.8595E-02	1.2769E-03	1.3733E-03
19	294.0	-8.8106E-02	1.1634E-03	1.2589E-03
20	324.0	-1.2403E-01	1.0401E-03	1.1343E-03
21	361.0	-1.6296E-01	8.7484E-04	9.0635E-04
69	337.0	-1.4222E-01	8.7448E-04	8.6275E-04
66	387.0	-1.8615E-01	8.7615E-04	8.8780E-04
67	402.5	-1.9984E-01	8.7646E-04	8.8139E-04
68	426.7	-2.2107E-01	8.7651E-04	8.7953E-04
22	387.0	-1.8546E-01	8.0212E-04	8.2881E-04
23	419.0	-2.1051E-01	7.1004E-04	7.3643E-04
24	449.0	-2.3128E-01	6.2114E-04	6.4719E-04
25	474.0	-2.4650E-01	5.4518E-04	5.7074E-04
26	504.0	-2.6222E-01	4.5183E-04	4.7687E-04
27	519.0	-2.6902E-01	4.0426E-04	4.3248E-04
28	543.2	-2.7826E-01	2.9525E-04	3.2669E-04
29	591.7	-2.8869E-01	7.0789E-05	1.0182E-04
30	644.6	-2.8739E-01	-1.8321E-04	-1.5261E-04
31	673.7	-2.8085E-01	-3.2725E-04	-2.9698E-04

TABLE 4-25. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 33 (CONTINUED)

Mode 1
Generalized Mass = 31.670 lb-sec^2/in.
Frequency = 1.8755 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	-2.7004E-01*	-4.7052E-04	-4.4415E-04
33	731.9	-2.5508E-01	-6.0757E-04	-5.9797E-04
34	761.0	-2.3532E-01	-7.4236E-04	-7.6052E-04
35	790.1	-2.1082E-01	-8.7542E-04	-9.2135E-04
36	819.2	-1.8182E-01	-9.9921E-04	-1.0661E-03
37	848.3	-1.4895E-01	-1.1081E-03	-1.1864E-03
38	877.5	-1.1292E-01	-1.2004E-03	-1.2847E-03
39	906.6	-7.4310E-02	-1.2776E-03	-1.3620E-03
40	937.4	-3.1291E-02	-1.3447E-03	-1.4249E-03
41	962.6	5.1917E-03	-1.3896E-03	-1.4645E-03
42	992.5	4.9604E-02	-1.4340E-03	-1.5088E-03
43	1025.0	9.9309E-02	-1.4737E-03	-1.5471E-03
44	1057.0	1.4928E-01	-1.5040E-03	-1.5732E-03
45	1090.0	2.0147E-01	-1.5251E-03	-1.5844E-03
46	1122.5	2.5297E-01	-1.5382E-03	-1.5827E-03
47	1133.0	2.6952E-01	-1.5408E-03	-1.5616E-03
48	1160.5	3.1256E-01	-1.5437E-03	-1.5610E-03
49	1175.7	3.3617E-01	-1.5443E-03	-1.5611E-03
50	1198.0	3.7102E-01	-1.5450E-03	-1.5700E-03
51	1210.0	3.8981E-01	-1.5455E-03	-1.5661E-03
52	1210.0	3.8981E-01	-2.0135E-03	-2.0137E-03
53	1240.0	4.5022E-01	-2.0135E-03	-2.0137E-03
54	1160.0	3.1141E-01	-1.5435E-03	-1.5538E-03
55	1176.0	3.3629E-01	-1.5446E-03	-1.5550E-03
56	1206.0	3.8293E-01	-1.5456E-03	-1.5658E-03
57	1212.0	3.9237E-01	-1.5458E-03	-1.5636E-03
58	1242.0	4.3914E-01	-1.5464E-03	-1.5557E-03
59	1267.0	4.7794E-01	-1.5465E-03	-1.5522E-03
60	1160.0	3.0886E-01	-1.7052E-03	-1.7046E-03
61	1176.0	3.3613E-01	-1.7052E-03	-1.7046E-03
62	1206.0	3.8727E-01	-1.7055E-03	-1.7055E-03
63	1212.0	3.9751E-01	-1.7056E-03	-1.7063E-03
64	1212.0	3.9751E-01	-1.8561E-03	-1.8567E-03
65	1242.0	4.5321E-01	-1.8563E-03	-1.8569E-03

*-2.7004E-01 = -2.7004×10^{-1}
**Includes bending and shear slope

TABLE 4-26. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 33

Mode 2
Generalized Mass = 28.740 lb-sec^2/in.
Frequency = 3.9548 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	7.7840E-01	2.0719E-03	2.8746E-03
2	-270.5	6.9794E-01	2.0586E-03	2.7065E-03
3	-230.5	5.8880E-01	2.0280E-03	2.7265E-03
4	-180.5	4.6113E-01	1.9918E-03	2.4176E-03
5	-156.0	4.0261E-01	1.9748E-03	2.3486E-03
6	-133.0	3.4927E-01	1.9598E-03	2.3024E-03
7	-82.0	2.3141E-01	1.9193E-03	2.3141E-03
8	-48.0	1.5249E-01	1.8823E-03	2.6881E-03
9	-1.0	9.7098E-03	1.8016E-03	2.9946E-03
76	20.0	-5.2675E-02	1.7503E-03	2.1092E-03
10	68.0	-1.3994E-01	1.5804E-03	1.7295E-03
11	118.0	-2.2117E-01	1.3649E-03	1.5127E-03
15	168.0	-2.9056E-01	1.1104E-03	1.2032E-03
70	-156.0	1.0000E 00	8.8740E-03	9.1348E-03
71	-82.0	3.3367E-01	8.4829E-03	8.4373E-03
72	-116.0	6.0773E-01	8.3561E-03	8.3561E-03
73	-48.0	1.5251E-01	3.5581E-03	3.8906E-03
74	-34.0	1.0270E-01	3.5580E-03	3.5580E-03
75	-17.0	4.1347E-02	2.2834E-03	2.9289E-03
79	14.0	-4.1591E-02	1.7628E-03	2.1310E-03
77	26.0	-6.3311E-02	1.7875E-03	1.7884E-03
78	62.0	-1.2773E-01	1.7878E-03	1.7951E-03
12	122.0	-2.4061E-01	1.1078E-03	1.0800E-03
13	141.0	-2.6127E-01	1.1082E-03	1.0897E-03
14	149.0	-2.6998E-01	1.1089E-03	1.0849E-03
16	199.0	-3.2607E-01	8.6445E-04	1.0112E-03
17	229.0	-3.5234E-01	6.1124E-04	7.3664E-04
18	264.0	-3.7232E-01	2.9978E-04	4.0230E-04
19	294.0	-3.7989E-01	2.1380E-05	1.0141E-04
20	324.0	-3.7833E-01	-2.6518E-04	-2.0583E-04
21	361.0	-3.6369E-01	-6.2680E-04	-6.8190E-04
69	337.0	-3.8175E-01	-6.3108E-04	-7.7109E-04
66	387.0	-3.5099E-01	-6.1685E-04	-5.2506E-04
67	402.5	-3.4219E-01	-6.1475E-04	-5.7956E-04
68	426.7	-3.2744E-01	-6.1439E-04	-5.9449E-04
22	387.0	-3.3817E-01	-7.7143E-04	-1.0532E-03
23	419.0	-3.0194E-01	-9.2207E-04	-1.2060E-03
24	449.0	-2.6396E-01	-1.0357E-03	-1.3215E-03
25	474.0	-2.2993E-01	-1.1098E-03	-1.3979E-03
26	504.0	-1.8693E-01	-1.1739E-03	-1.4639E-03
27	519.0	-1.6479E-01	-1.1957E-03	-1.5292E-03
28	543.2	-1.2630E-01	-1.2247E-03	-1.6014E-03
29	591.7	-4.8622E-02	-1.2075E-03	-1.5847E-03
30	644.6	3.2149E-02	-1.0744E-03	-1.4517E-03
31	673.7	7.2685E-02	-9.5014E-04	-1.3272E-03

TABLE 4-26. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 33 (CONTINUED)

Mode 2
Generalized Mass = 28.740 lb-sec^2/in.
Frequency = 3.9548 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	1.0892E-01*	-7.9383E-04	-1.1461E-03
33	731.9	1.3924E-01	-6.1421E-04	-9.1187E-04
34	761.0	1.6193E-01	-4.1013E-04	-6.3135E-04
35	790.1	1.7579E-01	-1.8484E-04	-3.1419E-04
36	819.2	1.8008E-01	4.7977E-05	1.7036E-05
37	848.3	1.7501E-01	2.6715E-04	3.2208E-04
38	877.5	1.6166E-01	4.6225E-04	5.8419E-04
39	906.6	1.4133E-01	6.3053E-04	7.8960E-04
40	937.4	1.1434E-01	7.7949E-04	9.4279E-04
41	962.6	8.9237E-02	8.8039E-04	1.0347E-03
42	992.5	5.6886E-02	9.8129E-04	1.1363E-03
43	1025.0	1.8400E-02	1.0733E-03	1.2263E-03
44	1057.0	-2.1971E-02	1.1458E-03	1.2928E-03
45	1090.0	-6.5432E-02	1.1983E-03	1.3310E-03
46	1122.5	-1.0894E-01	1.2327E-03	1.3382E-03
47	1133.0	-1.2285E-01	1.2398E-03	1.2910E-03
48	1160.5	-1.5847E-01	1.2477E-03	1.2902E-03
49	1175.7	-1.7792E-01	1.2493E-03	1.2943E-03
50	1198.0	-2.0693E-01	1.2515E-03	1.3234E-03
51	1210.0	-2.2269E-01	1.2534E-03	1.3142E-03
52	1210.0	-2.2269E-01	2.8520E-03	2.8525E-03
53	1240.0	-3.0827E-01	2.8522E-03	2.8527E-03
54	1160.0	-1.5710E-01	1.2475E-03	1.2768E-03
55	1176.0	-1.7762E-01	1.2507E-03	1.2817E-03
56	1206.0	-2.1605E-01	1.2537E-03	1.3085E-03
57	1212.0	-2.2399E-01	1.2542E-03	1.3014E-03
58	1242.0	-2.6269E-01	1.2557E-03	1.2810E-03
59	1267.0	-2.9448E-01	1.2560E-03	1.2717E-03
60	1160.0	-1.4734E-01	1.8138E-03	1.8114E-03
61	1176.0	-1.7632E-01	1.8139E-03	1.8115E-03
62	1206.0	-2.3068E-01	1.8150E-03	1.8148E-03
63	1212.0	-2.4158E-01	1.8153E-03	1.8173E-03
64	1212.0	-2.4158E-01	2.3963E-03	2.3981E-03
65	1242.0	-3.1355E-01	2.3973E-03	2.3992E-03

*1.0892E-01 = 1.0892 x 10^{-1}
**Includes bending and shear slope

TABLE 4-27. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 33

Mode 3
Generalized Mass = 6.7529 lb-sec^2/in.
Frequency = 6.2185 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	1.0000E 00	1.7296E-03	4.2793E-03
2	-270.5	8.8997E-01	1.6874E-03	3.7413E-03
3	-230.5	7.3765E-01	1.5905E-03	3.7943E-03
4	-180.5	5.7548E-01	1.4758E-03	2.8130E-03
5	-156.0	5.0878E-01	1.4224E-03	2.5939E-03
6	-133.0	4.5126E-01	1.3750E-03	2.4505E-03
7	-82.0	3.2485E-01	1.2477E-03	2.4965E-03
8	-48.0	2.3894E-01	1.1310E-03	1.3546E-03
9	-1.0	2.3147E-01	9.6819E-04	1.3577E-04
76	20.0	2.2812E-01	9.0632E-04	7.4359E-04
10	68.0	1.7752E-01	9.4765E-04	1.0739E-03
11	118.0	1.2335E-01	9.5805E-04	1.0870E-03
15	168.0	6.9391E-02	9.3442E-04	1.0532E-03
70	-156.0	-6.1120E-01	-9.4861E-03	-9.8802E-03
71	-82.0	1.0536E-01	-8.8952E-03	-8.8448E-03
72	-116.0	-1.7660E-01	-8.6992E-03	-8.6992E-03
73	-48.0	2.3889E-01	-1.4488E-03	-1.5895E-03
74	-34.0	2.5917E-01	-1.4493E-03	-1.4494E-03
75	-17.0	2.5436E-01	3.0017E-04	3.7297E-04
79	14.0	2.3358E-01	8.9346E-04	9.3499E-04
77	26.0	2.2350E-01	6.9435E-04	6.8861E-04
78	62.0	1.9879E-01	6.9323E-04	6.6530E-04
12	122.0	1.1360E-01	9.3730E-04	9.6972E-04
13	141.0	9.5341E-02	9.3678E-04	9.5755E-04
14	149.0	8.7667E-02	9.3605E-04	9.6106E-04
16	199.0	3.4904E-02	8.8522E-04	1.0887E-03
17	229.0	3.1412E-03	8.1651E-04	1.0229E-03
18	264.0	-3.0884E-02	7.0975E-04	9.1402E-04
19	294.0	-5.6574E-02	5.9564E-04	7.9351E-04
20	324.0	-7.8293E-02	4.6135E-04	6.5022E-04
21	361.0	-9.8702E-02	2.6926E-04	2.9721E-04
69	337.0	-9.4081E-02	2.6666E-04	1.8135E-04
66	387.0	-1.0854E-01	2.7741E-04	3.5074E-04
67	402.5	-1.1349E-01	2.7927E-04	3.0947E-04
68	426.7	-1.2036E-01	2.7959E-04	2.9767E-04
22	387.0	-1.0199E-01	1.8370E-04	8.3187E-05
23	419.0	-1.0306E-01	8.8159E-05	-1.4053E-05
24	449.0	-1.0140E-01	8.5284E-06	-9.5402E-05
25	474.0	-9.8238E-02	-5.0363E-05	-1.5654E-04
26	504.0	-9.2555E-02	-1.1186E-04	-2.2018E-04
27	519.0	-8.9034E-02	-1.3879E-04	-2.6464E-04
28	543.2	-8.1555E-02	-1.9192E-04	-3.3500E-04
29	591.7	-6.3241E-02	-2.6968E-04	-4.1386E-04
30	644.6	-4.0054E-02	-3.1070E-04	-4.5574E-04
31	673.7	-2.6700E-02	-3.1372E-04	-4.5921E-04

TABLE 4-27. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 33 (CONTINUED)

Mode 3
Generalized Mass = 6.7529 lb-sec^2/in.
Frequency = 6.2185 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	-1.3526E-02*	-3.0311E-04	-4.4181E-04
33	731.9	-1.0878E-03	-2.8023E-04	-4.1337E-04
34	761.0	1.0483E-02	-2.4509E-04	-3.7184E-04
35	790.1	2.0443E-02	-1.9779E-04	-3.0381E-04
36	819.2	2.8005E-02	-1.4091E-04	-2.1077E-04
37	848.3	3.2687E-02	-8.1690E-05	-1.1010E-04
38	877.5	3.4494E-02	-2.4987E-05	-1.5747E-05
39	906.6	3.3698E-02	2.6346E-05	6.0349E-05
40	937.4	3.0868E-02	7.3242E-05	1.1414E-04
41	962.6	2.7575E-02	1.0582E-04	1.4527E-04
42	992.5	2.2718E-02	1.3938E-04	1.7943E-04
43	1025.0	1.6343E-02	1.7131E-04	2.1130E-04
44	1057.0	9.1551E-03	1.9799E-04	2.3815E-04
45	1090.0	9.1710E-04	2.1899E-04	2.5942E-04
46	1122.5	-7.7645E-03	2.3425E-04	2.7024E-04
47	1133.0	-1.0577E-02	2.3766E-04	2.5642E-04
48	1160.5	-1.7638E-02	2.4131E-04	2.5654E-04
49	1175.7	-2.1517E-02	2.4223E-04	2.6176E-04
50	1198.0	-2.7476E-02	2.4360E-04	2.7997E-04
51	1210.0	-3.0800E-02	2.4485E-04	2.7760E-04
52	1210.0	-3.0800E-02	1.3758E-03	1.3761E-03
53	1240.0	-7.2086E-02	1.3760E-03	1.3762E-03
54	1160.0	-1.7344E-02	2.4182E-04	2.5710E-04
55	1176.0	-2.1536E-02	2.4362E-04	2.6196E-04
56	1206.0	-2.9386E-02	2.4517E-04	2.6808E-04
57	1212.0	-3.1008E-02	2.4536E-04	2.6251E-04
58	1242.0	-3.8766E-02	2.4591E-04	2.5533E-04
59	1267.0	-4.5064E-02	2.4601E-04	2.5194E-04
60	1160.0	-8.3835E-03	7.0583E-04	7.0368E-04
61	1176.0	-1.9643E-02	7.0597E-04	7.0381E-04
62	1206.0	-4.0769E-02	7.0698E-04	7.0650E-04
63	1212.0	-4.5020E-02	7.0726E-04	7.0850E-04
64	1212.0	-4.5020E-02	1.2470E-03	1.2482E-03
65	1242.0	-8.2484E-02	1.2481E-03	1.2493E-03

*-1.3526E-02 = -1.3526 x 10^{-2}
**Includes bending and shear slope

TABLE 4-28. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 33

Mode 4
Generalized Mass = 14.436 lb-sec^2/in.
Frequency = 7.6013 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	2.8324E-01	5.3798E-04	1.6170E-03
2	-270.5	2.4249E-01	5.2010E-04	1.3809E-03
3	-230.5	1.8635E-01	4.7940E-04	1.3834E-03
4	-180.5	1.2389E-01	4.3189E-04	9.6435E-04
5	-156.0	1.0634E-01	4.1004E-04	8.6437E-04
6	-133.0	8.7397E-02	3.9089E-04	7.9556E-04
7	-82.0	4.6734E-02	3.4057E-04	7.8900E-04
8	-48.0	2.0017E-02	2.9555E-04	5.4286E-04
9	-1.0	6.4517E-03	2.2611E-04	2.5611E-04
76	20.0	1.3543E-03	1.9471E-04	2.1279E-04
10	68.0	-8.3469E-03	1.6668E-04	1.8755E-04
11	118.0	-1.6876E-02	1.3207E-04	1.5260E-04
15	168.0	-2.3517E-02	9.2047E-05	1.0155E-04
70	-156.0	-3.5392E-02	-6.5519E-04	-6.8929E-04
71	-82.0	1.4354E-02	-6.0406E-04	-6.0045E-04
72	-116.0	-4.4615E-03	-5.8694E-04	-5.8694E-04
73	-48.0	2.0005E-02	4.0385E-05	7.1582E-05
74	-34.0	1.9440E-02	4.0326E-05	4.0322E-05
75	-17.0	1.2472E-02	1.6757E-04	3.0249E-04
79	14.0	2.6355E-03	1.9435E-04	2.7130E-04
77	26.0	1.7209E-04	1.9925E-04	1.9934E-04
78	62.0	-7.0158E-03	1.9931E-04	2.0079E-04
12	122.0	-1.9623E-02	9.1273E-05	8.2906E-05
13	141.0	-2.1241E-02	9.1407E-05	8.5834E-05
14	149.0	-2.1923E-02	9.1599E-05	8.4389E-05
16	199.0	-2.6282E-02	5.4532E-05	6.7316E-05
17	229.0	-2.7650E-02	1.6896E-05	2.3403E-05
18	264.0	-2.7573E-02	-2.7819E-05	-2.7755E-05
19	294.0	-2.6069E-02	-6.6180E-05	-7.2049E-05
20	324.0	-2.3256E-02	-1.0394E-04	-1.1480E-04
21	361.0	-1.8088E-02	-1.4896E-04	-1.6978E-04
69	337.0	-2.2315E-02	-1.4988E-04	-1.8012E-04
66	387.0	-1.4745E-02	-1.4761E-04	-1.3452E-04
67	402.5	-1.2549E-02	-1.4738E-04	-1.4313E-04
68	426.7	-8.9950E-03	-1.4734E-04	-1.4532E-04
22	387.0	-1.2324E-02	-1.6504E-04	-2.2950E-04
23	419.0	-4.7400E-03	-1.7857E-04	-2.4325E-04
24	449.0	2.6702E-03	-1.8496E-04	-2.4966E-04
25	474.0	8.9279E-03	-1.8564E-04	-2.5012E-04
26	504.0	1.6370E-02	-1.8088E-04	-2.4497E-04
27	519.0	2.0008E-02	-1.7624E-04	-2.4912E-04
28	543.2	2.6093E-02	-1.6136E-04	-2.4298E-04
29	591.7	3.6836E-02	-1.1528E-04	-1.9616E-04
30	644.6	4.5314E-02	-4.0570E-05	-1.2045E-04
31	673.7	4.8068E-02	1.1385E-05	-6.7599E-05

TABLE 4-28. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 33 (CONTINUED)

Mode 4
Generalized Mass = 14.436 lb-sec^2/in.
Frequency = 7.6013 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	4.9129E-02*	6.9407E-05	1.4056E-06
33	731.9	4.7983E-02	1.3025E-04	1.1318E-04
34	761.0	4.2586E-02	1.9133E-04	2.5834E-04
35	790.1	3.3004E-02	2.4599E-04	3.8839E-04
36	819.2	2.0265E-02	2.8480E-04	4.7045E-04
37	848.3	5.9600E-03	3.0398E-04	4.9540E-04
38	877.5	-8.4087E-03	3.0391E-04	4.7758E-04
39	906.6	-2.1729E-02	2.8783E-04	4.3352E-04
40	937.4	-3.4237E-02	2.5739E-04	3.8296E-04
41	962.6	-4.3349E-02	2.2445E-04	3.3937E-04
42	992.5	-5.2770E-02	1.7605E-04	2.8915E-04
43	1025.0	-6.1098E-02	1.1041E-04	2.1911E-04
44	1057.0	-6.6800E-02	3.2367E-05	1.2367E-04
45	1090.0	-6.9007E-02	-5.2896E-05	-1.1603E-05
46	1122.5	-6.6089E-02	-1.3966E-04	-1.5253E-04
47	1133.0	-6.4157E-02	-1.6392E-04	-1.7964E-04
48	1160.5	-6.2261E-02	-1.4380E-04	-6.7864E-05
49	1175.7	-6.1161E-02	-1.3843E-04	-4.1152E-05
50	1198.0	-6.0954E-02	-1.3000E-04	6.3748E-05
51	1210.0	-6.1625E-02	-1.2196E-04	5.9830E-05
52	1210.0	-6.1627E-02	7.3435E-03	7.3452E-03
53	1240.0	-2.8200E-01	7.3445E-03	7.3462E-03
54	1160.0	-5.6706E-02	-2.1961E-04	-4.1456E-04
55	1176.0	-4.8215E-02	-2.4471E-04	-5.3494E-04
56	1206.0	-3.2227E-02	-2.6288E-04	-3.7852E-04
57	1212.0	-3.0805E-02	-2.6275E-04	-2.4692E-04
58	1242.0	-2.3216E-02	-2.6238E-04	-2.5597E-04
59	1267.0	-1.6739E-02	-2.6233E-04	-2.5904E-04
60	1160.0	-2.7499E-01	-1.0693E-02	-1.0640E-02
61	1176.0	-1.0473E-01	-1.0696E-02	-1.0644E-02
62	1206.0	2.1489E-01	-1.0720E-02	-1.0705E-02
63	1212.0	2.7936E-01	-1.0727E-02	-1.0749E-02
64	1212.0	2.7936E-01	-2.3984E-02	-2.4006E-02
65	1242.0	1.0000E 00	-2.4013E-02	-2.4035E-02

*4.9129E-02 = 4.9129 × 10^{-2}
**Includes bending and shear slope

TABLE 4-29. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 33

Mode 5
Generalized Mass = 5.5682 lb-sec^2/in.
Frequency = 8.0349 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
1	-300.5	1.8656E-01	3.5233E-04	1.1464E-03
2	-270.5	1.5788E-01	3.3917E-04	9.7087E-04
3	-230.5	1.1843E-01	3.0928E-04	9.6850E-04
4	-180.5	7.8636E-02	2.7453E-04	6.5935E-04
5	-156.0	6.3301E-02	2.5861E-04	5.8439E-04
6	-133.0	5.0556E-02	2.4471E-04	5.3226E-04
7	-82.0	2.3444E-02	2.0942E-04	5.2266E-04
8	-48.0	5.8500E-03	1.7617E-04	3.5997E-04
9	-1.0	-3.2807E-03	1.2610E-04	1.6779E-04
76	20.0	-6.5368E-03	1.0320E-04	1.1861E-04
10	68.0	-1.1295E-02	8.0532E-05	8.7482E-05
11	118.0	-1.5034E-02	5.5124E-05	6.1680E-05
15	168.0	-1.7435E-02	2.7985E-05	2.7406E-05
70	-156.0	-1.3235E-02	-2.3587E-04	-2.5011E-04
71	-82.0	4.7468E-03	-2.1450E-04	-2.1293E-04
72	-116.0	-1.8225E-03	-2.0736E-04	-2.0736E-04
73	-48.0	5.8428E-03	5.4743E-05	8.1243E-05
74	-34.0	5.0766E-03	5.4725E-05	5.4724E-05
75	-17.0	3.4976E-04	9.9948E-05	1.9684E-04
79	14.0	-5.8356E-03	1.0328E-04	1.5855E-04
77	26.0	-7.2119E-03	1.1841E-04	1.1879E-04
78	62.0	-1.1502E-02	1.1852E-04	1.2121E-04
12	122.0	-1.6461E-02	2.7266E-05	1.9424E-05
13	141.0	-1.6871E-02	2.7392E-05	2.2215E-05
14	149.0	-1.7044E-02	2.7572E-05	2.0981E-05
16	199.0	-1.7896E-02	4.2272E-06	7.5518E-07
17	229.0	-1.7510E-02	-1.8408E-05	-2.6481E-05
18	264.0	-1.6054E-02	-4.3753E-05	-5.6204E-05
19	294.0	-1.3997E-02	-6.4118E-05	-8.0289E-05
20	324.0	-1.1253E-02	-8.2834E-05	-1.0186E-04
21	361.0	-7.0530E-03	-1.0323E-04	-1.1889E-04
69	337.0	-9.8524E-03	-1.0368E-04	-1.1860E-04
66	387.0	-4.5356E-03	-1.0287E-04	-9.9000E-05
67	402.5	-2.9585E-03	-1.0284E-04	-1.0204E-04
68	426.7	-4.7052E-04	-1.0284E-04	-1.0272E-04
22	387.0	-3.3359E-03	-1.0956E-04	-1.4597E-04
23	419.0	1.4153E-03	-1.1382E-04	-1.5026E-04
24	449.0	5.9381E-03	-1.1428E-04	-1.5061E-04
25	474.0	9.6779E-03	-1.1204E-04	-1.4806E-04
26	504.0	1.4035E-02	-1.0625E-04	-1.4184E-04
27	519.0	1.6129E-02	-1.0209E-04	-1.4238E-04
28	543.2	1.9561E-02	-9.0278E-05	-1.3524E-04
29	591.7	2.5367E-02	-5.7671E-05	-1.0204E-04
30	644.6	2.9507E-02	-8.6961E-06	-5.2318E-05
31	673.7	3.0550E-02	2.4183E-05	-1.8795E-05

TABLE 4-29. LATERAL MODAL DATA SLV-3C KICK STAGE MATH MODEL 33 (CONTINUED)

Mode 5
Generalized Mass = 5.5682 lb-sec^2/in.
Frequency = 8.0349 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
32	702.9	3.0534E-02*	6.0248E-05	2.4243E-05
33	731.9	2.9143E-02	9.7484E-05	9.5607E-05
34	761.0	2.5002E-02	1.3404E-04	1.8826E-04
35	790.1	1.8233E-02	1.6541E-04	2.6799E-04
36	819.2	9.5968E-03	1.8613E-04	3.1314E-04
37	848.3	2.2783E-04	1.9383E-04	3.1877E-04
38	877.5	-8.8641E-03	1.8938E-04	2.9642E-04
39	906.6	-1.6970E-02	1.7541E-04	2.5962E-04
40	937.4	-2.4332E-02	1.5324E-04	2.2309E-04
41	962.6	-2.9593E-02	1.3092E-04	1.9432E-04
42	992.5	-3.4927E-02	9.9472E-05	1.6151E-04
43	1025.0	-3.9496E-02	5.8136E-05	1.1730E-04
44	1057.0	-4.2440E-02	1.0414E-05	5.7429E-05
45	1090.0	-4.3160E-02	-4.1306E-05	-2.8529E-05
46	1122.5	-4.0619E-02	-9.2191E-05	-1.1575E-04
47	1133.0	-3.9202E-02	-1.0605E-04	-1.4047E-04
48	1160.5	-3.3015E-02	-1.6692E-04	-2.7374E-04
49	1175.7	-2.7989E-02	-1.8718E-04	-4.4714E-04
50	1198.0	-1.4384E-02	-2.2225E-04	-8.9446E-04
51	1210.0	-3.3959E-03	-2.5734E-04	-9.3271E-04
52	1210.0	-3.3886E-03	-3.3437E-02	-3.3444E-02
53	1240.0	1.0000E 00	-3.3441E-02	-3.3448E-02
54	1160.0	-3.6454E-02	-1.0753E-04	-1.1080E-04
55	1176.0	-3.4547E-02	-1.0835E-04	-1.2004E-04
56	1206.0	-3.0932E-02	-1.0871E-04	-9.5132E-05
57	1212.0	-3.0476E-02	-1.0851E-04	-8.7731E-05
58	1242.0	-2.7645E-02	-1.0795E-04	-9.8282E-05
59	1267.0	-2.5086E-02	-1.0786E-04	-1.0235E-04
60	1160.0	-5.2085E-02	-8.0285E-04	-7.9910E-04
61	1176.0	-3.9298E-02	-8.0309E-04	-7.9939E-04
62	1206.0	-1.5293E-02	-8.0481E-04	-8.0351E-04
63	1212.0	-1.0456E-02	-8.0531E-04	-8.0635E-04
64	1212.0	-1.0456E-02	-1.7578E-03	-1.7589E-03
65	1242.0	4.2345E-02	-1.7601E-03	-1.7611E-03

*3.0534E-02 = 3.0534×10^{-2}
**Includes bending and shear slope

TABLE 4-30. LONGITUDINAL MODEL DATA SLV-3C KICK STAGE MATH MODEL 34

Mode	1	2	3	4	5
Gen. Mass lb. sec.^{2}/in.	7.9021	19.957	10.159	10.564	1.5628
Natural Frequency cps	13.693	16.399	32.929	55.379	78.030
Node	Deflection in./in.	Deflection in./in.	Deflection in./in.	Deflection in./in.	Deflection in./in.
1	-6.3724-01	-9.5439-01	-2.6070-01	6.4774-02	5.5765-03
2	-3.3920-01	-3.1411-01	4.4447-01	-4.3077-01	-7.9122-02
3	-1.1942-01	1.4511-01	8.0755-01	-4.4213-01	-1.7552-02
4	-1.2353-01	1.5239-01	1.0000-00	-9.7023-01	2.1769-01
5	4.5119-01	-2.8872-01	-2.5470-02	3.0015-03	-1.2024-01
6	1.0000-00	-8.3173-01	-9.0501-01	-3.5366-02	1.0000-00
7	-7.4273-02	2.2456-01	6.9832-01	2.3163-02	-2.0098-01
8	-1.0673-01	4.8341-01	5.0112-01	9.0094-01	5.2973-02
9	-1.1943-01	5.8837-01	3.4191-01	9.7045-01	1.3190-01
10	-1.2483-01	6.3299-01	2.7423-01	1.0000-00	1.6545-01
11	-1.2759-01	6.5659-01	2.1956-01	9.1527-01	1.5332-01
12	-1.6764-01	9.9896-01	-5.7352-01	-3.1366-01	-2.2547-02
13	-1.6776-01	1.0000-00	-5.7593-01	-3.1742-01	-2.3089-02

TABLE 4-31. LATERAL MODAL DATA CENTAUR KICK STAGE MATH MODEL 35

Mode 1
Generalized Mass = 14.570 lb-sec^2/in.
Frequency = 7.8870 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
70	-156.0	1.0000E 00*	1.6407E-02	1.7444E-02
71	-82.0	-2.5249E-01	1.4851E-02	1.4915E-02
72	-116.0	1.0092E-01	8.3707E-03	8.3707E-03
73	-48.0	-3.0997E-01	7.7449E-04	2.0384E-03
74	-34.0	-3.2082E-01	7.7551E-04	7.7558E-04
75	-17.0	-4.0780E-01	-2.6225E-04	2.6198E-03
79	14.0	-4.8169E-01	-7.4808E-04	8.9305E-04
76	20.0	-4.7945E-01	-7.9917E-04	-7.0827E-04
77	26.0	-4.7759E-01	-3.2669E-05	-1.2249E-05
78	62.0	-4.7749E-01	-2.8348E-05	7.9538E-05
10	68.0	-4.2337E-01	-1.2162E-03	-1.3800E-03
11	118.0	-3.4407E-01	-1.6082E-03	-1.7833E-03
15	168.0	-2.4581E-01	-1.9540E-03	-2.1611E-03
12	122.0	-3.4122E-01	-1.9675E-03	-2.1241E-03
13	141.0	-3.0167E-01	-1.9649E-03	-2.0621E-03
14	149.0	-2.8514E-01	-1.9614E-03	-2.0705E-03
16	199.0	-1.7086E-01	-2.2063E-03	-2.5427E-03
17	229.0	-9.1297E-02	-2.4155E-03	-2.7549E-03
18	264.0	8.8053E-03	-2.6158E-03	-2.9562E-03
19	294.0	9.9589E-02	-2.7499E-03	-3.0894E-03
20	324.0	1.9383E-01	-2.8494E-03	-3.1794E-03
21	261.0	3.1271E-01	-2.9259E-03	-3.1004E-03
69	337.0	2.4284E-01	-2.9254E-03	-2.9092E-03
66	387.0	3.9542E-01	-2.9582E-03	-3.1889E-03
67	402.5	4.4553E-01	-2.9708E-03	-3.1700E-03
68	426.7	5.1824E-01	-2.9731E-03	-3.0983E-03

*1.0000E-00 = 1.0000×10^{-0}
**Includes bending and shear slope

TABLE 4-32. LATERAL MODAL DATA CENTAUR KICK STAGE MATH MODEL 35

Mode 2
Generalized Mass = 4.5811 lb-sec^2/in.
Frequency = 22.175 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
70	-156.0	-1.1336E-01*	-1.4580E-02	-1.5510E-02
71	-82.0	1.0000E 00	-1.3187E-02	-1.3771E-02
72	-116.0	6.7580E-01	-5.2453E-03	-5.2453E-03
73	-48.0	7.7480E-01	1.5620E-03	5.7008E-03
74	-34.0	7.5313E-01	1.5430E-03	1.5417E-03
75	-17.0	3.4068E-01	1.9398E-03	1.4119E-02
79	14.0	-9.4791E-02	1.7393E-03	8.6743E-03
76	20.0	-1.1526E-01	1.7003E-03	2.4138E-03
77	26.0	-1.3485E-01	4.3257E-03	4.3880E-03
78	62.0	-2.9587E-01	4.3469E-03	4.8754E-03
10	58.0	-2.0461E-01	1.2519E-03	1.6057E-03
11	118.0	-2.7010E-01	6.9367E-04	9.9230E-04
15	168.0	-3.0252E-01	5.6607E-05	-3.0377E-04
12	122.0	-3.4461E-01	-5.1594E-05	-1.3022E-03
13	141.0	-3.2638E-01	-3.1533E-05	-8.1344E-04
14	149.0	-3.1952E-01	-3.4342E-06	-8.9313E-04
16	199.0	-2.8222E-01	-4.1377E-04	-9.1100E-04
17	229.0	-2.4795E-01	-8.1746E-04	-1.3621E-03
18	264.0	-1.9226E-01	-1.2180E-03	-1.7958E-03
19	294.0	-1.3371E-01	-1.4975E-03	-2.0951E-03
20	324.0	-6.7158E-02	-1.7161E-03	-2.3463E-03
21	361.0	2.4192E-02	-1.8969E-03	-2.2834E-03
69	337.0	-2.1579E-02	-1.8972E-03	-1.9086E-03
66	387.0	8.8921E-02	-1.9782E-03	-2.5319E-03
67	402.5	1.3035E-01	-2.0118E-03	-2.5156E-03
68	426.7	1.8127E-01	-2.0180E-03	-2.3643E-03

*-1.13336E-01 = 1.13336×10^{-1}
**Includes bending and shear slope

TABLE 4-33. LATERAL MODAL DATA CENTAUR KICK STAGE MATH MODEL 35

Mode 3
Generalized Mass = 5.6746 lb-sec^2/in.
Frequency = 33.298 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
70	-156.0	2.8414E-03*	-2.7531E-03	-2.7006E-03
71	-82.0	2.0463E-01	-2.8319E-03	-3.0798E-03
72	-116.0	9.5116E-02	-2.1431E-03	-2.1431E-03
73	-48.0	1.9367E-01	-2.5278E-03	8.7868E-04
74	-34.0	2.2919E-01	-2.5408E-03	-2.5417E-03
75	-17.0	-2.4537E-02	-2.8566E-03	6.8153E-03
79	14.0	-2.3026E-01	-3.2607E-03	2.2468E-03
76	20.0	-2.1860E-01	-3.3150E-03	-4.0485E-03
77	26.0	-2.3494E-01	6.7985E-03	7.0396E-03
78	62.0	-4.9987E-01	6.8791E-03	8.8923E-03
10	68.0	1.3361E-01	-3.5565E-03	-7.3461E-03
11	118.0	4.8510E-01	-2.8281E-03	-6.4562E-03
15	168.0	7.6328E-01	-1.1423E-03	-2.5008E-04
12	122.0	1.0000E 00	-4.3840E-04	7.7439E-03
13	141.0	8.9543E-01	-5.6966E-04	4.5139E-03
14	149.0	8.5726E-01	-7.5310E-04	4.9681E-03
16	199.0	7.6146E-01	1.0987E-04	8.3302E-04
17	229.0	7.1459E-01	1.2469E-03	2.2679E-03
18	264.0	6.0880E-01	2.4403E-03	3.6836E-03
19	294.0	4.8233E-01	3.3266E-03	4.7198E-03
20	324.0	3.2703E-01	4.0707E-03	5.7969E-03
21	361.0	8.9524E-02	4.7422E-03	6.0683E-03
69	337.0	2.0868E-01	4.7497E-03	4.9974E-03
66	387.0	-9.9881E-02	5.0648E-03	7.1602E-03
67	402.5	-2.1144E-01	5.2051E-03	7.2222E-03
68	426.7	-3.4703E-01	5.2322E-03	6.7270E-03

