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MECHANICAL IMPACT SYSTEM DESIGN FOR ADVANCED SPACECRAFT (MISDAS)

Contract NAS9-4915

FINAL REPORT

13 May 1966

Prepared by

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FOREWORD

This document presents the results of a study of Mechanical Impact System Design for Advanced Spacecraft. The study comprised a Phase I, Design Concept Selection; Phase II, Preliminary Design and Analysis; and an Addendum for the MISDAS Application to the AES-type Spacecraft. The study was conducted by the Structures and Dynamics Department of the Space and Information Systems Division of North American Aviation, Inc. for the Manned Spacecraft Center of the National Aeronautics and Space Administration under Contract NAS9-4915. The MISDAS Study was performed by S&ID under the technical cognizance of J. McCullough of the Mechanical and Landing Systems Branch, NASA/MSC. The work was performed by a team of Research and Engineering personnel, and coordinated with Apollo and AES Engineering in those areas where implementation of the land impact system could influence vehicle design, cost, or schedule.

In order to present a complete documentation of the study, extensive use of information already presented in the Design Concept Selection and AES application phases of this study has been made in the preparation of this final report. This report was prepared by A. I. Bernstein, Project Manager, NAA/S&ID. Major contributors were A.S. Musicman, Project Engineer; H. Bransky, E.M. Vanalstyne, R. S. Barr, D. A. Reed, Jr., and E. G. Clegg, Design Engineers; J. Partin and D. Herting, Dynamic Engineers; C. D. Haynie, Manufacturing Engineer; R. Snyder, Jr. and W. A. Bateman, Structures Engineers; and A. Kusano, Weights Engineer.

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SUMMARY

The Space and Information Systems Division (S&ID) of North American Aviation, Inc. (NAA), under contract to the National Aeronautics and Space Administration, Manned Spacecraft Center (NASA/MSC), has performed a preliminary development study of an earth landing system for advanced Apollo-type spacecraft.

Contract NAS9-4915 involves a preliminary design study to select a landing impact-absorption system that (1) can be incorporated in an Apollo-type command module with minimum structural modification, (2) provides a stable landing platform, (3) prevents vehicle overturning and damage to the structure, and (4) permits reuse of the spacecraft with refurbishment after landing. The study, which encompasses preliminary design and limited stability analyses of candidate systems, is concerned with mechanical systems, i. e., devices that require contact with the landing surface to absorb impact energy.

In Phase I preliminary design, stability, and structural evaluations of candidate design concepts were conducted. These tradeoffs led to the recommendation that two concepts be studied further to identify an optimum system. One concept (Figure 1) employs a six-legged segmented heat shield; the other concept (Figure 2) uses an extended aft heat shield and 12 radially deployed skids. This work was reported in Reference 1.

In Phase II, completed in May 1966, preliminary design and structural and stability analyses were performed to obtain the weight and volume required to apply MISDAS to a 14,000-pound spacecraft. Major structural and landing system components were sized; tradeoff analyses determined that both landing systems were stable for the design conditions but required crew attenuation systems for vertical landing velocities above 15 fps, and that roll control of the spacecraft during landing is needed when effective ground coefficients of friction above 0.35 are encountered.

To perform the landing stability studies, analytical computer programs were developed that calculate and record the motion of the spacecraft about three axes as a function of time after ground contact. The programs consider variation in spacecraft vertical and horizontal velocity, attitude and orientation, shock strut load-stroke characteristics, and ground coefficient of friction. The stability analysis of the six-legged vehicle with segmented heat shield was performed with a new computer program which describes the

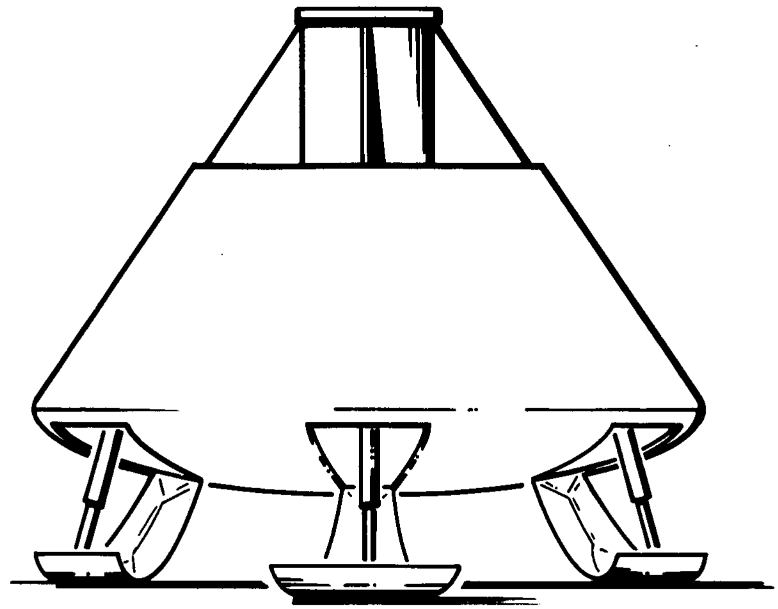


Figure 1. Segmented Heat Shield Design

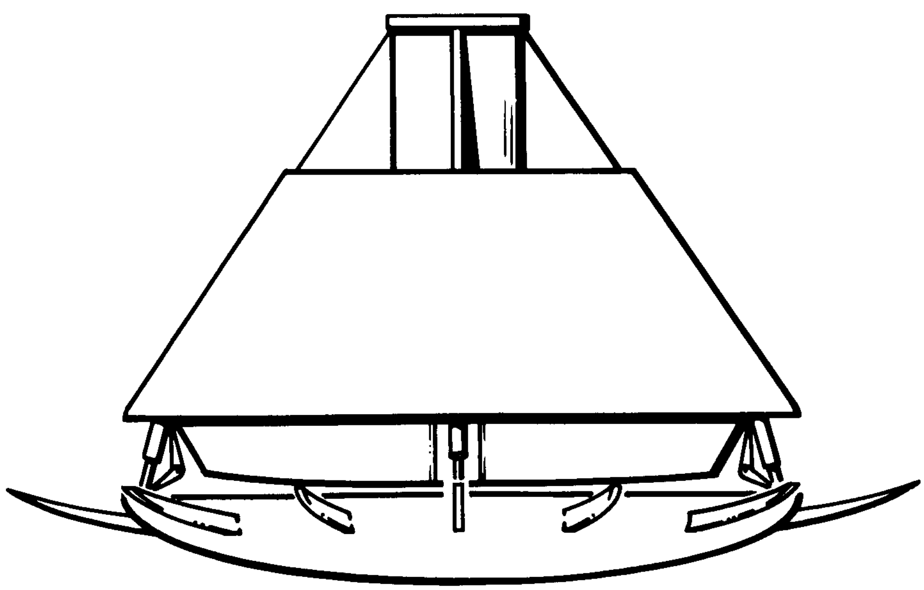


Figure 2. Radial Skid Design

vehicle's motion about three axes. An existing Apollo two-body stability analysis computer program was modified to describe the geometry of the vehicle with deployed heat shield and radial skids. The stability investigations indicated that both design concepts can perform stable landings over the specified design envelope of horizontal and vertical velocities, landing attitudes, and ground conditions. The design drawings and analysis presented in Phase II of the contract identified major members of each MISDAS installation, spacecraft compatibility problems, load paths, deployment sequence of moving parts, installation requirements, and structural member sizes. Table 1 presents a summary of characteristics of the two systems considered.

The six-legged, segmented heat shield concept is recommended for further development. This concept offers better landing stability, lighter weight, greater reliability of the retrorocket system, and simpler mechanical design than the deployed heat shield-radial skid concept. While the six-legged system will require development of a segmented heat shield system, this concept is considered to be technically feasible.

A program for the development and qualification of the MISDAS system is presented, with a preliminary schedule. This schedule is based on the MISDAS system requirements only, and is not intended to show the impact on spacecraft development schedule.

Under an extension of the contract a preliminary study was conducted on the application of these two concepts to an AES vehicle. This required study of a 10,600-pound spacecraft including preliminary design, structural and stability analysis using the specified landing velocities, ground conditions, and spacecraft attitudes; preliminary study of the relocation of equipment in the aft compartment; preliminary study of installation and deployment of the retrorocket system; and preliminary manufacturing and development studies. The two MISDAS concepts were found applicable to AES, able to provide stable landings, and feasible from a manufacturing viewpoint. This study is reported in Reference 2.

Table 1. Summary of System Characteristics

Criteria	Six Legged Heat Shield (Figure 1)	Radial Skid (Figure 2)
Land-Landing Stability $V_V = 0 - 15$ fps $V_H = 0 - 80$ fps $\mu = 0.35$	Stable	Stable
$V_V = 0 - 80$ fps $V_H = 0 - 80$ fps $\mu = 0 - 1.00$	Unstable for $\mu > 0.4$ and $V_V \geq 25$ fps - requires roll control	Unstable for $\mu > 0.4$ and $V_V \geq 25$ fps - requires roll control
Water-landing	Good landing and floating stability expected	Shield must be deployed prior to landing, compromising landing stability
Weight Penalty (14,000 pound) $V_V = 0 - 15$ fps $V_V = 0 - 20$ fps $V_V = 0 - 30$ fps	 673 lb 1244 lb 2406 lb	 955 lb 1166 lb 2226 lb
Manufacturing	Within state of the art	Within state of the art
Apparent Reliability	Good	Poor
Mechanical design simplicity	Good	Fair
Development problems	Heat shield requires development	Skid housings and mechanism exposure to environment
Retromotor installation (AES application)	Good	Poor
Spacecraft compatibility	Good	Good

INTRODUCTION

Future National Space Program missions will call for routine operational use of reentry vehicles which have enough maneuverability to make land landings at selected recovery sites and which can be reused with minimum refurbishment. The entry vehicles must be designed for normal and emergency landing on surfaces of varying slope, uniformity, and mechanical properties, and at critical combinations of vertical and horizontal velocity as dictated by local wind conditions and by the capability of future recovery systems utilizing glide chute concepts and retrorockets to limit the descent velocity. Furthermore, the landing systems must provide stable landing conditions and must protect the spacecraft and crew from excessive loads.

The design of a mechanical impact system for an Apollo-type spacecraft is the objective of this study. In addition to satisfying the criteria noted above, the system is designed to fit within the space available between the structure and heat shield and involves minimum modification of the Command Module structure. The attempt to incorporate a reliable, practical, mechanical impact system for earth-landing of Apollo imposes the following major design problems:

1. The vehicle must not turn over on landing.

2. The system must absorb landing impact energy without subjecting the structure, crew, or payload to excessive accelerations.

3. The system must fit within the limited space available between the Apollo heat shield and structure.

4. The system should satisfy current state-of-the-art standards for simplicity, reliability, and minimum weight.

The S&ID approach to this problem has consisted of the generation and screening of 10 design concepts; selection of two feasible concepts; determination of their dynamic landing characteristics through use of specially developed new computing tools; sizing of large key structural components through preliminary design and stress analysis efforts; assessment of weight and volume penalties involved in the incorporation of MISDAS to an Apollo-type spacecraft; and selection of one concept for recommendation to NASA for further design and analysis. These steps are discussed in detail in this report.

GUIDELINES, CONSTRAINTS, AND DESIGN CRITERIA

To evaluate the installation of MISDAS in an Apollo-type advanced spacecraft, the specific guidelines, constraints, and design criteria listed below were established. These criteria define the basic spacecraft geometry, landing conditions, stability requirements, acceleration limits, vehicle performance, ground surface properties, and material properties used in the study.

MISDAS DESIGN REQUIREMENTS

Design requirements for MISDAS are as follows:

1. The system will require contact with the landing surface to absorb impact energy.
2. The system will be stowed during flight and deployed prior to landing.
3. Deployment time is not to exceed 30 seconds.
4. The system will be designed for maximum reliability, simplicity, and efficiency.
5. The vehicle will not overturn during landing and shall not sustain damage to the inner structure.
6. The established crew tolerances for impact accelerations and onset rates will not be exceeded.
7. Design will be compatible with the Apollo structural drawings so that a minimum of structural modification is required for stowage and to support loads during impact.
8. The design will be optimized for minimum weight and stowed volume. It is a design goal to restrict the impact system weight to 3.5 percent of the total landing weight of the spacecraft.
9. No part of the system will be located inside the crew compartment.

10. The energy absorbing portion of the system can be designed for minor refurbishing after each landing.

11. Ultimate design loads for the overall system will be 1.33 times greater than those experienced while landing under the worst combination of the following performance criteria. Ultimate design loads for components which impact the ground shall be equal to those experienced while landing under the worst combination of the following performance criteria.

PERFORMANCE CRITERIA

Performance criteria for MISDAS, as applied to the basic Apollo-type spacecraft and for the AES application study, are tabulated below.

Item	MISDAS	MISDAS/AES Application
1. Vehicle landing weight	14,000 pounds	10,600 pounds
2. Rate of descent	0 to 15 fps	0 to 15 fps
3. Horizontal velocity	Figure 3	Figure 3
4. Landing surface	Soil and water	Soil and water
a. Ground slope	±5°	±5°
b. Holes and protuberances	±3 inches	—
c. Coefficient of friction	0.35 to 1.0	0.35
5. Spacecraft attitude		
a. Roll	±10°	±10°
b. Pitch	±10°	±10°
c. Yaw	±10°	±10°
d. Suspension angle	27° (Water impact) 0° (Land impact)	
e. Suspension angle tolerance	±2°	±2°

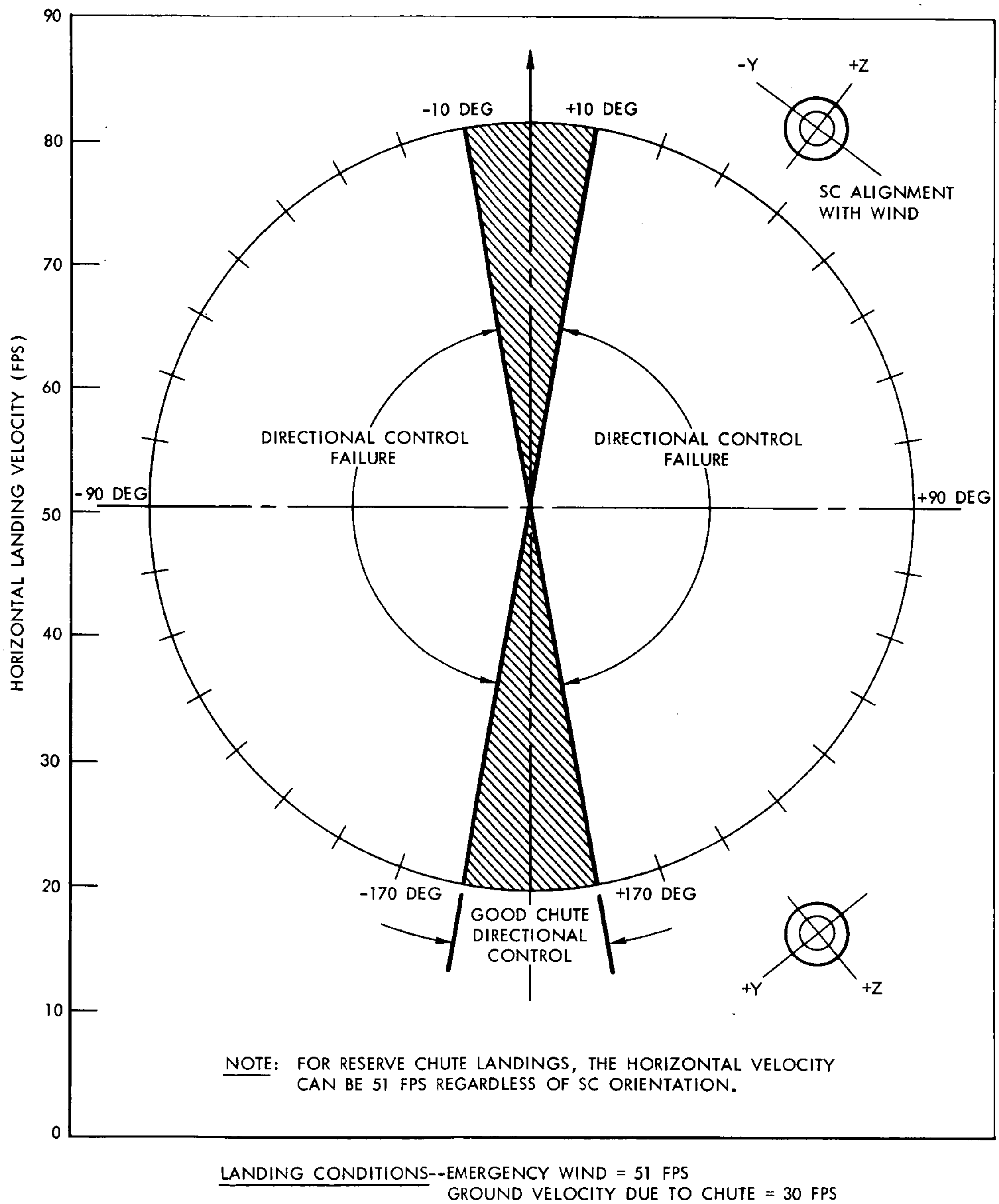


Figure 3. Effect of Spacecraft Alignment With Wind on Horizontal Velocity

It shall be a design goal for the system to accommodate landings of a roll angle of 180 degrees (backwards).

Figure 3 shows the basis for the horizontal velocity and spacecraft attitude criteria. This graph has horizontal velocity plotted as a function of spacecraft alignment with the wind direction (roll). This assumes emergency wind conditions of 51 feet per second and a parachute lift-to-drag ratio of 1, which provides a horizontal velocity of 30 feet per second.

The shaded area of the curve represents the normal landing conditions. At zero-degree roll, or direct alignment into the wind, the horizontal landing velocity would be 81 feet per second, while the vehicle landing at 180 degrees roll, or against the wind, would have a backward velocity of 21 feet per second.

The landing system designed under the subject contract will accommodate all combinations of horizontal velocities and wind alignment conditions shown in Figure 3, in addition to the reserve chute landing conditions. Descending on the reserve chute, the vehicle can land at a horizontal velocity of 50 feet per second, with roll attitude random with respect to wind direction.

SOIL CONDITIONS

All translational motion after initial contact is assumed to be in the form of skidding or sliding, acting parallel to the ground surface. No rebound, soil-vehicle deflection, earth cratering, or variation in the coefficient of friction during the landing sequence is considered.

MATERIAL PROPERTIES

The mechanical and physical properties of structural materials will be the guaranteed minimum values as given in the following documents:

1. MIL-HDBK-5, November 1964 revision (Reference 3)

2. MIL-HDBK-17, June 1965 revision (Reference 4)

3. S&ID Structures Manual, 543-G-11, revised December 15, 1965 (Reference 5)

SPACECRAFT DESIGN REQUIREMENTS

The spacecraft, when modified to incorporate the MISDAS system, will be capable of withstanding boost, abort, space environment, and atmospheric entry loads and water impact loads for a vertical velocity of 15 fps at touchdown. The effects on MISDAS and inner structure of landing velocities of 20 and 30 fps, and ground friction coefficients of 0.35 to 1.00 will be investigated for stable landings. These loads are specified in Apollo Requirements Manual ARM-6 (Reference 6). The factors of safety of 1.50 for atmospheric entry and 1.00 for water impact, specified in ARM-6 are applicable to this study.

PHASE I - INITIAL DESIGN CONCEPT SELECTION

In Phase I of the study, two mechanical impact systems which best satisfy the program objectives were selected and defined. The concepts studied included one suggested by NASA and nine proposed by the contractor. The major technological problem was imposed by the requirement that the spacecraft not turn over when landing at any critical combination of horizontal velocity up to 80 feet per second, descent velocity up to 15 feet per second, and touchdown attitude up to 42 degrees (suspension angle plus pitch angle plus ground slope). After considering concepts involving displaced heat shields, extended skids, extended legs, airplane-type landing gear, inflated air bags, and crushable structural components, the following 10 concepts, shown in Figures 4 through 13, were selected for preliminary evaluation:

Chordwise-deployed skids (Concept A)

Radially-deployed skids (Concept B)

Tricycle gear side landing (Concept C)

Forward-extended double shoes (Concept D)

Implanted anchor (Concept E)

LEM-type four-legged gear (Concept F)

Four-segment extendable heat shield (Concept G)

Forward-translated heat shield (Concept H)

Extended heat shield/airbag (Concept J)

Two-segment translated heat shield (Concept K)

Three concepts (D, H, and K) were eliminated for instability under side wind conditions. One new concept (Concept L, Figure 14), a six-segment hinged heat shield variation of Concept G, was formulated. These eight concepts were laid out to scale to assure that they fit in the limited space available outside the command module structure, to show where Apollo equipment must be relocated, and to identify modifications required for the Apollo heat shield or primary structure. Preliminary stability analyses were conducted to define the overturning stability envelope of the spacecraft

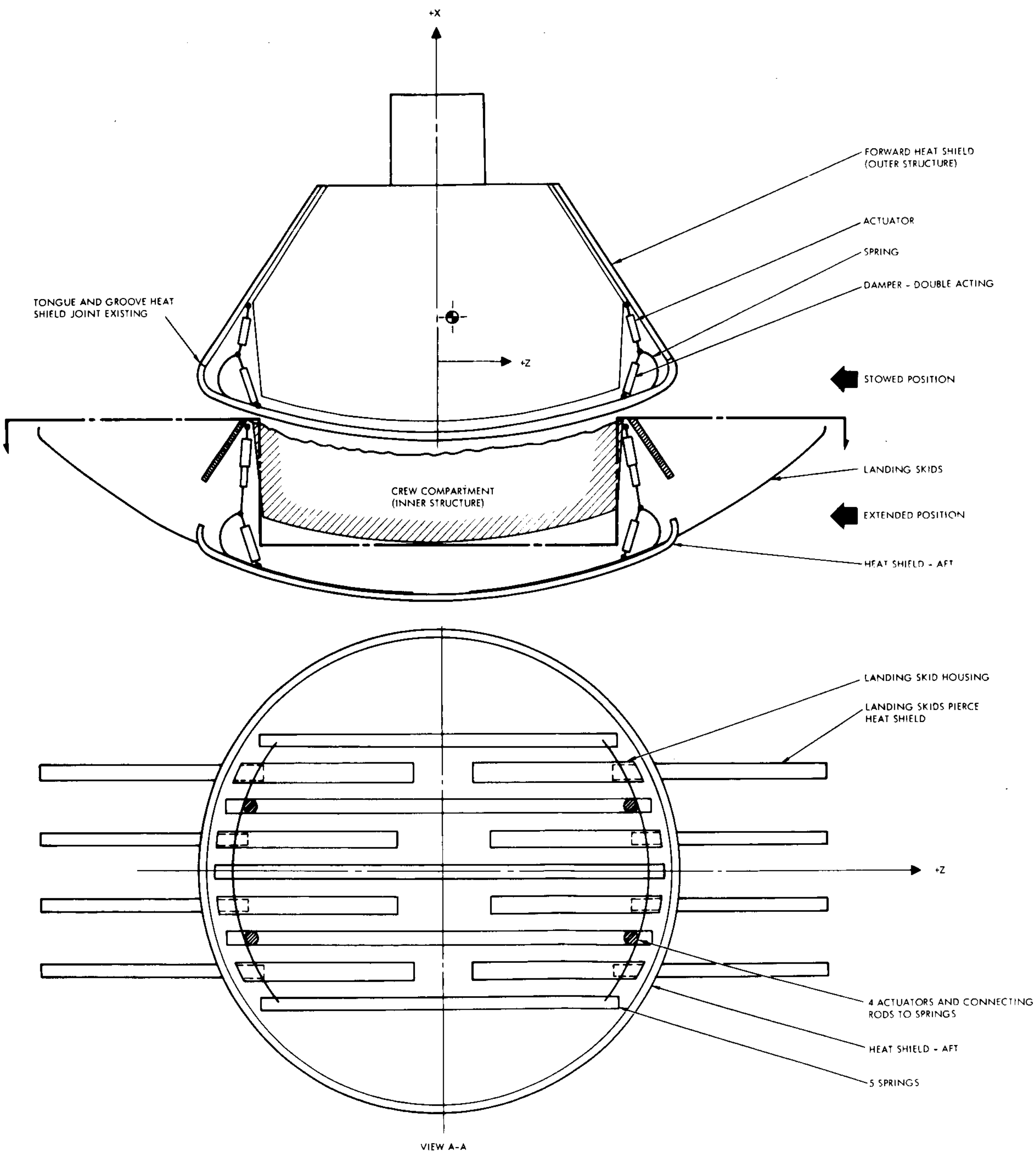


Figure 4. Concept A, Chordwise-Deployed Skids

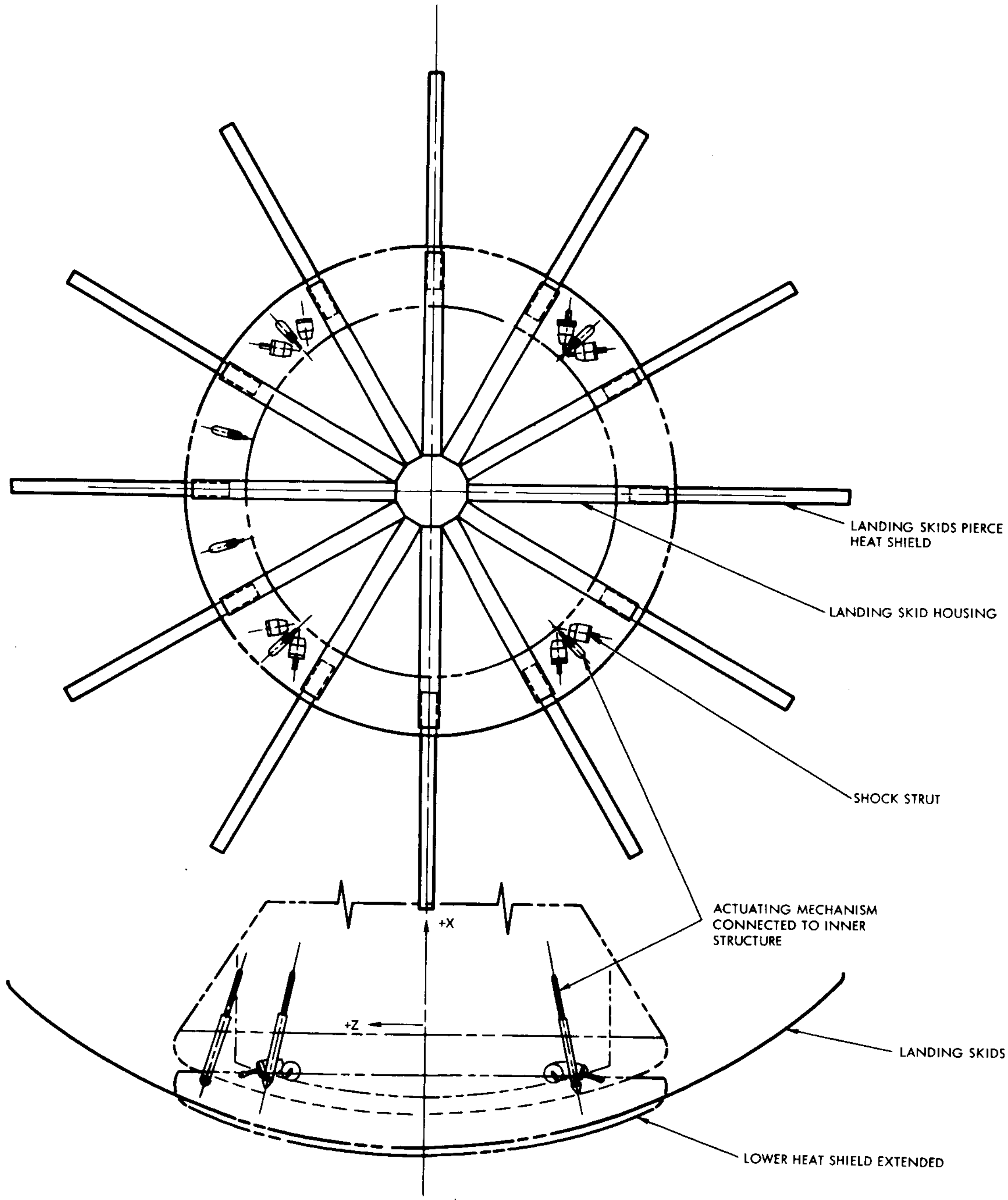


Figure 5. Concept B, Radially-Deployed Skids

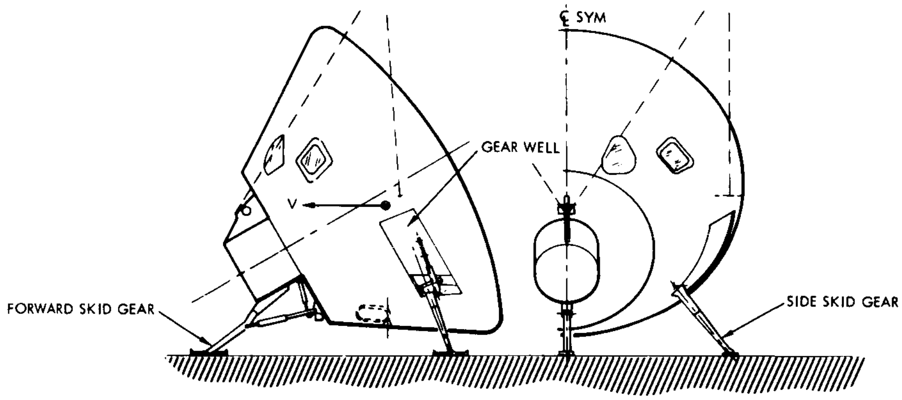


Figure 6. Concept C, Tricycle Landing Gear

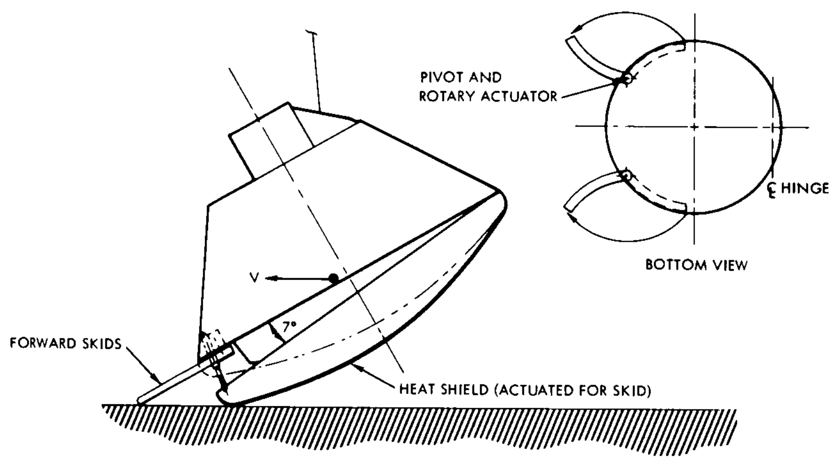


Figure 7. Concept D, Forward-Extended Double Shoes

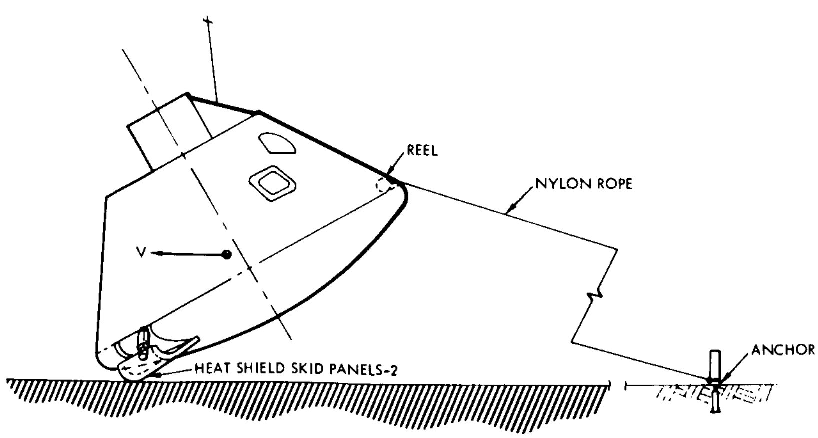


Figure 8. Concept E, Implanted Anchor

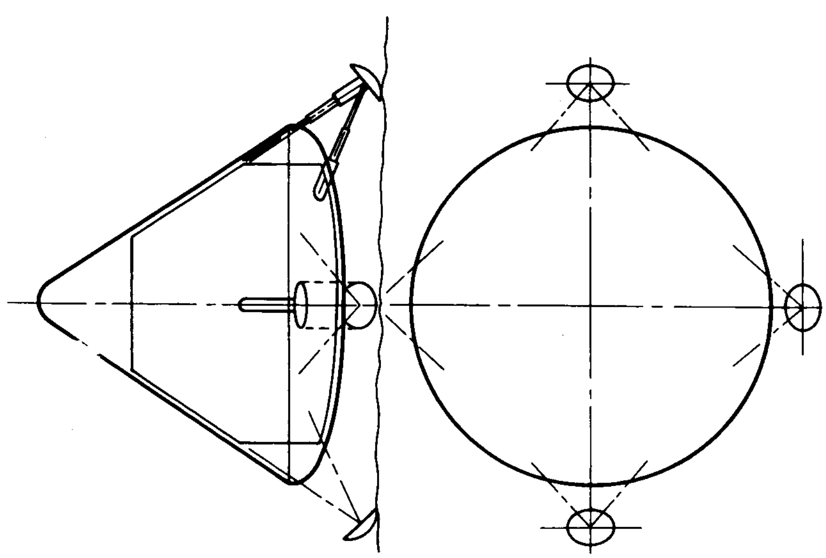


Figure 9. Concept F, LEM-Type Four-Legged Gear

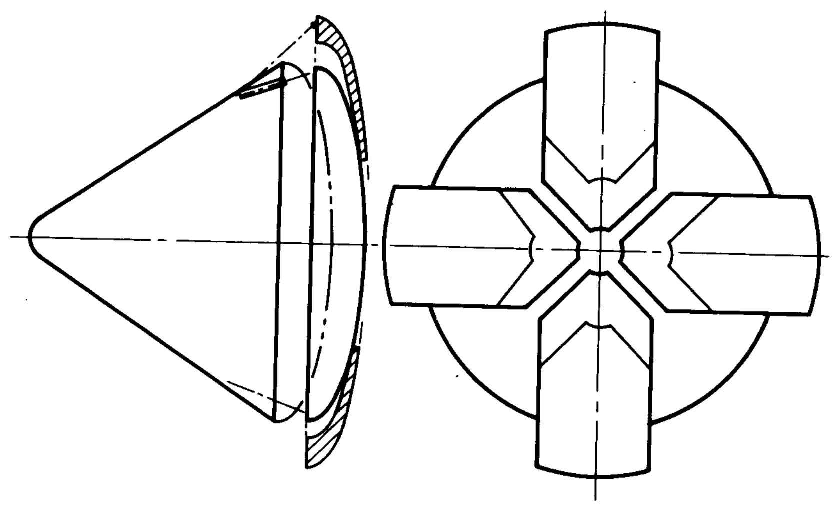


Figure 10. Concept G, Four-Segment Extended Heat Shield

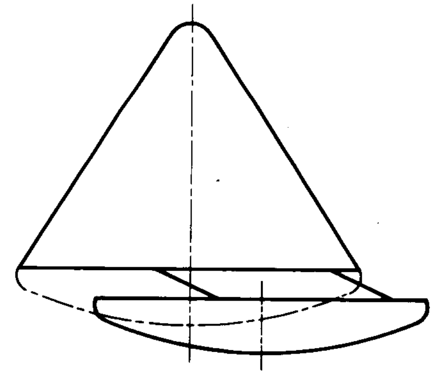


Figure 11. Concept H, Forward-Translated Heat Shield

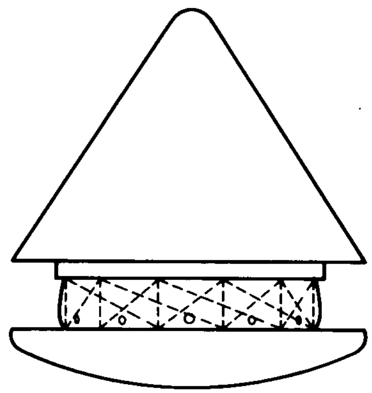


Figure 12. Concept J, Extended Heat Shield/Airbag

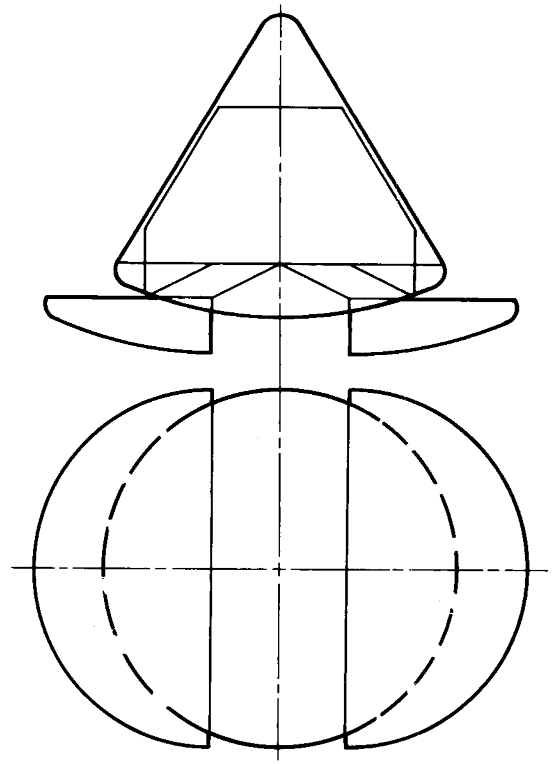


Figure 13. Concept K, Two-Segment Translated Heat Shield

in terms of velocity, spacecraft attitude, and soil conditions. The stability analyses were based on a two-body, three-degree-of-freedom model, considering all components as rigid bodies, and assuming a nondeforming ground surface. Structural and weights analyses were conducted to define member sizes and materials, weight and volume requirements, and effect on the Apollo structure.

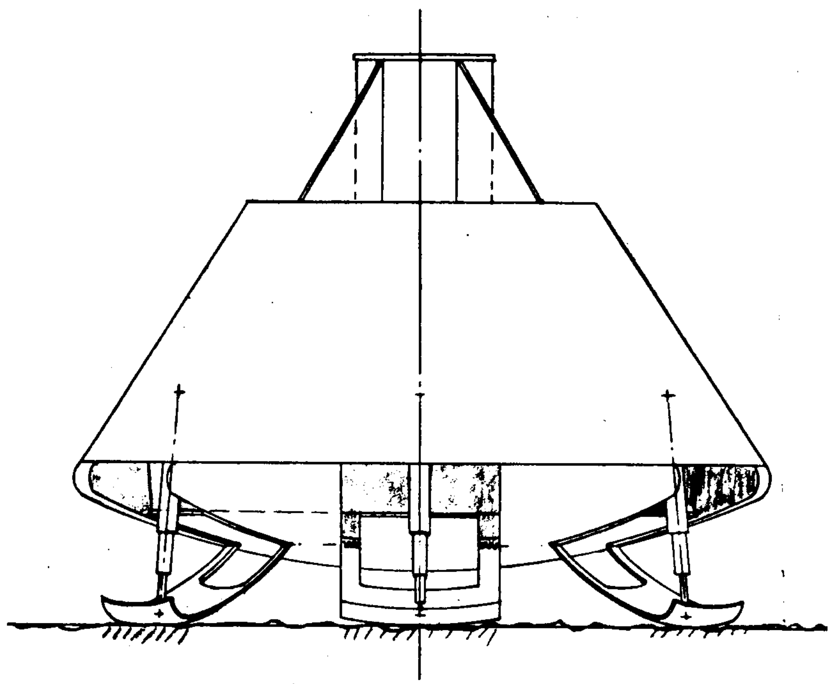


Figure 14. Concept L, Six-Segment Hinged Heat Shield Concept

Selection of an optimum design for the mechanical impact system followed a step-by-step screening and tradeoff analysis. The relative design efficiencies of the system was compared for the following items.

1. Impact system weight
2. Impact system volume
3. Stability envelope
4. Design reliability and efficiency

5. Required modification to Apollo

6. Reusability

7. Required refurbishment

8. Effect of increased rate of descent

Figure 15 shows the logic followed in the tradeoff analysis. A scoring system was used to select two candidate systems on the basis of weight, volume, stability, efficiency, compatibility with Apollo, reusability, and growth potential. These criteria provided a guide to the selection of the radial skid and hinged heat shield designs for detailed analysis. System weights are compared in Table 2. The radial skid system had been eliminated early in the tradeoff analysis because of a total weight of 1960 pounds resulting from absorbing part of the landing energy through bending of the skids. Further analysis under more favorable assumption (viz., changing the parachute hang angle so that ground impact will always occur on the heat shield, and so that the skids will only prevent tumbling) reduced the weight penalty to an acceptable value. These tradeoffs led to selection of two concepts for detailed analysis in Phase II: the deployed heat shield - radial skid system shown in Figure 5 and the six-legged segmented heat shield concept shown in Figure 14. The Phase I study, including design drawings, stability and structural analysis, and weights data, is presented in detail in Reference 1.

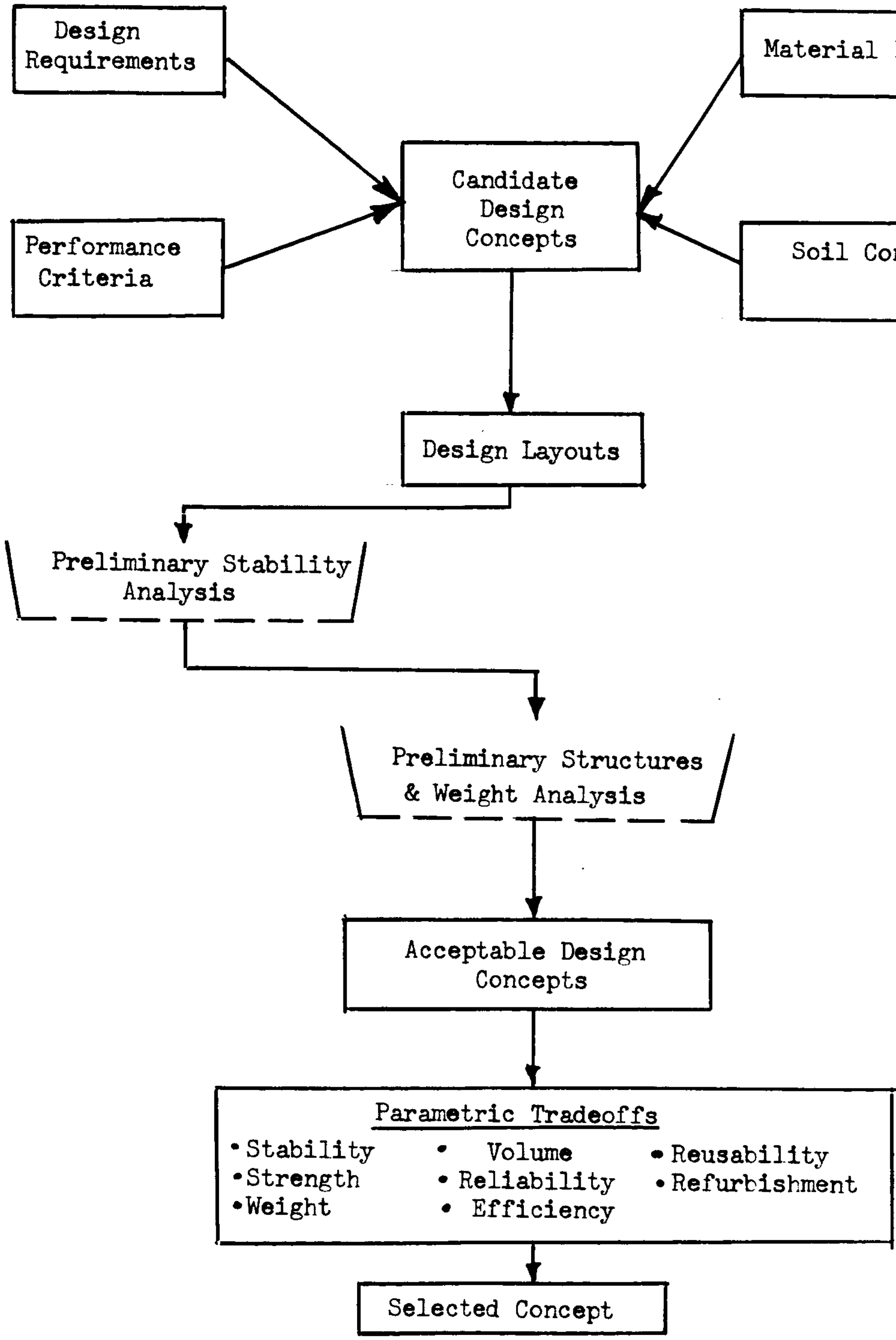


Figure 15. System Selection Logic

Table 2. MISDAS Preliminary Weight and Volume Comparison

Concept*	Description	Weight (lb)	Volume (cu ft)
A	Deployable heat shield/chordwise-extended skids	1300	1.6
B	Deployable heat shield/radially-extended skids	1960	3.2
C	Tricycle landing gear	1200	8.6
E	Implanted anchor	410	1.4
F	Deployable heat shield/four-legged gear	620	3.6
G	Four-segment translated heat shield	710	2.2
J	Extended heat shield/airbag	**	**
L	Six-segment hinged heat shield	610	1.6

*Reference 1.
**No analysis - concept unstable.

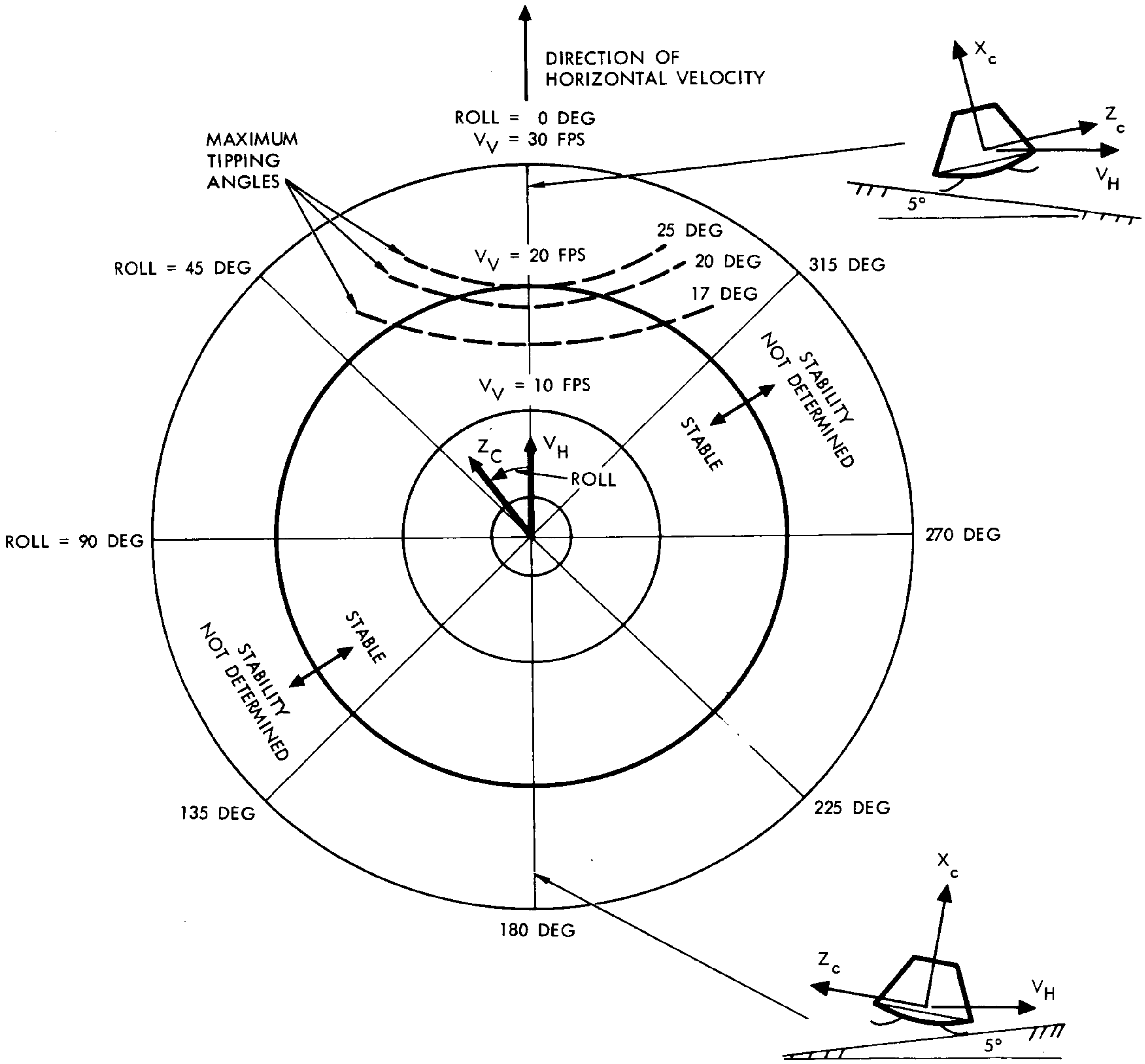
APPLICATION OF MISDAS TO AES

Under a modification to the MISDAS contract, a study was performed on the application of the two landing systems identified in Phase I to an AES-type vehicle. The study, described in detail in Reference 2, included the preliminary design, structural analysis, and stability analysis of the two landing systems using the AES-specified weight of 10,600 lb, horizontal landing velocities of zero to 80 fps, vertical landing velocities of zero to 15 fps. AES spacecraft attitudes, and a zero degree parachute hang angle; installation and deployment of the retrorocket systems; and preliminary manufacturing and development program studies.

To perform the landing stability analyses, computer programs were developed that calculate and record the motion of spacecraft about three axes as a function of time after ground contact. The stability analysis of the legged vehicle was performed employing a new computer program which describes the vehicle's motion about three axes. The Apollo two-body stability analysis computer program was modified to describe the geometry of the vehicle with deployed heat shield and radial skids. The investigations indicated that both designs can perform stable landings over the specified envelope of horizontal and vertical velocities, landing attitudes, and ground conditions. Figures 16 and 17 show results of these stability investigations for the two MISDAS concepts.

The preliminary technical studies of the application of MISDAS indicate the feasibility of installing either concept in the AES spacecraft. The radial skid/deployed heat shield design (Figure 1) and the six-segment hinged heat shield concept (Figure 2) can both provide stable landing and satisfactory impact attenuation within the range of horizontal and vertical velocities, spacecraft-ground attitudes, and ground conditions specified for the AES spacecraft.

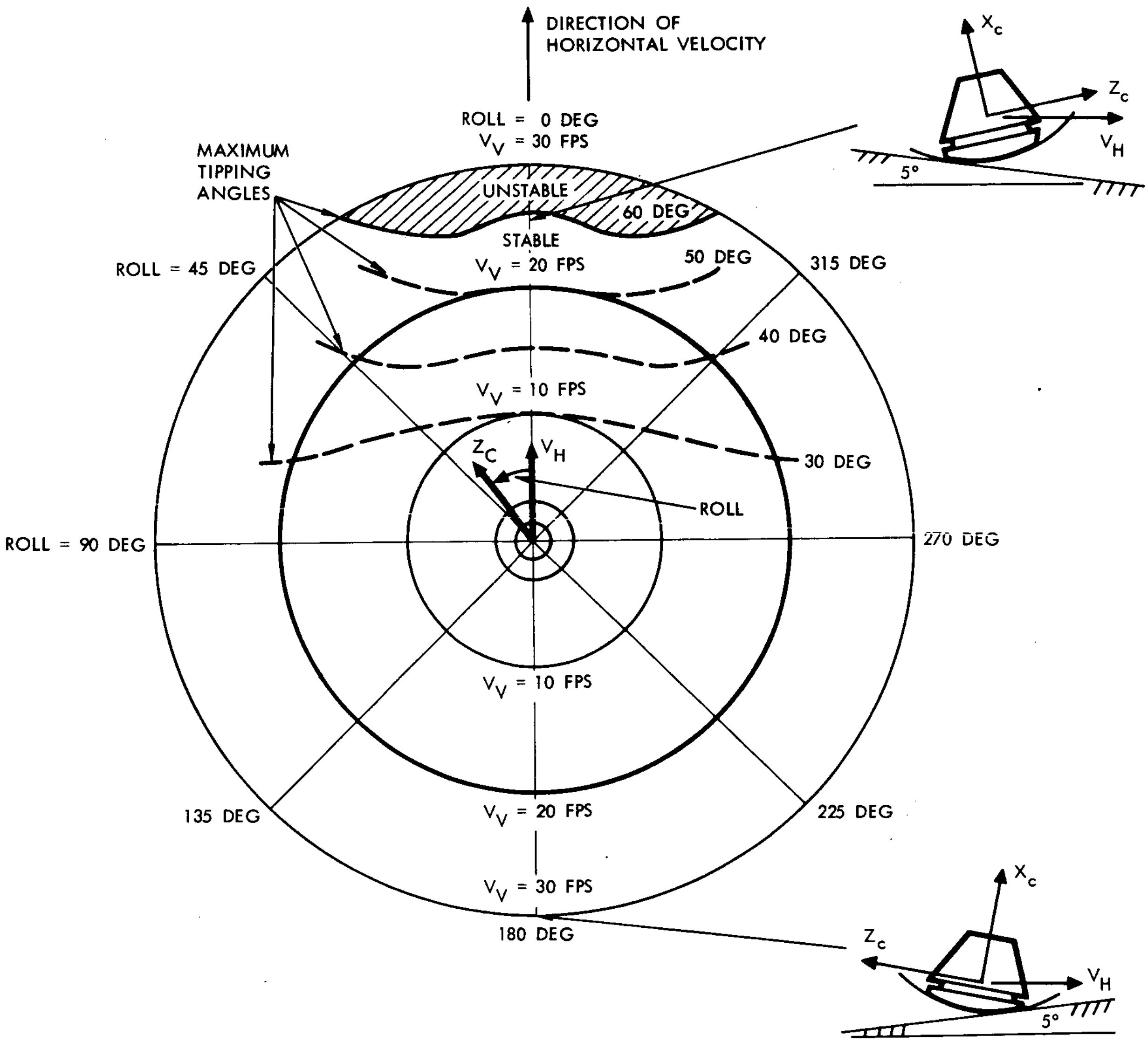
The loading conditions that design the structure of both concepts were ground impact, water impact, boost abort, and atmospheric entry. The guidelines, constraints, and design criteria section of the Apollo requirements manual ARM-6 were considered applicable to this structure. In accordance with contract requirements, a factor of 1.33 was used for structure that is essentially MISDAS. For structural components that impact the ground or water, applied loads were considered to be ultimate, because these items are expected to yield on impact, and the resulting distortion is not detremental to the objectives of the mission or crew safety.



MAXIMUM TIPPING ANGLES MAPPED AS A FUNCTION OF VERTICAL VELOCITY (FPS) AND ROLL ANGLE (DEGREE)

THE CAPSULE Y-Z PLANE IS AT A CONSTANT 17-DEGREE ANGLE WITH GROUND PLANE. (12 DEGREES PARACHUTE SWING ANGLE PLUS -5 DEGREES GROUND SLOPE COMBINED FOR MAXIMUM ANGLE WITH GROUND.) DIRECTION OF SLOPE HAS BEEN COORDINATED WITH ROLL TO PROVIDE ONE AND TWO LEG INITIAL CONTACT. V_H = 30 FPS. FRICTION COEFFICIENT = 0.35.

Figure 16. Stability Limits for Segmented Heat Shield Concept



MAXIMUM TIPPING ANGLES MAPPED AS A FUNCTION OF VERTICAL VELOCITY FPS AND ROLL ANGLE, DEGREE, FROM VELOCITY PLANE (60 DEGREES IS UNSTABLE).

COEF. OF FRICTION = 0.35
HORIZONTAL VELOCITY = 30.0 FPS
SLOPE = 5 DEGREES DOWN
DIRECTION OF SLOPE = ALONG HORIZONTAL VELOCITY
SWING ANGLE = 12 DEGREES

Figure 17. Stability Limits for Radial Skid Concept

Component-designed entry conditions were analyzed with a limit to ultimate factor of 1.50 to be consistent with Apollo design. The analysis considered a temperature range of -150 to 600 F for all components external to the inner structure and a temperature range of -150 to 200 F for the inner structure. All components were sized to low positive margins of safety to minimize overall system weight.

The stress and weights analyses indicated that the six-legged segmented heat shield concept can be incorporated in AES for a vehicle weight increase of 556 pounds; the radially deployed skid concept would require a weight increase of 737 pounds. Preliminary manufacturing and program development studies showed both systems to be technically feasible and capable of development and qualification in about the same time span. To conform with the AES engineering weight data, the Apollo Block II weight data was utilized as a base point to determine the weight penalty for adding a mechanical impact landing system. The weight penalty of the mechanical landing system is considered to be the weight of the landing gear system and the effect of all modification required on the aft heat shield structure and inner structure.

Within the landing criteria considered in this program, both vehicle concepts appear capable of stable land landings. Although not all possible landing cases were investigated, the most adverse conditions were identified. Several statements can be made regarding stability trends:

1. Vehicle stability will decrease sharply with an increase in the effective friction coefficient of the vehicle with the ground.

2. Vehicle stability decreases rapidly with an increase in normal velocity to the ground.

3. For friction independent of sliding velocity, horizontal velocity has little effect on stability except for its contribution to normal velocity.

4. The effects of ground slope, slope direction, parachute swing angle, parachute direction of swing, and roll angle on stability are not easily identified. Therefore, most of the stability study was done for different combinations of these angles. The most unstable condition was landing with horizontal velocity in the direction of downslope and a maximum impact angle of 17 degrees (5-degree ground slope plus 12-degree parachute angle, zero-degree direction of swing, roll angle of zero degrees).

5. A horizontal velocity of 30 fps has been used to determine the stability envelope. This velocity is sufficiently large to allow the vehicle to slide after initial impact without appreciably changing its normal velocity when landing on up or down slope. Larger horizontal velocities have been found to give a resultant decrease in normal velocity, with stabilizing effects on the vehicle landing up- or down-slope.

The design investigations of integration of retrorockets and the mechanical impact attenuation systems into the Block II Apollo command module indicated that such an integration is technically and physically feasible for both the segmented heat shield concept and the deployable heat shield/radial skid concept. It must be recognized that the actual structural modifications and equipment rearrangement of the high-density packaging in the aft equipment bay necessary to accommodate the retrorocket and mechanical impact attenuation systems are significant changes, although vehicle shape and mold lines are not affected. The requirements and conceptual design of the shock struts were reviewed by the Loud Company, Menasco Manufacturing Company, and the Cleveland Pneumatic Tool Company and found to be feasible.

A development program for MISDAS application was also presented. Specific areas recommended for follow-on included the development of segmented heat shields, extension of the stability analysis programs to incorporate the response of the ground-to-vehicle impact, and utilization of scale-model tests to verify the MISDAS/AES vehicle stability envelope.

The purpose of this phase of the study, Application of MISDAS to AES, was to determine the structural aspects and landing dynamic characteristics of a MISDAS system for an AES-type spacecraft. The design criteria established were not intended to encompass the complete AES operational requirements. The effects of system failure (e. g. , single retrorocket failure, failure of the heat shield to extend) were not within the scope of the study.

PHASE II-DESIGN AND ANALYSIS

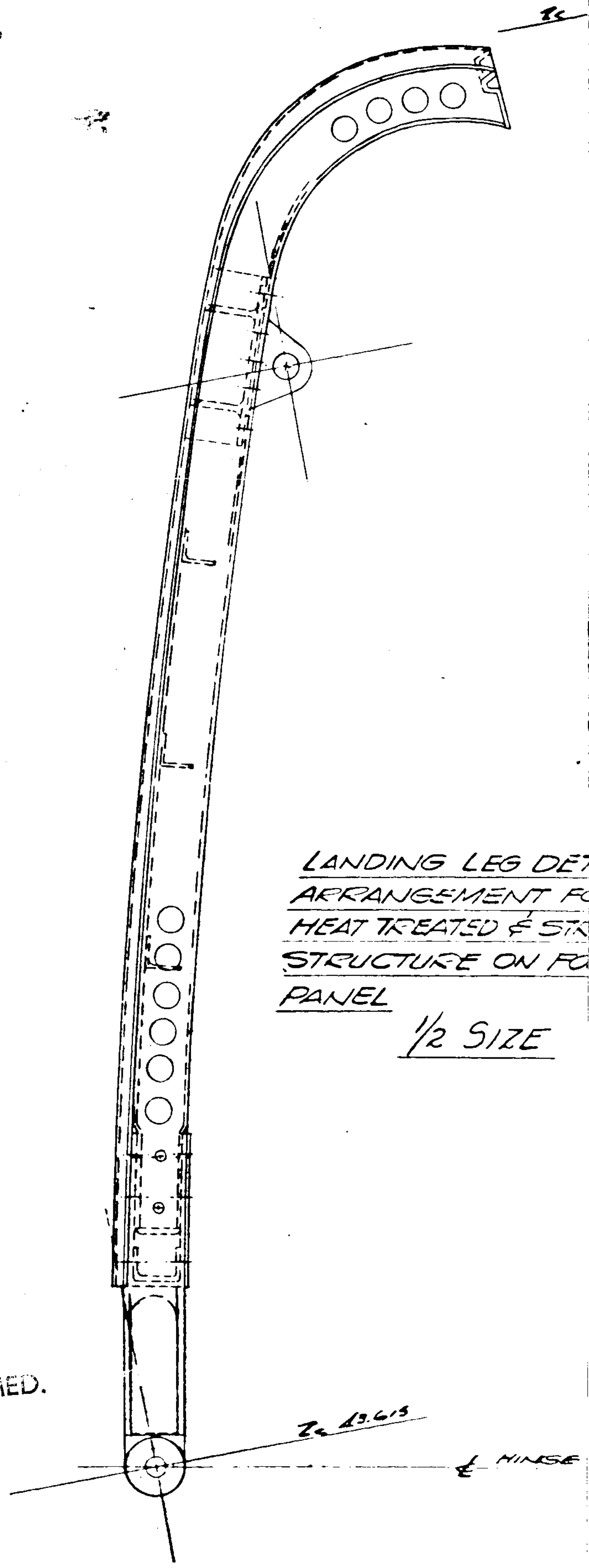
Phase II is concerned with application of the two landing systems identified in Phase I to an Apollo-type advanced spacecraft with a landing weight of 14,000 pounds. In addition investigations of the effects of emergency conditions, represented by vertical landing velocities of 20 and 30 fps, and ground friction coefficients from 0.35 to 1.00, on MISDAS components design, inner structure, and the vehicle stability were conducted.