*2.8414E-03 = 2.8414 x 10^{-3}
**Includes bending and shear slope

TABLE 4-34. LATERAL MODAL DATA CENTAUR KICK STAGE MATH MODEL 35

Mode 4
Generalized Mass = 1.1151 lb-sec^2/in.
Frequency = 49.133 cps

Node No.	Station No.	Deflection	Total** Slope rad./in.	Total** Slope rad./in.
70	-156.0	1.9873E-03*	-1.8585E-04	-1.0585E-04
71	-82.0	1.2779E-02	-3.0580E-04	-3.3624E-04
72	-116.0	-1.0087E-02	-6.6241E-04	-6.6241E-04
73	-48.0	3.9394E-02	-1.2483E-03	3.1997E-04
74	-34.0	5.6942E-02	-1.2553E-03	-1.2558E-03
75	-17.0	-6.2145E-02	-1.3852E-03	3.1791E-03
79	14.0	-1.5819E-01	-1.5587E-03	1.0303E-03
76	20.0	-1.5251E-01	-1.5937E-03	-1.3795E-03
77	26.0	-6.6396E-02	-2.7181E-02	-2.7614E-02
78	62.0	1.0000E 00	-2.7532E-02	-3.6300E-02
10	68.0	-8.1631E-02	-1.3564E-03	-1.4044E-03
11	118.0	-1.5482E-02	-1.0966E-03	-1.1998E-03
15	168.0	3.7893E-02	-8.0950E-04	-7.7184E-04
12	122.0	6.9675E-03	-7.9635E-04	-6.7223E-04
13	141.0	2.0386E-02	-7.9834E-04	-7.0191E-04
14	149.0	2.5827E-02	-8.0137E-04	-6.5411E-04
16	199.0	5.7188E-02	-5.6251E-04	-4.7441E-04
17	229.0	6.7189E-02	-3.3259E-04	-1.8982E-04
18	264.0	6.8362E-02	-8.3045E-05	1.0830E-04
19	294.0	6.1595E-02	1.0987E-04	3.4030E-04
20	324.0	4.8179E-02	2.7928E-04	6.1343E-04
21	361.0	1.9213E-02	4.4005E-04	7.4255E-04
69	337.0	3.1533E-02	4.4254E-04	5.2401E-04
66	387.0	-5.5655E-03	5.2021E-04	1.0324E-03
67	402.5	-2.4525E-02	5.5576E-04	1.0663E-03
68	426.7	-4.0415E-02	5.6262E-04	9.4163E-04

*1.9873E-03 = 1.9873 × 10^{-3}
**Includes bending and shear slope

TABLE 4-35. LATERAL MODAL DATA CENTAUR KICK STAGE MATH MODEL 35

Mode 5
Generalized Mass = 1.6287 lb-sec^2/in.
Frequency = 53.019 cps

Node No.	Station No.	Deflection	Bending Slope rad./in.	Total** Slope rad./in.
70	-156.0	-6.7664E-03*	-1.3446E-02	-1.3763E-02
71	-82.0	1.0000E 00	-1.2971E-02	-1.6086E-02
72	-116.0	5.3691E-01	1.5462E-03	1.5462E-03
73	-48.0	-2.9695E-01	3.8689E-03	3.5750E-03
74	-34.0	-3.5164E-01	3.9196E-03	3.9230E-03
75	-17.0	-1.6984E-01	1.6083E-03	-5.1893E-03
79	14.0	2.1644E-03	9.2242E-04	-2.9484E-03
76	20.0	2.4589E-03	8.6796E-04	3.7870E-04
77	26.0	5.1296E-03	-1.5817E-03	-1.6296E-03
78	62.0	6.9148E-02	-1.6100E-03	-2.3160E-03
10	68.0	-7.3196E-03	5.5593E-04	5.3523E-05
11	118.0	-4.3513E-03	3.6306E-04	-1.4800E-04
15	168.0	5.2326E-03	3.0405E-04	3.5830E-04
12	122.0	6.1016E-02	4.0914E-04	1.6749E-03
13	141.0	3.5779E-02	3.8884E-04	1.1452E-03
14	149.0	2.6519E-02	3.6084E-04	1.1530E-03
16	199.0	-7.6290E-04	2.3070E-04	1.5700E-04
17	229.0	-4.4922E-03	1.6736E-04	9.0969E-05
18	264.0	-6.4433E-03	1.0333E-04	2.2552E-05
19	294.0	-6.3465E-03	5.7359E-05	-2.7917E-05
20	324.0	-4.8552E-03	2.0084E-05	-7.7416E-05
21	361.0	-9.9188E-04	-1.2048E-05	-7.8366E-05
69	337.0	-1.3593E-03	-1.2173E-05	-1.6263E-05
66	387.0	2.0809E-03	-2.6992E-05	-1.2858E-04
67	402.5	4.5479E-03	-3.3198E-05	-1.2895E-04
68	426.7	5.7559E-03	-3.4335E-05	-9.7191E-05

*-6.7664E-03 = -6.7664×10^{-3}
**Includes bending and shear slope

TABLE 4-36. LONGITUDINAL MODAL DATA KICK STAGE MATH MODEL 42

Mode	1	2	3	4	5
Gen. Mass lb. sec.^{2}/in.	11.281	4.2383	1.5491	1.2744	0.87584
Natural Frequency cps	14.370	30.179	60.060	82.537	132.40
Node	Deflection in./in.	Deflection in./in.	Deflection in./in.	Deflection in./in.	Deflection in./in.
1	-9.3341-01	2.5642-01	-1.4397-02	-6.2526-02	2.3853-03
2	-4.5260-01	-3.2614-01	1.1515-01	1.0000-00	-1.0192-01
3	-1.0031-01	-6.5118-01	1.0075-01	3.6816-02	2.7004-01
4	-1.0413-01	-7.7673-01	2.8002-01	-1.7610-01	-1.2791-01
5	4.5236-01	5.5358-02	-1.2806-01	-5.0934-03	-2.6169-02
6	1.0000-00	1.0000-00	1.0000-00	2.9720-02	1.0132-01
7	2.3559-02	-5.2912-01	-3.0253-02	3.4084-02	1.0000-00

TABLE 4-37. LONGITUDINAL MODAL DATA KICK STAGE MATH MODEL 45

Mode	1	2	3	4	5
Gen. Mass lb. sec.^{2}/in.	5.1867	2.5965	2.8343	1.6813	0.94735
Natural Frequency cps	16.830	35.747	73.172	88.044	139.65
Node	Deflection in./in.	Deflection in./in.	Deflection in./in.	Deflection in./in.	Deflection in./in.
1	-5.5818-01	1.7397-01	-5.6021-02	-5.4535-02	1.0652-03
2	-1.6380-01	-3.8058-01	6.9220-01	1.0000-00	-5.0754-02
3	1.1765-01	-6.3948-01	2.8467-01	-2.0178-01	1.5939-01
4	1.2031-01	-7.1016-01	4.8831-01	-5.0924-01	-3.0716-01
5	5.3806-01	-1.3681-02	-3.8641-01	8.6415-02	-6.4834-02
6	1.0000-00	1.0000-00	1.0000-00	-1.9151-01	9.0643-02
7	2.1201-01	-5.5429-01	2.8560-02	-1.6660-01	1.0000.00

TABLE 4-38. LONGITUDINAL MODAL DATA KICK STAGE MATH MODEL 46

Mode	1	2	3	4	5
Gen. Mass lb. sec.^{2}/in.	1.8246	3.4608	1.4913	1.8484	1.4554
Natural Frequency cps	21.672	40.522	89.083	144.64	170.22
Node	Deflection in./in.	Deflection in./in.	Deflection in./in.	Deflection in./in.	Deflection in./in
1	-2.4762-01	2.0861-01	-5.3202-02	-2.6528-03	-2.5355-04
2	4.2509-02	-6.4590-01	1.0000-00	1.3579-01	1.8071-02
3	2.3614-01	-9.6761-01	-2.4837-01	-4.7438-01	-9.9310-02
4	2.3930-01	-1.0144-00	-3.1962-01	-1.1505-00	-5.3359-01
5	5.5649-01	-2.4328-01	-3.0573-01	1.0000-00	-8.1551-01
6	1.0000-00	1.0000-00	1.5636-01	-3.1960-01	1.9487-01
7	3.0761-01	-9.0393-01	-4.6074-01	3.9946-01	1.0000-00

5

ATLAS THRUST BUILDUP

Prior to launch, the Atlas booster is supported by two launcher arms and two auxiliary supports. Following engine ignition, the Atlas booster and sustainer engines build up to full thrust. Vehicle upward motion during this period is restrained by the launcher arms. The analysis of longitudinal and lateral loadings to which the Kick Stage is subjected during Atlas thrust buildup is presented in this section.

5.1 MATHEMATICAL MODEL

The mathematical model used in computing the transient axial responses during Atlas thrust buildup is shown in Figure 3-1. The nodes, which are identified on the figure, have weights as specified under Model 1 in Table 3-5. Stiffness properties of the springs in Model 1 are listed in Table 3-4. The derivation of the Kick Stage portion of the mathematical model is as described in Section 3.

5.2 THRUST BUILDUP CURVES

The thrust buildup curve for the MA-5 booster engines, uprated to 336K, is shown in Figure 5-1. The curve is a Convair modification of the revised specification curve presented in Reference 5-1. The modification consists of increasing the upper portion of the curve to a peak nominal thrust of 336K with a 5 percent allowance for thrust overshoot. As specified in Figure 5-1, the curve is representative of a wet-start condition. Figure 5-2 describes the thrust buildup for the Atlas MA-5 sustainer engine. This curve is based on the Rocketdyne specification curve provided in Reference 5-2. The upper portion was amended by Convair to reflect a maximum nominal thrust of 58,000 pounds having a 31 percent thrust overshoot. A dry-start condition is always employed for the sustainer engine.

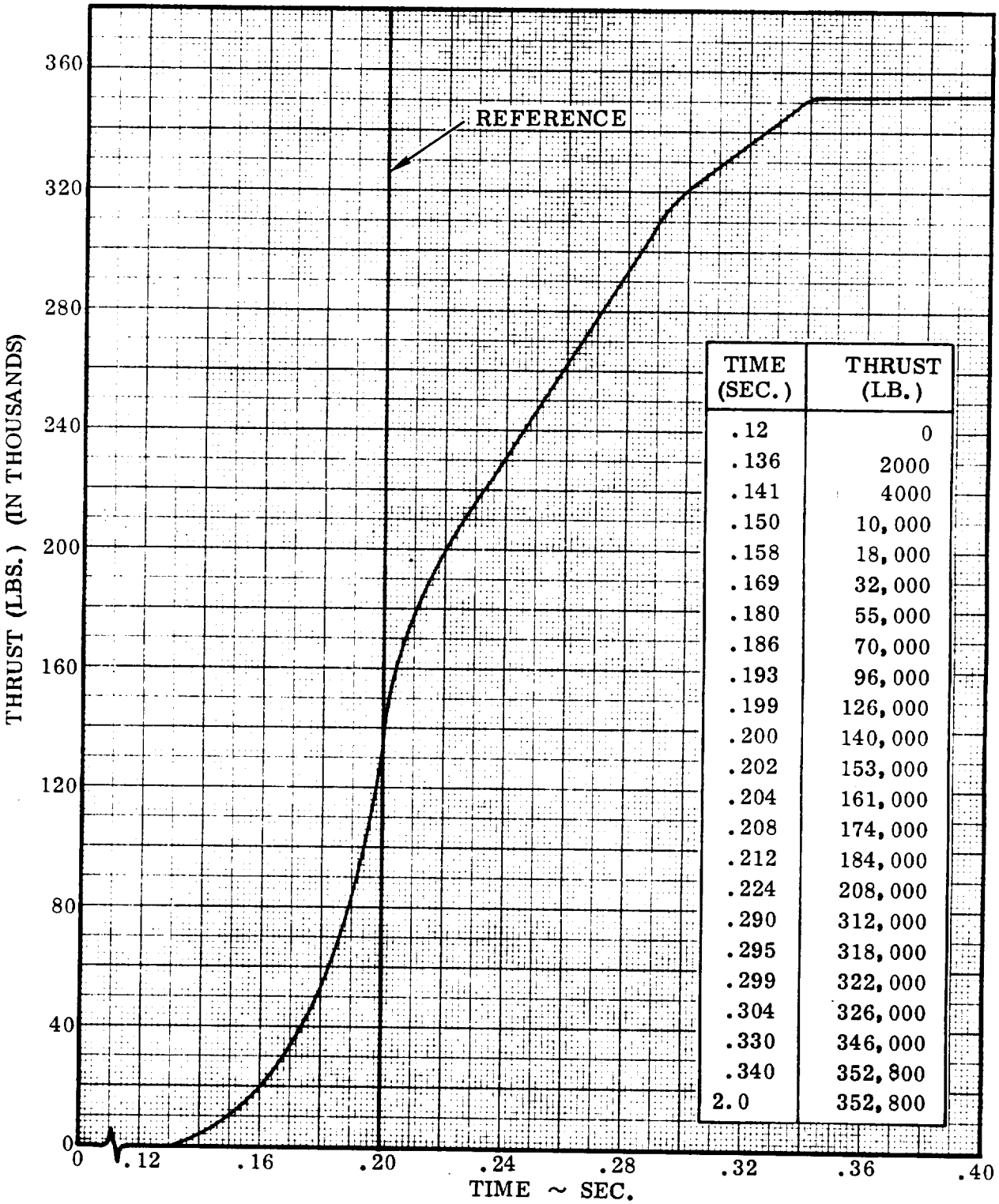
The booster and sustainer buildup curves used for this analysis are identical to those for SLV-3C. They represent thrust forces which are greater than typical curves and more severe than expected in reality (Reference 5-1). Past experience has yet to verify the overshoot values used herein. Thus axial loads presented in this section should be considered conservative.

5.3 METHOD OF SOLUTION

The mathematical model of Figure 3-1 was employed to derive the mode shapes. They were computed using an IBM 7094 computer program and are tabulated in Section 4 herein. Selected output from this program was used as input to the Forced Vibration Program, (see Reference 5-3) which computes responses due to applied forces. The booster and sustainer engine thrust buildup forces, as described in the previous

NOTES:

1) THE MA-5 BOOSTER THRUST BUILDUP SHALL BE TANGENT TO OR LEFT OF THE REFERENCE CURVE FOR VALUES OF THRUST BELOW 140,000 LB.
2) NOMINAL THRUST IS 336,000 LB.
3) THRUST BUILDUP CURVE INCLUDES 5% OVERSHOOT.

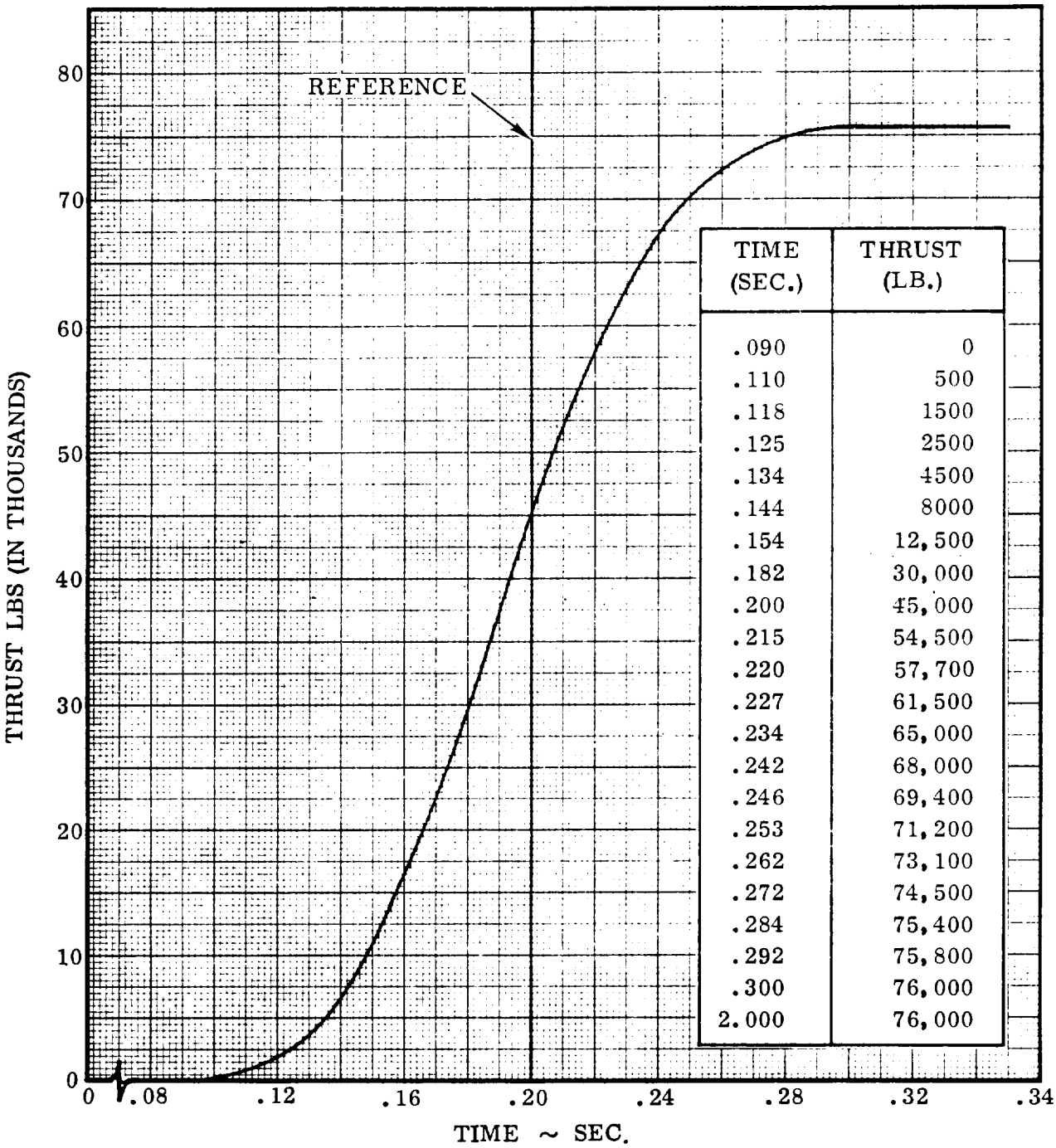


TIME (SEC.)	THRUST (LB.)
.12	0
.136	2000
.141	4000
.150	10,000
.158	18,000
.169	32,000
.180	55,000
.186	70,000
.193	96,000
.199	126,000
.200	140,000
.202	153,000
.204	161,000
.208	174,000
.212	184,000
.224	208,000
.290	312,000
.295	318,000
.299	322,000
.304	326,000
.330	346,000
.340	352,800
2.0	352,800

Figure 5-1. MA-5 Booster Thrust Buildup Specification (Wet Start)

NOTE:

THE MA-5 SUSTAINER THRUST BUILDUP SHALL BE TANGENT TO OR LEFT OF THE REFERENCE CURVE FOR VALUES OF THRUST BELOW 45,000 LB.



TIME (SEC.)	THRUST (LB.)
.090	0
.110	500
.118	1500
.125	2500
.134	4500
.144	8000
.154	12,500
.182	30,000
.200	45,000
.215	54,500
.220	57,700
.227	61,500
.234	65,000
.242	68,000
.246	69,400
.253	71,200
.262	73,100
.272	74,500
.284	75,400
.292	75,800
.300	76,000
2.000	76,000

Figure 5-2. Sustainer Engine Thrust Buildup (58000 lb. Nominal + 31% Overshoot)

paragraph, were applied simultaneously to mathematical model nodes 20 and 19, respectively. Transient axial response versus time for all masses was derived. Structural damping of 2 percent was assumed for each of the five modes in this computation.

A more detailed discussion of analyses used is presented in Section 4 of Reference 5-4.

5.4 RESULTS

5.4.1 MAXIMUM LONGITUDINAL ACCELERATIONS. Figures 5-3, 5-4, 5-5, and 5-6 describe the transient axial accelerations versus time during Atlas thrust buildup for the payload (node 1), liquid hydrogen (node 4), liquid oxygen (node 5), and Kick Stage engine (node 6), respectively. These response plots are typical of all Kick Stage masses, in that all masses have responses that are in phase. Maximum accelerations (positive and negative) are attained in the second cycle of response at identical times. This similarity in response time-history is typical of payload masses during Atlas thrust buildup (see Section II of Reference 5-4). Calculated maximum transient accelerations, in gravity units, for all Kick Stage masses are listed in Table 5-1, column I. Positive values signify upward acceleration.

In the past, comparisons of actual and calculated thrust buildup loads have indicated that only the first two theoretical peaks should be considered realistic. Therefore, the above mentioned maximums (column I of Table 5-1) should be considered invalid, and it is recommended that accelerations derived during the first cycle of response (column II of Table 5-1) be used. This latter data (column II) was included in the Total Loads Table 2-1 of Section 2. The data in column I of Table 5-1 was presented for general information and not intended for design.

The static acceleration of +1 g (due to gravity) given in column III of Table 5-1 must be added to the oscillatory peaks of column II.

5.4.2 MAXIMUM LATERAL ACCELERATIONS. Kick Stage lateral loads generated during Atlas thrust buildup have not been analyzed for this study. Investigation of launch data indicates that a "best guess" maximum transient response of ±0.8 g is adequate for design during this phase of launch (column IV of Table 5-1). A nominal static acceleration of ±0.02 g should be added to the above (column V of Table 5-1).

5.4.3 TRUSS LOADS. The maximum longitudinal truss loads occur at the times of peak longitudinal accelerations. This is attributed to the similarity in the response time-history of the Kick Stage masses; each mass acceleration reaches maximum magnitude at the same time. This is evidence of a Kick Stage quasi-rigid-body type response, which does not always occur in other thrust buildup cases (see section on Centaur Second Main Engine Start and Kick Stage Thrust Buildups).

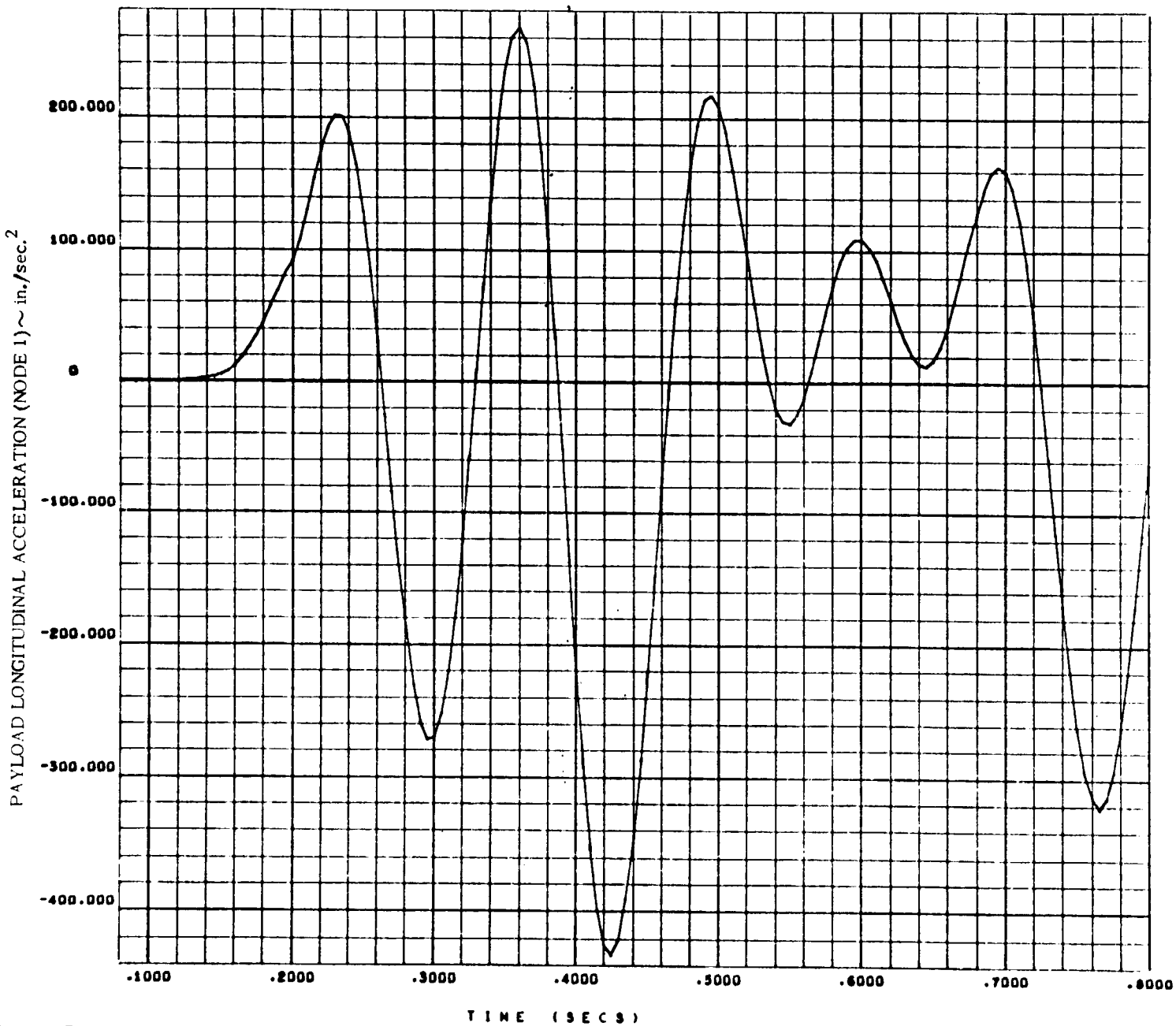


Figure 5-3. Longitudinal Response Time-History of Kick Stage Payload Mass (Mathematical Model No. 1) During Atlas Thrust Buildup

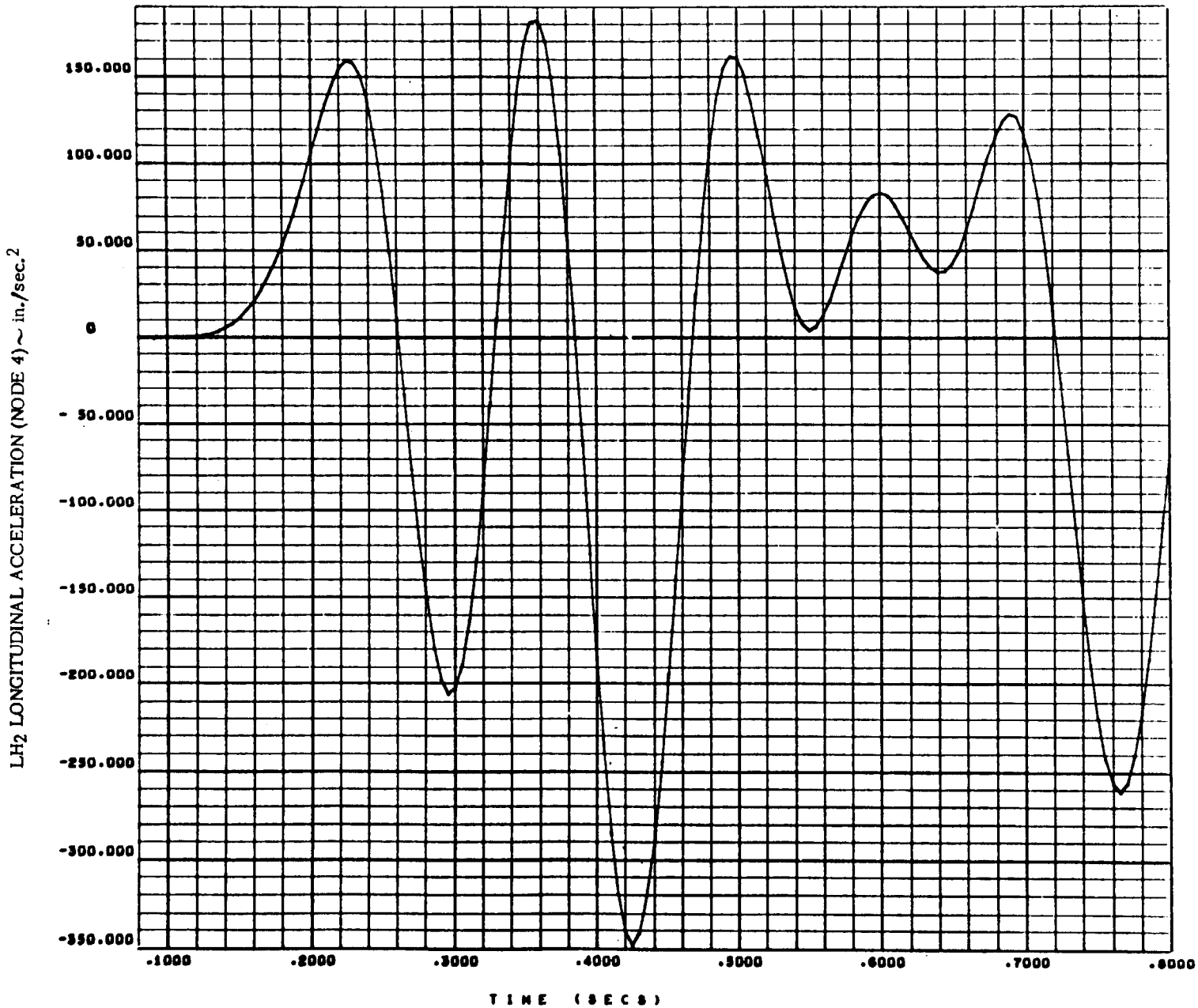


Figure 5-4. Longitudinal Response Time-History of Kick Stage LH_2 Mass (Mathematical Model No.1) During Atlas Thrust Buildup

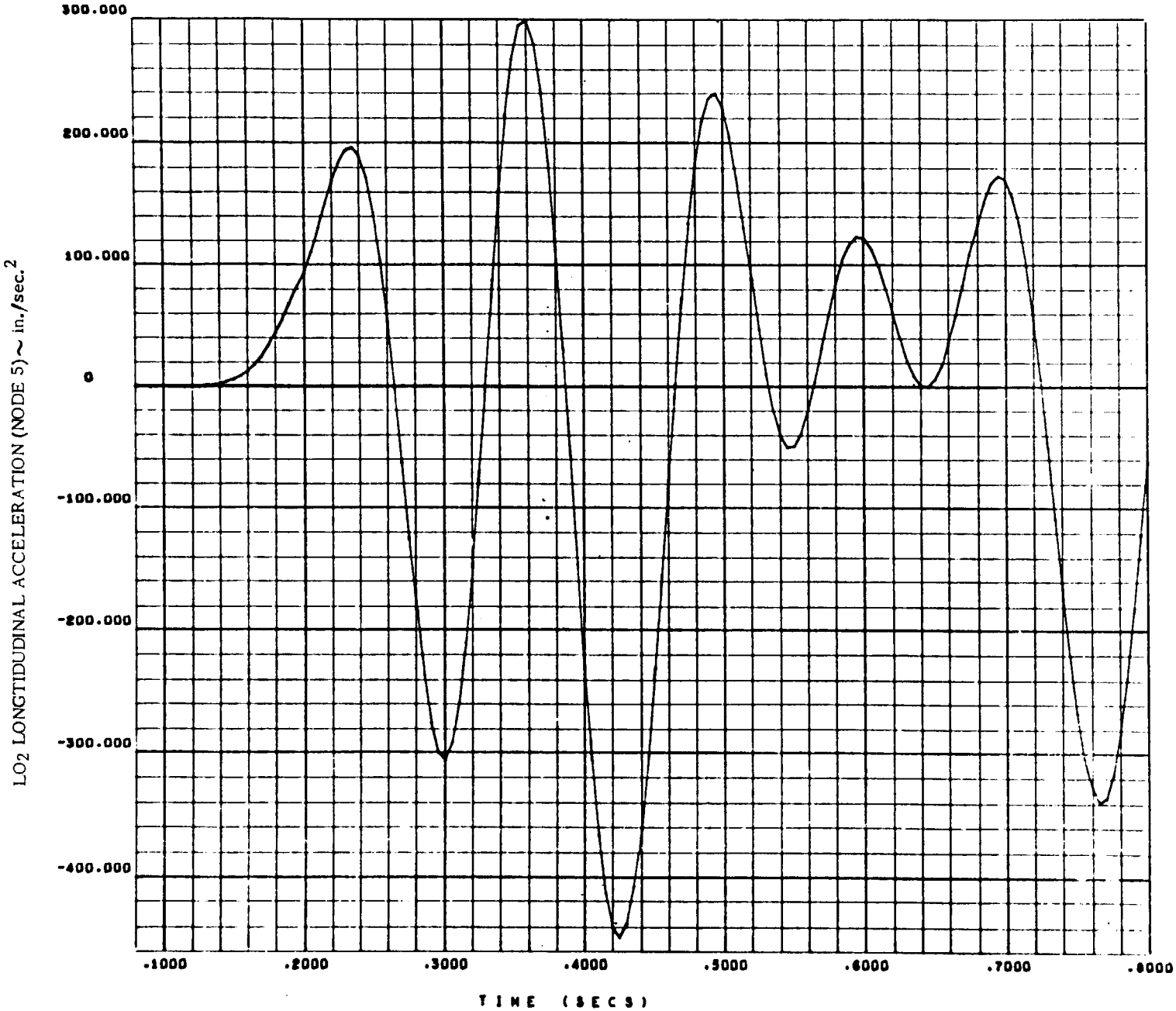


Figure 5-5. Longitudinal Response Time-History of Kick Stage LO_2 Mass (Mathematical Model No. 1) During Atlas Thrust Buildup

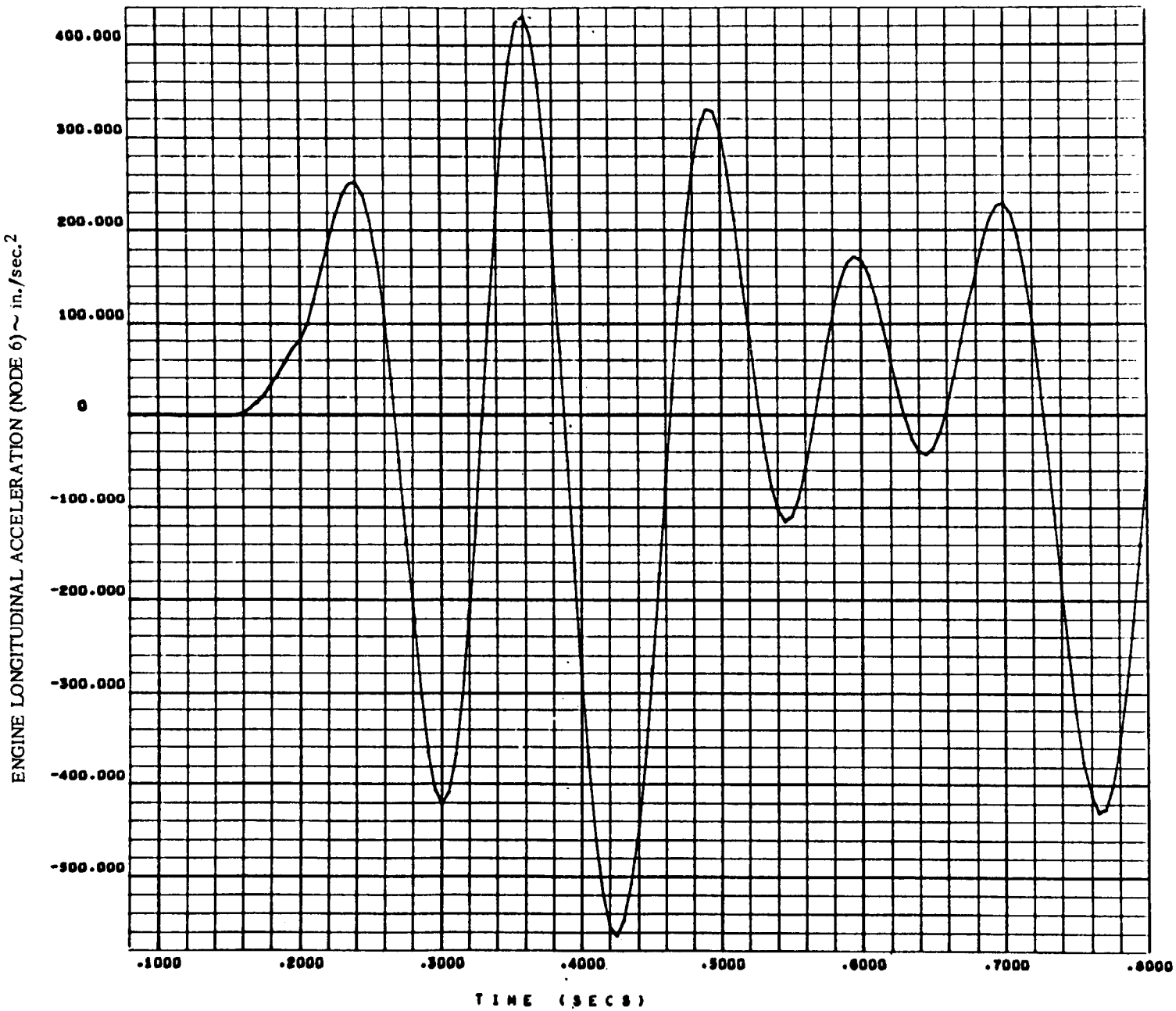


Figure 5-6. Longitudinal Response Time-History of Kick Stage Engine Mass (Mathematical Model No.1) During Atlas Thrust Buildup

TABLE 5-1. MAXIMUM RESPONSES OF KICK STAGE DURING ATLAS THRUST BUILDUP

Kick Stage Mass	I* Longitudinal Dynamic Load - 2nd Cycle Response (g's)	II Longitudinal Dynamic Load - 1st Cycle Response (g's)	III Longitudinal Static Load (g's)	IV Lateral Dynamic Load (g's)	V Lateral Static Load (g's)
Payload	+0.69 -1.12	+0.52 -0.70	+1.00	±0.8	±0.02
Payload Ring	+0.57 -0.99	+0.46 -0.60			
Forward Ring	+0.47 -0.9	+0.41 -0.53			
Hydrogen	+0.47 -0.90	+0.41 -0.53			
LO_2	+0.78 -1.1	+0.51 -0.79			
Engine	+1.12 -1.46	+0.65 -1.09			
Aft Ring	+0.44 -0.87	+0.40 -0.51	+1.00	±0.8	±0.02

*These values are presented for general information only. They are not for design use.

Truss Loads				Clearance Losses			
Dynamic Shear Load (lbs.)	Static Shear Load (lbs.)	Dynamic Axial Load (lbs.)	Static Axial Load (lbs.)	Payload to Nose Fairing (inches) Dynamic	Payload to Nose Fairing (inches) Static	Forward Ring to Nose Fairing (inches) Dynamic	Forward Ring to Nose Fairing (inches) Static
±4,000	±100	+2,409 -4,205	+5,000	±0.75	±0.019	±0.19	±0.005

Dynamic Bending Moment (in.-lb)	Static Bending Moment (in.-lb)
±503,500	±12,600

The maximum axial load on the truss was calculated (using loads of column II) to be +5000 pounds static (due to gravity), and +2409 pounds or -4205 pounds dynamic load.

The maximum bending moment and shear at the truss was determined using the "best-guess" maximum lateral acceleration of ±0.8 g dynamic and the nominal ±0.02 g static. These peak values were found to be as follows:

	Static	Dynamic
Truss Bending Moment	± 12,600 in.-lb	± 503,500 in.-lb
Truss Shear	± 100 lbs	± 4000 lbs

The loads, as presented in this section and Table 5-1, are incomplete for design use. These loads are to be combined with each other and employed as described in Section 2 herein. In addition, environmental loads are to be added in the manner prescribed in Section 2. Total design load factors to be used are summarized in Table 2-1.

5.4.4 PAYLOAD TO NOSE FAIRING, AND FORWARD RING TO NOSE FAIRING CLEARANCE LOSS. The clearance losses between the payload and nose fairing, and the forward ring and nose fairing were conservatively calculated. The maximum relative displacements were separately determined for the longitudinal and lateral axes. It was assumed that these peaks occurred simultaneously and that their resultant is in the direction perpendicular to the nose fairing wall.

In determining the longitudinal component, it is assumed that the relative deflection due to gravity is zero, and and that it is entirely attributed to dynamic motion. Results, which were obtained from the Forced Vibration output, are:

	Maximum Clearance Loss (inches)
Payload-to-Nose Fairing	0.05
Forward Ring-to-Nose Fairing	0.005

For the maximum lateral relative deflection, the motion of the nose fairing was assumed to be zero. The "best guess" lateral load factors of ±0.02 g static and ±0.8 g dynamic were applied to the Kick Stage and deflections determined.

Resultants of longitudinal and lateral clearance losses are presented in Table 5-1. Table 2-1 of Section 2, gives the clearance loss due to environmental vibration, which must be added to the values of Table 5-1 for design.

In view of the results obtained and the conservatism used in the above, the clearance losses during Atlas thrust buildup are not considered a critical design condition. Refer to Table 2-1 of Section 2, for a comparative summary at other flight times.

6

LAUNCH

The Kick Stage Booster was analyzed with the AC-9 type launcher (described in paragraph 6.1). As such, the launch will be a controlled release to the extent that airborne systems and engine thrust must be "go" before launch release is initiated.

Since the vehicle is in transition from ground holddown to flight during its launch, there are dynamic loads imparted to it by its launcher. These loads may or may not design the vehicle depending upon the loads incurred at other times. This section contains a preliminary evaluation of the launch loads for Kick Stage.

6.1 LAUNCHER AND VEHICLE MODELS

Three Kick Stage cases were analyzed in this study, cases number one, four and seven. The math models for these cases are presented in Section 3 of this report. The resultant free-free modes for case one are presented in Section 4 of this report.

An AC-9 type launcher model was used. This launcher had a R&D auxiliary support stabilizer system with one-half inch hydraulic tubing and did not have holddown and release cylinder back pressure (back pressure is a pressure applied to the bottom of the release cylinder rod pushing the launcher arms away from the vehicle after pin pull). This approach was taken for two reasons.

First, although a modified IOC* launcher auxiliary support stabilizer system with three-fourth inch hydraulic tubing is being installed in the SLV-3C launcher, the precise nature of the modification is as yet unknown. It was felt that whatever the modification, the R&D auxiliary support system with one-half inch tubing would result in a conservative analysis. Although it is not expected to be used, it should be noted than an unmodified IOC system with three-fourth inch tubing would result in launch loads (primarily longitudinal) higher than those stated in this report.

Second, although back pressure is highly desirable from a loads viewpoint, it is not at all certain that associated problems have been solved. Therefore, the status of back pressure is doubtful at this time. As a result the present launcher configuration; resulting in the severest loads, was used for analysis. However loads with 400 psi back pressure and a rise off characteristic desirable for the modified IOC system will be quoted for case number one to illustrate what may be achieved with these concepts.

*The term "IOC" stands for "Initial Operational Capability" and refers to the earliest version of the launcher used for D-series Atlas missiles.

6.2 METHOD OF SOLUTION

Figure 6-1 illustrates the basic launcher configuration and is applicable for the following discussion of the launch analysis. This discussion must first include some introductory remarks on launcher operation. These remarks refer to one side of the launcher only with the understanding that the functions are typical for two sides.

Launch is initiated after thrust buildup by the discharge of holddown pressure from the holddown and release cylinder. When this pressure has dropped to a level such that it exerts a force equal and opposite to the vertical force the vehicle exerts on the main support pin, rise-off occurs. At this time the vehicle starts out of the launch pad and starts rotating the launcher release arm back.

As the vehicle rises out of the pad the auxiliary support stabilizer force, which gives the vehicle yaw stability during holddown, starts decaying. This decay is dependent upon several launcher characteristics such as type of release cylinder blowdown decay characteristic, stabilizer system, etc. However at approximately 0.5 to 0.8 inch of vehicle rise the auxiliary support pin bottoms out. At this point the remaining auxiliary support force must decay abruptly to zero as the vehicle rises off the auxiliary support pin.

At about seven inches of vehicle rise differential-link geometry in the launcher release arm causes the kick strut to engage the main support pin via arm linkages. When this event occurs (herein called kick strut engagement), a kick strut load starts building up in the buggy spring. When the increasing kick strut load is large enough to overcome linkage and main support pin friction, lateral main support pin motion relative to the arm is initiated. At this time the main support pin is pulled and the load supporting the arm is transferred from the main support pin to the kick strut.

At approximately the same time that pin pull is occurring the piston in the holddown and release cylinder is disengaged from the release cylinder rod. This removes all holddown and release cylinder forces on the arm and thus on the vehicle. This event is commonly referred to as dog pull.

After dog pull and pin pull the launcher arm has performed its function in releasing the vehicle. However the vehicle, via the kick strut, must still push the arm up and over center onto the release arm snubber. This function typically results in the arm bouncing on the vehicle twice generating two peak kick strut transient loads.

The combined effect of the kick strut loads, on both sides of the vehicle, is largely responsible for lateral excitation since they are not precisely in phase. These loads also modify the vehicle longitudinal excitation to a large extent. The analysis quoted herein evaluates the result of the above transients on the Kick Stage and yields necessary preliminary design limit loads.

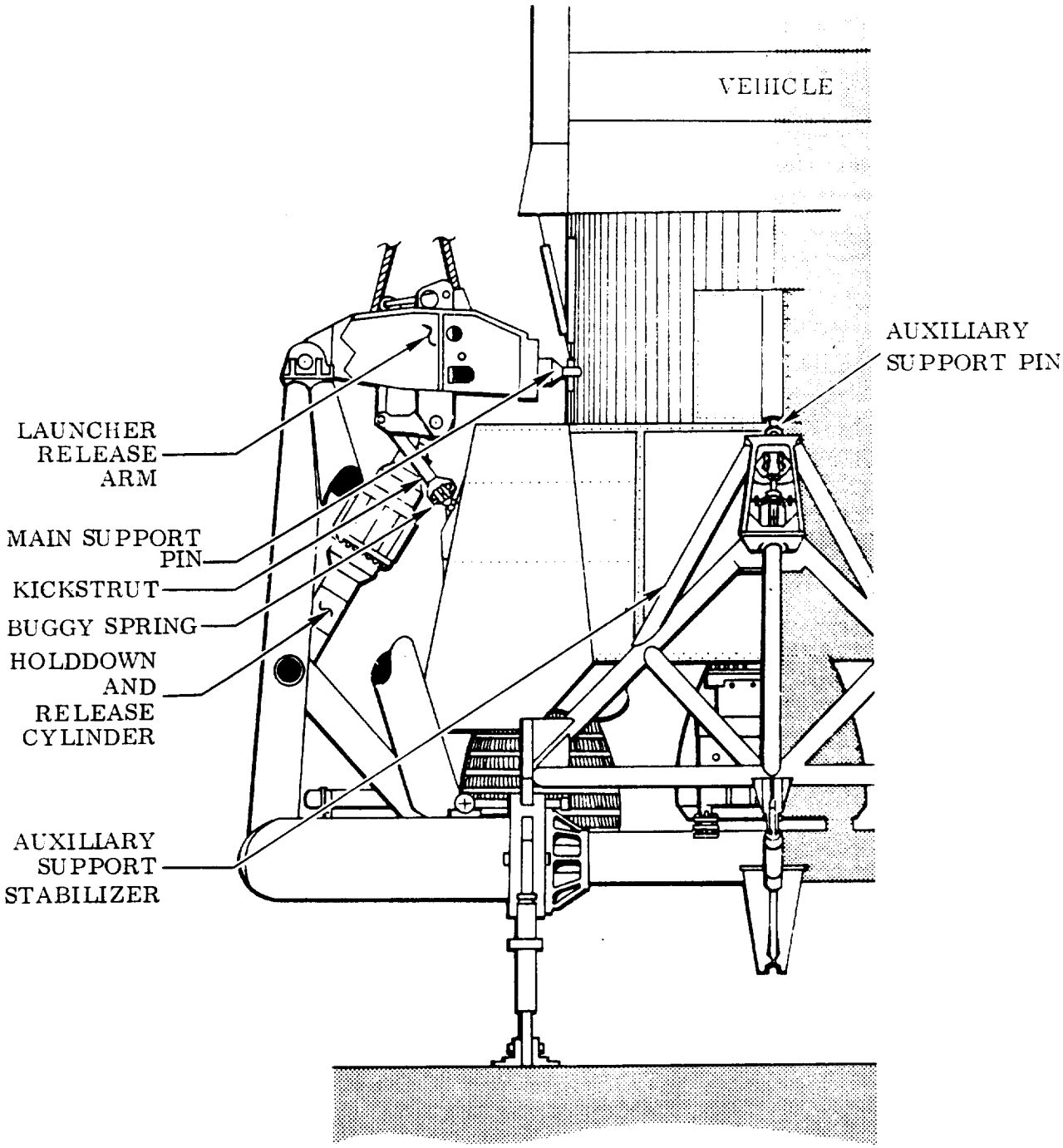


Figure 6-1. Launcher Configuration

In qualitative terms the past discussion completely describes the technique of analysis. Equations of motion describing the vehicle elastic and rigid body response in the pitch plane are programed on a digital computer. Also included are planar equations of motion describing arm rotations about their pivots and main support pin motion relative to the arms.

These equations are coupled together by springs at the main support pin-missile interface and the kick strut-missile interface. The springs are regulated by geometric relationships of the generalized coordinates. This results in the buggy spring being inoperative until the arm differential link geometry criteria is satisfied. Likewise, after the main support pins have traveled 1.8 inches relative to the arm the spring connecting them to the vehicle is then inoperative. The above two operations of course define kick strut engagement and pin pull in the analysis.

Holddown and release cylinder pressure and auxiliary support forces are programed as functions of time and vehicle vertical velocity at Station 1207.5, respectively. The holddown forces are stepped to zero after the release cylinder rod has extended 4.6 inches (dog pull). The auxiliary support forces are stepped to zero after Station 1207.5 on the vehicle has risen 0.5 inch. Back pressure forces, when used, are programed as a function of release cylinder rod extension. Vehicle engine thrust forces and booster turbine exhaust forces are considered as constants.

The above analysis was run on the digital computer for Kick Stage using all nominal parameters and a maximum thrust vector misalignment dispersion. Additional dispersions were evaluated by analyzing Atlas/Centaur LV-3C theoretical and experimental data. These results were incorporated into the Kick Stage analysis as lateral and longitudinal multiplicative factors. The tabular loads given in section 6.3 therefore contain a 1.32 lateral factor and a 1.17 longitudinal factor.

6.3 RESULTS

Longitudinal and lateral design limit accelerations for Kick Stage are presented in Tables 6-1 and 6-2. The resultant truss design limit loads are presented in Table 6-3. Nose fairing design limit clearance losses are presented in Table 6-4.

Some representative loads data are given in Figure 6-2 for the Kick Stage payload. The lateral and longitudinal loads are given for case number one with and without back pressure.

Analysis of the lateral and longitudinal acceleration data in Tables 6-1 and 6-2 and Figure 6-2 indicates that with back pressure loads may be reduced by up to 50 percent longitudinally and 70 percent laterally. If launch is a critical factor in Kick Stage design it would be well to consider usage of back pressure to reduce design loads and resultant structural weight requirements.

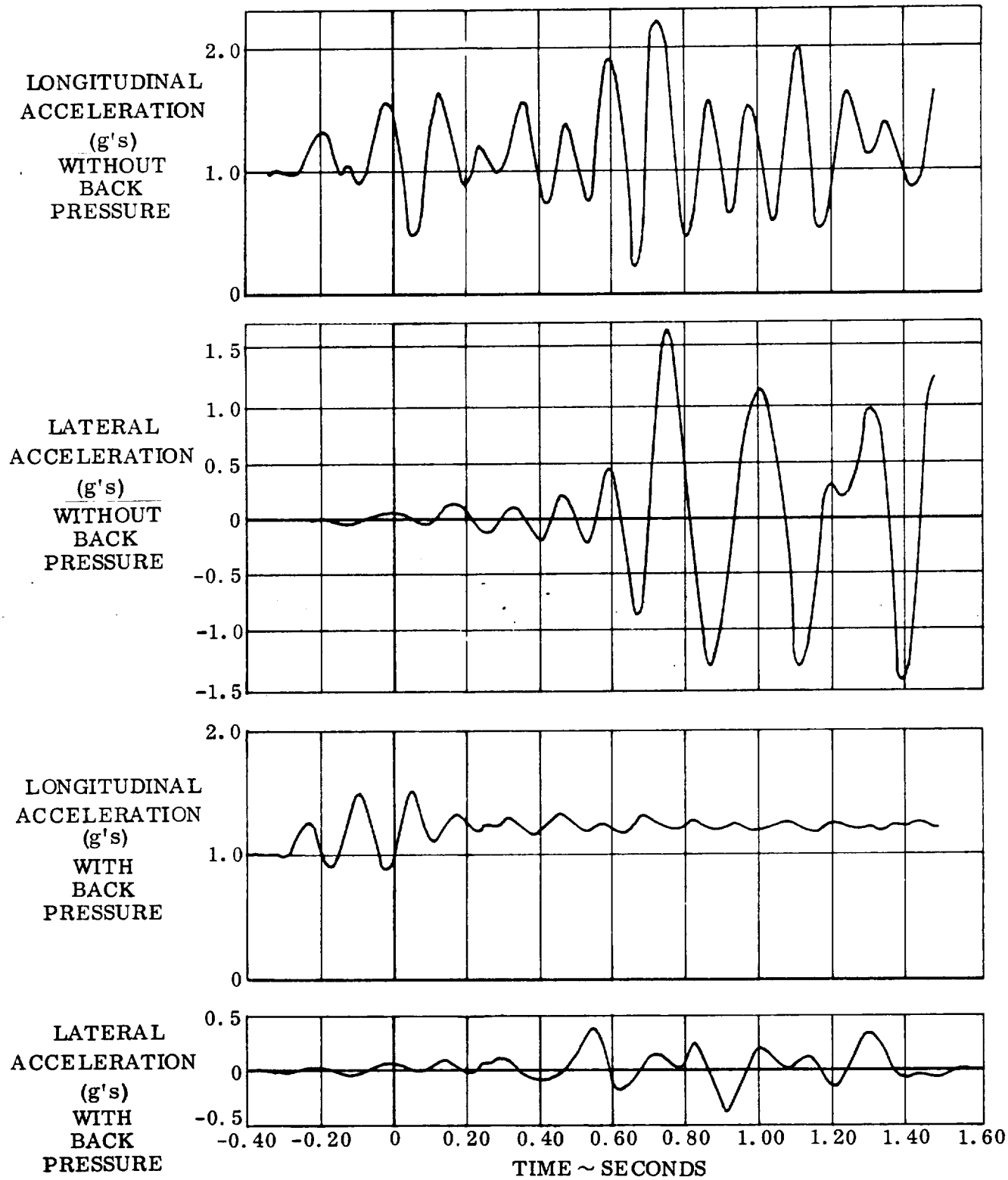


Figure 6.2 Kick Stage Payload Accelerations for Case 1
(With and Without Back Pressure)

TABLE 6-1. LONGITUDINAL DYNAMIC ACCELERATIONS* AT LAUNCH (g's)

	Case 1	Case 4	Case 7	Case 1 with Back Pressure
Payload	.99	.83	1.15	.33
Payload Ring	.88	.71	1.01	.29
Forward Ring	.78	.69	.82	.27
Hydrogen	.78	.70	.83	.27
LO_2	1.04	1.03	.95	.35
Engine	1.34	1.38	1.20	.44
Aft Ring	.75	.69	.69	.27

*Add 1.2g steady state.

TABLE 6-2. LATERAL DYNAMIC ACCELERATIONS AT LAUNCH (g's)

	Case 1	Case 4	Case 7	Case 1 with Back Pressure
Payload	1.72	1.55	2.38	.38
Payload Ring	.61	1.01	.61	.16
Forward Ring	.45	.82	.58	.12
Hydrogen	.40	.74	.54	.11
LO_2	.37	.52	.48	.08
Engine	.44	.44	.58	.09
Aft Ring	.36	.53	.46	.08

TABLE 6-3. TRUSS LOADS*

		Case 1	Case 4	Case 7	Case 1 with Back Pressure
Bending Moment (in.-lb)		9.4×10^5	1.9×10^5	12.2×10^5	2.2×10^5
Shear (lb)		6050	2070	7300	1400
Axial Force (lb)	Dynamic	4600	1640	5100	1500
	Static	6000	2760	6000	6000

*These loads are to be taken as acting simultaneously.

TABLE 6-4. DYNAMIC CLEARANCE LOSSES (in.)

	Case 1	Case 4	Case 7	Case 1 with Back Pressure
Payload to Nose Fairing	.48	.24	1.13	.12
Fwd ring to Nose Fairing	.095	.099	.190	.024

7

FLIGHT LOADS

This section contains lateral aeroelastic and bending mode response of the vehicle due to winds aloft and gusts in the Mach 1 to maximum aerodynamic pressure region of flight.

7.1 WINDS ALOFT RESPONSE

The objective, with respect to flight loads on the SLV-3C/Centaur/Kick Stage Vehicle, was a Launch Availability (L. A.) of 85 percent. To obtain loads corresponding to this L. A., data obtained in a previous study with a similar vehicle was utilized (Reference 7-1). This previous study made use of the COMBO Trajectory Simulation/Bending Moment/Plotter Program (Reference 7-2 and 7-3), and a statistical set of 33 real winter winds. For each run, at the time of maximum vehicle loading, the root-sum-square of the pitch plane and yaw plane angles of attack was obtained. Angle of attack is defined as the angle between the relative velocity vector (relative to the air) and the vehicle longitudinal axis.

These resultant angles of attack were then used to obtain an approximation of the 85 percent level for the SLV-3C/Centaur/Kick Stage Vehicle (Figure 7-1). The resultant angle of attack obtained was approximately 4.0 degrees. An allowance for a slower vehicle response time and the small wind profile sample size was added, bringing the total angle of attack to 4.4 degrees.

The angle of attack of 4.4 degrees is, therefore, the value used in the static aeroelastic portion of this section and is considered to be a reasonable approximation for this study. In Figure 7-1 it can be seen that maximum loads, due to wind profiles, would occur from roughly 70 to 80 seconds. Therefore, it seems reasonable to combine these loads at 72 seconds with the maximum gust loads at 72 seconds shown later in this section.

7.2 STATIC AEROELASTIC SOLUTION

Static aeroelastic loads are primarily predictable type loads, as compared to gust loads, which are considered random.

The static aeroelastic data was obtained using digital program Number 3558, static aeroelastic program (Reference 7-4). This program calculates the steady state loads and lateral deflections along the length of a trimmed vehicle, as the vehicle is subjected to an aerodynamic loading at a specific angle of attack. The deflections are calculated

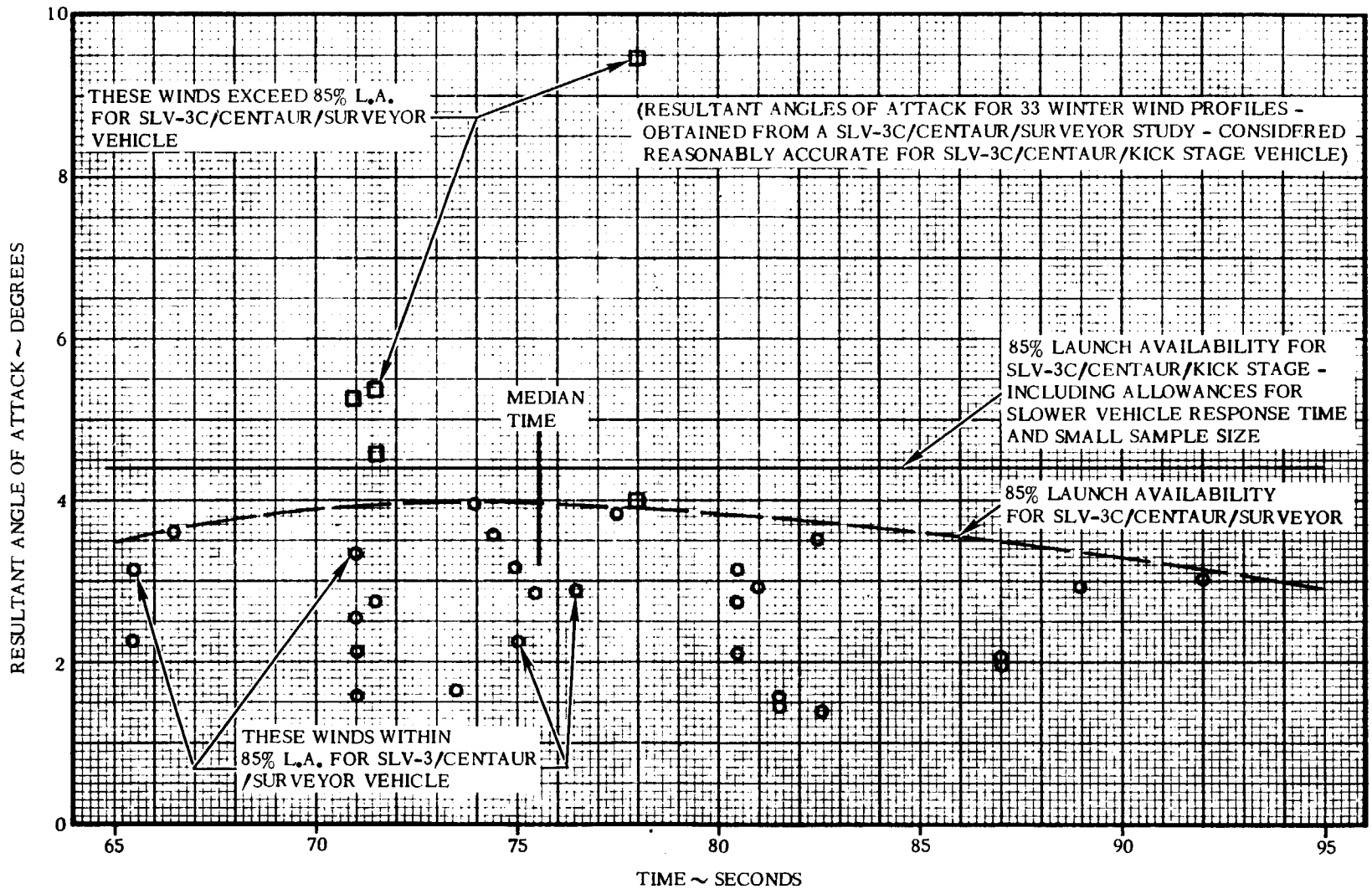


Figure 7-1. Resultant Angle of Attack Due to Winds Aloft

using the product of the vehicle load matrix, which includes the aerodynamic and inertia forces, and the vehicle flexibility matrix. The deflections are then used with the stiffness matrices to calculate the shears and moments. Since the system is elastically coupled through the aerodynamic forces, calculations of the elastic deflections and loads are made by iterating to the converged elastic shape.

Table 7-1 includes both the increment due to an angle of attack (C_y/β), and due to a zero angle of attack (C_{yo}). The C_y/β portion was also used as input to the gust response program.

The data presented in Tables 7-2 through 7-5 reflect the use of the 4.4 degrees angle of attack. Loads, due to other angles of attack, may be taken proportionally, with reasonable accuracy.

Table 7-2 is the summary of static aeroelastic results for the three non-critical times in flight. Table 7-3 is the summary for the critical flight time (72 seconds) for the various Mathematical Models (MM). Included in these tables are the rigid and elastic bending moments at various stations, the vehicle lateral accelerations, and engine gimbal angles.

The engine gimbal angles are the angles required to trim the vehicle and are further defined as follows:

a. Rigid. Engine gimbal angle measured relative to the undeformed axis using the load matrix of a rigid vehicle.

b. Control. Engine gimbal angle measured relative to the undeformed axis using the load matrix of the converged elastic shape of the vehicle.

c. Indicated. Same as "control" except gimbal angle is measured relative to the slope of the deformed axis at the gimbal node.

Table 7-4 summarizes the static aeroelastic loads at the base of the Kick Stage truss, for the various MM's at the critical time.

Loss of clearance between the nose fairing and the payload and between the nose fairing and the top of the Kick Stage truss, plus deflections, are summarized in Table 7-5.

Although the engine gimbal angles (Tables 7-2 and 7-3) appear large, and in one case exceeds the accepted limit of 5.0 degrees, this is not considered to be a serious problem. The 5.0 degree limit is for the pitch or yaw plane, whereas the angles in Tables 7-2 and 7-3 are due to a resultant angle of attack. Also, using pitch and yaw booster steering as is presently being used on Atlas/Centaur vehicles, would reduce the deflection. Another method for reducing engine deflection would be to gimbal the sustainer engine during the booster phase of flight (currently it is not gimbaled at that time).

TABLE 7-1. AERODYNAMIC COEFFICIENTS FOR FOUR TIMES IN FLIGHT

Node No.*	Station (in) (SLV-3C)	t = 56 sec. C_y/β 10^{-3}/deg	t = 56 sec. C_{yo} 10^{-4} N. D.	t = 64 sec. C_y/β 10^{-3}/deg	t = 64 sec. C_{yo} 10^{-4} N. D.	t = 72 sec. C_y/β 10^{-3} deg	t = 72 sec. C_{yo} 10^{-4} N. D	t = 80 sec. C_y/β 10^{-3} deg	t = 80 sec. C_{yo} 10^{-4} N. D.
1	-300	2.76	0	2.58	0	2.67	0	2.98	0
2	-270	3.96	0	3.87	0	3.92	0	4.08	0
3	-230	7.08	0	7.21	0	7.21	0	7.40	0
4	-180	7.39	0	7.44	0	7.25	0	7.46	0
5	-156	5.08	0.0562	4.72	0.0035	5.38	0.0107	5.67	0
6	-133	4.96	3.80	6.29	4.42	6.16	4.95	6.42	1.29
7	-82	3.01	-2.16	10.48	8.00	7.50	7.82	6.48	4.11
8	-48	0.203	-5.70	6.16	-11.50	4.27	-4.60	4.42	0.264
9	-1	0.205	-0.869	1.68	-3.24	1.44	-5.47	2.49	-1.69
76	20	0.387	2.78	-3.99	2.79	0.689	-0.685	2.27	-1.63
10	68	1.44	9.36	-4.07	9.75	0.436	14.92	1.81	7.54
11	118	-0.271	-10.29	3.37	-13.43	2.64	-7.04	3.19	3.66
15	168	-2.42	-7.49	-5.37	-8.19	-0.743	-14.37	0.921	-8.59
16	199	0.164	2.57	-2.03	0.994	-0.226	-6.10	0.527	-6.17
17	229	0.487	2.86	0.699	3.27	0.239	2.10	0.293	-1.44
18	264	0.440	1.92	1.54	3.17	0.565	2.92	-0.166	0.534
19	294	0.378	1.19	1.70	1.94	1.02	0.295	-0.182	0.713
20	324	0.423	1.17	1.84	1.86	1.09	0.150	-0.198	0.838
21	361	0.398	1.09	1.73	1.73	1.02	0.141	-0.186	0.790
22	387	0.366	1.01	1.59	1.59	0.935	0.129	-0.172	0.727
23	419	0.391	1.08	1.71	1.71	1.00	0.138	-0.183	0.778
24	449	0.347	0.956	1.51	1.51	0.887	0.123	-0.163	0.690
25	474	0.347	0.955	1.51	1.51	0.886	0.123	-0.163	0.689
26	504	0.284	0.782	1.24	1.24	0.726	0.100	-0.133	0.564
27	519	0.249	0.682	1.08	1.08	0.633	0.0875	-0.116	0.492

* Node numbers correspond to nodes labeled in Figure 3-2.

TABLE 7-1. AERODYNAMIC COEFFICIENTS FOR FOUR TIMES IN FLIGHT (CONTINUED)

		t = 56 sec.		t = 64 sec.		t = 72 sec.		t = 80 sec.	
Node No.	Station (in) (SLV-3C)	C_y/β 10^{-3}/deg	C_{yo} 10^{-4} N. D.	C_y/β 10^{-3}/deg	C_{yo} 10^{-4} N. D.	C_y/β 10^{-3}/deg	C_{yo} 10^{-4} N. D.	C_y/β 10^{-3}/deg	C_{yo} 10^{-4} N. D.
28	543	0.455	1.19	1.86	1.82	1.11	0.276	-0.213	0.922
29	592	0.590	1.14	1.33	1.36	0.541	2.10	-0.281	1.46
30	645	0.437	0.450	0.277	0.397	0.150	1.34	-0.180	1.56
31	674	0.330	-0.0684	-0.905	-0.492	-0.188	1.08	-0.124	1.16
32	703	0.362	-0.126	-0.607	-0.649	-0.571	1.54	-0.149	1.08
33	732	0.312	-0.0594	0.212	0.0049	-0.0101	0.228	-0.0992	0.874
34	761	0.273	-0.219	0.172	-0.246	0.128	-0.168	-0.0418	0.750
35	790	0.442	-0.150	0.339	-0.112	0.131	-0.358	0.0254	0.687
36	819	0.828	-0.0342	0.832	0.0362	0.0396	-0.699	0.179	0.449
37	848	1.80	-0.137	2.42	-0.272	0.747	-0.281	0.601	0.0016
38	878	2.41	-0.670	3.54	-0.748	2.31	-1.08	1.56	-0.450
39	907	1.25	-1.59	1.13	-2.30	2.35	-4.32	2.35	-2.03
40	937	0.572	3.77	-0.269	4.39	1.91	1.48	1.91	-1.34
41	963	0.305	5.26	-1.73	6.47	0.479	8.24	1.08	1.78
42	992	0.875	1.77	-1.05	3.03	-0.678	4.59	0.945	1.58
43	1025	1.50	1.57	1.98	2.42	-0.478	1.79	0.647	1.91
44	1057	3.14	-0.525	3.95	-1.17	1.56	-1.70	1.19	0.376
45	1090	4.41	-0.535	6.06	-1.22	4.36	-0.604	2.12	-0.625
46	1122	2.75	-0.225	4.26	-0.741	4.75	0.524	3.76	1.01
47	1133	-0.760	-1.95	-1.32	-1.65	0.251	-1.74	1.82	-0.962
54	1160	1.40	-2.38	-0.866	-2.01	0.0118	-2.44	0.783	-2.71
55	1176	3.57	-0.497	2.31	-0.854	1.68	-0.731	1.69	-1.21
56	1206	4.20	-1.12	4.23	-1.57	2.72	-0.946	2.01	-2.05
57	1212	7.65	1.01	9.67	0.950	7.34	2.94	4.89	2.36
59	1267	7.24	0.312	-0.0063	0	8.21	3.18	6.44	3.70

TABLE 7-1. AERODYNAMIC COEFFICIENTS FOR FOUR TIMES IN FLIGHT (CONTINUED)

NOTES:

Force at a specific point

$$F = \left[C_{yo} + \beta(C_y/\beta)\right] q S$$

where

F = Force - pounds

C_{yo} = Aerodynamic coefficient due to zero angle of attack - non-dimensional

C_y/β = Aerodynamic coefficient due to an angle of attack - ^{1}/degree

β = Angle of attack - degrees

q = Aerodynamic pressure

S = Vehicle reference area

TABLE 7-2. STATIC AEROELASTIC BODY BENDING MOMENT, VEHICLE LATERAL ACCELERATION AND ENGINE GIMBAL ANGLE FOR THREE NON-CRITICAL TIMES IN FLIGHT

Mathematical Model Flight Time Aerodynamic Pressure		8, 20 t = 56 sec. q = 473 lb/ft^2		9, 21 t = 64 sec. q = 622 lb/ft^2		11, 23 t = 80 sec. q = 792 lb/ft^2	
	Station (in) (SLV-3C)	Bending Moment (10^6 in.-lb)					
		Rigid	Elastic	Rigid	Elastic	Rigid	Elastic
Nose Fairing	-156	0.250	0.274	0.320	0.368	0.432	0.526
Nose Fairing	-48	0.789	0.867	1.095	1.261	1.431	1.746
Nose Fairing	+20	1.161	1.275	1.796	2.070	2.255	2.752
Interstage Adapter	+20	1.109	1.219	1.702	1.964	2.118	2.588
Centaur Top LH_2 Ring	168	1.791	1.971	2.791	3.238	3.740	4.564
Centaur Bottom LH_2 Ring	361	2.554	2.814	3.887	4.540	5.839	7.109
Atlas Top LO_2 Ring	519	2.818	3.112	4.324	5.060	6.419	7.830
Atlas LO_2 Tank	674	3.093	3.417	4.973	5.792	6.917	8.459
Atlas LO_2 Tank	703	3.112	3.438	5.040	5.868	7.007	8.572
Atlas LO_2 Tank	732	3.100	3.426	5.064	5.896	7.033	8.611
Atlas LO_2 Tank	761	3.056	3.379	5.030	5.857	7.009	8.588
Atlas Inter. Blkhd	937	2.204	2.452	3.738	4.376	5.161	6.393
Booster Sep. Joint	1133	0.796	0.849	1.255	1.490	1.807	2.253
Booster Rail Support	1160	0.532	0.592	0.861	1.021	1.271	1.573
Booster Gimbal Point	1206	0.0734	0.0692	0.0010	0.0015	0.100	0.083
		(g's)	(g's)	(g's)	(g's)	(g's)	(g's)
Vehicle Lateral Acceleration		0.0862	0.0933	0.156	0.176	0.227	0.272
Engine Gimbal Angle		(degrees)		(degrees)		(degrees)	
Rigid		1.03		2.33		3.17	
Control		1.27		2.88		4.22	
Indicated		1.54		3.43		5.04	

NOTE:
Angle of Attack = 4.4 degrees.

TABLE 7-3. STATIC AEROELASTIC BODY BENDING MOMENT, VEHICLE LATERAL ACCELERATION AND ENGINE GIMBAL ANGLE FOR CRITICAL TIME IN FLIGHT

Mathematical Model Numbers		10, 12, 13, 17 18, 19, 22, 24 25, 29, 30, 31		14, 15, 16 26, 27, 28		32, 33	
Description	Station (in.) (SLV-3C)	Bending Moment (10^6 in.-lb)					
		Rigid	Elastic	Rigid	Elastic	Rigid	Elastic
Nose Fairing	-156	0.380	0.451	0.380	0.456	0.380	0.451
Nose Fairing	-48	1.281	1.523	1.281	1.538	1.281	1.518
Nose Fairing	+20	2.031	2.417	2.029	2.440	1.455	1.725
Interstage Adapter	+20	1.913	2.279	2.006	2.414	1.909	2.266
Centaur Top LH_2 Ring	168	3.282	3.916	3.731	4.146	3.270	3.883
Centaur Bottom LH_2 Ring	361	4.949	5.911	5.187	6.257	4.927	5.852
Atlas Top LO_2 Ring	519	5.534	6.616	5.799	7.001	5.504	6.542
Atlas LO_2 Tank	674	6.242	7.442	6.531	7.865	6.204	7.354
Atlas LO_2 Tank	703	6.348	7.565	6.640	7.993	6.308	7.474
Atlas LO_2 Tank	732	6.397	7.623	6.691	8.054	6.356	7.530
Atlas LO_2 Tank	761	6.380	7.603	6.672	8.032	6.337	7.508
Atlas Inter Blkhd	937	4.733	5.675	4.953	6.000	4.733	5.642
Booster Sep. Joint	1133	1.687	2.027	1.766	2.142	1.687	2.014
Booster Rail Support	1160	1.195	1.423	1.248	1.502	1.195	1.415
Booster Gimbal Point	1206	0.125	0.108	0.124	0.107	0.125	0.108
		(g's)	(g's)	(g's)	(g's)	(g's)	(g's)
Vehicle Lateral Acceleration		0.201	0.234	0.209	0.245	0.201	0.232
Engine Gimbal Angle		(degrees)		(degrees)		(degrees)	
Rigid		2.75		2.92		2.75	
Control		3.59		3.84		3.56	
Indicated		4.29		4.56		4.26	

NOTE:

Time = 72 seconds
Dynamic pressure = 734 lb/ft^2
Angle of attack = 4.4 degrees

TABLE 7-4. STATIC AEROELASTIC LOADS AT BASE OF TRUSS (NODE 79)

Mathematical Model	Rigid Vehicle		Elastic Vehicle	
	BM (10^6 in.-lb)	Shear (10^3 lb)	BM (10^6 in.-lb)	Shear (10^3 lb)
8, 20	0.0538	0.428	0.0583	0.463
9, 21	0.0975	0.774	0.1102	0.875
11, 23	0.1411	1.124	0.1694	1.350
10, 12, 13, 17, 18, 19 22, 24 25, 29, 30, 31	0.1224	0.952	0.1422	1.105
14, 15, 16, 26, 27 28	0.0315	0.425	0.0369	0.498
32	0.400	7.471	0.477	8.871
33	0.387	7.258	0.461	8.617

NOTE:

Angle of attack = 4.4 degrees

TABLE 7-5. DEFLECTIONS AND LOSS OF CLEARANCE BETWEEN PAYLOAD AND NOSE FAIRING AND BETWEEN TOP OF TRUSS AND NOSE FAIRING

Math Model	Nose Fairing Deflection at -156 in. (inches)	Payload Deflection at -156 in. (inches)	Loss of Clearance at -156 in. (inches)	Nose Fairing Deflection at -48 in. (inches)	Kick Stage Fwd Ring Deflection at -48 in. (inches)	Loss of Clearance at -48 in. (inches)
8	2.27	1.74	0.53	1.46	1.27	0.19
9	3.70	2.81	0.89	2.42	2.05	0.37
10	4.58	3.54	1.04	2.98	2.58	0.40
11	5.21	4.02	1.19	3.37	2.91	0.46
12	4.58	3.55	1.03	2.98	2.59	0.39
13	4.58	3.51	1.07	2.98	2.56	0.42
14	5.22	4.23	0.99	3.52	3.12	0.40
15	5.22	4.24	0.98	3.52	3.13	0.39
16	5.22	4.21	1.01	3.52	3.11	0.41
17	4.58	3.49	1.09	2.98	2.57	0.41
18	4.58	3.50	1.08	2.98	2.58	0.40
19	4.58	3.43	1.15	2.98	2.56	0.42
20	2.27	1.75	0.52	1.46	1.27	0.19
21	3.70	2.84	0.86	2.42	2.06	0.36
22	4.58	3.58	1.00	2.98	2.59	0.39
23	5.21	4.09	1.12	3.37	2.93	0.44
24	4.58	3.59	0.99	2.98	2.59	0.39
25	4.58	3.57	1.01	2.98	2.59	0.39
26	5.22	4.24	0.98	3.52	3.13	0.39
27	5.22	4.25	0.97	3.52	3.13	0.39
28	5.22	4.23	0.99	3.52	3.13	0.39
29	4.58	3.56	1.02	2.98	2.59	0.39
30	4.58	3.57	1.01	2.98	2.59	0.39
31	4.58	3.55	1.03	2.98	2.59	0.39
32	4.23	3.635	0.595	2.67	2.67	0
33	4.24	3.65	0.59	2.67	2.67	0

NOTE:

Angle of Attack = 4.4 degrees, yaw plane

7.3 GUST RESPONSE SOLUTION

The gust response results were obtained using digital program Number 2466, gust response program (Reference 7-5). This program calculates the rigid and elastic loads and deflections of a vehicle subjected to a gust. The entire vehicle is assumed to be enveloped by same gust velocity at any one instant.

The vehicle is stabilized by an autopilot, which uses a second order lag filter, a lead filter, and an integral gain. The program utilizes normal mode theory with the engines included as part of the dynamic model, i. e., engines in the modes.

Shears and moments are calcaulated by the mode acceleration method. Normal accelerations and elastic deflections are also obtained from the gust response program.

7.4 INPUT DATA TO GUST RESPONSE PROGRAM

The gust response program was run at four different times in flight. These times, 56, 64, 72, and 80 seconds, correspond to altitudes of 17,100, 23,800 31,800, and 41,200 feet, respectively. The gust used in this study was "1-cosine" shaped, with a maximum peak wind speed of 30 feet per second. As can be seen from Figure 7-2, the peak wind speed of 30 feet per second was used in the runs for 72 and 80 seconds, with lesser values used for the other two times.