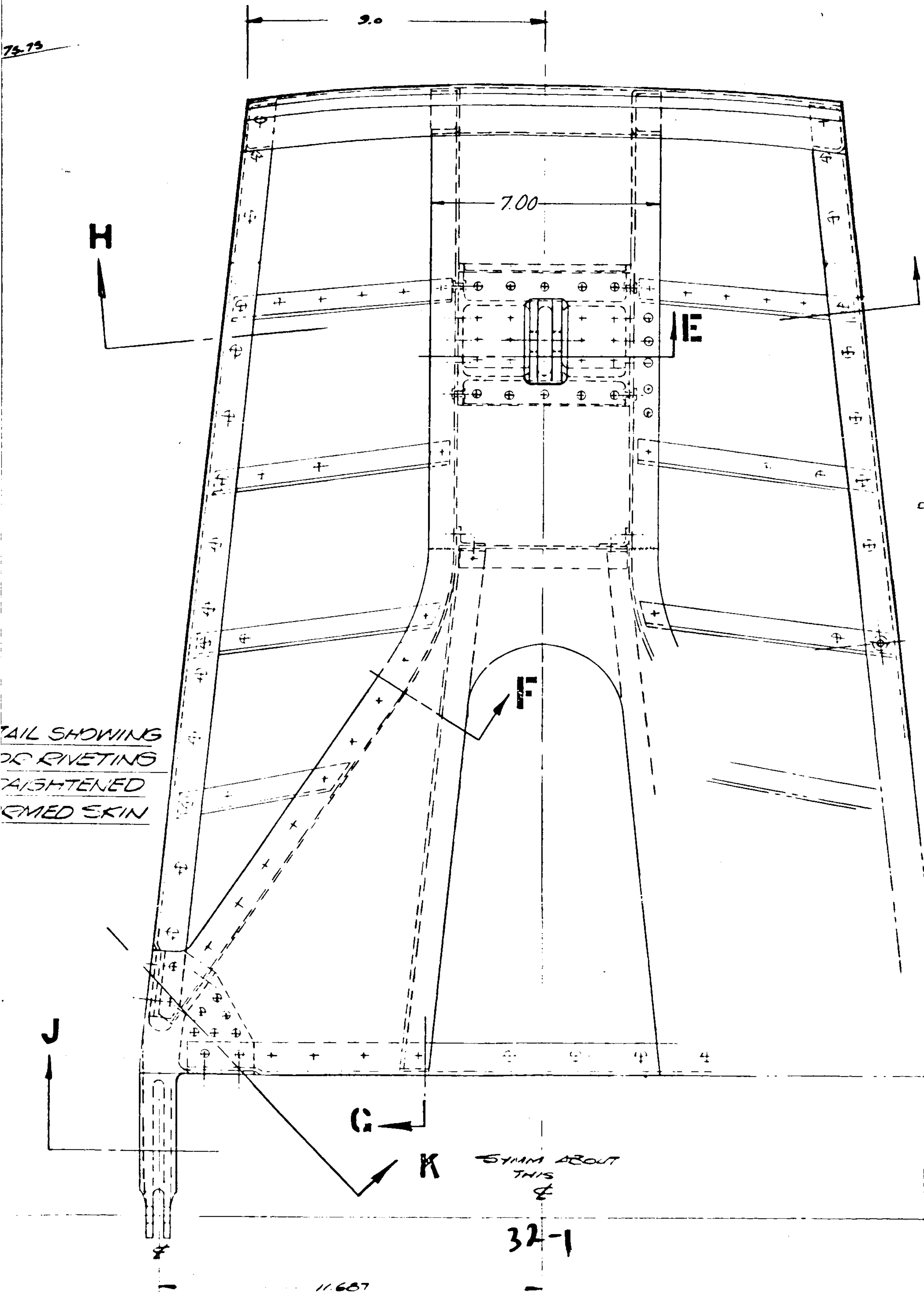
This phase of the study consisted of preliminary design and analysis of the two systems identified during phase I (i.e., the segmented heat shield and the radial skid systems). Design drawings were prepared, components were sized, and weights and volumes were calculated for both of the systems and their associated attachment members. Load path diagrams and drawings were prepared showing position sequence of landing system components from stowed position to impact. New weights and volumes were calculated for similar systems designed to sustain rates of descent of 20 and 30 fps. Manufacturing requirements of the two landing concepts were investigated and found to be feasible. These analyses resulted in the selection of the segmented heat shield-legged vehicle concept for recommendation to NASA for further design and study. A preliminary development and qualification plan and schedule was prepared.

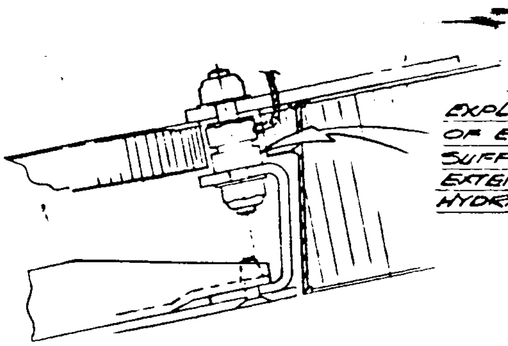
EVALUATION OF SIX-SEGMENT HEAT SHIELD CONCEPT

STRUCTURAL SYSTEM DESCRIPTION

The attenuation system shown on Figures 18 and 19 consists of six landing legs, each an identical segment of the command module base, stowed symmetrically within the base. Before impact, each leg is extended downward from inboard hinges by a single hydraulic strut which also provides dissipation of the impact energy. The landing legs or segments are recessed within the existing heat shield thickness leaving the same unoccupied gap between the heat shield and the spacecraft inner structure as in the current vehicle. The outside face of the landing legs conforms in contour to the base of the spacecraft, presenting an even spherical surface overall to which the aft ablator sections are bonded. Gaps in the heat shield are


LANDING LEG DET
ARRANGEMENT FO
HEAT TREATED & STR
STRUCTURE ON FO
PANEL
1/2 SIZE
Zc 43.615
℄ HINGE


9.0
73.73
7.00
H
E
F
TAIL SHOWING
OR RIVETING
TAIGHTENED
MED SKIN
J
G
K
SYMM ABOUT
THIS
℄
32-1
11.687



SECTION D
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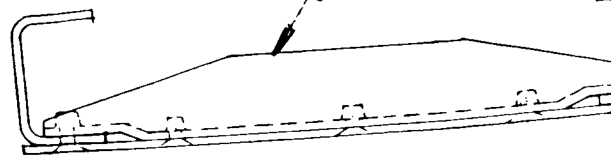

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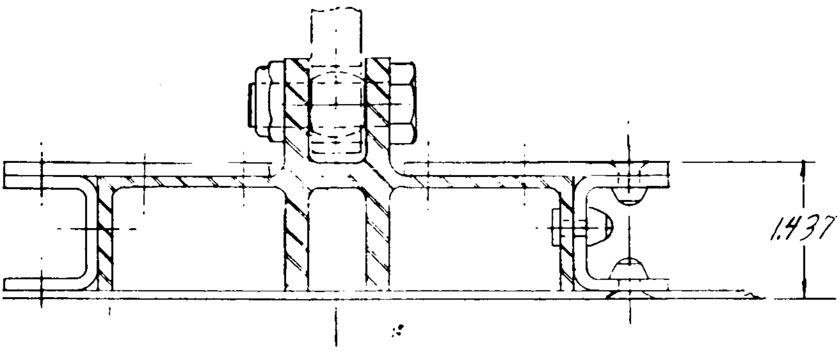
FULL SIZE



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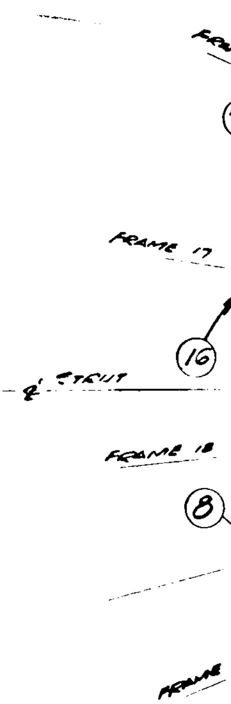
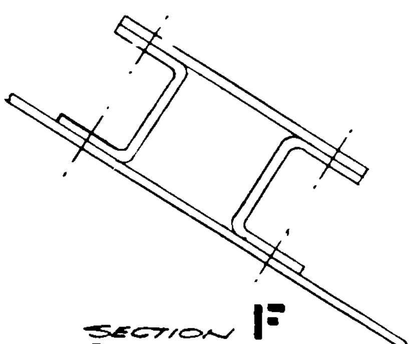
FULL SIZE





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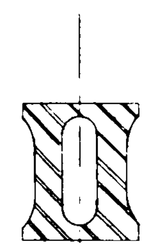
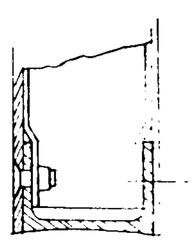
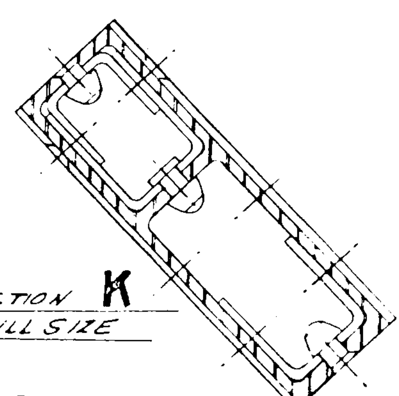
FULL SIZE



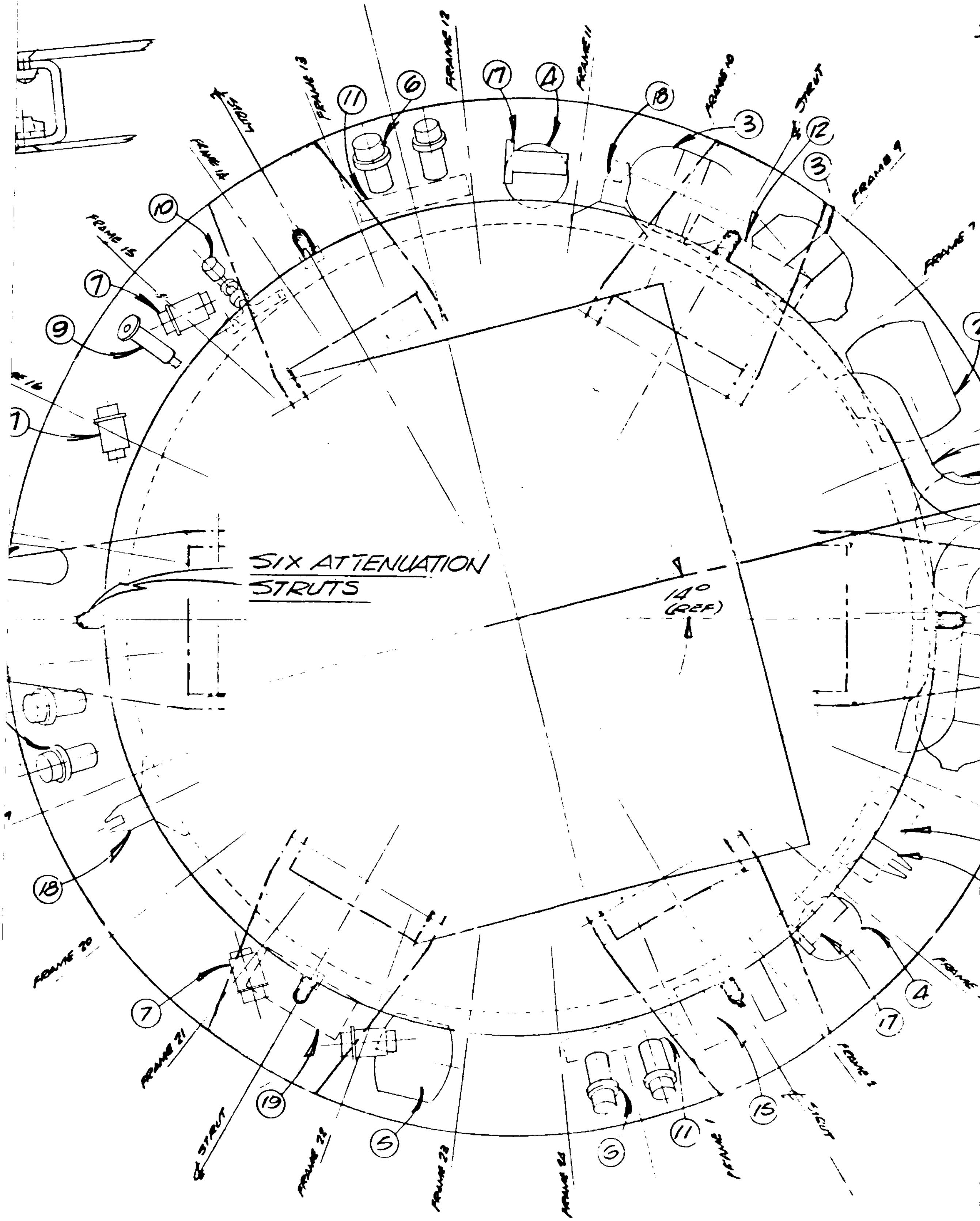
SECTION J
FULL SIZE



SECTION G
FULL SIZE



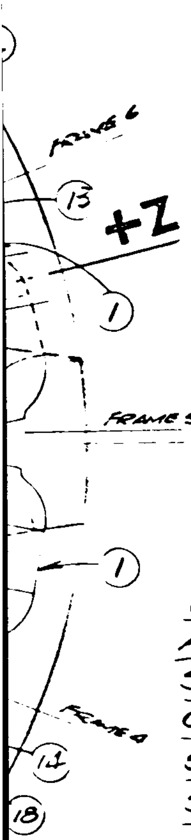
SECTION K
FULL SIZE



SIX ATTENUATION STRUTS
14°
(REF)
FRAME 7
FRAME 9
FRAME 10
FRAME 11
FRAME 12
FRAME 13
FRAME 14
FRAME 15
FRAME 20
FRAME 21
FRAME 22
FRAME 23
FRAME 24
FRAME 1
FRAME 2
℄ STRUT

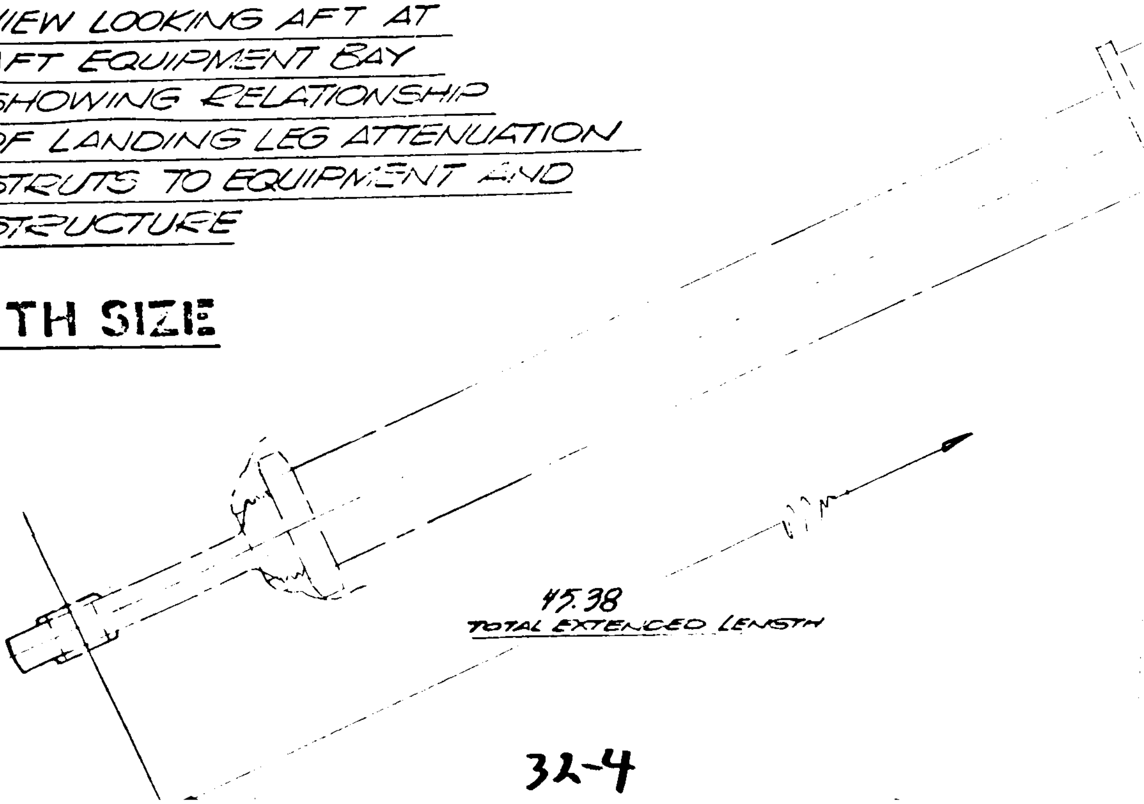
STRUT INFLUENCE ON AFT BAY EQUIPMENT

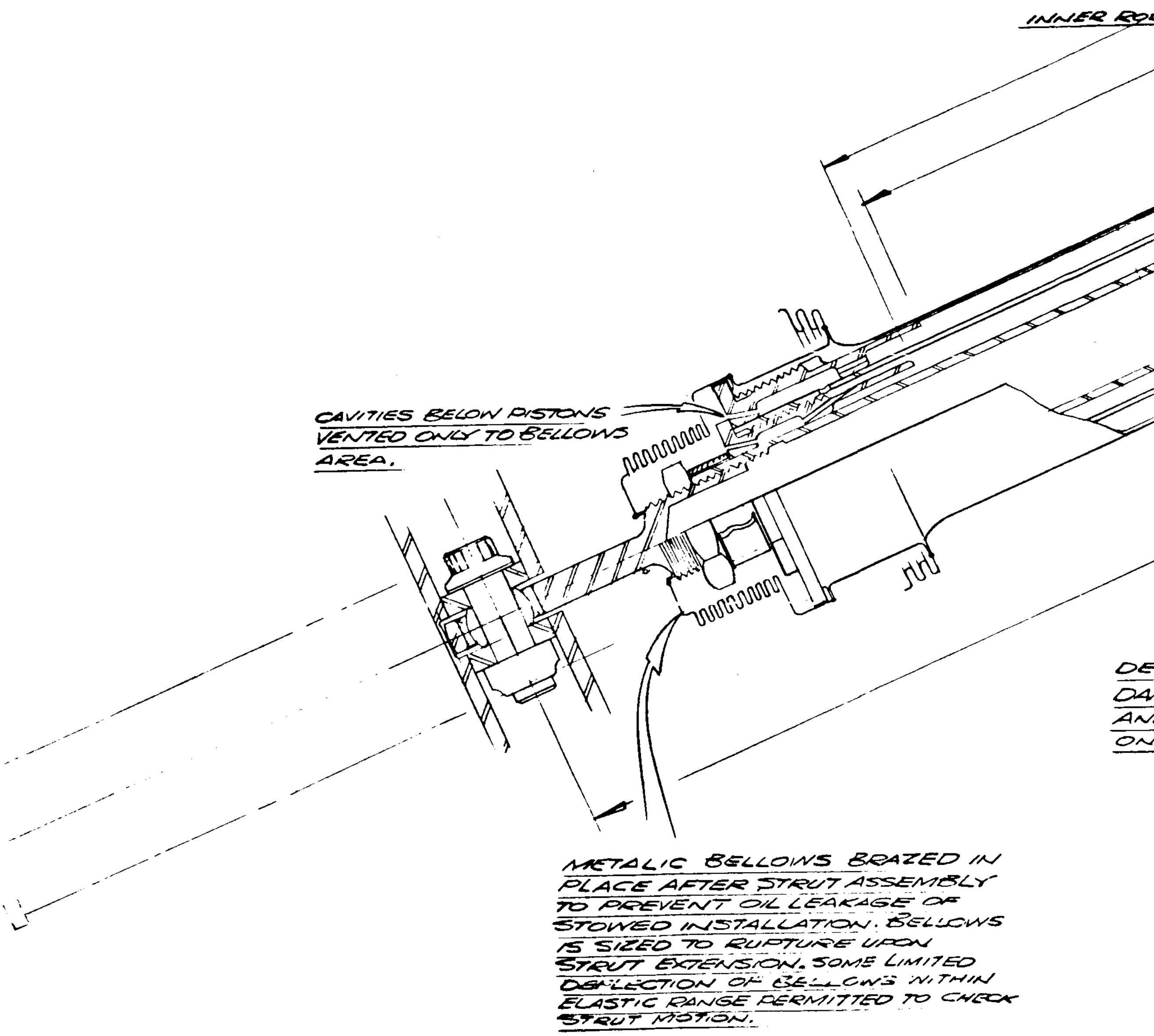
ITEM	DESCRIPTION	AFFECTED
1	OXIDIZER TANK (2)	NO
2	WASTE WATER TANK	NO
3	FUEL TANK (2)	NO
4	HELIUM TANK (2)	NO
5	POTABLE WATER TANK	RELOCATED
6	RCS YAW MOTORS (4)	NO
7	RCS ROLL MOTORS (4)	NO
8	RCS PITCH MOTORS (2)	NO
9	RELIEF DUMP NOZZLE	NO
10	STEAM VENT	NO
11	HELIUM PRESSURE PANEL (2)	NO
12	FUEL CONTROL PANEL	REARRANGED
13	ELECTRICAL UMBILICAL	NO
14	OXIDIZER CONTROL PANEL	NO
15	RCS MOTOR SWITCH (2)	RELOCATED
16	AIR VENT	NO
17	UPRIGHTING SYSTEM COMPRESSOR	NO
18	TENSION TIE	NO
19	RCS CONTROL PANEL	REARRANGED

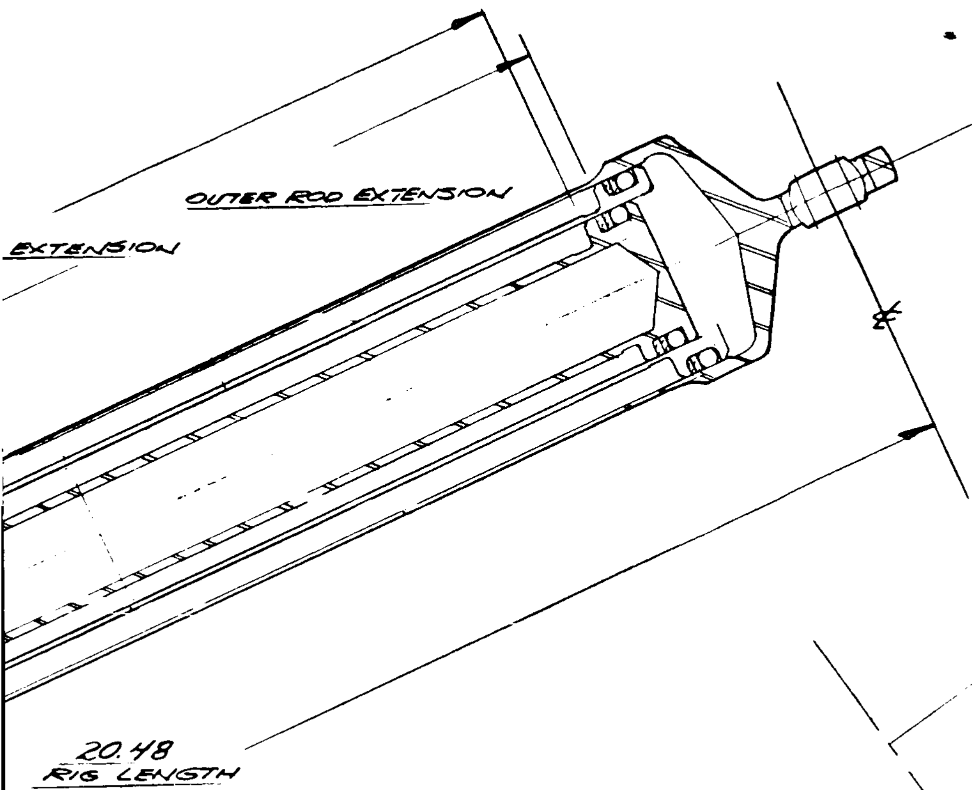


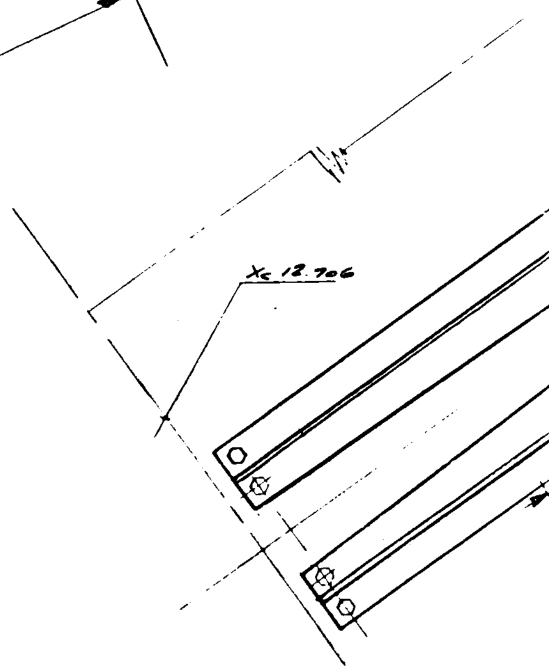
VIEW LOOKING AFT AT AFT EQUIPMENT BAY SHOWING RELATIONSHIP OF LANDING LEG ATTENUATION STRUTS TO EQUIPMENT AND STRUCTURE

TENTH SIZE

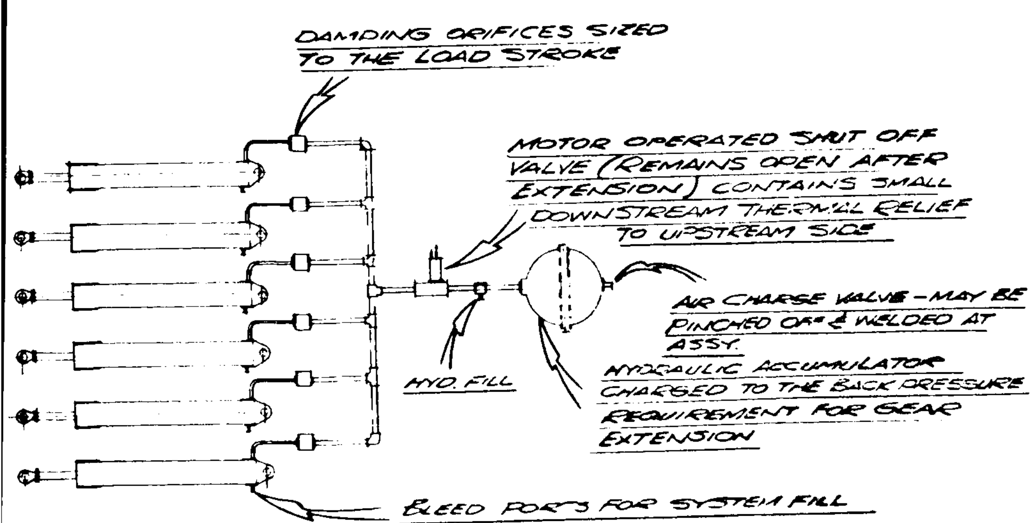



INNER ROD
CAVITIES BELOW PISTONS VENTED ONLY TO BELLOWS AREA.
METALIC BELLOWS BRAZED IN PLACE AFTER STRUT ASSEMBLY TO PREVENT OIL LEAKAGE OF STOWED INSTALLATION. BELLOWS IS SIZED TO RUPTURE UPON STRUT EXTENSION. SOME LIMITED DEFLECTION OF BELLOWS WITHIN ELASTIC RANGE PERMITTED TO CHECK STRUT MOTION.



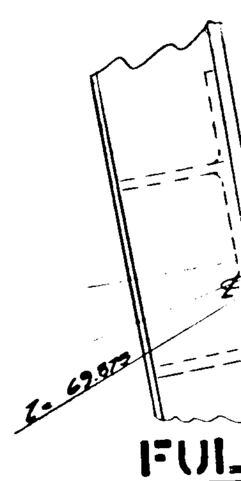


SECTION M
AIL OF TYPICAL HYDRAULIC
DENING STRUT FOR EXTENSION
ENERGY DISSIPATION ON OIL
E

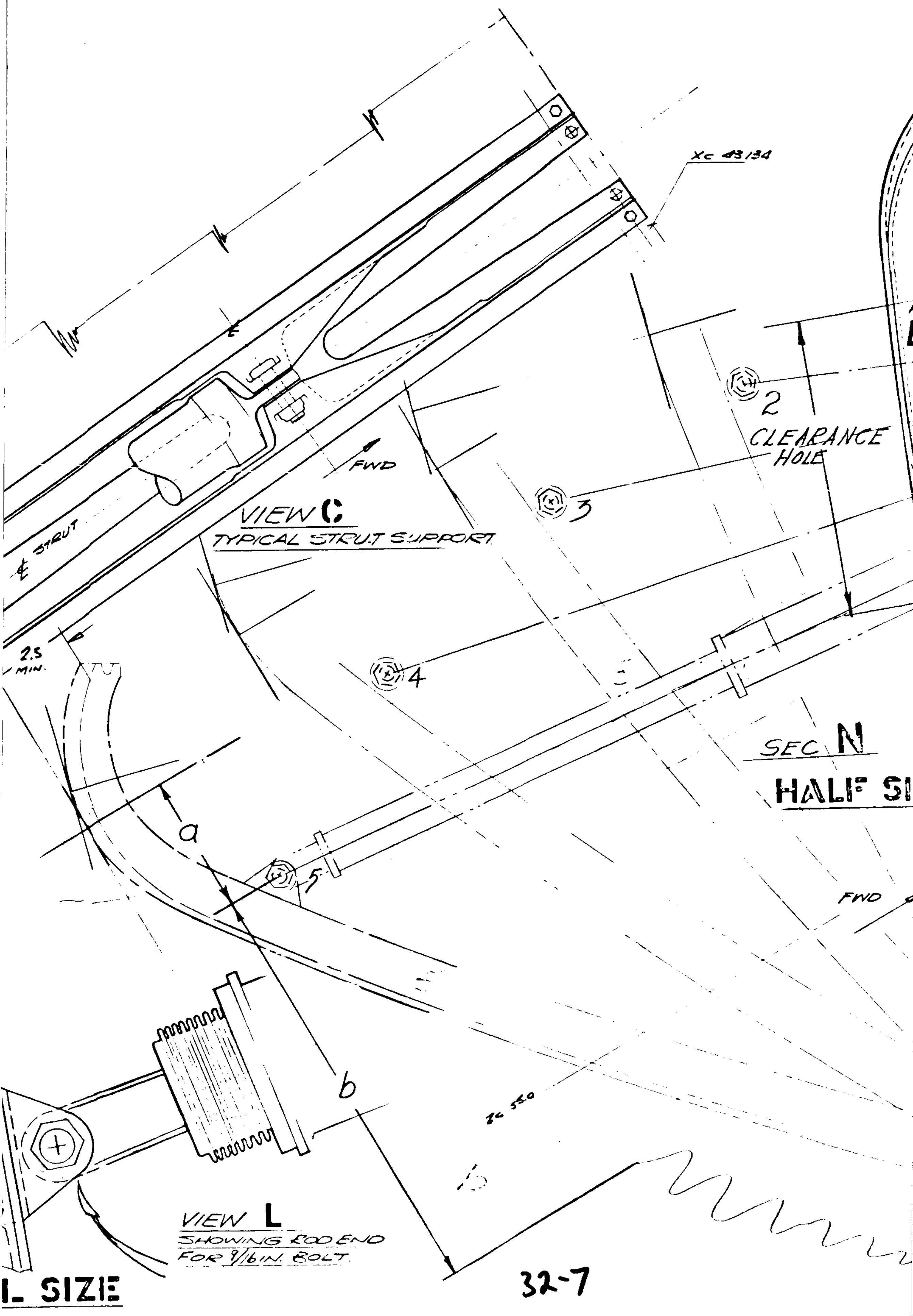


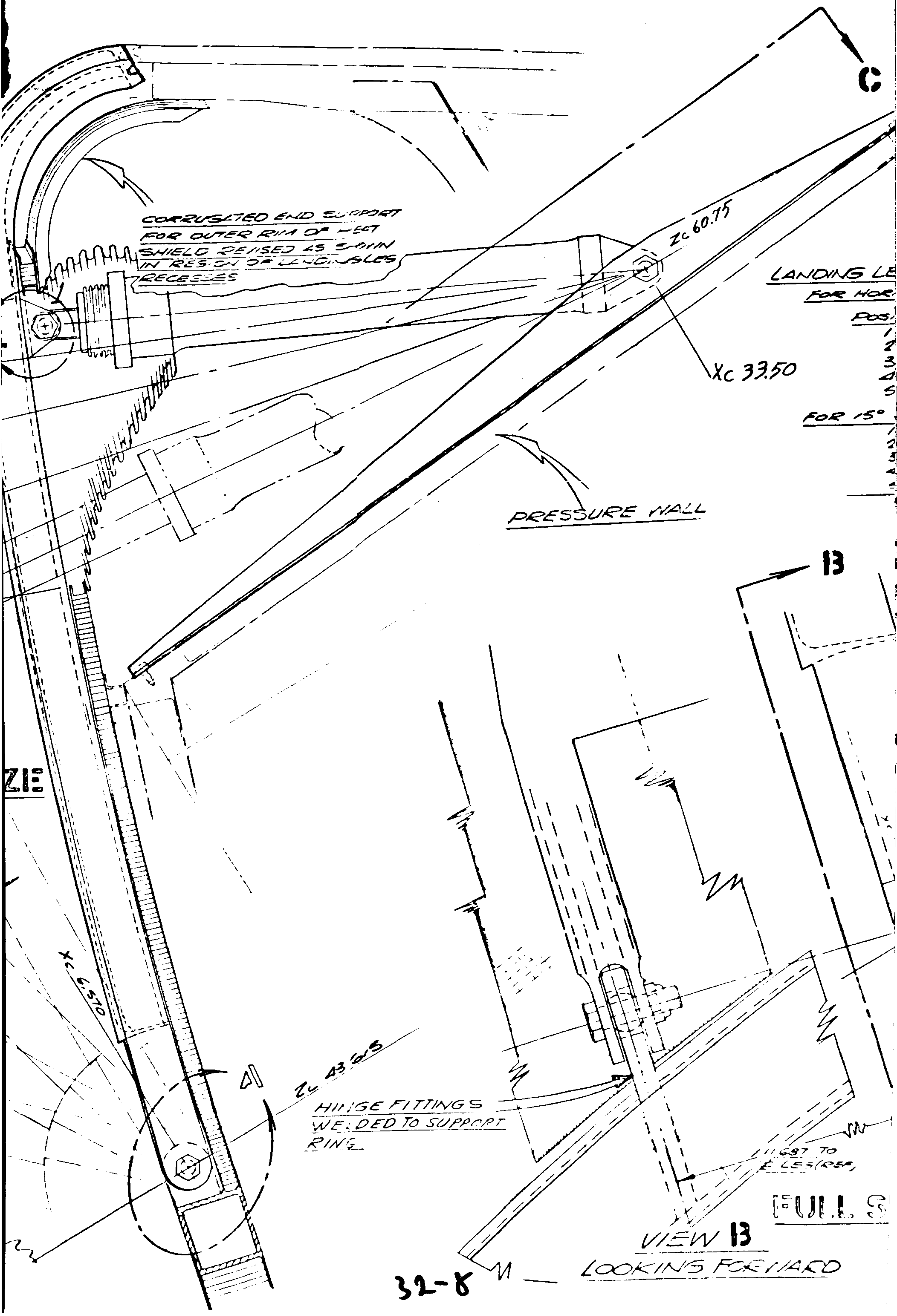
GRAM OF OIL INJECTION SYSTEM

32-6

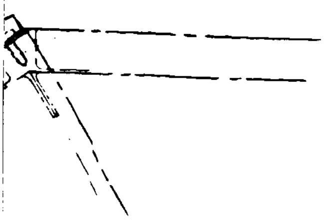


FUL


Xc 43134
2
CLEARANCE HOLE
3
4
5
FWD
VIEW C
TYPICAL STRUT SUPPORT
℄ STRUT
2.5 MIN.
a
b
SEC N
HALF SI
FWD
VIEW L
SHOWING ROD END
FOR 9/16 IN. BOLT
L SIZE


C
CORRUGATED END SUPPORT FOR OUTER RIM OF HEAT SHIELD REVISED AS SHOWN IN REGION OF LANDING LEG RECESSES
Zc 60.75
Xc 33.50
LANDING LE
FOR 15°
PRESSURE WALL
B
ZE
Xc 6.570
Zc 43.65
A
HINGE FITTINGS WELDED TO SUPPORT RING
VIEW B
LOOKING FORWARD
FULL S
32-8

NO



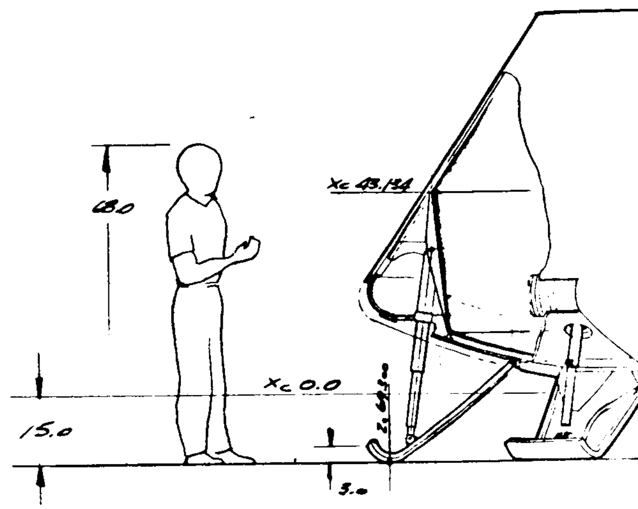
...S GEOMETRY

...ZONTAL GROUND & DESCENT

...TION	a	b	STRUT ∝°	LENGTH
	—	—	25	20.48
	—	—	21.5	27.88
	2.92	26.82	16	33.85
	4.05	24.26	10	40.12
	5.32	20.26	3.5	45.38

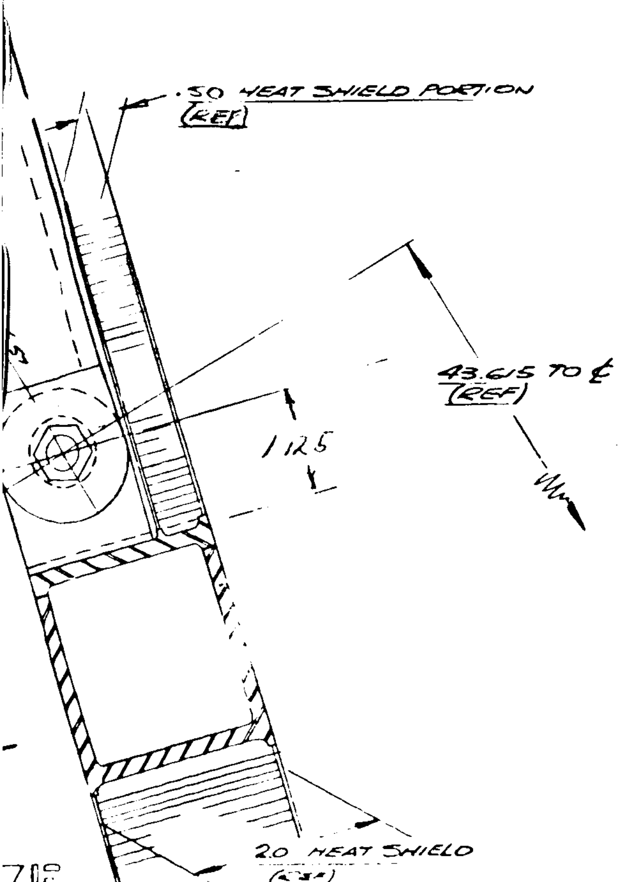
GROUND ANGLE LANDING

	a	b	STRUT ∝°
	—	—	11
	2.53	26.82	7
	4.51	24.55	2
	5.12	20.42	4.5
	5.62	15.05	10.5

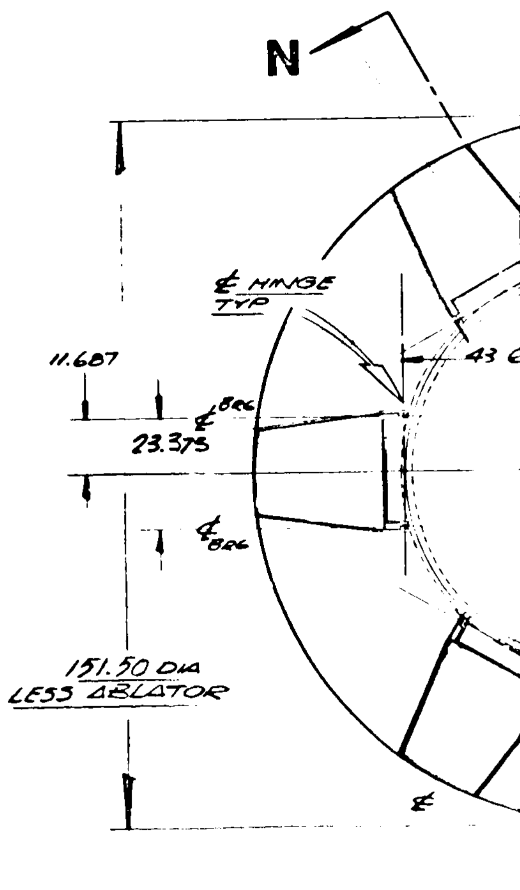


ATTEN...

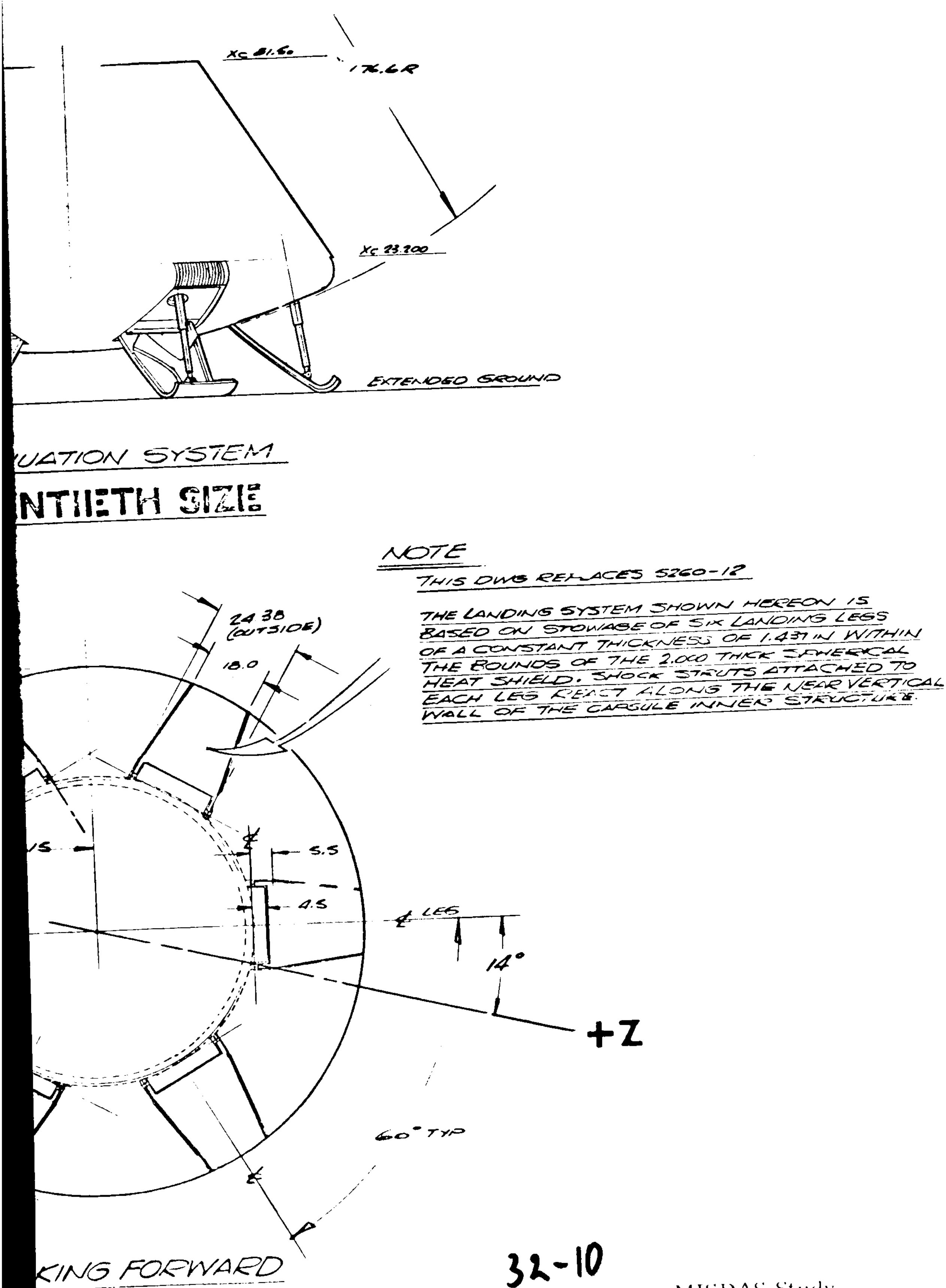
TWE...



VIEW A TYPICAL L.H. LEG HINGE FITTING

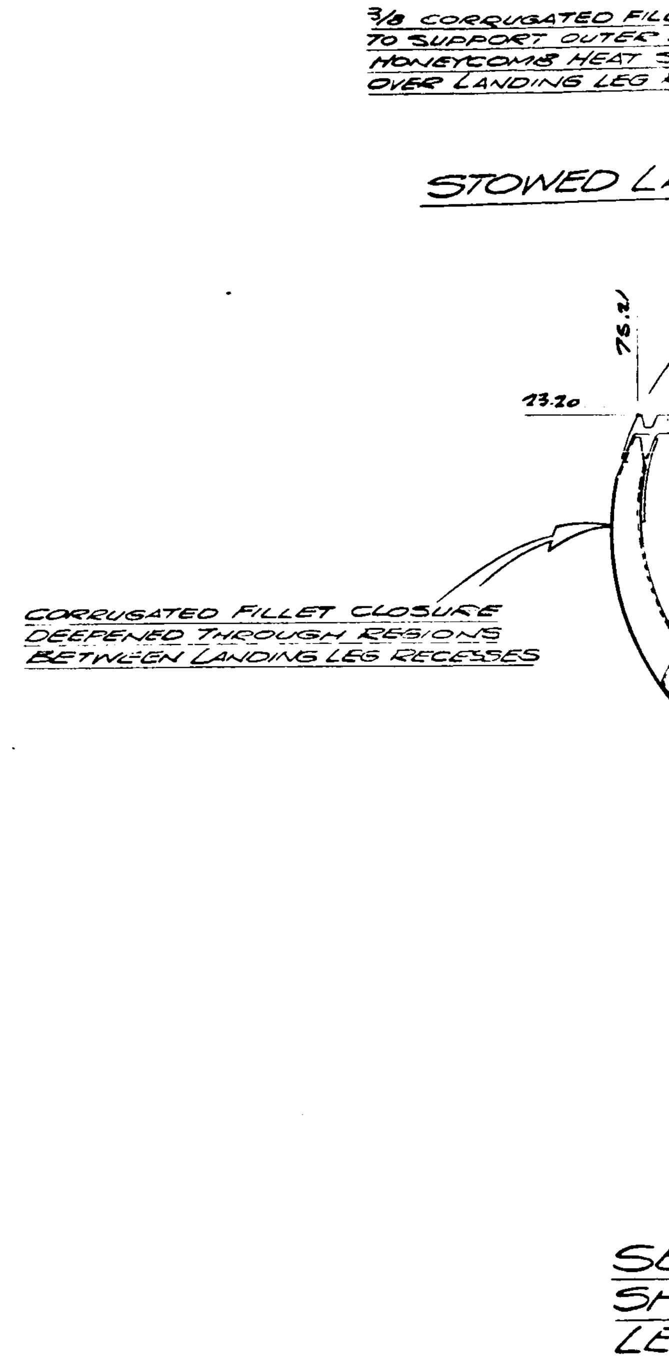


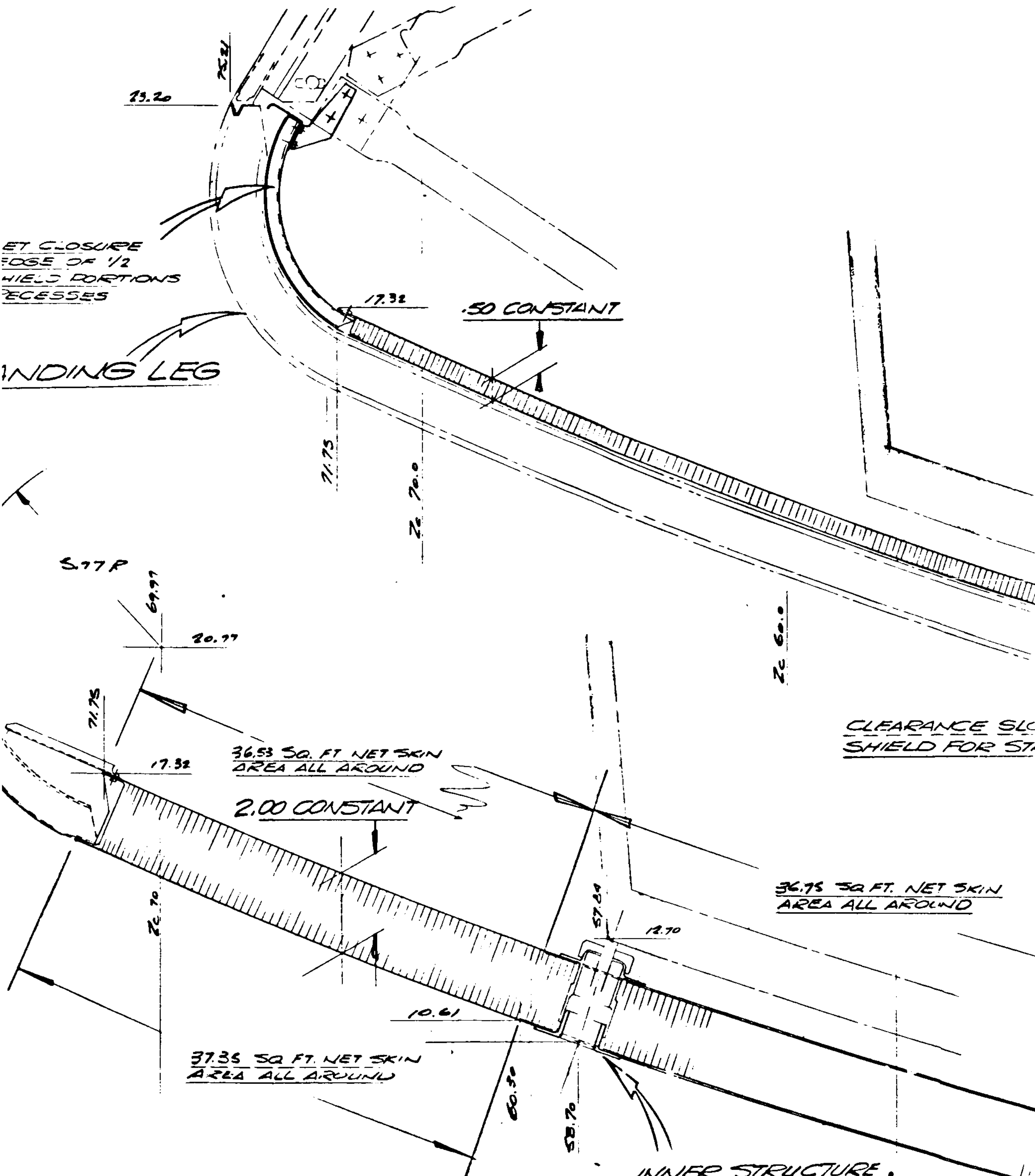
VIEW LOO...



32-10

Figure 18. Six-Radial-Leg Landing System - MISDAS Study

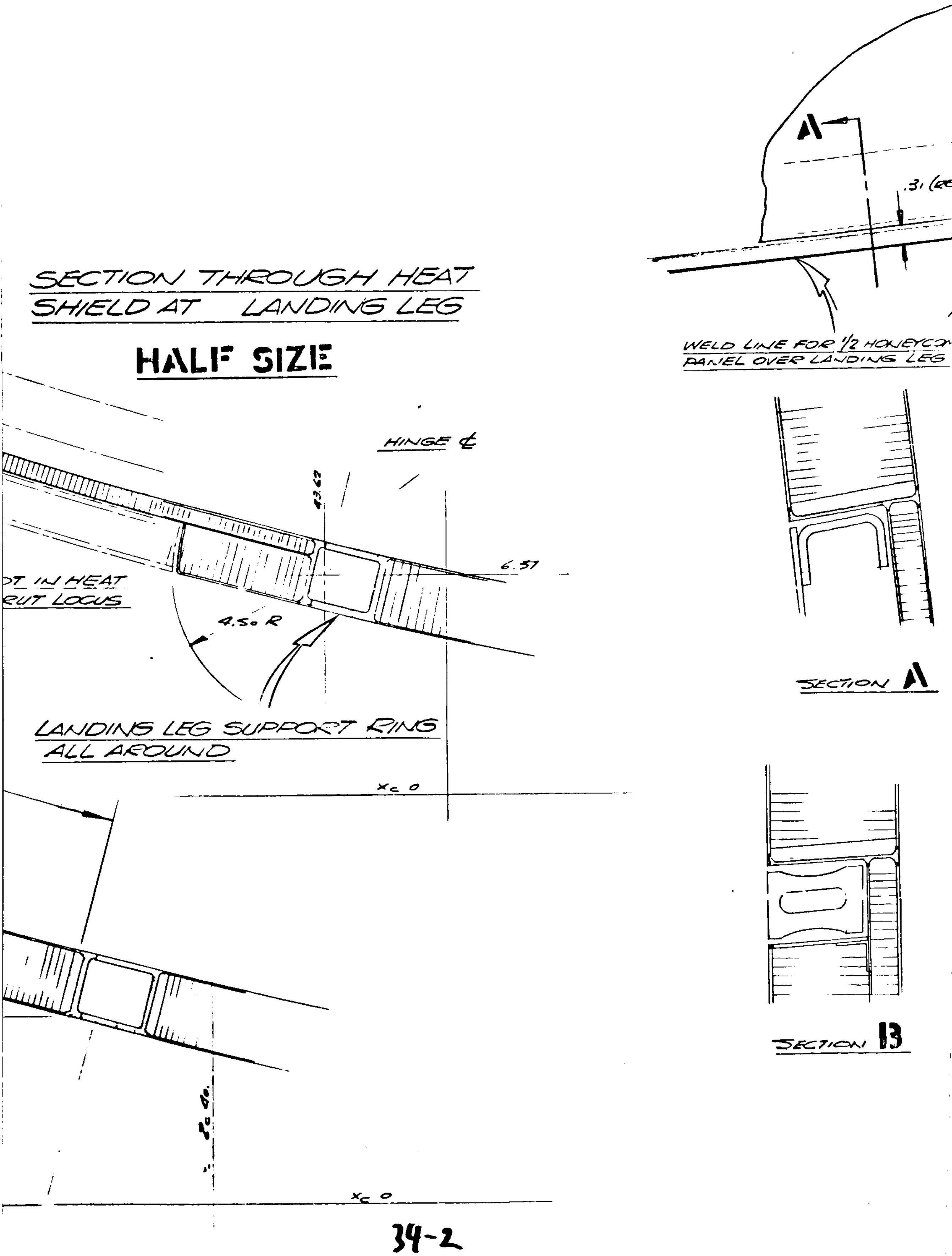

3/8 CORRUGATED FIL
TO SUPPORT OUTER
HONEYCOMB HEAT S
OVER LANDING LEG
STOWED L
75.2
13.20
CORRUGATED FILLET CLOSURE
DEEPENED THROUGH REGIONS
BETWEEN LANDING LEG RECESSES

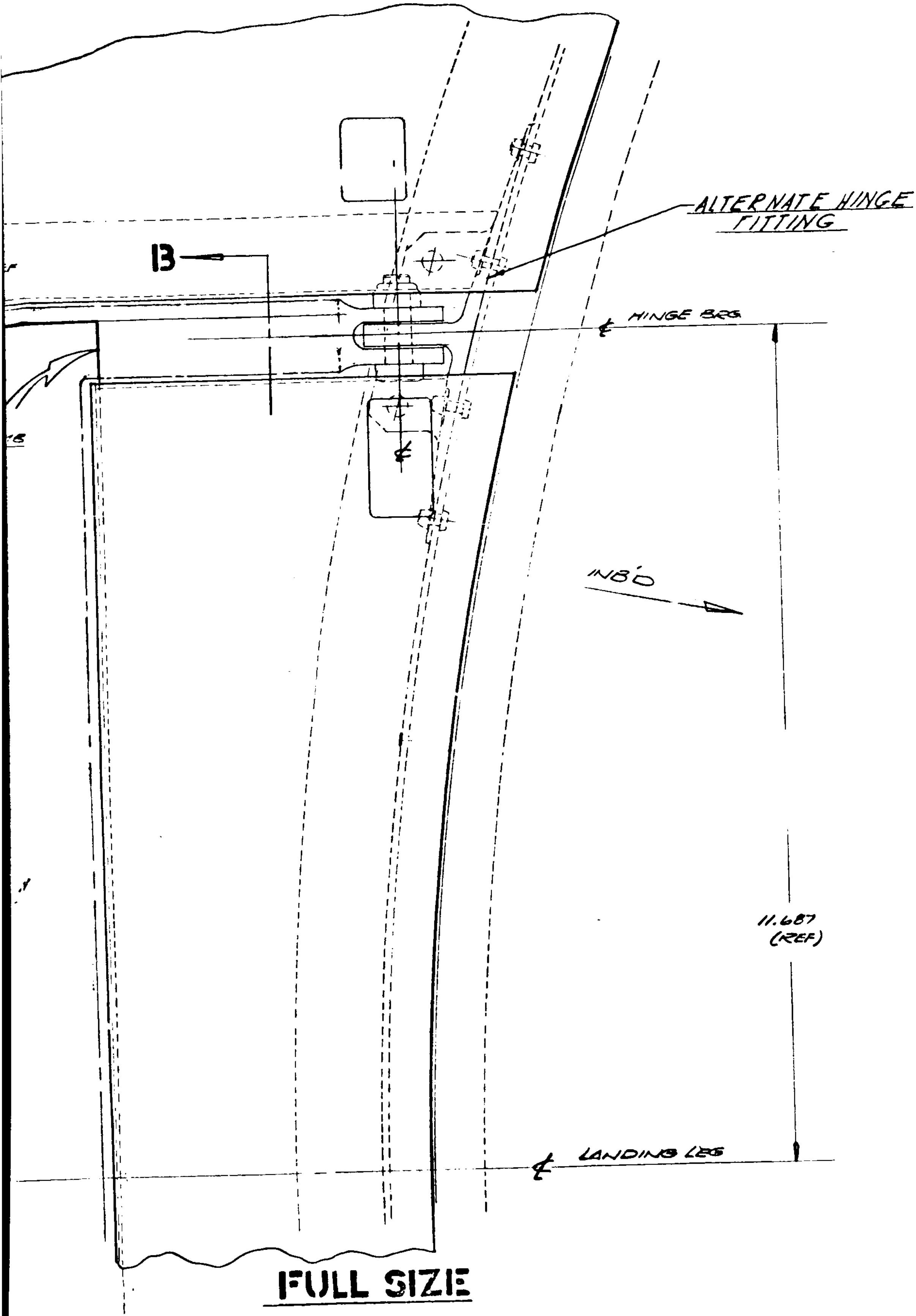


CTION THROUGH HEAT
IELD BETWEEN LANDING
SS

Zc 60

HALF SIZE

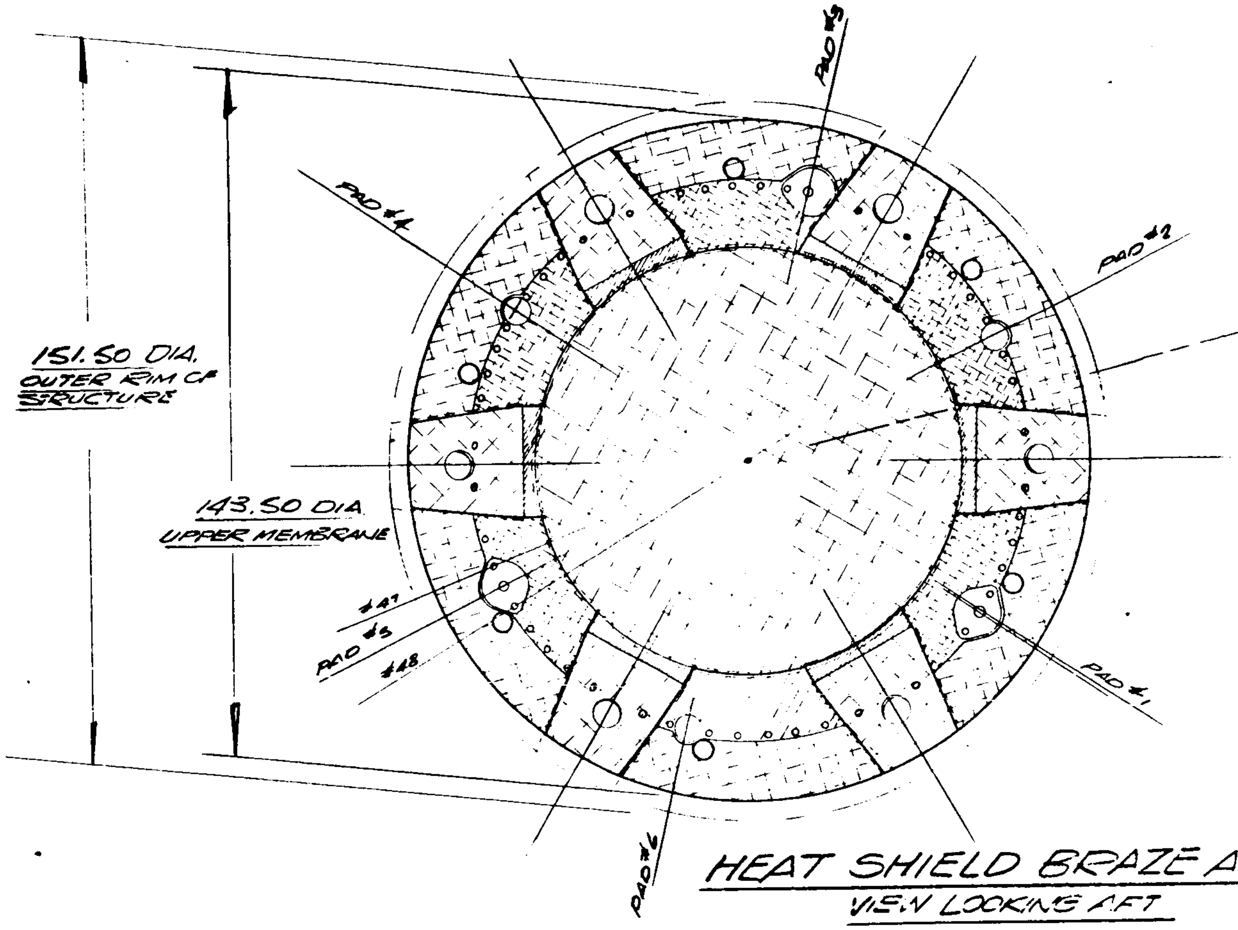

SECTION THROUGH HEAT SHIELD AT LANDING LEG
HALF SIZE
HINGE ¢
43.62
6.57
4.50 R
LANDING LEG SUPPORT RING ALL AROUND
x_c 0
x_c 0
WELD LINE FOR 1/2 HONEYCOM
PANEL OVER LANDING LEG
SECTION A
SECTION B



FULL SIZE

VIEW LOOKING FORWARD AT LANDING LEG HINGE

34-3



20TH S

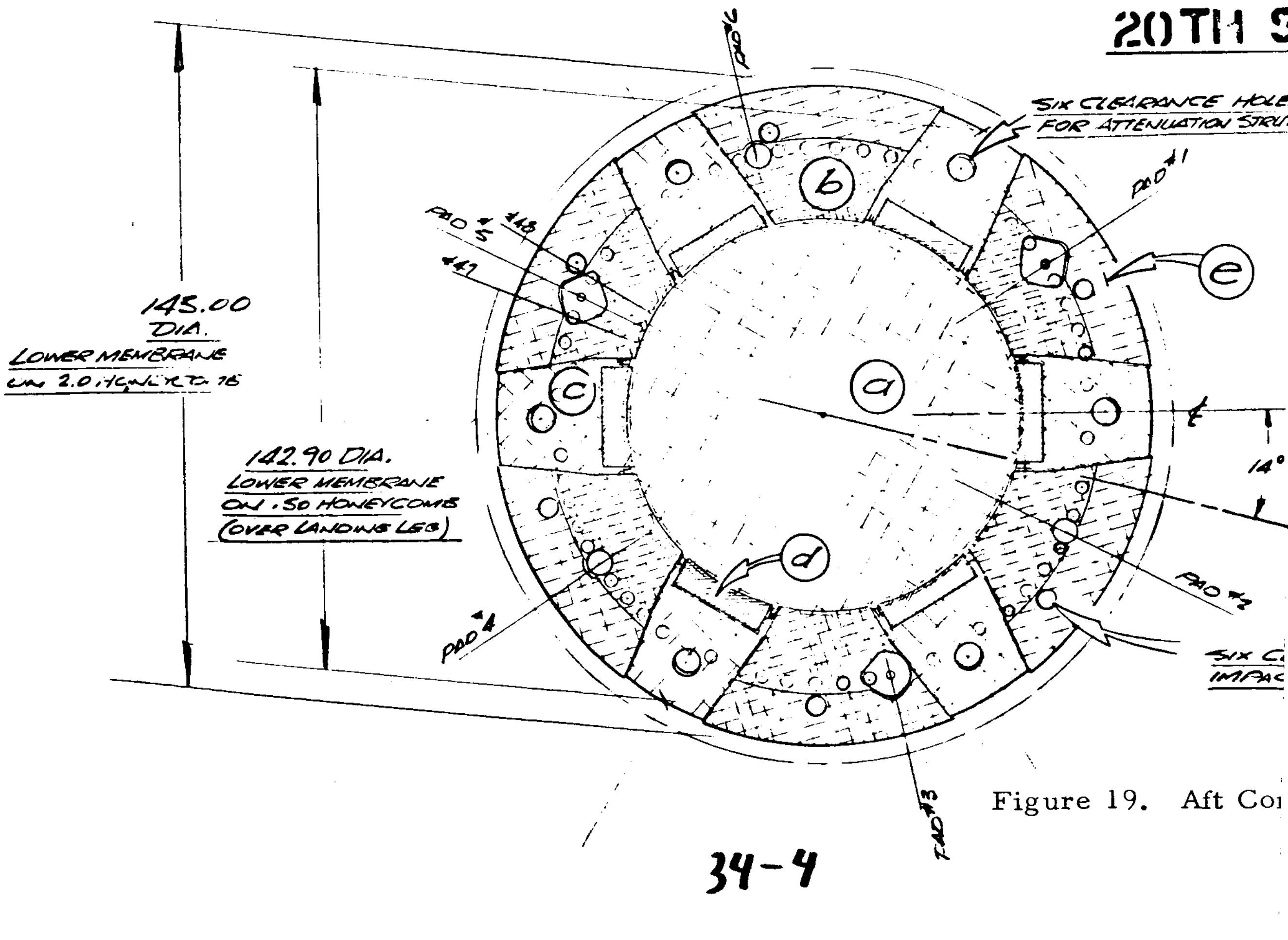


Figure 19. Aft Co

)

+Z

SSY

IZE

HONEYCOMB AREAS

PORTION	DESCRIPTION	NOM. AREA
a	CIRCULAR CENTER PORTION OF 2.0 THICK HONEYCOMB SANDWICH.	40.0 FT^2
b	SIX CIRCULAR SECTORS OF 2.0 HONEYCOMB SANDWICH FROM RING TO ℄ INCLUDING PATTERN OF SUPPORTS.	19.0 FT^2
c	SIX PANELS OF 0.50 HONEYCOMB SANDWICH OVER LANDING LEG STOWAGE RECESSES	29.1 FT^2
d	SIX FILL PORTIONS OF 1.5 HONEYCOMB SANDWICH FROM RING OUTWARD TO LANDING LEG INBOARD CLOSURE	4.4 FT^2
e	SIX CIRCULAR SECTORS OUTBOARD OF PATTERN OF SUPPORTS & BETWEEN LANDING LEG RECESSES.	27.0 FT^2

+Z

EARANCE HOLES FOR
RETRO MOTORS

partment Heat Shield for Use With Six-Leg Landing System

34-5

to be filled with silicone gasket seals bonded to the nonmoving structure. The seals possess sides sloped from the motion of extension to minimize the friction of scrubbing as the landing legs extend. Geometric arrangement of the impact attenuation system was sized for a touchdown clearance of 15 inches for the heat shield.