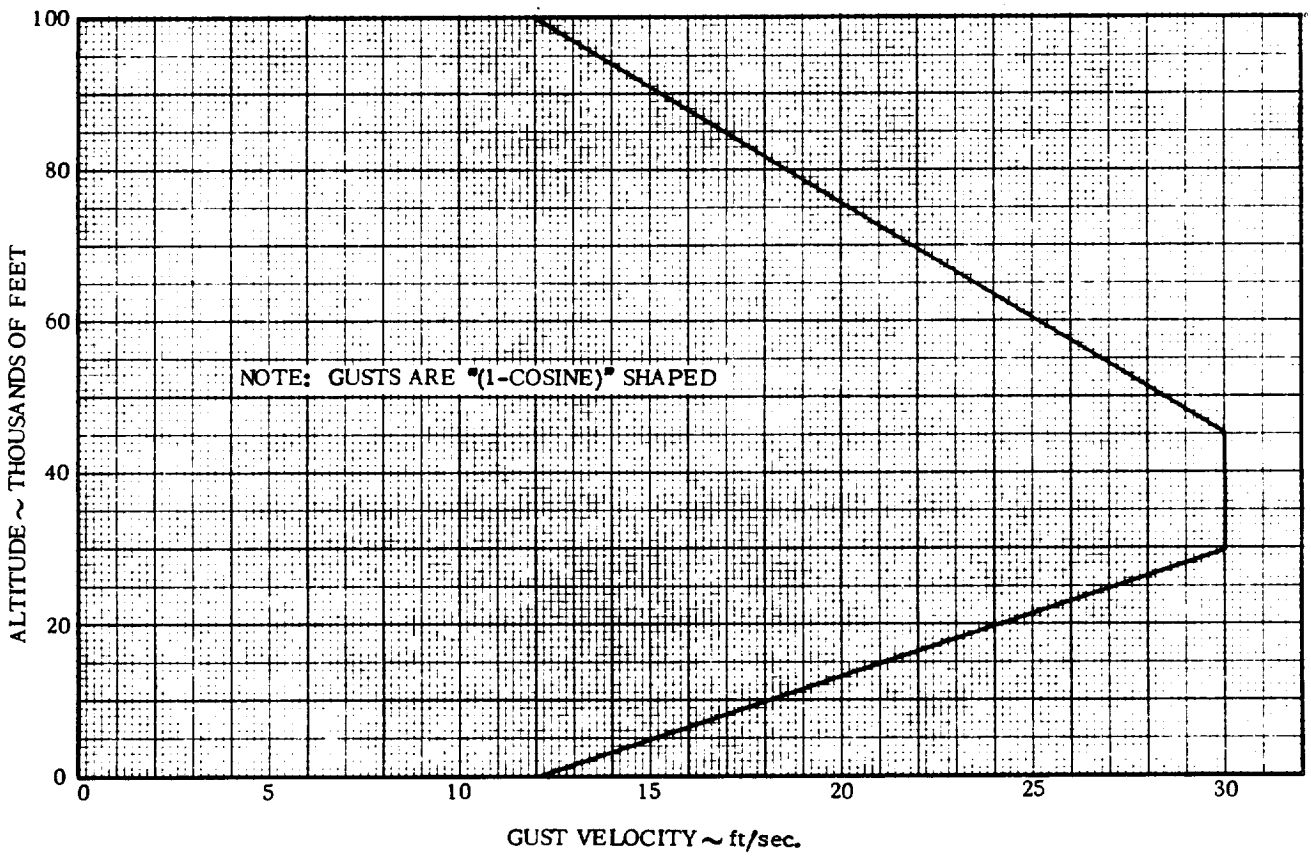


Figure 7-2. Gust Velocity versus Altitude

The gust wave length was tuned to the vehicles third, fourth, and fifth modes. An earlier study indicated that tuning the gust to these modes gave noticeably greater payload response than other wave lengths. This is due to being close to the uncoupled natural frequency of the payload.

Input to the gust response program (Tables 7-6 through 7-9), consists of various engine, trajectory, autopilot, and gust parameters. It also includes vehicle structure, component, propellant, and propellant slosh masses. Vehicle damping is also included.

The gust response program calculates vehicle response for an incremental angle of attack, and, therefore, only the C_y/β portion of Table 7-1 (Aerodynamics Coefficients) was utilized.

TABLE 7-6. TRAJECTORY DATA

Time Seconds	Altitude Feet	Mach No. N. D.	Dynamic Pressure lb/ft^2	Booster Thrust (Total) (lb)	Sustainer Thrust (lb)	Vehicle Weight (lb)	Axial Acceleration (g's)
56	17, 100	0. 77	473	354, 400	69, 750	234, 260	1. 75
64	23, 800	1. 01	622	359, 560	72, 680	221, 620	1. 79
72	31, 800	1. 30	734	364, 610	75, 450	209, 020	1. 90
80	41, 200	1. 68	792	369, 280	77, 870	196, 440	2. 10

TABLE 7-7. AUTOPILOT INPUT

Description	Value
Autopilot Displacement Gain	1. 8 deg/deg
Integrator Loop Gain	0. 18 $sec.^{-1}$
Rate Gyro Loop Gain	0. 45 sec.
Filter Time Constant, Lead	0. 0 sec.
Filter Time Constant, Lag	0. 0338 sec.
Natural Freq. of 2nd Order Lag Filter	15. 5 rad./sec.
Damping of 2nd Order Lag Filter	0. 5
Natural Freq. of Rate Gyro	157. 0 rad./sec.
Damping of Rate Gyro	0. 6

TABLE 7-8. GUST DATA

Time Seconds	Vehicle Velocity ft/sec	Gust Period				
		100 ft Wavelength Seconds	300 ft Wavelength Seconds	500 ft Wavelength Seconds	750 ft Wavelength Seconds	1000 ft Wavelength Seconds
56	831	0.120	0.361	0.602	0.903	1.203
64	1060	0.094	0.283	0.472	0.708	0.943
72	1315	0.076	0.228	0.380	0.570	0.761
80	1622	0.062	0.185	0.308	0.462	0.617

NOTE:

In addition to these gusts, others were used that were tuned to specific modes.

TABLE 7-9. SLOSH MASSES AND NATURAL FREQUENCY

SLV-3C VEHICLE						
	Liquid Oxygen			RP-1		
Time Second	Weight (lb)	Center of Gravity inches (SLV-3C)	Natural Frequency rad./sec.	Weight (lb)	Center of Gravity inches (SLV-3C)	Natural Frequency rad./sec.
56	12,290	652.54	4.63	8924	1011.09	4.63
64	12,290	671.75	4.68	8924	1023.20	4.68
72	12,290	691.00	4.82	8924	1035.23	4.82
80	12,290	710.15	5.06	8924	1047.27	5.06
CENTAUR VEHICLE						
	Liquid Oxygen			Liquid Hydrogen		
Time Second	Weight (lb)	Center of Gravity inches (SLV-3C)	Natural Frequency rad./sec.	Weight (lb)	Center of Gravity inches (SLV-3C)	Natural Frequency rad./sec.
56	3,158	332.70	6.71	193.4	203.88	5.52
64	3,158	332.70	6.79	193.4	203.88	5.59
72	3,158	332.70	6.99	193.4	203.88	5.75
80	3,158	332.70	7.34	193.4	203.88	6.04

TABLE 7-9. SLOSH MASSES AND NATURAL FREQUENCY (CONTINUED)

NOTE:

Natural Frequency

$$\omega = \sqrt{\frac{32.2 \eta x}{L_p}}$$

where

ω = Natural Frequency - rad./sec.

ηx = Axial Acceleration - g's

L_p = Slosh Hinge Arm - feet

$L_{p_{ATLAS}}$ = 2.716 feet

$L_{p_{CENTAUR\ LO2}}$ = 1.25 feet

$L_{p_{CENTAUR\ LH2}}$ = 1.84 feet

7.5 GUST RESPONSE

The most critical time in flight, for both the aluminum structure and the Be-Al alloy structure, was determined by running the gust response program at four specific times in flight. The times used were 56, 64, 72, and 80 seconds, which correspond to MM's 8, 9, 10, and 11 for the aluminum structure, and MM's 20, 21, 22, and 23 for the lock alloy structure ($E = 30 \times 10^6$). In both sets it was determined that the most critical time was 72 seconds (Table 7-10). The responses of specific important masses for the MM's run at the critical time are summarized in Table 7-11.

Figures 7-3 through 7-12 contain plots of lateral acceleration versus gust time of various important masses for several 72 second MM's. Included are the payload, liquid hydrogen, liquid oxygen, and engine masses for MM's 10, 14, 17, 22, and 32.

Figures 7-13 and 7-14 show the relative difference in clearance between the forward ring and the nose fairing, and between the payload and the nose fairing for MM 10.

Figure 7-15 shows plots of both shear and bending moment for the Kick Stage truss near the aft ring for MM 10.

TABLE 7-10. SUMMATION OF MAXIMUM GUST RESPONSE DATA FOR MATH MODELS 8 THROUGH 11, AND 20 THROUGH 23

Type of Response	Units	Mode		Maximum Response							
			MATH MODEL	8	9	10	11	20	21	22	23
			FLIGHT TIME	56	64	72	80	56	64	72	80
Payload Acceleration	g's	3		-0.732	-1.041	-1.127	-1.059	-0.579	-0.831	-0.870	-0.799
		4		-0.739	-1.044	-1.126	-1.061	-0.578	-0.825	-0.863	-0.787
		5		-0.743	-1.049	-1.134	-1.065	-0.587	-0.843	-0.868	-0.798
Payload Ring and Equipment Acceleration	g's	3		0.167	0.252	0.290	0.276	-0.289	-0.414	-0.436	-0.403
		4		0.168	0.250	0.288	0.275	-0.286	-0.410	-0.430	-0.395
		5		0.171	0.254	0.292	0.279	-0.289	-0.416	-0.431	-0.400
Forward Ring & Equipment Acceleration	g's	3		0.154	0.231	0.265	0.252	-0.255	-0.365	-0.382	-0.352
		4		0.157	0.235	0.270	0.256	-0.251	-0.362	-0.379	-0.344
		5		0.159	0.237	0.273	0.258	-0.254	-0.366	-0.377	-0.348
LH_2 and Structure Acceleration	g's	3		0.147	0.222	0.255	0.242	-0.243	-0.349	-0.365	-0.336
		4		0.151	0.226	0.261	0.246	-0.241	-0.347	-0.362	-0.328
		5		0.153	0.229	0.263	0.249	-0.243	-0.350	-0.359	-0.331
LO_2 and Structure Acceleration	g's	3		-0.135	0.202	0.231	0.215	-0.163	-0.233	0.259	0.238
		4		0.136	0.206	0.236	0.220	-0.163	-0.233	0.256	0.234
		5		0.141	0.213	0.243	0.227	-0.161	-0.232	0.254	0.232
Engine and Structure Acceleration	g's	3		-0.131	-0.178	0.202	0.187	-0.147	0.220	0.240	0.218
		4		-0.131	0.181	0.208	0.192	-0.149	0.217	0.239	0.218
		5		-0.129	0.187	0.213	0.197	-0.148	0.217	0.238	0.217

TABLE 7-10. SUMMATION OF MAXIMUM GUST RESPONSE DATA FOR MATH MODELS 8 THROUGH 11, AND 20 THROUGH 23 (CONTINUED)

Type of Response	Units	Mode		Maximum Response							
			MATH MODEL	8	9	10	11	20	21	22	23
			FLIGHT TIME	56	64	72	80	56	64	72	80
Aft Ring and Beam Acceleration	g's	3		0.139	0.210	0.240	0.225	-0.171	-0.244	0.267	0.246
		4		0.142	0.215	0.246	0.230	-0.170	-0.244	0.263	0.241
		5		0.147	0.222	0.253	0.236	-0.169	-0.243	0.261	0.239
Payload - Nose Fairing Relative Deflection	Inches	3		-0.289	-0.418	-0.451	-0.419	-0.244	-0.352	-0.363	-0.326
		4		-0.289	-0.417	-0.450	-0.418	-0.246	-0.354	-0.364	-0.327
		5		0.292	0.411	-0.442	0.411	-0.245	-0.354	-0.364	-0.327
Forward Ring - Nose Fairing Relative Deflection	Inches	3		-0.076	-0.109	-0.117	-0.110	-0.079	-0.114	-0.118	-0.106
		4		-0.076	-0.109	-0.117	-0.110	-0.080	-0.115	-0.119	-0.107
		5		-0.074	-0.107	-0.115	-0.108	-0.080	-0.115	-0.118	-0.107
Aft Ring and Beam Bending Moment	10^5 In.-lbs	3		3.837	5.451	5.904	5.559	3.276	4.696	4.916	4.520
		4		3.853	5.444	5.874	5.539	3.248	4.676	4.889	4.423
		5		3.879	5.477	5.925	5.569	3.302	4.745	4.877	4.494

TABLE 7-11. SUMMARY OF MAXIMUM ACCELERATIONS FOR IMPORTANT MASSES AT CRITICAL FLIGHT TIME (72 SECONDS)

Math Model	Mass			
	Payload (g's)	LH_2 & Structure (g's)	LO_2 & Structure (g's)	Engine & Structure (g's)
10	-1.134	0.263	0.243	0.213
12	-1.156	0.263	0.228	0.199
13	-1.049	0.256	0.264	0.232
14	-1.046	-0.643	-0.466	-0.446
15	-0.983	-0.614	-0.474	-0.453
16	-1.250	-0.750	-0.432	-0.413
17	-0.930	0.298	0.274	0.241
18	-0.976	0.299	0.268	0.236
19	-0.821	0.297	0.286	0.250
22	-0.870	-0.365	0.256	0.240
24	-0.823	-0.371	0.273	0.259
25	-0.988	-0.361	0.223	0.203
26	-0.880	-0.588	-0.481	-0.444
27	-0.863	-0.580	-0.483	-0.446
28	-0.921	-0.614	-0.476	-0.439
29	-1.130	0.262	0.216	0.187
30	-1.080	0.270	0.215	0.189
31	-1.145	0.263	0.237	0.206
32	-0.964	0.291	0.242	-0.226
33	-0.819	0.318	0.262	-0.236

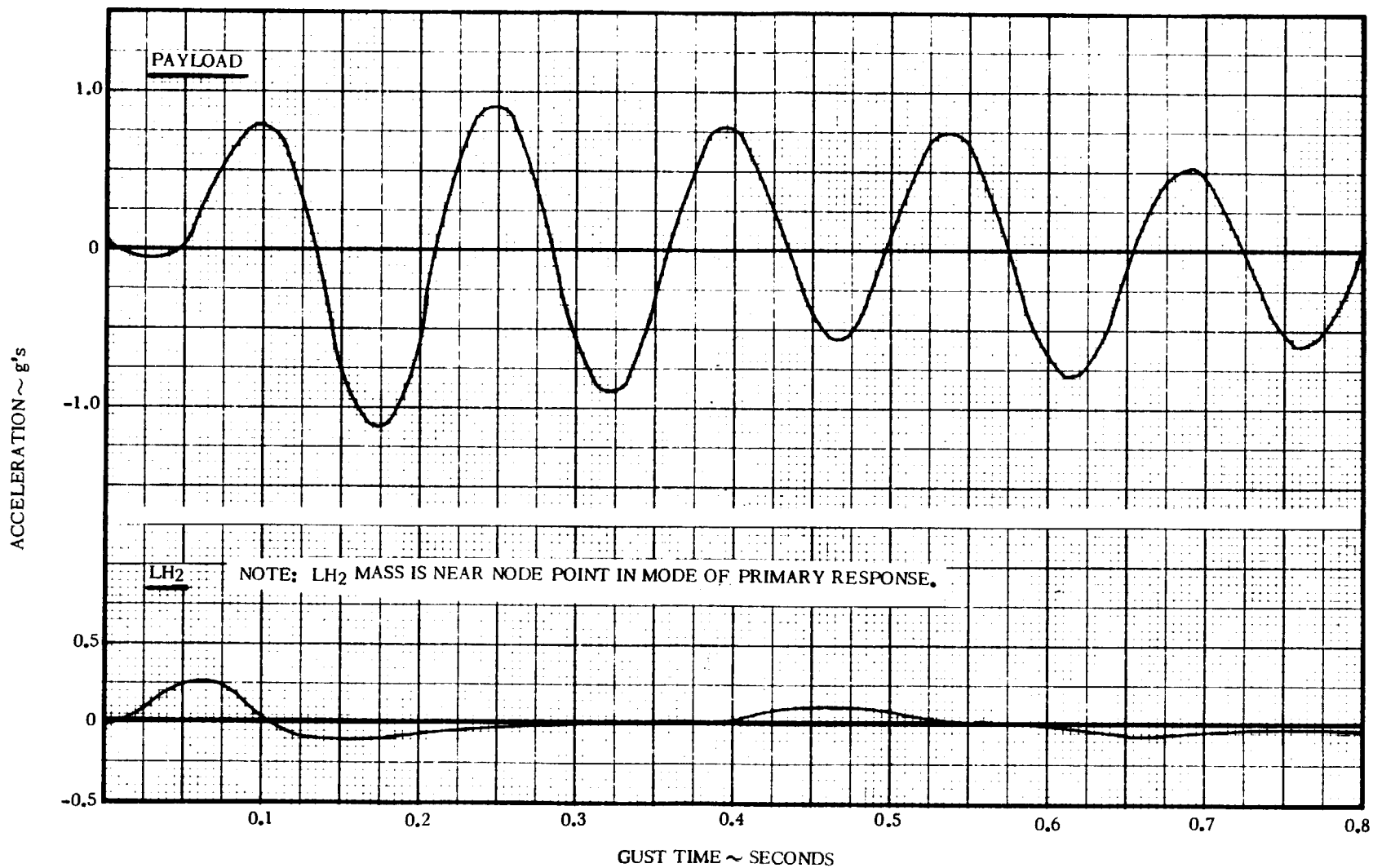


Figure 7-3. Payload and Liquid Hydrogen/Structure Lateral Acceleration - Mathematical Model 10

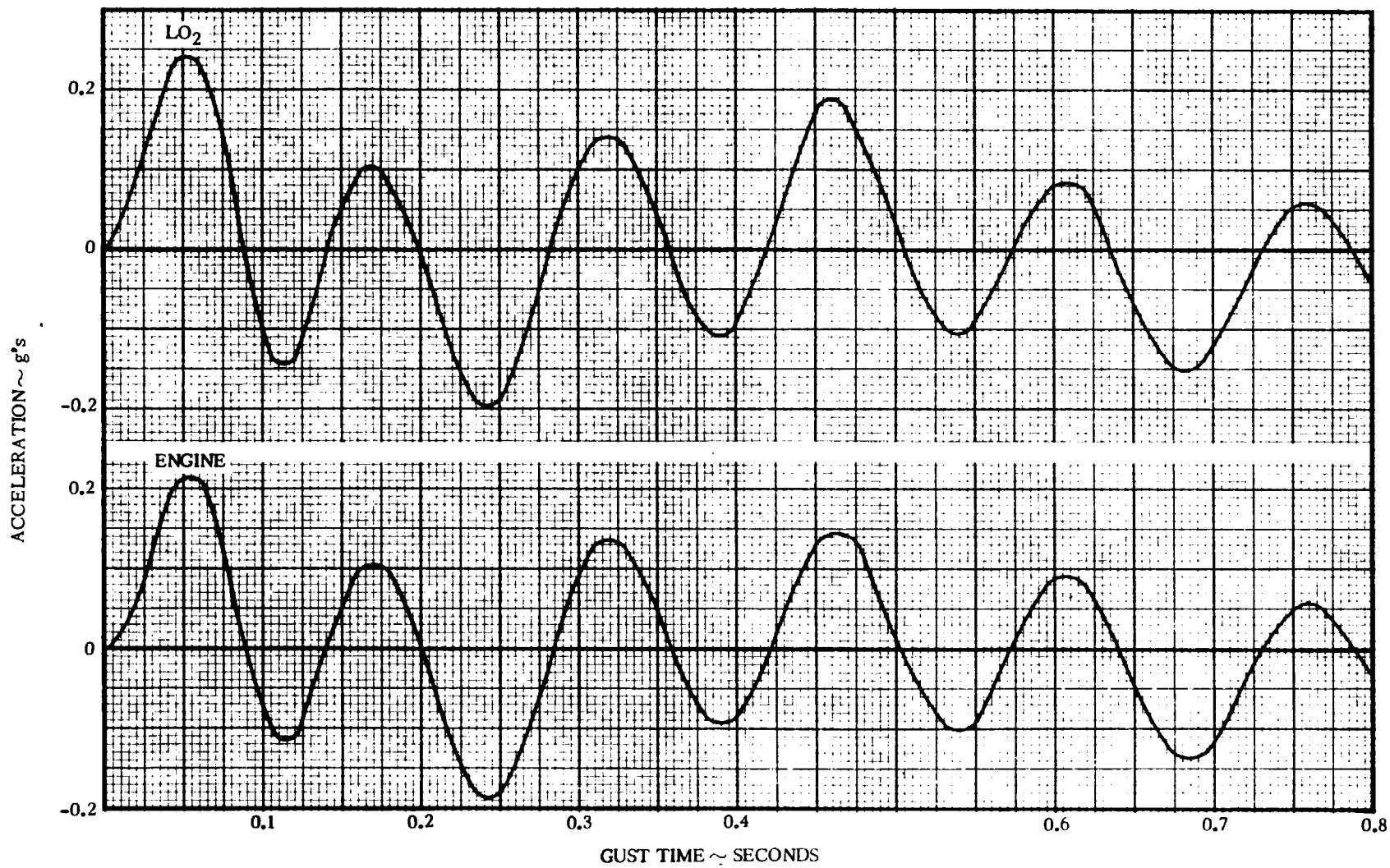


Figure 7-4. Liquid Oxygen/Structure and Engine/Structure Lateral Acceleration - Mathematical Model 10

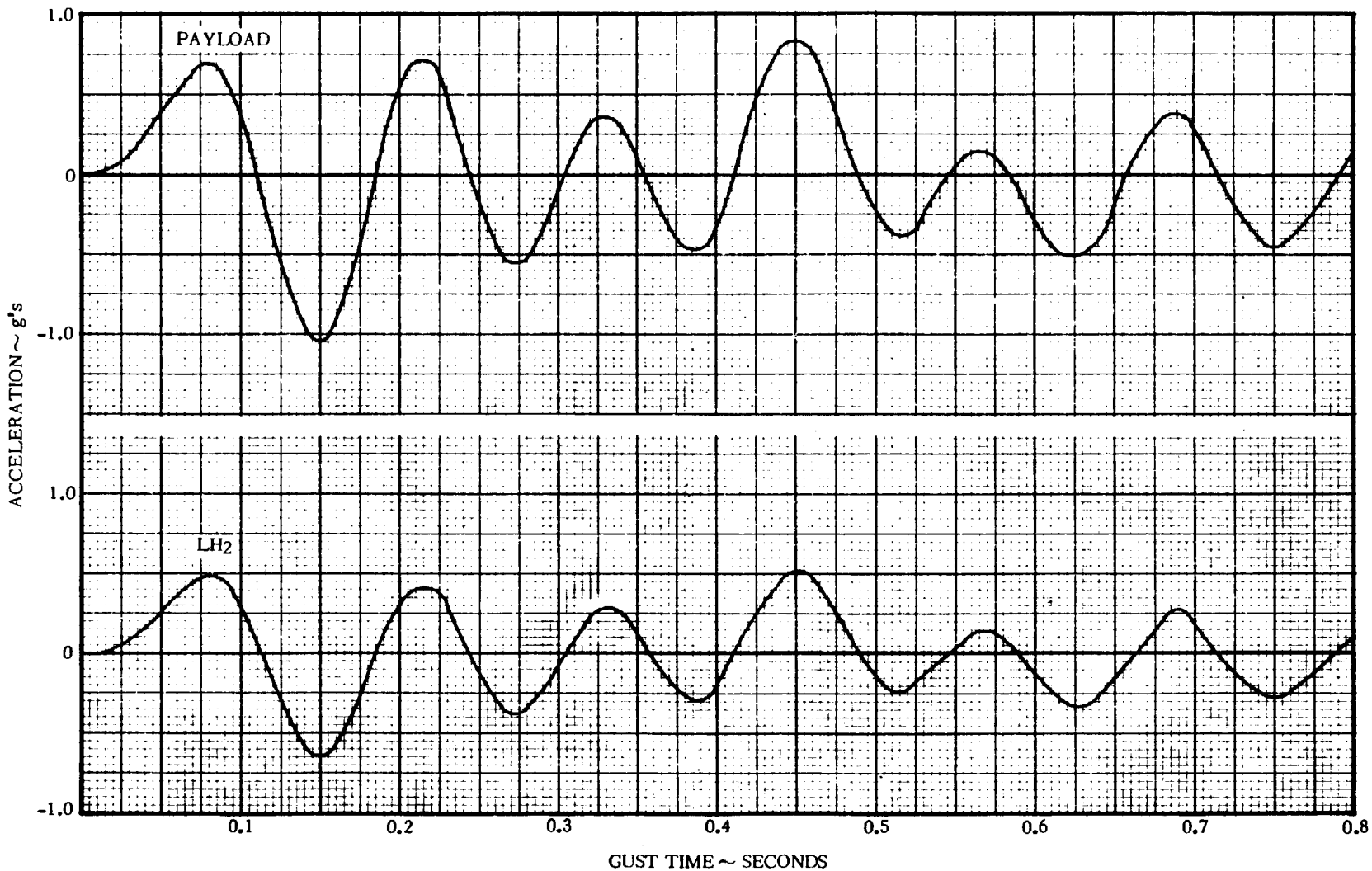


Figure 7-5. Payload and Liquid Hydrogen/Structure Lateral Acceleration - Mathematical Model 14

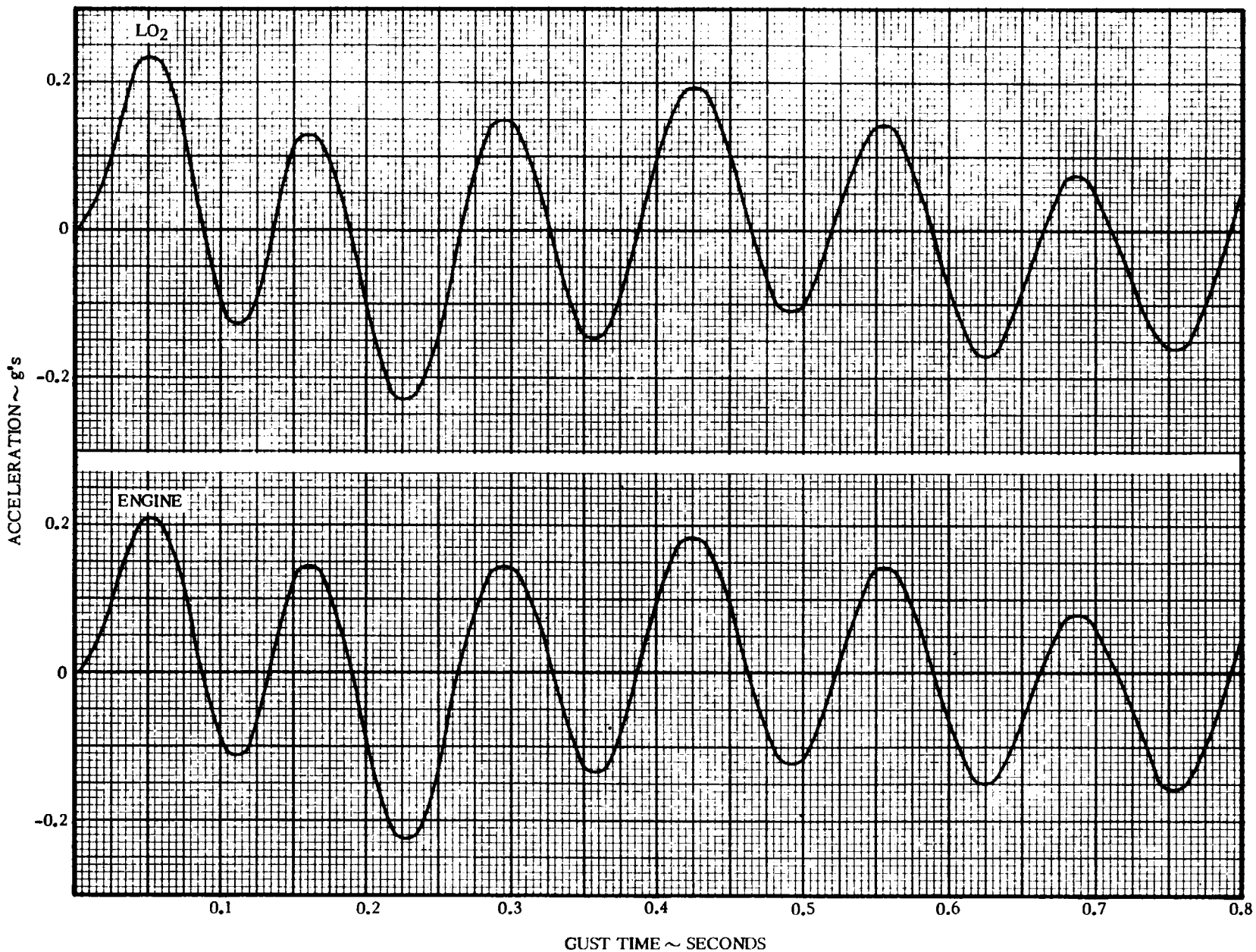


Figure 7-6. Liquid Oxygen/Structure and Engine/Structure Lateral Acceleration - Mathematical Model 14

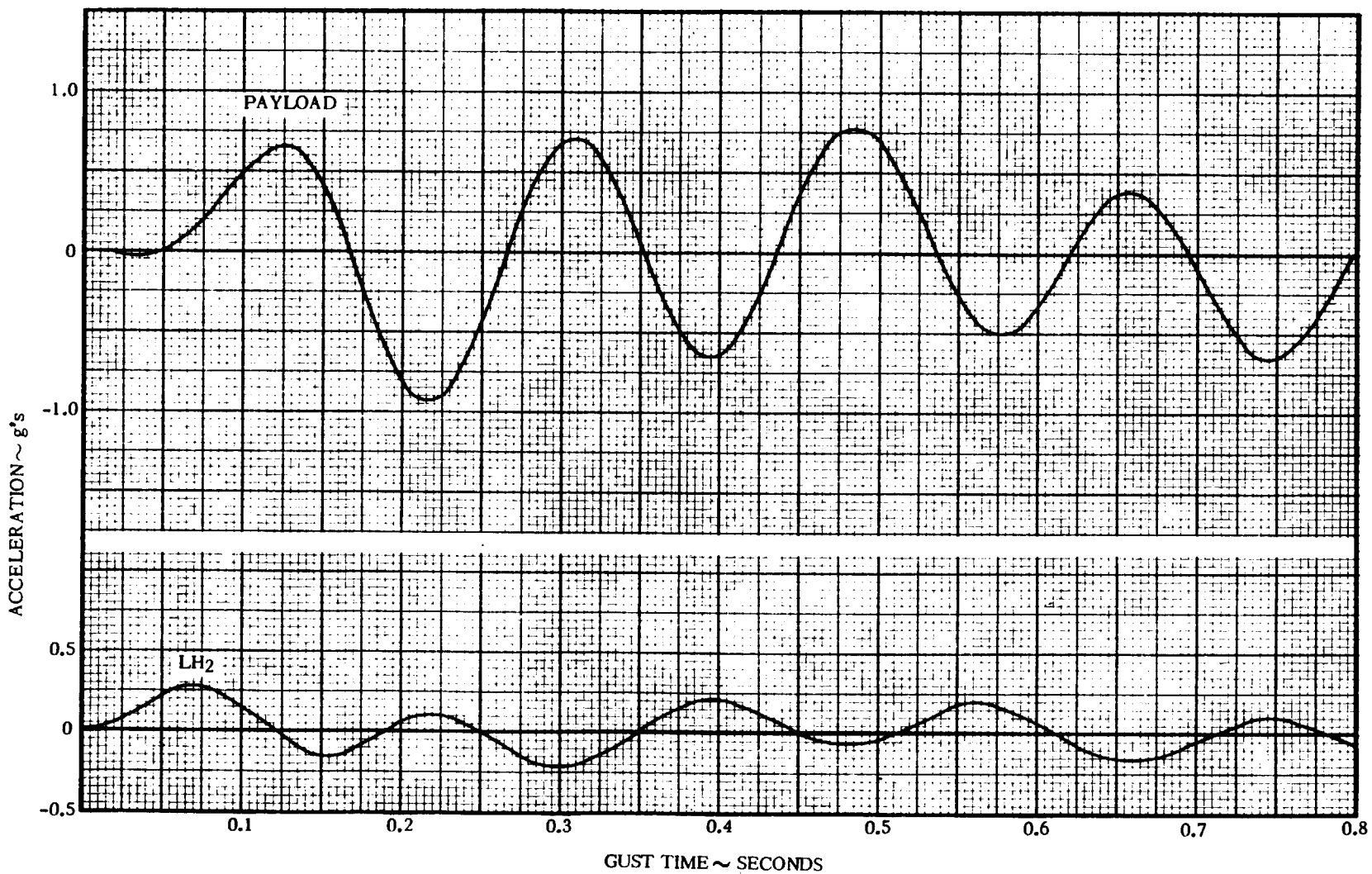


Figure 7-7. Payload and Liquid Hydrogen/ Structure Lateral Acceleration - Mathematical Model 17

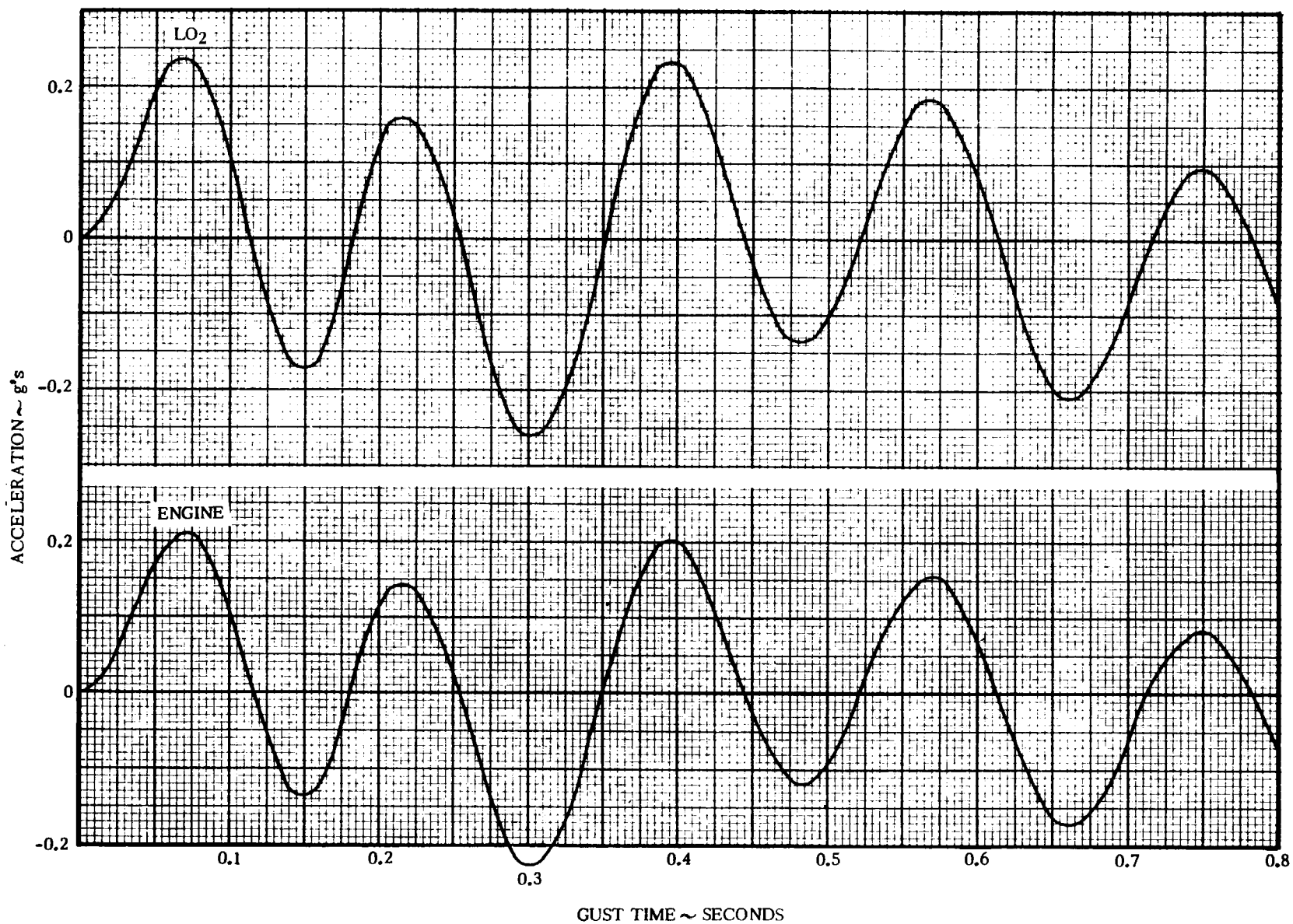


Figure 7-8. Liquid Oxygen/Structure and Engine/ Structure Lateral Acceleration - Mathematical Model 17

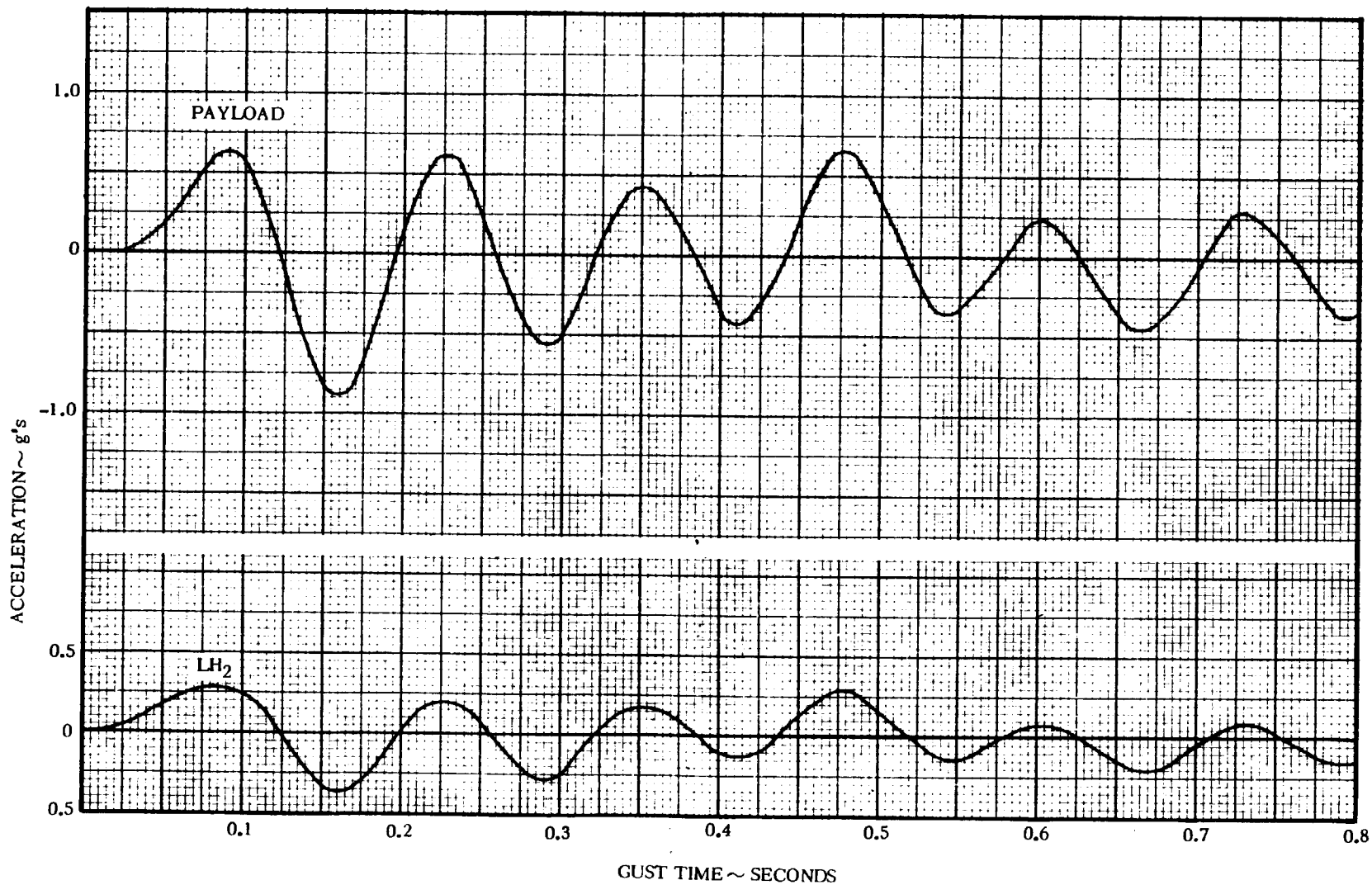


Figure 7-9. Payload and Liquid Hydorgen/Structure Lateral Acceleration - Mathematical Model 22