The extendable legs are sized to be located within recesses in the lower face of the spacecraft heat shield. Their shape conforms to that of the vehicle lower convex surface and the peripheral rim of the command module. The peripheral rim, duplicated on the leg segments, forms a natural skid along the translation vector of landing.

Each landing leg is retained in its stowage recess by an explosive tension bolt on each side which must be released prior to landing system extension. The landing leg design embodies bending material directly connecting the points of load concentration (i.e., the footprint, the attenuation strut rod, and the hinge points on the body). Depth of the bending material at any point remains a constant at 1.44 inches for stowage compatibility in the heat shield.

Dissipation of impact energy in the attenuation system is by the ejection of oil from a hydraulic strut on each of the six landing leg segments as it compresses in landing. The oil displaced in attenuation is that which was previously introduced to the struts to extend the legs.

The struts operate in a duty length from 20.50 inches retracted to 45.38 inches extended, and derive their 24.88-inch operational range from two coaxial rods and pistons. Each strut is provided with a bleed line located above the pistons that may be pinched off and welded at the conclusion of fill and bleed of the system. Hydraulic oil is filled throughout the system, but only above the pistons and in the retracted configuration. Cavities in the cylinder below the pistons contain no oil, and are, therefore, vented externally to permit cylinder cavity evacuation as the struts are extended. The unsealed end of the strut is equipped with a brazed bellows closure that safeguards against inadvertent oil leakage past the piston seals. The bellows should deflect sufficiently to permit limited stroking of the struts in system checkout, be of sufficient strength to resist an internal atmosphere in the vacuum environment, and be readily fractured by the force of rod extension.

The cylindrical body of each strut is provided with a conical bellows brazed to it and to the heat shield over the recess through which the rods operate. When installed, the bellows form sealed closures at each clearance hole to prevent flow of the hot gas from the landing retromotors to the inner structure of the spacecraft.

The aft heat shield ablative material and thickness distribution can be the same as for the basic Apollo vehicle. Gaps in the heat shield ablator made necessary by the extendable landing legs are filled with gasket material conforming to the currently recommended silicone synthetic compounded to the Apollo specification (Reference 7). Portions of the ablator over the legs are bonded to them in precise shapes that present faying edges geometrically shaped to match the extending motion with minimum bind and interference. To achieve this, each gap in the ablator possesses a wall normal to the surface on the fixed side, and a sloped wall on the movable side so the legs can be withdrawn from the stowed position at an angle open to the motion, thus, minimizing scrubbing.

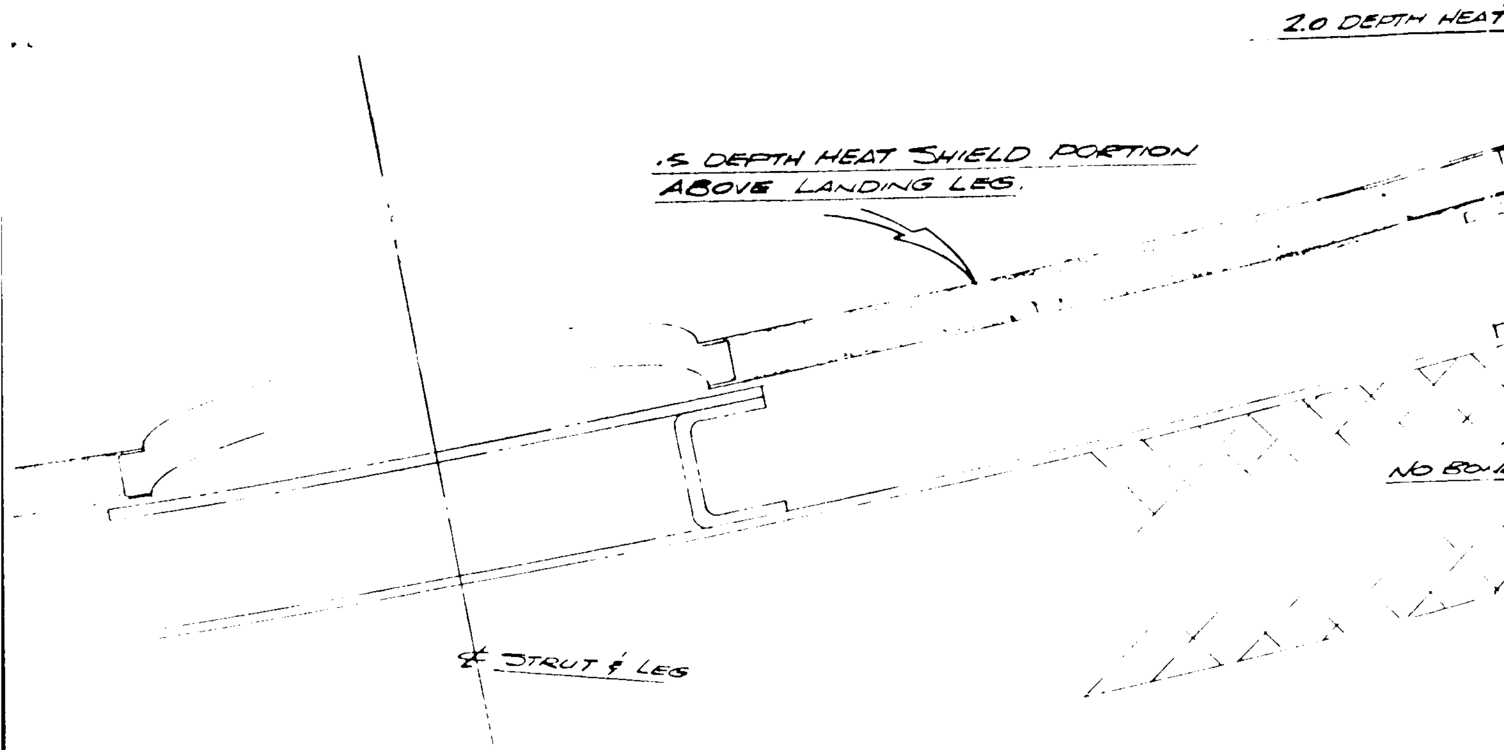
The inboard center portion of the landing leg segments, a length of about 22 inches, has a face which is a surface of revolution about the leg hinge center line, except for a slight draft to aid the leg motion. The nominal radius of the surface is 4.5 inches, which is considered a reasonable minimum to avoid a feather edge on the external surface of the ablator panel on the leg. The requirement to rotate the inboard side of the landing legs 4.5 inches from the hinge center line leaves narrow arms of 4.5 inches on each side as supports from the two hinges. The hinge arms have been provided with ablator plugs sloped to jettison from the vehicle as the force of the landing leg extension fractures their attachment. These details are shown in Section C of Figure 20.

SYSTEM OPERATION

Deployment of the landing impact system starts with a landing signal emitted by an altitude sensing system. This signal is followed by actuation of the explosive bolts which retain the legs and introduction of pressure into the struts by a two-way valve. The resultant force in the struts opens the landing legs from the fixed heat shield and extends them to the landing position. Landing energy is spent by ejection of the pressurized oil from the compressed struts. Landing loads are transmitted to the command module inner structure through strut attachments on the side wall and through the leg hinges that connect to the fixed portion of the heat shield.

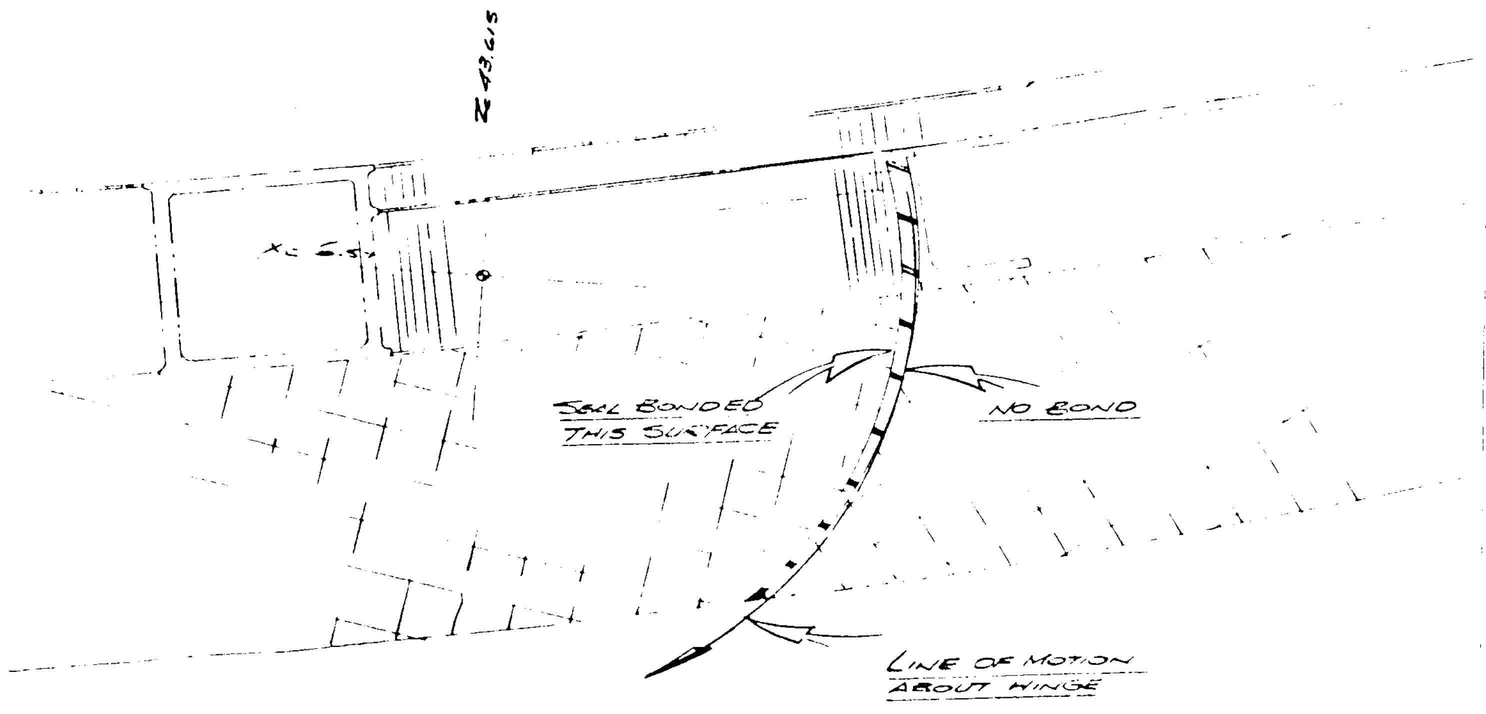
SPACECRAFT COMPATIBILITY

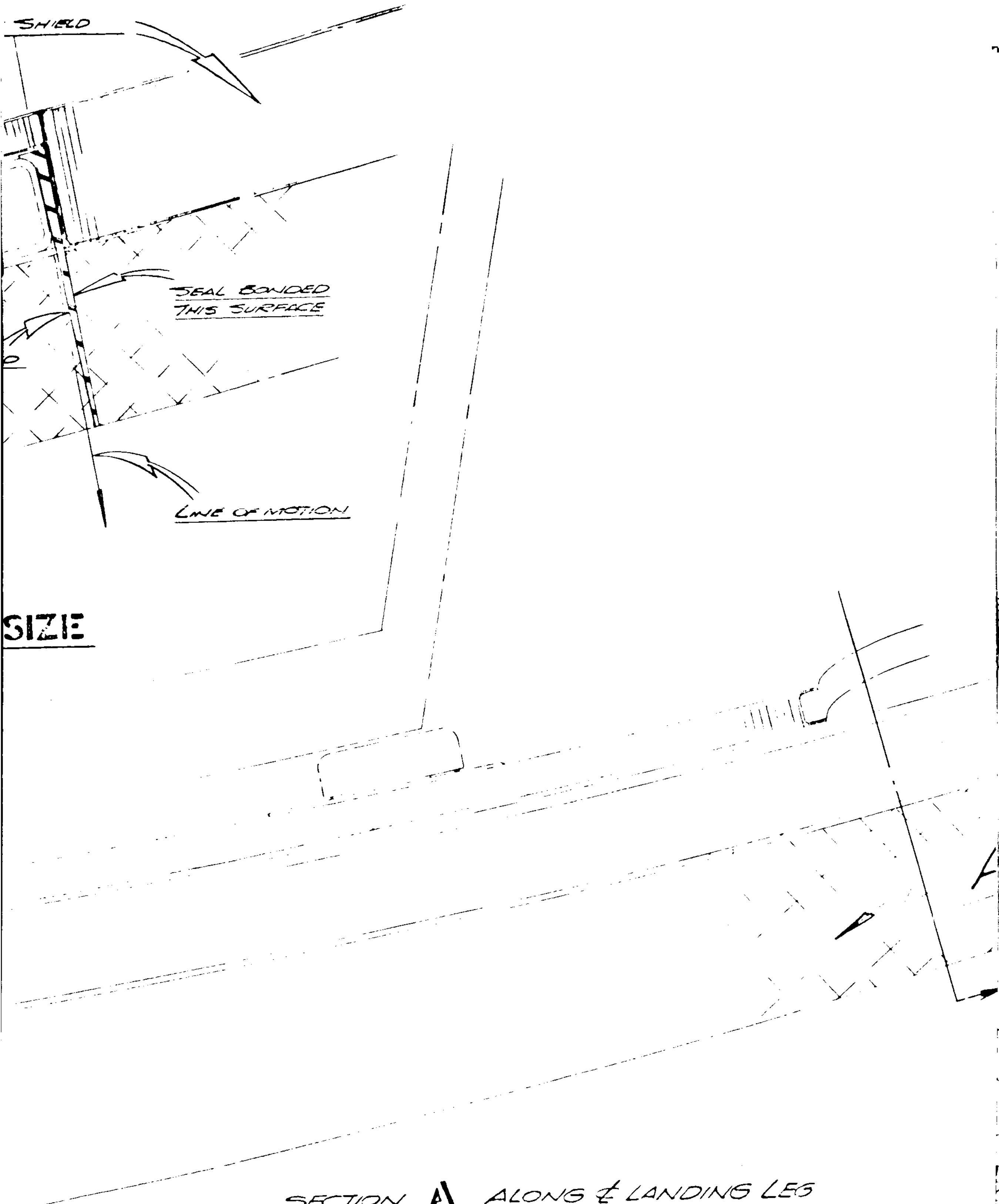
The command module inner structure will require modifications to accommodate the landing impact system attachments. The design of the aft heat shield was modified to incorporate the legged segments within the contours of the Apollo command module. Technical problems derived from manufacturing and operation of this heat shield have been studied and feasible solutions are presented in Figure 20.



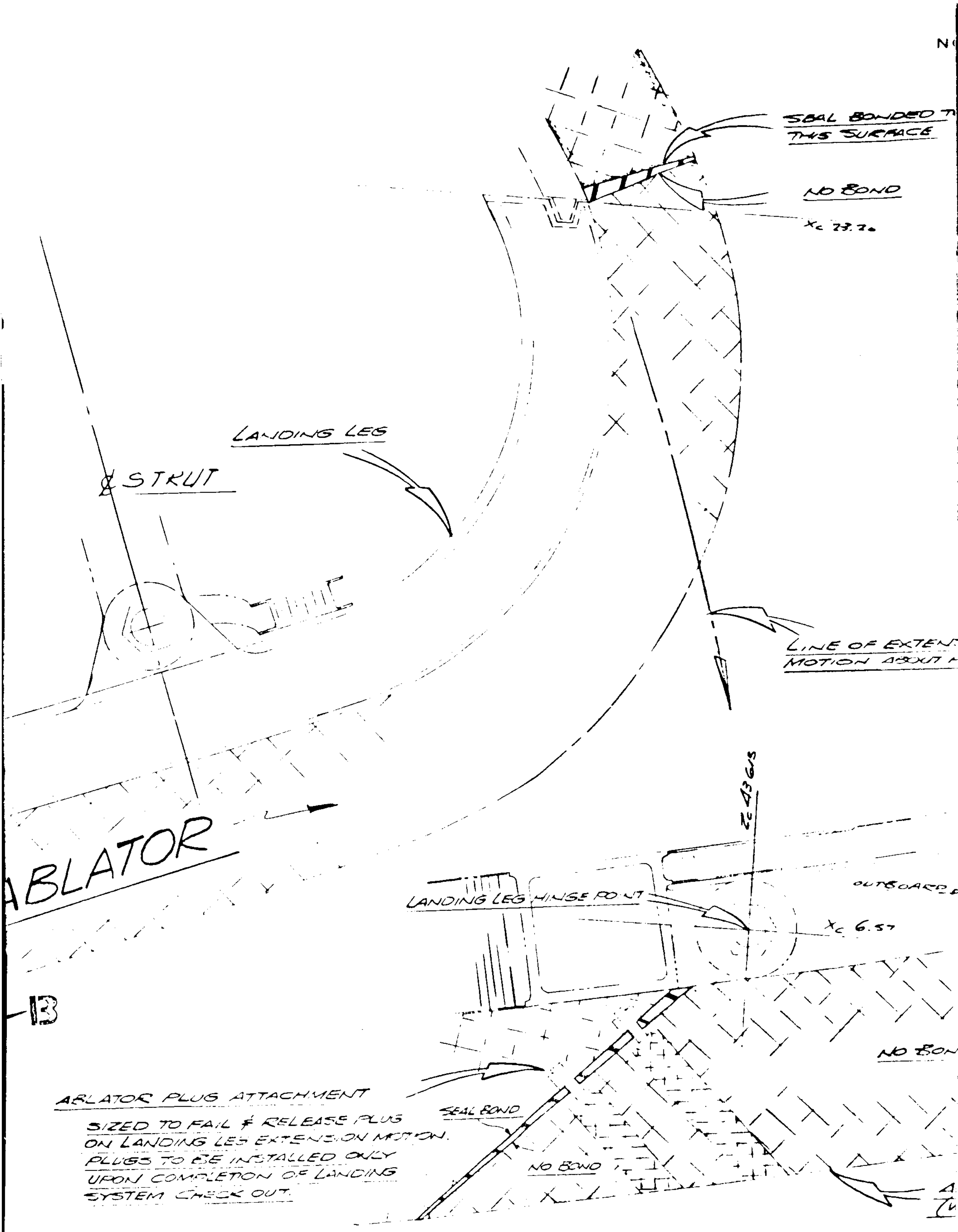
SECTION B THROUGH LANDING LEG
SHOWING SIDE BOUNDARY SEAL

FULL





SECTION A ALONG ℄ LANDING LEG
SHOWING SEAL ABOUT HINGE AND
AT TOE OF SHOE



SECTION C THROUGH LANDING LEG HING
SHOWING ABLATIVE PLUG FOR DISPLACE
AND SEAL ARRANGEMENT

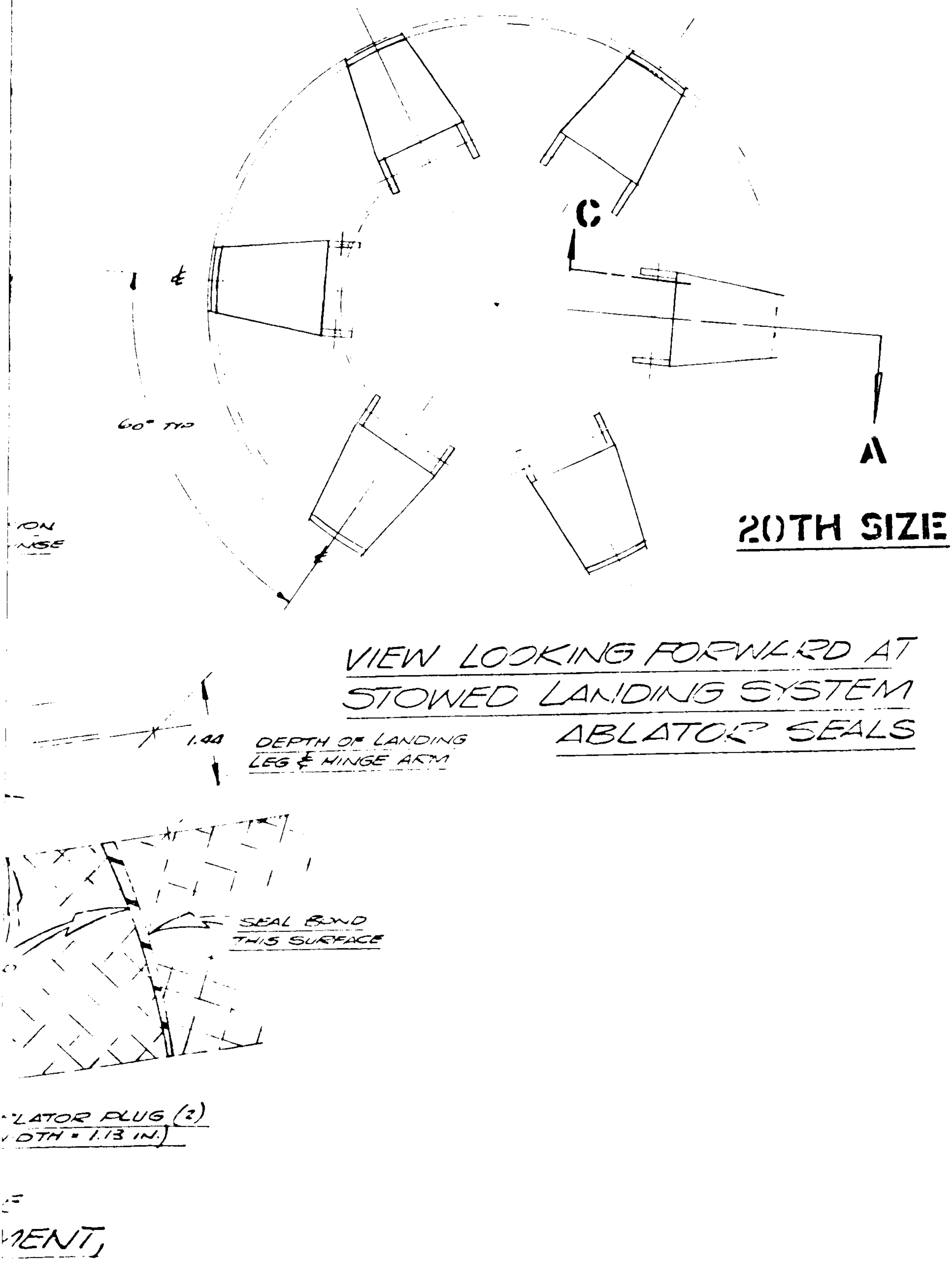


Figure 20. Ablator Seal Arrangement - Six-Leg Landing System, MISDAS Study

PACKAGING CONSIDERATIONS

Figure 21 illustrates a packaging arrangement for the four retromotors required to attain the vertical landing velocities given in the Guidelines, Constraints, and Design Crtieria Section, the subsystem components, and six deployable heat shield segments. The structural and mechanical details of the segmented heat shield concept are shown in Figure 18. The six segments are symmetrically located in the heat shield with the axis of the pattern positioned 14 degrees off the command module +Zc axis. The retromotors are unsymmetrically positioned 30 and 40 degrees either side of the command module -Zc axis.

Installation of the landing leg extension and damping cylinder and the four retromotors in the command module aft compartment equipment bay will require the following revisions in the location of the subsystem components and the aft compartment frames:

1. The reaction control system motor switches located between Frames 1 and 2 will require repositioning in the same area due to installation of the landing leg extension and damping cylinder.

2. Frames 4 and 7 will require redesign to provide for installation of the retromotors at these locations. The Block II side wall attach fittings will be redesigned to provide support for the retromotors and attach provisions for the new frames.

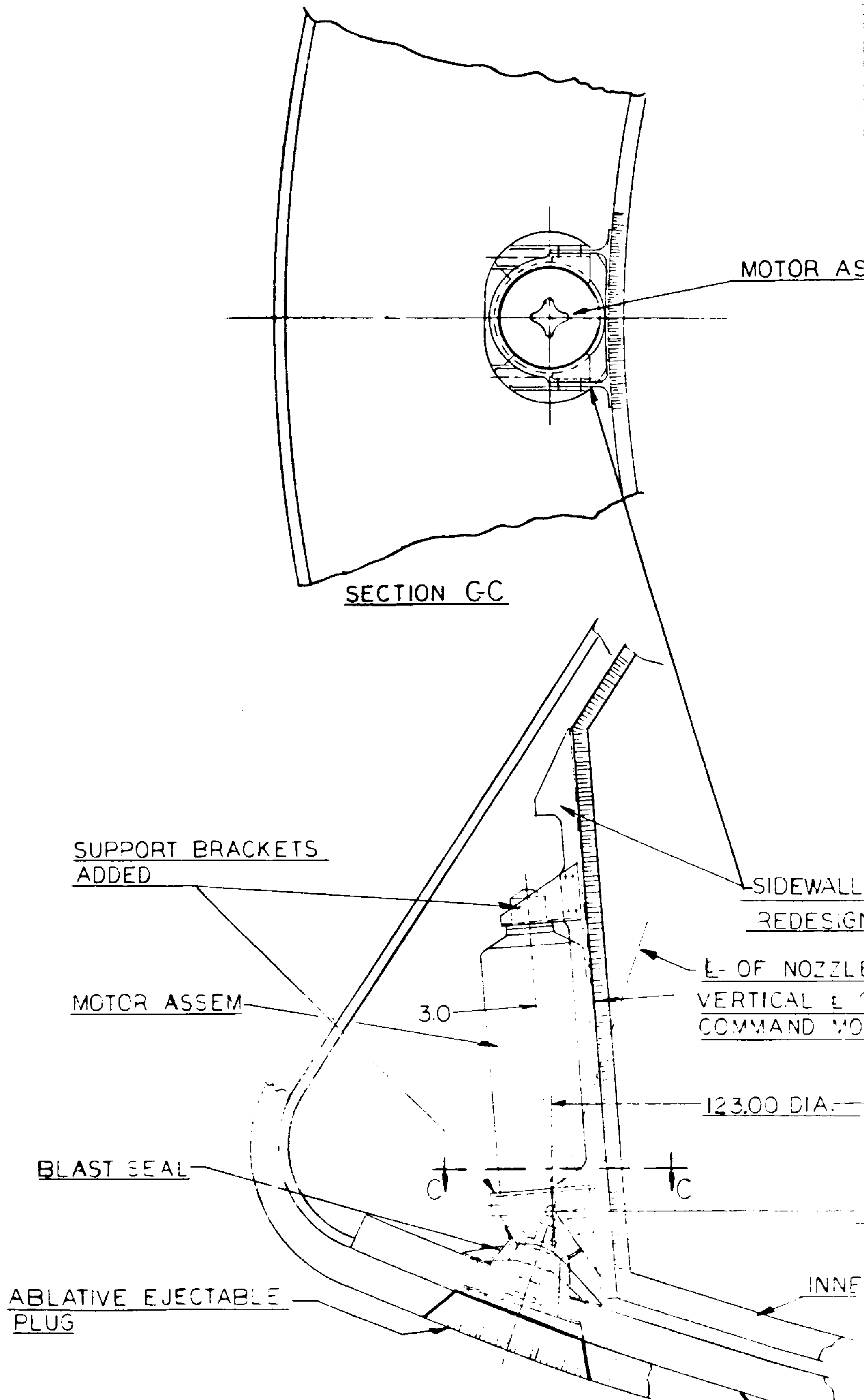
3. Frame 5 will require redesign to accommodate installation of the landing leg extension and damping cylinder.

4. The arrangement of the fuel control panel between Frames 9 and 10 will require modification in the same area due to installation of landing leg extension and damping cylinder.

5. The drinking water tank and plumbing located between Frames 13 and 14 will require relocating between Frames 22 and 23 to provide space for the landing leg extension and damping cylinder. New support structure for both the water tank and cylinder will be required.

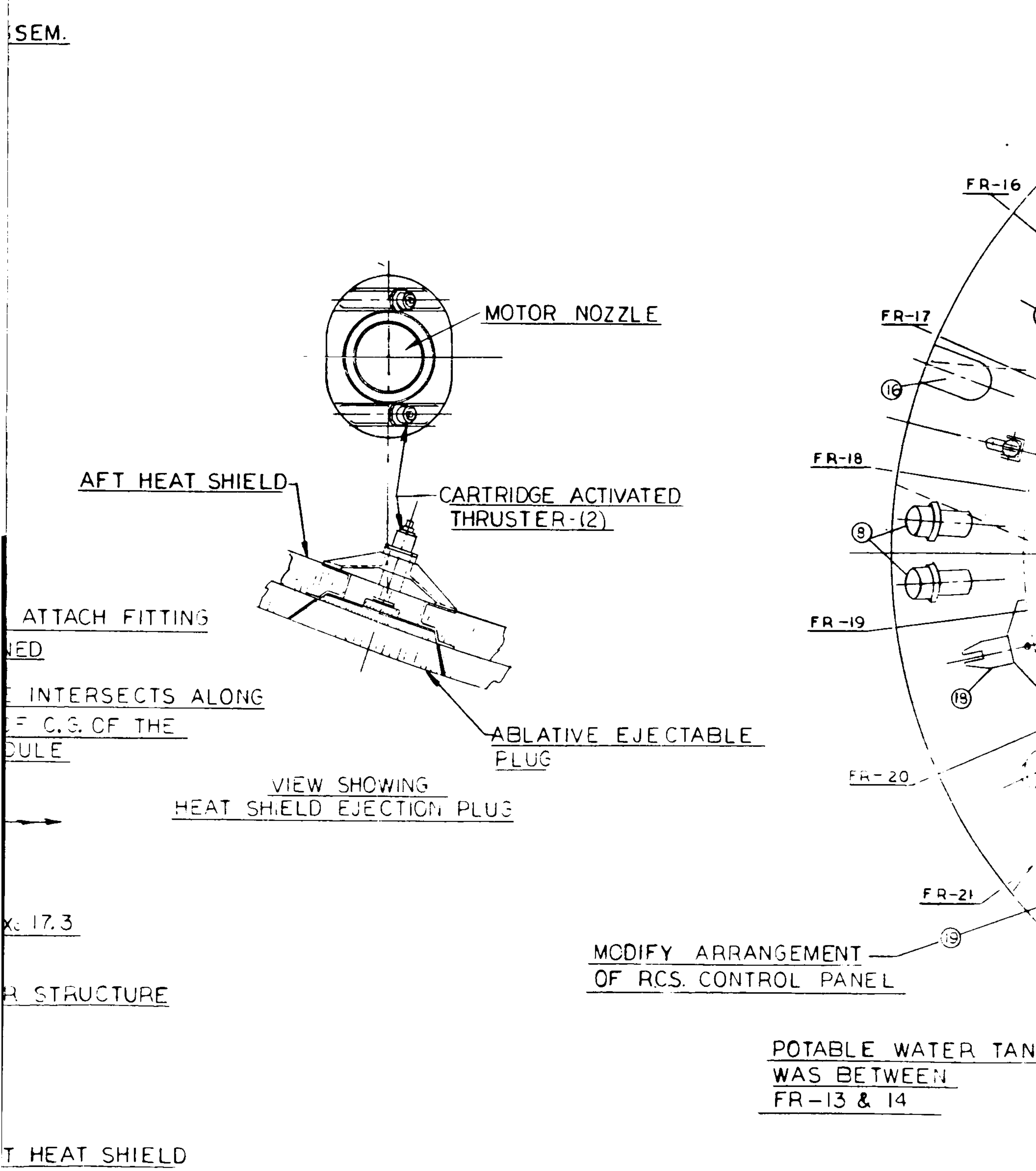
6. The retromotors located between Frames 16 and 17 and between Frames 21 and 22 will require design of supports compatible with the present aft compartment structure.

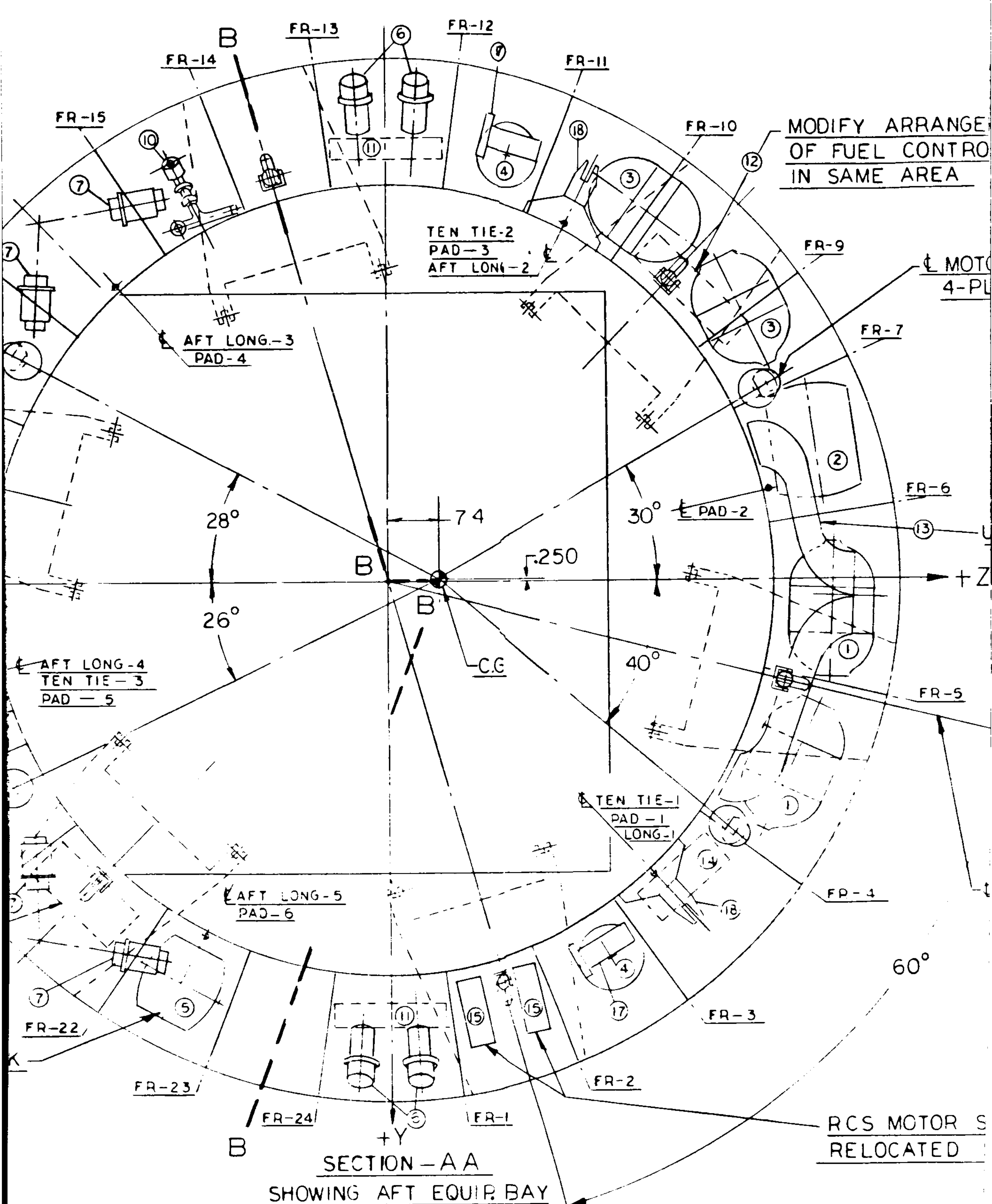
7. The landing leg extension and dampening cylinders between Frames 17 and 18 and between Frames 21 and 22 will require design of support structure. The RCS control panel between Frames 21 and 22 will require modification to accommodate the landing leg and damping cylinder and its support structure which is added to this area.



SECTION THRU AFTCOMPARMENT
SHOWING MOTOR INSTALLATION
TYPICAL 4-PLACES

PRECEDING PAGE BLANK NOT FILMED.


SEM.
MOTOR NOZZLE
AFT HEAT SHIELD
CARTRIDGE ACTIVATED
THRUSTER-(2)
ATTACH FITTING
ED
INTERSECTS ALONG
C.G. OF THE
ULE
ABLATIVE EJECTABLE
PLUG
VIEW SHOWING
HEAT SHIELD EJECTION PLUG
17.3
STRUCTURE
T HEAT SHIELD
FR-16
FR-17
FR-18
FR-19
FR-20
FR-21
16
8
19
MODIFY ARRANGEMENT
OF RCS. CONTROL PANEL
POTABLE WATER TAN
WAS BETWEEN
FR-13 & 14



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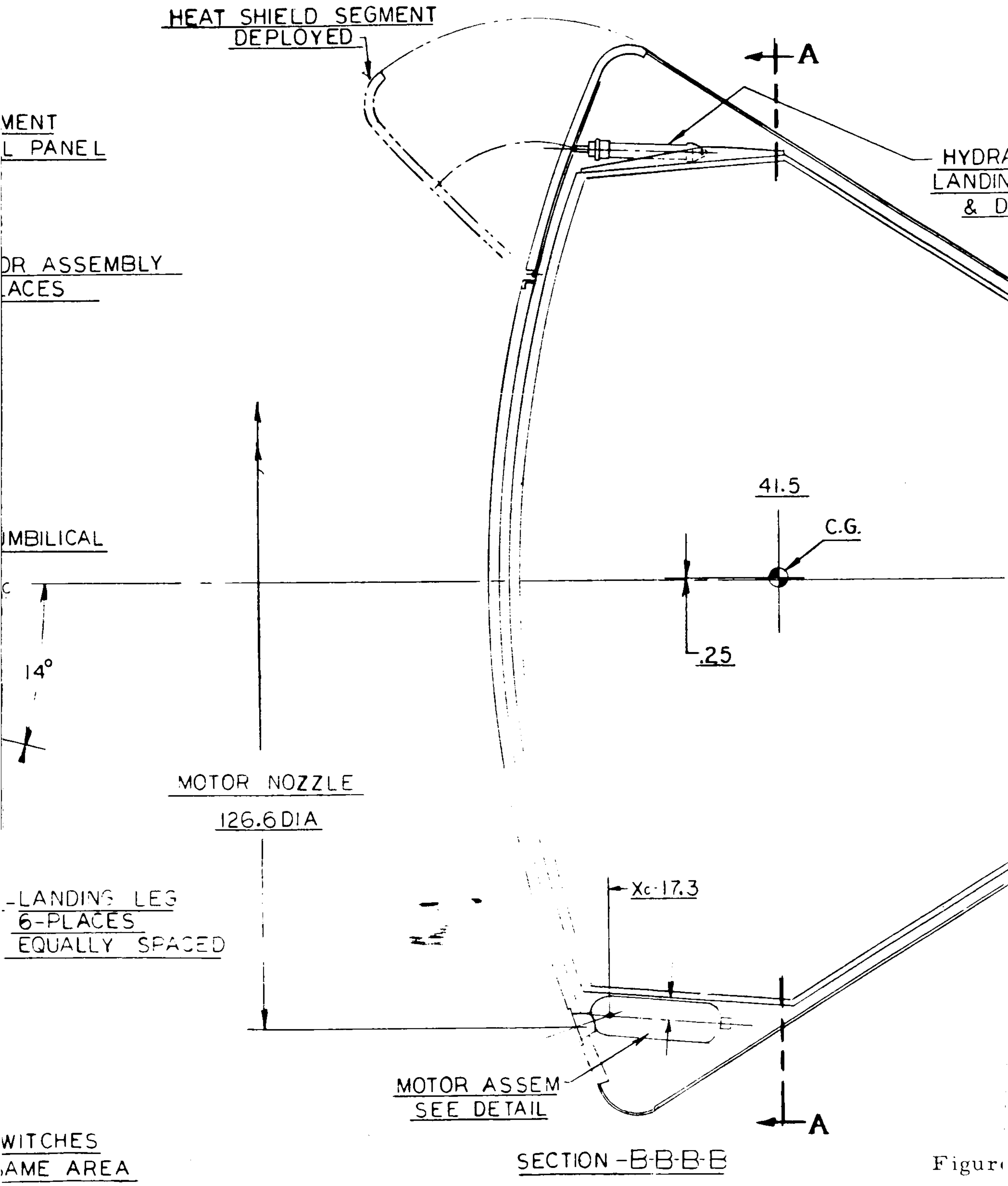
LOOKING AFT

42-2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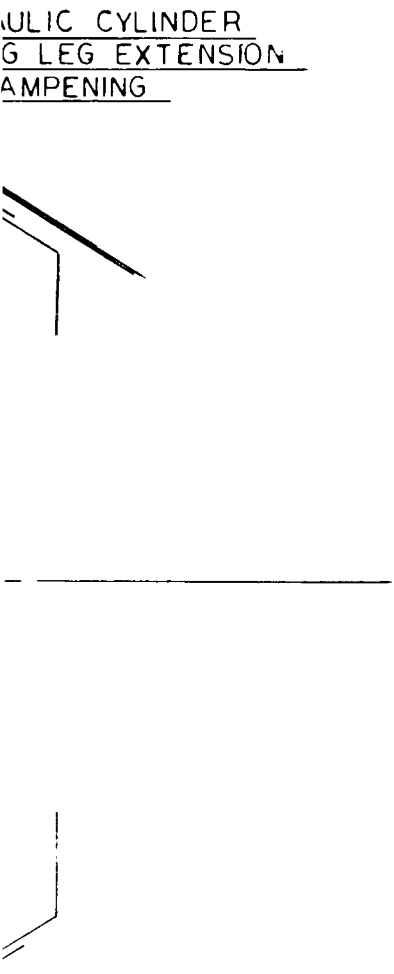


1. OXIDIZER TANK 2
2. WASTE WATER TANK
3. FUEL TANK 2
4. HELIUM TANK 2
5. POTABLE WATER TANK
6. YAW RC ENGINE 4
7. ROLL RC ENGINE 4
8. PITCH RC ENGINE 2
9. RELIEF DUMP NOZZLE
10. STEAM VENT
11. HELIUM PRESSURE PANEL 2
12. FUEL CONTROL PANEL
13. ELECTRICAL UMBILICAL
14. OXIDANT CONTROL PANEL
15. RCS MOTOR SWITCH
16. AIR VENT
17. UPRIGHTING SYSTEM COMPRESSOR
18. TENSION TIE
19. RCS CONTROL PANEL

NOTE

ALL BLOCK-II EQUIP IN AFT COMP'T.
REMAINS UNCHANGED EXCEPT AS NOTED

21. Retromotor Assembly Installation Segmented Heat Shield Concept, MISDAS Study

STRUCTURAL ANALYSIS

Stress and deflection analyses were performed to verify the technical feasibility of the six-segmented heat shield concept installation in a 14,000-pound vehicle for an impact velocity of 15 fps. Stress calculations were also performed to determine the effect of vertical velocities of 20 and 30 fps on MISDAS structural design. These analyses included studies of the principal components of the impact attenuation system, the aft heat shield, and affected portions of the command module inner structure. A complete analysis has been performed for the 15-fps impact velocity, which establishes the sizes of the principal components of the impact system and demonstrates the structural integrity of the command module inner structure. Loads resulting from the higher impact velocities of 20 and 30 fps exceed the structural capability of the command module inner structure. Sufficient analysis has been made in Appendix A for these velocities to determine the size of the principal components of the impact system, and to show the nature and extent of the changes required to reestablish the structural integrity of the command module inner structure. The analyses are based on Figures 18 and 19, and the design criteria presented in the Guidelines, Constraints, and Design Criteria section. Load paths are shown in Figure 22.

Critical Conditions

The critical design conditions are ground impact, water impact, 20-g entry, and boost abort. The land impact condition is critical for design of the shock strut, the shock strut attachment fittings, the command module inner structure aft section from Sta Xc 14 to Xc 42, the deployable legs, and the box section ring in the aft heat shield. The water impact condition is critical for aft heat shield honeycomb panel design within a radius of 58 inches. The 20-g entry condition is critical for aft heat shield torsional section design. Boost abort loads design the heat shield attachment to the inner structure.

Assumptions

The structural design criteria presented in the Guidelines, Constraints, and Design Criteria section are consistent with the Apollo Requirements Manual ARM-6 (Reference 6), with the following exceptions: the water impact condition was limited to a consideration of 15, 20 and 30 fps impact velocity for a vehicle weight of 14,000 pounds. The ground impact condition was based on a shock strut load derived from the dynamic analysis.

The following factors were applied to the design limit loads to establish the ultimate load to be considered:

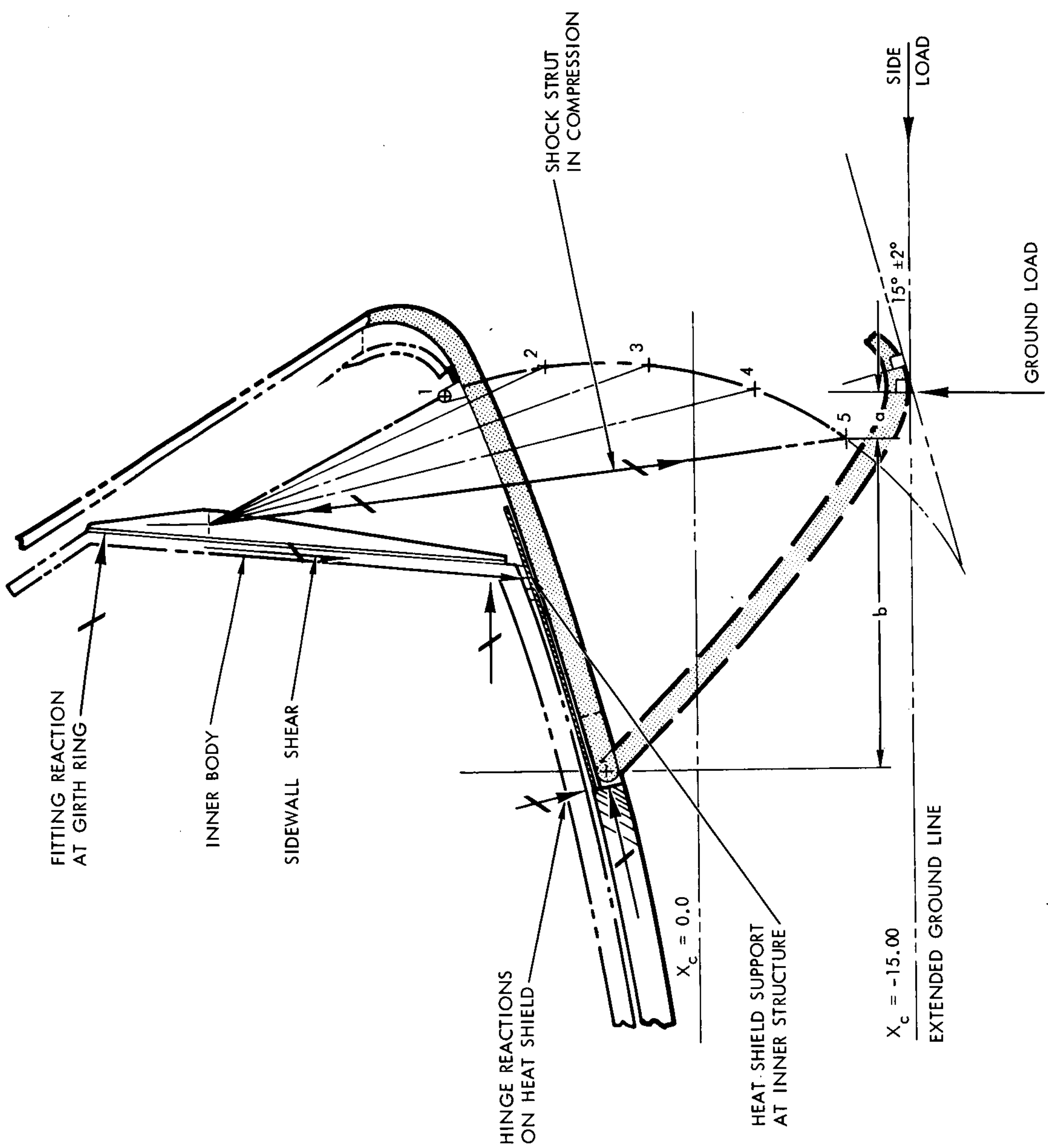


Figure 22. Load Path for Six-Legged System

1. Ground impact

   Deployable legs: 1.00

   All other structure: 1.33

2. Water impact

   All structure: 1.00

3. 20-g entry

   All structure: 1.50

The 1.33 factor for the structure was specified in Paragraph IV-A-11 of Exhibit A of Contract NAS9-4915. The factor of 1.00 is used for the components designed to impact on ground or water, because these components are expected to yield on impact.

The aft heat shield, deployable legs, and the shock struts were analyzed for a temperature of 600 F and the inner structure for a temperature of 200 F. These values are the maximum temperatures used for the Apollo analysis. The value of 600 F is conservative in that it is the maximum temperature expected at the ablator-heat shield interface.

Principal Results and Conclusions

The design concept shown in Figure 18 can satisfy the structural design criteria. The member sizes derived from this study were used to calculate the system weights shown under the Mass Properties discussion for the six-segment concept. Table 3 shows the critical conditions, stress, and margin of safety for each major component. The stress calculations are presented in Appendix A of this report. Principal results are discussed below.

The aft heat shield substructure has been modified to accommodate the six deployable legs within the contour, with changes resulting in the available load paths. All loads are applied to the heat shield, either as distributed loads or loads concentrated at selected points. These loads are reacted by the aft bulkhead ring of the command module inner structure. The primary load path assumed is through that portion of the aft heat shield substructure that has retained a full 2-inch depth. A secondary load path is available through the 0.50-inch honeycomb panels forward of the deployable leg wells. Conservatively, and for simplicity of analysis, these 0.50-inch panels have been assumed to carry no primary loads; however, their presence is essential to the heat shield structure to minimize differential deflection between the segments during atmospheric entry. A box section ring 88 inches in diameter has been welded into the structure to pick up the deployable leg hinges.

Table 3. Critical Stresses and Margins of Safety For The Six-Segmented Heat Shield Concept (14,000-Pound Vehicle Descending at 15 fps)

Item	Material	Size (inches)	Critical Condition	Stress (psi)	Allowable Stress (psi)	Margin of Safety	Design Factor of Safety
Aft heat shield skin	Steel, PH14-8	t = 0.019 t = 0.055	Water impact	145,000	150,000	0.03	1.00
Aft heat shield core	Steel, PH14-8	3/16 Cell 0.003 Foil	Water impact	684	910	0.33	1.00
Toroidal corrugated skin	Steel, PH14-8	Foil 0.015 Skin 0.020	20-g entry	31,800	44,100 (buckling)	0.39	1.50
Aft heat shield ring (88-inch diameter)	Steel, PH14-8	t = 0.156	Ground impact	76,500	77,000 (after welding)	0.0	1.33
Deployable leg beams	Steel, PH14-8	t = 0.156 and 0.125	Ground impact	140,420	156,000	0.11	1.00
Deployable leg skin	Steel, PH14-8	t = 0.080	20-g entry	72,300	156,000	1.16	1.50
Deployable leg stiffness	Steel, PH14-8	t = 0.080	20-g entry	94,500	156,000	0.65	1.50
Shock absorber support	Aluminum alloy, 7075-t6		Ground impact	50,460	60,000	0.19	1.33
Inner structure aft sidewall skin	Aluminum alloy, 2014-t6	t = 0.026	Ground impact	35,800	38,000	0.06	1.33
Inner structure aft sidewall skin bonds	Epoxy adhesive		Ground impact	753	1,320	0.76	1.33
Shock absorber	Steel, 180,000 HT		Ground impact	90,500	91,000 (Column allowable)	0.07	1.33

NOTE: During this preliminary analysis, a minimum positive margin of safety, including zero, has been considered acceptable to minimize the weight of structural components.

Within this ring, the structure is considered as a spherical shell; outboard of the ring, the 2-inch deep segments carry the loads from the heat shield to the inner structure aft bulkhead ring in bending. The loss of hoop continuity in the toroidal portion of the aft heat shield has been compensated for by an increase in the depth and the gauge of the corrugated foil and skin.

The land impact loads on the deployed legs are applied to the outer skin and reacted by a shock strut and two hinges per leg. To achieve the required bending and torsional stiffness in the limited depth available, the legs have been designed as box sections of riveted construction. Since the leg in the retracted position forms part of the heat shield, and in this position, is subjected to entry air loads, stiffeners have been added on the forward surface of the outer skin to provide a panel stiffness equivalent to the fixed portion of the heat shield.

The aft heat shield is bolted to the inner structure at the aft bulkhead ring. To react the tensile loads present in the boost abort condition, 7/16-inch bolts are required because space available between the deployable segments permits installation of only 36 bolts; 59 are used in the present Apollo. The forward end of each shock strut is attached to a fitting which introduces the load to the inner structure aft sidewall. For the 15-fps impact velocity consideration, this fitting is bolted to the girth ring and the aft bulkhead ring, and is bonded to the aft sidewall skin. The aft sidewall skin then reacts the vertical component of the shock strut load in shear. The radial component of the shock strut load is carried in bending by the fitting and is reacted by the rings. The loads associated with impact velocities in excess of 15 fps require a different design (Appendix A, Pages 5.4 and 5.12).

Effects of Increased Vertical Velocity and Increased Friction Coefficient

A study was performed to determine the effects of vertical landing velocities of 20 and 30 fps and of effective ground coefficients of friction in excess of 0.35 on the structural design of the MISDAS components and the spacecraft inner structure. This study, limited to stable landing conditions defined by the dynamic landing analysis, consisted of a stress analysis and component sizing for loads derived from vertical landing velocities of 20 and 30 fps. No analysis was performed for coefficients of friction larger than 0.35 because the spacecraft is not stable under those conditions without roll control. The analysis shows that loads derived from 20 and 30 fps vertical velocities exceed the structural capability of the Apollo command module inner structure. Sufficient analysis has been performed (Appendix A) to show the nature and extent of changes required to reestablish the structural integrity of command module inner structure and landing system components. The major revisions are described in the following paragraphs.

Skin gauges required by the aft heat shield substructure, calculated for impact velocities of 15, 20, and 30 fps, are as follows:

Velocity (fps)	Skin Gauge (inches	88-Inch Diameter Ring Cross Area (in.^{2})
15	0.019 to 0.055	1.48
20	0.018 to 0.085	3.50
30	0.032 to 0.148	4.10

The toroidal portion of the aft heat shield, designed by entry air loads was not affected by the increased impact loads. The 0.50-inch honeycomb panel covering the deployable leg wells had to be moved forward to provide the additional leg volume required to design for the 30-fps impact velocity, reducing the clearance between the heat shield and inner structure to 0.3 inch.

Analysis of the deployable leg beam shows that the increased loads associated with an impact velocity of 20 fps require two "I" section members in place of two channels to provide increased moment of inertial and increased shear attachment capability. A sketch of the required section is shown on Page 5.3 of Appendix A. To achieve the moment of inertia and additional shear attachment capability required by an impact velocity of 30 fps, more members are necessary and an increase of 0.50 inch in the deployable leg beam depth is required.

The sketch on Page 5.10 of Appendix A shows the changes required to provide clearance for the increased leg section depth; the sketch on Page 5.11 shows the changes required by the deployable leg beam. Some weight saving would result from increasing the number of leg hinges from 2 to 4 and, thus, reducing the magnitude of the concentrated loads on the aft heat shield hinge support ring. However, the additional cut-outs in the aft heat shield sub-structural required for this change would increase the complexity of the design.

Some structural redesign of the command module inner structure is required to support the loads imposed by impact velocities of 20 and 30 fps. For these conditions, a longeron is required at each shock strut location. The longerons must be welded into the basic weld assembly of the aft section in the same manner as on the existing Apollo. The shock strut attachment fittings are located on these longerons with threaded fasteners. The required longeron sections for 20- and 30-fps impact velocities are shown in sketches presented in Appendix A, Pages 5.4 and 5.12, respectively. The reaction to the shock strut radial load at the girth ring Station 43 exceeds the structural capability of the ring section in the area of the main access hatch. Doubling of the moment capability of this ring in the critical area is required by the impact loads associated with 20-fps velocity; four times the moment capability is required by the 30-fps velocity. The analysis conservatively assumes that all the vertical impact load imposed on the inner structure is reacted in shear by the aft sidewall skins. To support this shear, the skin and weld land thickness on the aft portion of the inner structure must be increased as shown in the stress calculations of Appendix A.

Tables 4 and 5 show material, size, critical conditions, and factor of safety achieved for major components of the segmented heat shield concept modified to sustain landing at 20 and 30 fps, respectively.

STABILITY ANALYSIS

The landing stability characteristics of the segmented heat shield vehicle were determined through the use of "LEGGED," a FORTRAN IV computer program which is a three-dimensional mathematical model of a legged spacecraft. When initial conditions (i.e., landing parameters) are loaded, the program simulates the dynamics of a real spacecraft making an earth landing. The ground reactions produce forces and torques in the spacecraft. The laws of motion are integrated, using small time increments to produce linear and angular acceleration, velocity, and displacement time histories. Use of the FORTRAN IV feature NAMELIST allows for a flexible input sequencing. This program is, therefore, very useful in parametric studies. Loading time for the object deck is 30 seconds, and computer time per landing case is on the order of 10 to 15 seconds. The LEGGED program is described in detail in Report SID 65-278, presented as Appendix C of this report.

The geometry of essential points on the spacecraft is described by the coordinates of each point in a coordinate system fixed to the spacecraft (capsule initial system). For example, the center of gravity is located by loading in its three coordinates in the capsule initial system. The same approach is used to establish the location of each strut end. Any number of struts are allowed, and each may have different stroking properties. However, once a strut is located on the vehicle, the strut tip deforms (moves) in a straight line toward the strut end attached to the spacecraft. The properties of each strut must be expressible as a load-stroke curve which can be formed by a series of straight lines. The principal strut property is plastic deformation, but provisions are made for the inclusion of velocity damping and elasticity. The struts (legs) are considered to be massless.

Table 4. Critical Stresses and Margins of Safety for the Six-Segmented Heat Shield Concept (14,000-Pound Vehicle Descending at 20 fps)

Item	Material	Size (inches)	Critical Condition	Stress (psi)	Allowable Stress (psi)	Margin of Safety	Design Factor of Safety
Aft heat shield skin	Steel, PH14-8 MO	t = 0.018 to 0.085	Water impact	150,000	150,000	0.0	1.00
Aft heat shield core	Steel, PH14-8 MO	3/16 cell 0.003 foil	Water impact	1,068	1,610	0.50	1.00
Aft heat shield ring (88-inches diameter)	Steel, PH14-8 MO	t = 0.350	Ground impact	68,100	77,000 (after welding)	0.13	1.33
Deployable leg beams	Steel, PH14-8 MO	t = 0.1875 and 0.156	Ground impact	149,400	156,000	0.04	1.00
Shock absorber fitting	Aluminum alloy, 7075-t6		Ground impact	59,900	60,000	0.0	1.33
CM inner structure Aft sidewall skin	Aluminum alloy, 2014-t6	t = 0.045	Ground impact	36,800	38,000	0.03	1.33
CM inner structure Aft sidewall skin bonds	Epoxy adhesive		Ground impact	1,330	1,320	0.0	1.33
CM inner structure Ring of longeron weld lands	Aluminum alloy, 2014-t6	t = 0.070	Ground impact	14,400	15,000 (after welding)	0.04	1.33
CM inner structure Girth ring station Xc 43	Aluminum alloy, 2014-t6		Ground impact	108,000	60,000	0.0*	1.33
Shock absorber	Steel, 180,000 HT		Ground impact	119,500	120,000 (Column allowable)	0.0	1.33

NOTE: Nominal Weld Land Thickness = 0.060

During this preliminary analysis, a minimum positive margin of safety, including zero value, has been considered acceptable to minimize the weight of structural components.