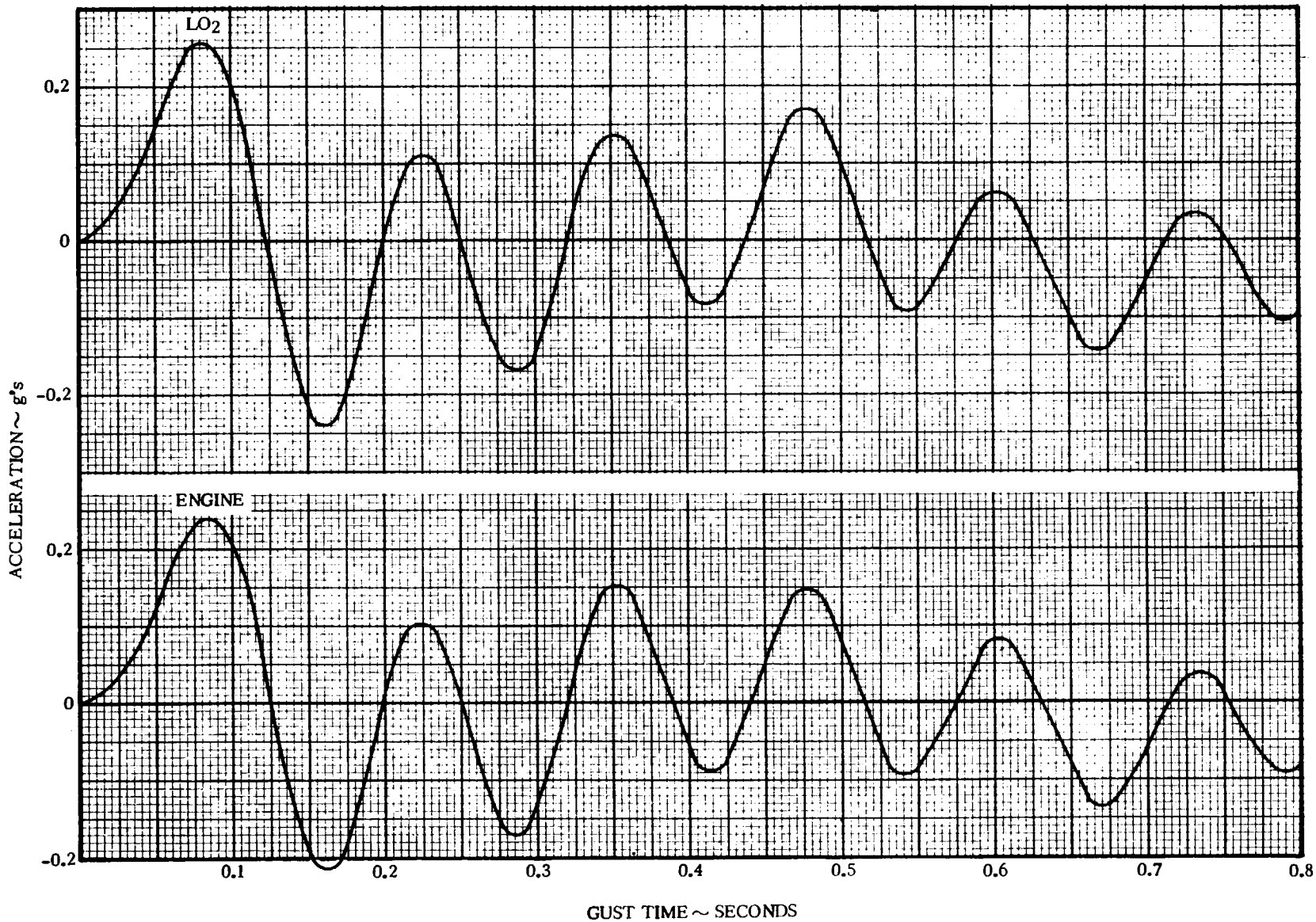


Figure 7-10. Liquid Oxygen/Structure and Engine/Structure Lateral Acceleration - Mathematical Model 22

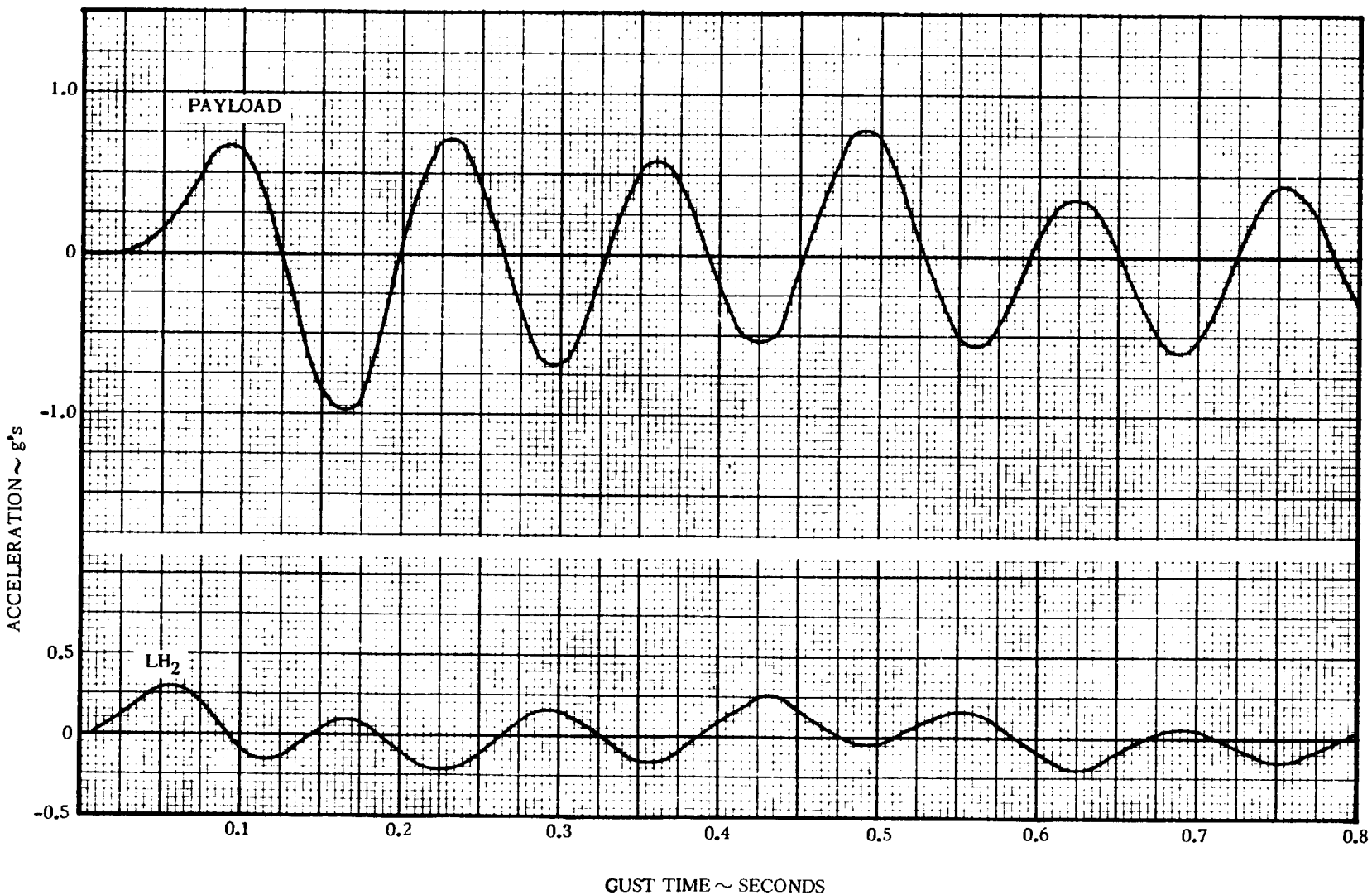


Figure 7-11. Payload and Liquid Hydrogen/Structure Lateral Acceleration - Mathematical Model 32

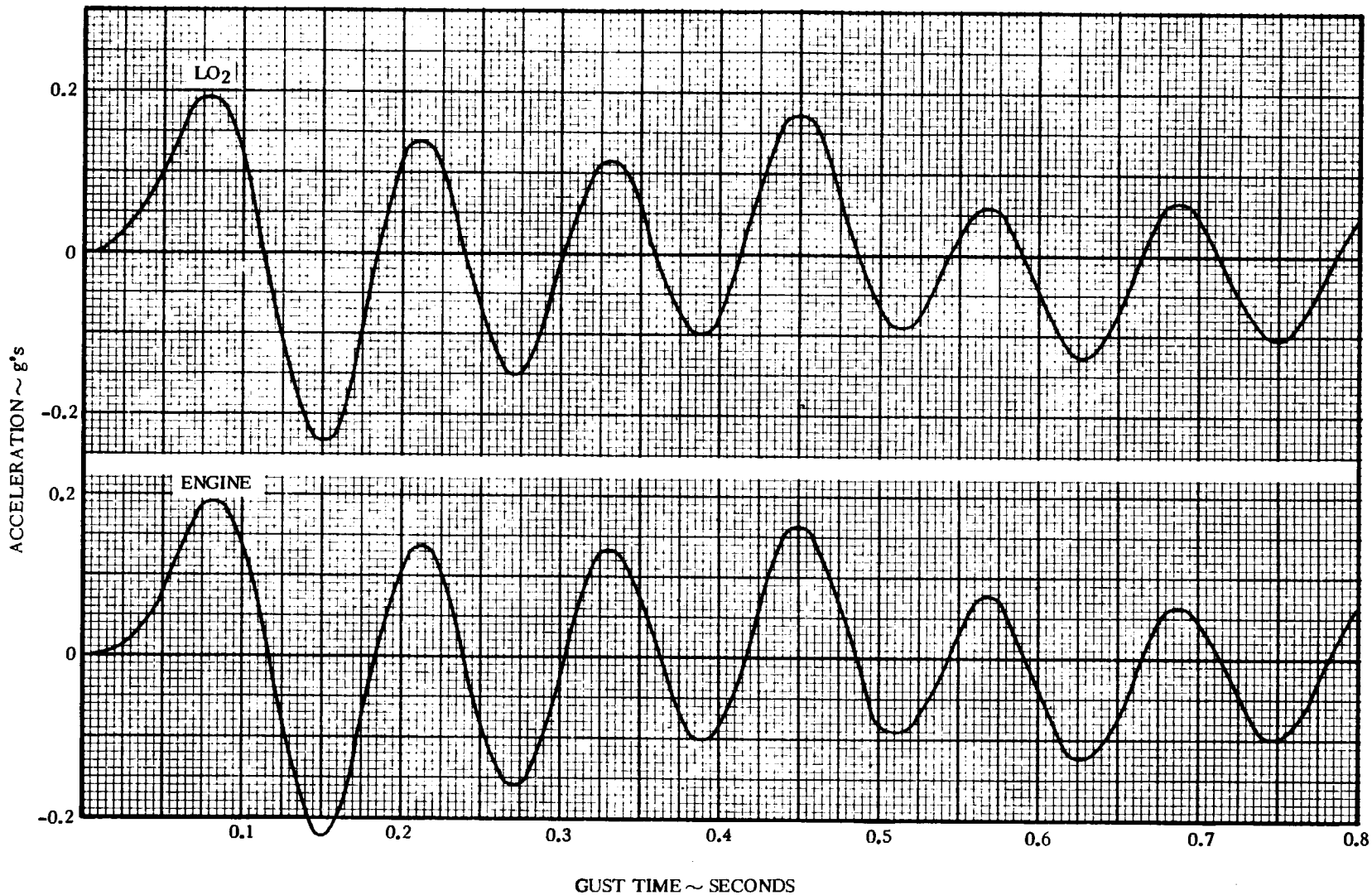


Figure 7-12. Liquid Oxygen/Structure and Engine/Structure Lateral Acceleration - Mathematical Model 32

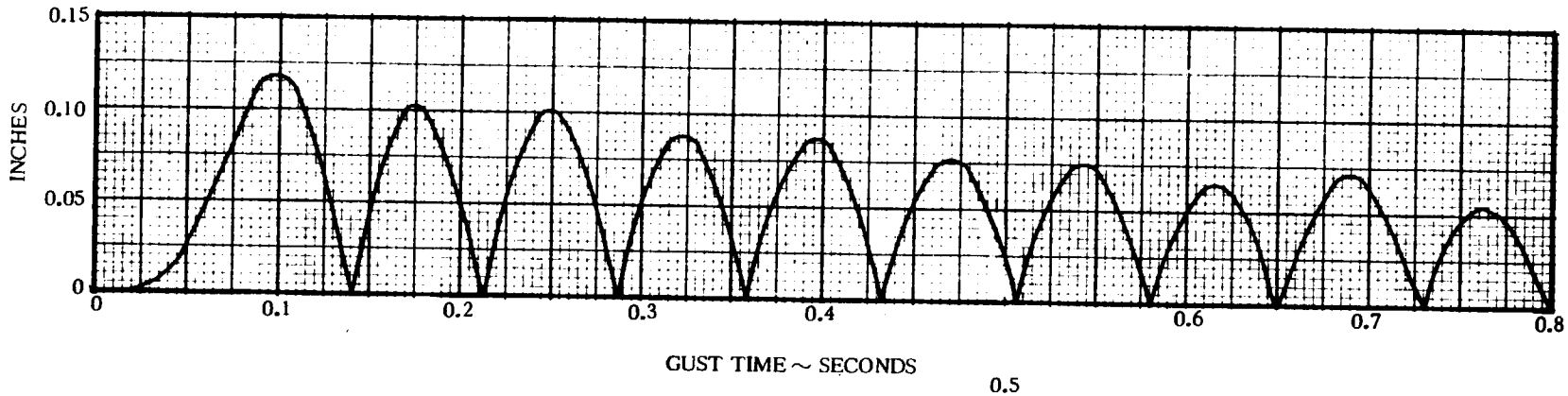


Figure 7-13. Relative Difference in Clearance Between Forward Ring and Nose Fairing - Mathematical Model 10

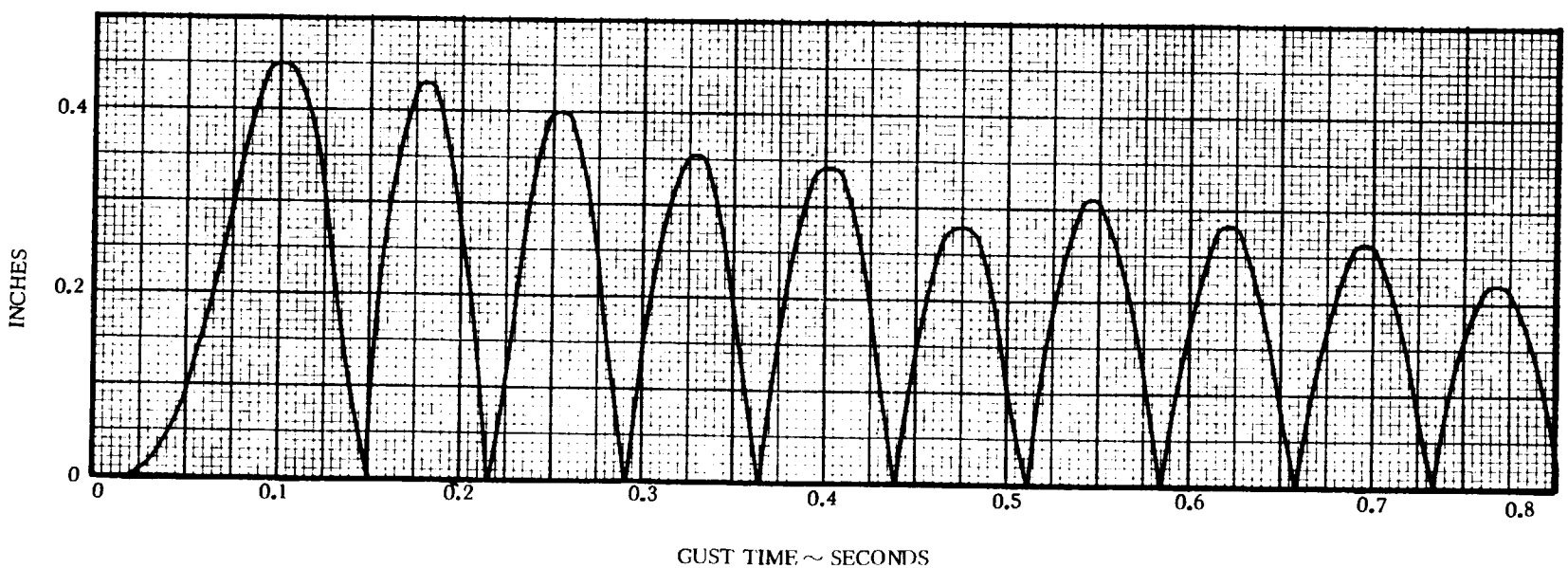


Figure 7-14. Relative Difference in Clearance Between Payload and Nose Fairing - Mathematical Model 10

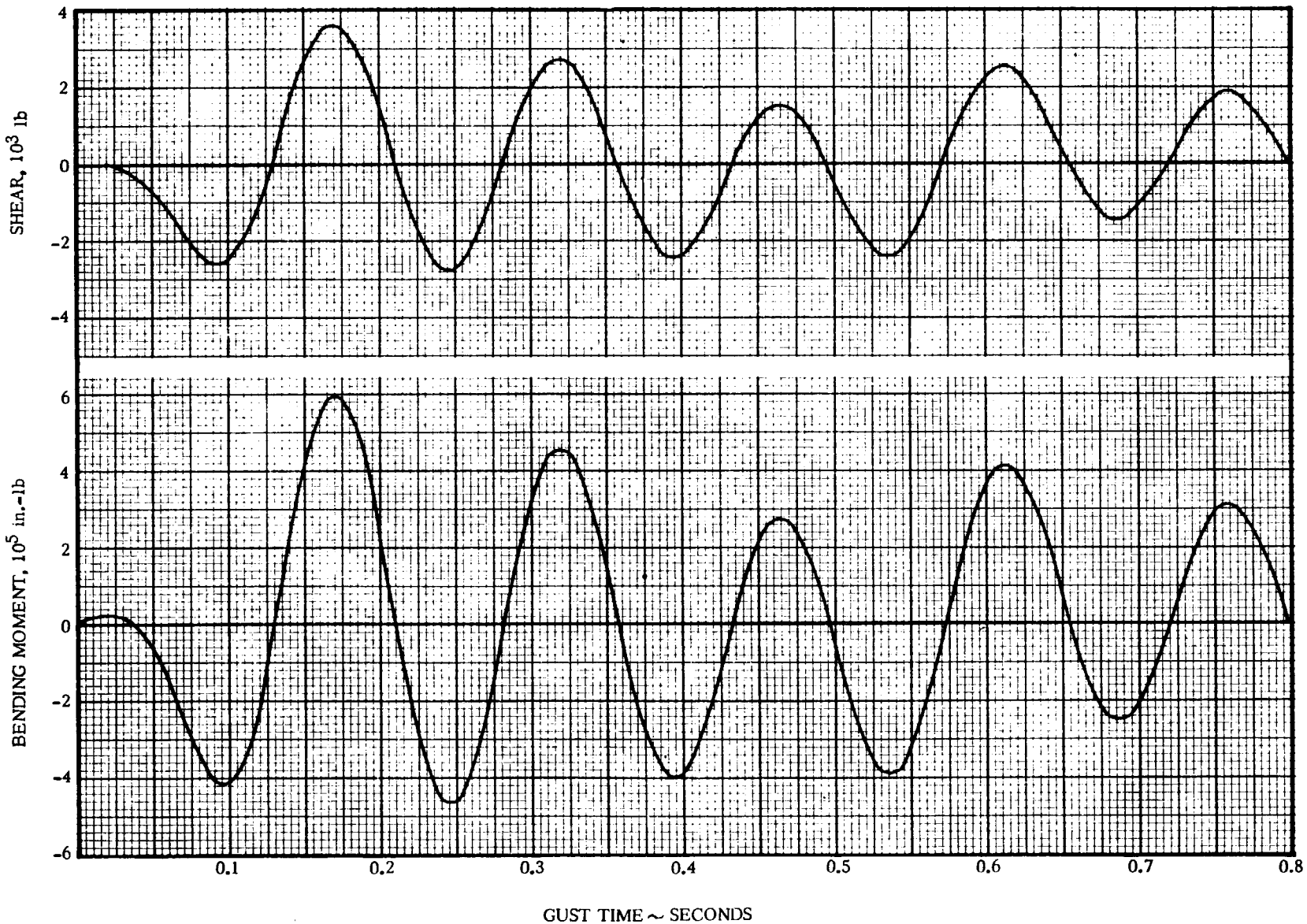


Figure 7-15. Shear and Bending Moment for Kick Stage Truss Near Aft Ring - Mathematical Model 10

7.6 NOSE FAIRING "OUT-OF-ROUND"

Clearance loss between the nose fairing and the payload and between the nose fairing and the forward ring due to nose fairing "out-of-round" is summarized in Figure 7-16 and Table 7-12. The "out-of-round" condition stems from wall differential pressure due to steady state aerodynamic loads and from bending of the nose fairing.

The out-of-round deflection data shown in Table 7-12 is based in part on experimental data which contained a small amount of unsymmetrical deflections. These effects are due to unsymmetrical structures (doors, cutouts, etc.) which are part of the nose fairing.

The nose fairing to forward ring tie used in MM 32 and 33 has been assumed to prevent relative motions of these parts except for the out-of-round deflection which is shown. This also may be eliminated depending on the detail of the tie.

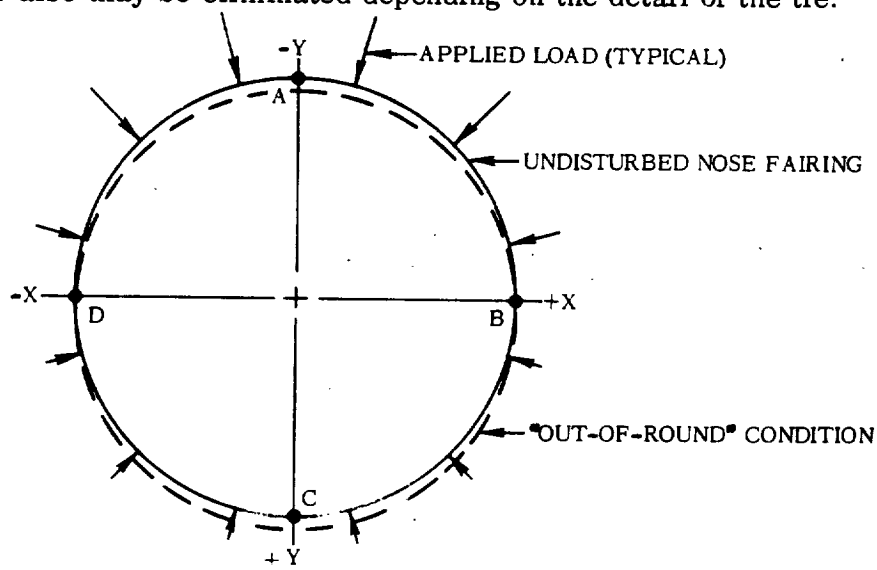


Figure 7-16. Nose Fairing "Out-of-Round" Displacement

TABLE 7-12. NOSE FAIRING "OUT-OF-ROUND" DISPLACEMENTS

Load Condition	Node	Station Inches (SLV-3C)	Radial "Out-of-Round" Displacements (Inboard = -, Outboard = +)			
			A	B	C	D
I	5	-156	-0.05	-0.13	+ 0.09	-0.10
II	5	-156	-0.01	-0.06	+ 0.02	-0.05
I	8	-48	-0.05	-0.08	+ 0.02	-0.09
II	8	-48	-0.01	-0.04	+ 0.005	-0.04

LOADING CONDITION I - STATIC AEROELASTIC LOADS
LOADING CONDITION II - ROOT-SUM-SQUARE OF GUST AND DISPERSIONS LOADS

7.7 FLIGHT LOADS SUMMARY

Table 7-13 summarizes the static and dynamic responses of specific points along the vehicle for the critical time in flight.

The dynamic responses tabulated in Table 7-13 represent, in addition to the gust, responses due to lack of wind profile persistance, errors in balloon data, and transonic buffet of the entire vehicle. Also, response due to a 0.7 degree angle of attack for miscellaneous trajectory dispersions was root-sum-squared with the gust responses.

The static response consists of data obtained for an angle of attack of 4.4 degrees.

The axial load on the truss is the product of the vehicle longitudinal acceleration (1.9 g's) and the weight bearing on the truss. The weight for the 3000 pound payload is 5000 pounds, and the weight for the 300 pound payload is 2300 pounds.

The clearance losses between the nose fairing and the payload and between the nose fairing and the forward ring for the static response includes the static aeroelastic loss and the appropriate "out-of-round" deflection. The dynamic clearance loss includes the loss due to gust response, dispersions and the proper "out-of-round" deflection from Table 7-12.

The static and dynamic clearance losses were calculated using the following formulas:

$$\text{Clearance Loss}_{\text{STATIC}} = \left[\left(C + A\right)^2 + B^2\right]^{\frac{1}{2}}$$

$$\text{Clearance Loss}_{\text{DYNAMIC}} = \left[\left(\frac{0.7}{4.4}\,C + A'\right)^2 + \left(B'\right)^2 + G^2\right]^{\frac{1}{2}}$$

where

C = Clearance loss due to static aeroelastic load.

A, A′ = Point A deflection for appropriate "out-of-round" condition.

B, B′ = Point B deflection for appropriate "out-of-round" condition.

G = Clearance loss due to gust and dispersions load.

The static aeroelastic and gust results, as summarized in this section, appear to be valid when compared to data for the shorter Atlas/Centaur vehicles.

TABLE 7-13. SUMMARY OF STATIC AND DYNAMIC RESPONSES OF SPECIFIC POINTS ALONG THE VEHICLE (TIME = 72 SECONDS)

			Mass Accelerations							Truss Loads			Clearance Loss	
Math Model	Kick Stage Case	Type of Response	Payload (g's)	Payload Ring (g's)	Forward Ring (g's)	Hydrogen (g's)	Oxygen (g's)	Engine (g's)	Aft Ring (g's)	Bending Moment (10^6 in.-lb)	Shear (10^3 lb)	Axial Force (10^3 lb)	Payload to Nose Fairing (in.)	Fwd. Ring to Nose Fairing (in.)
10	1	Static	0.234	←				→	0.234	0.142	1.105	9.50	1.10	0.46
		Dynamic	1.135	0.295	0.275	0.266	0.246	0.216	0.256	0.562	3.784	0	0.49	0.14
12	2	Static	0.234	←				→	0.234	0.142	1.105	9.50	1.09	0.45
		Dynamic	1.157	0.298	0.275	0.265	0.231	0.202	0.241	0.609	3.910	0	0.48	0.14
13	3	Static	0.234	←				→	0.234	0.142	1.105	9.50	1.13	0.48
		Dynamic	1.050	0.290	0.266	0.258	0.266	0.235	0.277	0.549	3.562	0	0.53	0.17
14	4	Static	0.245	←				→	0.245	0.0369	0.498	4.37	1.05	0.46
		Dynamic	1.047	0.733	0.665	0.644	0.468	0.447	0.482	0.135	1.732	0	0.34	0.13
15	5	Static	0.245	←				→	0.245	0.0369	0.498	4.37	1.04	0.45
		Dynamic	0.984	0.698	0.635	0.615	0.475	0.455	0.489	0.128	1.660	0	0.32	0.13
16	6	Static	0.245	←				→	0.245	0.0369	0.498	4.37	1.07	0.47
		Dynamic	1.251	0.864	0.776	0.751	0.434	0.414	0.448	0.160	2.018	0	0.38	0.15
17	7	Static	0.234	←				→	0.234	0.142	1.105	9.50	1.15	0.47
		Dynamic	0.931	0.285	0.301	0.300	0.277	0.244	0.288	0.476	2.952	0	0.58	0.14
18	8	Static	0.234	←				→	0.234	0.142	1.105	9.50	1.14	0.46
		Dynamic	0.976	0.286	0.302	0.302	0.271	0.238	0.282	0.500	3.088	0	0.55	0.13
19	9	Static	0.234	←				→	0.234	0.142	1.105	9.50	1.21	0.48
		Dynamic	0.822	0.283	0.298	0.299	0.289	0.253	0.301	0.417	2.633	0	0.68	0.16
22	1S	Static	0.234	←				→	0.234	0.142	1.105	9.50	1.06	0.45
		Dynamic	0.870	0.437	0.384	0.367	0.262	0.242	0.270	0.492	3.568	0	0.41	0.15
24	2S	Static	0.234	←				→	0.234	0.142	1.105	9.50	1.05	0.45
		Dynamic	0.824	0.443	0.388	0.372	0.276	0.262	0.285	0.467	3.434	0	0.39	0.14
25	3S	Static	0.234	←				→	0.234	0.142	1.105	9.50	1.07	0.45
		Dynamic	0.988	0.428	0.383	0.363	0.227	0.206	0.233	0.552	3.897	0	0.44	0.16
26	4S	Static	0.245	←				→	0.245	0.0369	0.498	4.37	1.04	0.45
		Dynamic	0.881	0.659	0.608	0.598	0.483	0.446	0.498	0.119	1.575	0	0.32	0.13
27	5S	Static	0.245	←				→	0.245	0.0369	0.498	4.37	1.03	0.45
		Dynamic	0.864	0.649	0.600	0.581	0.485	0.447	0.500	0.118	1.556	0	0.32	0.12
28	6S	Static	0.245	←				→	0.245	0.0369	0.498	4.37	1.05	0.45
		Dynamic	0.922	0.690	0.635	0.616	0.478	0.440	0.493	0.125	1.636	0	0.33	0.13
29	7S	Static	0.234	←				→	0.234	0.142	1.105	9.50	1.08	0.45
		Dynamic	1.131	0.374	0.279	0.265	0.219	0.190	0.229	0.607	3.999	0	0.46	0.15

TABLE 7-13. SUMMARY OF STATIC AND DYNAMIC RESPONSES OF SPECIFIC POINTS ALONG THE VEHICLE (TIME = 72 SECONDS) (CONTINUED)

			Mass Accelerations							Truss Loads			Clearance Loss	
Math Model	Kick Stage Case	Type of Response	Payload (g's)	Payload Ring (g's)	Forward Ring (g's)	Hydrogen (g's)	Oxygen (g's)	Engine (g's)	Aft Ring (g's)	Bending Moment (10^6 in.-lb)	Shear (10^3 lb)	Axial Force (10^3 lb)	Payload to Nose Fairing (in.)	Fwd. Ring to Nose Fairing (in.)
30	8S	Static	0.234	←				→	0.234	0.142	1.105	9.50	1.07	0.45
		Dynamic	1.081	0.402	0.286	0.272	0.218	0.192	0.227	0.588	3.940	0	0.45	0.14
31	9S	Static	0.234	←				→	0.234	0.142	1.105	9.50	1.09	0.45
		Dynamic	1.146	0.304	0.272	0.265	0.239	0.209	0.249	0.605	3.894	0	0.48	0.15
32	1	Static	0.232	←				→	0.232	0.477	8.871	9.50	0.655	0.09
		Dynamic	0.964	0.319	0.302	0.293	0.244	0.229	0.254	0.396	9.018	0	0.28	0.04
33	7	Static	0.232	←				→	0.232	0.461	8.617	9.50	0.65	0.09
		Dynamic	0.820	0.310	0.323	0.320	0.264	0.239	0.275	0.312	8.738	0	0.38	0.04

8

MAXIMUM BOOSTER ACCELERATION

The maximum booster acceleration analysis determines the longitudinal and lateral limit loads as well as the vehicle bending moments at the instant prior to Atlas Booster Engine Cutoff (BECO). These loads are caused mainly by weight offset and centerline misalignment of the various stages. Secondary effects, liquid sloshing and aerodynamic loading, contribute approximately 20 percent more load. The bending moment that occurs at this time is approximately equal to a ten percent increase in the axial load. Maximum Booster Acceleration (MBA) is an important design condition.

To simplify the analysis, it was found expeditious to assume superposition of the various load causing factors. That is, the analysis was broken up into three distinct parts;

a. Weight Offset and Centerline Misalignment

b. Liquid Sloshing

c. Aerodynamic Loading

In addition, only the 3000 pound payload was considered. Results of the analysis may be found in Figure 8-1.

8.1 CENTER OF GRAVITY (CG) OFFSET AND MISALIGNMENT

The bending moments caused by various weight offsets and centerline misalignments of the various stages were calculated for a rigid vehicle just prior to Atlas BECO. The following assumptions were made for this part of the analysis:

1. The vehicle was rigid and consisted of many discrete mass points whose weights were concentrated at the CG of each of the masses.
2. All propellants were treated as if they were rigid structures.
3. External aerodynamic forces and forces acting on the tank walls due to sloshing propellants were excluded.
4. Engine deflection was static and the vehicle was in the trimmed condition.
5. The engine thrust consisted of a fixed sustainer and a controlled booster thrust. The total thrust vector passed through the vehicle CG.
6. Small angle approximations for engine gimbaling and misalignments were used.

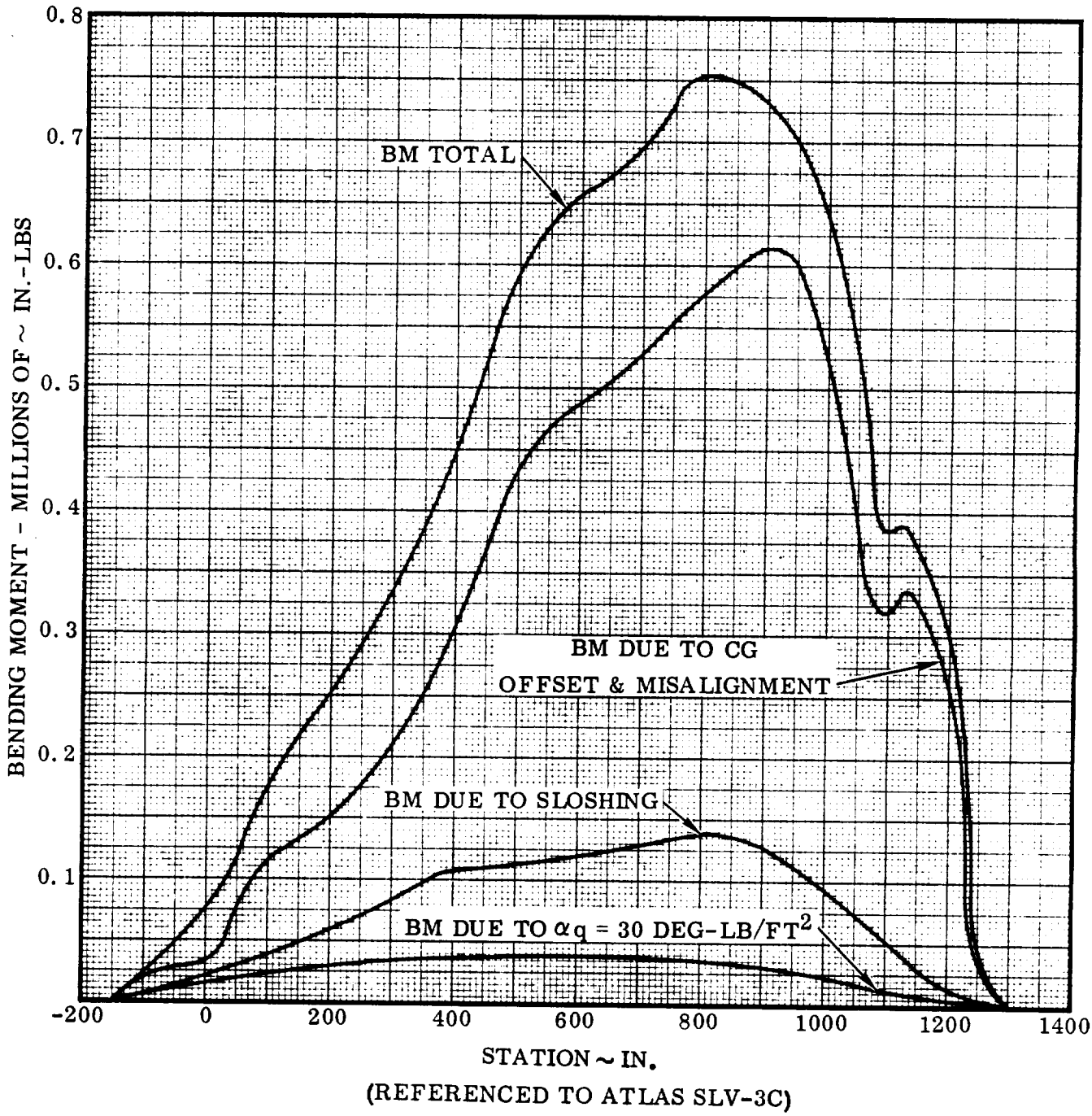


Figure 8-1. Maximum Booster Acceleration Bending Moments

7. The thrust from the booster and sustainer engines was applied at the same point at Station 1212.

8. The following were the maximum centerline misalignment angles caused by manufacturing tolerances:

   (a) 1/8 degree at Station 519 (sustainer - Centaur interstage adapter)

   (b) 1 minute-28 seconds at Station 361 (Centaur interstage adapter - Centaur)

   (c) 1 minute-28 seconds at Station 168 (Centaur-Kick Stage interstage adapter)

   (d) 1 minute-28 seconds at Station 18 (Kick Stage interstage adapter-Kick Stage)

   (e) 1 minute-28 seconds at Station 82 (Kick Stage-Payload).
   All station numbers are referenced to Atlas SLV-3C.

9. Kick Stage radial offset can be as much as 1 inch.

10. Payload radial offset can be as much as 1.5 inch.

The propellant masses were obtained from a digital computer run, Program 2520, for SLV-3C. However, in order to obtain inputs which were compatible with Program 2697C, Bending Moments Due To CG Offset and Misalignment, it was necessary to divide the Atlas fuel and LO_2 propellants into smaller discrete masses. This too, adds greater accuracy to the calculations. Propellant in the main LO_2 line was calculated by assuming that its density was 70.0 pounds/ft.^{3} The fixed thrust, taken as 82,327 pounds, acts along the vehicle centerline, while the control thrust, taken as 382,100 pounds acts to provide the net thrust vector through the vehicle CG.