*Redesign of this member to sustain increased loads has been considered out of the scope of this program. Weight calculations allow for changes necessary to obtain positive margins of safety.

Table 5. Critical Stresses and Margins of Safety for the Six-Segmented Heat Shield Concept (14,000-Pound Vehicle Descending at 30 fps)

Item	Material	Size (inches)	Critical Condition	Stress (psi)	Allowable Stress (psi)	Margin of Safety	Design Factor of Safety
Aft heat shield skin	Steel, PH14-8 MO	t = 0.032 to 0.148	Water impact	150,000	150,000	0.0	1.00
Aft heat shield core	Steel, PH14-8 MO	1/8 cell 0.003 foil	Water impact	1,600 (Local area)	1,610	Zero	1.00
Aft heat shield ring (88-inch diameter)	Steel, PH14-8 MO	t = 0.350 0.250	Ground impact	115,000	156,000	0.35	1.33
Deployable leg beams	Steel, PH14-8 MO	t = 0.1875	Ground impact	154,700	156,000	0.01	1.00
Shock absorber fitting	Aluminum alloy, 7075-T6		Ground impact	58,750	60,000	0.02	1.33
CM inner structure Aft sidewall skin	2014-T6 Aluminum alloy	t = 0.100	Ground impact	37,300	38,000	0.02	1.33
CM inner structure Aft sidewall skin bonds	Epoxy adhesive	Bonded overlap increase 1.42	Ground impact	1,310	1,320	0.0	1.33
CM inner structure Ring and longeron weld lands	Aluminum alloy, 2014-T6	t = 0.150	Ground impact	14,900	15,000	0.0	1.33
CM inner structure Girth ring station Xc 43	Aluminum alloy, 2014-T6		Ground impact	238,000	60,000	0.0*	1.33
Shock absorber	Steel, 180,000 HT		Ground impact	156,000	156,000	0.0	1.33

NOTE: Nominal land thickness = 0.060

During this preliminary analysis, a minimum positive margin of safety, including zero value, has been considered acceptable to minimize the weight of structural components.

*Redesign of this member to sustain increased loads has been considered out of the scope of this program. Weight calculations allow for changes necessary to obtain positive margins of safety.

The ground is considered as a rigid surface that has a constant friction coefficient with the spacecraft's legs. The ground may have a slope and a direction of slope.

A partial list of vehicle input data for the program includes:

1. Number of legs
2. Acceleration of gravity
3. Coordinates of cg
4. Mass properties
5. Coordinates of each end of each strut
6. Load-stroke properties of each strut

The initial value (landing parameter) data includes:

1. Horizontal and vertical velocities
2. Roll, pitch, and yaw
3. Angular velocities
4. Ground slope and direction of slope
5. Friction coefficient with ground
6. Parachute swing angle and direction of swing

The program output is primarily in the form of CRT plotting. Time histories are plotted from the instant of impact for the following quantities:

1. Acceleration, velocity, and displacement of the cg in a direction normal to the earth
2. Roll, pitch, and yaw measured relative to the earth (earth y-z coordinate axes from plane of ground)
3. Stroke of each strut (versus time)

Angle Conventions

To define roll, pitch, and yaw, the vehicle is first rolled about its vertical axis, then pitched about its y axis, then yawed about the z axis on the capsule. The roll angle is always measured as the counterclockwise angle from the horizontal velocity to the vertical plane containing the capsule z axis. Axis convention is identified in Figure 23.

The ground slope is defined by a maximum slope and a direction of slope. The direction of slope is measured in a counterclockwise angle (right-hand rule) from the horizontal velocity. Positive slope is upslope.

The vehicle attitude may be defined by a parachute swing angle and its direction of swing. Direction of swing is defined as the angle between the vertical plane containing the capsule z axis and the vertical plane containing the parachute riser lines. Positive swing and zero-direction of swing are the same as positive pitch angle.

Horizontal and vertical velocity vectors always form the basic reference plane.

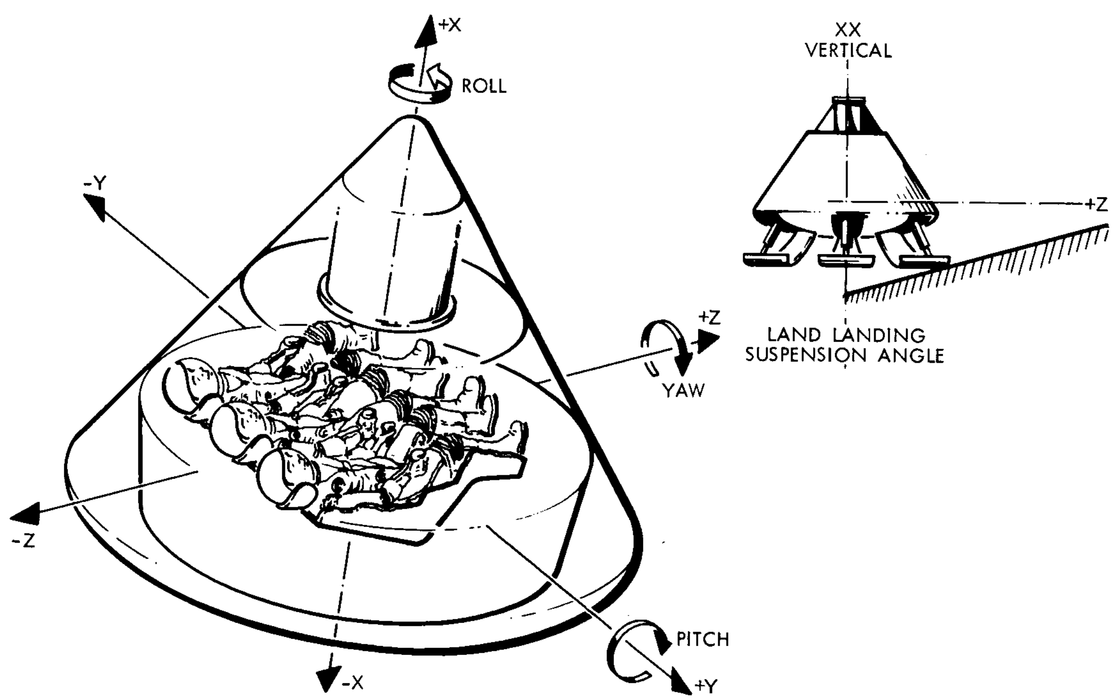


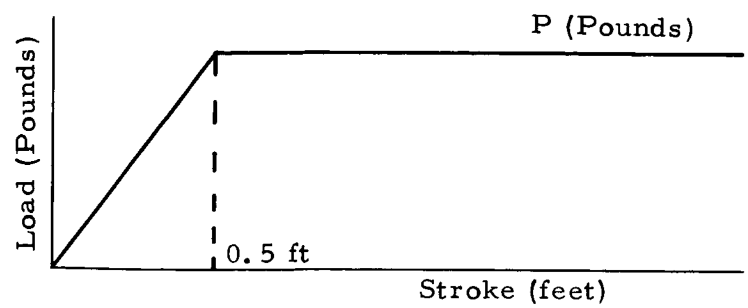
Figure 23. MISDAS/AES Land Landing Attitude, Six-Legged System

Landing Stability Considerations

Landing stability of the 14,000-pound vehicle has been studied under a variety of conditions, including vertical velocities of 20- and 30-fps, and ground coefficients of friction of 0.35 to 1.0 and above. These analysis have been based on those performed for the AES application, with strut loads directly scaled from those used for the 10,600-pound vehicle (Reference 2). Strut load-stroke properties used were the same for each of the six legs. The stroke of each leg was from the initial location of the movable strut tip toward the fired strut tip, in capsule initial coordinates with a straight line as a path of motion. Center of gravity location, and strut tip coordinates used were as indicated in the following table:

	x	y	z
Center of Gravity (inches)	36.9	1.79	6.25
Movable Strut Tips (inches)			
Leg 1	-15.0	-34.67	60.05
Leg 2	-15.0	-69.34	0.0
Leg 3	-15.0	-34.67	-60.05
Leg 4	-15.0	34.67	-60.05
Leg 5	-15.0	69.34	0.0
Leg 6	-15.0	34.67	60.05
Fixed Strut Tips (inches)			
Leg 1	40.0	-34.67	60.05
Leg 2	40.0	-69.34	0.0
Leg 3	40.0	-34.67	-60.05
Leg 4	40.0	34.67	-60.05
Leg 5	40.0	69.34	0.0
Leg 6	40.0	34.67	60.05

Load stroke properties for each strut are shown in Figure 24, including collapsing loads for the mathematical strut model, considered to be in direct contact with the ground; the actual strut, as defined in Figure 18; and the maximum crew compartment acceleration measured normal to earth.



Six-Segment Heat Shield Concept				
Vehicle Weight (pounds)	Vertical Velocity (fps)	Collapsing (P) Strut Loads (pounds): Actual Strut	Collapsing (P) Strut Loads (pounds): Mathematical Strut	Maximum Crew Compartment Acceleration (g Normal to Earth)
10,600	15	31,300	25,000	14.2
14,000	15	41,300	33,000	14.2
14,000	20	73,600	58,785	25.2
14,000	30	165,200	131,950	56.6

Figure 24. Load-Stroke Properties for the Legged Vehicle With Six x-x Axis Struts

The strut loads used in the stability analyses of a 10,600-pound legged vehicle resulted in total accelerations on the crew compartment which are less than maximum allowable Apollo values shown in Figure 25. For a landing with 80 fps horizontal velocity toward a 5-degree upslope, 15 fps vertical velocity, and angular attitude such that six legs contact simultaneously; the crew compartment will experience a 11.2-g acceleration normal

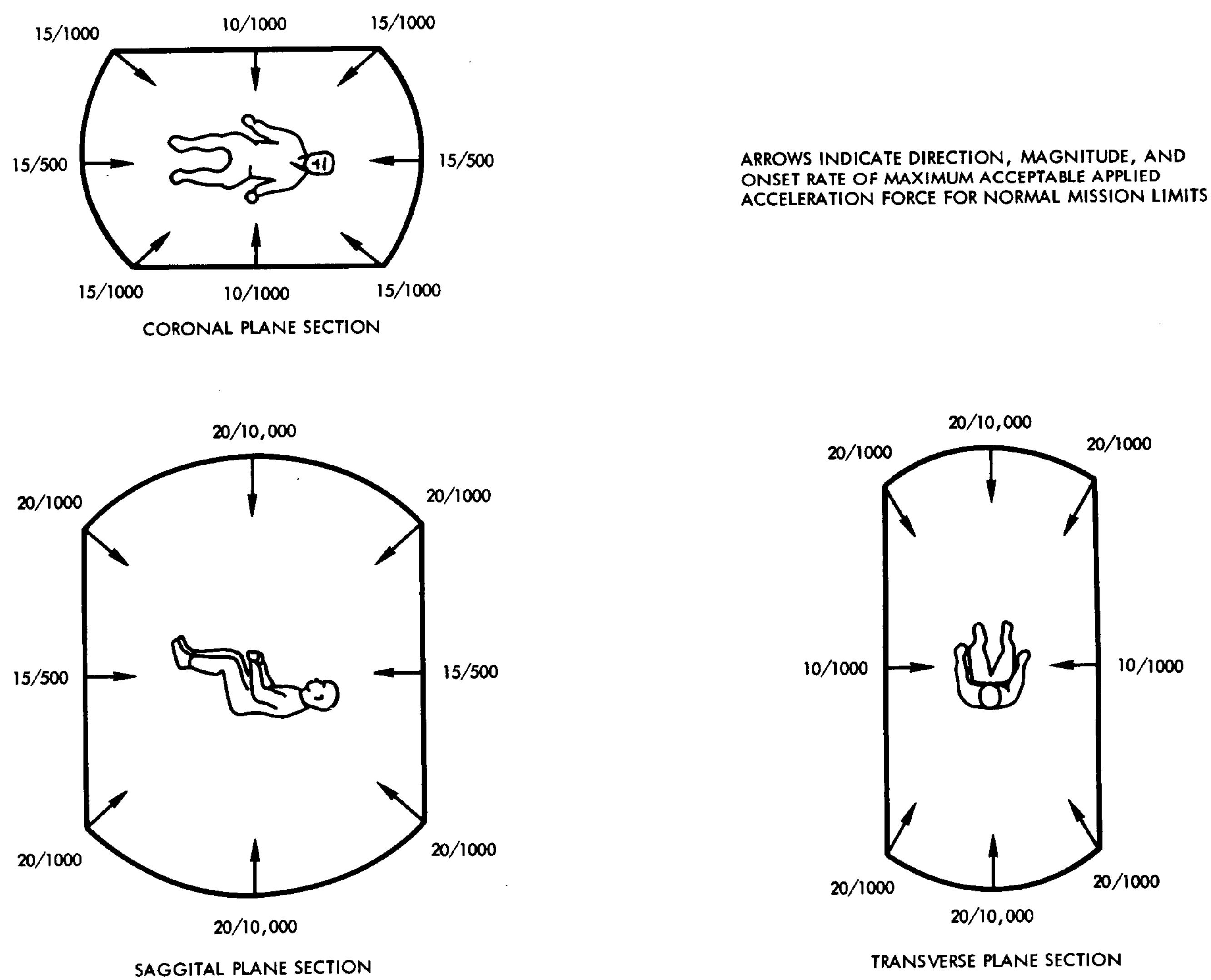


Figure 25. Apollo Normal Mission Impact Limits

to the ground plane and an onset rate of 28.4 g/ft. For a 0.35 coefficient of friction, the total acceleration will be 15.0 g. The landing described above has been found to result in the most severe accelerations. It represents the condition of maximum normal velocity (22 fps) with all struts stroking simultaneously. The strut properties of Figure 24 and a capsule weight of 10,600 pounds have been assumed.

The strut loads assumed for the 14,000-pound vehicle have been linearly scaled up from those of the 10,600-pound AES vehicle. Figure 24 tabulates strut loads and resulting crew compartment accelerations as functions of the weights of the two different spacecraft. It will be noted from Figure 24 that crew couch attenuators will be required for landings significantly greater than 15 fps vertical velocity. The vertical velocity at which crew tolerances will be exceeded (without couch attenuators) depends upon the effective friction coefficient at impact. Figure 24 also assumes that strut stroking length is the same for both vehicle weights.

Shock struts have been designed to satisfy (1) the landing stability criteria; (2) space available for stowing them during flight and length required to open the deployable legs upon landing; crew tolerance to acceleration and onset rate without additional attenuation in the crew support system; and (4) requirements to prevent damage to the permanent structure during landing. Requirements 1, 2, and 3 determined the length, total strut stroke, and maximum slope of the load-stroke curve, and these characteristics satisfy requirement 4 since the struts were not sufficiently soft to permit the inner structure to hit the ground under the worst landing conditions obtained with V_V = 15 fps and $\mu = 0.35$.

To simplify the analysis, the same strut characteristics were used in the analysis of effects of higher vertical velocities and coefficients of friction, because although some advantages could be obtained from considering longer strokes or softer struts, it was beyond the scope of this program to optimize the strut design.

Stability of Segmented Heat Shield Concept

The stability envelopes derived in this study apply to both the MISDAS and the AES spacecraft since strut loads (Figure 24)are linearly proportional to vehicle weight.

The six-leg vehicle was found to be stable within the landing criteria defined in the guidelines, constraints, and design criteria section. For a vertical velocity less than or equal to 15 fps and coefficient of friction equal to 0.35, the vehicle showed good stability for various combinations of the random variables, slope, slope direction, roll, chute swing angle, and chute swing direction. The worst landing condition was for horizontal velocity toward a 5-degree downslope, roll = 0, direction of swing = 0, swing angle = +12 degrees. Even under these conditions, the capsule only slightly exceeded the initial 17-degree angle which the capsule's x axis made with a ground normal.

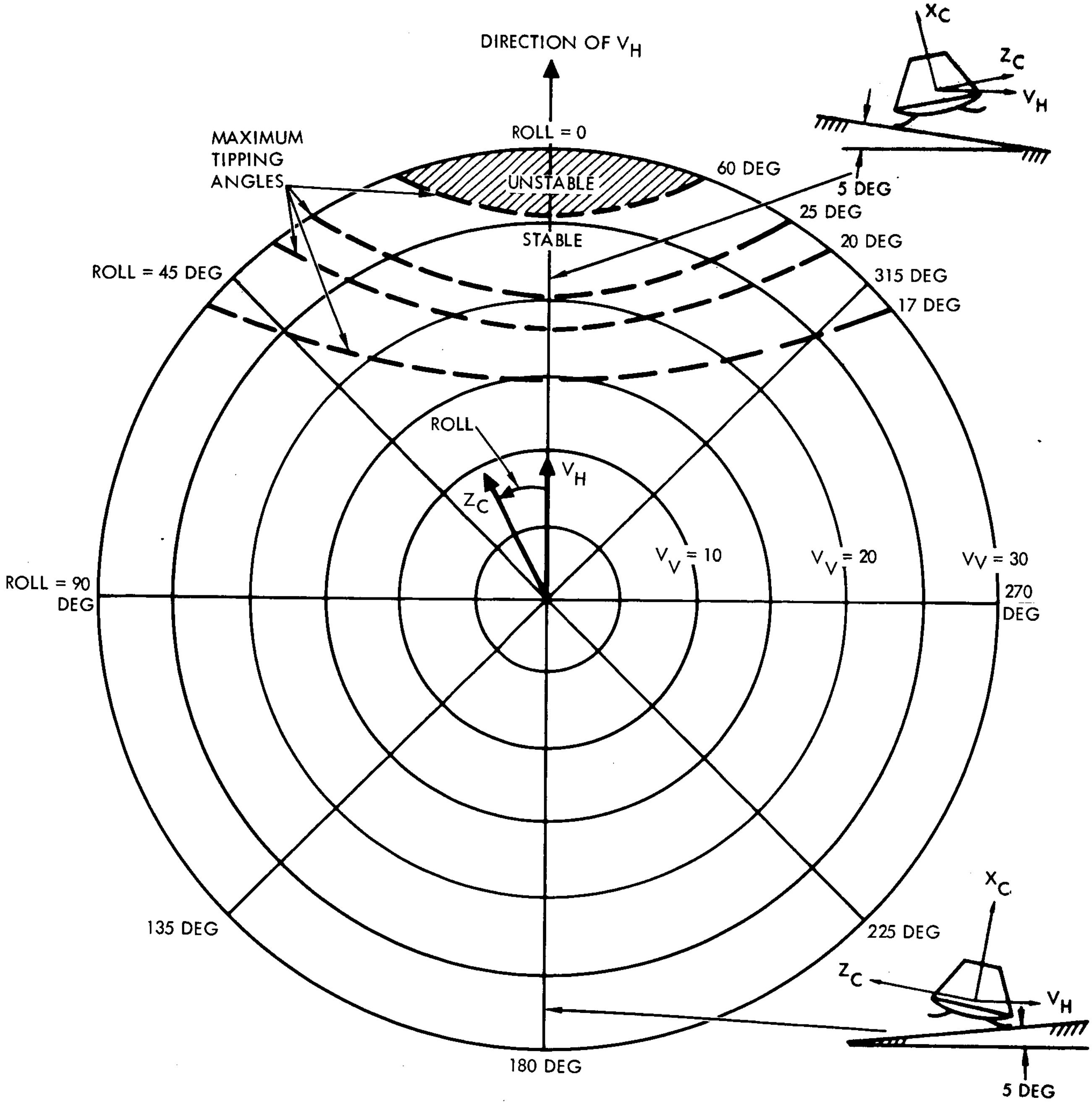
A quantity called maximum tipping angle is mapped as a function of vertical velocity and roll angle in Figure 26. This angle is the maximum value in degrees that the capsule's x axis forms with a ground normal during a landing. It should be noted that only one landing at 15 fps vertical velocity or less had a maximum tipping angle greater than the initial impact angle (17 degrees). Runs have been made at higher vertical velocity, resulting in greater maximum tipping angles. The worst landings of these runs are at approximately zero roll angle, with horizontal velocity toward downslope, and capsule attitude such that a 17-degree angle (obtained by combination of the most adverse slope, pitch or yaw, and parachute hang angle) is formed by the ground plane and the capsule's y-z plane. Referring to Figure 26, an unstable condition is achieved at a vertical velocity of approximately 25 fps. The most severe landings with regard to strut stroking were made landing upslope at 80 fps horizontal velocity. Upslope landings caused maximum strut stroking, but had the net effect of stabilizing the spacecraft.

A study of the stability of the legged spacecraft at higher vertical velocities and friction coefficients greater than 0. 35 has been accomplished. The resulting information is shown in Figure 27. Lines of constant vertical velocity are mapped onto a plot of roll versus coefficient of friction. This plot indicates that stable landings can be made for coefficients of up to approximately 1. 0 if the roll angle of the spacecraft can be controlled. With roll = 180 deg ±45 deg and positive pitch relative to the ground plane (or roll = 0 deg ±45 deg and negative pitch), stable landings are indicated. Note that roll angle is measured from the horizontal velocity to the vertical plane containing the capsule's z axis.

MASS PROPERTIES

The weight increase assessment for adding the six-legged Mechanical Impact System to the Apollo-type Advanced Spacecraft consists of the weight of the landing gear system plus the effects of all modifications required on the aft heat shield and inner structure.

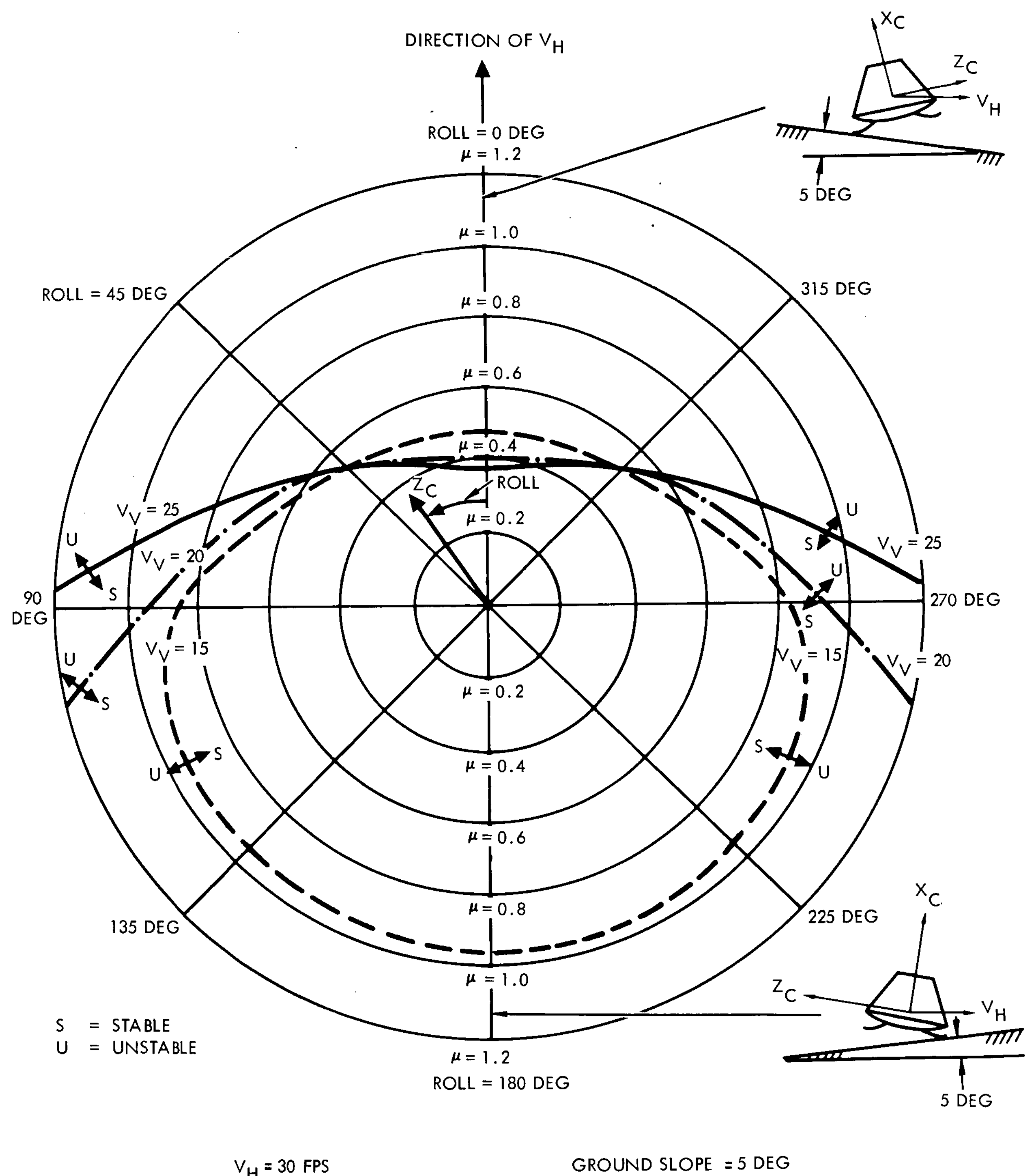
Apollo Block II weight and mass properties information presented in Reference 8 was used as a base point for all calculations; weight changes due to structural modifications of aft heat shield and inner structure are based on details of Figures 18 and 19, and the stress analysis presented in Appendix A for a vertical velocity of 15 fps and ground coefficient of friction $\mu = 0.35$.



MAXIMUM TIPPING ANGLES MAPPED AS A FUNCTION
OF VERTICAL VELOCTIY (FPS) AND ROLL ANGLE (DEG)

COEFFICIENT OF FRICTION = 0.35.
HORIZONTAL VELOCITY = 30 FPS
SLOPE = 5.0 DEG DOWN
DIRECTION OF SLOPE = ROLL
SWING ANGLE = 12.0 DEG

Figure 26. Stability Limits for Six-Leg Vehicle



V_H = 30 FPS
SWING ANGLE = 12 DEG
SWING DIRECTION = 0

GROUND SLOPE = 5 DEG
DIRECTION OF SLOPE = ROLL
TWO LEG INITIAL CONTACT

Figure 27. Stability of Legged Vehicle as a Function of Roll (Deg) Versus Coefficient of Friction (μ)

Table 6 presents a detailed weight breakdown of the six-legged heat shield MISDAS concept. Weight of heat shield and permanent structure components affected by MISDAS installation are shown in Table 7 for the Advanced Spacecraft and the basic Apollo Block II vehicle.

The net weight penalty imposed by MISDAS six-legged system to the 14,000-pound spacecraft landing with vertical velocity of up to 15 fps on ground with coefficient of friction of up to 0.35 is 673 pounds, or 4.81 percent of the spacecraft weight.

Volume required to install the six-segment system in the aft equipment bay was assessed. This volume includes the space required for storage and operation of the system. Total volume penalty imposed by a system designed to sustain landings with vertical velocity of up to 15 fps and ground coefficient of friction $\mu = 0.35$ is 2.8 cu ft.

Tables 6 and 7 show the increased weight and volumes of landing system and structural components redesigned to sustain land landings of increased sinking velocity. Calculations leading to these values have been based on the structural drawings (Figures 18 to 19) and the stress analysis presented in Appendix A.

MANUFACTURING CONSIDERATIONS

This section presents a manufacturing plan for the six-legged landing system shown in Figures 18, 19 and 20. Although the overall landing system configuration shown in the drawings has been retained, a limited number of structural details have been modified to enhance the producibility of the installation. These changes have been incorporated in the structural analysis. The pictorial manufacturing plan shown in Figure 28 illustrates a sequence of assembly to produce the finished landing system hardware utilizing current state-of-the-art techniques and many of the existing Apollo tools.

Aft Heat Shield Fabrication

Although the aft heat shield from which the six landing legs deploy is similar in appearance to the present Apollo aft heat shield, all details of this assembly should be considered new. The new assembly will still bolt to the bottom of the inner crew compartment and provide a seal with the inner crew compartment heat shield at the mold line surface.

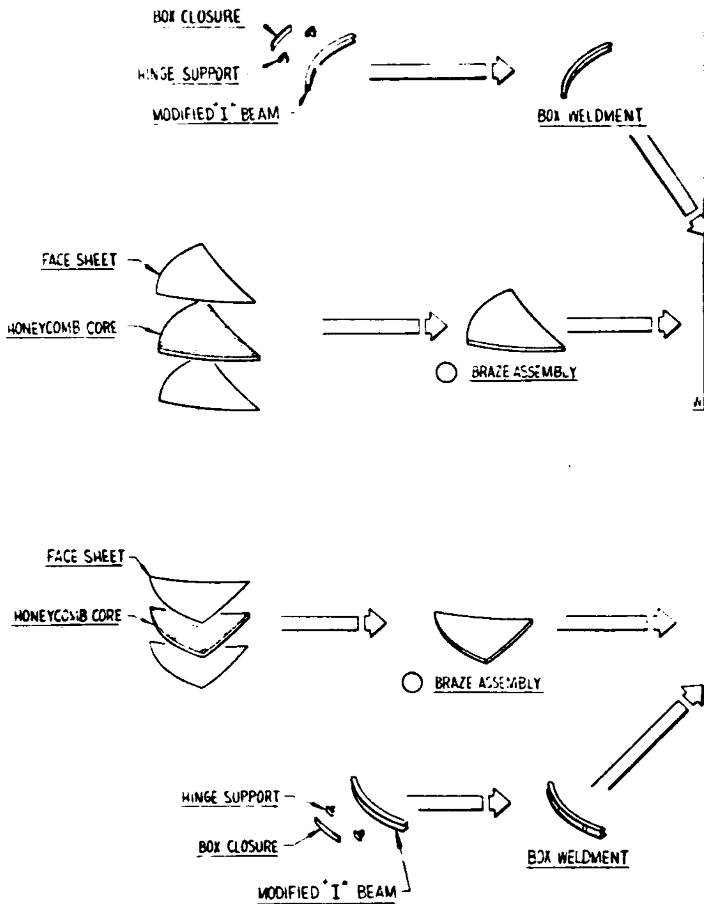
As shown in Figure 28, the center section of the aft heat shield has been divided into six segments, rather than one full honeycomb panel braze assembly with unpredictable faying surface braze joints. From past experience, reliability of faying surface braze joints in brazed sandwich panels has been questionable. On the other hand, the reduction of faying surface braze joints results in smaller panel sizes, imposing additional fusion weld requirements.

Table 6. MISDAS Segmented Heat Shield Concept Detail Weight Breakdown

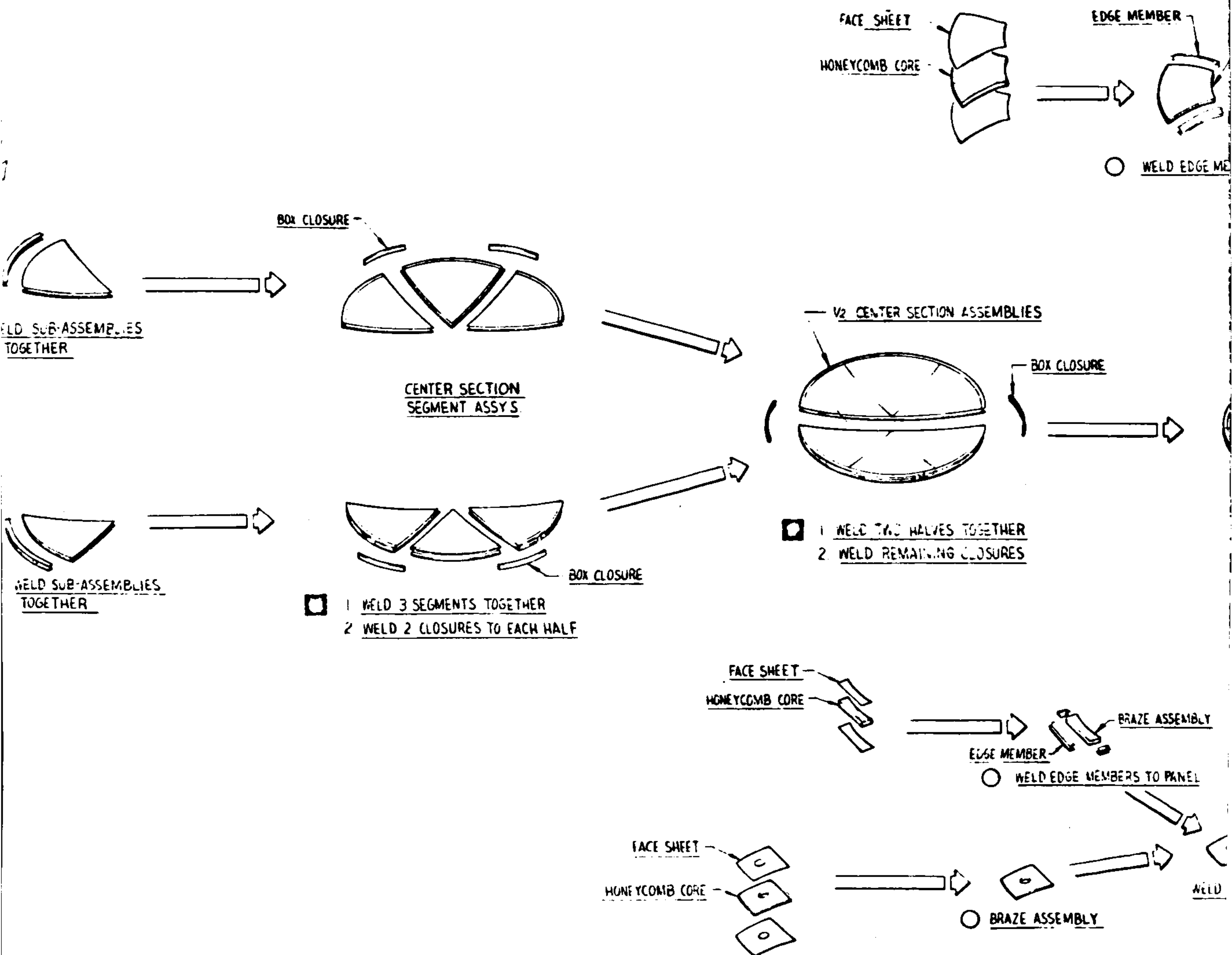
Item	Weight (lb) $\mu = 0.35$ V_v = 15 fps	V_v = 20 fps	V_v = 30 fps
Structural modification	-126.0	+11.0	+436.0
Landing gear system	(799.0)	(1,233.0)	(1,970.0)
Leg assembly	(447.0)	(636.0)	(897.0)
Skin	165.0	182.0	215.0
Stiffeners	157.0	265.0	374.0
Edge members	76.0	119.0	184.0
Hinge fittings	24.0	36.0	73.0
Strut attachment fittings	21.5	28.0	39.0
Hardware	3.5	6.0	12.0
Frame-leg support	132.0	257.0	410.0
Shock strut assembly	(161.0)	(250.0)	(486.0)
Struts (6)	112.0	178.0	370.0
Attachment fittings - sidewall	42.0	63.0	101.0
Conical bellows	3.0	3.0	3.0
Hardware	4.0	6.0	12.0
Hydraulic and pneumatic system	(52.0)	(83.0)	(170.0)
Hydraulic accumulator	12.5	20.0	44.0
Motor valve	2.0	2.0	2.0
Valves	0.5	0.5	0.5
Damping orifices	1.0	1.0	1.0
Plumbing	7.0	10.0	16.0
Electrical provisions	2.5	2.5	2.5
Support and attaching parts	1.5	2.0	4.0
Hydraulic fluid	24.0	44.0	99.0
Gas (helium)	1.0	1.0	1.0
Leg release mechanism	7.0	7.0	7.0
Total mechanical landing system penalty	673.0	1,244.0	2,406.0
Total volume allotment (~cu ft)	2.8	3.6	5.8

Table 7. MISDAS Segmented Heat Shield Concept Structural Modification Weight Breakdown

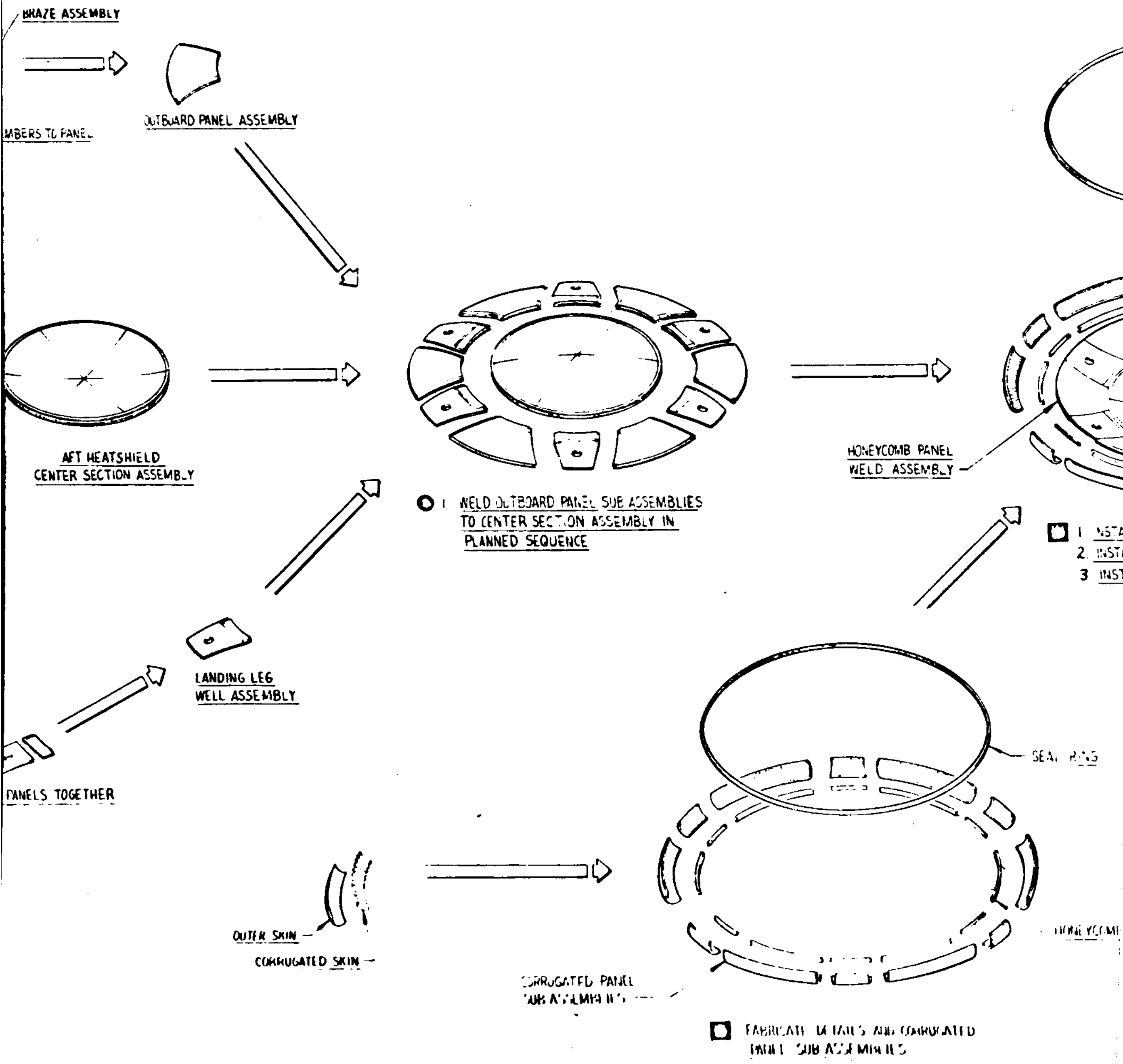
Item	Weight (lb)			
	Base Point Apollo Block II (9165)	$\mu = 0.35$		
		V_v = 15 fps	V_v = 20 fps	V_v = 30 fps
Aft heat shield structure	(763.3)	(622.3)	(721.3)	(942.3)
Honeycomb panel	(559.6)	(414.5)	(513.5)	(734.5)
Core	202.9	160.0	176.0	188.0
Face sheets	306.6	203.5	286.5	495.5
Braze	51.1	51.0	51.0	51.0
Frames and rings				
Ring-outer rim	55.1			
Body to heat shield attachment	55.9	37.0	37.0	37.0
Fitting and attachment	33.0	33.0	33.0	33.0
Closeouts	7.1	21.0	21.0	21.0
Toroidal assembly	(52.6)	(116.8)	(116.8)	(116.8)
Corrugation	16.6	28.0	28.0	28.0
Skin	17.7	22.5	22.5	22.5
Splice and attach	18.3	22.3	23.3	23.3
Rim		44.0	44.0	44.0
Inner structure - aft section	(177.0)	(192.0)	(230.0)	(434.0)
Honeycomb panels	122.0	137.0	167.0	344.0
Girth ring	55.0	55.0	63.0	90.0
Total	940.3	814.3	951.3	1,376.3
Total structural modification		-126.0	+ 11.0	+436.0

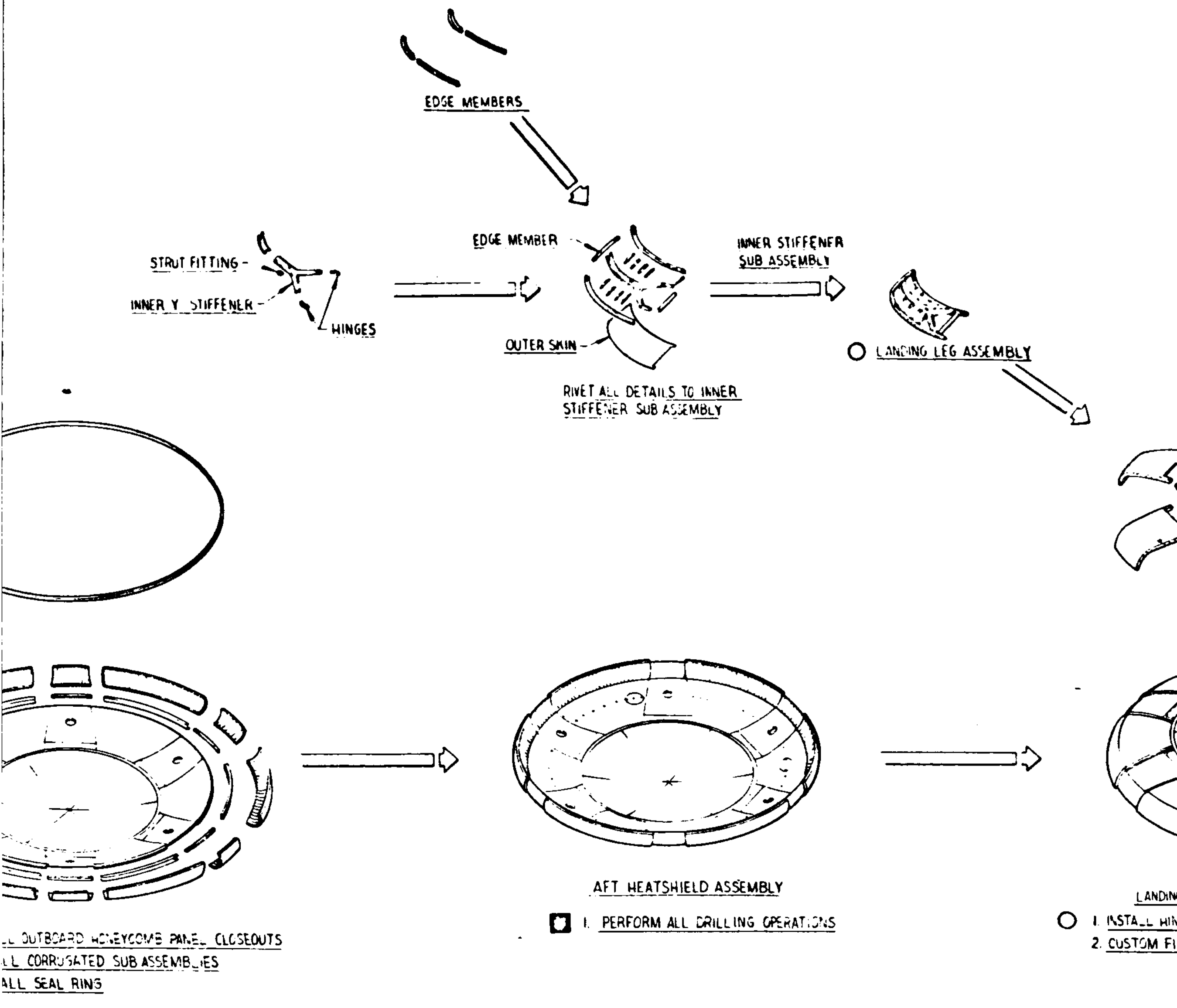


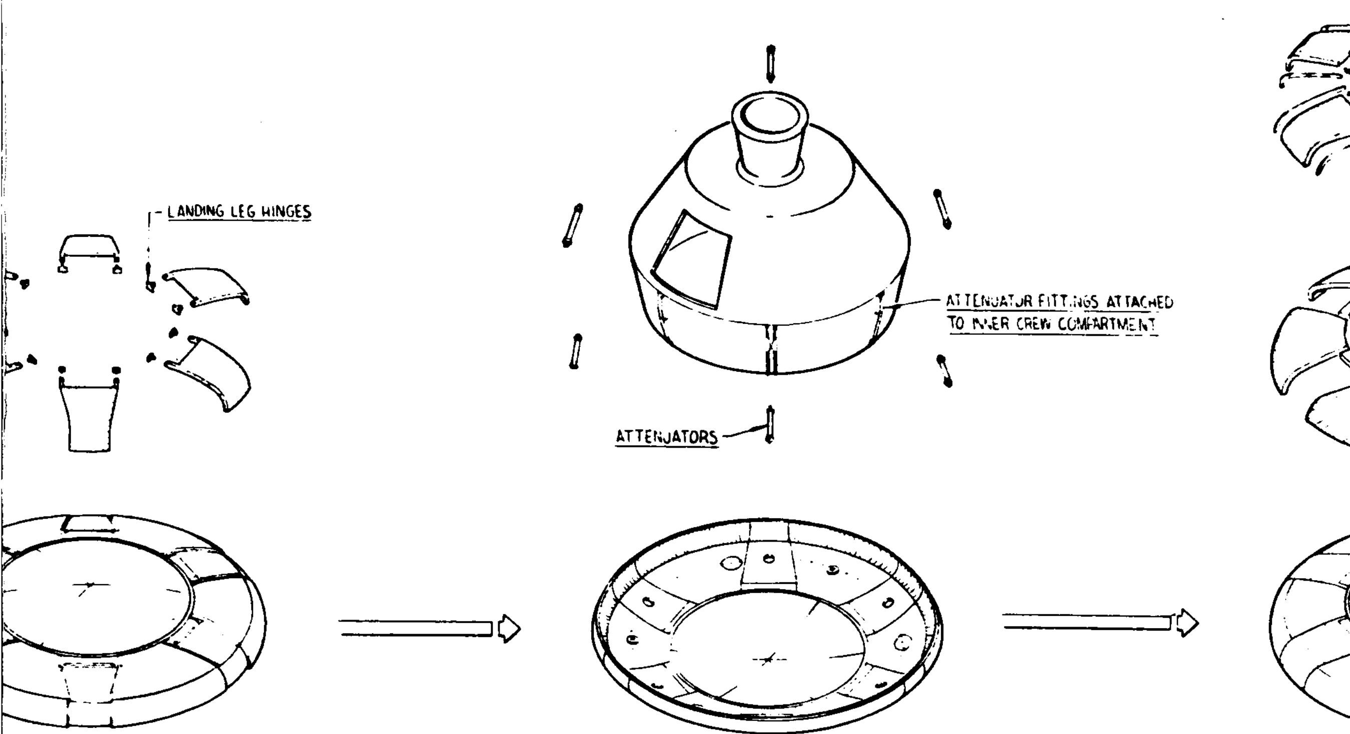
BOX CLOSURE
HINGE SUPPORT
MODIFIED "I" BEAM
BOX WELDMENT
FACE SHEET
HONEYCOMB CORE
BRAZE ASSEMBLY
FACE SHEET
HONEYCOMB CORE
BRAZE ASSEMBLY
HINGE SUPPORT
BOX CLOSURE
MODIFIED "I" BEAM
BOX WELDMENT



FACE SHEET
HONEYCOMB CORE
EDGE MEMBER
WELD EDGE ME
BOX CLOSURE
CENTER SECTION SEGMENT ASSYS.
TOGETHER
1/2 CENTER SECTION ASSEMBLIES
BOX CLOSURE
1 WELD TWO HALVES TOGETHER
2 WELD REMAINING CLOSURES
WELD SUB-ASSEMBLIES TOGETHER
BOX CLOSURE
1 WELD 3 SEGMENTS TOGETHER
2 WELD 2 CLOSURES TO EACH HALF
FACE SHEET
HONEYCOMB CORE
BRAZE ASSEMBLY
EDGE MEMBER
WELD EDGE MEMBERS TO PANEL
FACE SHEET
HONEYCOMB CORE
BRAZE ASSEMBLY
WELD


BRAZE ASSEMBLY
MBERS TO PANEL
OUTBOARD PANEL ASSEMBLY
AFT HEATSHIELD
CENTER SECTION ASSEMBLY
1. WELD OUTBOARD PANEL SUB ASSEMBLIES
TO CENTER SECTION ASSEMBLY IN
PLANNED SEQUENCE
HONEYCOMB PANEL
WELD ASSEMBLY
LANDING LEG
WELD ASSEMBLY
PANELS TOGETHER
SEAL RING
OUTER SKIN
CORRUGATED SKIN
CORRUGATED PANEL
SUB ASSEMBLIES
FABRICATE DETAILS AND CORRUGATED
PANEL SUB ASSEMBLIES


EDGE MEMBERS
STRUT FITTING
INNER Y STIFFENER
HINGES
EDGE MEMBER
OUTER SKIN
RIVET ALL DETAILS TO INNER STIFFENER SUB ASSEMBLY
INNER STIFFENER SUB ASSEMBLY
LANDING LEG ASSEMBLY
AFT HEATSHIELD ASSEMBLY
1. PERFORM ALL DRILLING OPERATIONS
OUTBOARD HONEYCOMB PANEL CLOSEOUTS
CORRUGATED SUB ASSEMBLIES
ALL SEAL RING
LANDIN
1. INSTALL HIN
2. CUSTOM FI



LEG INSTALLATION
GES ON CENTER BOX STRUCTURE
EACH LANDING LEG ASSEMBLY

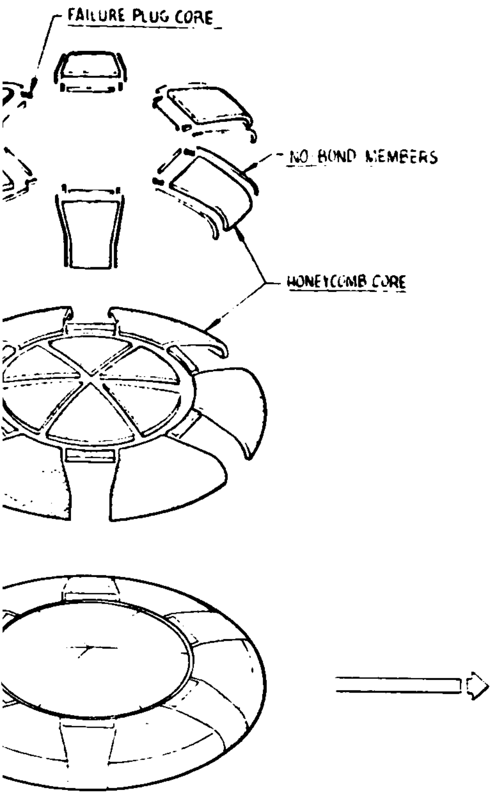
AFT HEATSHIELD FIT CHECK

1. BOLT AFT HEATSHIELD TO INNER CREW COMPARTMENT
2. ATTACH ATTENUATORS
3. DEPLOY LANDING LEG ASSEMBLIES
4. CHECK DEPLOYMENT CLEARANCES ON ALL COMPONENTS

1 BOND HO
2 INSTALL
LEGS &
3. INJECT
4 GRIND T

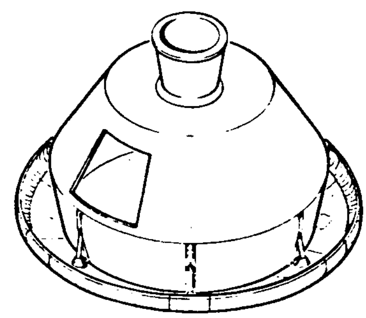
Figur

66-4



ABLATIVE APPLICATION

EYCOMB CORE TO HEATSHIELD
IO-BOND MEMBERS AROUND LANDING
ILURE PLUGS
BLATIVE MATERIAL
MOLD LINE CONTOUR



AFT HEATSHIELD INSTALLATION & LANDING SYSTEM CHECK OUT

1. BOLT AFT HEATSHIELD TO INNER CREW COMPARTMENT.
2. INSTALL ATTENUATORS AND LINES
3. CHECK OUT LANDING SYSTEM DEPLOYMENT.
4. INSTALL EXPLOSIVE LANDING LEG RETAINERS.
5. ATTACH ATTENUATOR BELLOWS
6. INSTALL ABLATIVE FAILURE PLUGS BELOW HINGE ARMS

e 28. Manufacturing Breakdown—MISDAS Study Six-Leg Landing System

66-5

Although the more reliable panel configuration is recommended, fabrication development of the one-piece center section braze assembly, including the landing leg stiffening ring member, is feasible.

As proposed in Figure 28, each of the six pie-shaped center section segments consists of one honeycomb panel braze assembly and one stiffening ring weldment. All assemblies are compound contoured. Two formed chem-milled face sheets and one 2-inch thick honeycomb core comprise the braze assembly. The panel will be fabricated with extra material around the periphery for subsequent trimming operations. Each weld assembly consists of one modified "I" beam main ring member, two hinge support members, and one rolled closure which forms the outer side of the box section between the two hinge supports. All details will be heat-treated before welding into an assembly. The ring section will be machined in the heat-treated condition. Additional material will be provided on the weldments for subsequent trimming operations.

To complete the pie-shaped center section segment assembly, the honeycomb panels must first be prepared for welding to the ring member weldments. This is accomplished by the removal of a small portion of the core and the brazing alloy deposit from both face sheets in the area to be welded. The honeycomb panel and weldment must then be match trimmed before subsequent tacking and simultaneous butt fusion welding of the upper and lower surfaces. Progressively, three of these panels can be welded together to form each half of the heat shield center section assembly. Subsequent welding of two center section halves and welding of closures to the ring member between the hinge supports at each of the six weld joints will complete the inner heat shield assembly.

The brazed honeycomb panels, located outboard of the center section and inboard of the corrugated heat shield structure would be the next panels to be welded to the center section assembly. Three different panel configurations must be used. A 1.5-inch thick honeycomb panel is located in the area of the six landing leg wells and between the hinges. A 1/2-inch thick panel is located outboard of this panel. These two panels, when welded in place, form the landing leg well cavity. The third panel configuration is 2 inches thick and occupies the area between the landing leg wells. All panel edge members will be welded to the braze assemblies after the braze operation. Panel preparation and edge member installation at the outboard panel edges will be defferred until all welding on the heat shield has been completed.

The sequence in which these outboard panels are welded to the center section main box structure, and to one another, is very critical. The assembly must be analyzed to determine a logical order to minimize weld shrinkage problems. It may be necessary to simulate the landing leg assembly with tooling to ensure proper location for each honeycomb panel. As shown in

Figure 28 the two panels in the landing leg well area are welded together first to eliminate areas of weld shrink entrapment. Progressively, and in proper sequence, each honeycomb panel must be trimmed and welded into place.

Subsequent fabrication operations outboard of the honeycomb panel welded heat shield structure can follow procedures similar to those established for the Apollo aft heat shield assembly. The outboard panel edges will be trimmed and de-cored, and closeouts riveted in place. Corrugated panel subassemblies will be riveted to the panel closeouts, and the terminating seal ring member will be installed by riveting to the upper edge of the corrugated panels. All of these rivet operations, and the subsequent drilling of attach holes through the heat shield assembly, can be accomplished with existing Apollo tools.

Landing Leg Segment Fabrication

Because installation of the landing leg assemblies onto the aft heat shield will be the next operation performed, fabrication of the landing leg assemblies will be briefly discussed at this time. The assemblies shown in Figure 18 are designed as riveted, stiffened skin structures of PH 14-8 Mo corrosion resistant steel or equivalent. One "Y" shaped inner channel stiffener, one inboard and two side channel edge members, one outboard seal member, two hinge fittings, one strut attach fitting, one mold line skin, and eight angle stiffeners comprise the details required to fabricate each landing leg assembly. The most rigid and difficult member to form will be the "Y" shaped inner channel stiffener. To facilitate forming on drop hammer dies, this detail has been designed in two pieces with one weld toward the outboard end.

Progressive dies will be used to arrive at the final configuration. All forming and welding will be accomplished with material in the annealed condition, with subsequent heat treatment, straightening, and heat aging.

Each landing leg assembly can be fabricated in two stages as illustrated in Figure 28. Both of the hinge fittings and the one strut attach fitting will first be riveted to the "Y" channel utilizing an assembly fixture to hold each fitting in the proper location. Riveting of the outer mold line skin, panel edge members, and angle stiffeners to the initial internal assembly structure will complete the landing leg assembly.

Landing Leg System Installation

With the heat shield assembly in an inverted position, each landing leg assembly will be custom fitted to one of the landing leg wells. The two outboard explosive retainers for each landing leg assembly can also be temporarily installed, or simulated at this time, in order that mold line smoothness can be obtained. Bolting of the landing legs in stowed position will be required for the next operations.

Fit check will still include bolting to the inner crew compartment and checking the interface of all mating components. Assuming the actuator brackets have previously been installed on the inner crew compartment, installation of the hydraulic cylinders will make it possible to check stroke clearance during deployment fit check of the landing leg assemblies. All structural work on the aft heat shield will be completed during this fit check operation. Upon completion of fit check, the aft heat shield, with landing legs again bolted in stowed position, will be removed from the inner crew compartment assembly in preparation for the installation of the ablator.

Ablator Installation

Ablator installation procedures will be basically similar to those now used on the existing Apollo aft heat shield. Honeycomb core will be bonded to the basic heat shield structures, followed by injection of the ablator into the core, and final grinding to the mold line configuration. Ablative application procedures similar to those used for Apollo heat shield access panels are employed where "no-bond" members must be installed around the periphery of each landing leg assembly to allow proper deployment. In addition, ablative failure plugs, also surrounded with "no-bond" members, are required in the area of the landing leg hinge arms. These plugs will be removable for checkout of the entire landing system upon completion of the ablator installation. Although some development work is anticipated for these areas containing ablative separation requirements, AVCO, fabricator of the Apollo ablative heat shield, considers the concept feasible.

Installation on Crew Compartment Structure

Final installation of the aft heat shield on the inner crew compartment should require no additional structural effort, because of the initial fit-check operation. After being bolted to the inner crew compartment, the attenuation struts and lines can be connected for a landing system checkout. This will be done with the ablative failure plugs removed from beneath each of the landing leg hinge arms. After the deployment checkout, the landing legs will be secured in stowed position with the explosive retainer nuts and failure plugs replaced. The last operation will be the final attachment of the bellows between the attenuator struts and landing leg assemblies.

EVALUATION OF RADIAL SKID CONCEPT

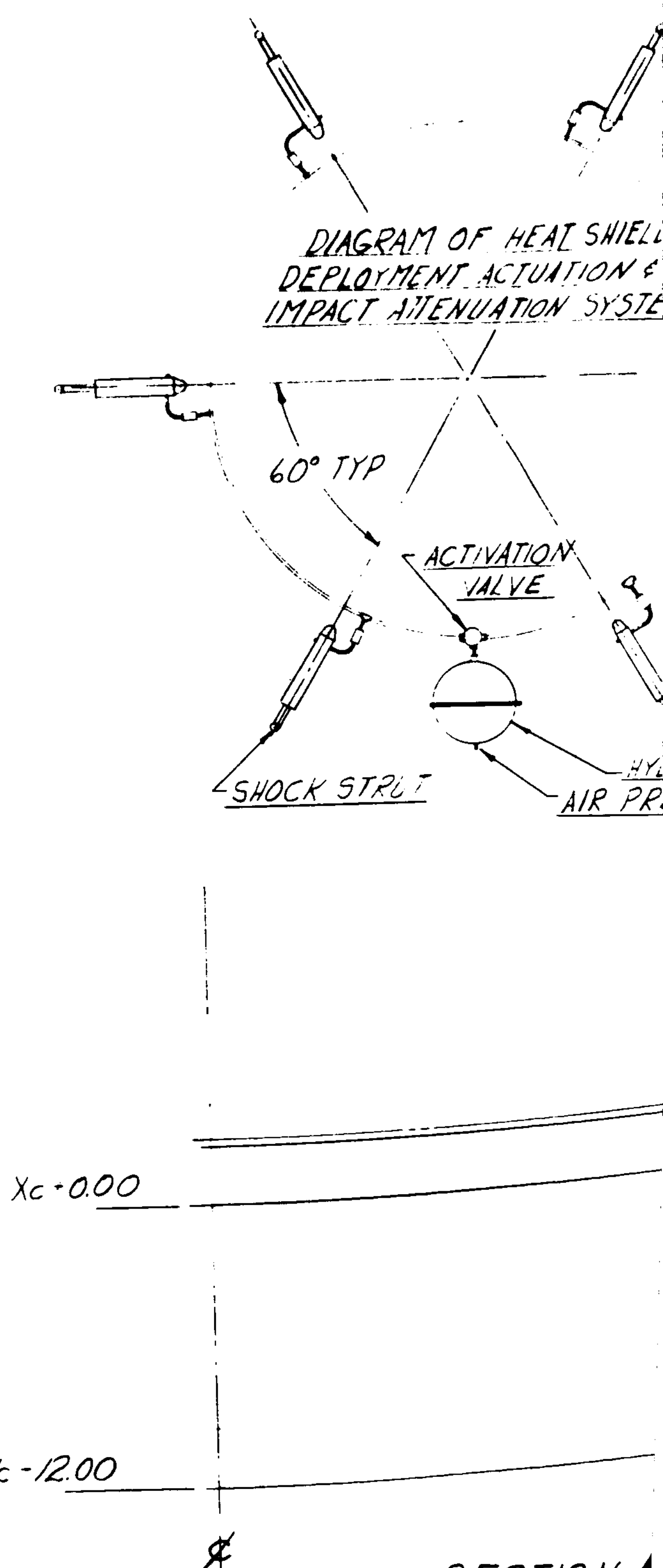
The design of this system encompasses the use of a deployable aft heat shield and a series of radially extendable landing skids to prevent overturning of the command module. For the specified range of landing attititudes given in the Guidelines, Constraints, and Design Criteria section, the skids do not contact the ground at initial impact. They do make contact when the spacecraft tends to tip over, and prevent its overturning. The forces applied to the spacecraft at landing impact are attenuated by shock absorbers located between the deployable heat shield and the inner body structure. The horizontal forces are absorbed by friction of the heat shield sliding over an unprepared landing surface.

Functionally, this system design is very similar to Concept B previously discussed in Reference 1. Specifically, it differs in the parachute hang angle, number of attenuators used for vertical forces, the deployed length of the radial skids, and the incorporation of folding braces to resist the lateral loads due to the friction on the heat shield.

A reevaluation of the original design has shown that a significant weight reduction can be made in the impact attenuation and skid structure while satisfying the established design criteria summarized in the Guidelines, Constraints, and Design Criteria section.

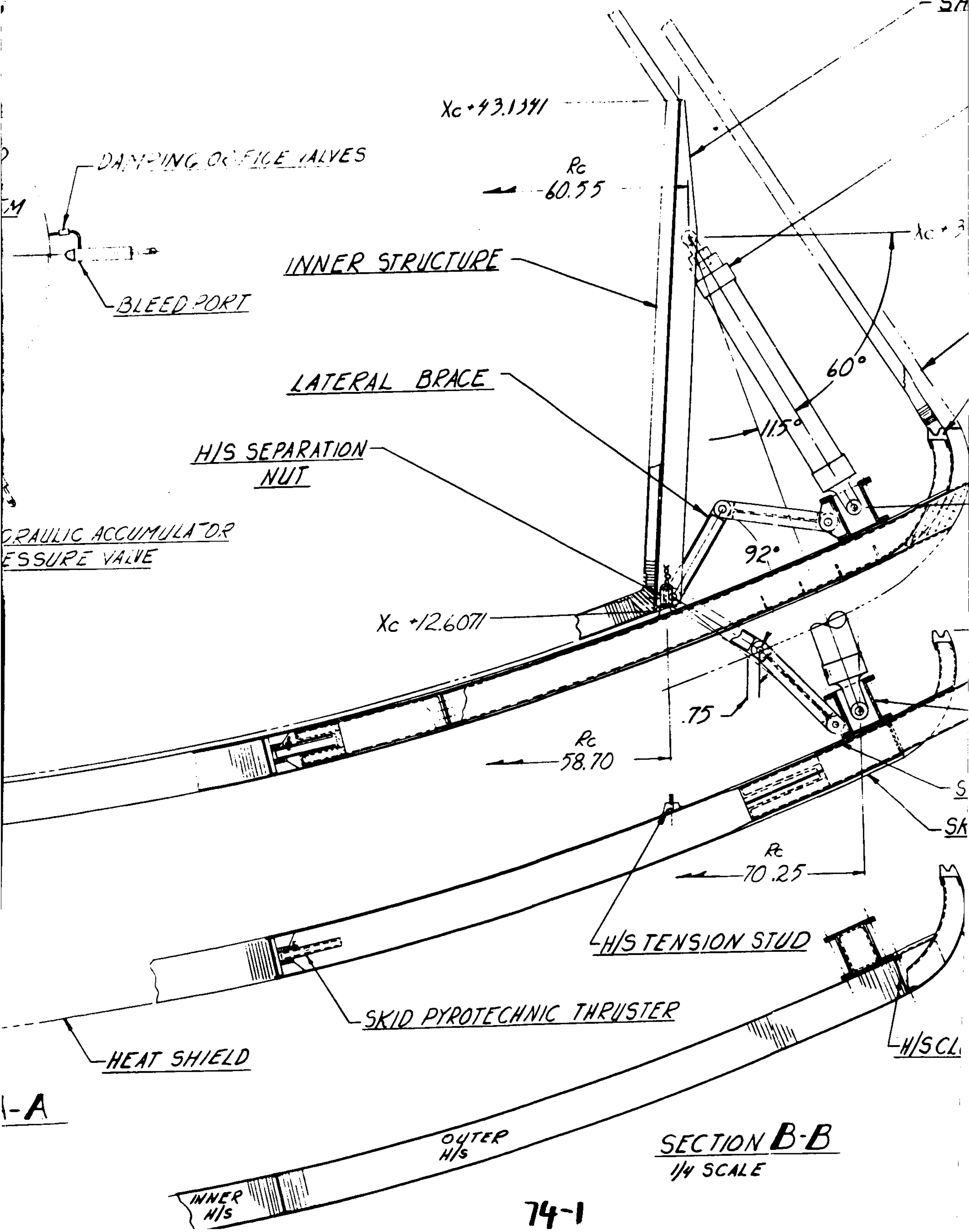
STRUCTURAL SYSTEM DESCRIPTION (FIGURES 29 and 30)

The structural hardware of this concept consists of a command module heat shield modified to include 12 lightweight rectangular steel tubes within individual rectangular housings. An inner and an outer support ring complete the primary framing of the honeycomb heat shield. A series of tension studs and separation nuts in the same location as the Apollo tension bolts attach the heat shield to the inner body. Also attached to the heat shield are six combination actuator/attenuator struts located in the vertical plane at 60-degree intervals. The aft end of each shock absorber is attached to the heat shield outer support ring, while the forward rod end is connected to the inner body support. This forward end incorporates a threaded adjustment for final position length. Spherical bearings in both ends provide compensation for angular misalignment. Heat shield inner body lateral movement or horizontal rotation is resisted by six folding braces (torque scissors) between the inner body supports and the outer support ring, located directly below the six shock absorbers.



SECTION

1/4 SCALE



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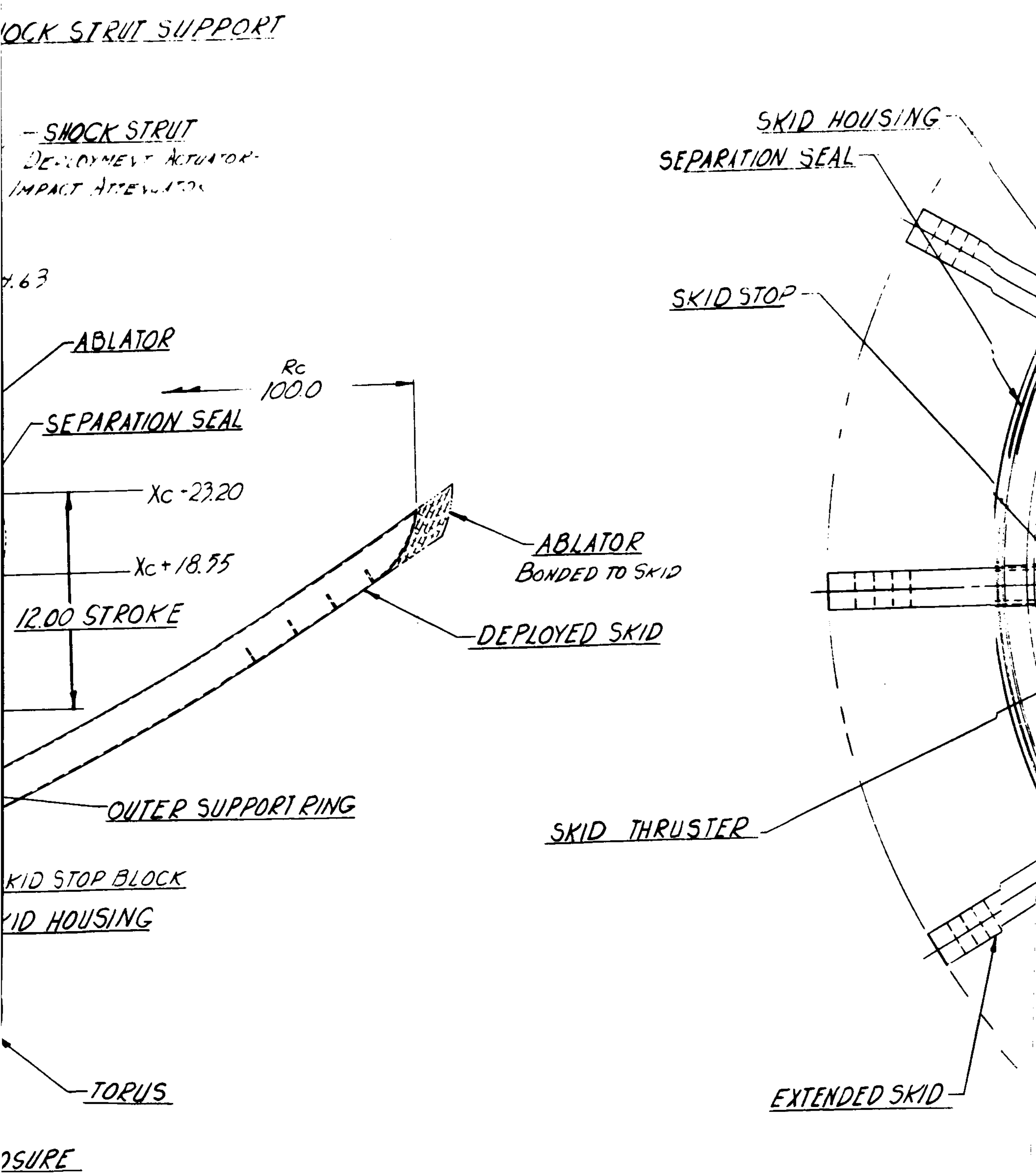
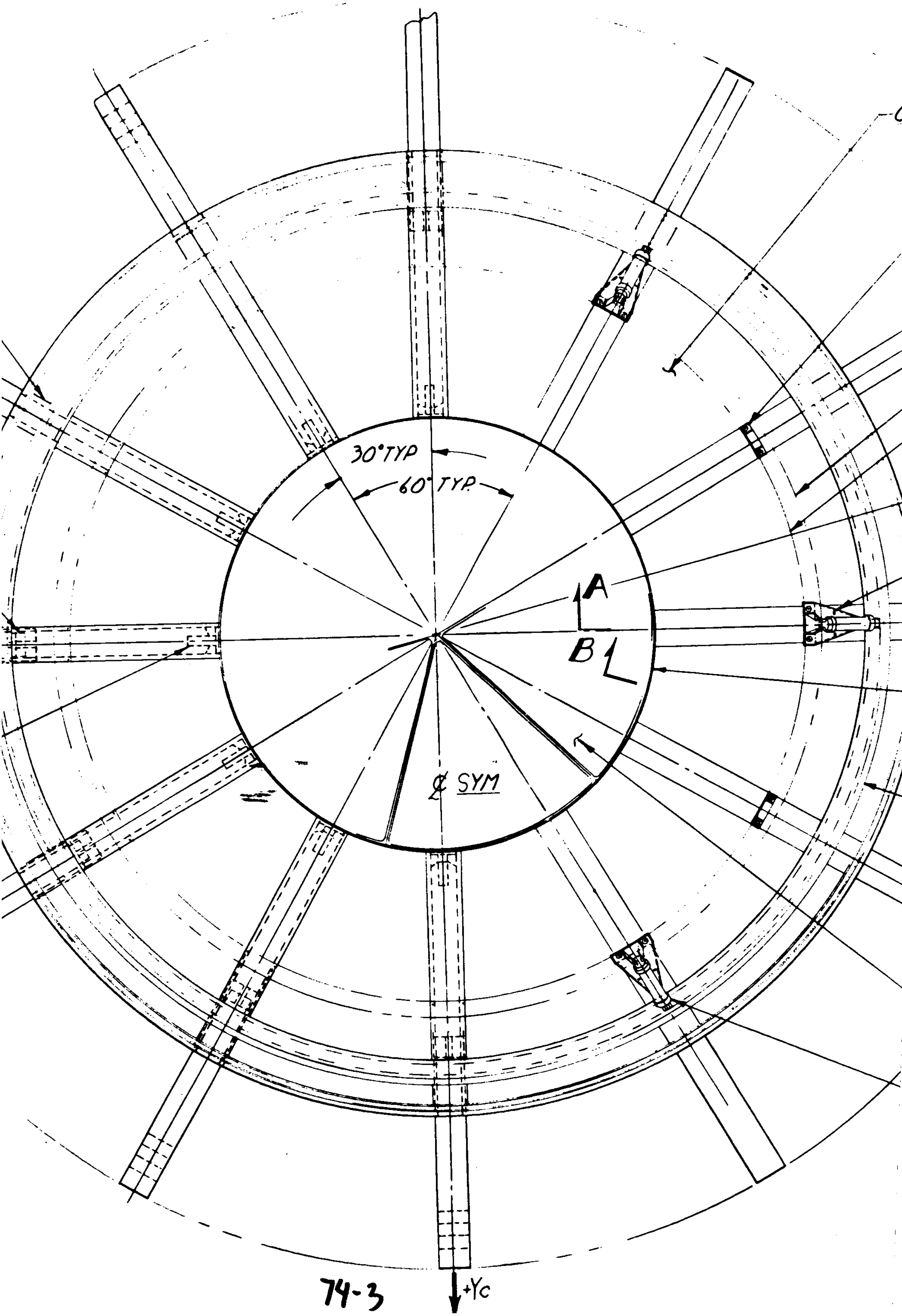
SECTION B-B
1/4 SCALE


OCK STRUT SUPPORT
SHOCK STRUT
IMPACT
.63
ABLATOR
Rc
100.0
SEPARATION SEAL
Xc -23.20
Xc +18.55
12.00 STROKE
ABLATOR
BONDED TO SKID
DEPLOYED SKID
OUTER SUPPORT RING
KID STOP BLOCK
ID HOUSING
TORUS
SURE
SKID HOUSING
SEPARATION SEAL
SKID STOP
SKID THRUSTER
EXTENDED SKID



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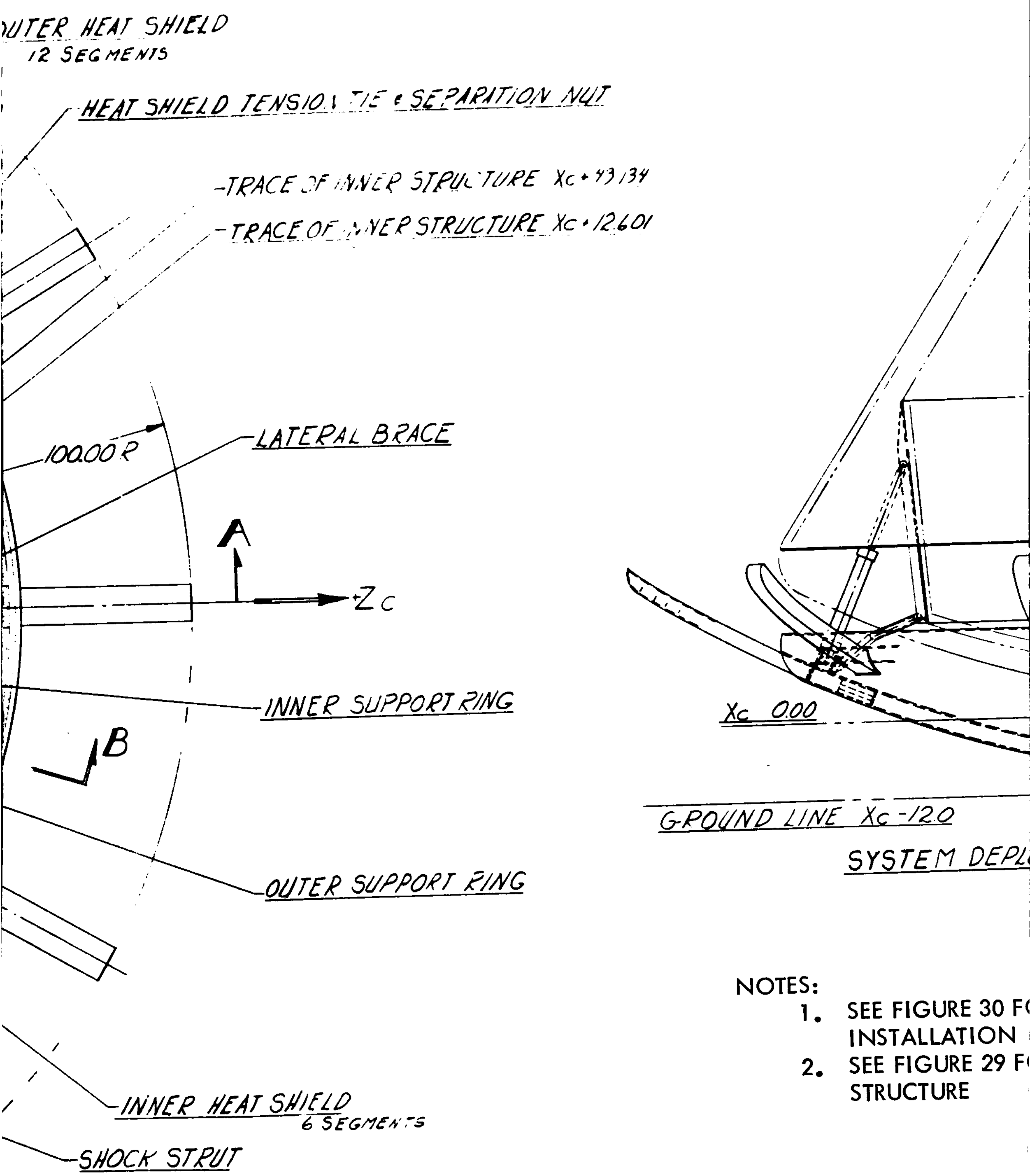
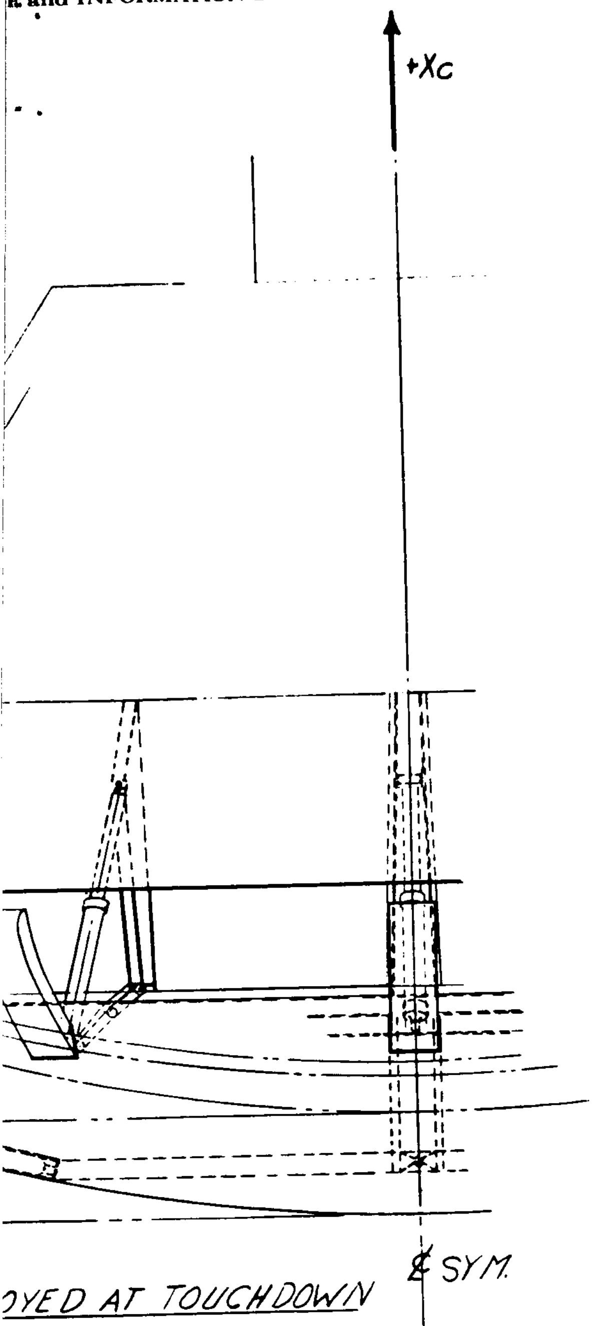


Figure 29. Deployable Heat Shield
MISDAS

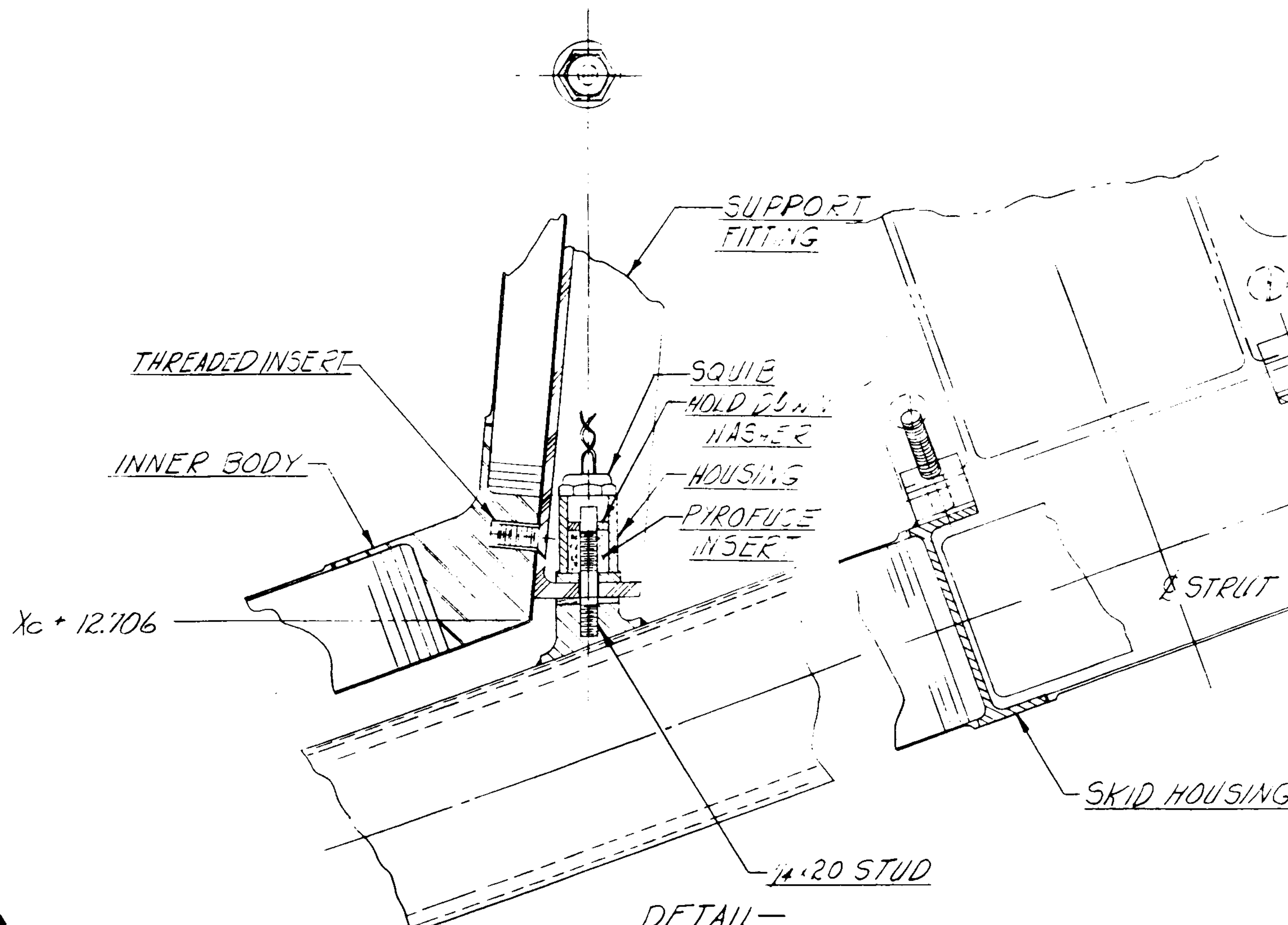


OR AFT H/S EQUIPMENT

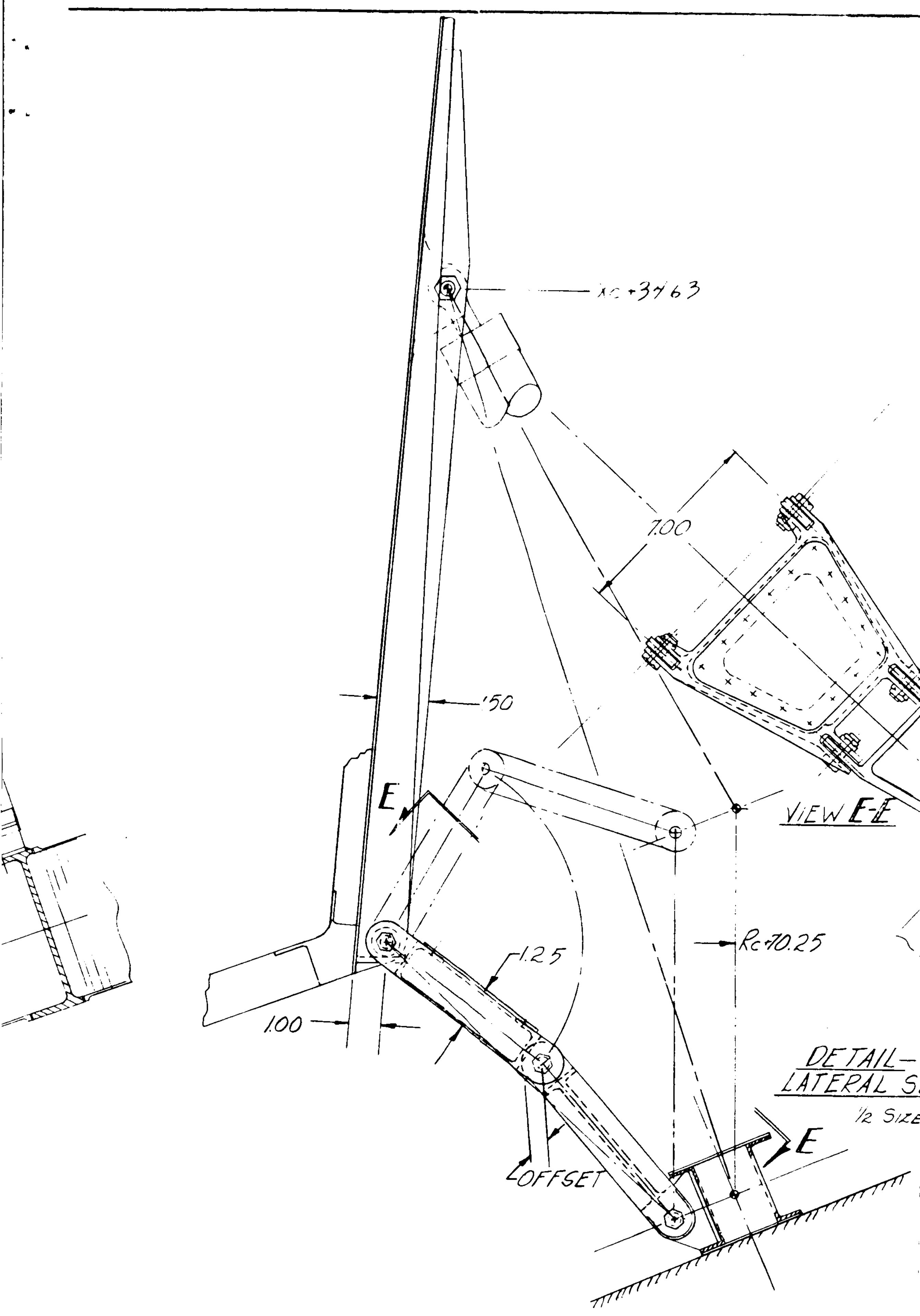
OR DETAILS OF SYSTEM

With Radially Extended Skids -
Study

-



DETAIL—
HI-TENSION TIE &
SEPARATION NUT
FULL SIZE



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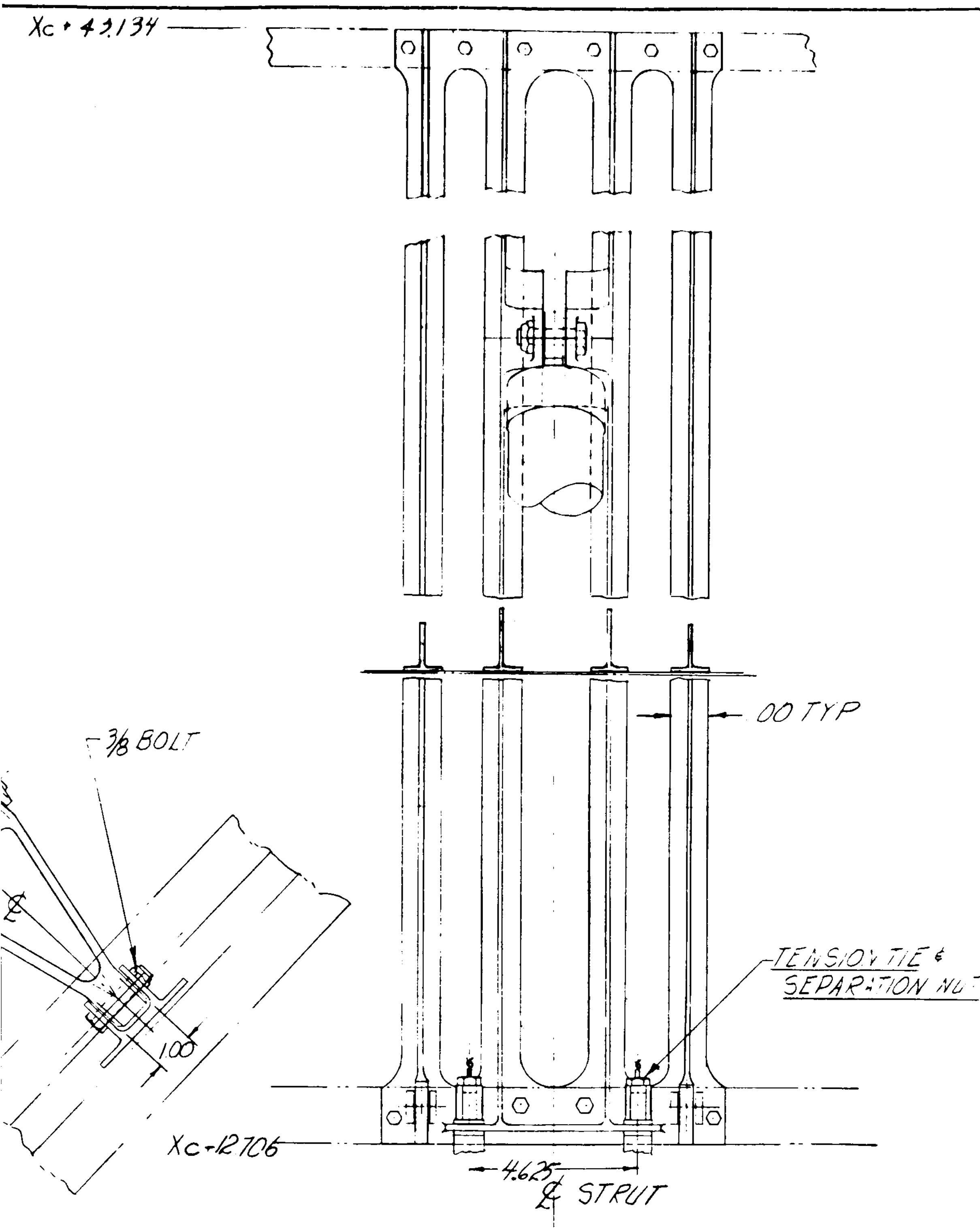
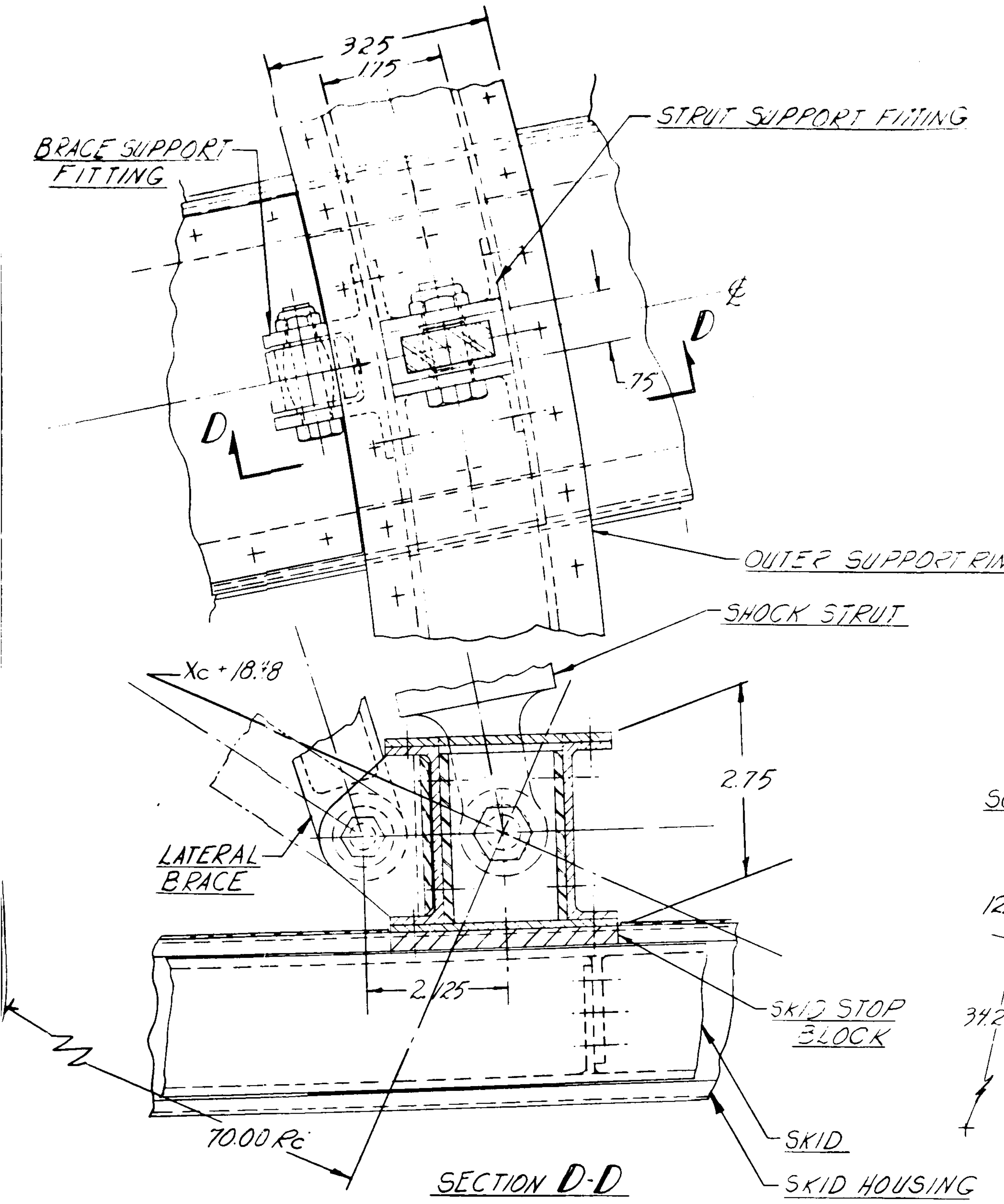
VIEW E-E
Rc+70.25
1.25
1.00
OFFSET
E
DETAIL-
LATERAL S
½ SIZE



UPPORT BRACE

DETAIL-SUPPORT FITTING
SHOCKSTRUT, LATERAL BRACE
& TENSION TIE

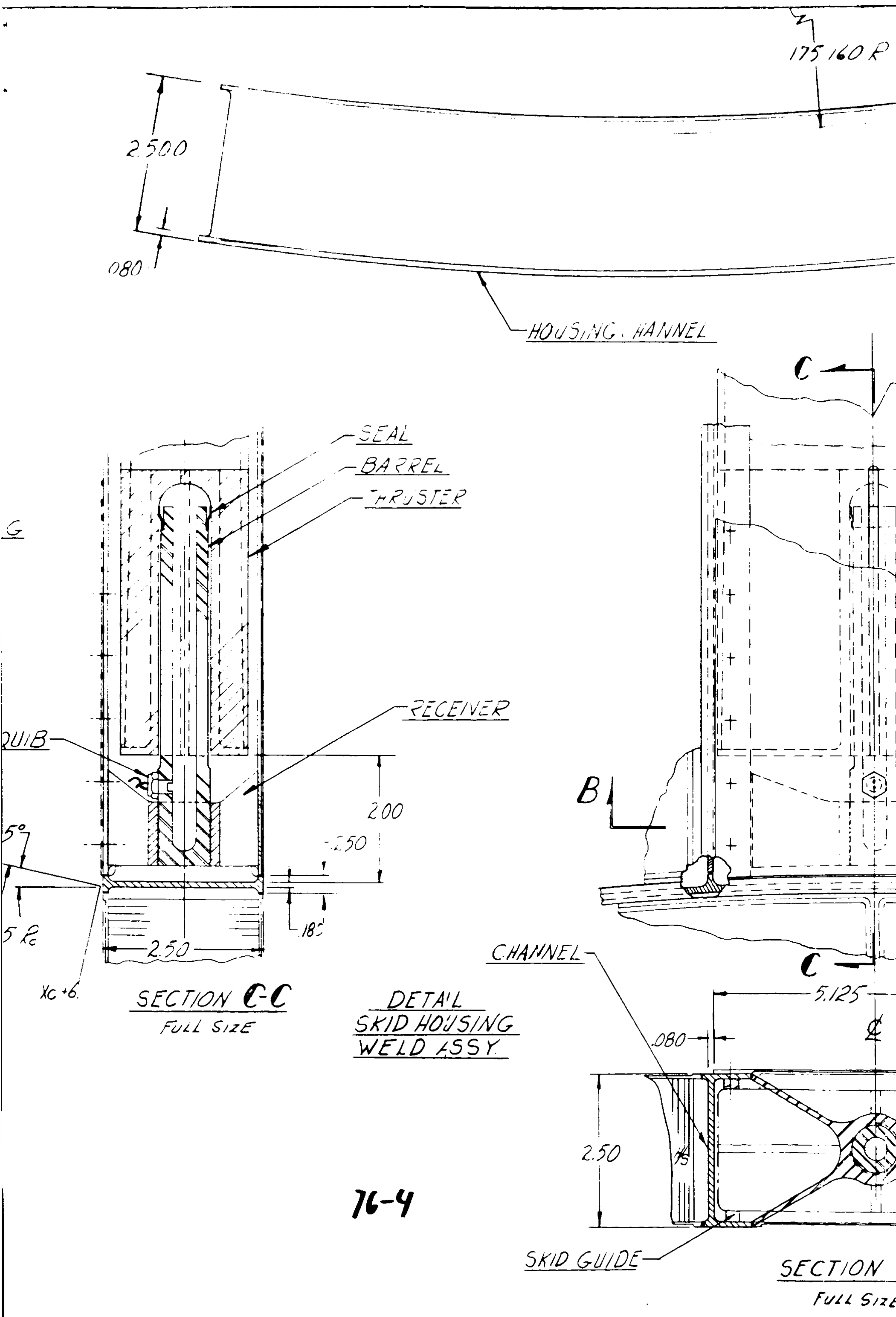
1/2 SIZE



SECTION D-D

FULL SIZE

DETAIL
OUTER SUPPORT RING -
BRACE & STRUT SUPPORT FITTINGS



175.160 R
2.500
.080
HOUSING CHANNEL
SEAL
BARREL
THRUSTER
RECEIVER
QUIB
2.00
.250
.185
2.50
Xc +6.
SECTION C-C
FULL SIZE
DETAIL
SKID HOUSING
WELD ASSY
C
B
CHANNEL
5.125
.080
2.50
SKID GUIDE
SECTION
FULL SIZE

76-4

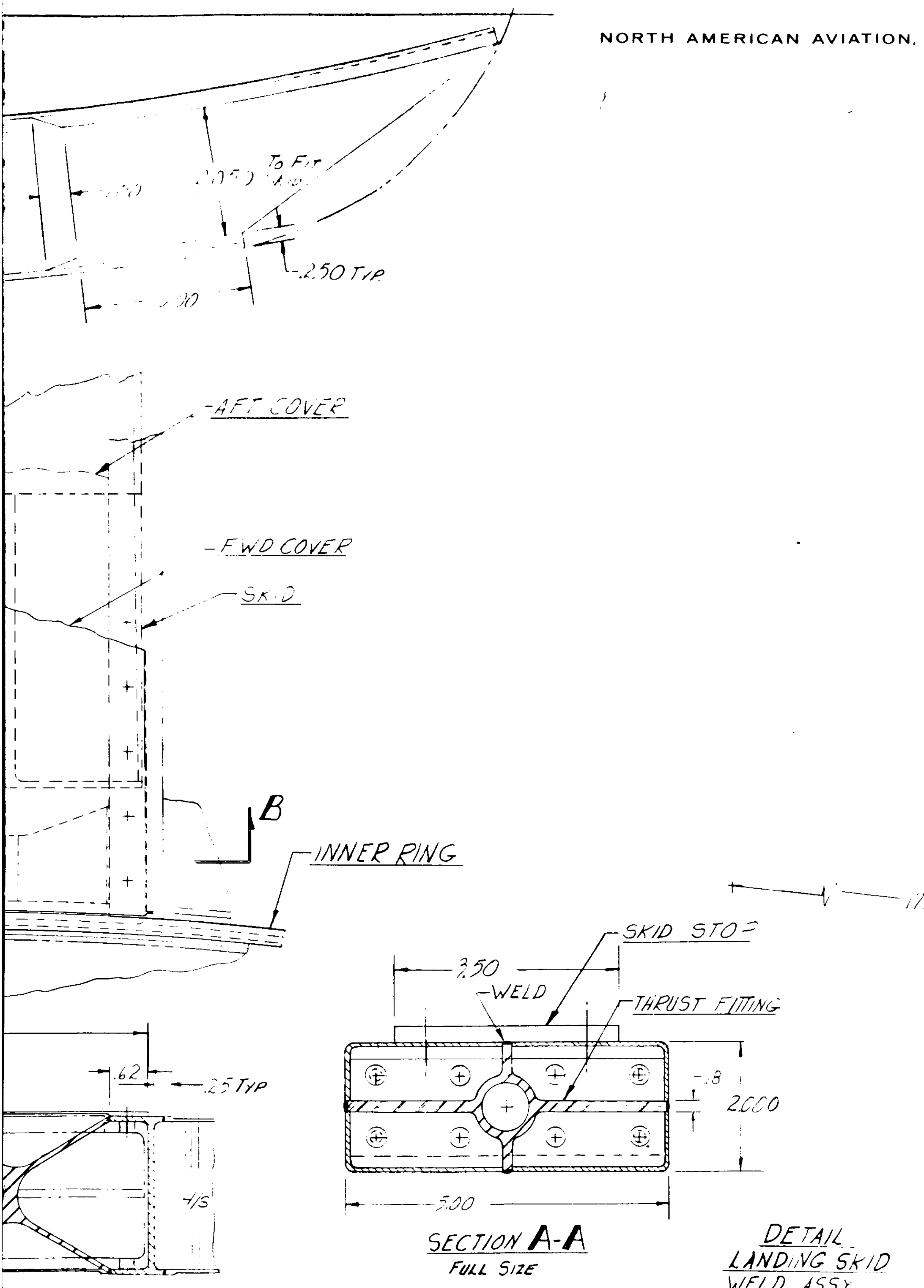
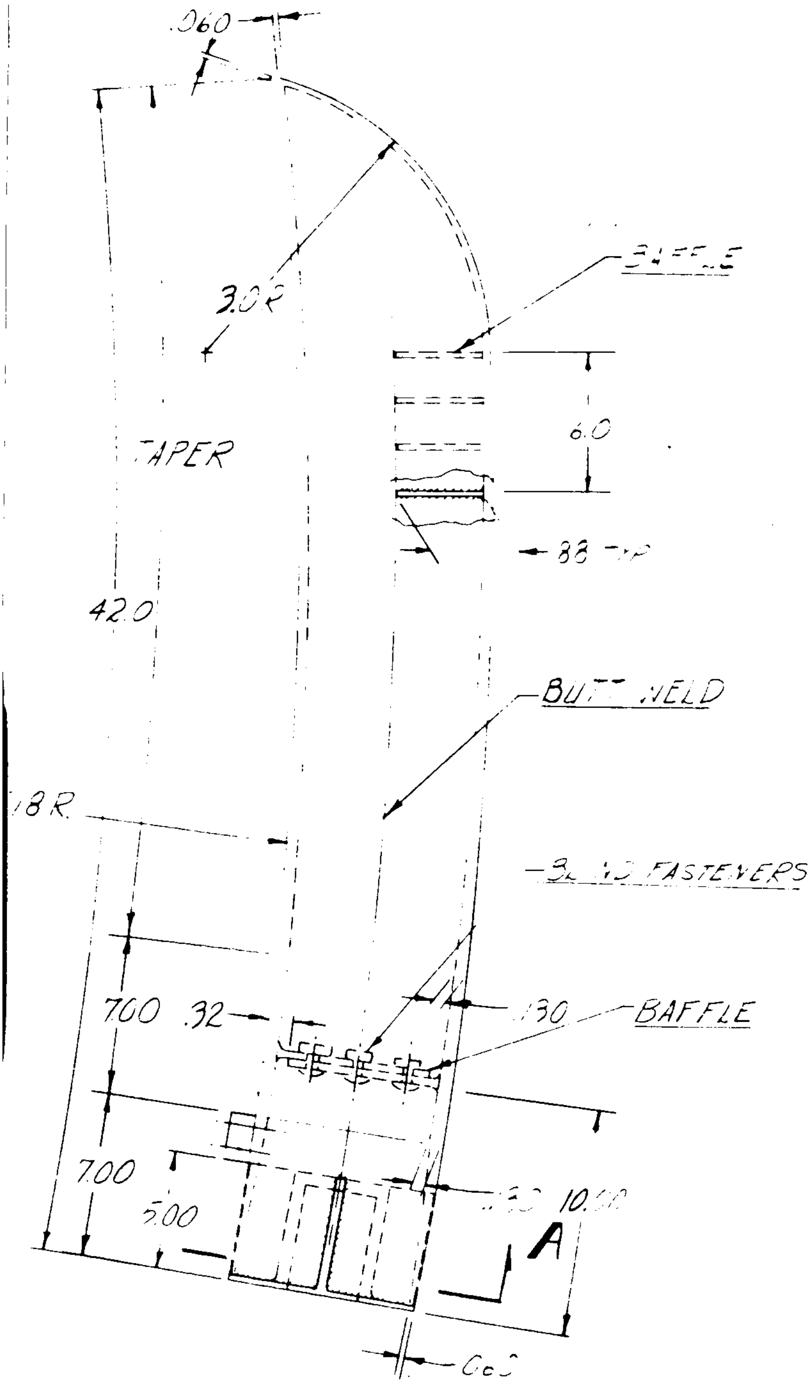


Figure 30. Struct



ıre Details Deployable Heat Shield - MISDAS

SYSTEM OPERATION

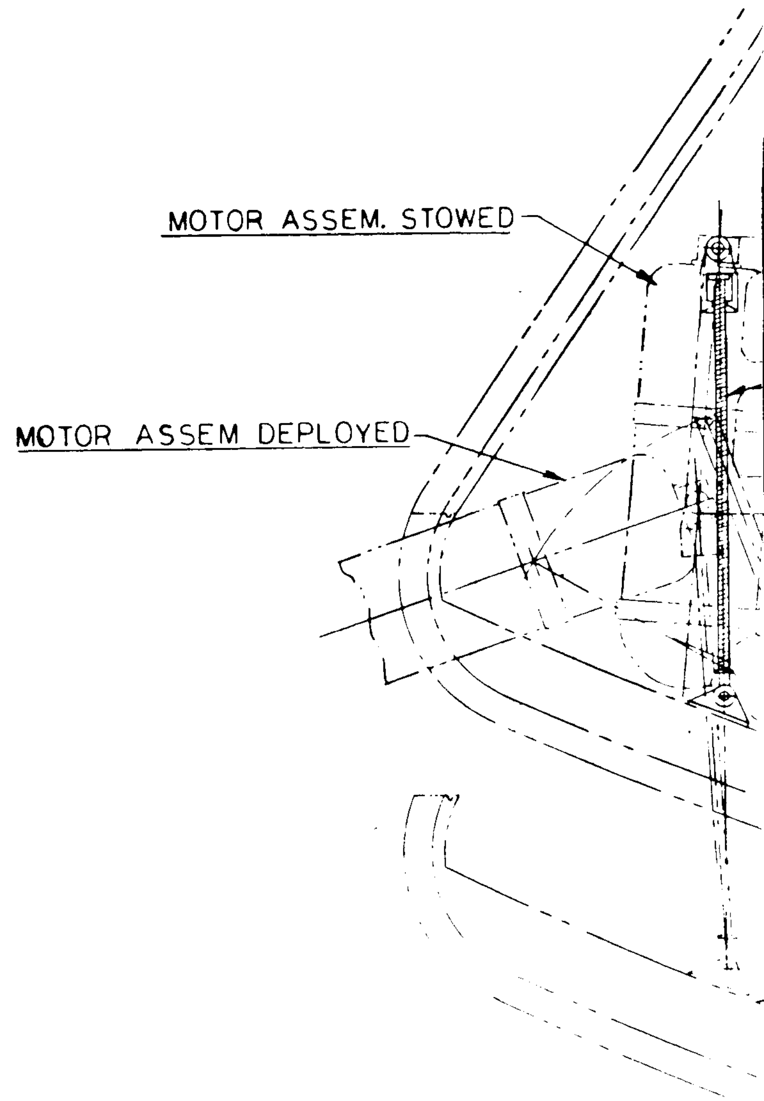
Sequentially, the deployment of the landing impact system follows the landing signal, with the release of the heat shield tension tie. An electrically initiated set of squibs within the separation nuts activates a structural Pyro-fuze insert by high temperature which releases the tension study. A pressure-charged hydraulic accumulator is then activated to pressurize and extend the shock absorber struts. The accumulator maintains pressure in the shock struts, permitting them to absorb impact energy by flow of oil through the damping orifices. In sequence or concurrent with the heat shield extension, electrically initiated squibs activate the pyrotechnic thrusters in the skids and propel them radially through the skid housings. The skids are stopped and locked in their extended position with sufficient overlap provided for socket action to resist the bending moment from the loads on the outer portion of the skid during landing. Associated electronic and mechanical units complete the systems and integrate the sequencing sections into a highly reliable and efficient ground landing system. Components similar to those used for airplane bomb, tank and pylon jettison systems and canopy and seat ejection could be developed for the skid extension. Thus, the concept is considered technically feasible.

SPACECRAFT COMPATIBILITY

The command module inner body will require modifications to accommodate the landing impact system. A number of systems and associated components within the aft heat shield compartment as identified on page 81 will require relocation and refitting for space and operating accommodations. The additional support structure will have to be added and located on the outer walls of the inner body for structural continuity. The tension ties between the command module and service module do not require structural redesign. Minor modifications to equipment and fittings in the reduced clearance space between the command module floor structure and heat shield may be required. These changes have been described in Reference 2.

PACKAGING CONSIDERATIONS

Figure 31 illustrates a packaging arrangement of the four retromotors required to attain the desired vertical landing velocities, the subsystem components, the torque links, and skid deployment cylinders in the aft equipment bay. The twelve radial skid assemblies are positioned symmetrically in the aft heat shield with the plane of two skids on the Zc-axis. The structural and mechanical details of the deployment system for the radial skid deployable heat shield concept are shown in Figure 29. The four retromotors are unsymmetrically located 28 and 40 degrees either side of the +Zc-axis and 22 degrees either side of the -Zc-axis.



ALTERNATE METHOD O
DEPLOYING MOTOR ASSE

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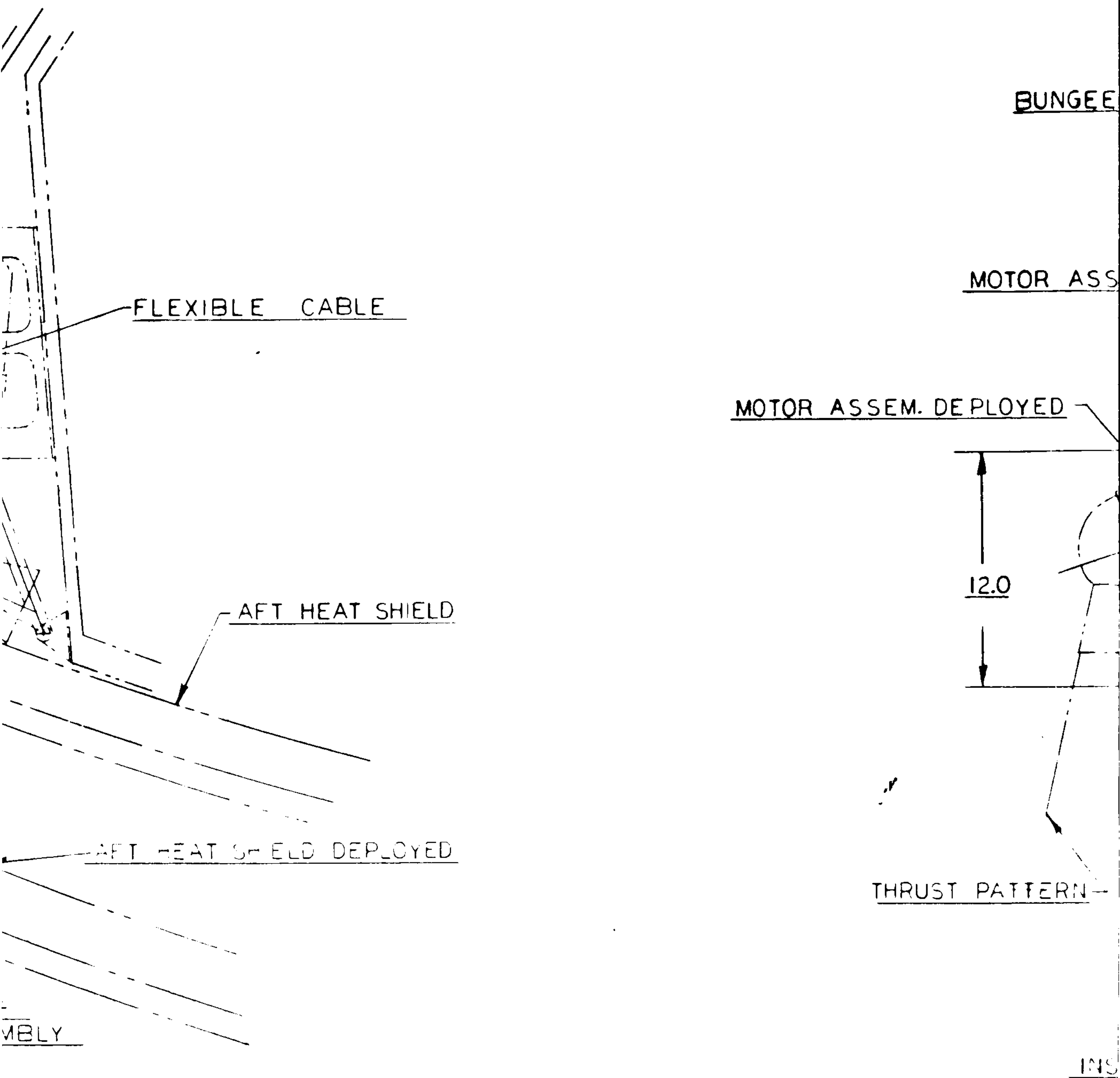
BUNGEE
FLEXIBLE CABLE
MOTOR ASS
MOTOR ASSEM. DEPLOYED
12.0
AFT HEAT SHIELD
AFT HEAT SHIELD DEPLOYED
THRUST PATTERN
MBLY
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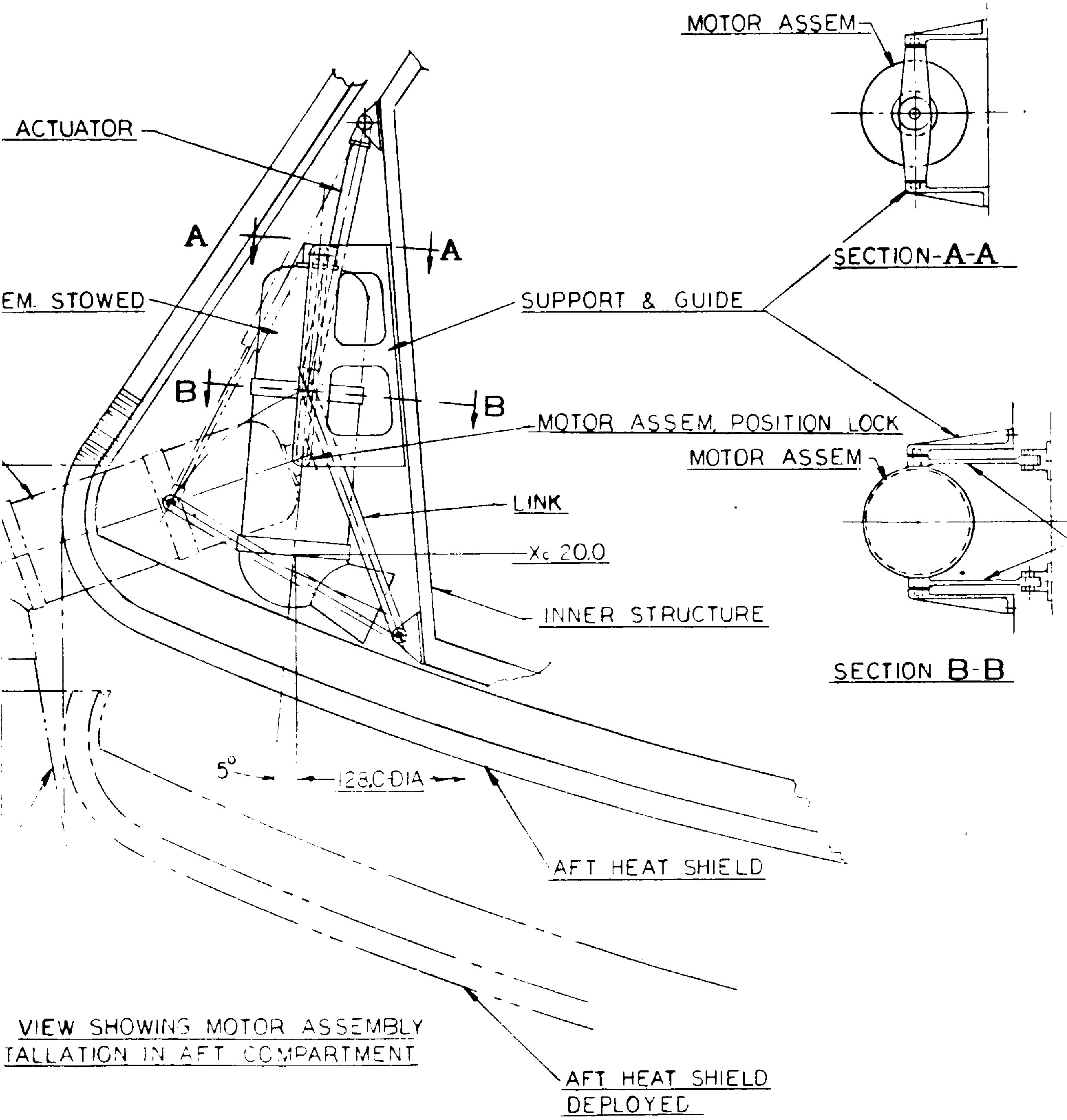
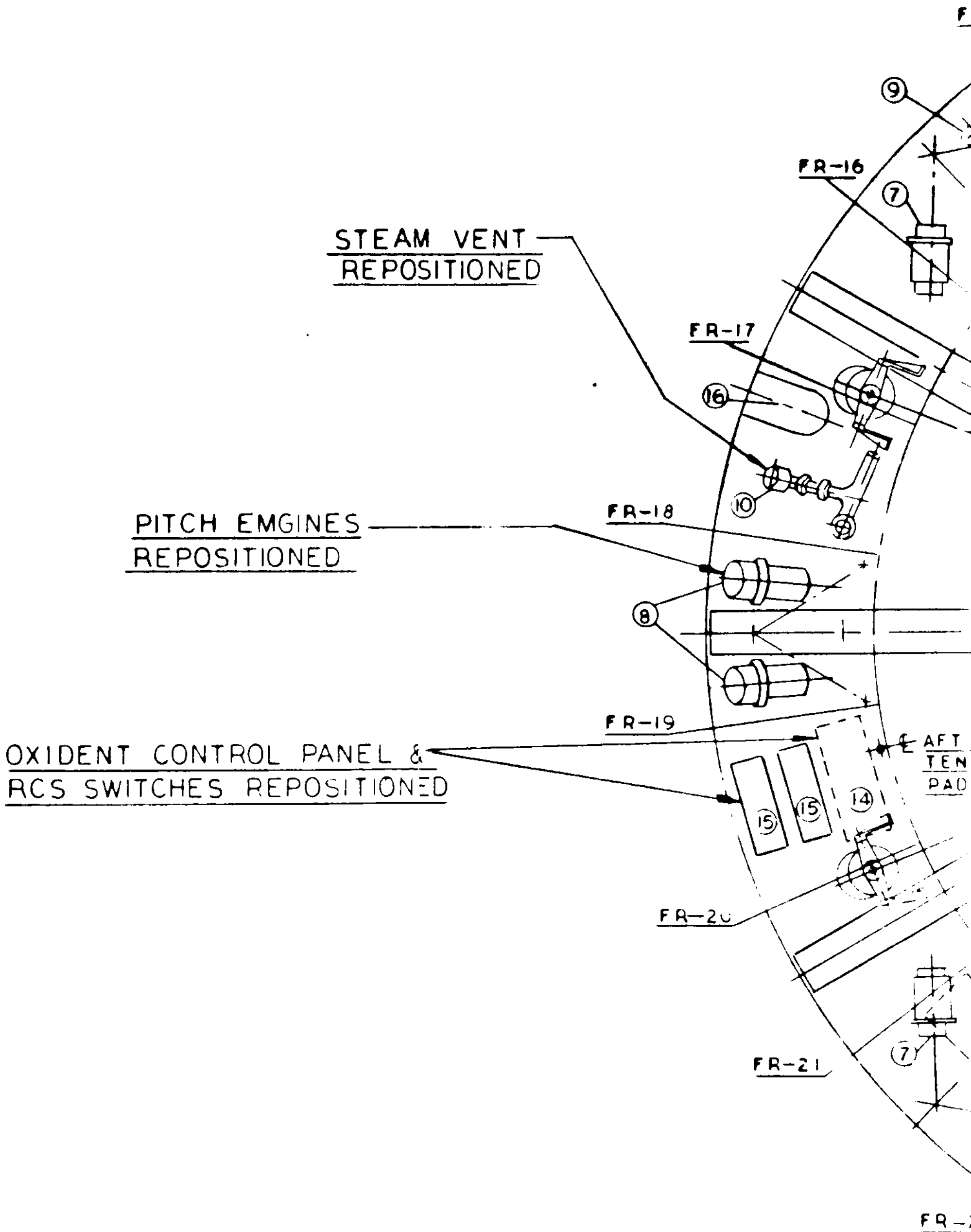
80-1

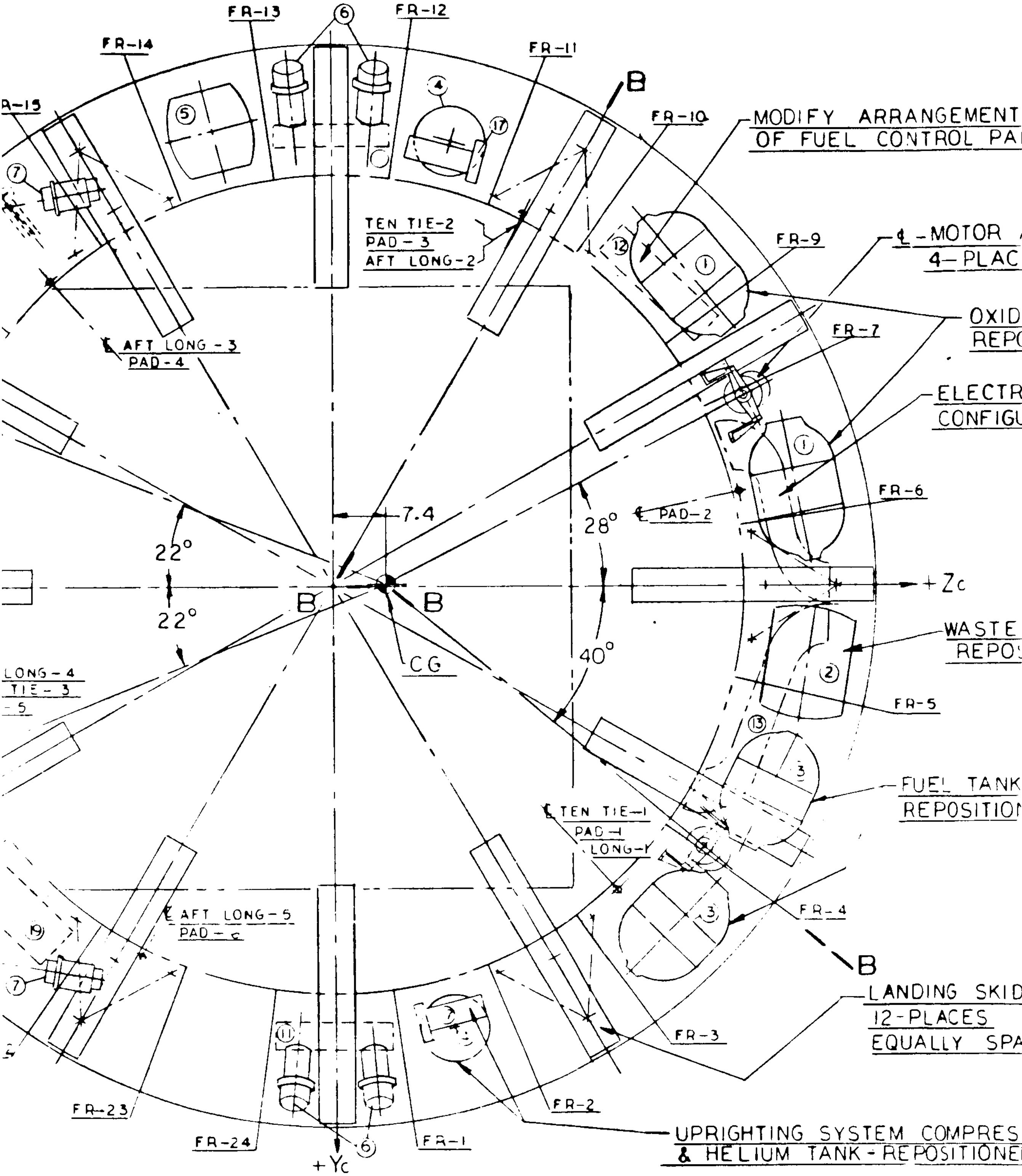


VIEW SHOWING MOTOR ASSEMBLY
TALLATION IN AFT COMPARTMENT

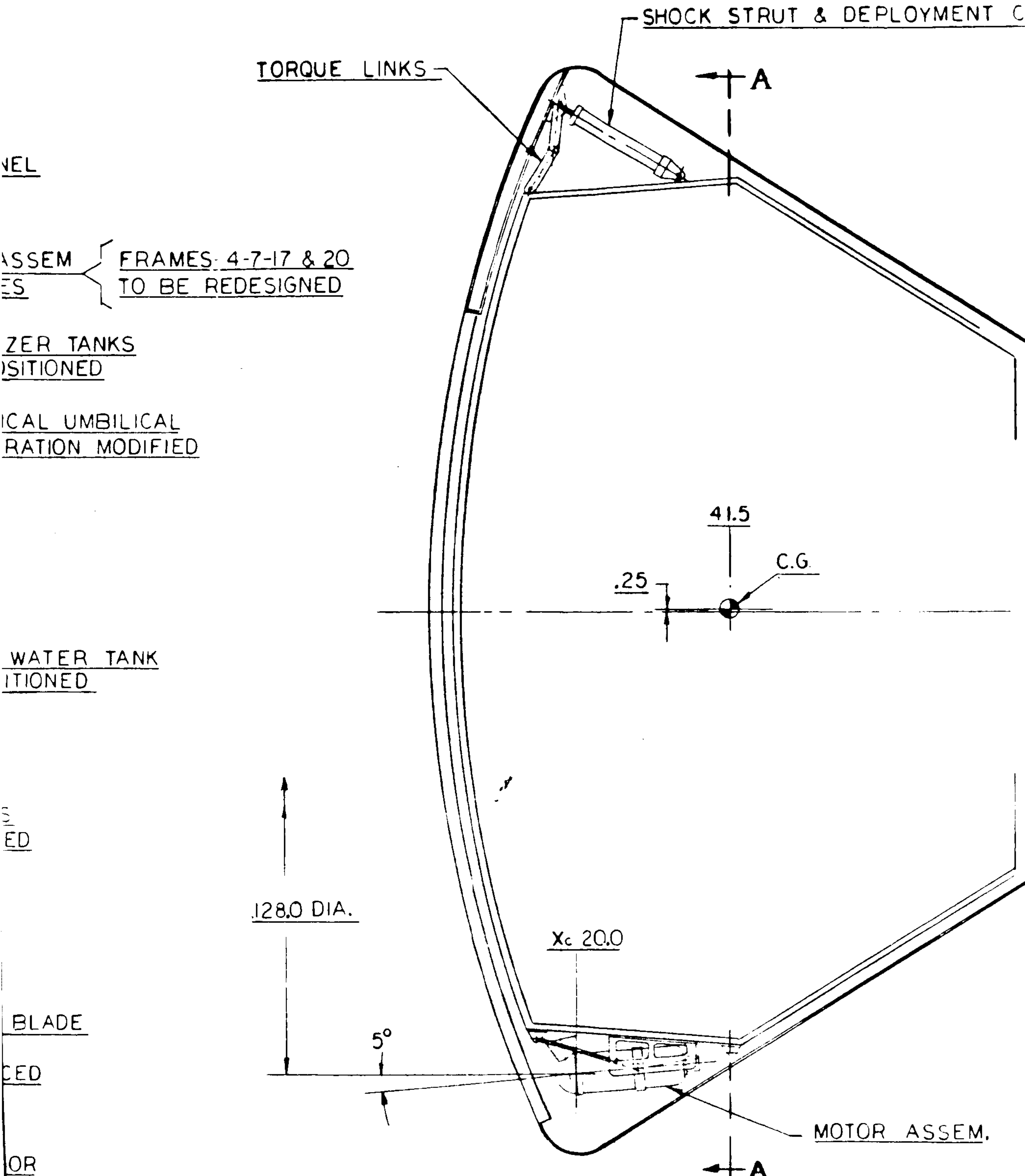
-LINK



STEAM VENT
REPOSITIONED
PITCH EMGINES
REPOSITIONED
OXIDENT CONTROL PANEL &
RCS SWITCHES REPOSITIONED
FR-16
FR-17
FR-18
FR-19
FR-21



SECTION A-A
SHOWING AFT EQUIP BAY
LOOKING AFT



SECTION B-B-B-B

80-5

Figure 31.