To obtain the maximum bending moment it was necessary to determine in which lateral plane the centerline misalignments and radial offsets would be taken. This was accomplished by determining the pitch and yaw axis bending moments of an aligned vehicle from Program 2697C. For this particular case, bending moments are caused only by component weight offset and vehicle lateral and longitudinal acceleration. The critical plane was then found in the direction of the vector sum of these bending moments, at a particular station. Station 938 was chosen as the point at which the critical plane should be determined. It is at this station that the Atlas fuel and LO_2 tanks are joined and, from a design standpoint, is considered as a critical area. Using the data obtained for the aligned case, at Station 938, the critical plane was found to be 52° 44' off the pitch plane in Quadrants 2 and 4. Analysis of the particular problem at hand indicated that Quadrant 2 should be selected as the direction in which the centerline misalignments and radial offsets should be taken.

The computer input was then modified to incorporate the critical plane in which the misalignments and offsets were taken, and the vehicle bending moments recalculated. Since the correct direction was chosen for the critical plane, in this case Quadrant 2, the bending moments were greater than those obtained for the aligned case.

8.2 LIQUID SLOSH

Bending moments and accelerations caused by slosh were calculated with the following assumptions:

1. Propellant slosh was represented by a pendulum analogy.
2. Propellant masses were composed of rigid slosh masses at the ends of the pendulums and rigid fixed masses.
3. Shear forces were considered acting at the pendulum hinge point.
4. Slosh angles were taken as 1/4 degree (zero-to-peak).
5. Centaur fuel and Kick Stage propellant tanks were assumed to have negligible slosh mass.
6. Unequal tanking of the Kick Stage oxygen bottles was not considered a slosh problem but rather a weight offset.
7. Rigid body rotational acceleration was $\ddot{\theta} = .0157$ rad/sec.^{2}

Maximum shear forces due to slosh and engine deflection were calculated as follows, where the slosh mass and pendulum hinge points were obtained from Program 2520 for SLV-3C.

$$F_{n_{LC}} = -\ddot{Z}m_{p_{LC}}\phi_{LC} = -(5.756)(3870)\left(-\frac{.25}{57.3}\right) = 97 \text{ pounds (Centaur } LO_2)$$

$$F_{n_{FA}} = -\ddot{Z}m_{p_{FA}}\phi_{FA} = -(5.756)(5750)\left(\frac{.25}{57.3}\right) = -144 \text{ pounds (Atlas fuel)}$$

$$F_{n_{LA}} = -\ddot{Z}m_{p_{LA}}\phi_{LA} = -(5.756)(9770)\left(\frac{.25}{57.3}\right) = -245 \text{ pounds (Atlas } LO_2)$$

$$F_{n_{T_c}} = -T_c\delta = -382,100\delta \text{ (Engine deflection)}$$

where

F_n = normal shear force ~ pounds

m_p = pendulum mass ~ pounds

$\ddot{Z}$ = longitudinal acceleration ~ g's

ϕ = slosh angle ~ radians

δ = engine deflection ~ radians

The worst combination of pendulum amplitudes was used in the analysis.

The two basic equations of equilibrium which were solved were that the sum of all the forces acting on the vehicle and the sum of all moments acting on the vehicle are zero. From the simultaneous solution of these two equations, it is possible to obtain both the engine deflection (δ = .187°) and the lateral acceleration ($\ddot{y}$ = .0105 g's). Inserting the calculated values of engine deflection, and lateral acceleration, into the equations of equilibrium, the force and bending moment at each discrete mass may be obtained.

The solution of the slosh problem has been reexamined with respect to initial estimates of both the engine deflection (δ = .15°) and lateral acceleration ($\ddot{y}$ = .01 g). These values were determined concurrently with the estimate for the rigid body rotational acceleration, $\ddot{\theta}$. Since the estimated values of the engine deflection and lateral acceleration are in close agreement with the calculated values, it can be concluded that both the estimate for the rotational acceleration and the bending moments are realistic.

8.3 AERODYNAMIC LOADING

Design of the vehicle necessarily includes assumptions of the angle of attack, with respect to the free air stream. However, because of dispersions in both the vehicle angle of attack and dynamic pressure, due principally to the pitch program voltage variations, atmospheric variations and trajectory considerations, an αq (angle of attack × aerodynamic pressure) of 30 deg-lb/ft^2 has been used. The value of αq has been obtained as the maximum design criteria for jettison of the booster engine structure.

To maintain vehicle equilibrium, the total force vector, including aerodynamic terms, necessarily passes through or near the CG of the vehicle. The vehicle is therefore in a trimmed condition with both the rotational velocity and rotational acceleration being approximately zero.

Interpolation of the vehicle aerodynamic moment coefficients, obtained from previous analyses of currently flown Atlas/Centaur vehicles, was considered reasonable for the longer SLV-3C configuration. At maximum booster acceleration, changes in the aerodynamic moment coefficients with respect to Mach number are small. Therefore, moment coefficients at Mach 2.5 were used in the analysis. The bending moments associated with aerodynamic loading may now be calculated from:

$$M_j = M_{c_j}(\alpha q)\, AL - \sum_{i=1}^{n} \ddot{X}\, W_i \ell_i$$

where

M_j = Bending moment at Station j ~ in.-lb

M_{c_j} = Coefficient of total bending moment at Station j ~per degree

α = Angle of attack ~ degrees

q = Dynamic pressure $\sim$ lb/ft^2

A = Reference area $\sim$ 78.5 ft^2

L = Reference length $\sim$ 1500 inches

W_i = Mass at Station i $\sim$ lbs

ℓ_i = Moment arm from Station i to Station j $\sim$ inches

$\ddot{X}$ = Vehicle lateral acceleration $\sim$g's

n = Number of discrete vehicle masses

All Stations i are forward of Station j, about which the bending moments are to be found.

8.4 RESULTS

Weight offset and misalignment resulted in approximately .03 g lateral acceleration at the Kick Stage with a maximum of .62 million in.-lb bending moment in the Atlas vehicle. The additional lateral load incurred at Kick Stage because of slosh was found to be approximately .04 g's. The other factors entering into the analysis are considerably smaller than either of the contributions of slosh or CG offset so that the total lateral load factor is rounded off at approximately 0.1 g. Relative motion between the shroud and the Kick Stage forward ring was calculated as approximately .02 inch for the 0.1 g load, while the relative motion between the payload and the shroud was .08 inch for the 0.1 g load. The maximum bending moment from all contributions is .75 million in.-lbs in the Atlas with approximately .080 million in.-lbs at the base of the Kick Stage aft ring and beam (Station 14). It is recommended that a maximum steady-state longitudinal acceleration of 5.8 g's be used for design to provide mission flexibility.

Should assumptions of centerline misalignments, radial offsets, etc., prove to be too small, then portions of this analysis should be reviewed for redetermination of the load factors.

9

CENTAUR MAIN ENGINE START & CUTOFF

Engine thrust forces are the largest forces experienced by a vehicle during flight. Longitudinal loads produced during a thrust buildup or cutoff are a significant factor for consideration in vehicle design. Results of analyses for determining Kick Stage longitudinal transient responses during Centaur second Main Engine Start (MES), and first and second Main Engine Cutoffs (MECO) are presented herein.

In addition, the existence of two Centaur engines introduces the possibility of an unsymmetric thrust loading at engine start and shutdown. Kick Stage lateral loads induced by this phenomenon have been analyzed and results are included in this section.

9.1 MATHEMATICAL MODEL

Three Kick Stage/Payload configurations were employed for each of the longitudinal analyses at Centaur second main engine cutoff. These consisted of the two-ring and three-ring Kick Stage design, each with the 3,000-pound payload, and the 300-pound payload on the two-ring Kick Stage configuration.

Longitudinal response at Centaur first main engine cutoff was analyzed for two configurations. Both were two-ring versions of the Kick Stage, one having the 3,000-pound payload, and one with the 300-pound payload.

The configuration used for analyzing the lateral response due to unsymmetric thrust at Centaur second main engine start and cutoff, is the 3,000-pound payload on the two-ring Kick Stage.

Table 9-1 summarizes the configurations and their corresponding model numbers used for analyses in this section. Figures 3-1 and 3-2 of Section 3 present the longitudinal and lateral math models respectively. These models have been modified to represent vehicle configuration at the flight time of Centaur buildup and cutoff. Nodes have been eliminated and weights have been corrected to reflect jettison of Atlas, nose fairing, insulation panels, interstage adapter, and depletion of fuel.

Weight and stiffness data for the above models are presented in Tables 3-4 through 3-7.

9.2 CENTAUR THRUST BUILDUP, CUTOFF, AND DIFFERENTIAL CURVES

The curves for Centaur thrust buildup (Figure 9-1) and cutoff (Figure 9-2), are based on the specification curves of Reference 9-1. Reference 9-1 presents a nominal

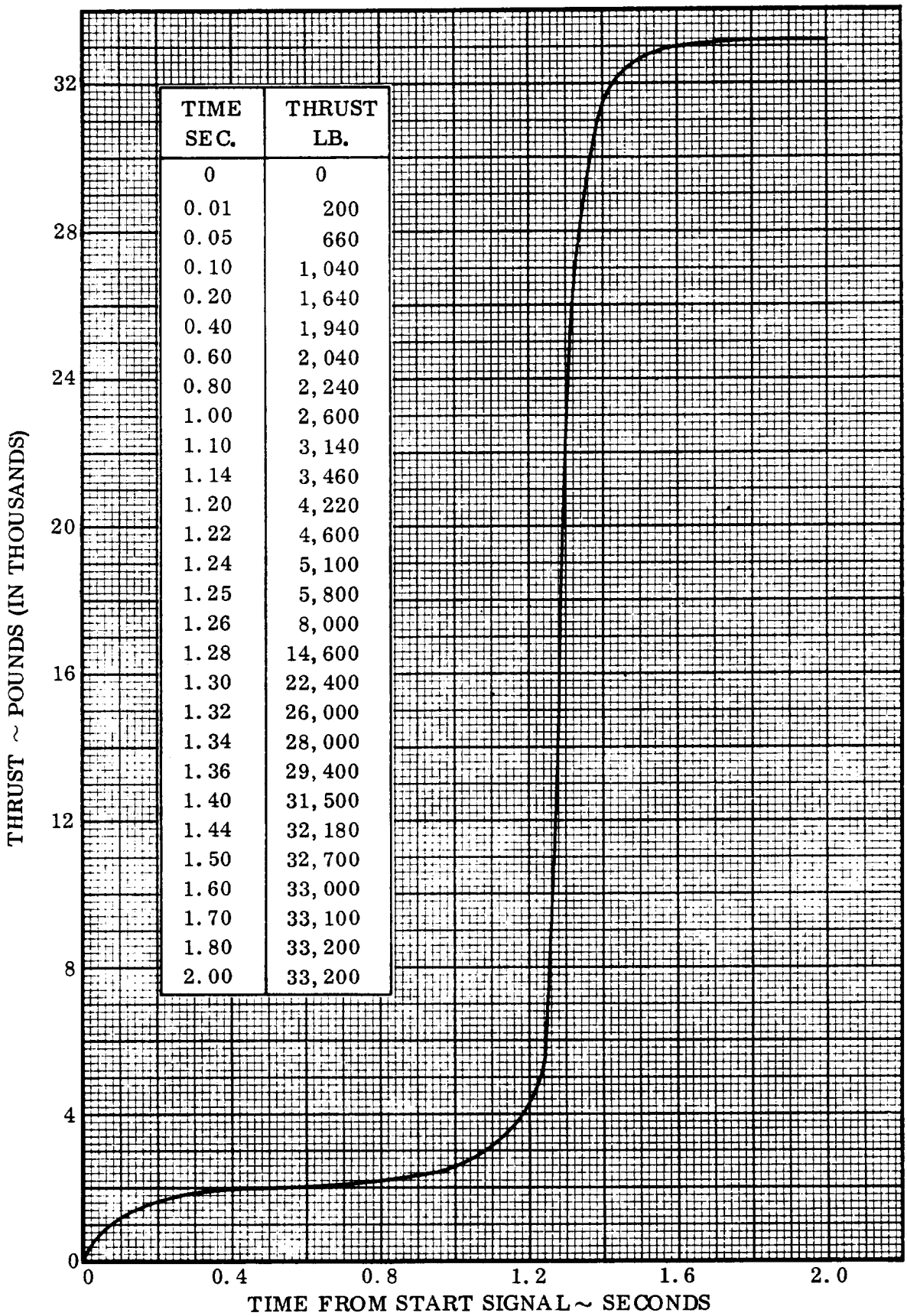
TABLE 9-1. CONFIGURATIONS ANALYZED FOR CENTAUR MES AND MECO

Event	Math Model No.	Kick Stage Case No.	Type of Model	Payload Weight (lb)	Kick Stage Configuration
Centaur 2nd Main Engine Start	34	1	Longitudinal	3000	2-Ring
	35	1	Lateral	3000	2-Ring
	36	4	Longitudinal	300	2-Ring
	37	7	Longitudinal	3000	3-Ring
Centaur 1st Main Engine Cutoff	34	1	Longitudinal	3000	2-Ring
	36	4	Longitudinal	300	2-Ring
Centaur 2nd Main Engine Cutoff	38	1	Longitudinal	3000	2-Ring
	39	1	Lateral	3000	2-Ring
	40	4	Longitudinal	300	2-Ring
	41	7	Longitudinal	3000	3-Ring

buildup and cutoff curve and the envelope of the three standard deviation (3σ) for one RL10A-3-3 engine. The Centaur stage has two identical RL10A-3-3 engines.

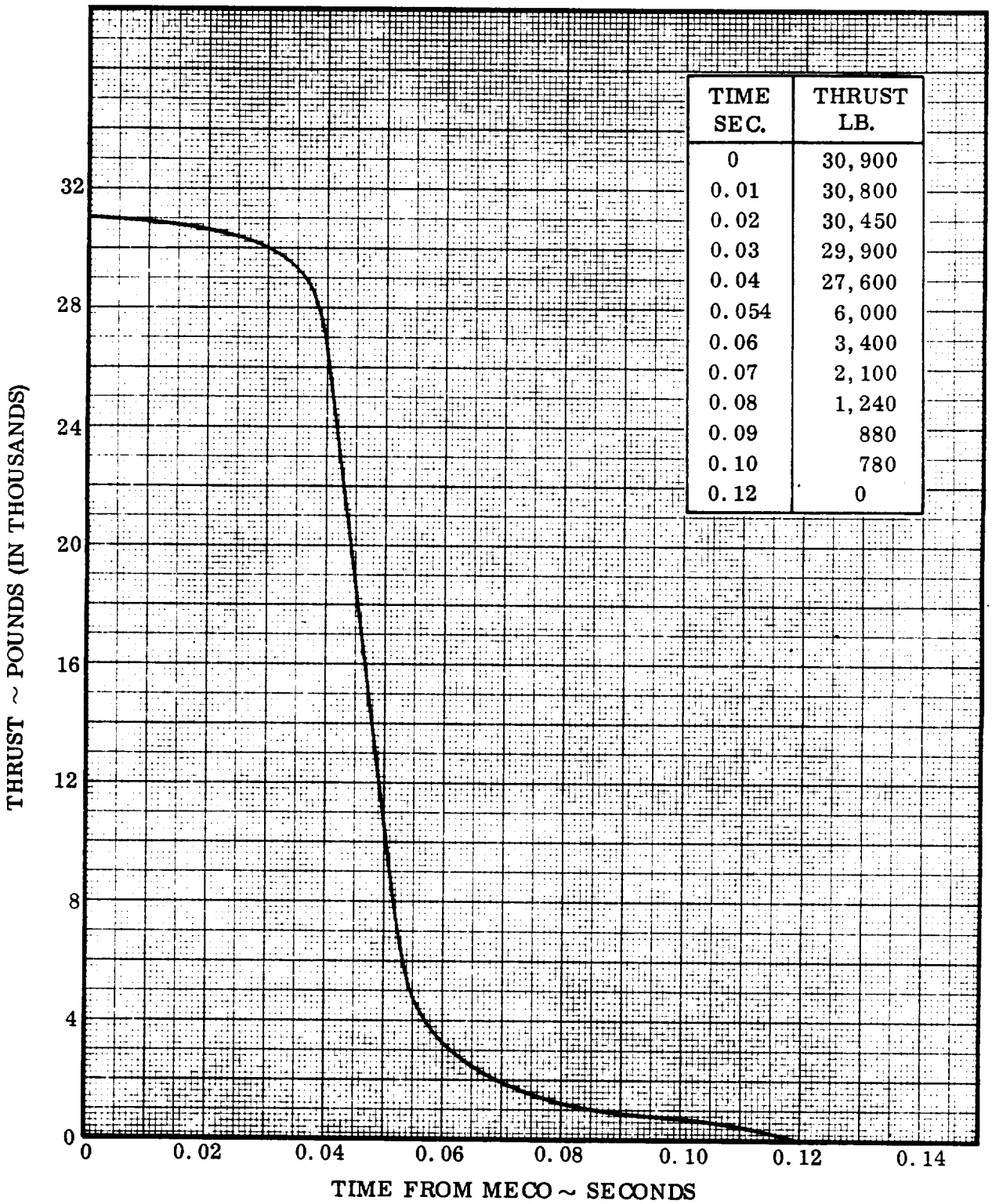
For design purposes, it is desirable to represent the worst case condition, or statistically the three-sigma condition, for the two-engine system. Probability theory indicates that the three-sigma combination of two random variables is the root-sum-square of the three-sigma values of the variables. Thus, the buildup and cutoff curves used in this analysis (Figures 9-1 and 9-2) are twice the nominal, for one engine, plus $\sqrt{2}$ times the three-sigma dispersion for one engine. The high thrust dispersions are used for each of these curves.

The maximum differential thrust curves during Centaur thrust buildup and cutoff were also derived from the specification curves of Reference 9-1. The differential thrust is taken to be 0.707 times the high thrust dispersion above nominal, plus 0.707 times the low thrust dispersion below nominal. These derived values, plotted versus time, are given in Figures 9-3 and 9-4 for Centaur thrust buildup and cutoff respectively.



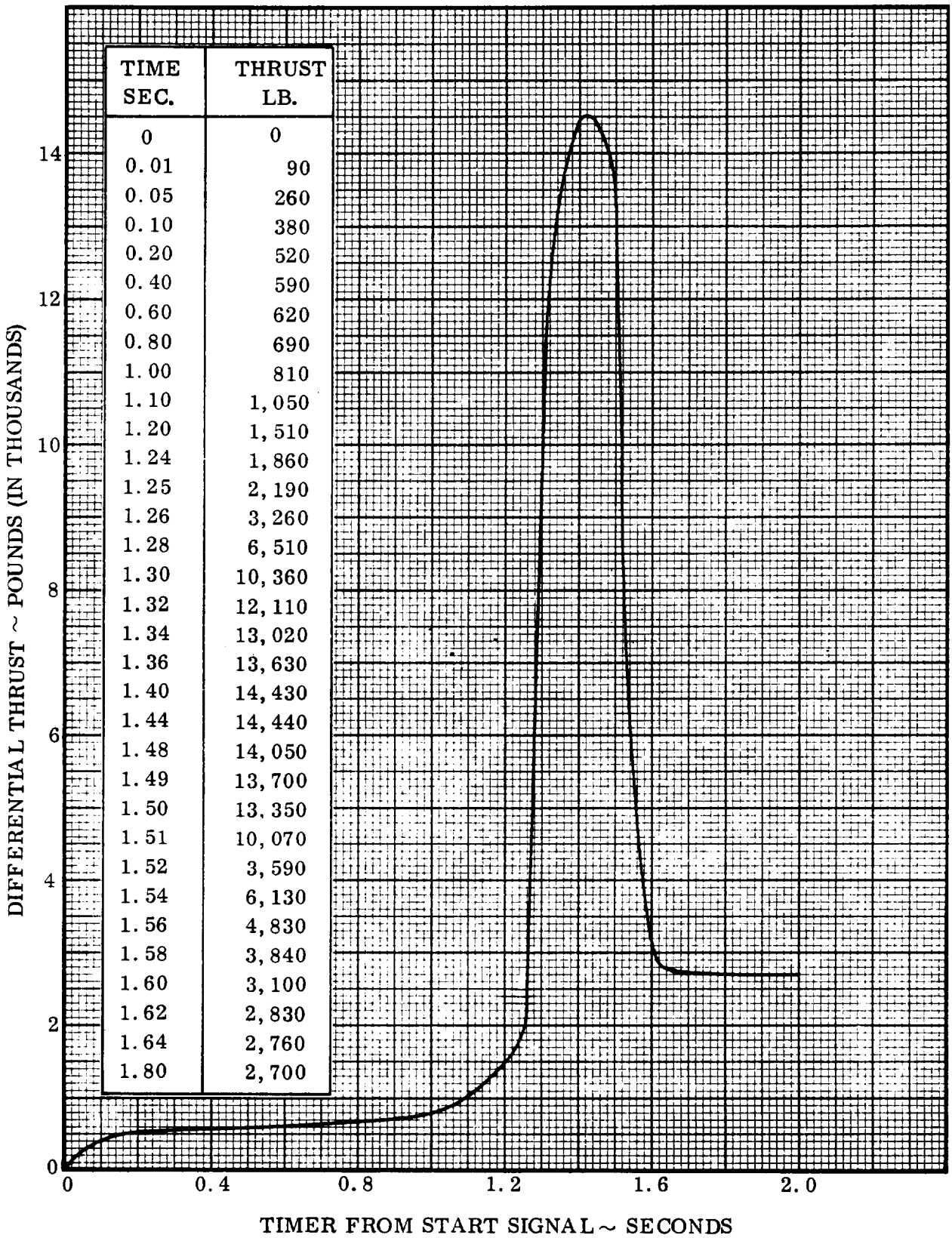
TIME SEC.	THRUST LB.
0	0
0.01	200
0.05	660
0.10	1,040
0.20	1,640
0.40	1,940
0.60	2,040
0.80	2,240
1.00	2,600
1.10	3,140
1.14	3,460
1.20	4,220
1.22	4,600
1.24	5,100
1.25	5,800
1.26	8,000
1.28	14,600
1.30	22,400
1.32	26,000
1.34	28,000
1.36	29,400
1.40	31,500
1.44	32,180
1.50	32,700
1.60	33,000
1.70	33,100
1.80	33,200
2.00	33,200

Figure 9-1. Thrust Buildup Specification for Double RL10A-3-3 Engine



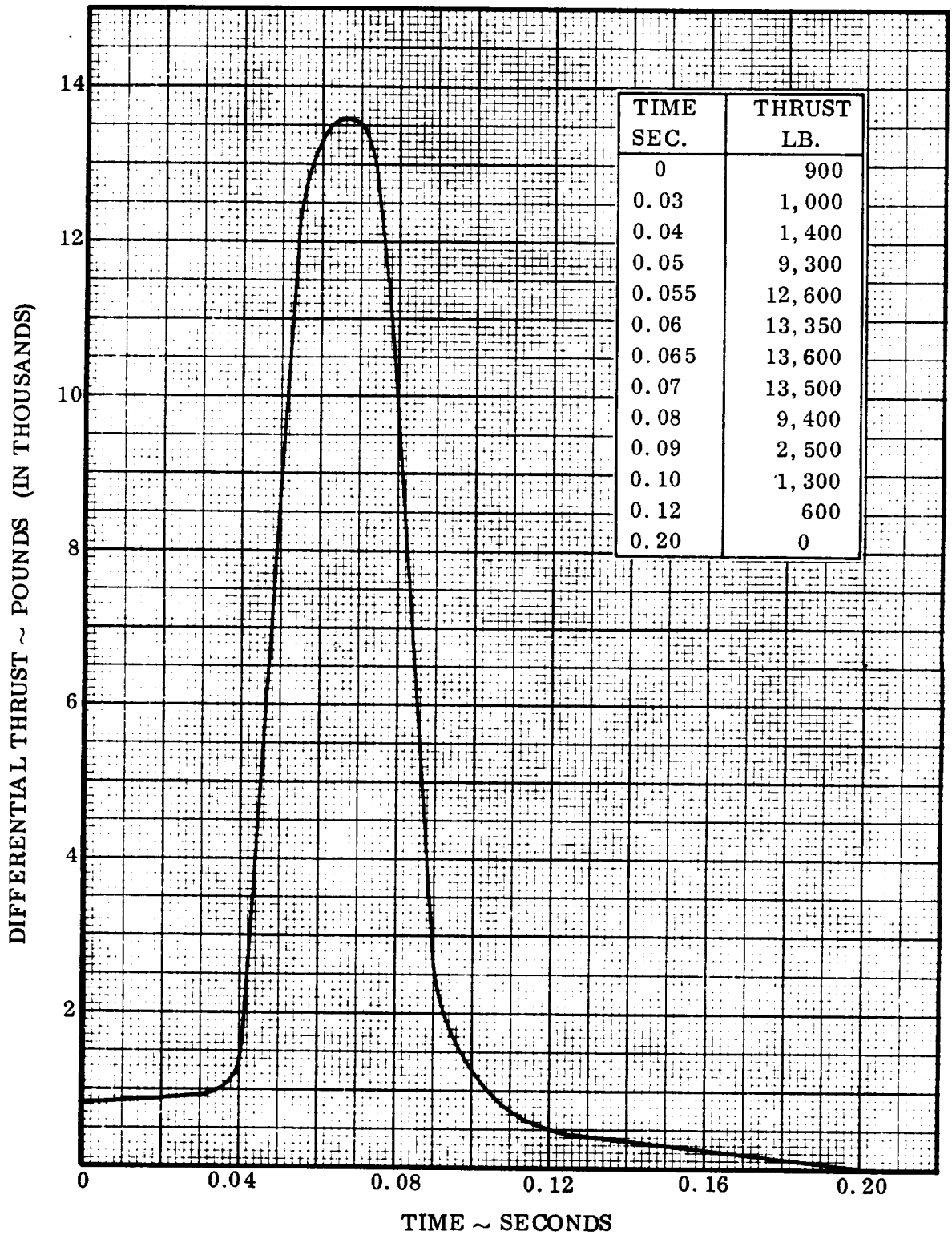
TIME SEC.	THRUST LB.
0	30,900
0.01	30,800
0.02	30,450
0.03	29,900
0.04	27,600
0.054	6,000
0.06	3,400
0.07	2,100
0.08	1,240
0.09	880
0.10	780
0.12	0

Figure 9-2. Maximum Thrust Decay for Two RL10A-3-3 Engines



TIME SEC.	THRUST LB.
0	0
0.01	90
0.05	260
0.10	380
0.20	520
0.40	590
0.60	620
0.80	690
1.00	810
1.10	1,050
1.20	1,510
1.24	1,860
1.25	2,190
1.26	3,260
1.28	6,510
1.30	10,360
1.32	12,110
1.34	13,020
1.36	13,630
1.40	14,430
1.44	14,440
1.48	14,050
1.49	13,700
1.50	13,350
1.51	10,070
1.52	3,590
1.54	6,130
1.56	4,830
1.58	3,840
1.60	3,100
1.62	2,830
1.64	2,760
1.80	2,700

Figure 9-3. Maximum Differential Thrust Between C_1 and C_2 of RL10A-3-3 During Thrust Buildup



TIME SEC.	THRUST LB.
0	900
0.03	1,000
0.04	1,400
0.05	9,300
0.055	12,600
0.06	13,350
0.065	13,600
0.07	13,500
0.08	9,400
0.09	2,500
0.10	1,300
0.12	600
0.20	0

Figure 9-4. Maximum Differential Thrust Between C_1 and C_2 of RL10A-3-3 During Engine Shutdown

9.3 METHOD OF SOLUTION

9.3.1 SYMMETRIC CENTAUR THRUST BUILDUP AND CUTOFF. The method of solution employed for this analysis is similar to that used for Atlas Thrust Buildup (Section 5). The mathematical model for Atlas thrust buildup has the vehicle fixed to the launcher. However, at Centaur thrust buildup and cutoff the vehicle is free. Therefore, input to the Forced Vibration Program included one rigid body translational mode, in addition to five elastic modes.

The forcing function as presented in Figures 9-1 and 9-2 was applied to node 13 of the mathematical model used. Using structural damping of two percent for each of the five elastic modes, the axial response was determined for all vehicle masses. Reference 5-4 presents a more-detailed discussion of the analysis used herein.

9.3.2 UNSYMMETRIC CENTAUR THRUST BUILDUP AND CUTOFF. The lateral mathematical model of Figure 3-2, modified as required, was used to derive one translational and one rotational rigid body mode plus five elastic modes.

These modes plus external forces were combined by means of computer program 2465 (Reference 5-3) to determine the various responses of the Kick Stage/Centaur vehicle.

The external moment due to the differential thrust was simply r times the curves in Figures 9-3 and 9-4, where r is the radius to the engine gimbal points (25 inches). This moment, as well as the lateral control force, act at the Centaur gimbal station (node 67 of Figure 3-2).

Using rigid body analysis, the engine command deflection (δ_c) was determined from the following simplified autopilot equation:

$$\delta_c = A\theta + B\dot{\theta}$$

where

$A = 0.24$ (dimensionless)

$B = 0.32$ second

θ = vehicle rigid-body rotation (degrees)

$\dot{\theta}$ = vehicle rigid-body rotation rate (deg/sec)

A time constant of 0.2 second for the engine servomechanism was used to determine the lag between the engine response and engine command.

A short numerical integration was used to solve the rigid-body and autopilot problem resulting in the engine deflection, and the lateral component of the control thrust.

This lateral component of the control thrust, and the external moment due to the differential thrust, applied to the Centaur gimbal station (node 67 of Figure 3-2), were the external forces used as input to the computer program.

9.4 RESULTS

9.4.1 MAXIMUM LONGITUDINAL ACCELERATIONS. Table 9-2 summarizes the maximum longitudinal responses of the Kick Stage masses during Centaur second MES, first MECO, and second MECO for the configurations analyzed. Positive values signify upward accelerations.

The positive dynamic value presented in Table 9-2 is the portion of response that exceeds the nominal steady-state thrust either after Centaur thrust buildup or before Centaur thrust cutoff.

Dynamic values for Centaur thrust cutoff cases in Table 9-2 which have a superscript s are maximums which are attained prior to thrust cutoff. Negative dynamic loads for thrust cutoff are measured relative to zero steady-state thrust.

Inspection of Table 9-2 reveals that the maximum longitudinal payload dynamic response occurs for the 300 pound payload configurations. However, due to the lighter weight of the payload the total force generated is less than that generated by the 3000-pound payload. The maximum payload loads, both negative and positive, occurred for the two-ring Kick Stage version with a 3000-pound payload.

The three-ring Kick Stage with the 3000-pound payload at Centaur second cutoff produced maximum longitudinal loads in both directions for the hydrogen mass. Maximum LO_2 response was generated in both directions at Centaur second cutoff for the two-ring Kick Stage/3000-pound payload configuration.

The peak engine loads occurred at two different Kick Stage configurations during Centaur second cutoff. The maximum positive load of 1.82 + 2.69 g's was attained on the three-ring/3000-pound Kick Stage, and the maximum negative of -5.60 g's was developed for the two-ring/300-pound configuration.

The response of each Kick Stage mass that yields a maximum load is underlined in Table 9-2.

An illustrative response time history of four Kick Stage masses (payload, liquid hydrogen, liquid oxygen, and engine) for each flight phase analyzed is presented in Figures 9-5 to 9-16. Kick Stage configuration is denoted on each figure. As can be seen from the figures, masses of the Kick Stage do not have similar response time histories for these analyses.

TABLE 9-2. MAXIMUM LONGITUDINAL RESPONSES DURING CENTAUR MAIN ENGINE START AND CUTOFF

Flight Phase	Math Model No.	Type of Response	Maximum Response of Masses (G's)							Truss Loads 10^3 (lbs) Axial
			Payload	Payload Ring	Forward Ring	Hydrogen	LO_2	Engine	Aft Ring	
Centaur Second Main Engine Start	34	Static	0 + 1.67	0 + 1.67	0 + 1.67	0 + 1.67	0 + 1.67	0 + 1.67	0 + 1.67	0 + 8.35
		Dynamic	+ 0.36	+ 0.27	+ 0.24	+ 0.25	+ 0.25	+ 0.39	+ 0.24	+ 1.35
			0	0	0	0	0	0	0	0
	36	Static	0 + 1.96	0 + 1.96	0 + 1.96	0 + 1.96	0 + 1.96	0 + 1.96	0 + 1.96	0 + 4.51
		Dynamic	+ 0.76	+ 0.67	+ 0.62	+ 0.66	+ 0.61	+ 0.85	+ 0.60	+ 0.37
			0	0	0	0	0	0	0	0
	37	Static	0 + 1.67	0 + 1.67	0 + 1.67	0 + 1.67	0 + 1.67	0 + 1.67	0 + 1.67	0 + 8.35
		Dynamic	+ 0.31	+ 0.27	+ 0.31	+ 0.35	+ 0.28	+ 0.46	+ 0.25	+ 1.10
			0	0	0	0	0	0	0	0
Centaur First Main Engine Cutoff	34	Static	1.67 + 0	1.67 + 0	1.67 + 0	1.67 + 0	1.67 + 0	1.67 + 0	1.67 + 0	8.35 + 0
		Dynamic	+ 0.42	+ 0.05[s]	+ 0.18	+ 0.53	+ 0.05[s]	+ 1.06	+ 0.09	+ 0.26[s]
			- 2.60	- 0.95	- 1.23	- 1.65	- 1.14	- 4.34	- 1.06	- 6.24
	36	Static	1.96 + 0	1.96 + 0	1.96 + 0	1.96 + 0	1.96 + 0	1.96 + 0	1.96 + 0	4.51 + 0
		Dynamic	+ 3.35	+ 0.45	+ 0.40	+ 0.50	+ 0.07[s]	+ 0.94	+ 0.07[s]	+ 0.133[s]
			- 5.62	- 1.98	- 1.52	- 1.86	- 1.51	- 5.24	- 1.13	- 3.99

NOTE:

s Denotes maximum occurred prior to thrust cutoff.

Values underlined are maximums for the mass.

TABLE 9-2. MAXIMUM LONGITUDINAL RESPONSES DURING CENTAUR MAIN ENGINE START AND CUTOFF (CONTINUED)

Flight Phase	Math Model No.	Type of Response	Maximum Response of Masses (G's)							Truss Loads 10^3 (lbs) Axial
			Payload	Payload Ring	Forward Ring	Hydrogen	LO_2	Engine	Aft Ring	
Centaur Second Main Engine Cutoff	38	Static	1.82+0	1.82+0	1.82+0	1.82+0	1.82+0	1.82+0	1.82+0	9.10+0
		Dynamic	+0.45	+0.12^s	+0.95	+1.59	+0.12^s	+1.38	+0.71	+0.32
			-2.77	-1.16	-1.50	-1.94	-1.08	-5.18	-1.30	-5.66
	40	Static	2.18+0	2.18+0	2.18+0	2.18+0	2.18+0	2.18+0	2.18+0	5.02+0
		Dynamic	+5.59	+0.83	+0.48	+0.98	+0.18^s	+1.44	+0.18^s	+1.00
			-7.72	-2.46	-1.68	-2.04	-1.43	-5.60	-1.29	-5.87
	41	Static	1.82+0	1.82+0	1.82+0	1.82+0	1.82+0	1.82+0	1.82+0	9.10+0
		Dynamic	+0.12^s	+0.12^s	+1.06	+1.67	+0.12^s	+2.69	+0.12^s	+0.09
			-2.03	-0.90	-1.95	-2.25	-1.39	-4.35	-1.81	-4.44

NOTE:

s Denotes maximum occurred prior to thrust cutoff.

Values underlined are maximums for the mass.