YLINDER

1. OXIDIZER TANK - 2
2. WASTE WATER TANK
3. FUEL TANK - 2
4. HELIUM TANK - 2
5. POTABLE WATER TANK
6. YAW RC ENGINE - 4
7. ROLL RC ENGINE - 4
8. PITCH RC ENGINE - 2
9. RELIEF DUMP VALVE
10. STEAM VENT
11. HELIUM PRESSURE PANEL - 2
12. FUEL CONTROL PANEL
13. ELECTRICAL UMBILICAL
14. OXIDENT CONTROL PANEL
15. RCS MOTOR SWITCH
16. AIR VENT
17. UPRIGHTING SYSTEM COMPRESSOR
18. TENSION TIE - 3
19. RCS CONTROL PANEL

NOTE

FOR RADIALLY EXTENDED SKIDS INSTALLATION SEE Figure 28. Manufacturing Breakdown

Retromotor Assembly Installation Deployed Heat Shield Concept - MISDAS Study

80-6

[redacted]

Installation of the four retromotors, shock struts, and torque links in the aft compartment equipment bay of the command module will require the following relocation of subsystems and aft compartment frames:

1. The uprighting system compressor and the helium tank between Frames 1 and 2, and the RCS switches were repositioned between Frames 19 and 20 to allow space for installation of the structural and mechanical details of the skid deployment system between Frames 2 and 3.

2. The oxidizer tanks, waste water tanks, and fuel tanks between Frames 4 and 11 must be repositioned between Frames 3 and 4 and between Frames 19 and 20 to accommodate the installation of the structural and mechanical details of the skid deployment system between Frames 5 and 6 and between Frames 10 and 11.

3. The structural and mechanical details of the skid deployment system located at Frames 15 and 22 require redesign and modification of the roll RCS engine support structure. The steam vent requires repositioning to a location between Frames 17 and 18.

4. The pitch engines between Frames 18 and 19 must be repositioned due to the structural and mechanical details of the skid deployment system located in this area.

5. The aft compartment Frames 5, 7, 17, and 20 must be redesigned to accommodate installation of the retromotors located at these positions.

6. The electrical umbilical may require rearrangement to be compatible with the modifications previously noted.

STRUCTURAL ANALYSIS - RADIAL SKID CONCEPT

To verify the technical feasibility of the radial skid concept installation in a 14, 000 lb vehicle for an impact velocity of 15 fps, stress and deflection analyses were performed. Stress calculations were also performed to determine the effect of vertical velocities of 20 and 30 fps on MISDAS structural design. These analyses included studies of the principal components of the impact attenuation system, the aft heat shield, and affected portions of the command module inner structure. For the 15 fps impact velocity, structural and deflection analyses have been performed which establish the sizes of the principal components of the impact system and establishes the structural integrity of the command module inner structure. The analyses are based on Figures 29 and 30, using the design criteria specified in the Guidelines, Constraints, and Design Criteria section. The primary load paths are shown in Figure 32, and the principal results are summarized in Table 8. The complete stress analysis is presented in Appendix A. The materials considered and their structural properties are discussed in Appendix B. The major aspects of the structural study are discussed in the following paragraphs.

Critical Conditions

The critical design conditions are ground impact, skid contact, water impact, and boost abort. The ground impact condition requirements are critical for the shock struts and their attachment fittings to the inner structure. Skid contact loads design the aft heat shield inner ring at 34-inch radius, the skid housing, the skids, and the Lox ring at 71-inch radius. The skid contact loading condition occurs when the spacecraft rocks sufficiently for the deployed skid to touch the ground. The water impact condition is critical for the design of the aft heat shield honeycomb panels within a 58-inch radius. The boost abort load designs the attachment of the aft heat shield to the inner structure.

Assumptions

The design was based on the loads and criteria given in the Apollo Requirements Manual ARM-6 (Reference 6) with the following exceptions. The water impact condition was limited to consideration of 15 fps impact velocity for a vehicle weight of 14, 000 pounds. The ground impact condition was based on a shock strut load derived from the dynamic analysis. The skid contact condition was taken as a one-g load acting at the end of the skid, with two skids in contact with the ground and the load distributed over 8 inches of the skid.

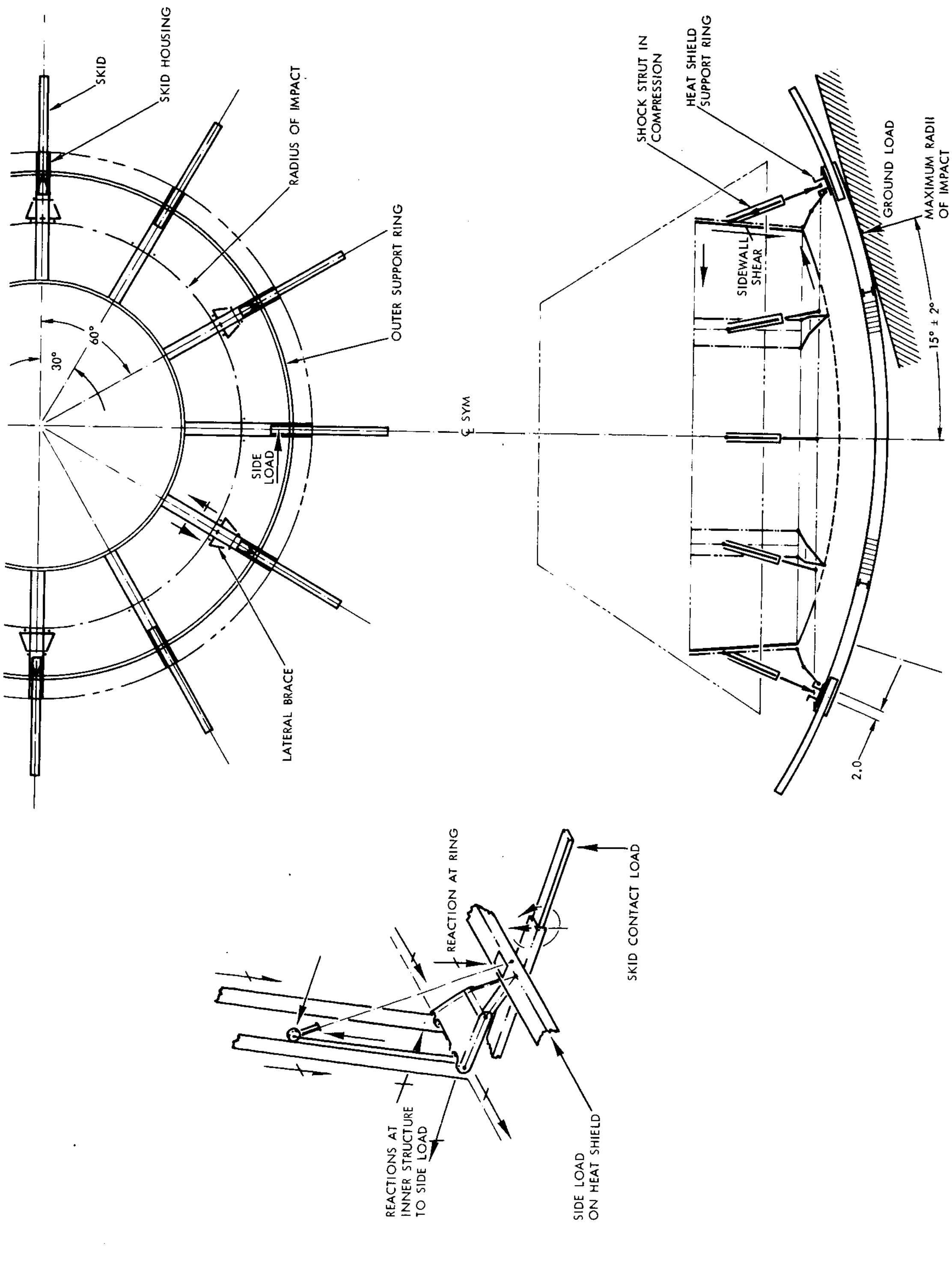


Figure 32. Structural Diagram, Deployable Heat Shield System

Table 8. Critical Stresses and Margins of Safety for Radial Skid Concept
(14, 000-lb Vehicle Descending at 15 fps)

Item	Material	Size (inches)	Critical Condition	Stress (psi)	Allowable Stress (psi)	Margin of Safety	Design Factor of Safety
Aft heat shield skin	Steel, PH14-8 Mo	t = 0. 016 to 0. 036	Water impact	119, 000	135, 000	0. 13	1. 00
Aft heat shield core	Steel, PH14-8 Mo	3/16 cell 0. 003 foil	Water impact	680	910	0. 033	1. 00
Skid	Steel, PH14-8 Mo	t = 0. 130	Skid contact	111, 000	118, 000	0. 06	1. 00
Skid housing	Steel, PH14-8 Mo		Skid contact	228, 000	230, 000 Bending modulus	0. 01	1. 33
Aft heat shield ring (34R)	Steel, PH14-8 Mo		Skid contact	130, 000	156, 000	0. 20	1. 33
Aft heat shield ring (71R)	Steel, PH14-8 Mo		Skid contact	145, 000	156, 000	0. 08	1. 33
Shock absorber fitting	Aluminum alloy 7075-T6		Ground impact	58, 800	60, 000	0. 02	1. 33
Side load links	Aluminum alloy 7075-T6		Ground impact	56, 100	60, 000	0. 07	1. 33
CM inner structure Aft sidewall skin	Aluminum alloy 2014-T6	t = 0. 018	Ground impact	34, 600	38, 000	0. 10	1. 33
CM inner structure Aft sidewall skin bonds	Epoxy adhesive		Ground impact	499	1, 320	1. 64	1. 33
Shock absorber	Steel, 180, 000 H. T.		Ground impact	93, 500	95, 500 Column Allowable	0. 11	1. 33

The following factors were applied to the design limit loads to establish the ultimate load to be considered:

1. Ground impact

   All structure: 1.33

2. Skid contact

   Skids: 1.00

   All other structure: 1.33

3. Water impact

   All structure: 1.00

The aft heat shield and skids were analyzed for a temperature of 600 F and the inner structure for a temperature of 200 F. These values are the maximum temperatures used for the Apollo analysis. The value of 600 F is conservative in that it is the maximum temperature expected at the ablator-heat shield interface.

Principal Results and Conclusions

For this concept, the hoop continuity and overall stiffness of the Apollo heat shield substructure is retained; therefore, the ability of the structure to support flight loads is not affected by the introduction of the skid housings. It should be noted, that the increase in the vehicle weight causes a proportionate increase in entry loads. With the heat shield deployed, all loads are reacted at the six strut attachment points. To distribute the resulting concentrated loads at these six points, a box section ring has been added to the structure forward of the inner face sheet at a 71-inch radius. The radial skid housings are designed to react the skid loads, to distribute these loads into the structure, and to be sufficiently stiff to replace the heat shield material removed to accommodate their installation.

The 12 extendible skids are subject to ground contact loads when the vehicle tips over. These loads are carried in bending to the skids housings welded into the heat shield and supported by the inboard and outboard rings. The outboard ring picks up the six shock struts which transfer the load to the command module inner structure aft sidewall.

In the retracted position, the aft heat shield is bolted to the inner structure at the aft bulkhead ring with 24 Pyrofuze bolts. These bolts carry the tension loads that occur at this interface. The lateral shear is taken by 59 studs in the aft bulkhead ring. With the aft heat shield deployed at the time of impact, the vertical loads to which it is subjected are transmitted to the inner structure by the shock struts. A linkage is provided to carry the lateral loads on the aft heat shield to the inner structure. The forward end of the shock strut is attached to a fitting which introduces the loads to the inner structure aft sidewall. For the 15 fps impact velocities considered, this fitting is bolted to the girth ring and the aft bulkhead ring, and is bonded to the aft sidewall skin. The aft sidewall skin then reacts the vertical component of the shock strut load in shear. The radial component of the shock strut load is carried in bending by the fitting and is reacted by the rings. The results of this analysis are given in Table 8.

Effects of Impact Velocities of 20 and 30 fps

The increased impact velocities have no effect on those items of the aft heat shield substructure which are designed by the skid contact condition, with the exception of the shock strut support ring at 71-inches radius. The increased ring section required for ground impact velocities of 20 and 30 fps are shown in sketches on Pages 5.1 and 5.7 of Appendix A.

The water impact condition determines the skin thickness of the aft heat shield. A comparison of the skins required for the different velocities is given as follows:

Velocity (fps)	Skin Gauge (in.)
15	0.016 to 0.036
20	0.014 to 0.049
30	0.023 to 0.054

Sketches showing the skin profile for the different velocities are given on Pages 3.2, 5.6, and 5.13 of Appendix A.

No design changes are required for the descent velocity of 20 fps. The increase in load can be supported by increasing the shock strut support fitting, and by using a thicker aft side wall skin as shown on Page 5.4 of the calculations. To accommodate a descent velocity of 30 fps, extensive changes to the aft portion of the inner structure would be required in the manner suggested for the higher velocities on the segmented heat shield concept. The vertical reaction of the shock struts requires a longeron welded into the basic weldment of the inner structure for each shock strut fitting. A sketch of this longeron and the method of attaching the shock strut fitting is shown on Page 5.10 of Appendix A. The skin gauge, all weld lands between skins and longerons, and weld lands between skins and rings would require increased thicknesses to support time resulting shear. None of the shear is assumed to be distributed into the forward sidewall of the inner structure with the result that the sizes given on Page 5.11 of Appendix A is slightly conservative. The girth ring at station Xe 43 in its present form cannot support the radial component of the shock strut load and would require an increase in its bending capability for the critical section in the area of the main access hatch. The magnitude of the change required is shown on Page 5.12 of Appendix A.

The results of the stress calculations are given in Tables 9 and 10.

LANDING STABILITY ANALYSIS

The stability characteristics of the vehicle with deployed heat shield and extended skids were determined through the use of 6DØF, a versatile FORTRAN IV computer program used for solution of Apollo-type vehicle impact dynamics. 6DØF uses a mathematical model of an Apollo-type two-body spacecraft-heat shield and hull. When initial landing parameters are loaded, the program simulates the dynamics in three dimensions of a real spacecraft making an earth landing. The action of the ground on the deployed heat shield produces forces on the heat shield struts. The struts then act to apply forces and torques to the spacecraft itself. The 6DØF program is described in report SID 66-279, presented as Appendix D of this report.

The laws of motion are integrated using small time increments to produce linear and angular acceleration, velocity, and displacement time histories of the deployed heat shield and the pressure hull.

Use of the NAA system computing feature (DECRD) allows for a very flexible input sequencing which makes this program particularly useful in parametric studies. Loading time for the object deck is about 30 seconds; computing time per landing case is on the order of 60 seconds.

The geometry of essential points on the spacecraft is described by the coordinates of each point in a coordinate system fixed to the spacecraft (capsule initial system). Important points, such as center of gravity, struts ends, etc. are located by loading in their coordinates. Up to eight massless struts are allowed and each may have different stroking properties. The

Table 9. Critical Stresses and Margins of Safety for Radial Skid Concept (14,000-lb Vehicle Descending at 20 fps)

Item	Material	Size (inches)	Critical Condition	Stress (psi)	Allowable Stress (psi)	Margin of Safety	Design Factor of Safety
Aft heat shield skin	Steel, PH14-8 Mo	t = 0.016 to 0.036	Water impact	135,000	135,000	Zero	1.00
Aft heat shield core	Steel, PH14-8 Mo	1/8 cell 0.003 foil	Water impact	1,060	1,610	0.36	1.00
Aft heat shield ring (71R)	Steel, Ph14-8 Mo		Ground impact	156,000	156,000	Zero	1.33
Shock absorber fitting	Aluminum alloy 7075-T6		Ground impact	57,250	60,000	0.05	1.33
Side load links	Aluminum alloy 7075-T6		Ground impact	57,700	60,000	0.04	1.33
CM inner structure Aft sidewall skin	Aluminum alloy 2014-T6	t = 0.030	Ground impact	36,800	38,000	0.03	1.33
CM inner structure Aft sidewall skin bonds	Epoxy adhesive		Ground impact	885	1,320	0.49	1.33
Shock absorber	Steel, 180,000 H.T.		Ground impact	119,000	121,000 Column Allowable	0.02	1.33

NOTE: During this preliminary analysis, a minimum positive margin of safety, including zero, has been considered acceptable to minimize the weight of structural components.

Table 10. Critical Stresses and Margins of Safety for Radial Skid Concept (for 14, 000-lb vehicle descending at 30 fps)

Item	Material	Size (inches)	Critical Condition	Stress (psi)	Allowable Stress (psi)	Margin of Safety	Design Factor of Safety
Aft heat shield skin	Steel, PH14-8 Mo	t = 0.027 to 0.097	Water impact	135,000	135,000	Zero	1.00
Aft heat shield core	Steel, PH14-8 Mo	1/8 cell 0.003 foil	Water impact	1,600 (local area)	1,610	Zero	1.00
Aft heat shield ring (71R)	Steel, PH14-8 Mo		Ground impact	155,000	156,000	0.01	1.33
Shock absorber fitting	Aluminum alloy 7075-T6		Ground impact	57,000	60,000	0.05	1.33
Side load links	Aluminum alloy 7075-T6		Ground impact	59,500	60,000	Zero	1.33
CM inner structure Aft sidewall skin	Aluminum alloy 2014-T6	t = 0.066	Ground impact	38,000	38,000	Zero	1.33
CM inner structure Aft sidewall skin bonds	Epoxy adhesive	Bond overlap increased to 0.95	Ground impact	1,320	1,320	Zero	1.33
CM inner structure Ring and longeron weld lands	Aluminum alloy 2014-T6	t = 0.100	Ground impact	15,000	15,000 (after welding)	Zero	1.33
CM inner structure Girth ring sta Xc 43	Aluminum alloy 2014-T6		Ground impact	168,000	60,000	Negative margin section requires 180% increase	
Shock absorber	Steel, 180,000 H.T.		Ground impact	152,500	156,000	0.02	1.33

NOTE

During this preliminary analysis, a minimum positive margin of safety, including zero value, has been considered acceptable to minimize the weight of structural components.

*Redesign of this member to sustain increased loads has been considered out of the scope of this program. Weight calculations allow for changes necessary to obtain positive margins of safety.

struts are the only connecting elements between the pressure hull (crew compartment) and the deployed heat shield and they are assumed to be pin-ended. The analysis is based on the following assumptions on spacecraft and ground properties.

The properties of each strut must be expressible as a load-stroke curve that can be formed by a series of straight lines. Plastic deformation is the principal strut property, but provisions are made for inclusion of elasticity and frictional properties. The struts are considered to be massless.

The ground is considered as a rigid plane that has a constant friction coefficient with the heat shield. The ground may have a slope and direction of slope.

The crew compartment, or hull, is considered as a rigid mass. The heat shield is considered to have mass and to have plastic and elastic properties which can be expressed as a load-deflection curve as in the case of the strut properties. Coordinates of 73 points on the heat shield are loaded to define its shape. All deflections of the heat shield are taken as normal to the ground plane. It should be noted that the load-deflection properties of the heat shield effectively include both ground and heat shield properties. These properties were obtained by successively varying heat shield data so that results from 6DØF agreed with accelerometer data from Apollo boilerplate drop tests. These heat shield properties, as given in Appendix D, were not obtained analytically or by directly measuring load-deflection properties of the heat shield.

A partial list of input data to the program includes:

1. Acceleration of gravity
2. Coordinates of cg
3. Mass properties of hull and heat shield
4. Coordinates of strut ends
5. Load-stroke properties of struts
6. Coordinates of heat-shield defining points
7. Load-deflection properties of heat shield points

Initial value (landing parameter) data include:

1. Horizontal and vertical velocities

2. Roll, pitch, and yaw

3. Angular velocities

4. Ground slope and direction of slope

5. Friction coefficient with ground

The program's output is primarily in the form of CRT plotting. Time histories are plotted from the instant of impact for the following quantities:

1. Acceleration, velocity, and displacement of the heat shield cg in a direction normal to the earth

2. Roll, pitch, and yaw measured relative to the earth (earth y-z coordinate axes form plane of ground)

3. Acceleration, velocity, and displacement of the hull are given relative to the heat shield

4. Stroke of each strut (versus time)

Angle Conventions

Angle conventions for the radial skid system are as discussed below: The vehicle is first rolled about its vertical axis, then pitched about its y axis, then yawed about the z axis on the capsule. The roll angle is always measured as the counterclockwise angle from the horizontal velocity to the vertical plane that contains the capsule z axis. The net pitch angle is measured as the upward angle from the horizontal plane to the capsule z axis (Figure 33). The ground slope is defined by a maximum slope and a direction of upslope. The direction of upslope is measured in a counterclockwise angle (right-hand rule) from the horizontal velocity. Positive slope is upslope. Horizontal and vertical velocity always form the basic reference plane.

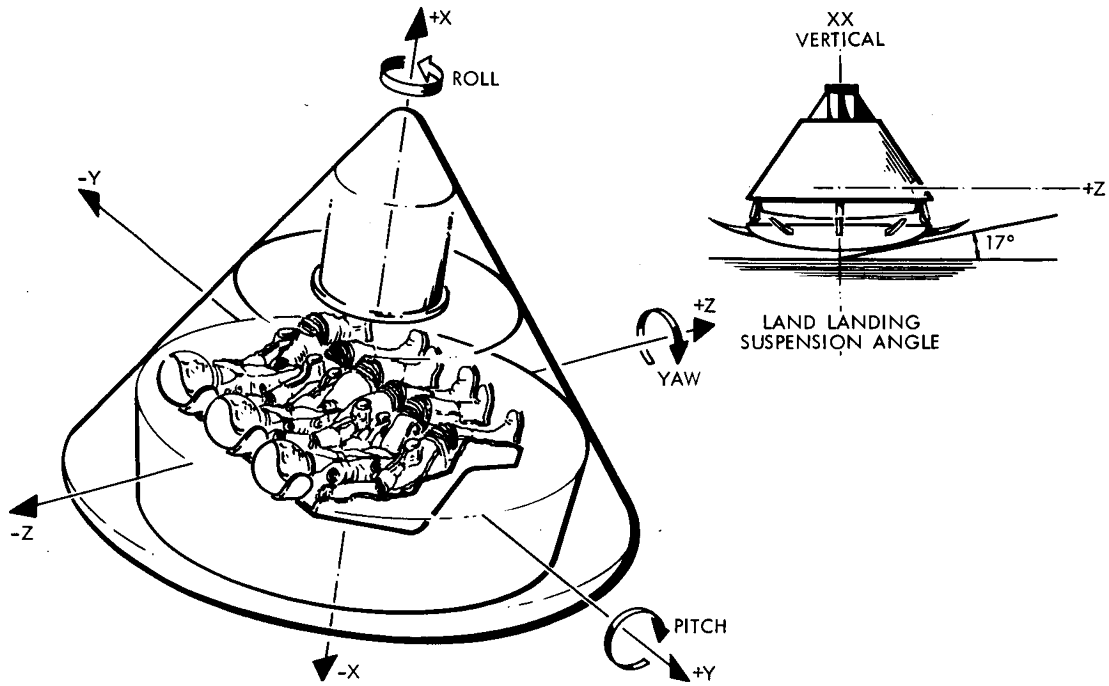


Figure 33. MISDAS Land Landing Attitude, Deployable Heat Shield System

Landing Stability Considerations

Landing stability of the 14,000-pound vehicle has been studied under a variety of conditions, including the increased vertical velocities of 20 and 30 fps, and ground coefficients of friction of 0.35 to 1.0, and above. These analyses have been based on those performed for the AES application, with strut loads directly scaled from those used with the 10,600-pound vehicle (Reference 2). Because the computer program is limited to a total of eight struts four horizontal and four vertical struts have been considered.

The initial locations of the ends of the eight struts used for the capsule initial system are indicated in the following table.

Strut No.		1	2	3	4	5	6	7	8
	x	18.25	18.25	18.25	18.25	18.25	18.25	18.25	18.25
Heat shield	y	0	-73.0	0	73.0	-73.0	73.0	-73.0	73.0
	z	73.0	0	-73.0	0	0	0	0	0
	x	46.0	46.0	46.0	46.0	18.25	18.25	18.25	18.25
Capsule	y	0	-61.0	0	61.0	0	0	0	0
	z	61.0	0	61.0	0	73.0	73.0	-73.0	-73.0

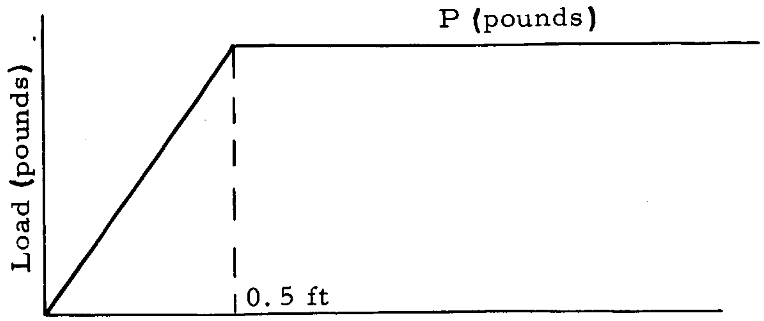
The vertical struts used the force-stroke function given in Figure 33 for compression. To retain the heat shield to the capsule in other attitudes, dummy coloumb friction forces were added to the vertical struts in tension and to the lateral struts in both directions. The axial forces were 14,900 pounds for each of the four vertical struts, and 55,000 pounds per lateral strut for the 10,600-pound vehicle landing at 15 fps on a ground with a coefficient of friction $\mu = 0.35$. Thus, the strut loads in the actual configuration with six vertical struts was 23,000 pounds per vertical strut.

Loads for the 14,000-pound spacecraft were scaled directly from these values and are shown in Figure 34. The resulting crew compartment accelerations shown in Figure 34 indicate that for vertical velocities above 15 fps, crew couch attenuators will be required. The vertical velocity at which crew tolerances will be exceeded depends on the effective ground friction coefficient at impact.

Results of Stability Analysis

Stability envelopes derived in this phase have been obtained by linearly scaling strut loads to vehicle weight from those used in the AES application for the 10,600-pound vehicle.

For landing conditions consistent with the design criteria presented in the Guidelines, Constraints, and Design Criteria Section, this vehicle showed good stability. The landings that were most nearly unstable for horizontal velocity were directed downslope. Figure 35 shows the maximum tipping angles mapped as a function of vertical velocity and roll angle. The figure shows that a maximum tipping angle of 40 degrees will be reached when landing at 15-fps vertical velocity, down a 5-degree slope, zero-degree direction of swing, and 12-degree swing angle. This landing is the worst obtained for vertical velocities of 15 fps or less.

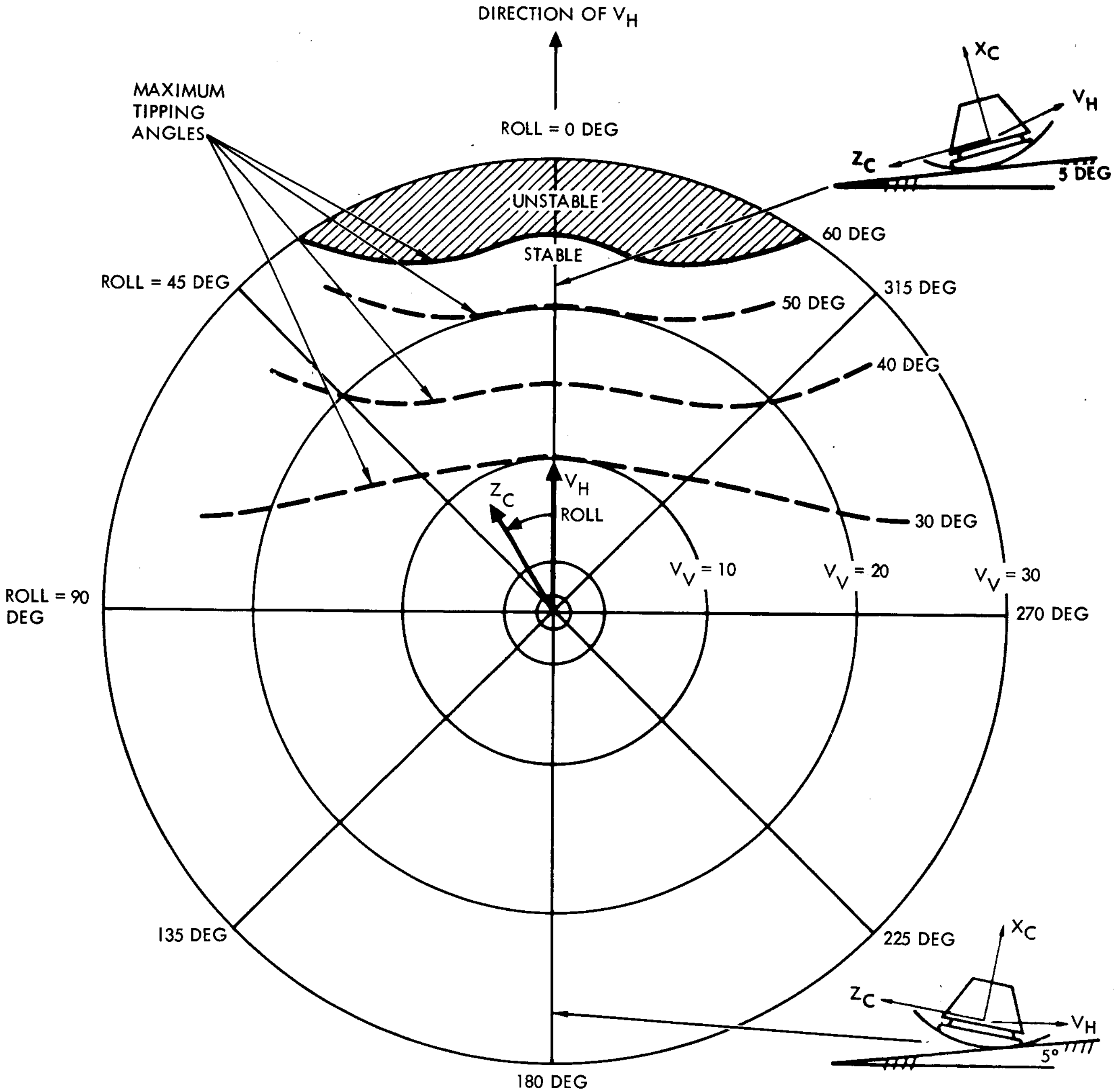


Radial Skid Concept				
Vehicle Weight (pounds)	Vertical Velocity (fps)	Collapsing Load P (Mathematical Strut) (pounds)	Collapsing Load of Actual Strut (pounds)	Max Crew Compartment Acceleration (g normal to earth)
10,600	15	34,900	23,300	17.0
14,000	15	46,130	30,756	17.0
14,000	20	82,120	54,746	30.3
14,000	30	184,540	123,024	68.0

Figure 34. Mathematical Load-Stroke Properties for the Radial Skid System With Four X-X Axis Struts

Landings upslope tend to stabilize the capsule, but lead to greater strut stroking. The landing at V_H = 80 fps and V_V = 15 fps is a severe case since the struts previously described for this concept will be stroked in such a way that the heat shield will be closed on one side after impact. Stiffer struts will be required for vertical velocities above 15 fps.

Load-stroke characteristics of the struts used in the analysis have been derived to satisfy requirements of landing stability criteria, capsule geometry constraints, crew acceleration and onset rate tolerances, and protection of permanent structure from damage on landing. The single stroke that satisfies these requirements was chosen and used for the



NOTE

MAXIMUM TIPPING ANGLES MAPPED AS FUNCTION OF VERTICAL VELOCITY FPS AND ROLL ANGLE, DEG, FROM VELOCITY PLANE (60 DEG IS UNSTABLE)

COEFFICIENT OF FRICTION = 0.35.
HORIZONTAL VELOCITY = 30.0 FPS
SLOPE = 5.0 DEG DOWN
DIRECTION OF SLOPE = ALONG HORIZONTAL VELOCITY
SWING ANGLE = 12.0 DEG

Figure 35. Stability Limits for Deployed-Heat-Shield-With-Skids Vehicle

analysis. The characteristics of longer and softer struts and their advantages and disadvantages have not been investigated but are considered an interesting subject for future studies.

A study of the stability of the skid system spacecraft at higher vertical velocities and friction coefficients greater than 0.35 has been accomplished. The resulting information is shown in Figure 36. Constant lines of vertical velocity are mapped onto a plot of roll versus coefficient of friction. This plot indicates that stable landings could be made for coefficients of friction greater than 1.0 if the roll angle of the spacecraft could be controlled. With

roll = 180±45 degrees and positive pitch relative to the ground plane (or roll = 0±45 degrees and negative pitch), stable landings are indicated. It should be noted that roll angle is measured from the horizontal velocity to the vertical plane that contains the capsule z axis.

Mass Properties

The weight penalty for adding the radial skid MISDAS system to the Apollo advanced spacecraft consists of the landing gear system weight plus the effects of all modifications required on the aft heat shield and inner structure.

Apollo Block II weight and mass properties information presented in Reference 8 was used as a base point for all calculations; weight changes due to structural modifications of the aft heat shield and inner structure are based on details of Figures 29 and 30, and the stress analysis presented in Appendix A for a landing vertical velocity of 15 fps and 0.35 ground coefficient of friction.

Table 11 presents a detailed weight breakdown of the radial skid MISDAS concept. The weight of heat shield and inner structure components affected by MISDAS installation is shown in Table 12 for the advanced spacecraft and for the basic Apollo Block II vehicle.

The net weight penalty imposed by the MISDAS radial skid system to the 14,000-pound spacecraft landing on ground with a vertical velocity of up to 15 fps and a coefficient of friction of up to $\mu = 0.35$ is 955 pounds or 6.82 percent of the landing weight.

The volume requirements of MISDAS installation in the spacecraft aft equipment bay was also assessed. This volume includes the space required by the stored mechanisms and their operation. The total volume required by the radial skid system for landings with sinking velocity of up to 15 fps and $\mu = 0.35$ is 3.5 cubic feet.

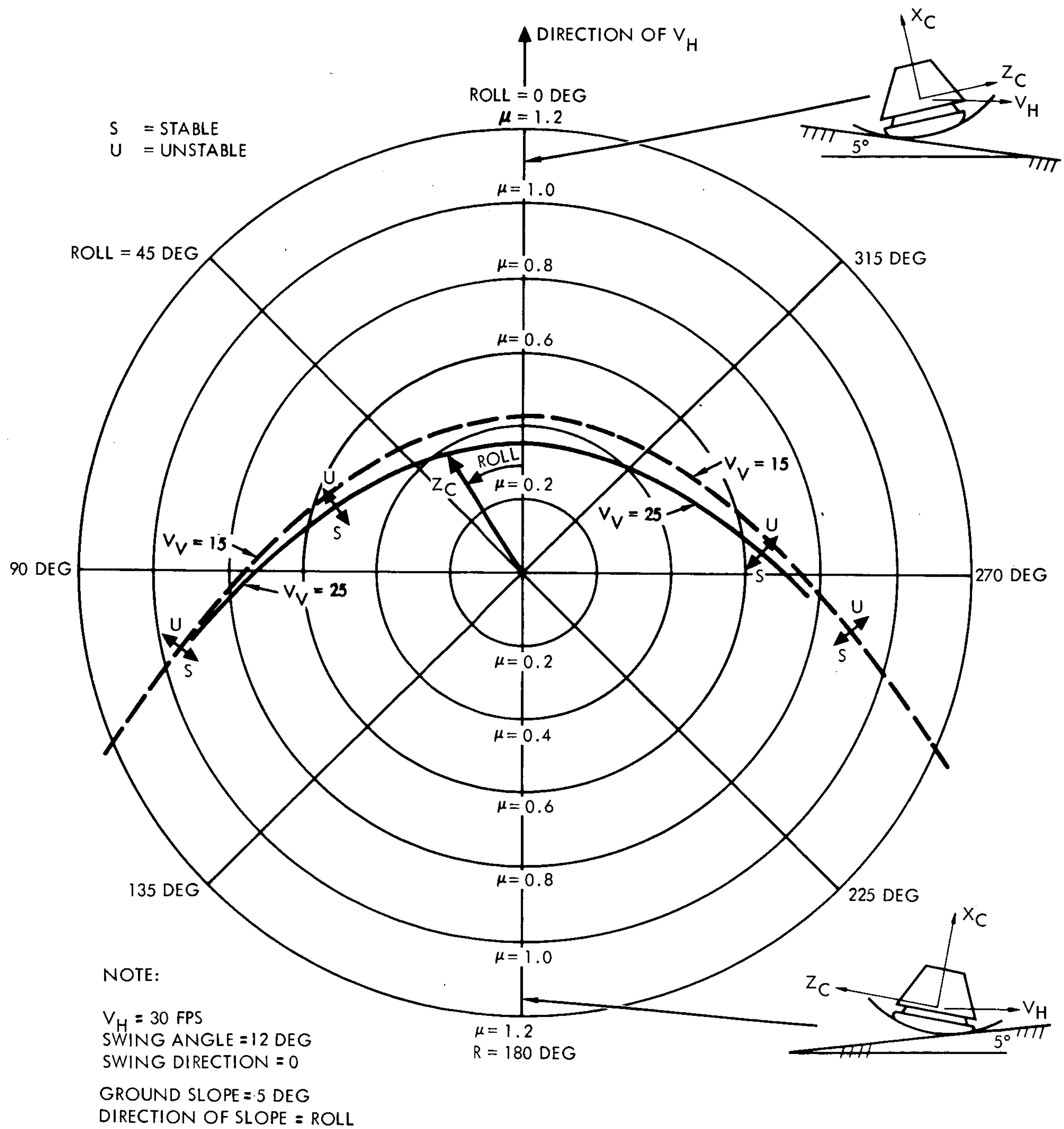


Figure 36. Stability of Skid System Vehicle as a Function of Roll (Deg) and Coefficient of Friction (μ)

Table 11. MISDAS Deployable Heat Shield/Radially Extended Skid Concept Detail Weight Breakdown

Item	Weight (lb) $\mu = 0.35$ V_v = 15 fps	V_v = 20 fps	V_v = 30 fps
Structural modification	-162.0	-71.0	+261.0
Landing gear assembly	(1117.0)	(1237.0)	(1965.0)
Skin assembly	(633.0)	(633.0)	(633.0)
Skid housing (12)	303.0	303.0	303.0
Skids (12)	272.0	272.0	272.0
Inner ring	17.0	17.0	17.0
Skid extension device	41.0	41.0	41.0
Ring, outer support	300.0	341.0	770.0
Shock strut assembly	(150.0)	(221.0)	(473.0)
Struts (6)	75.0	105.0	244.0
Lateral supports	30.0	54.0	97.0
Attach fitting - sidewall	40.0	54.0	117.0
Hardware	5.0	8.0	15.0
Hydraulic and pneumatic system	(34.0)	(42.0)	(89.0)
Hydraulic accumulator	6.0	8.5	22.0
Motor valve	2.0	2.0	2.0
Valves	.5	.5	.5
Dampning orifices	1.0	1.0	1.0
Plumbing	7.0	7.0	10.0
Electrical provision	2.5	2.5	2.5
Support and attaching parts	1.5	1.5	2.0
Hydraulic fluid	13.0	19.0	48.0
Gas (helium)	.5	.5	1.0
Total mechanical landing system penalty	955.0	1166.0	2226.0
Total volume allotment (cu ft)	3.5	5.3	7.6

Table 12. MISDAS Deployable Heat Shield/Radially Extended Skid Concept Structural Modification Weight Breakdown

Item	Weight (lb)			
	Base Point Apollo Blk II (9/65)	$\mu = 0.35$		
		V_v = 15 fps	V_v = 20 fps	V_v = 30 fps
Aft heat shield structure	(763.3)	(598.3)	(666.3)	(860.3)
Honeycomb panel	(559.6)	(392.0)	(460.0)	(654.0)
Core	202.9	157.0	165.0	181.0
Face sheets	305.6	190.0	250.0	428.0
Braze	51.1	45.0	45.0	45.0
Frames and rings				
Ring outer rim	55.1	55.1	55.1	55.1
Body to heat shield attachment	55.9	56.0	56.0	56.0
Fitting and attachment	(33.0)	33.0	33.0	33.0
Closeouts	7.1	10.0	10.0	10.0
Toroidal assembly	(52.6)	(52.2)	(52.2)	(52.2)
Corrugation	16.6	15.0	15.0	15.0
Skin	17.7	16.0	16.0	16.0
Splice and attachment	18.3	21.2	21.2	21.2
Inner structure - aft section	(177.0)	(180.0)	(203.0)	(341.0)
Honeycomb panels	122.0	125.0	148.0	261.0
Girth ring	55.0	55.0	55.0	80.0
Total	940.3	778.3	869.3	1201.3
Total structural modification		-162.0	-71.0	+261.0

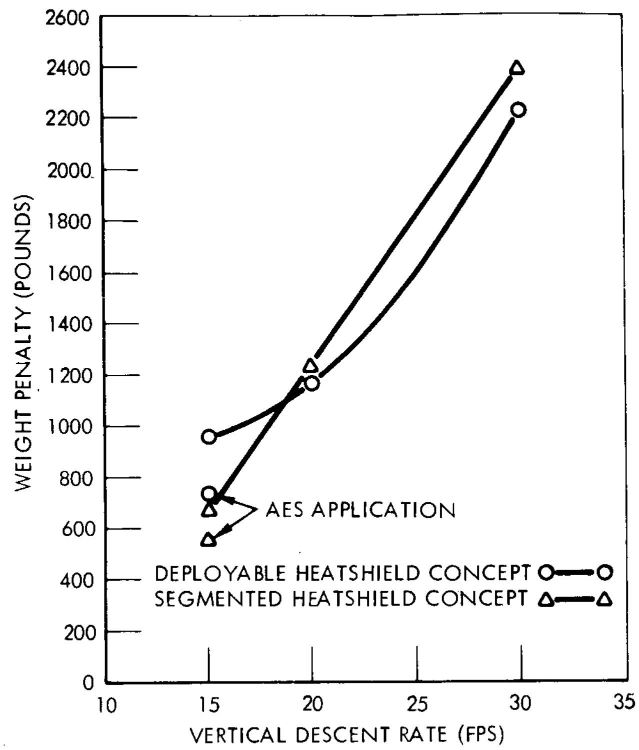


Figure 37. Weight Penalty Vs Vertical Descent Rate for MISDAS Mechanical Landing System

Tables 11 and 12 show the increase in radial skid MISDAS weight penalty due to system redesign to sustain increased vertical velocity landings. Values were obtained from calculations based on preliminary design drawings (Figures 29 and 30) and the stress analysis presented in Appendix A. Weight trends for both the radial skid and six-legged heat shield systems are compared in Figure 37, which also shows, for purposes of comparison, the weight penalty associated with MISDAS application to an AES-type spacecraft (Reference 2).

MANUFACTURING CONSIDERATIONS

The manufacturing requirements study has emphasized the utilization of the Apollo tooling and fabrication techniques as much as possible. The changes on the crew compartment are comparatively minor. In general, these include installation of additional items, such as the actuators and support bracketry. Manufacturing considerations placed few constraints on the aft heat shield basic engineering design. Minor changes were made in some areas to improve the producibility aspects. The materials contemplated for these units are the same as currently used on Apollo, PH 14-8 Mo and PH 17-4.

Crew Compartment

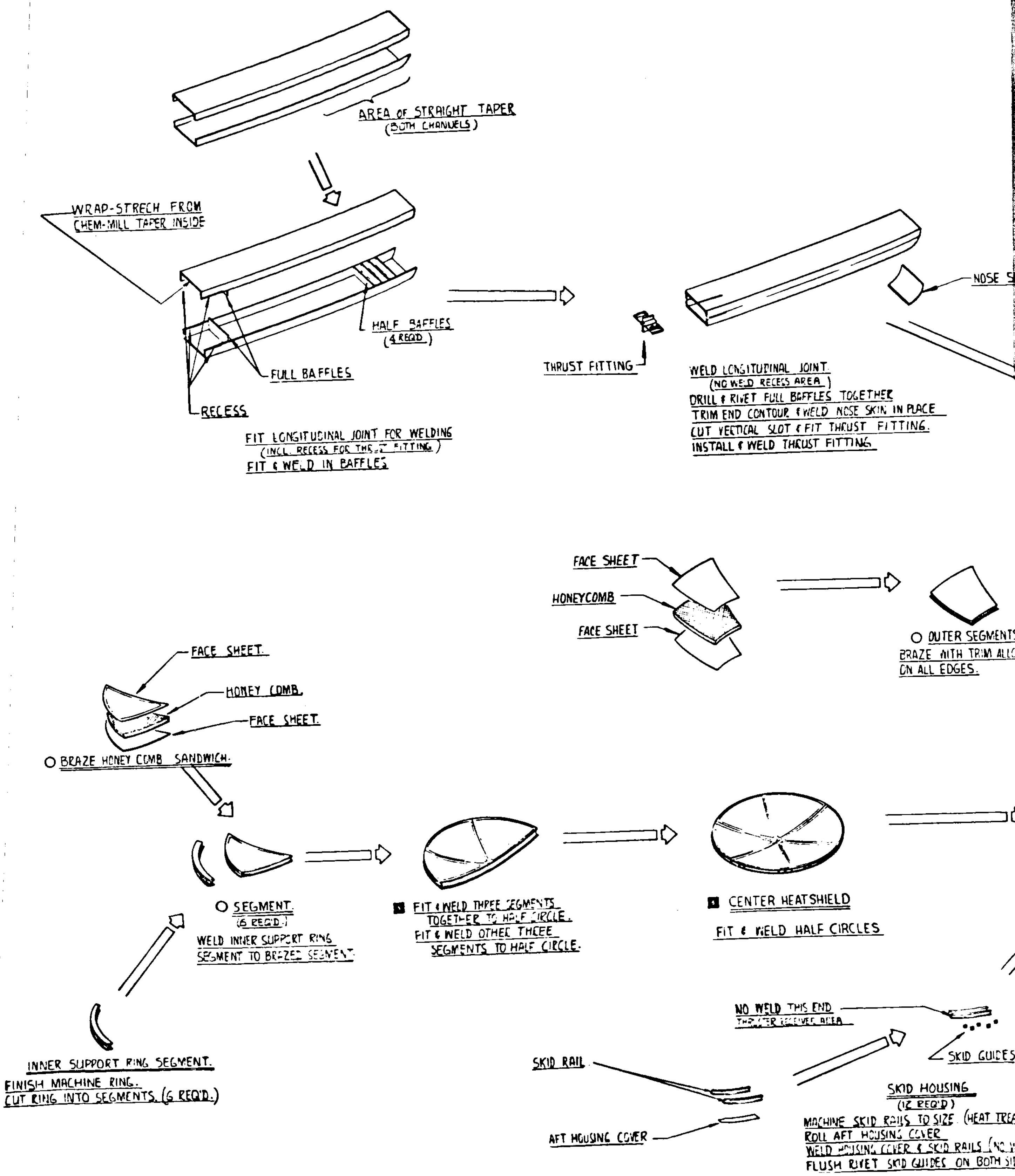
To incorporate MISDAS in the Apollo-type spacecraft involves some minor changes in the crew compartment, requiring installation of support brackets, actuators, lateral braces, new attach points for joining to the aft shield, wiring and attendant systems for firing attach bolts and skid extender propellant, and other miscellaneous hardware (Figure 38). The attachment of this hardware is to be accomplished on a completed unit with very little tooling involved.

Aft Heat Shield

The aft heat shield structure is fabricated as a six-segmented center heat shield of brazed honeycomb to which are welded 12 skid housings and 12 truncated pie-shaped outer segments of brazed honeycomb. This subassembly is finished to the same diameter as the Apollo heat shield. Attached to the periphery is a corrugated toroidal structure much the same as the one currently used. Additionally, an outer support ring is riveted to the inner surface of the shield to which the actuators are joined. Skids are inserted within the skid housings and the whole unit has ablation material added in the usual manner, except that the ablation material added to the skid will be separated with a "no-bond" separator, permitting extension of the skid.

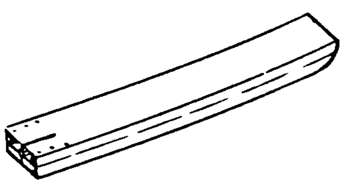
The center portion of the heat shield consists of six segments. Each segment is a honeycomb sandwich with stretch-formed face sheets, chem-mill sculptured to provide welding lands and then braze-heat-treated with the core. The inner support ring segment is machined as a ring in the heat-treated condition and then segmented. The brazed segment subassembly will be trimmed to fit, decored, and excess braze alloy removed prior to butt-welding to the inner support ring segment. Three of the segments will be handled in a similar manner. These two half circles will then be joined to complete this subassembly. In general, butt-fusion welding of both surfaces of sandwich panels will be done concurrently.

This particular manufacturing approach was used for the center heat shield as it was believed to be more predictable based on past experiences, particularly with reference to the B-70. The possibility of butt-welding the edge member, as a full ring, to a one-piece center portion was considered, but it was believed a full ring weld, even though done in a staggered fashion, would introduce excessive stresses and distortion. Another method that should be studied further involves a completely brazed one-piece assembly rather than a segmented assembly. The edge member would be machined as a full ring, the skins stretch-formed, and the whole unit braze-heat-treated as a complete assembly. Experience on the B-70 has indicated that brazed faying surfaces were troublesome, lacking consistency and reliability.


AREA OF STRAIGHT TAPER
(BOTH CHANNELS)
WRAP-STRECH FROM
CHEM-MILL TAPER INSIDE
HALF BAFFLES
(4 REQD)
FULL BAFFLES
RECESS
FIT LONGITUDINAL JOINT FOR WELDING
(INCL. RECESS FOR THRUST FITTING)
FIT & WELD IN BAFFLES
THRUST FITTING
NOSE S
WELD LONGITUDINAL JOINT
(NO WELD RECESS AREA)
DRILL & RIVET FULL BAFFLES TOGETHER
TRIM END CONTOUR & WELD NOSE SKIN IN PLACE
CUT VERTICAL SLOT & FIT THRUST FITTING.
INSTALL & WELD THRUST FITTING
FACE SHEET
HONEYCOMB
FACE SHEET
O OUTER SEGMENTS
BRAZE WITH TRIM ALL
ON ALL EDGES.
FACE SHEET.
HONEY COMB.
FACE SHEET.
O BRAZE HONEY COMB SANDWICH.
O SEGMENT.
(6 REQ'D.)
WELD INNER SUPPORT RING
SEGMENT TO BRAZED SEGMENT.
FIT & WELD THREE SEGMENTS
TOGETHER TO HALF CIRCLE.
FIT & WELD OTHER THREE
SEGMENTS TO HALF CIRCLE.
CENTER HEATSHIELD
FIT & WELD HALF CIRCLES
INNER SUPPORT RING SEGMENT.
FINISH MACHINE RING.
CUT RING INTO SEGMENTS. (6 REQ'D.)
NO WELD THIS END
SKID GUIDES
SKID RAIL
SKID HOUSING
(12 REQ'D)
MACHINE SKID RAILS TO SIZE (HEAT TREA
ROLL AFT HOUSING COVER
WELD HOUSING COVER & SKID RAILS (NO W
FLUSH RIVET SKID GUIDES ON BOTH SI
AFT HOUSING COVER

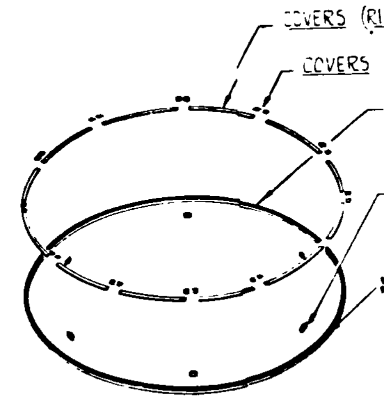
IN

(12 REQD)
VANCES



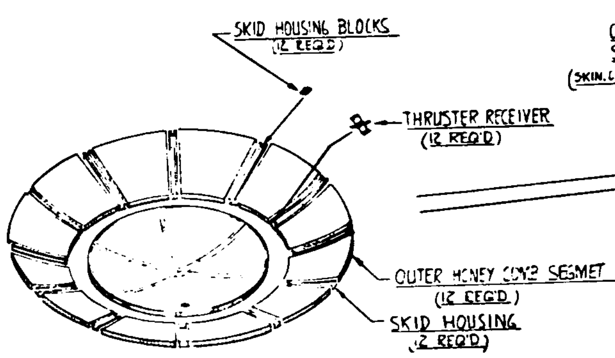
O SKID ASSEMBLY (12) REQ'D

HEAT TREAT & STRAIGHTEN
REAM THRUST FITTING
DRILL & TAP HOLES FOR SKID STOP
MACHINE SKID IN AREA OF RAILS



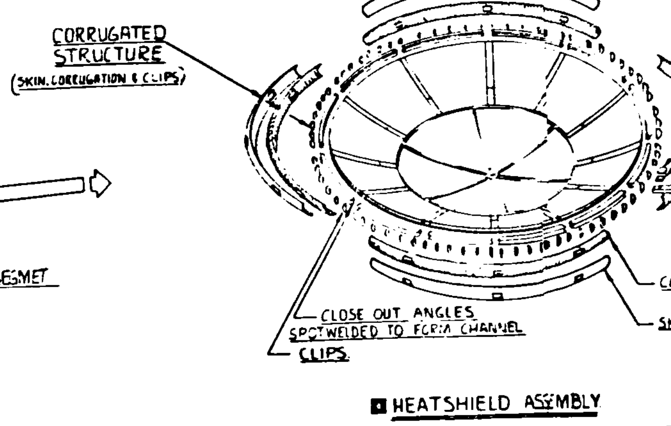
O OUTER SUPPORT RING.

MACHINE RING (HEAT TREATED.
LOCATE & RIVET ACTUATOR ATACH BRACKETS.
DRILL HOLES THRU BOTH FLANGES FOR ATTACHING COVER
(COVERS ATTACHED AFTER INSTALLATION.)



● AFT HEATSHIELD SUB-ASSEMBLY

INSTALL SKID HOUSINGS & WELD TO CENTER HEATSHIELD.
FIT & WELD OUTER SEGMENTS TO CENTER HEATSHIELD & THEN TO SKID HOUSING.
WELD SKID HOUSING BLOCKS TO SKID HOUSING.
FINISH MACHINE INNER RAILS OF SKID HOUSING & SKID GUIDES.
LOCATE & WELD THRUSTER RECEIVER IN END OF SKID HOUSING.
(USE APPLY TOOLING)
MACHINE SKID HOUSING BLOCKS TO MATE WITH CREW COMPARTMENT.
MACHINE OUTER PERIPHERY FOR INSTALLATION OF CORRUGATED STRUCTURE.

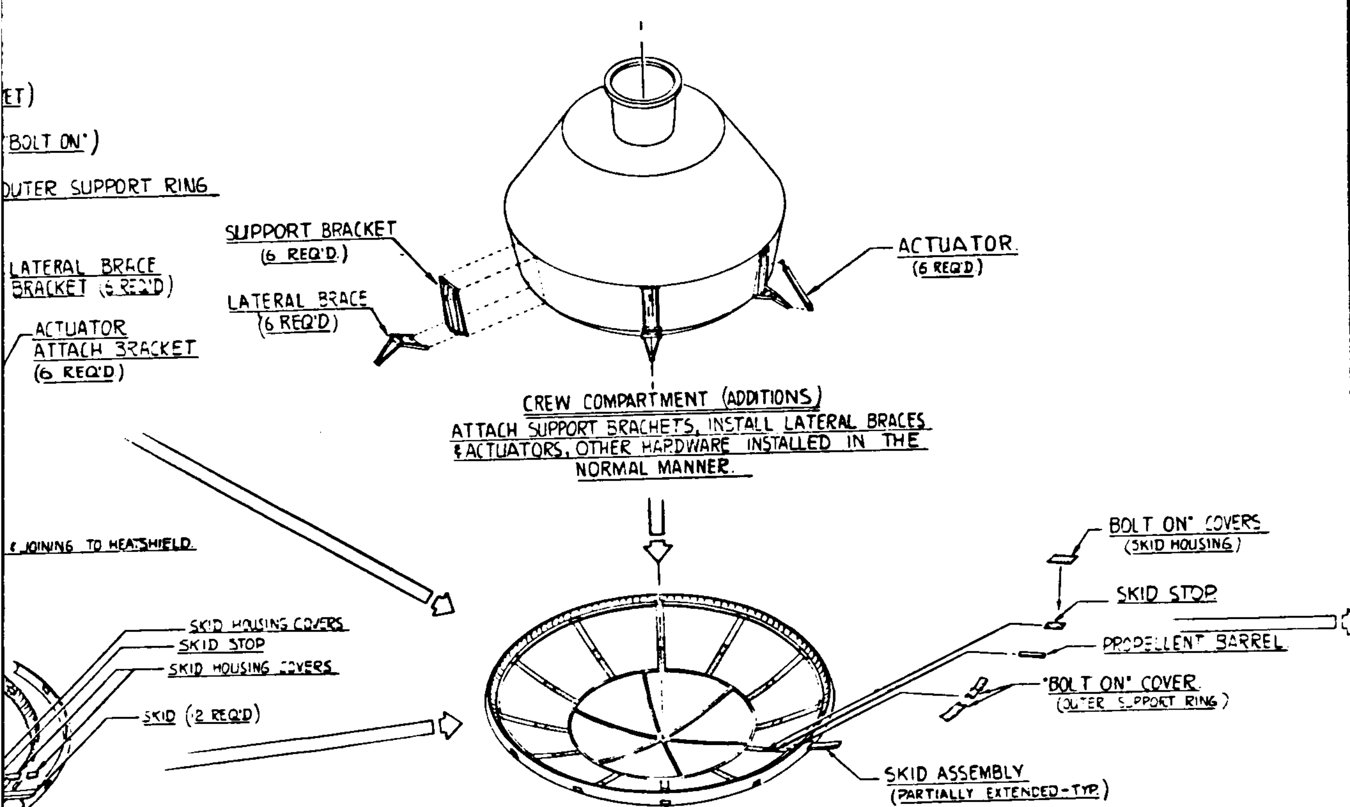


■ HEATSHIELD ASSEMBLY

INSTALL OUTER RING, BLIND RIVET TO HONEY COMB SECT
INSTALL LATERAL BRACE BRACKETS, LOCATING FROM AC
CHECK FIT OF SKID IN HOUSING. REMOVE & IDENTIF
INSTALL SUPPORT RING COVERS WHICH RIVET TO RING
RIVET SKID HOUSING COVERS IN PLACE (INBOARD COVE
RECHECK FIT OF SKID & ESTABLISH SKID STOP POSITI
INSTALL CORRUGATED STRUCTURE.
REINSTALL SKIDS & TEMPORARILY ATTACH IN THEIR CL
SEND TO VENDOR FOR INSTALLATION OF ABLATIVE MA

ED)

ELD IN AREA OF THRUSTER RECEIVER.)
ES OF HOUSING.



RRUGATION

IN.

ONS & RIVET TO HOUSINGS.
UATOR ATTACHMENT LUGS

'BOLT ON' COVERS INSTALL LATER)
R BOLTS ON.)
N.

SED POSITION.
ERIAL.

■ FINAL ASSEMBLY - HEAT SHIELD.
VENDOR INSTALL ABLATIVE MATERIAL, PROTECTIVELY PACK & RETURN TO S&ID.
REMOVE TEMPORARY SKID ATTACHMENT, ADD SKID STOP & EXTEND SKID PARTIALLY.
INSTALL PROPELLENT BARREL IN THRUST RECEIVER & RETRACT SKID.
INSTALL 'BOLT ON' SKID HOUSING COVERS.
INSTALL CREW COMPARTMENT.
ATTACH LATERAL BRACE & ACTUATOR TO OUTER RING & INSTALL 'BOLT ON' COVERS.
INSTALL EXPLOSIVE TYPE ATTACHMENT FOR JOINING CREW COMPARTMENT & AFT HEATSHIELD ASSEMBLY.

INS
&

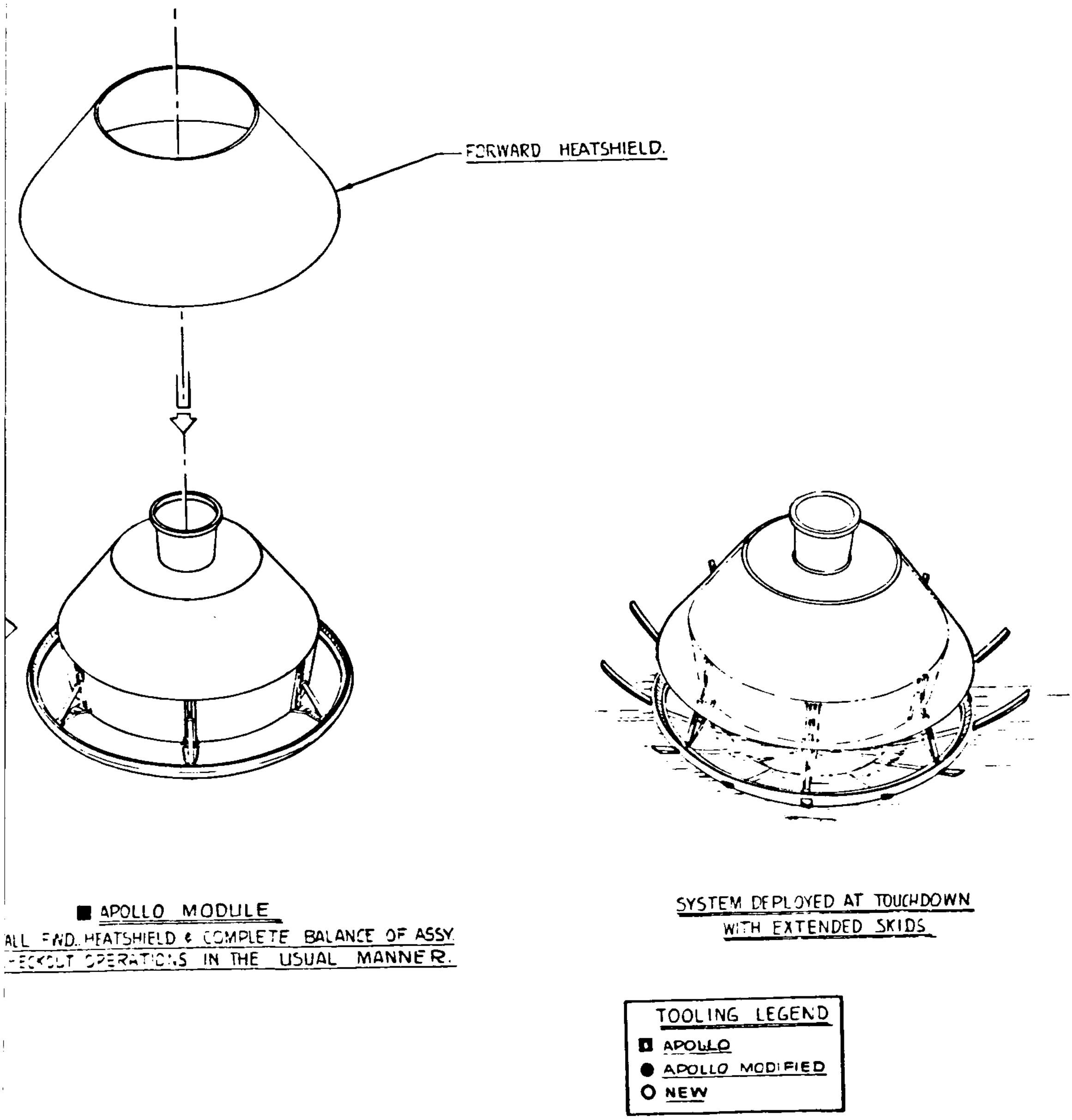


Figure 38. Manufacturing Breakdown, Deployable Heat Shield Extended Skids, MISDAS Study

Therefore, development effort would be necessary to verify a consistent process. This latter method would reduce weight as well as cost, when a technique is developed.

The 12 outer segments of honeycomb will be made in a manner similar to the previously described center heat shield. The face sheets will be stretch-formed and chem-mill sculptured and then brazed to the core in the usual manner. No edge members are necessary; however, excess trim will be allowed for fitup at the next assembly.

The skid housing assembly is a machined and welded assembly consisting of two machined skid rails, an aft-housing cover and a series of skid guides which are riveted to the inside of the rails to steady the skid as it extends. The skid rails will be machined completely out of heat-treated contoured bars. The connecting sheet is rolled, chem-mill sculptured to provide welding lands, and then notched to permit insertion and welding of the thruster receiver at a later operation. The two side rails (right and left) will be butt-welded to the connecting sheet, except in the area of the thruster receiver attachment. The skid guides (of either Teflon or aluminum) will be installed on the inside surface of the sides and flush riveted. Material is left on the skid bearing surfaces so that a light finishing cut can be taken after all welding has been completed, and will be done on the next assembly.

Aft Heat Shield Subassembly

During the aft heat shield subassembly operations, the 12 skid housings and outer segments are butt-weld joined to the center heat shield as well as to each other. Additionally, the 12 thruster receivers and 24 skid housing blocks are welded in place. The sequence of operations is important and will probably be as outlined here. The skid housings will be installed first and butt-welded to the inner support ring at the surfaces provided. The outer end of the housing will be jig-located. After fitting and trimming, the outer segments will be welded to the center heat shield and then to the skid housing. A welding sequence for the radial welds will be developed on the first few units.

The 24 skid housing blocks will be welded to the upper rail surfaces. A light finishing cut will then be taken on the skid bearing surfaces of the skid housing. The thruster receiver will be installed next, its location determined by apply-type tooling, indexing from the skid bearing surfaces. This will be a manual-type weld operation.

Machining of the skid housing blocks to mate with the crew compartment is one of the last operations performed. The hole pattern will be match-drilled, requiring a comparatively simple master. The last operation in this fixture is to machine and decore the outer periphery of the honeycomb outer segments and skid housing for installation of the corrugated structure. The unit is now ready for final assembly operations which include installation of the skids, outer support ring, as well as the corrugated structure.

Skids

Manufacturing of the skids involves forming the channels wrap-stretch formed and chem-mill tapered on the inside surface in the required area. The longitudinal joint, including the recessed area for acceptance of the thrust fitting, will be machined for welding. The two full baffles are located and welded, one in each section. Four half baffles are located in the lower section and welded. The longitudinal weld is made, after which the two full baffles are riveted together. The outboard end will be cut to contour and the nose skin welded into place. A vertical slot is cut in the inboard end and the thrust fitting is mated and welded to the skid. The completed weld assembly will then be heat-treated, after which the thrust fitting is reamed and holes will be drilled and tapped for the skid stop. Those areas that ride in the skid housing rails will be machined to final dimensions and curvature to ensure a sliding fit.

Outer Support Ring

The load-carrying outer support ring will be machined in one piece (except for the covers) out of heat-treated material. This method was selected over fabricating the unit of formed sheet material wrap-stretch/wipe-formed on a Cyril Bath stretch former. Tooling and fabrication costs will be high for the stretching operation, trimming after stretching, weld-joining the segments together, and flush-riveting the lower cover plates. In addition, the fit of the formed sheet metal part on the heat shield may require additional hand work before riveting to the structure. The machined part should not present these problems. After machining, the actuator attach brackets will be located and riveted within the ring. The covers will be made, holes drilled for their attachment, and the parts identified for relocation at final assembly. Since the holes in the flange for attaching the ring to the structure are not easily accessible, they will be drilled at the time the cover holes are drilled by drilling straight through from the upper flange.

Final Structural Assembly

The first operation in the final structural assembly is to blind-rivet the outer support ring to the aft heat shield subassembly. Rivet holes will be drilled from holes previously drilled in the ring flanges. The lateral brace bracket locates from the actuator attach bracket and rivets in conjunction with the attachment procedure previously mentioned. The riveted ring covers will then be installed, leaving the bolted covers for later installation. At this point, the skids will be inserted to verify their fit, and rework where necessary. The skids will be removed and the skid housing covers riveted (inboard covers bolt on) in place. Next, the skids will be reinstalled, the skid stop bolted in place, and the correct stop position established. Temporarily, the skids will be attached in their closed position for shipment to the contractor for installation of the ablative material. The toroidal corrugated structure will be installed as the last operation in the same fixture and in the manner currently used. The unit will then be ready for shipment to the ablative installation contractor.

Ablative Installation

It is anticipated that the ablator installation will follow the procedures used for Apollo. The contractor will install ablative material in the usual manner except for the end of the skids. To ensure positive movement at extension, the ablative material will be added to the skid as a plug with a Teflon or other "no-bond" separator between it and the balance of the heat shield ablator. The total heat shield will then be ground to the correct contour and returned to S&ID.

Final Buildup

In going through the final buildup, only those items peculiar to the MISDAS installation will be considered. The order in which they are mentioned is not necessarily critical, unless they are sequencing operations. The installations and operations required will be interspersed with those normally associated with a conventional Apollo buildup. For instance, installation of those items containing explosives will be installed as late in the process as possible and by personnel experienced and trained in their handling.

Before installation of the crew compartment, the temporary skid attachment will be removed and the skid partially extended to permit installation of the propellant barrel in the thruster receiver, which has already been welded to the skid housing. The skid will be retracted, verifying clearances, etc., and its position will be fixed.

The bolt-on skid housing covers will then be installed. During installation of the crew compartment, the lateral arrestor brace and the actuator will be joined to the outer support ring, after which bolt-on covers will be installed, closing out the support ring box section. Explosive-type attachments will be installed, joining the crew compartment and aft heat shield. Electrical circuitry for firing these breakaway units will be checked out prior to final hookup. The balance of operations and checkout will proceed as normal Apollo manufacturing operations.

CONCLUSIONS AND RECOMMENDATIONS

MISDAS CONCEPT SELECTION

Two mechanical landing system concepts were selected from a total of ten studied during Phase I of this contract: the six-segment heat shield and the radial skid - deployable heat shield. A more detailed analysis of these two concepts was conducted during Phase II to evaluate their characteristics and select one for further design, development, and qualification for manned service.

Evaluation of the two systems studied under the requirements set up in the Guidelines, Constraints, and Design Criteria section leads to the following conclusions

1. Both systems absorb energy on contact with the landing surface
2. Both systems are stowed in the aft bay compartment during flight and are deployed prior to landing.
3. The required deployment time of 30 seconds is ample for operation of either system
4. Both systems are designed for maximum reliability, simplicity, and efficiency. A quantitative evaluation of these factors was considered to be beyond the scope of this program.
5. Both systems will prevent overturning of the landing vehicle and damage to the inner structure under specified landing conditions.
6. Crew tolerances for impact accelerations and onset rates will not be exceeded by the spacecraft landing with vertical velocities of up to 15 fps. Higher vertical velocities will require additional energy dissipation, (i. e., on the crew couches).
7. MISDAS design involved minimum inner structure modification. Significant changes affect only the heat shield and heat shield support design and manufacturing

8. MISDAS weight addition could not be restricted to 3.5 percent of the 14000-pound landing weight during this preliminary study. Weight fraction of the legged system is 673 pounds or 4.81 percent. Weight fraction of the radial skid system is 955 pounds or 6.82 percent. Figure 37 illustrates the weight required by both the radial skid system and the six-legged heat shield system for V_V = 15, 20, and 30 fps and include weight of the system for the AES application (10,600-pound spacecraft). It is to be noted that weight of the six-legged heat shield system grows more rapidly than the weight of the radial skid system because the radial skids are not assumed to absorb landing energy but to prevent tumbling, and are always designed for the same load conditions.

9. No part of either system is located inside the crew compartment

10. Both systems are reusable after normal landings. They require replacement of the spent heat shield and minor refurbishment of the energy absorption mechanism.

11. Ultimate load factors used during MISDAS design and analysis are consistent with requirements of Paragraph IV-A-11 of Exhibit A of Contract NAS9-4915.

The two systems studied during Phase II have been compared to select and recommend the system that best answers the selection criteria requirements. The requirements for selection were as follows:

Landing stability characteristics for

$$(1)\quad \left.\begin{array}{r} V_V = 0 \text{ to } 15 \text{ fps} \\ V_H = 0 \text{ to } 80 \text{ fps} \\ = 0 \text{ to } 0.35 \end{array}\right\} \quad \text{(Basic requirement)}$$

$$(2)\quad \left.\begin{array}{r} V_V = 0 \text{ to } 30 \text{ fps} \\ V_H = 0 \text{ to } 80 \text{ fps} \\ = 0 \text{ to } 1.00 \end{array}\right\} \quad \text{(Growth potential)}$$

Weight
Simplicity of design, manufacture, and operation
Development problems
Retromotor installation
Spacecraft compatibility

A comparison of the two systems based on these characteristics is presented in Table 13. It shows that, although both systems are stable for land landing conditions defined in the Design Criteria, instability characteristics for higher coefficients of friction and sinking velocities, landing characteristics, apparent reliability, mechanical design simplicity, and retromotor installation favor selection of the six-legged concept. Manufacturing and development problems have been identified in both systems and are not considered to be beyond the scope of normal engineering development.

Weight penalties imposed by the landing system favor selection of the six-legged concept for conditions encompassed by the design criteria landings with veritical velocities above 15 fps. Ground coefficients of friction higher than 0.35 show weight advantage for the radial skid concept. However, these are considered abnormal conditions and, except for their structural effects, they have been out of the scope of the program.

The six-legged concept is recommended for further design and analysis because of its lighter weight for specific landing conditions, good landing stability characteristics, potential reliability, mechanical design simplicity, and retromotor installation characteristics.

SUGGESTED FOLLOW-ON PROGRAMS

A final definition of the MISDAS installation in AES will require a detail design, development, fabrication, and test program. The major steps and preliminary schedule in such a program are outlined in the following section and in Figure 39. It is recommended that a follow-on effort be initiated, especially in the following areas.

Development of Segmented Heat Shields

This effort should involve (1) investigation of problems related to space exposure, entry, deployment, and landing of a craft with a heat shield segmented to permit deployment and use of portions of it as landing and impact absorption element, (2) study of heat shield splices, ablative non-adhesive edge members, hinge and separation lines, and deployment devices, and (3) fabrication and testing of segmented ablative heat shield specimen under representative entry conditions to evaluate edge erosion, ablation, and sealing.

Stability of Legged Vehicles

This effort should involve the expansion of computer programs developed under Contract NAS9-4915 to cover more realistic situations, ground conditions, and vehicle attitude than those assumed during the contract.

Table 13. System Comparison

Criteria	Six-Legged Heat Shield	Radial Skid
Landing Stability V_V = 0-15 fps V_H = 0-80 fps μ = 0-0.35 (Land landing)	Stable, with maximum tipping angle of 20 degrees.	Stable, with maximum tipping angle of 40 degrees.
Landing Stability V_V = 0-30 fps V_H = 0-80 fps μ = 0-1.0	Becomes unstable for $\mu \cong 0.4$, roll = 0, and positive pitch relative to earth - requires less roll control (Figure 27).	Becomes unstable for $\mu \cong 0.4$, roll = 0, and positive pitch relative to earth - requires more roll control (Figure 36).
Landing Stability AES application V_V = 0-15 fps V_H = 0-80 fps (Water landing)	Legs need not be extended to expose retrorockets; good floating stability expected.	Shield must be deployed to expose retros, with impact stability problems.
Weight Penalty V_V = 0-15 fps V_H = 0-80 fps μ = 0-0.35 W = 14000 lb	673 lb	955 lb
W = 10600 lb (AES application)	556 lb	737 lb
V_V = 0-20 fps V_H = 0-80 fps μ = 0-0.35 W = 14000 lb	1244 lb	1166 lb
V_V = 0-30 fps V_H = 0-80 fps μ = 0-0.35 W = 14000 fps	2406 lb	2226 lb
Manufacturing	Mostly within state of the art. Few development problems.	Mostly within state of the art. Few development problems.
Reliability Considerations	No need to deploy landing mechanism to deploy retrorockets and attain V_V = 15 fps, no problem on water landing.	Heat shield must be deployed to expose retrorockets and attain V_V = 15 fps, complicated water landing.
Mechanical Design Problems	Deployment of heat shield segments.	Deployment of radial skids. Deployment of retrorockets.
Development Problems	Heat shield - ablator seals around segments. Shock absorbers - need development to meet requirements.	Shock absorbers must be developed to meet requirements; skid housing manufacturing; skid deployment after exposure to environment.
Retromotor Installation (AES application)	Good - reaction forces are applied directly to inner structure.	Poor - heat shield must be deployed to expose and deploy retros; forces applied to inner structure through extension mechanism.
Spacecraft Compatibility (AES application)	Good - equipment must be relocated in and out of aft bay compartment.	Good - equipment must be relocated in and out of bay compartment.

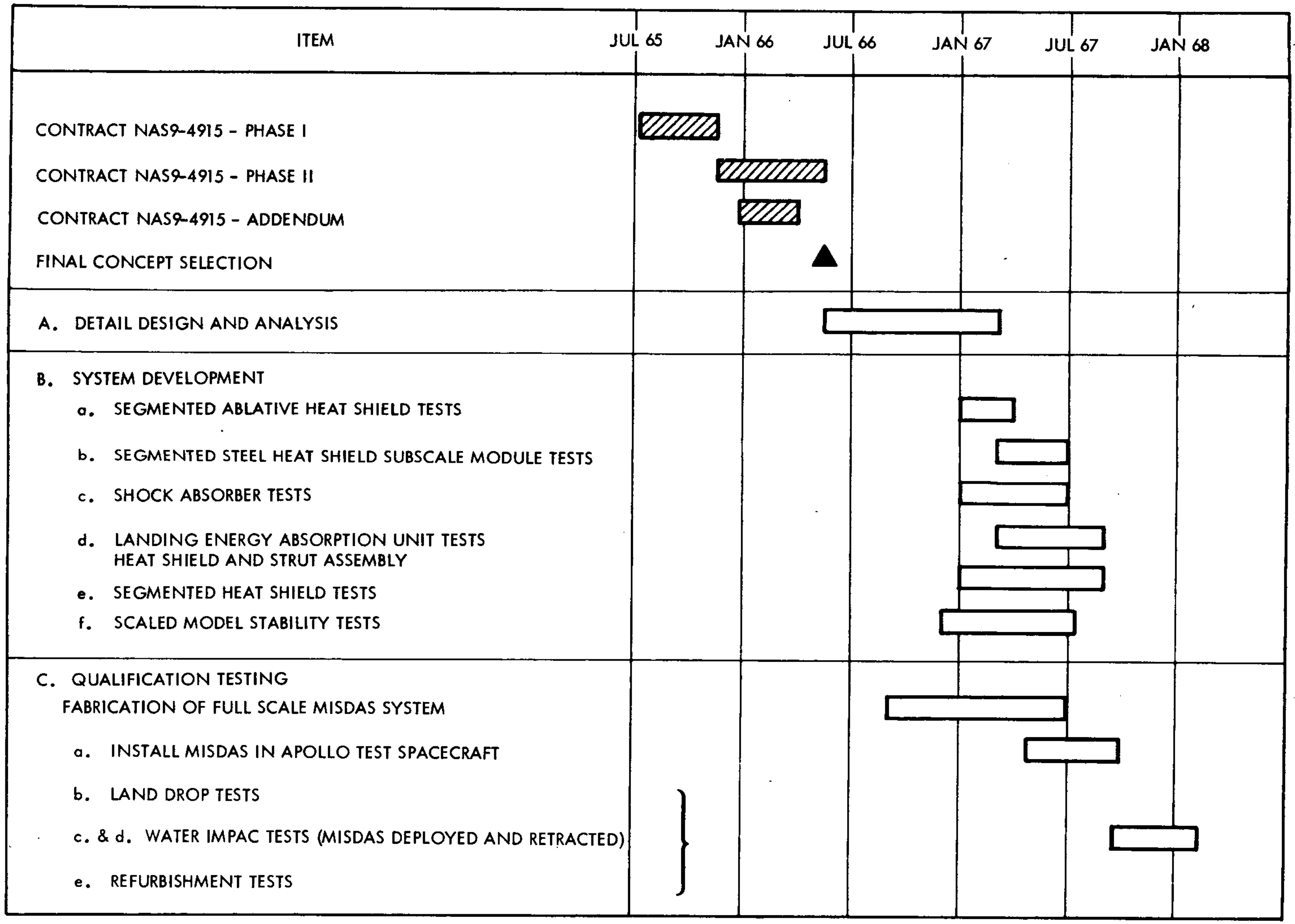


Figure 39. Suggested Design, Development, and Qualification Program, Preliminary Schedule

Scale Model Tests of Stability and Impact Attenuation

Verification should be made of stability and attenuation values obtained theoretically through model testing, to raise confidence level and to determine the influence ground slope, terrain discontinuities, ground coefficient of friction, etc. The 1/4.5-scale Apollo command module models and test facility used by Southwest Research Institute for their investigation of dynamic landing effects could be modified to incorporate the deployable legs on the models and implement a land landing MISDAS test system (Reference 9).

Installation of MISDAS on Apollo Boiler Plate

Verification should be made of volume and weight requirements of actual hardware; structural effects of landing loads on inner structure and support bracketry; overall acceleration levels in the vehicle, specially life support systems; verification by testing of water landing capability of a vehicle equipped with ground landing attenuation systems.

Shell Dynamics of Land Impact

Analytical and test verification should be made of the interaction of a spherical shell structure (simulating the Apollo heat shield) impacting land. Analytical programs should be developed to account for soil elasticity and deformation of shell structure.

SUGGESTED DESIGN, DEVELOPMENT, AND QUALIFICATION PROGRAM

1. Detail Design and Analysis

   a. Prepare design specifications

   b. Prepare drawings

      (1) Impact attenuation mechanisms

      (2) Structural modifications

      (3) Systems relocation

   c. Build a MISDAS/Vehicle integration mockup

   d. Modify dynamic landing stability program to include:

      (1) Realistic soil characteristics

(2) Dig-in conditions

(3) Real strut characteristics - strut optimization

e. Perform dynamic analysis

f. Perform structural analysis

g. Perform detailed test programs

(1) Development

(2) Qualification

(3) Acceptance

h. Prepare manufacturing plan

(1) Tooling

(2) Facilities

Areas where detail design and analysis are necessary include:

(a) Ablative and steel heat shield redesign

(b) Impact attenuation members installation, deployment, and operation

(c) Shock struts

(d) Heat shield support members

(e) Command module modified structure

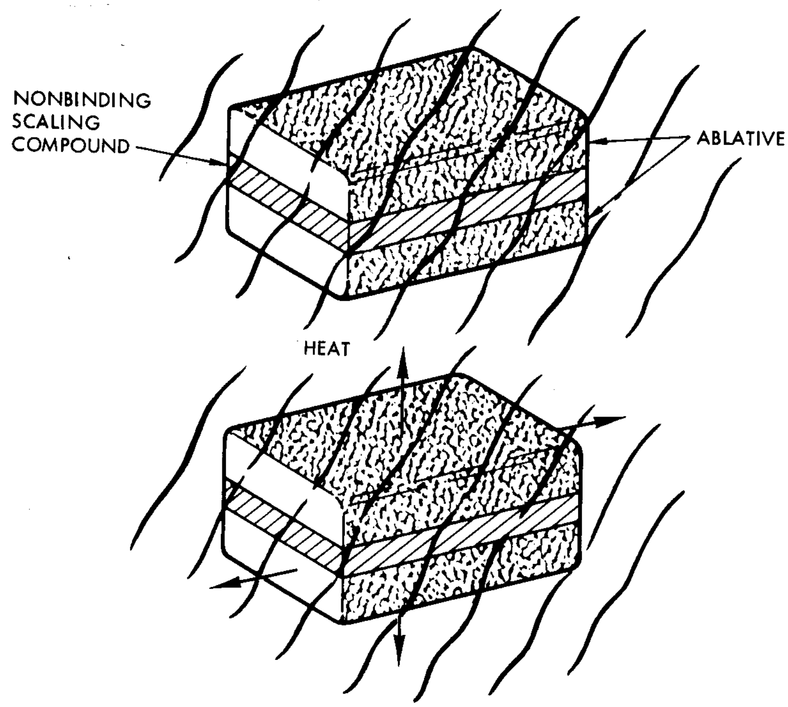
2. System Development

a. Segmented ablative heat shield tests (see sketch)

(1) Exposure of joined ablative samples to space environment

(2) Exposure to entry conditions, including thermal-structural tests of joined samples to determine

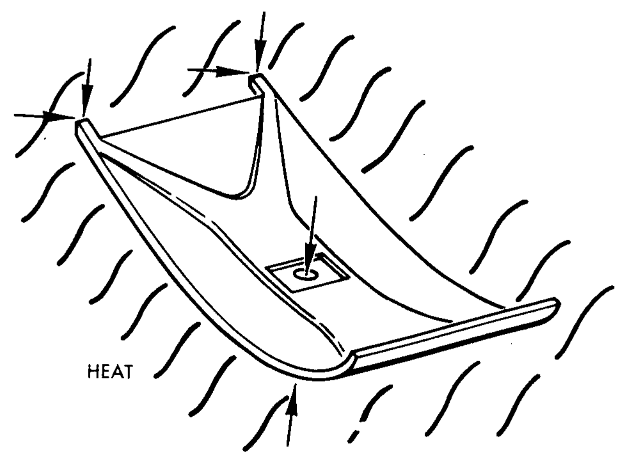
effects of strain, erosion, material degradation, bonding material expansion, hardening and softening of thermal protection materials, heat shield, landing shoes, and land and water impact



b. Thermal-structural tests of segmented steel heat shield (reduced scale model). See sketch below.

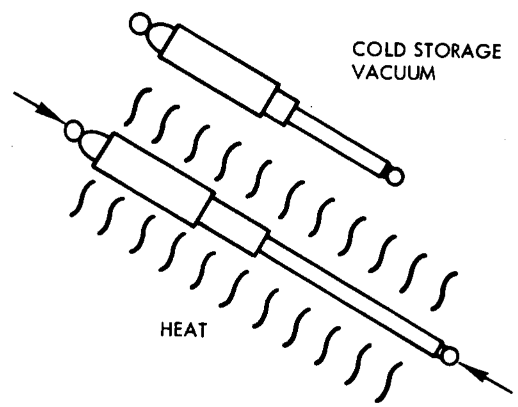
(1) Thermal effects of space and entry conditions: strain, distortion

(2) Structural effects of entry, deployment, and landing forces



c. Shock absorber system. See sketch below.

(1) Space environment effects (temperature, vacuum) on seals, structural materials, and fluids



(2) Load - stroke characteristics required by dynamic landing

(3) Reusability requirements

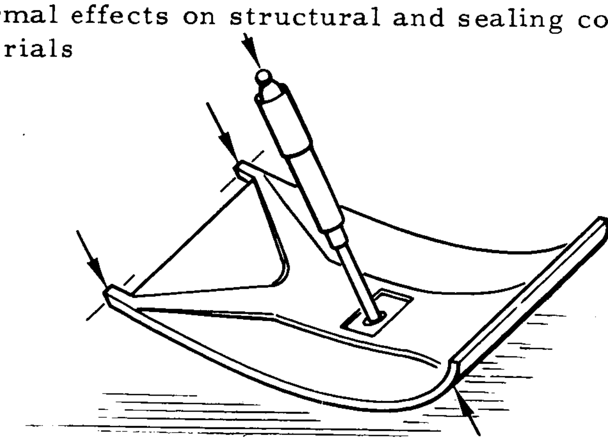
d. Landing energy absorption unit tests (assembly of heat shield and deployed or undeployed struts). See sketch below.

(1) Space environment effects on joints, bearings, seals, etc.

(2) Entry conditions effects on unit

(a) Thermal and load induced deflections and stresses

(b) Thermal effects on structural and sealing compound materials



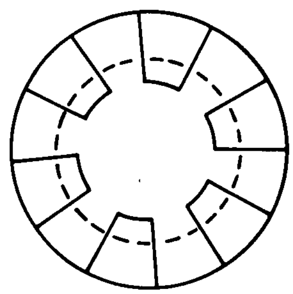
(3) Land and water landing. See sketch .

(a) Total unit energy absorption characteristics

(b) Deformations caused by landing on different soils

(c) Energy absorption characteristics on water landings (deployed and undeployed units)

e. Segmented heat shield tests (reduced scale)



(1) Mechanical and thermal stresses and deflections

(2) Entry loads

(3) Land landing impact (deployed system)

(4) Water landing impact (deployed and undeployed system)

f. Scaled spacecraft model with MISDAS installed tests

(1) Land landing stability

(2) Water landing stability

(a) Deployed system

(b) Undeployed system

(c) Flotation stability

3. Qualification Test Plan

   a. Install MISDAS on Apollo boilerplate or used spacecraft

   b. Land drop tests (MISDAS deployed)

      (1) Mechanical integrity of support structures, energy absorption system, heat shield (deflections)

      (2) Stability verification

      (3) Crew g limits verification

   c. Water impact drop tests

      (1) Crew g limits verification

      (2) Floating stability

      (3) Command module water tightness verification

   d. Water impact drop tests (MISDAS not deployed)

      (1) Crew g limits verification

      (2) Structural integrity

      (3) Floating stability

      (4) Command module water tightness verification

   e. Refurbishment and reusability

      (1) Land and water impact effects on permanent structure, MISDAS attach structure, energy absorption components, steel heat shield fixed portions, steel heat shield rings, hinges, and moving portions

REFERENCES

1. Bernstein, A. I. Mechanical Impact System Design for Advanced Spacecraft (MISDAS); Phase I - Design Concept Selection. NAA S&ID, SID 65-1205 (20 September 1965).

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3. MIL-HDBK-5. (Rev. November 1965).

4. MIL-HDBK-17. (Rev. June 1965).

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9. Baker, W. E. and P. S. Westine, Model Tests for Determination of the Structural Response of the Apollo Command Module to Water Impact. AIAA/ASME Seventh Structures and Materials Conference, April 18 - 20, 1966.

10. Apollo Materials and Producibility. NAA S&ID Bulletin No. 16.

11. Aerospace Structural Materials Application Handbook (1965) AF 33(616)-7792.

12. NAA, S&ID Specification MB0130-019, Silicone Rubber, Low Temperature Resistant, Room Temperature Curing (RTV560).

APPENDIX A

STRUCTURAL ANALYSIS CALCULATIONS

This appendix presents the structural analysis calculations performed in support of Contract NAS9-4915, Phase II, completed 13 May 1966.

This analysis is based on Figures 18, 19, 29, and 30, and the Guidelines, Constraints, and Design Criteria section of this report. Summaries of loads and margins of safety are included in this report. Allowable stresses are given in Appendix B.

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EFFECT OF INCREASING DESCENT VELOCITY TO 30 FT/SEC

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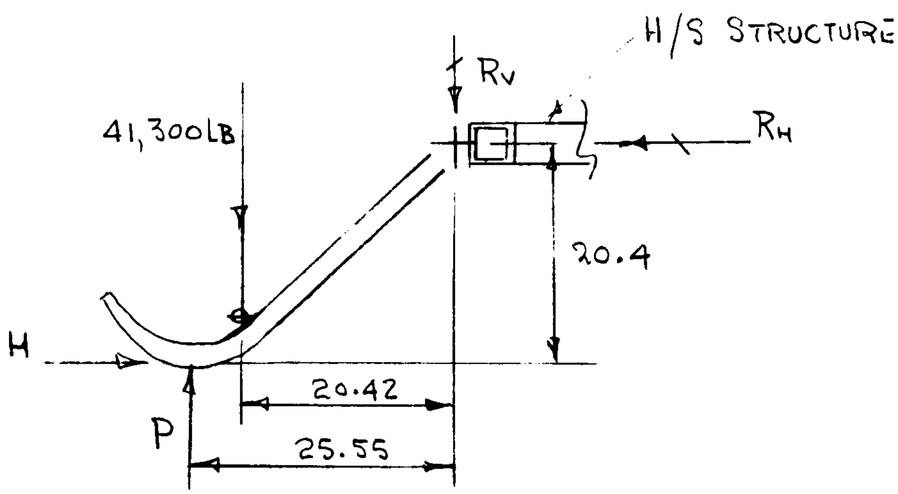
VEHICLE WEIGHT 14,000 LB.
VERTICAL VELOCITY 15 FT / SEC $\mu = .35$

MAX STRUT LOAD = 41,300 LB (SID 66-409, Page 55

FACTORS USED IN ANALYSIS.

FOR DEPLOYABLE LEG 1.00
FOR SHOCK STRUT AND ALL OTHER STRUCTURE 1.33.



$$P = \frac{41,300\ (20.42)}{25.55 - (.35)(20.40)} = 45,900 \text{ LB.}$$

$H = 45,900\ (.35) = 16,050$ LB

$R_V = 45,900 - 41,300 = 4,600$ LB

$R_H = 16,050$ LB.

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LEG LOADS

"H" ACTING OUTBOARD

$$P = \frac{41,300\ (20.42)}{25.55 + (.35)(20.4)} = 25,800 \text{ LB.}$$

$$H = -(.35)\ 25,800 = -9050 \text{ LB.}$$

$$R_V = 25,800 - 41,300 = -15,500 \text{ LB.}$$

$$R_H = \quad = -9050 \text{ LB.}$$

LEG LOADS WHEN H = 0

$$P = \frac{41,300\ (20.42)}{25.55} = 33,000 \text{ LB.}$$

$$R_V = 33,000 - 41,300 = -8,300 \text{ LB}$$

$$R_H = 0$$

LEG LOADS WHEN 'H' ACTS AT 45° (INBOARD)

$$P = \frac{41,300\ (20.42)}{25.55 - (.35)(.707)(20.4)} = 41,100 \text{ LB}$$

$$H = .35\ (41,100) = 14,400 \text{ LB}$$

$$R_V = -100 \pm \frac{(.707)\ 14,400\ (20.4)}{23.375} = -8300 \text{ LB}$$

$$R_H = \frac{(.707)\ 14,400\ (25.55)}{23.375} + \frac{.707)\ 14,400}{2} = 16,220 \text{ LB (MAX)}$$

LEG LOADS WHEN 'H' ACTS AT 45° (OUTBOARD)

$$P = \frac{41,300\ (20.42)}{25.55 + (.35)(.707)(20.4)} = 27,550 \text{ LB.}$$

$$H = .35\ (27,550) = 9650 \text{ LB}$$

$$R_V = -6875 \pm \frac{(.707)\ 9650\ (20.4)}{23.375} = -12,835 \text{ LB (MAX)}$$

$$R_H = \frac{.707\ (9650)\ 25.55}{23.375} + \frac{(.707)\ 9650}{2} = 10,900 \text{ LB.}$$

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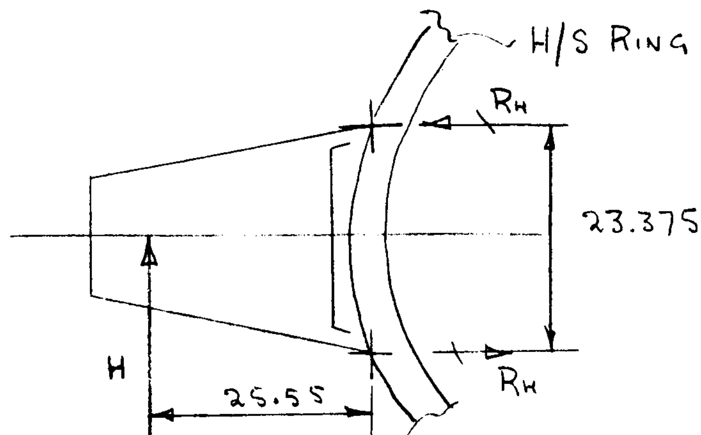
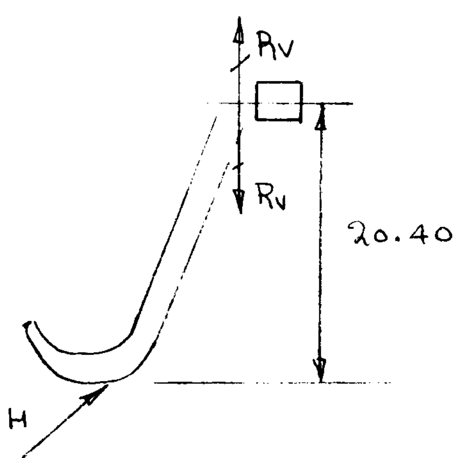
LEG LOADS WHEN "H" ACTS AT 90°



HINGE REACTIONS (IN THE PLANE OF THE RING).

$$R_H = \frac{.35(33,000)25.55}{23.375} = 12,600 \text{ LB.}$$



HINGE REACTIONS (OUT OF THE PLANE OF THE RING)

$$R_V = \frac{.35(33,000)20.4}{23.375} = 10,100 \text{ LB.}$$

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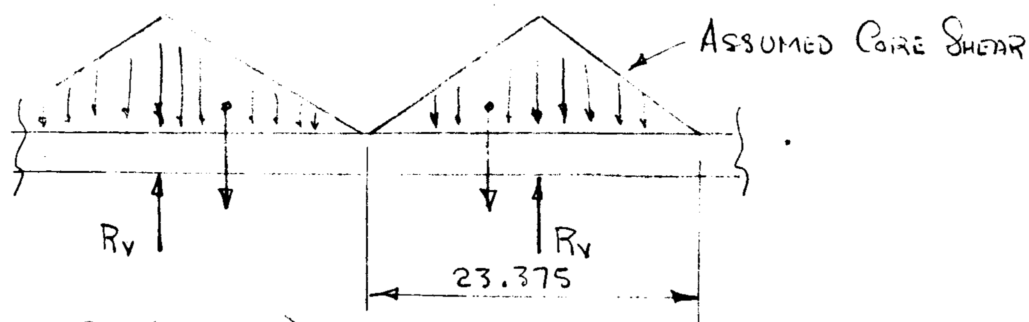
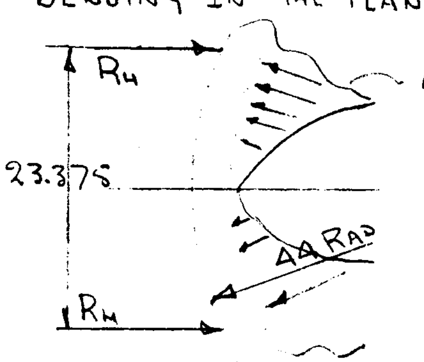
RING AT 44" RAD IN AFT HEAT SHIELD SUB-STRUCTURE

BENDING OUT OF THE PLANE OF THE RING.



$$M_V = \frac{R_V\,(23.375)}{12} = 1.945\,R_V$$

BENDING IN THE PLANE OF THE RING.



$$M_H = \frac{R_H\,(23.375)}{12} = 1.945\,R_H$$

WHEN H ACTS AT 45° (INBOARD)

$M_V = 8800(1.945) = 17{,}150$ LB INS

$M_H = 16{,}220(1.945) = 31{,}600$ LB INS

WHEN H ACTS AT 45° (OUTBOARD)

$M_V = 12{,}835(1.945) = 25{,}000$ LB INS

$M_H = 10{,}900(1.945) = 21{,}200$ LB INS

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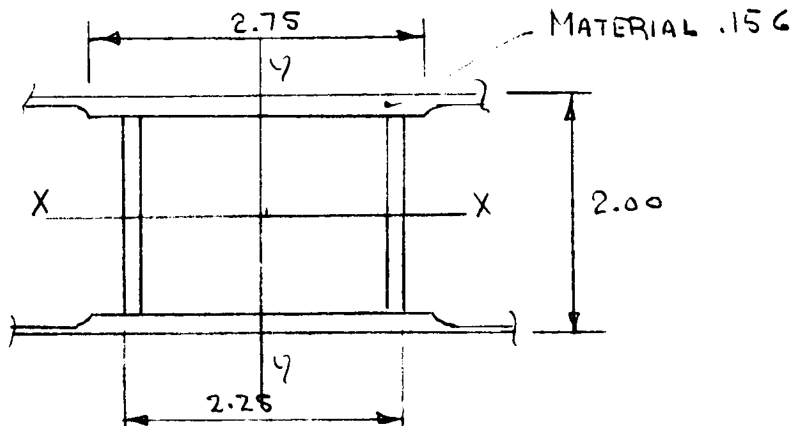
RING IN AFT HEAT SHIELD (44 RAD)

RING SECTION.



$I_{XX} = .156(2.75)(.922)^2(2) + .156(1.788)^3(2)/12$
$= .730 + .148 = .878 \text{ INS}^4$

$I_{YY} = .156(1.788)(1.047)^2(2) + .156(2.75)^3(2)/12$
$= .611 + .542 = 1.153 \text{ INS}^4$

GROUND IMPACT "H" ACTING (INBOARD)

$$f_B = \left\{ \frac{M_V\,(1.00)}{I_{XX}} + \frac{M_H\,(1.375)}{I_{YY}} \right\} 1.33$$

$$= \left\{ \frac{17,150}{.878} + \frac{31,600\,(1.375)}{1.153} \right\} 1.33$$

$$= (19,600 + 37,700)\,1.33 = 76,500 \text{ P.S.I}$$

$$MS = \frac{77,000}{76,500} - 1 = 0.00$$

"H" ACTING (OUTBOARD)

$$f_B = \left\{ \frac{25,000\,(1.00)}{.878} + \frac{21,200\,(1.375)}{1.153} \right\} 1.33$$

$$= (28,500 + 25,300)\,1.33 = 71,600 \text{ P.S.I}$$

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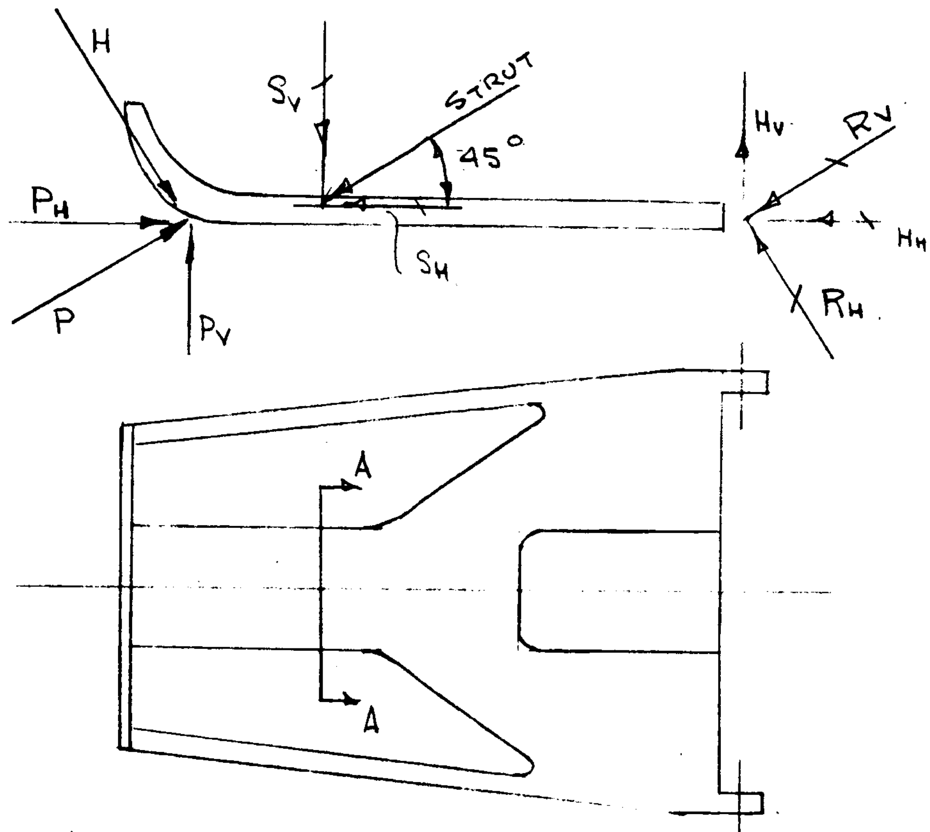
DEPLOYABLE LEG.



STRUT LOAD = 41,300 LB
P = 45,900 LB
H = 16,050 LB
R_H = 16,050 LB
R_V = 4,600 LB

$H_H = R_H \sin\Theta + R_V \cos\Theta$
$= 16{,}050(.707) + 4600(.707)$
$= 11{,}350 + 3250 = 14{,}600$ LB

$H_V = 11{,}350 - 3250 = 8{,}100$ LB.

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DEPLOYABLE LEG

$$P_V = P\cos\Theta - H\sin\Theta$$
$$= 45{,}900(.707) - 16{,}050(.707)$$
$$= 32{,}400 - 11{,}350 = 21{,}050 \text{ LB}$$

$$P_H = P\sin\Theta + H\cos\Theta$$
$$= 32{,}400 + 11{,}350 = 43{,}750 \text{ LB}$$

BENDING MOMENT AT SECTION AA

$$M = 8100(26.0) = 210{,}600 \text{ LB INS.}$$

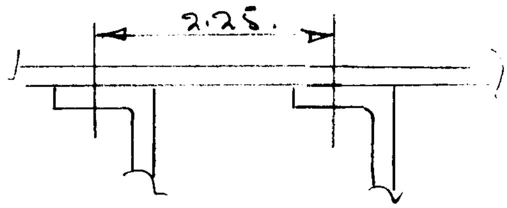
END LOAD = 43,750 LB (COMPRESSION)

SHEAR = 21,050 LB

SECTION AA

COMPRESSIVE ALLOWABLE OF .156 STEEL PLATE AT 600°F

RIVET CENTERS 2.25 INCHES.



$$\frac{\sigma_{CR}}{\eta} = \frac{K\pi^2 E}{12[1-\mu^2]}\left(\frac{t}{b}\right)^2$$
$$= \frac{6.98(\pi)(25)(10)^6}{12[1-.33^2]}\left(\frac{.156}{2.25}\right)^2$$
$$= 262{,}000 \text{ PSI}$$

USE FULL COMPRESSIVE ALLOWABLE OF 156,000 P.S.I.

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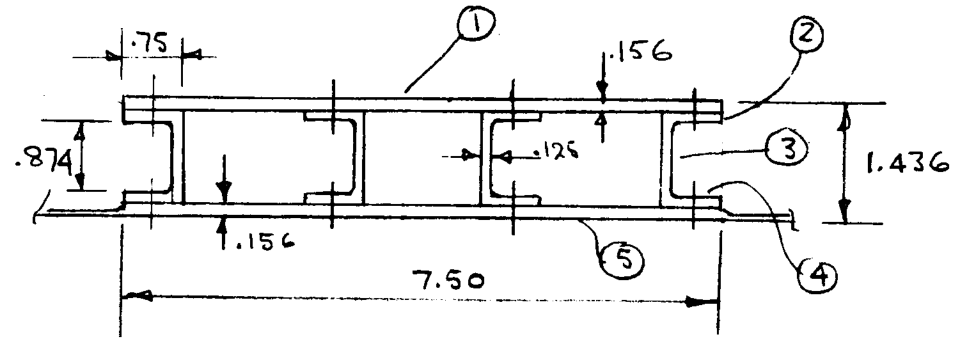
DEPLOYABLE LEG

SECTION A A



ITEM	AREA	Y_{NA}	$A\,Y_{NA}^2$	I_o
1	1.170	0.640	0.480	.0024
2	.375	.500	.0937	.0005
3	.437	0	0	.0279
4	.375	.500	.0937	.0005
5	1.170	.640	0.480	.0024
	3.527		1.1474	.0337

$$\begin{array}{r} .0337 \\ 1.1474 \\ \hline 1.1811 \end{array}$$

$$f_c = \frac{210,600\,(.718)}{1.1811} + \frac{43,750}{3.527}$$
$$= 128,000 + 12,420$$
$$= 140,420 \text{ P.S.I.}$$

$$MS = \frac{156,000}{140,420} - 1 = 0.11$$

SHEAR ON ATTACHMENTS

$$q = \frac{21,050\,(1.17)(.64)}{1.1811} = 13,300 \text{ LB/IN}$$

1/4 HUCKS AT 1.25 PITCH ALLOWABLE SHEAR PER INCH

$$= \frac{4 \times 4650}{1.25} = 14,900 \text{ LB/IN}$$

$$MS = \frac{14,900}{13,300} - 1 = 0.12$$

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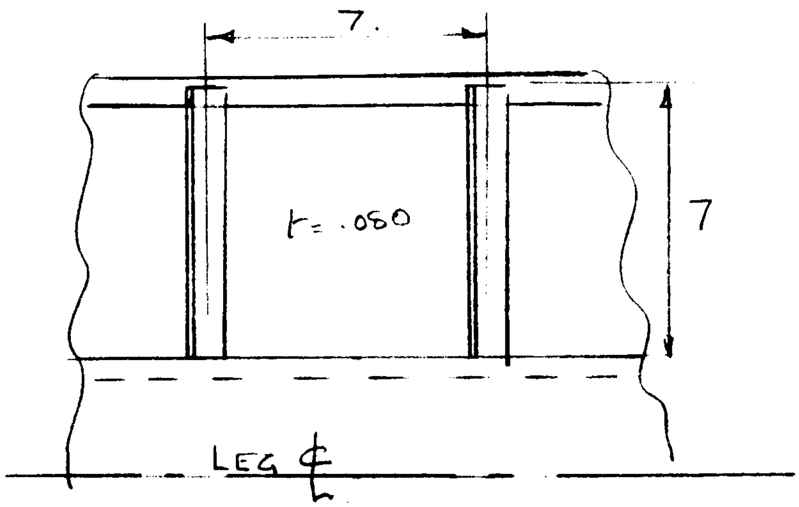
DEPLOYABLE LEG

OUTER SKIN – AERODYNAMIC LOADING AT ENTRY.

MAX^M PRESSURE = 25.5 (1.32)
= 33.60 PSI.



$$f_{MAX} = \frac{.75(\omega)(b)^2}{t^2\,(2.61)}$$

$$= \frac{.75\,(33.60)\,(7)^2}{(.080)^2\;2.61} = 72{,}300\ \text{PSI}$$

HIGH MARGIN.

PANEL DEFLECTION

$$Y = \frac{.1422\,\omega\, b^4}{E\,t^3\,(3.12)}$$

$$= \frac{.1422\,(22.45)\,(2400)}{25\,(10)^6\,(5.12)\,(10)^{-4}\,(3.21)} = 0.186$$

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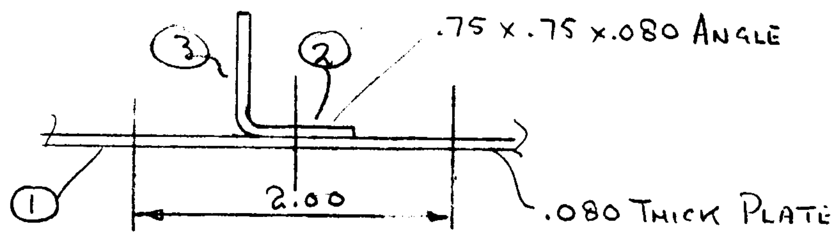
DEPLOYABLE LEG SKIN STIFFENERS
SECTION PROPERTIES



ITEM	AREA	Y_{xx}	AY_{xx}	Y_{NA}	AY_{NA}^2	I_o
1	.160	.040	.0064	.106	.00179	.00008
2	.0575	.120	.0069	.026	.00004	.00003
3	.060	.455	.0272	.309	.00574	.00281
	.2775				.00757	.00292

$$Y_{NA} = \frac{.0405}{.2775} = .146$$

$$\begin{array}{r} .00292 \\ \underline{.00757} \\ .01049 \end{array}$$

$$M = \frac{wl^3}{8} = \frac{33.60(7)^3}{8} = 1445 \text{ LB INS.}$$

$$\text{SHEAR} = \frac{wl^2}{2} = \frac{33.60(7)^2}{2} = 812 \text{ LB.}$$

$$f_B = \frac{1445(.684)}{.01049} = 94{,}500 \text{ P.S.I}$$

$$M_S = \frac{156000}{94{,}500} - 1 = 0.65$$

SHEAR FLOW AT ATTACHMENTS.

$$q = \frac{VQ}{I} = \frac{812(.160)(.106)}{.01049} = 1320 \text{ LB/IN.}$$

3/16 HUCKS AT 1.9 CENTERS. $q_{ALL} = \frac{2620}{1.9} = 1380$

$$MS = \frac{1380}{1320} - 1 = 0.04.$$

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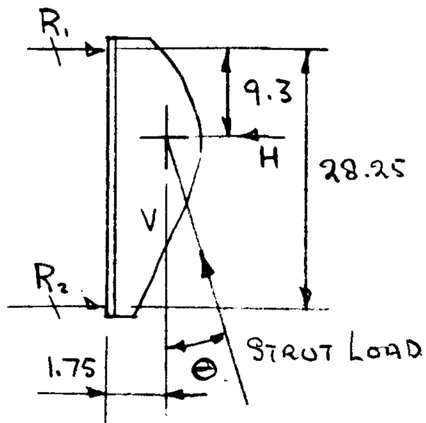
INNER STRUCTURE SIDEWALL FITTING.



COND	θ	SIN	COS
2	31.5	.522	.853
3	25.25	.426	.904
4	17.5	.301	.954
5	9.75	.168	.985

STRUT LOAD = 41,300 (1.33)
= 55,066 LB

RESOLVING STRUT LOAD.

COND	V	H	R_1	R_2
2	46,900	28,700	22,150	6550
3	49,600	23,450	18,775	4675
4	52,400	16,600	14,390	2210
5	54,000	9,260	9,560	- 300

COND 5 LOAD ON BOND.

$q = \frac{54000}{29} = 1865$ LB / IN (AVERAGE)

ASSUME TRIANGULAR DISTRIBUTION

$q_{MAX} = 1865(2) = 3730$ LB/IN.

BASE OF FITTING 4" WIDE

BOND STRESS $= \frac{3730}{4} = 932.5$ PSI

BOND ALLOWABLE AT 200°F = 1320 PSI.

$MS = \frac{1320}{932.5} - 1 = 0.42$

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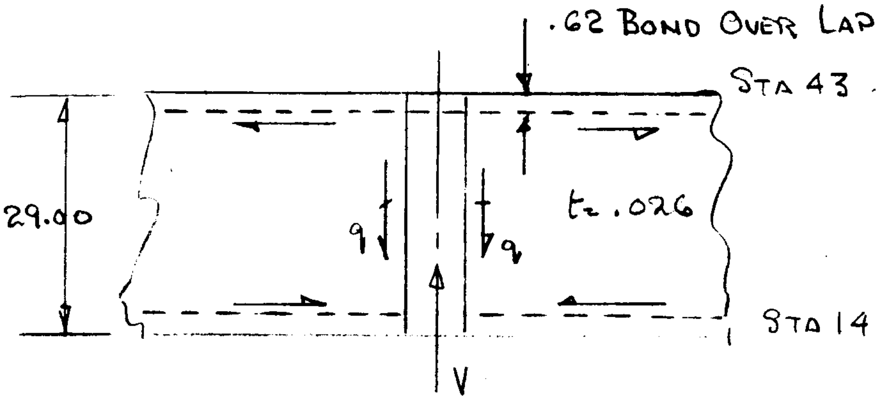
INNER STRUCTURE AFT SIDEWALL SKIN



$V = 54{,}000$ LB. (REF PAGE 1.11 COND(5))

ASSUME SHEAR CONCENTRATION FACTOR OF 2.0

$$q_{AV.} = \frac{54{,}000}{(2)\,29} = 932.5 \text{ LB/IN.}$$

$$q_{MAX} = 932.5\,(2.0) = 1865 \text{ LB/IN.}$$

$$\text{SKIN STRESS} = \frac{1865}{(2)\,.026} = 35{,}800 \text{ P.S.I.}$$

$$MS = \frac{38000}{35800} - 1 = 0.06$$

RING TO SKIN BOND STRESS (STA 43)

$$f_{BOND} = \frac{932.5}{(2)(.62)} = 753 \text{ PSI}$$

$$MS = \frac{1320}{753} - 1 = 0.76$$

WELD AT STA 14

$$f_s = \frac{932.5}{(.026+.060)} = 10{,}850 \text{ P.S.I.}$$

WELD SHEAR ALLOWABLE $= 25{,}000\,(.60) = 15{,}000$ P.S.I.

$$MS = \frac{15{,}000}{10850} - 1 = 0.38$$

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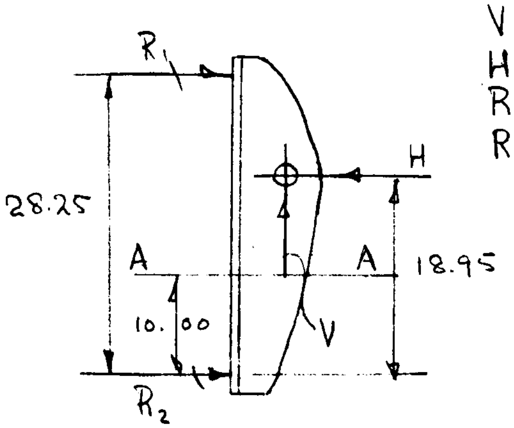
SIDEWALL FITTING

COND 2

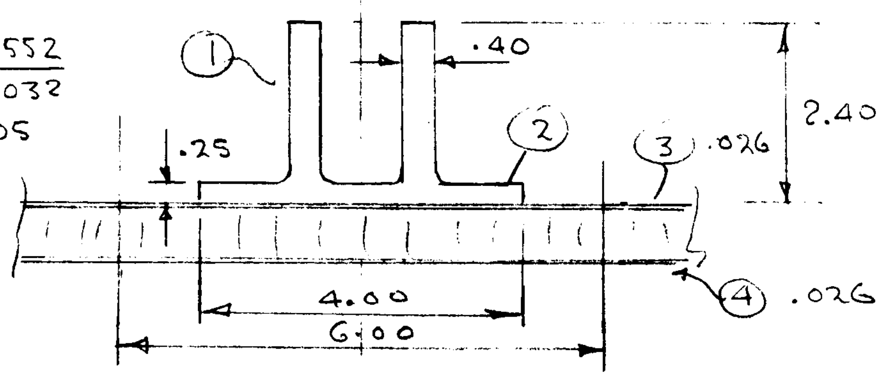
V = 46,900 LB
H = 28,700 LB.
R_1 = 22,150 LB
R_2 = 6550 LB.