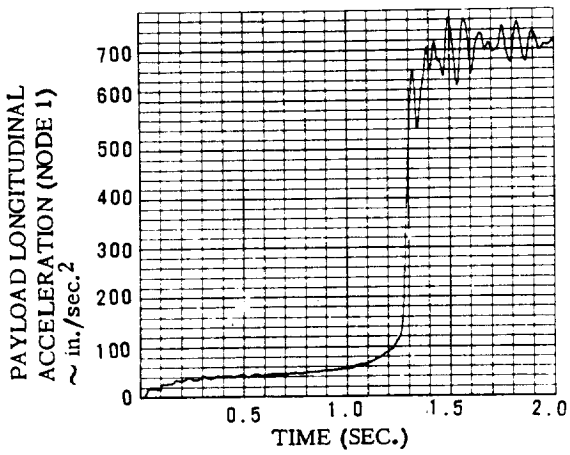


Figure 9-5

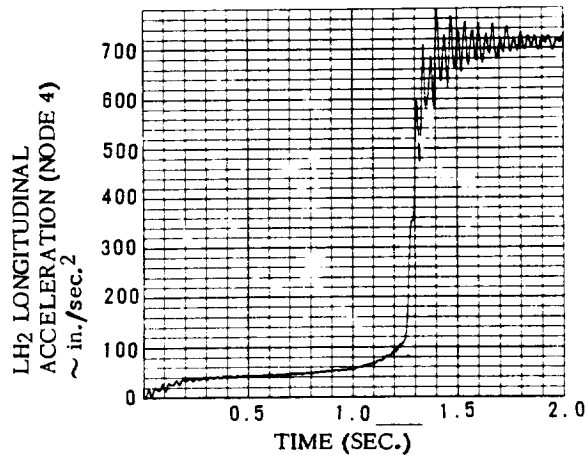


Figure 9-6

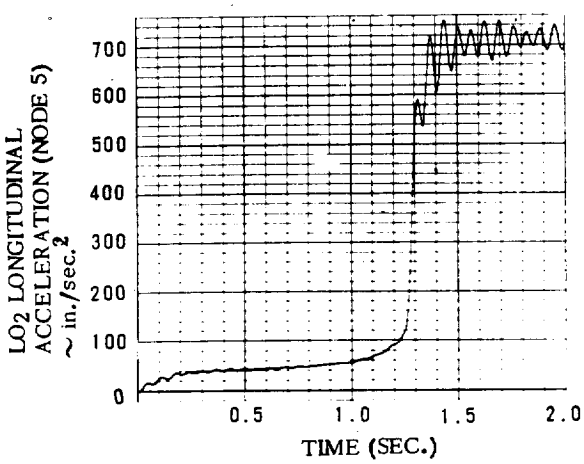


Figure 9-7

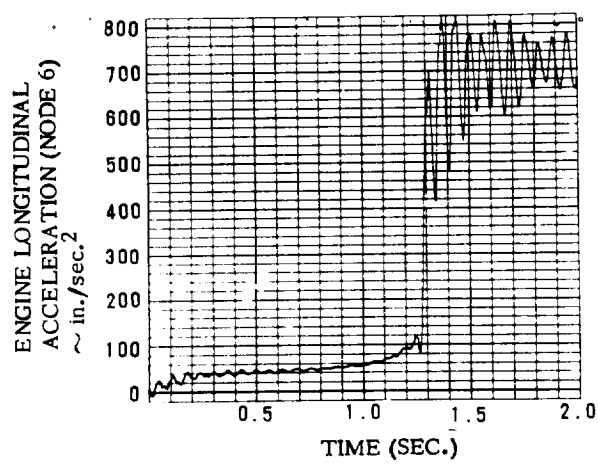


Figure 9-8

Longitudinal Response Time-Histories of Kick Stage Masses (Mathematical Model No. 37) During Centaur 2nd Main Engine Start

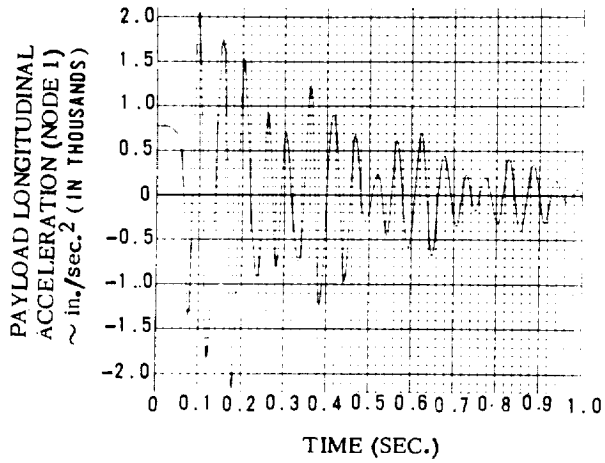


Figure 9-9

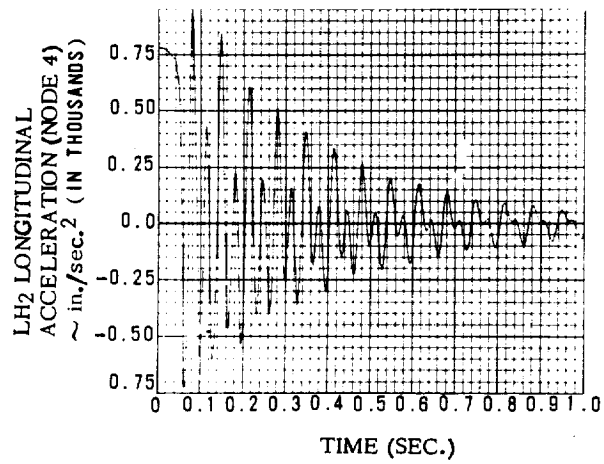


Figure 9-10

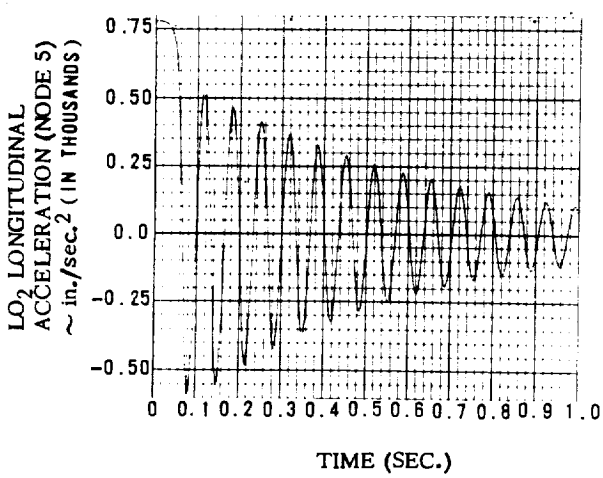


Figure 9-11

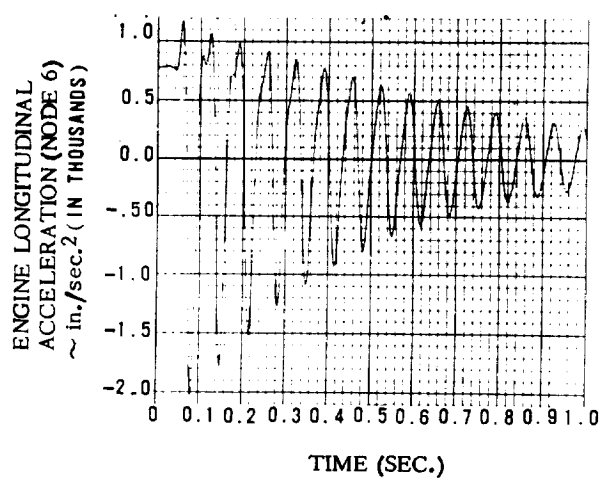


Figure 9-12

Longitudinal Response Time-Histories of Kick Stage Masses (Mathematical Model No. 36) During Centaur 1st Main Engine Cutoff

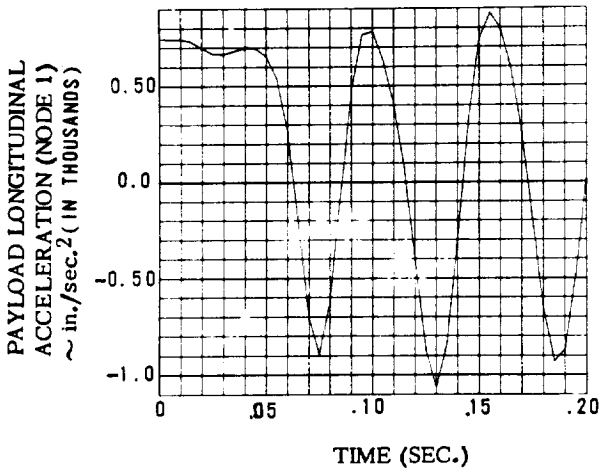


Figure 9-13

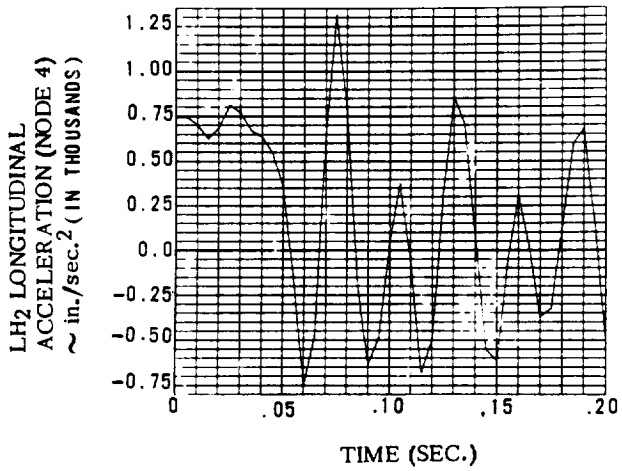


Figure 9-14

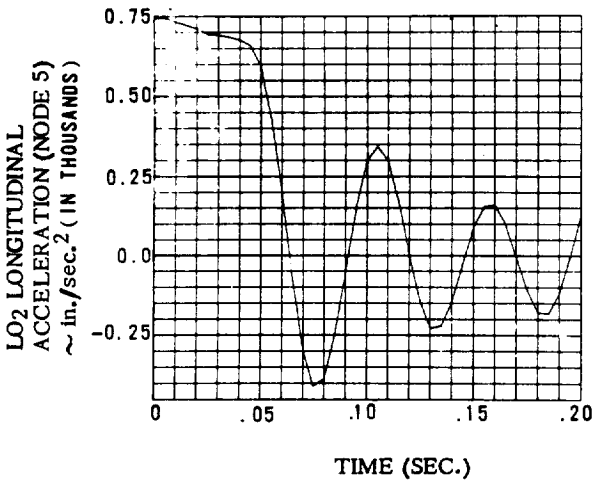


Figure 9-15

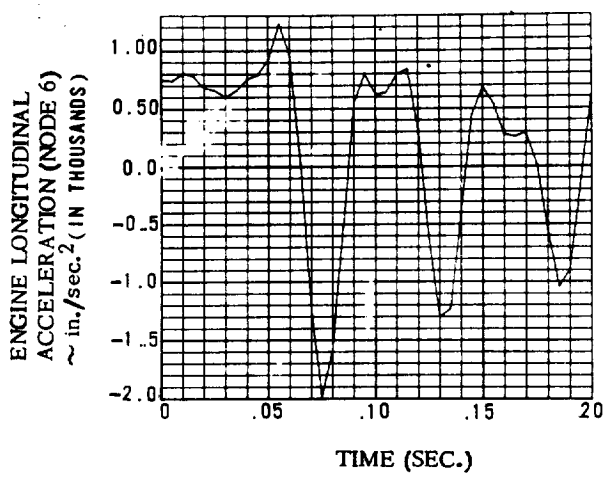


Figure 9-16

Longitudinal Response Time-Histories of Kick Stage Masses (Mathematical Model No. 38) During Centaur 2nd Main Engine Cutoff

In the Centaur thrust cutoff analyses, conditions exist where tanked propellants attain negative accelerations. This is indicative of the propellants no longer remaining at the bottom of the tank. In reality, this could represent a situation where the propellants shatter into large or small pieces that tend to remain in suspension or impact against the forward bulkhead. In the analyses herein the propellants are constrained to the tanks, and the math models used do not account for this phenomenon. Therefore, for cases of negative propellant accelerations the math models are somewhat inaccurate, but the errors introduced are considered to add conservatism (the analytical loads are considered to be equal to or higher than reality).

9.4.2 MAXIMUM LATERAL ACCELERATIONS. Maximum lateral responses of all Kick Stage masses due to unsymmetric loading at Centaur second MES and second MECO are summarized in Table 9-3. The maximum loads derived are relatively small, with Centaur second MECO yielding the greater responses for all masses.

It should be understood that these maximum lateral loads are not concurrent with the maximum longitudinal loads of the previous Section 9.4.1. However, it is difficult to estimate what portion of these lateral loads is realistically associated with the maximum longitudinal loads. Therefore, since these lateral loads are small, it would create no great loss of efficiency (or weight increase) to employ them in conjunction with the maximum longitudinal loads for design purposes.

Figures 9-17 to 9-20, and 9-21 to 9-24 show time history lateral responses at Centaur second MES and second MECO respectively, for four Kick Stage masses.

9.4.3 TRUSS LOADS. Maximum axial truss loads are presented in Table 9-2. (Positive axial loads represent compression.) The maximum axial loads occur with the 3000-pound payload on the two-ring configuration of Kick Stage. Truss compression load is maximum during Centaur second MES and the maximum tension load was attained at Centaur first MECO.

Since Kick Stage masses do not exhibit similar response time histories for the analyses in this section, the peak truss load is dependent on a combination of load and phase relationships of the mass responses. The maximum truss load does not necessarily occur at the time of peak response of the payload. (The payload is the largest mass above the truss.)

Loads, as presented in this section and Tables 9-2 and 9-3, are incomplete for design use. These loads are to be combined with each other and employed as described in Section 2. In addition, environmental loads are to be added in the manner prescribed in Section 2. Total design load factors to be used are summarized in Table 2-1.

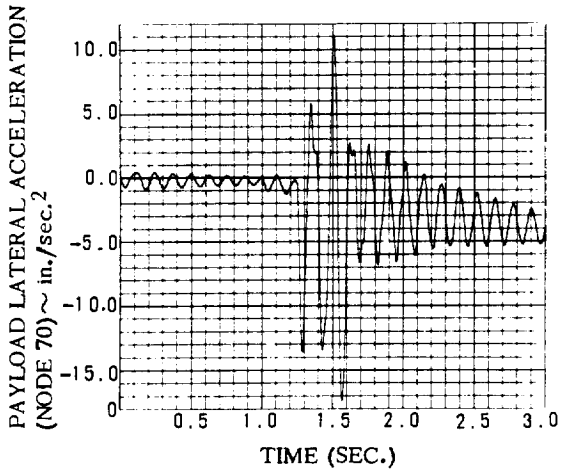


Figure 9-17

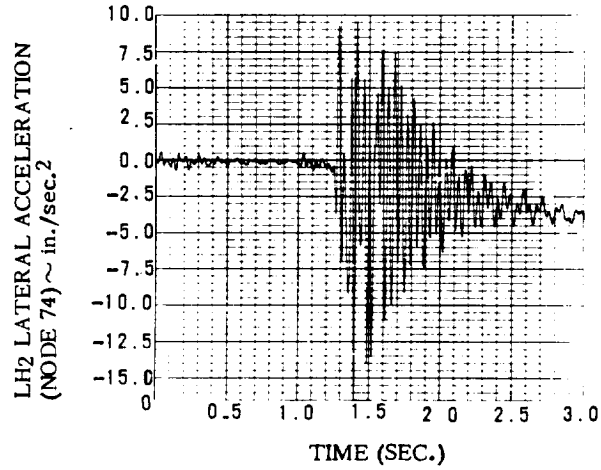


Figure 9-18

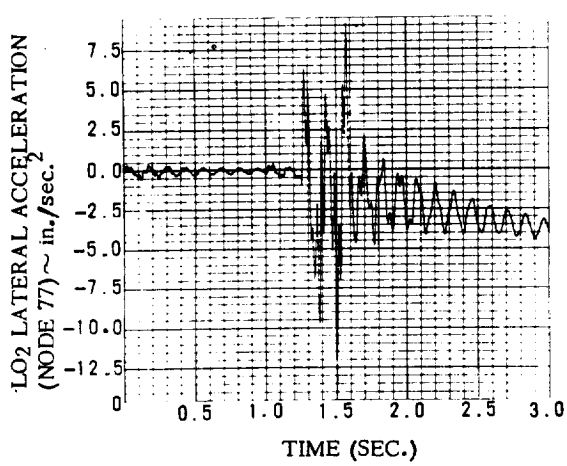


Figure 9-19

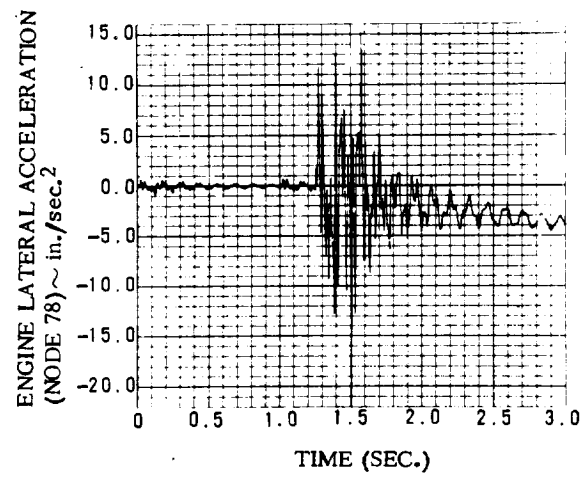


Figure 9-20

Lateral Response Time-Histories of Kick Stage Masses (Mathematical Model No. 35) During Centaur 2nd Main Engine Start

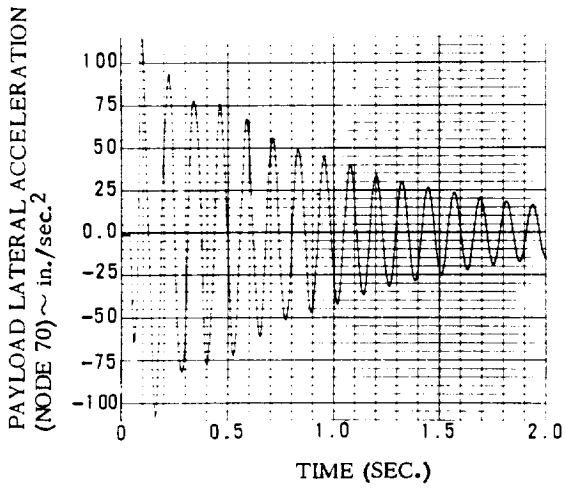


Figure 9-21

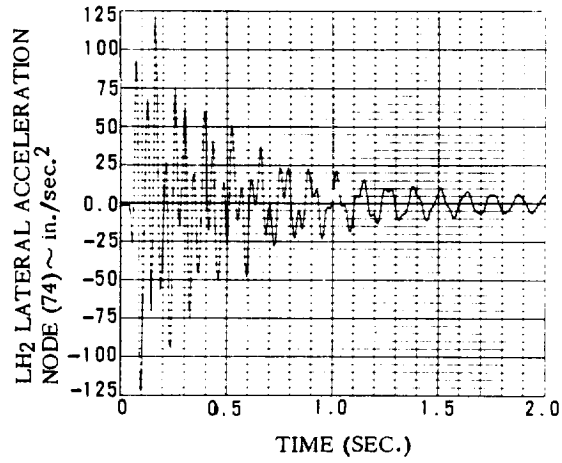


Figure 9-22

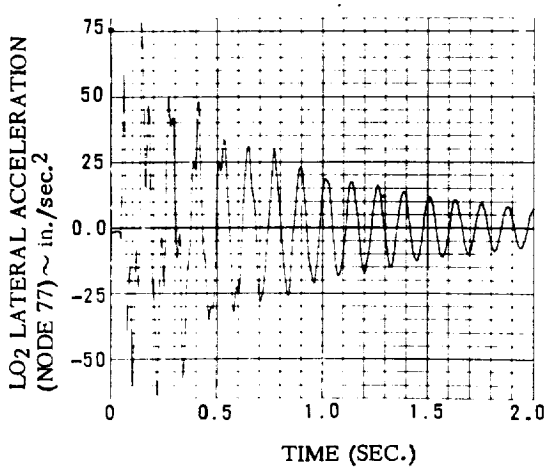


Figure 9-23

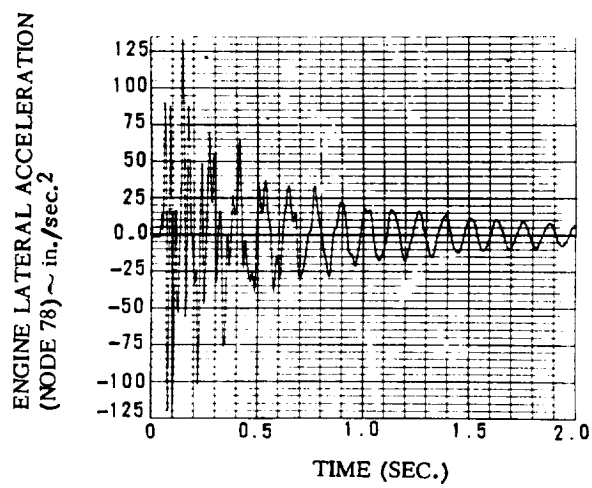


Figure 9-24

Lateral Response Time-Histories of Kick Stage Masses (Mathematical Model No. 39) During Centaur 2nd Main Engine Cutoff

TABLE 9-3. MAXIMUM LATERAL RESPONSES DURING CENTAUR MAIN ENGINE START AND CUTOFF

Flight Phase	Math Model No.	Maximum Response of Masses (g's)								Truss Loads	
		Type of Response	Payload	Payload Ring	Forward Ring	Hydrogen	LO_2	Engine	Aft Ring	Bending Moment 10^6 in.-lb	Shear 10^3 lbs.
Centaur Second Main Engine Start	35	Static	0	0	0	0	0	0	0	0	0
		Dynamic	±0.05	±0.05	±0.04	±0.04	±0.04	±0.06	±0.04	±0.03	±0.16
Centaur Second Main Engine Cutoff	39	Static	0	0	0	0	0	0	0	0	0
		Dynamic	±0.30	±0.36	±0.32	±0.32	±0.20	±0.35	±0.20	±0.16	±1.02

10

KICK STAGE MAIN ENGINE START AND CUTOFF

10.1 MATHEMATICAL MODELS

Originally, it was planned to determine loads for only five Kick Stage Main Engine Start (MES) and Main Engine Cutoff (MECO) conditions. Because of the relatively great loads developed and their possible importance, it was decided to expand these to 10 conditions shown in Table 10-1.

TABLE 10-1. TEN CONDITIONS INVESTIGATED

Load	Mathematical Models	Kick Stage Case	Payload Weight	Rings
MES 1	42	1	3,000	2
MES 1	43	4	300	2
MES 1	44	7	3,000	3
MECO 1	45	1	3,000	2
MECO 1	45A	4	300	2
MES 2	45	1	3,000	2
MECO 2	46	1	3,000	2
MECO 2	46A	4	300	2
MECO 2	46B	4 MOD.*	300	2
MECO 2	46C	1 MOD.**	3,000	2

NOTES:
*Modified to stiffen payload, payload primitive frequency = 60 cps
**Modified to include beryllium-aluminum cruciform beam

As per the format of this study, the spring and mass parameters are shown in Section 3, and the corresponding modes in Section 4. Special attention should be focused on the response of the engine and Liquid Oxygen (LO_2) mass which is largely caused by the flexibility of the cruciform beam.

10.2 THRUST TRANSIENTS

The RL10A3-3 thrust buildup and thrust decay curves are shown in Figures 10-1 and 10-2. These curves are taken from Pratt and Whitney specifications (see Reference 9-1).

10-3. METHOD OF SOLUTION

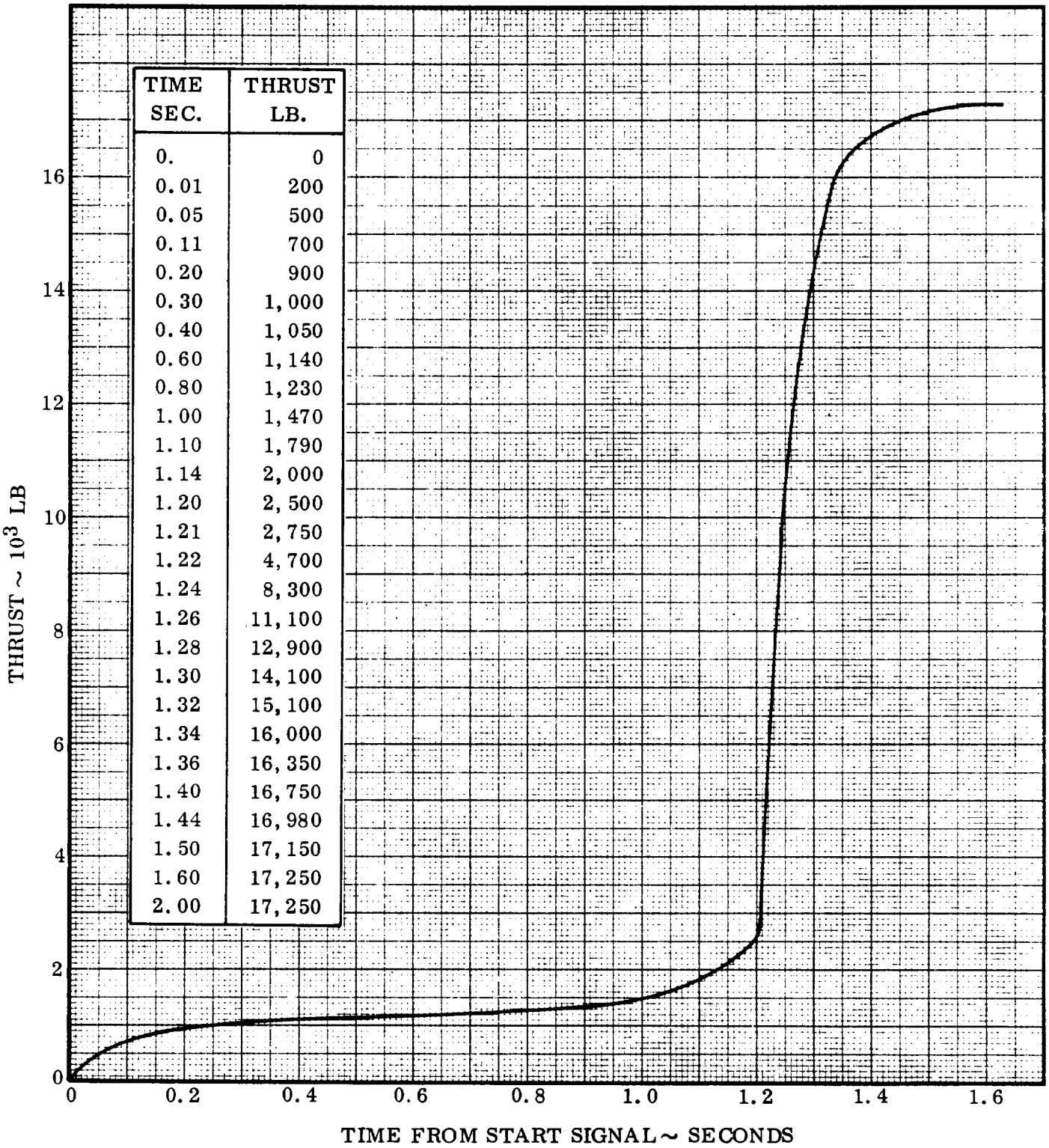
The method of solution for these Kick Stage MES and MECO transients is very similar to the longitudinal part of the Centaur transients discussed in Section 9. It is not necessary, of course, for the engines to gimbal due to thrust unbalance so that the Kick Stage solution is simpler for that reason. The computer program used is discussed in detail in Reference 5-3.

10.4 RESULTS

Table 10-2 is a summary of the longitudinal response due to Kick Stage thrust transients. The various Mathematical Models (MM) are as described earlier with the 46B model having the stiffened payload and the 46C model having the beryllium-aluminum cruciform beam. The static accelerations of each mass have two valves to show the initial and final nominal values. The "Dyn +" load is the transient forward acceleration or the static acceleration due to high (within specification) thrust, in excess of the maximum nominal acceleration, whichever is greater. The "Dyn -" load is the minimum (maximum negative) acceleration. The load factors that result in the greatest loads (load factor times weight) are underlined. Some loads during MECOs are maximum prior to the thrust decay. These are marked with a superscript "S" (for static).

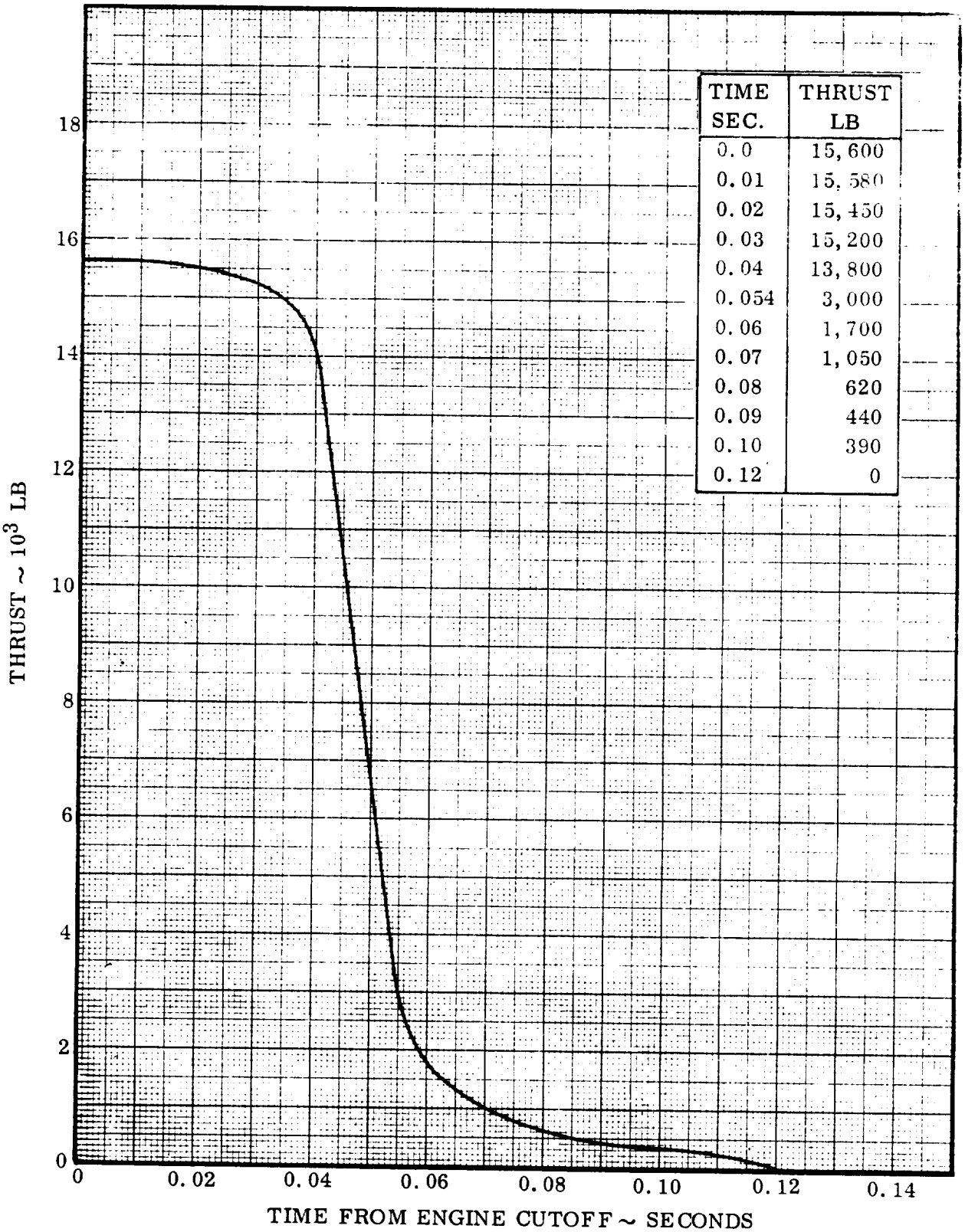
Four figures have been included to show a typical acceleration response during a MES. These are Figures 10-3, 10-4, 10-5, and 10-6 which show the response of the payload, Liquid Hydrogen (LH_2) mass, LO_2 mass and engine, respectively for MM42 and are typical of other MES's. Figures 10-7, 10-8, 10-9, and 10-10 show various response during MECO's.

The maximum payload forward acceleration can be seen to occur just prior to Kick Stage MECO number 2 (KMECO2) as shown in Table 10-2, MM46, and also Figure 10-9. This figure is typical of many responses where the steady thrust load prior to MECO is more critical than the transient following. The maximum negative load on the payload occurred at KMECO1 with MM45 (see Figure 10-7).



TIME SEC.	THRUST LB.
0.	0
0.01	200
0.05	500
0.11	700
0.20	900
0.30	1,000
0.40	1,050
0.60	1,140
0.80	1,230
1.00	1,470
1.10	1,790
1.14	2,000
1.20	2,500
1.21	2,750
1.22	4,700
1.24	8,300
1.26	11,100
1.28	12,900
1.30	14,100
1.32	15,100
1.34	16,000
1.36	16,350
1.40	16,750
1.44	16,980
1.50	17,150
1.60	17,250
2.00	17,250

Figure 10-1. Single RL10A-3-3 Engine Thrust Buildup Specification



TIME SEC.	THRUST LB
0.0	15,600
0.01	15,580
0.02	15,450
0.03	15,200
0.04	13,800
0.054	3,000
0.06	1,700
0.07	1,050
0.08	620
0.09	440
0.10	390
0.12	0

Figure 10-2. Single RL10A-3-3 Engine Maximum Thrust Decay

TABLE 10-2. KICK STAGE LONGITUDINAL RESPONSE FOR THRUST TRANSIENTS

Condition MM Kick Stage Case	Type Load	Payload G's	Payload Ring G's	Forward Ring G's	LH_2 G's	LO_2 G's	Engine G's	Aft Ring G's	Axial Load on Truss 10^3 lb
KMES1	Static	0+1.27	0+1.27	0+1.27	0+1.27	0+1.27	0+1.27	0+1.27	0+6.35
42	Dyn+	+0.41	+0.36	+0.34	+0.39	+0.30	+0.54	+0.28	+1.49
1	Dyn-	-0	-0	-0	-0.11	-0	-0	-0.11	-0
KMES1	Static	0+1.65	0+1.65	0+1.65	0+1.65	0+1.65	0+1.65	0+1.65	0+3.80
43	Dyn+	+1.15	+0.47	+0.42	+0.53	+0.29	+0.63	+0.36	+1.21
4	Dyn-	-0.07	-0.05	-0	-0.05	-0	-0.37	-0	-0.10
KMES1	Static	0+1.27	0+1.27	0+1.27	0+1.27	0+1.27	0+1.27	0+1.27	0+6.35
44	Dyn+	+0.67	+0.51	+0.51	+0.62	+0.42	+1.22	+0.35	+2.29
7	Dyn-	-0	-0	-0.04	-0.10	-0	-0.32	-0	-0
KMECO1	Static	2.10+0	2.10+0	2.10+0	2.10+0	2.10+0	2.10+0	2.10+0	8.86+0
45	Dyn+	+0.29	+0.37	+1.43	+1.71	+0.55	+3.91	+1.47	$+0.36^S$
1	Dyn-	-3.30	-1.65	-2.79	-3.03	-2.31	-7.86	-2.49	-6.37
KMECO1	Static	3.38+0	3.38+0	3.38+0	3.38+0	3.38+0	3.38+0	3.38+0	5.14+0
45A	Dyn+	+5.14	+0.46	+0.42	+0.74	$+0.13^S$	+4.32	+0.31	+0.41
4	Dyn-	-7.49	-4.15	-3.35	-3.69	-1.17	-6.10	-2.49	-4.45
KMES2	Static	0+2.10	0+2.10	0+2.10	0+2.10	0+2.10	0+2.10	0+2.10	0+8.86
45	Dyn+	+0.55	+0.46	+0.48	+0.53	+0.57	0+.59	+0.56	+1.85
1	Dyn-	-0	-0	-0	-0	-0	-0.05	-0	-0
KMECO2	Static	3.13+0	3.13+0	3.13+0	3.13+0	3.13+0	3.13+0	3.13+0	11.99+0
46	Dyn+	$+0.13^S$	$+0.13^S$	+2.13	+2.38	+4.13	+7.18	+2.96	$+0.50^S$
1	Dyn-	-3.18	-1.85	-3.56	-3.67	-5.57	-12.38	-4.07	-6.28

TABLE 10-2. KICK STAGE LONGITUDINAL RESPONSE FOR THRUST TRANSIENTS (CONTINUED)

Condition MM Kick Stage Case	Type Load	Payload G's	Payload Ring G's	Forward Ring G's	LH_2 G's	LO_2 G's	Engine G's	Aft Ring G's	Axial Load on Truss 10^3 lb
KMECO2	Static	7.18+0	7.18+0	7.18+0	7.18+0	7.18+0	7.18+0	7.18+0	8.12+0
46A	Dyn+	+2.81	$\underline{+0.28^S}$	$\underline{+0.28^S}$	$+0.28^S$	$+0.28^S$	+3.48	$\underline{+0.28^S}$	$+0.36^S$
4	Dyn-	-8.97	$\underline{-4.15}$	$\underline{-3.87}$	-3.93	-2.02	-8.31	-3.43	-3.48
KMECO2	Static	7.18+0	7.18+0	7.18+0	7.18+0	7.18+0	7.18+0	7.18+0	8.12+0
46B	Dyn+	$+0.28^S$	$\underline{+0.28^S}$	$\underline{+0.28^S}$	$+0.28^S$	$+0.28^S$	$\underline{+4.63}$	$\underline{+0.28^S}$	$+0.33^S$
4 MOD	Dyn-	-5.47	-3.81	-1.85	-1.94	-2.25	-10.02	-1.16	-3.78
KMECO2	Static	3.13+0	3.13+0	3.13+0	3.13+0	3.13+0	3.13+0	3.13+0	11.99+0
46C	Dyn+	$\underline{+0.13^S}$	$+0.13^S$	+1.54	+1.53	+1.88	+2.79	+1.96	$\underline{+0.50^S}$
1 MOD	Dyn-	-2.12	-1.85	-3.54	-3.82	-4.33	-6.56	-3.79	-3.18

NOTES:

1. S means that this load is essentially the static axial load prior to cutoff.
2. Underlined values show maximum forces.

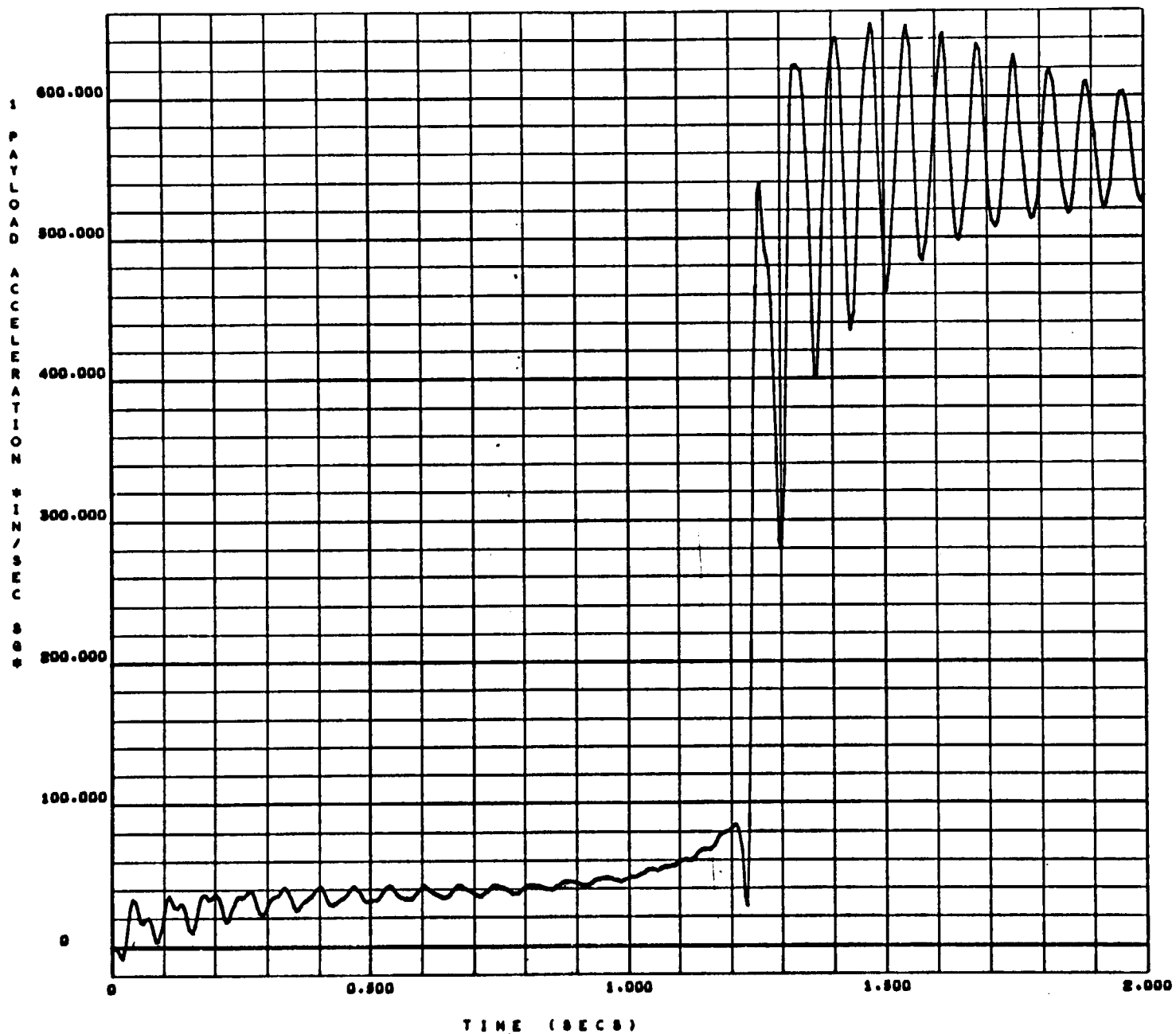


Figure 10-3. Payload Response During Kick Stage 1st Main Engine Start (Model = 42)

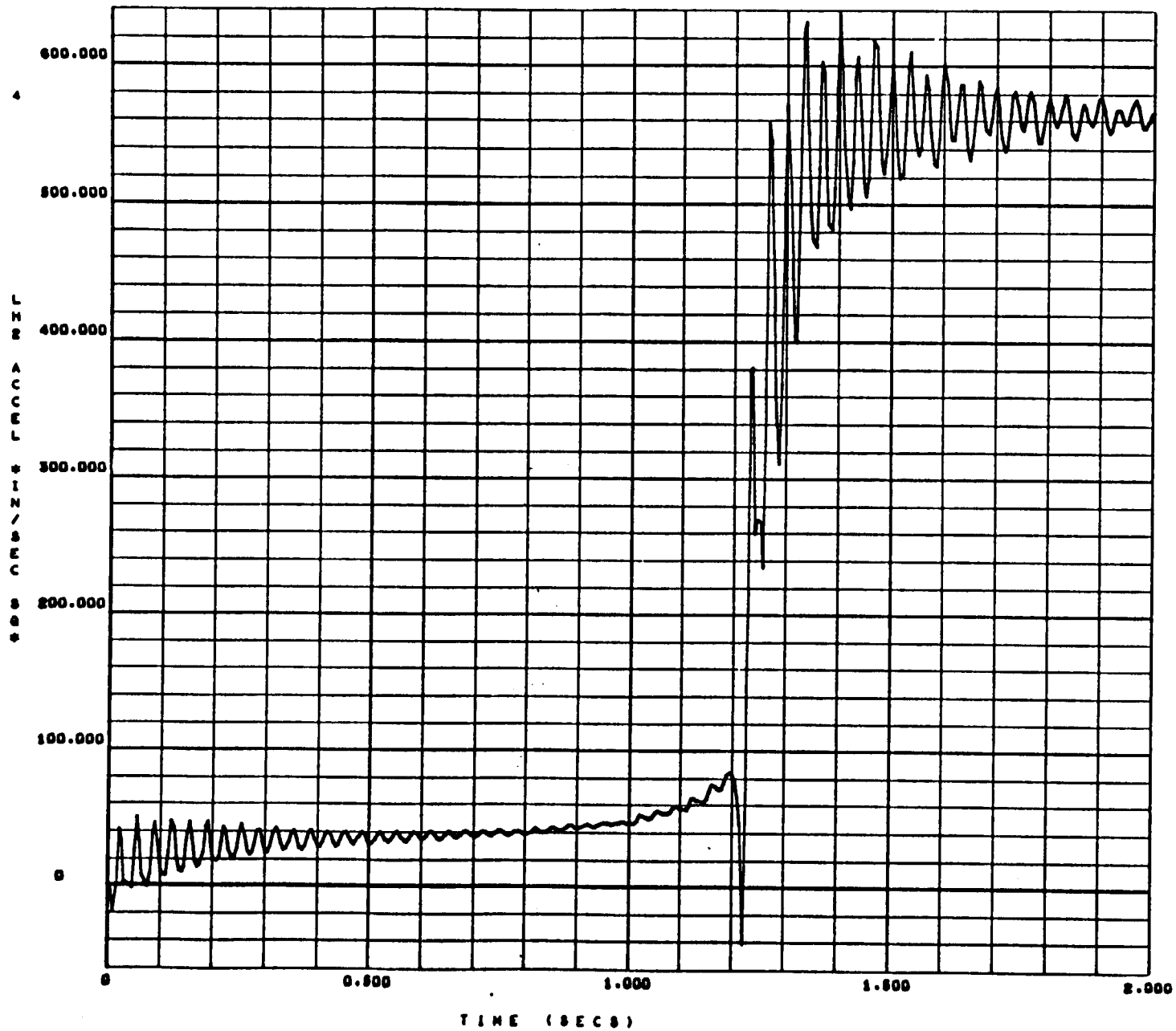


Figure 10-4. LH_2 Mass Response During Kick Stage 1st MES (Model = 42)

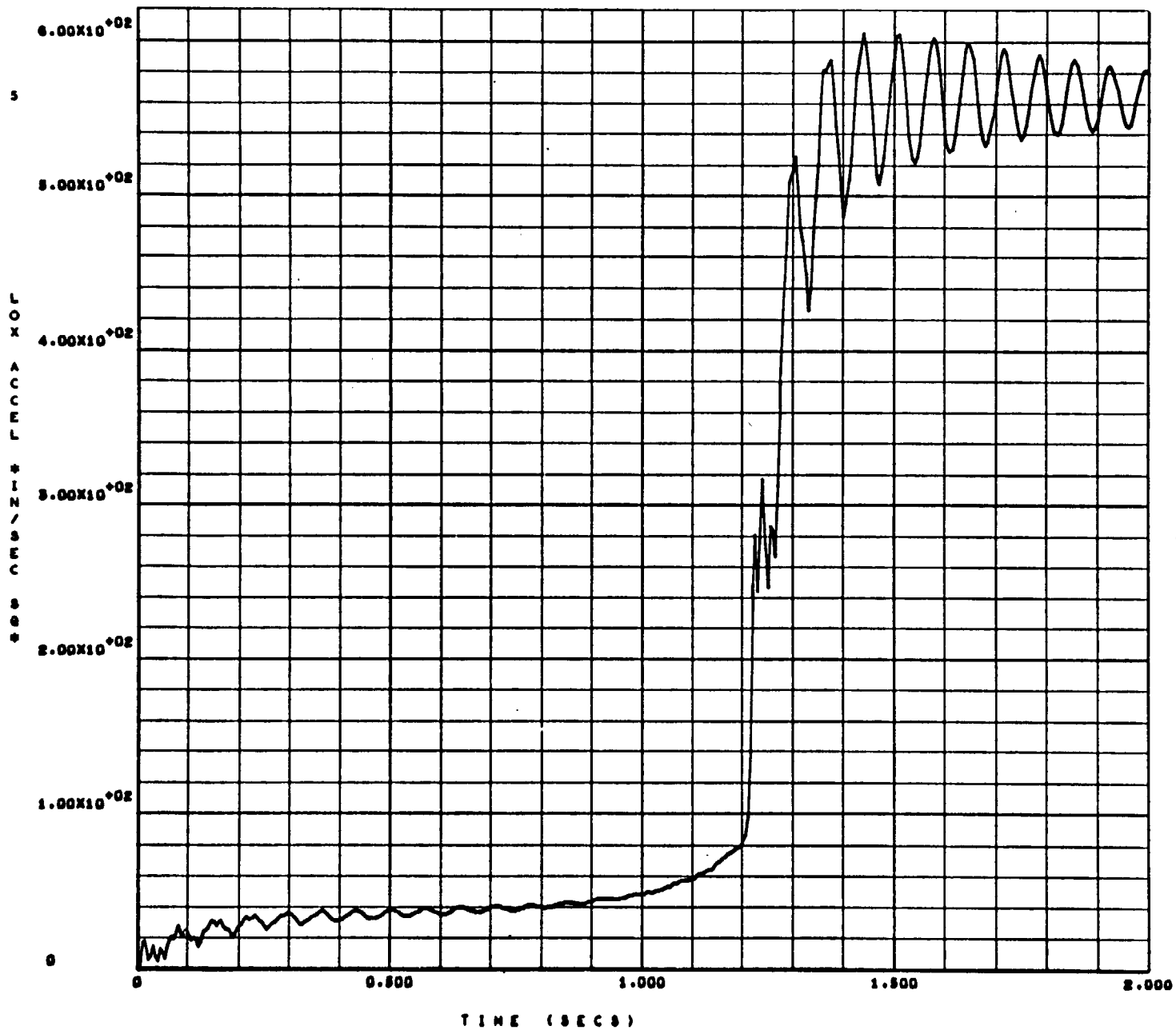


Figure 10-5. LO_2 Mass Response During Kick Stage 1st MES (Model = 42)

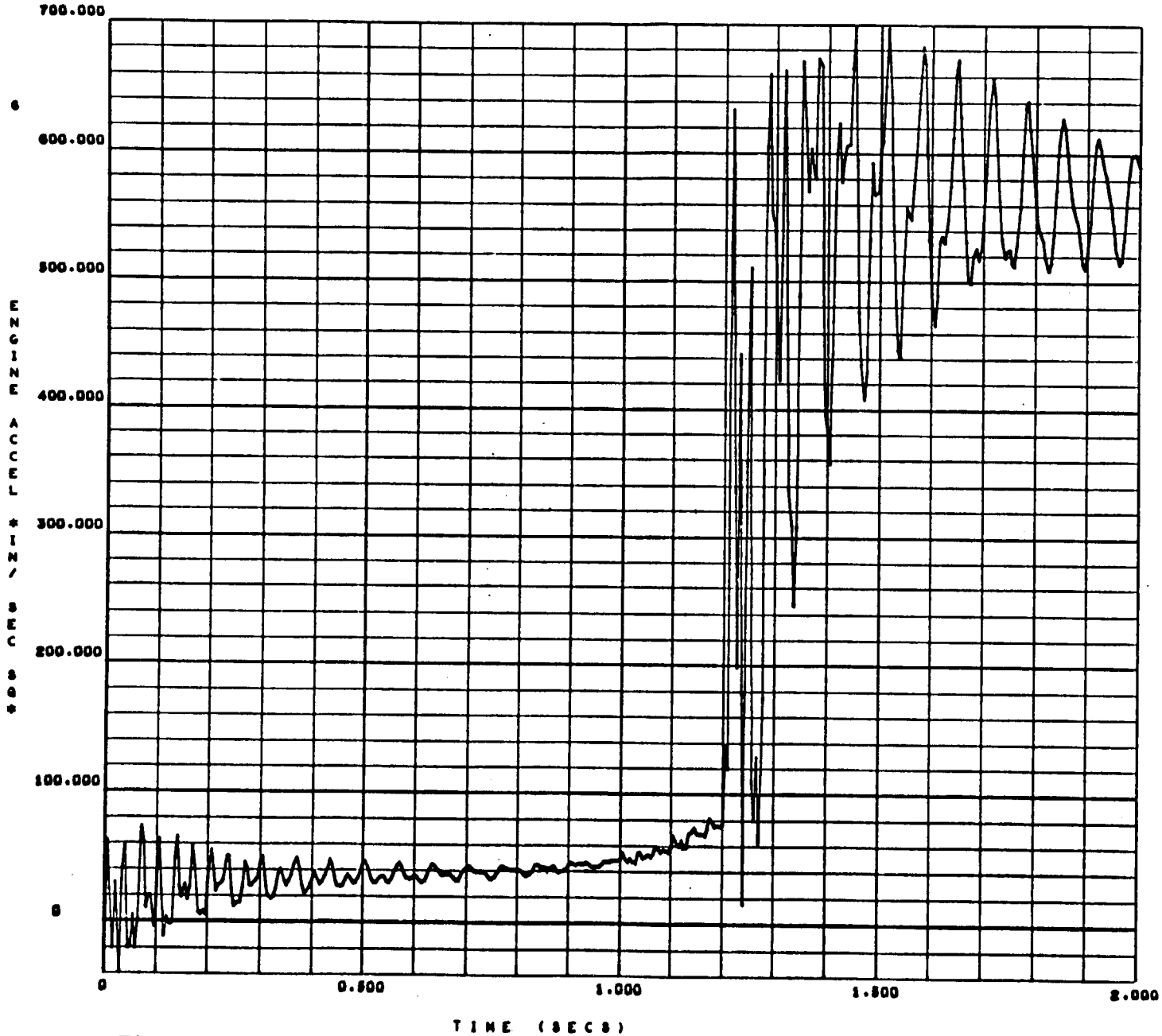


Figure 10-6. Engine Response During Kick Stage 1st MES (Model = 42)

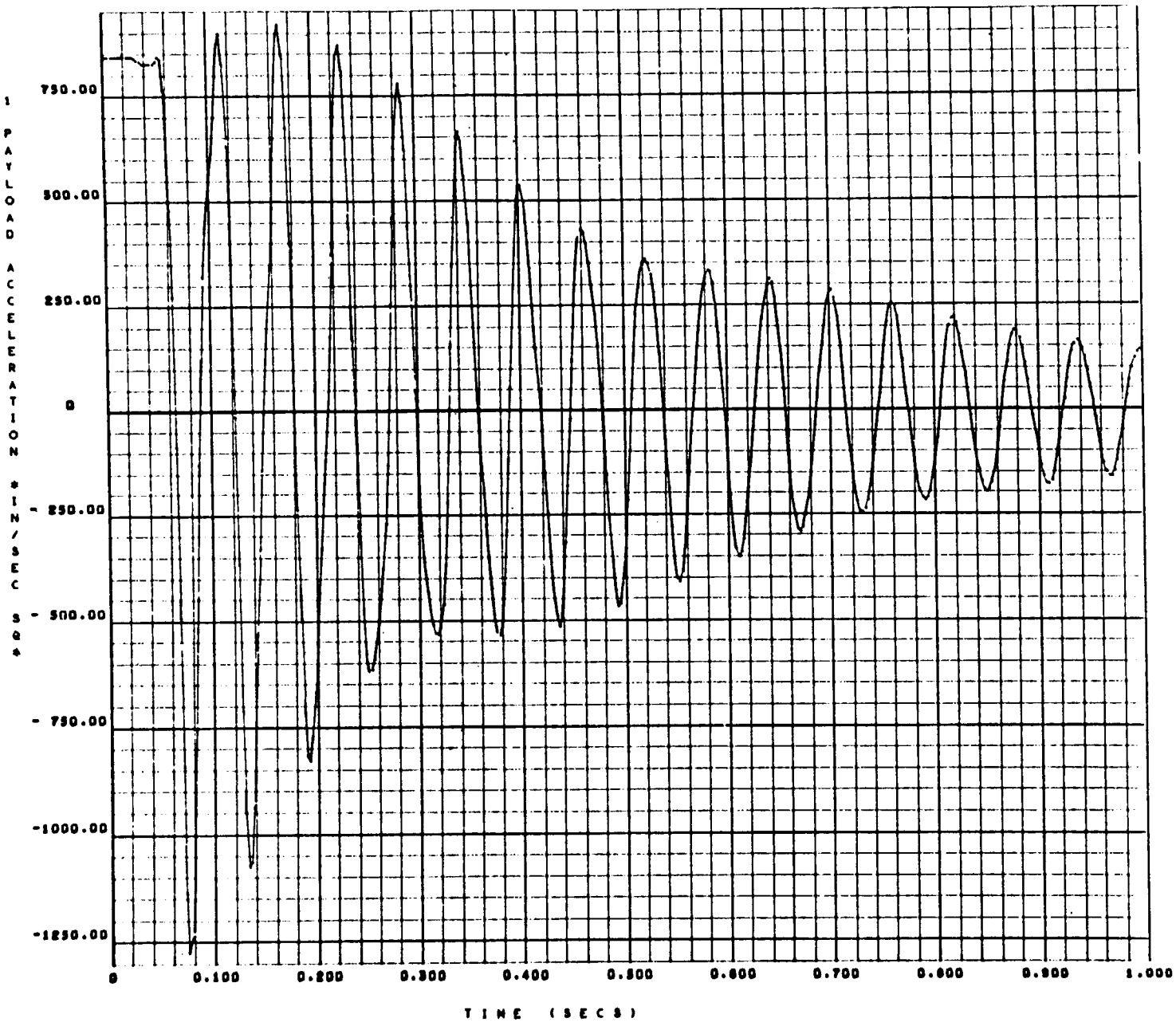


Figure 10-7. Payload Response During Kick Stage 1st MECO (Math Model 45)

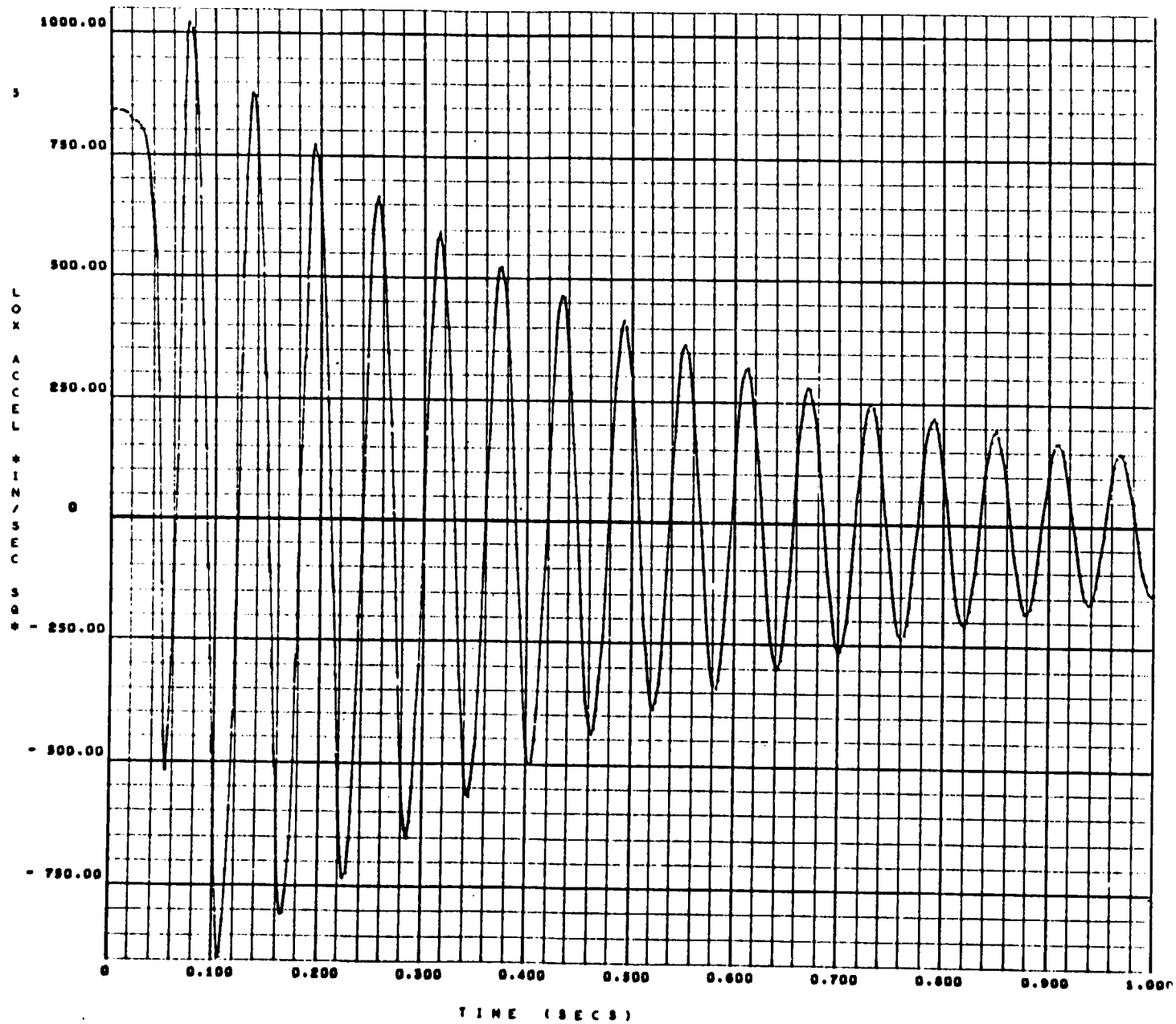


Figure 10-8. LO_2 Response During Kick Stage 1st MECO (Math Model 45)

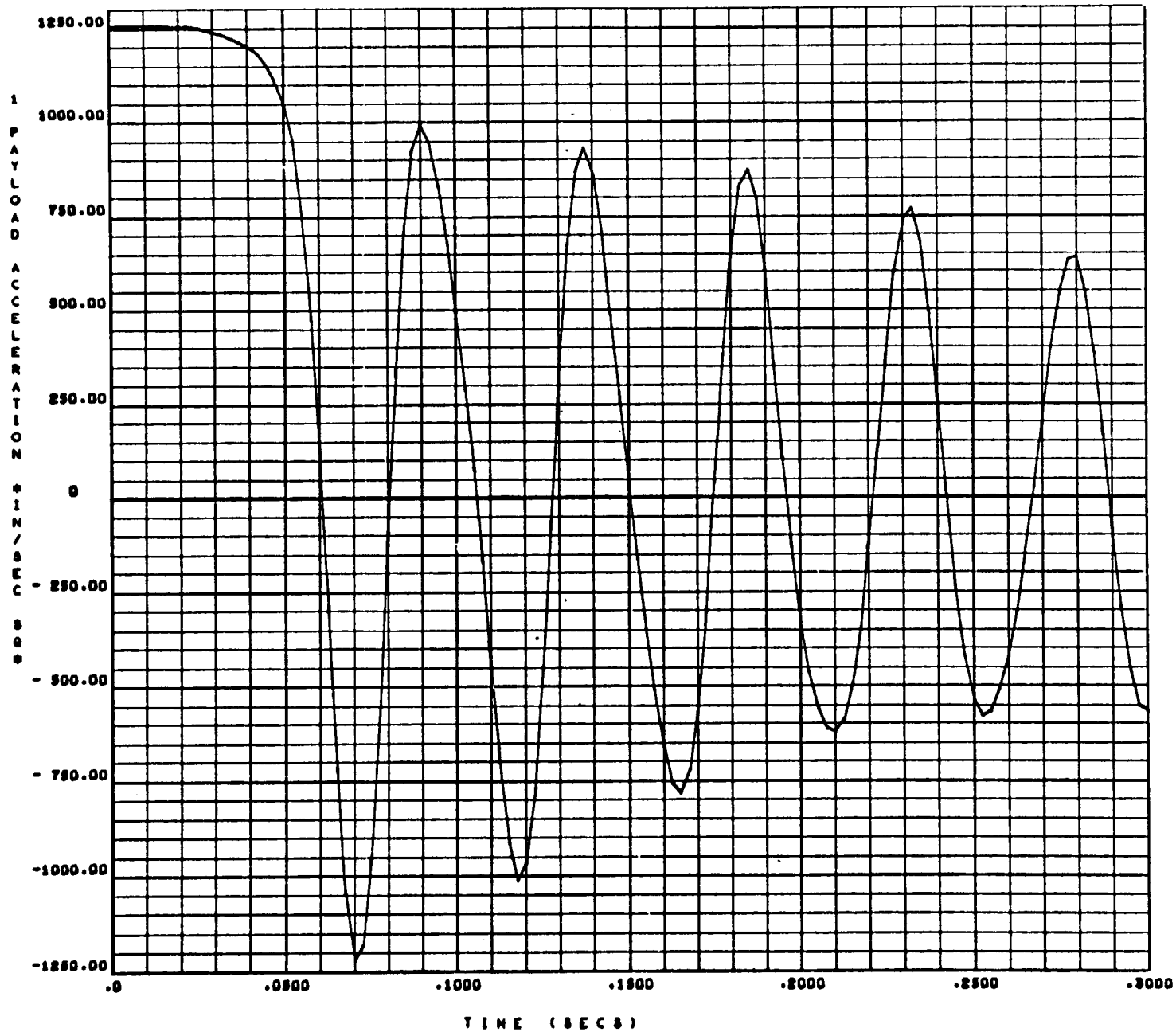


Figure 10-9. Payload Response During Kick Stage 2nd MECO (Model = 46)

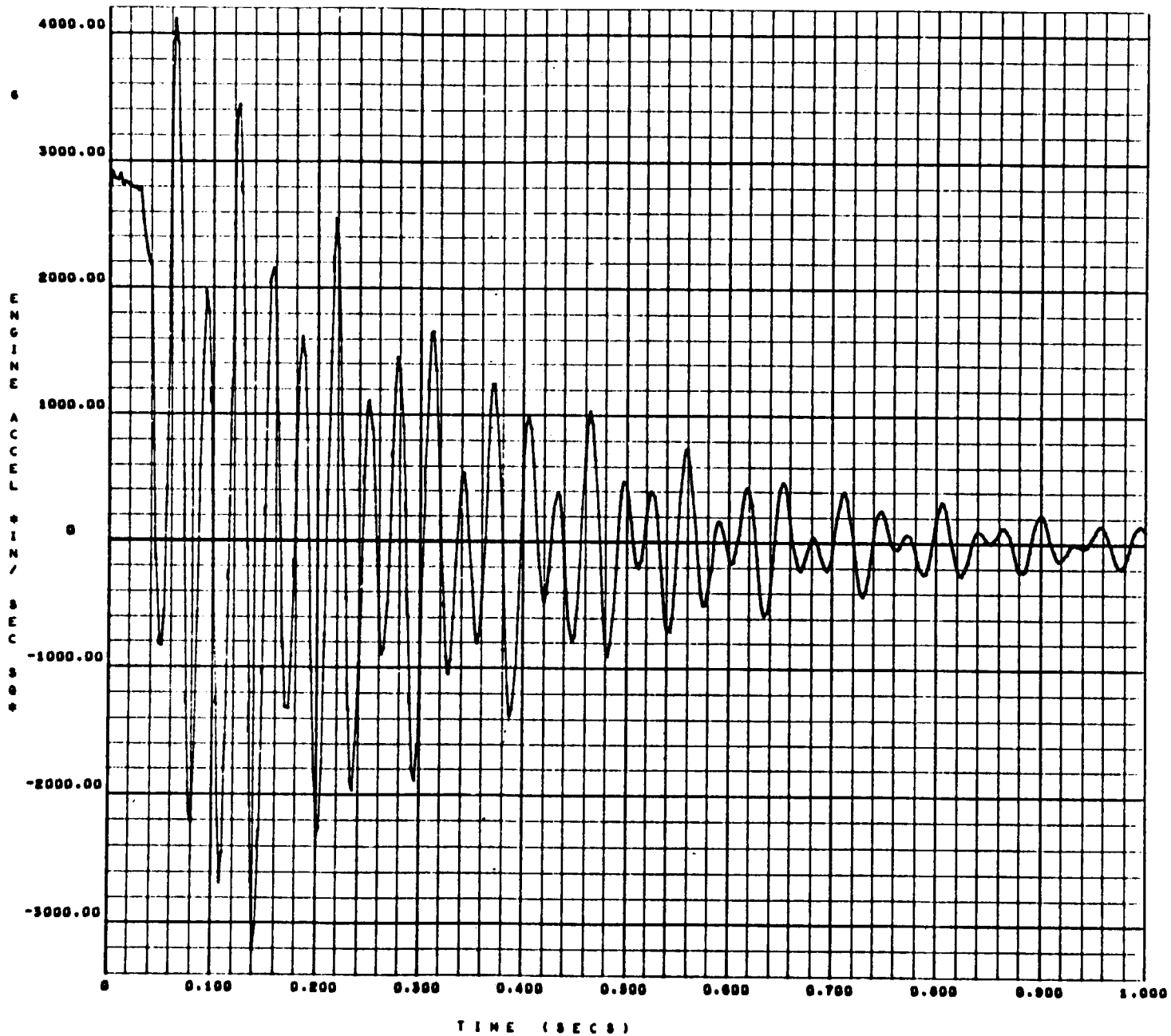


Figure 10-10. Engine Response During Kick Stage 2nd MECO (Math Model 46A)

The maximum forward loads on both propellant tanks occurred at KMES1, MM43. It seems obvious that the greater mass of liquid at first start combined with the smaller payload weight (to give a larger static acceleration) has caused this situation. These responses are very similar, except for magnitudes, to Figures 10-4 and 10-5. The maximum negative response of the propellants was indicated for KMECO1 for the LO_2 mass. It should be noted that the linear model used in the analysis does not make allowance for the possible separation of the liquid when under negative (reversed) acceleration. It seems quite possible that these negative loads may be smaller than shown in Table 10-2. The maximum negative acceleration of the LO_2 mass is shown in Figure 10-8. The response of the LH_2 mass under the worst negative acceleration is quite similar to that figure.

Another problem related to liquid acceleration is shown in Figure 10-4 where it can be seen that a short duration negative acceleration spike exists at a time of 1.22 seconds in the MES. This type of response might cause irregular or out of specification performance of the engine. In Figure 10-5 it may be seen that the LO_2 mass is free of such problems.

The engine response at KMECO2 is the most severe of the various conditions analyzed. Figure 10-10 shows the engine acceleration versus time for MM46A (300 pound payload) and is typical of all these KMECO2 responses except for amplitude. The tension capabilities of the engine gimbal must, of course, be able to support the forward acceleration loads of the engine mass (less thrust, if any). These loads are in the order of 10 to 11 g's for MM46 and MM46A. It was noted that the use of the beryllium-aluminum cruciform beam in MM46C reduced these loads to almost half. It is recommended that the use of the stiff beam be considered as a means of reducing dynamic response and saving weight.

The negative acceleration of the engine mass will produce compression in the gimbal, but is not considered critical since the gimbal must be designed to the maximum thrust (as well as actuator loads and propellant line loads). During the MECO transient, the loss of thrust is greater than the vibratory engine load.

The right hand column of Table 10-2 shows the axial load at the base of the truss (near the aft ring). It may be noted that these loads follow the pattern of loads on the payload mass and are maximum for the same conditions. The load in each strut is not the same for these truss loads due to the flexibility of the aft ring. Plus loads are compression while negative loads are tension.

The lateral response of the Kick Stage was considered briefly and some "best guess" values were estimated to help complete the load summary in Section 2. These values are shown in Table 10-3.

TABLE 10-3. "BEST GUESS" LATERAL RESPONSE ESTIMATES FOR KICK STAGE MES AND MECO

	Lateral Acceleration (All Masses) G's	Truss Bending Moment 10^6 in.-lb	Truss Shear 10^3 lb
MES	± 0.1	± 0.05	± 0.33
MECO	± 0.15	± 0.01	± 0.08

With respect to the 3-ring design which has only been analyzed once in MM44, it may be noted that all dynamic responses are larger than the corresponding 2-ring design (MM42). In addition, the detrimental effect of the softer cruciform beam in MM46 as compared to the stiff beam in MM46C reinforces the conclusion that the softer 3-ring design is not optimum.

11

ENVIRONMENTAL VIBRATION

Environmental vibration load factors are well recognized as important in the design of smaller components such as 20-pound electronics packages. It has also been established that for larger items such as an entire Mercury Capsule (Reference 11-1) smaller random environmental load factors exist. It is the purpose of this section to account for these loads.

11-1 VARIATION WITH TIME

Environmental vibration is usually high at the time of launch due to ground reflected noise. After a few seconds of flight the vibration drops off to about a quarter of its value only to rise again during the Mach 1 - Max q period. This second maximum is generally about the same in magnitude as launch, but in some specific cases may be more or less. After Max q the levels fall again and are generally less than half at Maximum Booster Acceleration (MBA) just prior to Booster Engine Cut-Off. During the Sustainer phase of the Atlas flight, environmental levels continue to be low in general. The only exceptions are the BECO and SECO transients when the Atlas engines are cut off. These transients sometimes produce significant torsional response of the upper stages at 60 to 100 cps, but have not been considered to be a designing condition except for small components.

During firing of the Centaur second stage, environmental levels in the payload area are somewhat lower than they were at launch or Max q. However, they are considered to be approximately the same for conservatism.

Kick Stage firing is expected to produce approximately 80 percent of the Centaur stage levels, based on the cube-root of the thrust ratio.

11-2 ENVIRONMENTAL LOAD FACTORS

The magnitudes of these loads were based largely upon empirical data and experience gathered from past flights of Atlas and Atlas/Centaur vehicles. They are intended to include the general effects of aerodynamic buffet, acoustics and engine transmitted mechanical vibration at higher frequencies.

Table 11-1 presents the recommended environmental loads. These load factors are considered to be random and uncorrelated with other specific loads such as those resulting from Atlas thrust buildup. It should be noted that the loads in the table are the same for Centaur firing as for launch except for the models where the forward ring is connected to the nose fairing. In this case, it is recommended that environmental

TABLE 11-1. KICK STAGE ENVIRONMENTAL LOAD FACTORS - GRAVITIES

	Wt./lb.	Atlas TBU Launch Mach 1/Max q	Maximum Booster Acceleration	Centaur Firing	Kick Stage Firing
Payload	300	2.32	1.16	2.32	1.84
	3000	.74	.37	.74	.58
P/L Ring	436	1.93	.96	1.93	1.52
Forward Ring	174	3.1[2]	1.53	3.1	2.4
LH_2	1390	1.08	.54	1.08	.85
	610	x[1]	x	x	1.29
	220	x	x	x	2.1
LO_2[4]	6130	1.03/.51	.51/.26	1.03/.51	.81/.41
	2250	x	x	x	1.34/.67
	290	x	x	x	3.7/1.87
Aft Ring	290	2.4	1.18	2.4	1.87
Engine	380	2.1	1.03	2.1	3.0[3]

1 This is not a normal design condition.

2 Should be increased 2 g's when connected to nose fairing for models 32 and 33.

3 Engine vibration while operating is a difficult problem. The 3 g's recommended here seems conservative based on Centaur data. Additional static firing data for Kick Stage should be obtained to refine this number.

4 The larger values are for individual bottles, smaller values are for the group of bottles as a whole.

levels be increased to 5.1 g's on the forward ring to account for more direct transmission of vibration to this structure. The exact mechanism to be used for this connection should be evaluated when more details are available and this number revised accordingly.

The table presents two numbers for the LO_2 mass vibration, where the larger is for use with the structure of each bottle alone and the smaller is for use with the entire cluster of four bottles as a whole.

Methods used to derive these load factors involve the use of mass attentuation inversely proportional to the square root of the mass. The magnitudes were evaluated high enough to include 50 percent more than the maximum expected environment in operation for conservatism. These load factors are believed to be uncorrelated with each other (random) so that they can be added by means of "Root Sum Squaring" (RSS).

This method differs from that used a few years ago for the design of the support structure for Surveyor in that earlier the various partial loads were added while in this method the various loads are RSS'ed if they are random and uncorrelated. Steady-state loads are correlated and must be added as before.

11-3 ENVIRONMENTAL TRUSS LOADS

During the flight of AC-2 it was determined that approximately 0.16 million in.-lb (zero-to-peak) bending moment was indicated by strain gages in the Atlas/Centaur adapter due only to high frequency environmental loads (Reference 11-2). In a similar manner 0.2 million in.-lb was recorded on the second Mercury-Atlas flight (Reference 11-1). Treating this data empirically and assuming that the difference between an aerodynamically loaded payload and a shrouded one is a factor of three, it seemed that both of these vehicles if shrouded by a nose fairing would see an environmental bending moment of 0.05×10^6 in.-lb or a little more. The point of interest is that these loads are similar in spite of the fact that there is a weight ratio of 10 to 1. The factor of three above seems to be reasonable, based on comparisons of Surveyor responses inside a nose fairing and Mercury data.

The 0.05×10^6 in.-lb load was doubled to allow for some random variations from vehicle to vehicle and further increased by a factor of 1.5 to add conservatism. The resulting 0.15×10^6 in.-lb was used as a limit for the truss bending moments shown in Table 11-2. The shear and axial loads shown in that table are based on RSS totals of the environmental load factors shown in Table 11-1 except for the case where the forward ring is tied to the nose fairing. In this case, the nose fairing was assumed to support the Kick Stage and reduce the lateral loads to approximately one-third.

In the case of MBA, the truss loads were cut in half in accordance with the general trend mentioned earlier. The truss bending moments during Centaur and Kick Stage firing were taken proportional to the shear loads for those cases where the shear

TABLE 11-2. KICK STAGE ENVIRONMENTAL TRUSS LOADS AND LOSS OF CLEARANCE

Payload Weight		Time*							Forward Ring tied to Nose Fairing		Loads at Truss Base			Loss of Clearance (inches)	
300 lb.	3000 lb.	Launch	Max q	MBA	Centaur Fire	K.S. MES 1	K.S. MES 2	K.S. MECO2	No	Yes	Bend. Mom. 10^6 (in.lb.)	Shear lb.	Axial Load lb.	Payload to Nose Fairing	Forward Ring to Nose Fairing
	X	X							X		.15	2850	2850	.04	.02
X		X							X		.15	1930	1930	.11	.02
	X	X								X	.05	1000	2850	.04	0
	X		X						X		.15	2850	2850	.23	.22
X			X						X		.15	1930	1930	.25	.22
	X		X							X	.05	1000	2850	.23	0
X	X			X					X		.08	1425	1425	.06	.01
	X				X				Nose Fairing Jettison		.15	2850	2850	Nose Fairing Jettison	
X					X						.15	1930	1930		
	X					X					.15	2250	2250		
X						X					.13	1530	1530		
	X						X				.15	2220	2220		
X							X				.11	1240	1240		
	X							X			.13	1458	1458		
X								X			.09	1062	1062		

*The time shown as Launch also includes Atlas Thrust Buildup.
The time shown as Max q includes all Gust solutions.
MBA is the abbreviation for Max. Booster Acceleration.
MES and MECO stand for Main Engine Start and Main Engine Cutoff respectively.
K.S. MES 2 includes the time of K.S. MECO 1 (Kick Stage first MECO).

load was less than 1700 pounds. Since these loads are small they are not considered worthy of more elaborate analysis.

11-4 ENVIRONMENTAL LOSS OF CLEARANCE

The loss of clearance due to environmental effects has been calculated for the payload or forward ring by assuming the displacement to be equivalent to that for sinusoidal motion at 20 or 40 cps respectively and the acceleration load shown in Table 11-1. In addition, for the Mach 1 to Max q times of flight, a buffet response of the nose fairing of 0.22 inch has been RSS'ed with the motion of the payload. For simplicity the loss of clearance at MBA was taken as half the value shown at launch for the 300 pound payload. The other models should be somewhat less, and cannot reasonably be critical at that time.

12

REFERENCES

3-1 "Stiffness and Deflection Analysis of Complex Structures", J. of the Aero Sciences, Turner, Clough, Martin and Topp, Vol. 23 #9 September 1956.

3-2 "Energy Theorems and Structural Analysis", Aircraft Engineering, J. H. Argyris. October, November, December 1954, February, March, April, May 1955.

4-1 General Dynamics/Astronautics Report No. DDE64-050, "General Missile Vibration Program #2342", Gieseke, Appleby and Tonelli, 20 August 1964.

5-1 General Dynamics/Convair Report No. GDC-DDE65-063 "Dynamic Longitudinal Loads Analyses Performed in Support of the MA-5 Thrust Buildup Specification Curve Revision", J. W. Kittle, October 1965.

5-2 Rocketdyne Report No. R3952S "YLR-NA-7 Rocket Engine Thrust Buildup Specification" revised 19 June 1964.

5-3 General Dynamics/Convair Report No. CCD-PROG-010 "Documentation of Digital Program #2465" (Forced Vibration Program), dated 17 June 1964.

5-4 General Dynamics/Convair Report No. GDC-DDE66-012 "Dynamic Loads Analysis of Space Vehicle Systems - Launch and Exit Phase" by R. H. Schuett, B. A. Appleby, and J. D. Martin, dated June 1966.

5-5 General Dynamics/ Convair Report No. GD/A-BTD64-120 "Centaur/Surveyor-Peculiar Structural Dynamics Analyses", T. T. Serrani, dated 15 July 1964.

7-1 General Dynamics/Convair Report No. GDC-BTD66-112 "Structural Design Criteria, SLV-3C Booster Vehicle", D. L. Zentner, October 1966.

7-2 General Dynamics/Astronautics Report No. GD/A63-0967, "The COMBO Flight Program", H. B. Hilton, 15 October 1963.

7-3 General Dynamics/Convair Report No. GD/C-BTD65-053 "Centaur Bending Moments and Plotter Sections of COMBO Program #3591", J. A. Steele, 1 May 1965.

7-4 General Dynamics/Astronautics Report No. CCD-PROG-013, "Static Aeroelastic Program (SAP) #3558", A. L. Odorico, October 1964.

7-5 General Dynamics/Astronautics Report No. CCD-PROG-012, "Gust Response Program #2466", A. L. Odorico, 25 September 1964.

8-1 General Dynamics/Astronautics Report No. CD-63-039-AWS, "Digital Computer Program 2520, IBM Basic Data Program (Green Door)", by J. Krell and P. McGowan, dated 25 June 1965.

8-2 General Dynamics/Convair Report No. CCD-PROG-021, "Digital Computer Program 2697C, Bending Moments Due To C.G. Offset and Misalignment", by J. B. Laufer, T.E. Johnson, and V.K. Bertel, dated 20 September 1965.

9-1 Pratt and Whitney RL10A-3-3 "Engine Specification #2265A", Rev. 1 dated 11 October 1965.

11-1 General Dynamics/Astronautics Report No. AE61-0743, "Project Mercury Structural Dynamic Analysis (Atlas 67D; MA-2)", by A. F. Leondis, dated 10 August 1961.

11-2 General Dynamics/Astronautics Report No. GD/A63-1380, "Structural Dynamic Analysis of Atlas/Centaur AC-2 Flight Data", by E. C. Noble and R. T. Mattson, dated 28 May 1964.

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