SECTION A A

M = 10.00 (6550) = 65,500 LB INS.
END LOAD = 8080 LB. (TENSION)

$y_{NA} = \frac{4.552}{3.032} = 1.505$



ITEM	AREA	y_{xx}	Ay_{xx}	y_{NA}	Ay_{NA}^2	I_o
1	1.720	2.075	3.560	.570	.560	.665
2	1.000	.875	.875	.630	.396	.0052
3	.156	.737	.115	.768	.092	
4	.156	.013	.002	1.492	.348	
	3.032		4.552		1.396	.6702

$$\begin{array}{r} .6702 \\ 1.396 \\ \hline 2.0662 \end{array}$$

$$f_T = \frac{65,500\,(1.505)}{2.0662} + \frac{8080}{3.032}$$
$$= 50,460 \text{ P.S.I}$$

$$MS = \frac{60,000}{50,460} - 1 = 0.19$$

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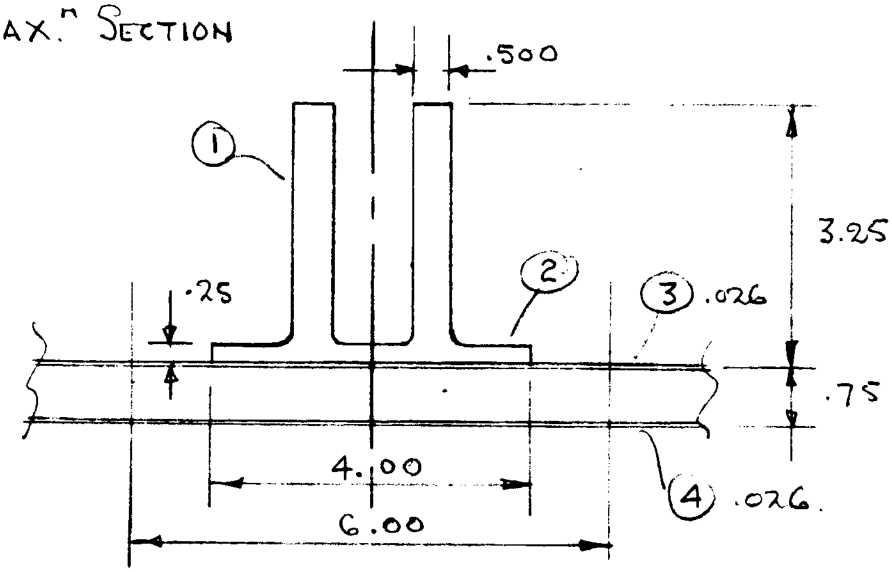
SIDEWALL FITTING

MAX.^M SECTION



ITEM	AREA	Y_{XX}	$A Y_{XX}$	Y_{NA}	$A Y_{NA}^2$	I_o
①	3.00	2.500	7.500	.530	.845	2.25
②	1.00	.875	.875	1.095	1.200	.005
③	.156	.737	.115	1.233	.232	
④	.156	.013	.002	1.957	.597	
	4.312		8.492		2.880	2.255

$$Y_{NA} = \frac{8.492}{4.312} = 1.970$$

$$\begin{array}{r} 2.255 \\ 2.88 \\ \hline 5.135 \end{array}$$

$M_{MAX} = 6550\,(18.95) = 124{,}000$ LB INS

END LOAD $= 46{,}900/2 = 23{,}450$ LB

$$f_T = \frac{124{,}000\,(1.970)}{5.135} + \frac{23{,}450}{4.312}$$

$$= 47{,}700 + 5440$$

$$= 53\,140 \text{ P.S.I.}$$

$$MS = \frac{60{,}000}{53{,}140} - 1 = 0.13$$

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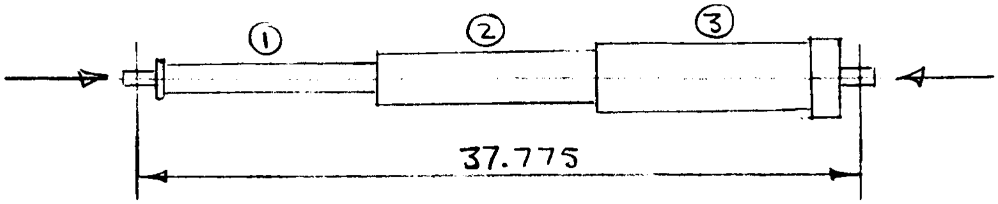
SHOCK STRUT

LOAD = 31,000 (1.32) = 41,300 LB (LIMIT)

= 41,300 (1.33) = 55 066 LB (ULTIMATE)



ITEM	THICKNESS	DIAM.	AREA	I	ρ	ℓ
①	.120	1.75	.615	.204	.576	12.5
②	.090	2.25	.610	.355	.733	11.0
③	.090	2.75	.750	.664	1.065	14.2

$$\frac{\ell}{\rho} = \frac{12.5}{.576} + \frac{11.0}{.733} + \frac{14.2}{1.065}$$

$$= 21.8 + 15.0 + 13.3 = 50.1$$

COLUMN ALLOWABLE = 91,000 PSI

$$f_c = \frac{55,066}{.610} = 90\,500 \text{ PSI}$$

$$MS = \frac{91,000}{90,500} - 1 = 0.01$$

$$\text{PRESSURE} = \frac{55,066}{\pi\,(1.225)^2} = 10,500 \text{ PSI}$$

$$\text{HOOP STRESS} = \frac{PR}{t} = \frac{10,500\,(1.33)}{.090} = 155,000 \text{ PSI}$$

$$MS = \frac{156,000}{155,000} - 1 = 0.01$$

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WATER IMPACT CONDITION

LOAD ON AFT HEAT SHIELD $= 14{,}000\,(8.00)$
$= 112{,}000$ LB

PRESSURE ON IMPACT AREA ($630\ \text{INS}^2$)

$$= \frac{112{,}000}{630} = 178 \text{ P.S.I}$$

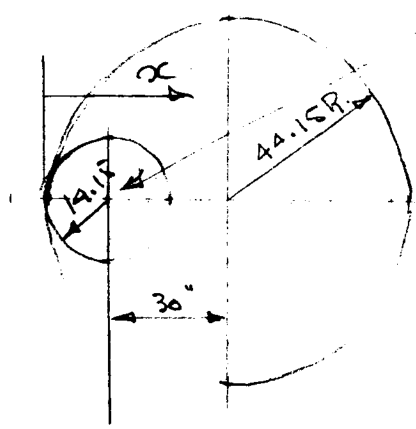
LINE LOAD ON 44" RAD RING

$$\text{MEAN} = \frac{112{,}000}{\pi(88.3)} = 405 \text{ LB/IN.}$$

$$\text{MIN} = \frac{405\,(14.15)}{44.15} = 129.5 \text{ LB/IN.}$$

$$\text{MAX} = \frac{405\,(74.15)}{44.15} = 680 \text{ LB/IN.}$$

BENDING ON CENTER PANEL



IMPACT POINT

M FOR $\alpha = 14.15$

$$= 680(14.15) - \frac{(680+129.5)}{2}7.07$$

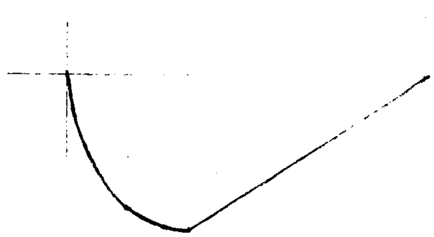
$$= 6790 \text{ LB INS}$$

M FOR $\alpha = 28.3$

$$= 60(129.5) = 7770 \text{ LB INS}$$

MAX SKIN THICKNESS $= .030$

$$f = \frac{7770}{2(.030)} = 130{,}000 \text{ P.S.I}$$



B M DIAGRAM

$$MS = \frac{135{,}000}{130{,}000} - 1 = 0.04$$

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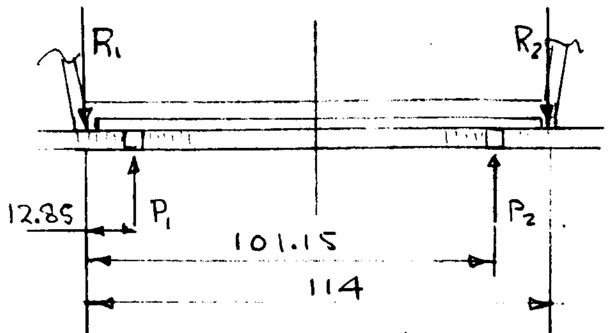
HEAT SHIELD SKINS (CONT^D)

RING R = 44 TO INNER STRUCTURE RING R = 57.



$P_1 = 2(129.5) = 259$ LB/IN

$P_2 = 2(680) = 1360$ LB/IN

$114 R_2 = 101.15(259) + 12.85(1360)$

$R_2 = \frac{43,700}{114} = 384$ LB/IN.

$R_1 = 259 + 1360 - 384 = 1235$ LB/IN.

BENDING MOMENT AT P_1

$= 1235(12.85) = 15,900$ LB INS

$f_B = \frac{15,900}{2(.055)} = 145,000$ P.S.I. $(t = 0.55)$

$MS = \frac{150,000}{145,000} - 1 = 0.00$

BENDING MOMENT AT P_2.

$= 384(12.85) = 4930$ LB INS.

$(t = .019)$

$f_B = \frac{4930}{2(.019)} = 130,000$ P.S.I

$MS = \frac{135000}{130,000} - 1 = 0.04.$

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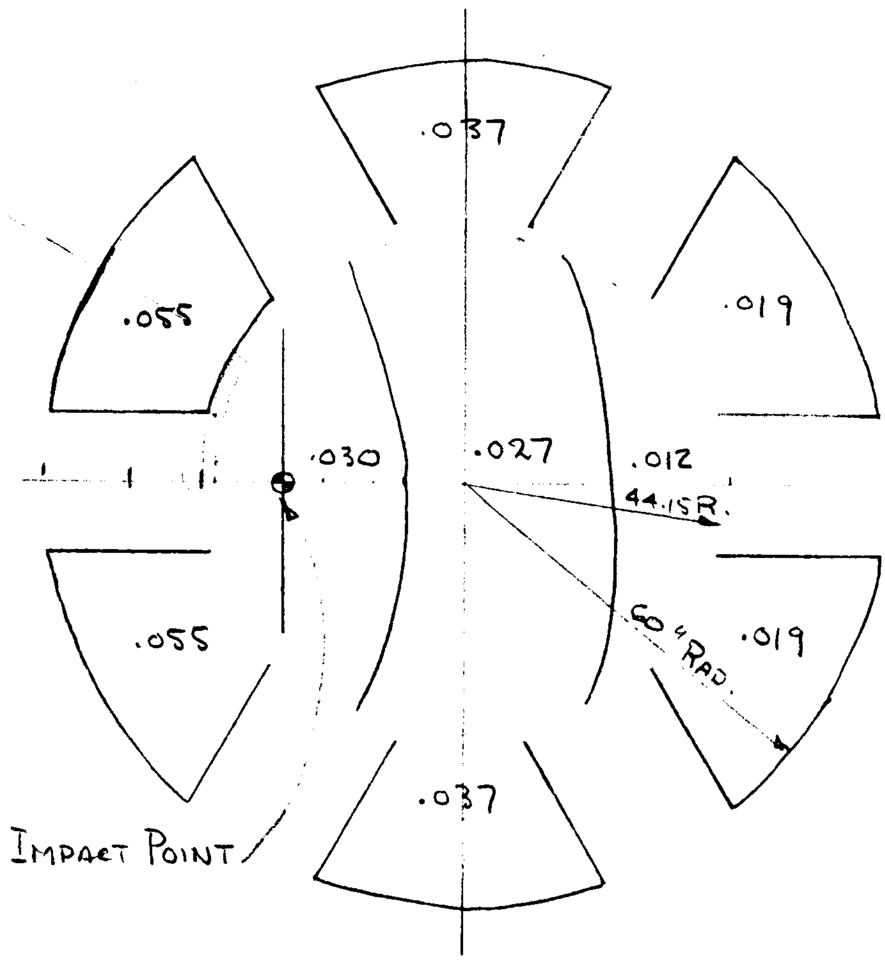
AFT HEAT SHIELD SKIN THICKNESS.



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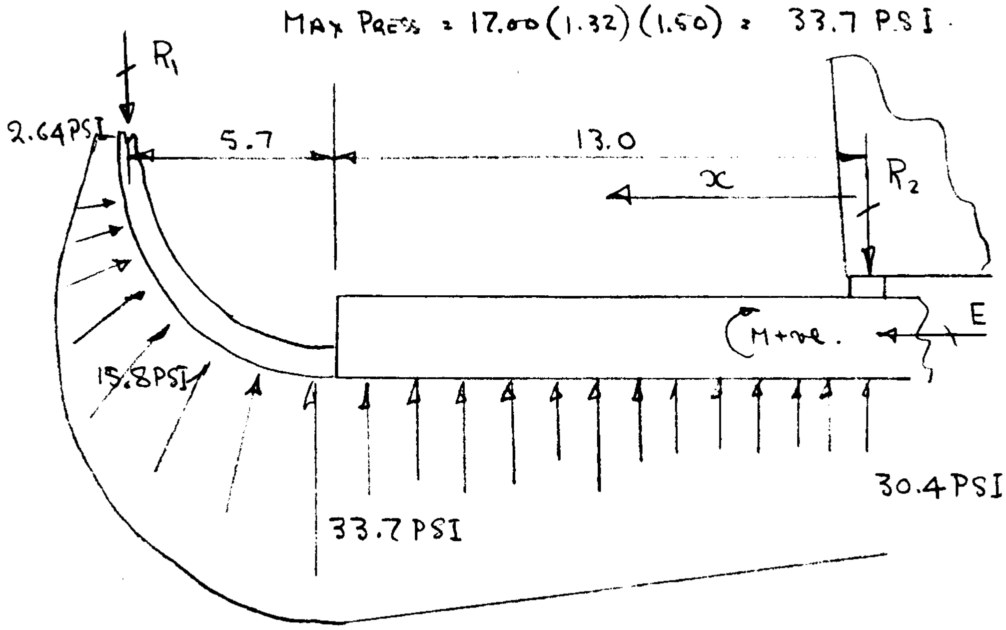
AFT HEAT SHIELD STRUCTURE

ENTRY AIR LOAD CONDITION

MAX PRESS = 17.00 (1.32) (1.50) = 33.7 PSI



TOTAL VERTICAL LOAD (PER INCH)

$$wl = \{30.4(13) + 1.65(13)\} + \{4(11.1) + 2(22.6) + 1.7(5.55)\}$$
$$= 517 \text{ LB}$$

TOTAL HORIZONTAL LOAD (PER INCH)

$$w_\eta = 5.55(4) + 2.64(1.7) + 4.23(1.7) = 36.2 \text{ LB.}$$

ASSUME ALL w_η IS REACTED AT E. THEN E = 36.2 LB.

EQUATING DEFLECTIONS.

$$\delta = \frac{R_1 l^3}{3EI} = \frac{wl^4}{8EI} \qquad R_1 = \frac{3wl}{8}$$

$$R_1 = \frac{3(517)}{8} = 194 \text{ LB}$$

$$R_2 = 517 - 194 = 323 \text{ LB.}$$

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AFT HEAT SHIELD STRUCTURE
BENDING OF SEGMENTED SECTION.

M AT $x = 0$
$-194(18.7) + 517(8.28) + 36.2(2.37)$
$= -3630 + 4280 + 86 = 736$ LB INS.

M AT $x = 3$
$-194(15.7) + 427.1(6.67) + 86$
$= -3040 + 2850 + 86 = -104$ LB INS.

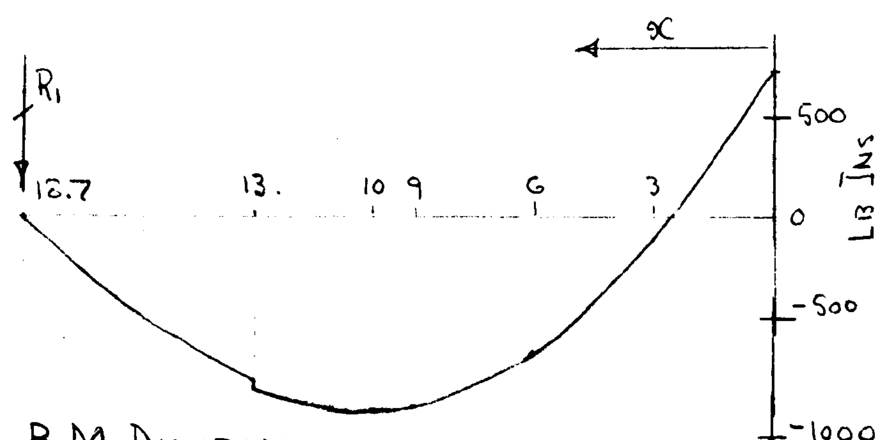
M AT $x = 6$
$-194(12.7) + 329.3(5.14) + 86$
$= -2465 + 1690 + 86 = -689$ LB INS

M AT $x = 9.0$
$-194(9.7) + 231.76(3.7) + 86$
$-1880 + 855 + 86 = -939$ LB INS

M AT $x = 10.0$
$-194(8.7) + 198.96(3.2) + 86$
$= -1685 + 636 + 86 = -963$ LB INS

M AT $x = 12.99$
$-194(5.7) + 99(1.935) + 86$
$-1105 + 191.5 + 86 = -827.5$ LB INS

M AT $x = 13.01$
$-194(5.7) + 99(1.935) + 36.2(2.87)$
$= -1105 + 191.5 + 104 = -809.5$ LB INS



B M DIAGRAM.

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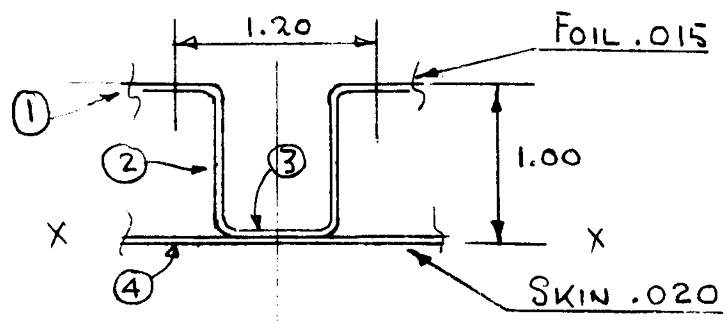
AFT HEAT SHIELD (TOROIDAL SECTION)



ITEM	AREA	Y_{XX}	AY_{XX}	Y_{NA}	AY_{NA}	I_o
1	.009	.993	.00895	.654	.00385	
2	.0285	.510	.0145	.171	.00083	.00218
3	.009	.027	.00024	.312	.00087	
4	.024	.010	.00024	.329	.00260	
	.0705		.02393		.00815	.00218

$$Y_{NA} = \frac{.02393}{.0705} = .339$$

$$\begin{array}{r} .00218 \\ \underline{.00815} \\ .01033 \end{array}$$

AT x = 13.01

$$f_T = \frac{809.5(1.2)(.661)}{.01033} = 62{,}000 \text{ PSI}$$

$$f_c = \frac{809.5(1.2)(.339)}{.01033} = 31{,}800 \text{ PSI}$$

BUCKLING ALLOWABLE ITEM 4

$$\sigma_{CR} = \frac{K E \pi^2}{12[1-\mu^2]}\left[\frac{t}{b}\right]^2 = \frac{6.98(25)(10)^6\pi^2}{12[1-.33^2]}\left(\frac{.020}{1.20}\right)^2$$

$$= 44{,}100 \text{ P.S.I}$$

BUCKLING ALLOWABLE ITEM 2

$$= \frac{10(25)(10)^6\pi^2}{12(1-.33^2)}\left(\frac{.015}{1.00}\right)^2 = 56{,}200 \text{ PSI.}$$

$$MS = \frac{44{,}100}{31{,}800} - 1 = 0.39.$$

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AFT HEAT SHIELD DEFLECTIONS

WATER IMPACT

FROM R = 44 TO R = 57

$$\delta = \frac{1}{EI}\iint M\,dx\,dx = \frac{1}{EI}\frac{Wx^3}{3}$$

$Wx = 15{,}900$ LB INS.

$$EI = 25(10)^6(.055)(2) = 2.75(10)^6$$

$$\delta = \frac{15{,}900(12.85)^2}{3(2.75)(10)^6} = .318 \text{ INCHES}$$

DEFLECTION OF CENTER PANEL.

$$\delta = \frac{96 W R^2}{144 \pi E t^3}$$

SKIN THICKNESS = .030

$$I \text{ OF PANEL} = .030(1)^2(2) = .060$$

$$I \text{ OF SOLID PLATE} = \frac{bd^3}{12} \qquad d^3 = \frac{12(I)}{B}$$

$$\text{EQUIVALENT } t^3 = \frac{12(I)}{B} = \frac{12(.060)}{1} = .720$$

$$\delta = \frac{96(14{,}000)(8)(44)^2}{144\pi(25)(10)^6(.72)} = 2.560 \text{ INS.}$$

$$\text{TOTAL DEFLECTION} = 2.560 + .318$$
$$= 2.878 \text{ INCHES.}$$

THE AFT HEAT SHIELD WILL CONTACT THE INNER STRUCTURE.

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RING AT 44" RAD IN AFT HEAT SHIELD SUB STRUCTURE

$W = 14{,}000$ LB $\quad V = 20$ FT/SEC $\quad \mu = .35$

LOAD INCREASE FACTOR

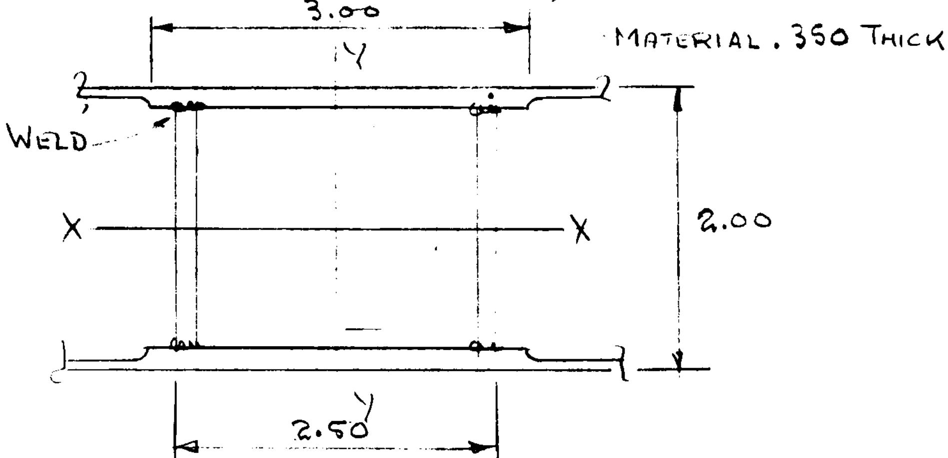
$$= \frac{(20)^2}{(15)^2} = \frac{400}{225} = 1.78$$

REF PAGE 1.4

$$M_V = 17{,}150\,(1.78) = 30{,}500 \text{ LB INS}$$

$$M_H = 31{,}600\,(1.78) = 56{,}200 \text{ LB INS}$$

REVISED RING SECTION (REF PAGE 1.5)



$$I_{xx} = 3.00(.35)(.825)^2(2) + (.70)(1.3)^3/12 = 1.558 \text{ INS}^4$$

$$I_{yy} = 1.30(.35)(1.07)^2(2) + (.70)(3.00)^3/12 = 2.620 \text{ INS}^4$$

$$f_B = \left\{\frac{M_V\,(1.00)}{I_{xx}} + \frac{M_H\,(1.375)}{I_{yy}}\right\} 1.33$$

$$= \left\{\frac{30{,}500\,(1.00)}{1.558} + \frac{56{,}200\,(1.500)}{2.62}\right\} 1.33$$

$$= (19{,}600 + 31{,}600)\,1.33 = 68{,}100$$

$$MS = \frac{77{,}000}{68{,}100} - 1 = 0.13.$$

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DEPLOYABLE LEG 20 FT/SEC $\mu = .35$

REF PAGE 1.7

AT SECTION AA

BENDING MOMENT = 210,600 (1.78) = 374,000 LB INS.

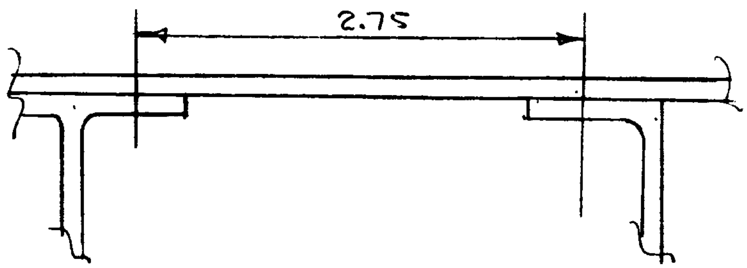
END LOAD = 43,750 (1.78) = 78,000 LB.

SHEAR = 21,050 (1.78) = 37,400 LB

SECTION AA

COMPRESSIVE ALLOWABLE OF .1875 STEEL PLATE AT 600°F

RIVET CENTERS 2.75 INCHES.



$$\frac{\sigma_{CR}}{\eta} = \frac{K\pi^2 E}{12(1-\mu^2)}\left(\frac{t}{b}\right)^2$$

$$= \frac{6.98(\pi)(25)(10)^6}{12(1-.33^2)}\left(\frac{.1875}{2.75}\right)^2$$

$$= 252,000 \text{ PSI}$$

USE FULL COMPRESSIVE ALLOWABLE OF 156,000 P.S.I.

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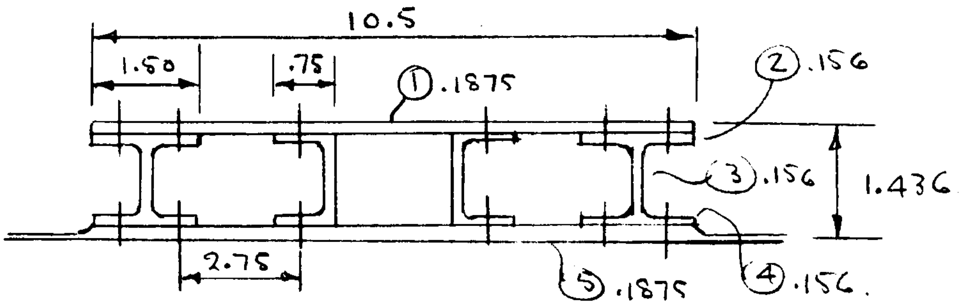
DEPLOYABLE LEG $W = 14{,}000$ LB $V = 20$ FT/SEC $\mu = .35$

SECTION AA (REF PAGE 1.8)



ITEM	AREA	Y_{NA}	AY_{NA}^2	I_o
①	1.970	.640	.805	.0058
②	.700	.484	.164	.001
③	.468	0	0	.022
④	.700	.484	.164	.001
⑤	1.97	.640	.805	.0058
	5.808		1.938	.0356
				1.938
				1.9736

$$f_c = \frac{374{,}000\,(.718)}{1.9736} + \frac{78000}{5.808}$$

$$= 136{,}000 + 13{,}400 = 149{,}400 \text{ PSI}$$

$$MS = \frac{156{,}000}{149{,}400} - 1 = 0.04$$

SHEAR ON ATTACHMENTS

$$q = \frac{37{,}400\,(1.97)\,(.64)}{1.9736} = 23{,}900 \text{ LB/IN}$$

6 ROWS OF 1/4 HUCKS AT 1.15 PITCH

$$\text{ALLOWABLE SHEAR/INCH} = \frac{6\,(4650)}{1.15} = 24{,}300 \text{ LB/IN}$$

$$MS = \frac{24300}{23{,}900} - 1 = 0.01$$

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SIDEWALL FITTING - SHOCK STRUT TO COMMAND MODULE INNER STRUCT.

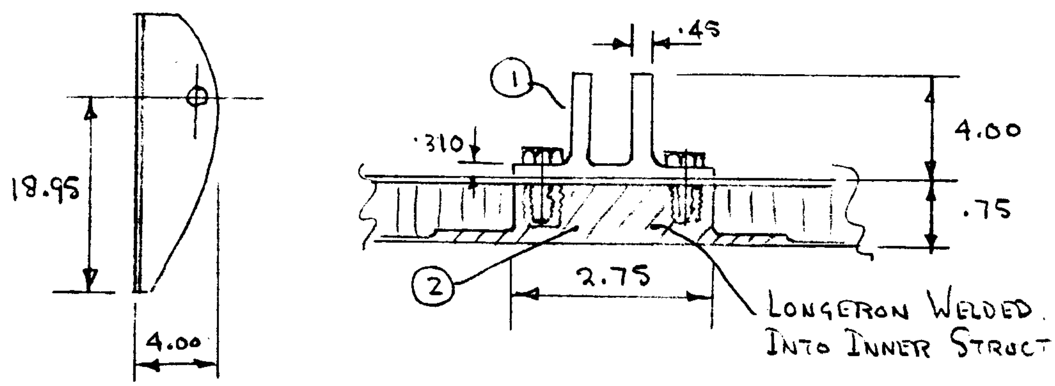
$W = 14{,}000$ LB $V = 20$ FT/SEC $\mu = .35$

REF PAGE 1.14.

MAX BENDING MOMENT = 124,000 (1.78) = 220,500 LB INS.

" END LOAD = 23,450 (1.78) = 41,600 LB.

SECTION PROPERTIES MAX SECTION.



NOTE: THE AXIAL LOAD APPLIED TO THE INNER STRUCTURE BY THE SHOCK STRUTS IS GREATER THAN THE MAIN LONGERON LOADS.

ITEM	AREA	Y_{xx}	AY_{xx}	Y_{NA}	AY_{NA}^2	I_o
1	3.320	2.905	9.630	1.115	4.130	3.360
2	2.910	.530	1.540	1.260	4.620	.274
	6.230		11.170		8.750	3.634
						8.750
						12.384

$$Y_{NA} = \frac{11.170}{6.230} = 1.790$$

$$f_c = \frac{220{,}500\,(2.96)}{12.384} + \frac{41{,}600}{6.230}$$

$$= 53{,}200 + 6700 = 59{,}900 \text{ P.S.I}$$

F_{cy} FOR 7075-T6 AT 200° = 60,000 P.S.I.

MS = ZERO.

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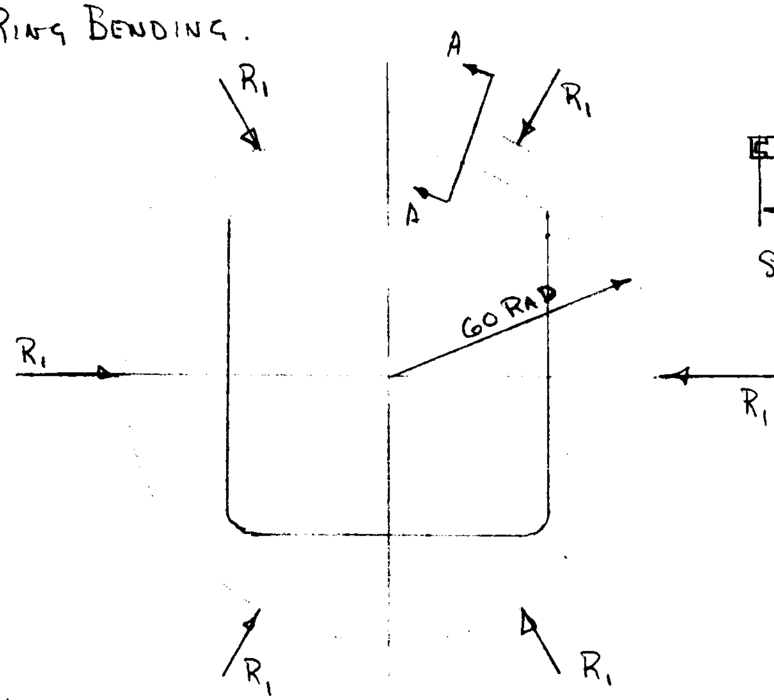
COMMAND MODULE INNER STRUCTURE GIRTH RING STA X_c 43.

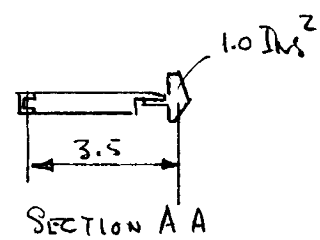
$W = 14{,}000 \quad V = 20$ FT/SEC $\quad \mu = .35$

REF PAGE 1.11

CONDITION (2) $R_1 = 22{,}150\,(1.78) = 39{,}400$ LB.

RING BENDING.





APPROX BM $= K_B R_1 r$ — (ASSUMING RING SECTION CONSTANT)

$= .16\,(39{,}400)\,60 = 379{,}000$ LB INS

$f_B = \dfrac{379{,}000}{3.5} = 108{,}000$ P.S.I

MIN RING SECTION WILL REQUIRE INCREASING BY

$\dfrac{108{,}000}{60000} = 1.80 \qquad 80\,\%$.

SECTION INCREASE IS ASSUMED TO AFFECT RING CAPS ONLY, MAINTAINING SAME BEAM WIDTH.

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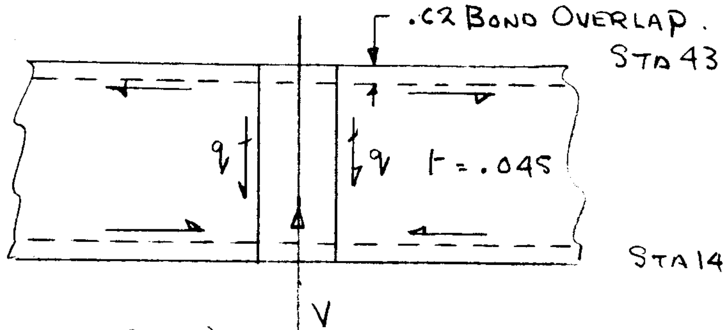
COMMAND MODULE INNER STRUCTURE AFT SIDEWALL SKIN

$W = 14{,}000$ LB $V = 20$ FT/SEC $\mu = .35$

REF PAGE 1.12



$V = 54{,}000\,(1.78) = 96{,}400$ LB.

$$q_{MAX} = \frac{96{,}400\,(2)}{(2)\,29} = 3320 \text{ LB/IN.}$$

SKIN THICKNESS .045

$$f_s = \frac{3320}{(2)\,.045} = 36{,}800 \text{ P.S.I.}$$

$$MS = \frac{38{,}000}{36{,}800} - 1 = 0.03$$

RING TO SKIN BOND STRESS (STA 43)

$$f_{s\,BOND} = \frac{3320}{(4)\,(.62)} = 1330 \text{ P.S.I}$$

MS = ZERO (NOTE LIMIT OF EXISTING INNER STRUCTURE RING)

STRESS ON WELD AT STA 14 AND 43.

$$f_s = \frac{3320}{(2)(.045+.060)} = 15{,}850 \text{ PSI}$$

WELD ALLOWABLE 15,000 P.S.I

NEW RINGS AND LONGERONS REQUIRED WITH THICKER WELD LANDS

SAY .070 LAND THICKNESS. THEN -

$$f_s = \frac{3320}{(2)(.045+.070)} = 14{,}400 \text{ P.S.I.}$$

$$MS = \frac{15{,}000}{14{,}400} - 1 = 0.04$$

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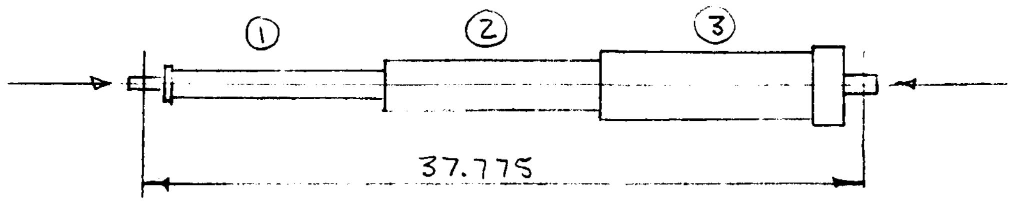
SHOCK STRUT $W = 14{,}000$ LB $V = 20$ FT/SEC $\mu = .35$

LOAD = 55,066 (1.78) = 98,000 LB (ULT).

REF PAGE 1.15



ITEM	THICKNESS	DIAM	AREA	I	ρ	ℓ
①	.100	2.75	.819	.730	.942	12.5
②	.100	3.25	.990	1.230	1.115	11.0
③	.120	3.75	1.368	2.270	1.289	14.2

$$\frac{\ell}{\rho} = \frac{12.5}{.942} + \frac{11.0}{1.115} + \frac{14.2}{1.289}$$

$$= 13.3 + 9.85 + 11.0 = 34.15$$

COLUMN ALLOWABLE = 120,000 PSI

$$f_c = \frac{98{,}000}{.819} = 119{,}500 \text{ PSI}$$

$$MS = \frac{120{,}000}{119{,}500} - 1 = \text{ZERO}$$

$$\text{INTERNAL PRESSURE} = \frac{98{,}000}{\pi(1.755)^2} = 10{,}000 \text{ PSI}$$

$$\text{WALL STRESS (ITEM 3)} = \frac{10{,}000\,(1.815)}{0.120} = 151{,}000 \text{ PSI}$$

$$MS = \frac{156{,}000}{151{,}000} - 1 = 0.03$$

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WATER IMPACT CONDITION

W = 14,000 LB V = 20 FT/SEC μ = .35

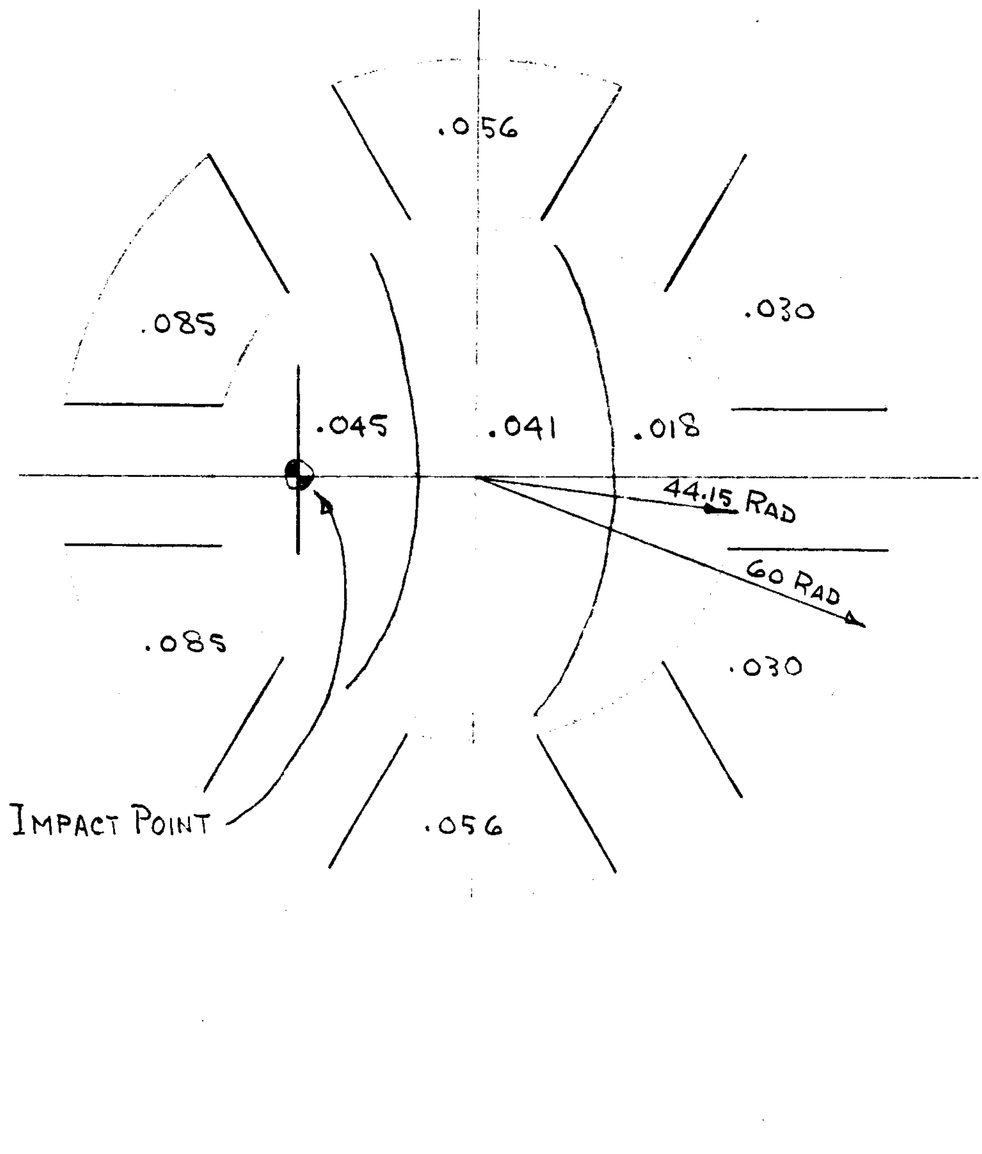
FROM CRITERIA IMPACT FORCE = 12.5g FOR 20 FT/SEC.

LOAD ON AFT H/S = 14,000 (12.5) = 175,000 LB.

LOAD INCREASE FACTOR = 12.5/8 = 1.56.

REF PAGE 2.1 AND 2.3.

AFT HEAT SHIELD SKIN THICKNESS.



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RING AT 44" RAD IN AFT HEAT SHIELD SUB STRUCTURE

$W = 14{,}000$ LB $\quad V = 30$ FT/SEC $\quad \mu = .35$

LOAD INCREASE FACTOR

$$= \frac{(30)^2}{(15)^2} = \frac{900}{225} = 4.00$$

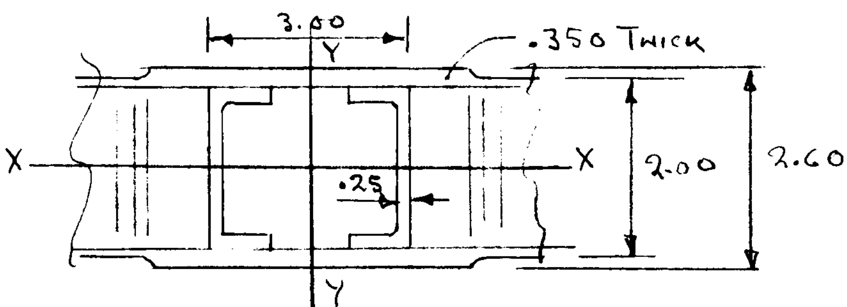
REF PAGE 1.4

$M_V = 17{,}150(4.00) = 68{,}600$ LB INS.

$M_H = 31{,}600(4.00) = 126{,}400$ LB INS

REVISED RING SECTION (REF PAGE 1.5)

TO ACCOMMODATE THE HIGHER LOADS ASSOCIATED WITH A VELOCITY OF 30 FT/SEC, A CHANGE IN THE DESIGN CONCEPT IS REQUIRED. A BUILT UP BOLTED SECTION IS BEING CONSIDERED WHICH ELIMINATES THE WELDS AT THE POINTS OF MAXIMUM STRESS AND PERMITS THE USE OF 156,000 PSI ALLOWABLE (180,000 PSI HEAT TREAT STEEL AT 600°F).



$$I_{xx} = 3.00(.35)(1.125)^2(2) + .50(1.9)^3/12 = 2.926$$

$$I_{yy} = 1.90(.25)(1.375)^2(2) + .70(3.00)^3/12 = 3.375$$

$$f_B = \left\{ \frac{M_V(1.3)}{I_{xx}} + \frac{M_H(1.5)}{I_{yy}} \right\} 1.33$$

$$= \frac{68{,}600(1.3)}{2.926} + \frac{126\,400(1.5)}{3.375}$$

$$= (30{,}400 + 56{,}400)\,1.33 = 115{,}000 \text{ PSI}$$

$$MS = \frac{156{,}000}{115{,}000} - 1 = 0.35$$

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DEPLOYABLE LEG W = 14,000 LB V = 30 FT/SEC μ = .35

REF PAGE 1.7

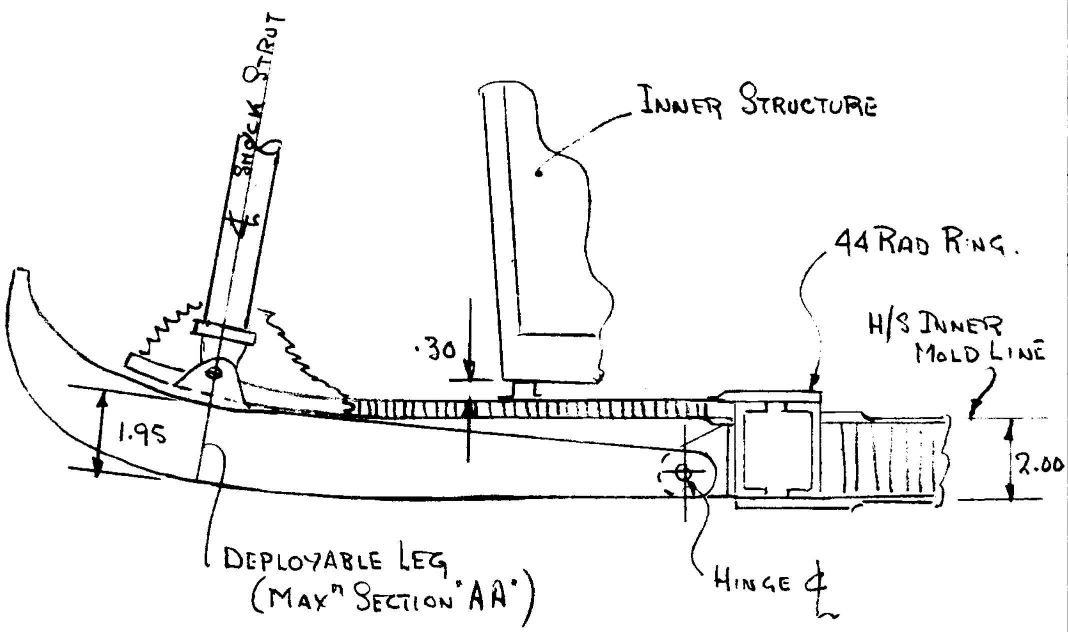
AT SECTION AA

BENDING MOMENT = 210,600 (4) = 842,400 LB INS.

END LOAD = 43,750 (4.00) = 155,000 LB.

SHEAR = 21,000 (4.00) = 84,000 LB

TO ACCOMMODATE THIS LOAD INCREASE, THE LEG SECTION MUST BE INCREASED IN DEPTH. TO OBTAIN THE REQUIRED SPACE FOR THIS CHANGE, THE HALF INCH HONEYCOMB PANEL HAS BEEN LOCATED FORWARD OF THE AFT HEAT SHIELD INNER MOLD LINE AS SHOWN IN THE SKETCH BELOW.



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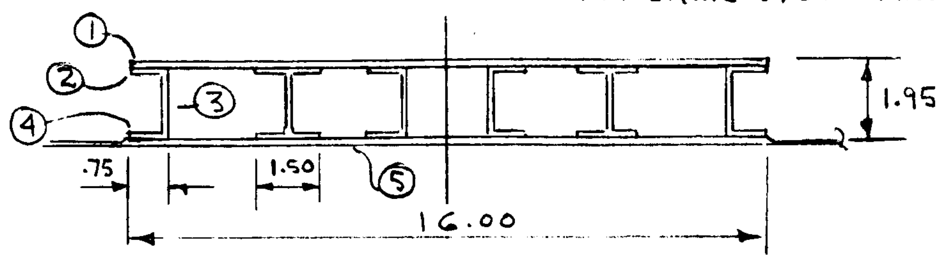
DEPLOYABLE LEG W = 14,000 LB V = 30 FT/SEC μ = .35
REF PAGE 1.8 SECTION AA

MATERIAL .1875 THICK



ITEM	AREA	Y_{NA}	$A\,Y_{NA}^2$	I_o
1	3.000	.881	2.330	.0088
2	1.125	.694	.541	.0033
3	1.350	0	0	.1620
4	1.125	.694	.541	.0033
5	3.000	.881	2.330	.0088
	9.600		5.742	.1862
				5.742
				5.9282

$$f_c = \frac{842{,}000\,(.975)}{5.928} + \frac{155{,}000}{9.6}$$

$$= 138{,}500 + 16{,}200 = 154{,}700 \text{ PSI}$$

$$MS = \frac{156{,}000}{154{,}700} - 1 = 0.01$$

SHEAR ON ATTACHMENTS

$$q = \frac{VQ}{I} = \frac{84{,}000\,(3.00)(.881)}{5.9282} = 37{,}500 \text{ LB/IN.}$$

8 ROWS OF 1/4 HUCKS AT 0.95 PITCH

$$\text{ALLOWABLE SHEAR / INCH} = \frac{8\,(4650)}{0.95} = 39{,}200 \text{ LB/IN}$$

$$MS = \frac{39{,}200}{37{,}500} - 1 = 0.04$$

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SIDEWALL FITTING - SHOCK STRUT TO COMMAND MODULE INNER STRUCT.

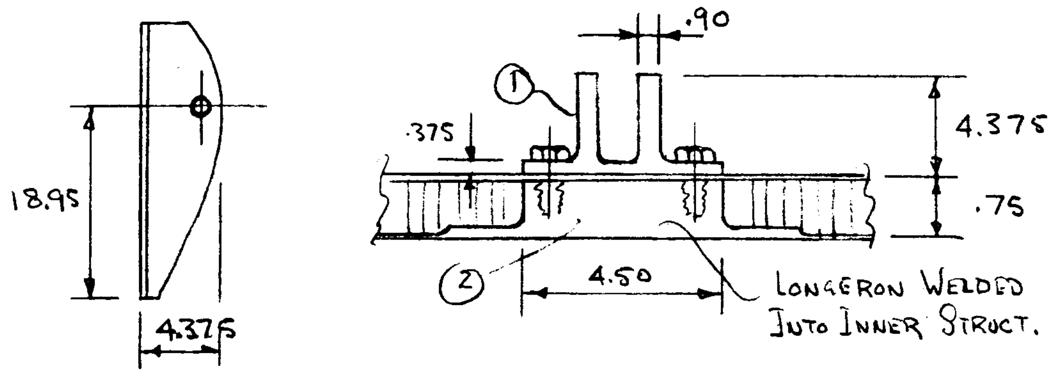
W = 14,000 LB V = 30 FT/SEC μ = .35

REF PAGE 1.14

MAX BENDING MOMENT = 124,000 (4) = 496,000 LB INS.

MAX END LOAD = 23,450 (4) = 93,800 LB.

SECTION PROPERTIES - MAX SECTION.



ITEM	AREA	Y_{xx}	AY_{xx}	Y_{NA}	AY_{NA}^2	I_o
1	7.20	3.125	22.45	1.060	8.09	9.60
2	5.07	0.562	2.84	1.503	11.47	.53
	12.27		25.29		19.56	10.13

$Y_{NA} = \dfrac{25.29}{12.27} = 2.065$ $\quad \dfrac{19.56}{29.69}$

$$f_c = \frac{496,000\,(3.060)}{29.69} + \frac{93,800}{12.27}$$

$$= 51,100 + 7650 = 58,750 \text{ P.S.I.}$$

$$MS = \frac{60,000}{58,750} - 1 = 0.02$$

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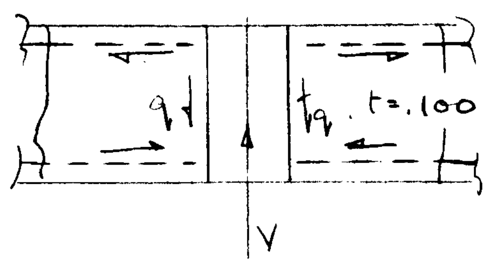
COMMAND MODULE INNER STRUCTURE AFT SIDEWALL SKIN.

$W = 14{,}000$ LB $\quad V = 30$ FT/SEC $\quad \mu = .35$

REF PAGE 1.12



$V = 54{,}000\,(4.0) = 216{,}000$ LB.

$q_{MAX} = \frac{216{,}000\,(2)}{(2)\,29} = 7460$ LB/IN

SKIN THICKNESS = 0.100

$f_s = \frac{7460}{(2)\,.100} = 37\,300$ P.S.I.

$MS = \frac{38{,}000}{37{,}300} - 1 = 0.02$

RING TO SKIN BOND STRESS (STA 43)

$f_{s\,BOND} = \frac{7460}{(4)\,(1.42)} = 1310$ PSI.

M.S. = ZERO

NOTE DEPTH OF RING AT STA X_c 43 INCREASED 0.20 INS.

STRESS ON WELD AT STA 14 AND 43

$f_s = \frac{7460}{(2)(.100 + .150)} = 14{,}900$ P.S.I.

M S = ZERO

REQUIRED WELD LAND THICKNESS = 0.150 ON RINGS AND LONGERONS TO ACHIEVE ZERO MARGIN.

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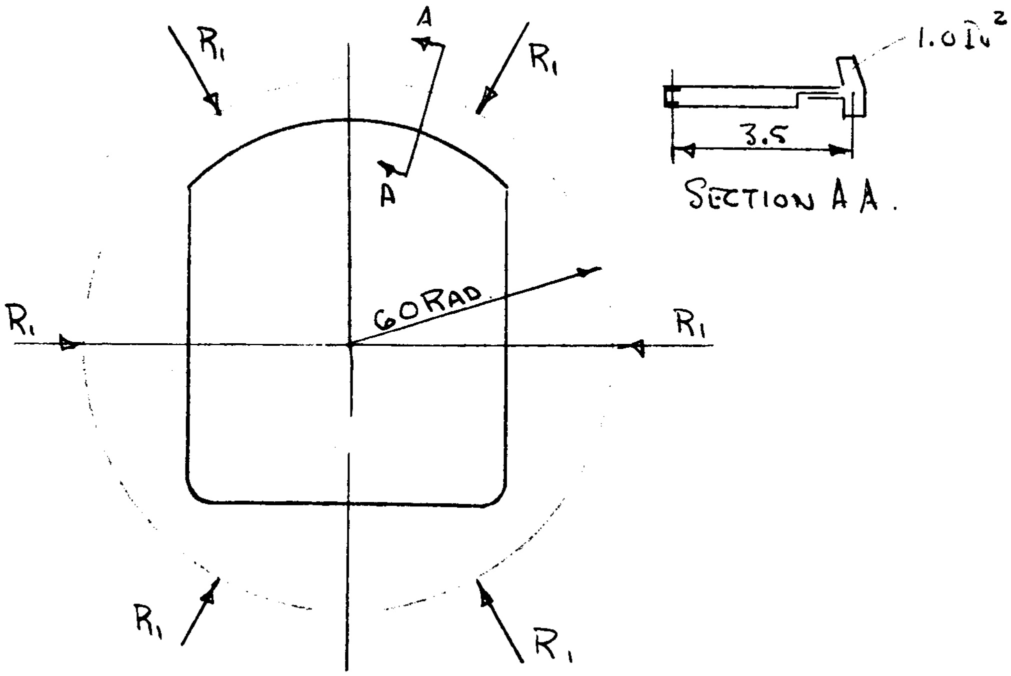
COMMAND MODULE INNER STRUCTURE GIRTH RING STA X_c 43.

$W = 14{,}000$ LB $V = 30$ FT/SEC $\mu = .35$

REF PAGE 1.11

CONDITION ② $R_1 = 22{,}150\,(4.0) = 88{,}600$ LB.

RING BENDING.



APROX BM $= K_B R_1 r$

$= .16\,(88{,}600)\,60 = 830{,}000$ LB INS

$$f_B = \frac{830{,}000}{3.5} = 238{,}000 \text{ P.S.I}$$

MIN RING SECTION WILL REQUIRE INCREASING BY

$$\frac{238{,}000}{60000} = 3.98 = 298\%$$

MATERIAL IS ASSUMED TO BE ADDED TO BEAM CAPS, WITHOUT CHANGING THE RING WIDTH

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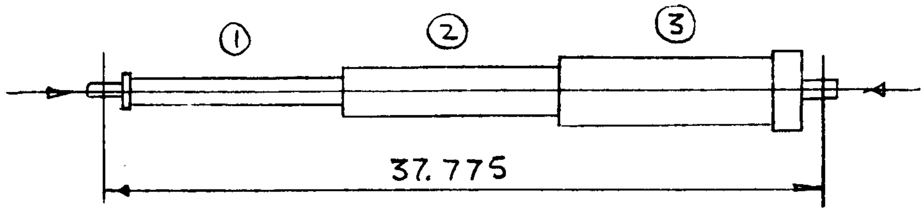
SHOCK STRUT $W = 14{,}000$ LB $V = 30$ FT/SEC $\mu = .35$

REF PAGE 1.15

LOAD $= 55{,}066\,(4.0) = 220{,}264$ LB (ULT.)



ITEM	THICKNESS	DIAM	AREA	I	ρ	ℓ
①	.150	4.62	2.10	5.25	1.58	12.5
②	.160	5.12	2.45	7.24	1.72	11.0
③	.180	5.62	3.07	11.40	1.93	14.2

$$\frac{\ell}{\rho} = \frac{12.5}{1.58} + \frac{11.0}{1.72} + \frac{14.2}{1.93}$$

$$= 7.95 + 6.40 + 7.35 = 21.70$$

COLUMN ALLOWABLE $= 156{,}000$ P.S.I.

$$f_c = \frac{220{,}264}{2.10} = 105{,}000 \text{ PSI}$$

$$MS = \frac{156{,}000}{105{,}000} - 1 = 0.49$$

INTERNAL PRESSURE $= \dfrac{220{,}264}{\pi\,(2.63)^2} = 10{,}100$ PSI.

WALL STRESS

ITEM ① $= \dfrac{10{,}100\,(2.235)}{.150} = 151{,}000$ PSI

ITEM ② $= \dfrac{10{,}100\,(2.48)}{.160} = 156{,}000$ PSI

ITEM ③ $= \dfrac{10{,}100\,(2.72)}{.180} = 153{,}000$ PSI

MS = ZERO.

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WATER IMPACT CONDITION.

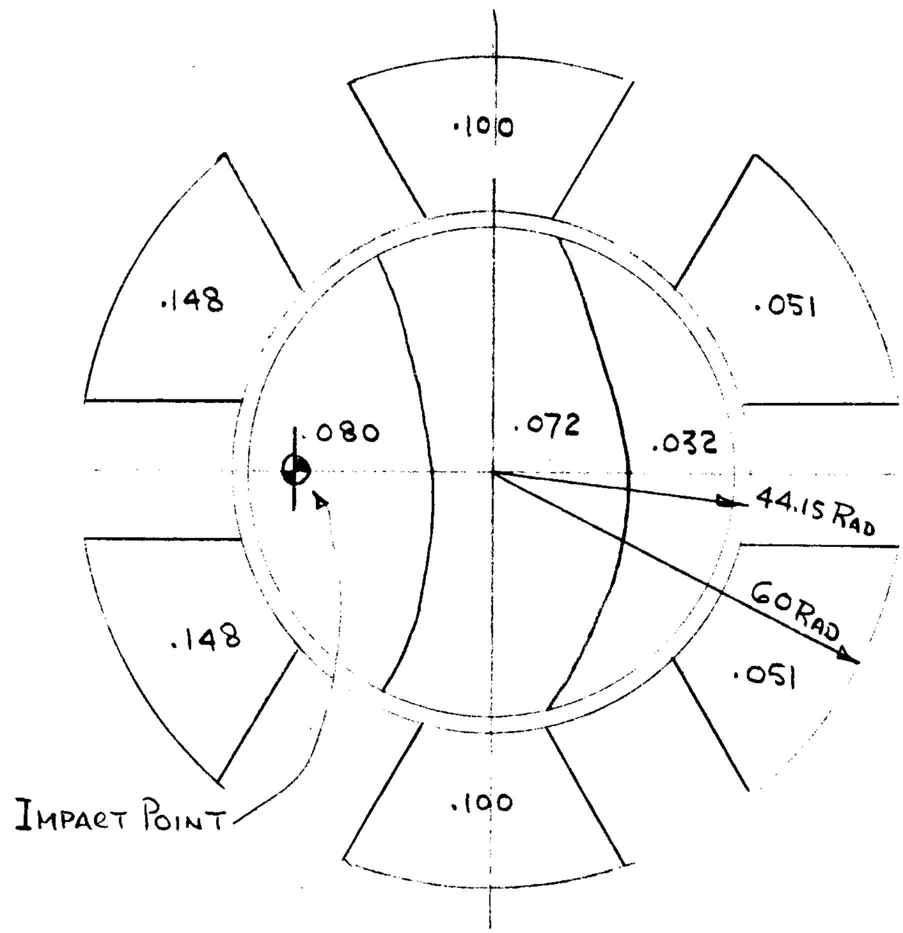
$W = 14{,}000$ LB $V = 30$ FT/SEC $\mu = .35$

FROM CRITERIA IMPACT FORCE = 21.5 g. FOR 30 FT/SEC.

LOAD INCREASE FACTOR = $\frac{21.5}{8.0}$ = 2.69.

REF PAGE 2.1 AND 2.3

AFT HEAT SHIELD SKIN THICKNESS.



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EFFECT OF INCREASING DESCENT VELOCITY TO 20 FT/SEC.

EFFECT OF INCREASING DESCENT VELOCITY TO 30 FT/SEC.

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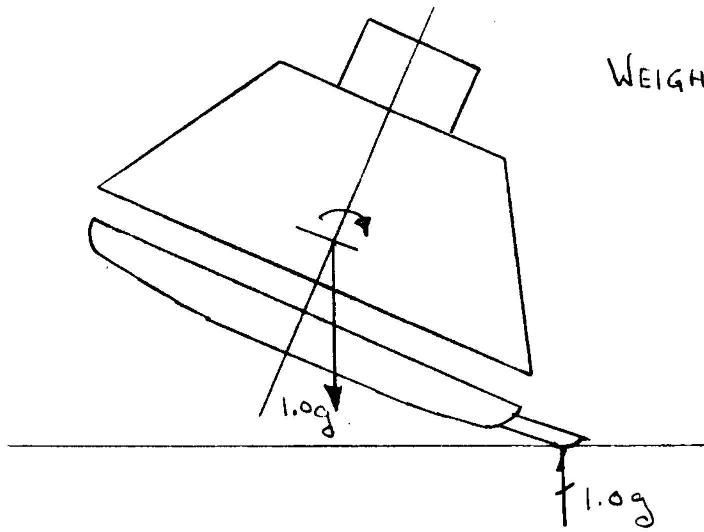
LOAD ON SKIDS

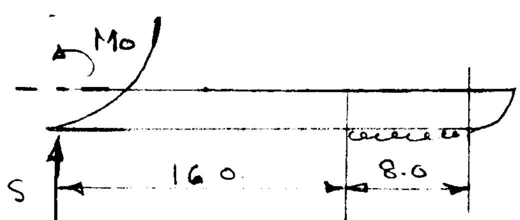
ASSUME MAXIMUM TUMBLING LOAD IS 1.0 g AT THE END OF THE SKID.



LIMIT LOAD = 14,000 LB
ULTIMATE = 14,000 (1.33) = 18,666 LB

THE ANALYSIS IS BASED ON THE FOLLOWING

1. THE LOAD IS ACTING ON TWO SKIDS
2. THE LOAD IS DISTRIBUTED OVER 8" OF SKID
3. THE SKID AS A LIMIT TO ULTIMATE FACTOR OF 1.0
4. THE HEAT SHIELD SUB-STRUCTURE AS A FACTOR OF 1.33.



$$M_o \text{ (ON STRUCTURE)} = \frac{20(18,666)}{2} = 186,660 \text{ LB INS}$$

$$S = 18,666/2 = 9,333 \text{ LB.}$$

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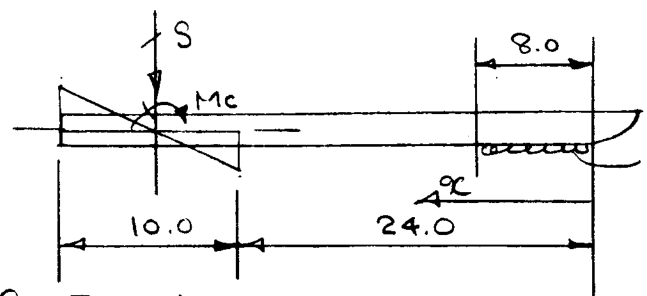
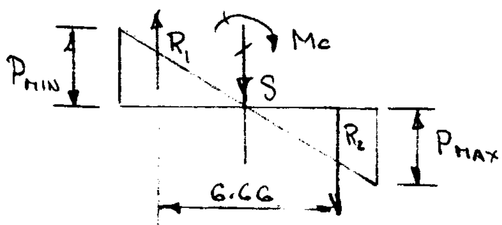
SKID BENDING



S = 7000 LB

$M_c = 7000\ (25) = 175{,}000$ LB INS



$\frac{175{,}000}{6.66} = 26{,}300$ LB.

$P_{MAX} = \frac{26{,}300}{(.5)\,5.0} + \frac{7000}{10} = 11{,}200$ LB

$P_{MIN} = \frac{26{,}300}{(.5)\,5.0} - \frac{7000}{10} = 9{,}800$ LB

MOMENT

$x = 4 \quad M = \frac{\omega x^2}{2} = \frac{875\,(4)^2}{2} = 7000$ LB INS

$x = 5.5 \quad M = \frac{875\,(5.5)^2}{2} = 13{,}250$ LB INS

$x = 8.0 \quad M = \frac{875\,(8)^2}{2} = 28{,}000$ LB INS.

$x = 24 \quad M = 7000\,(20) = 140{,}000$ LB INS

$x = 26.5 \quad M = 7000\,(22.5) - 21450\,(1.25) = 130{,}700$ LB INS

$x = 29 \quad M = 7000\,(25) - \frac{175{,}000}{2} - \frac{7000\,(2.5)}{10}$

$= 175{,}000 - 87{,}500 - 8750 = 78{,}750$ LB INS.

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SKID MOMENT OF RESISTANCE.

FOR t = .060

MR = 25,200 (.630) = 15,000 LB INS

FOR t = .080

MR = 44,600 (.820) = 36,600 LB INS

FOR t = .100

MR = 70,000 (1.001) = 70,070 LB INS

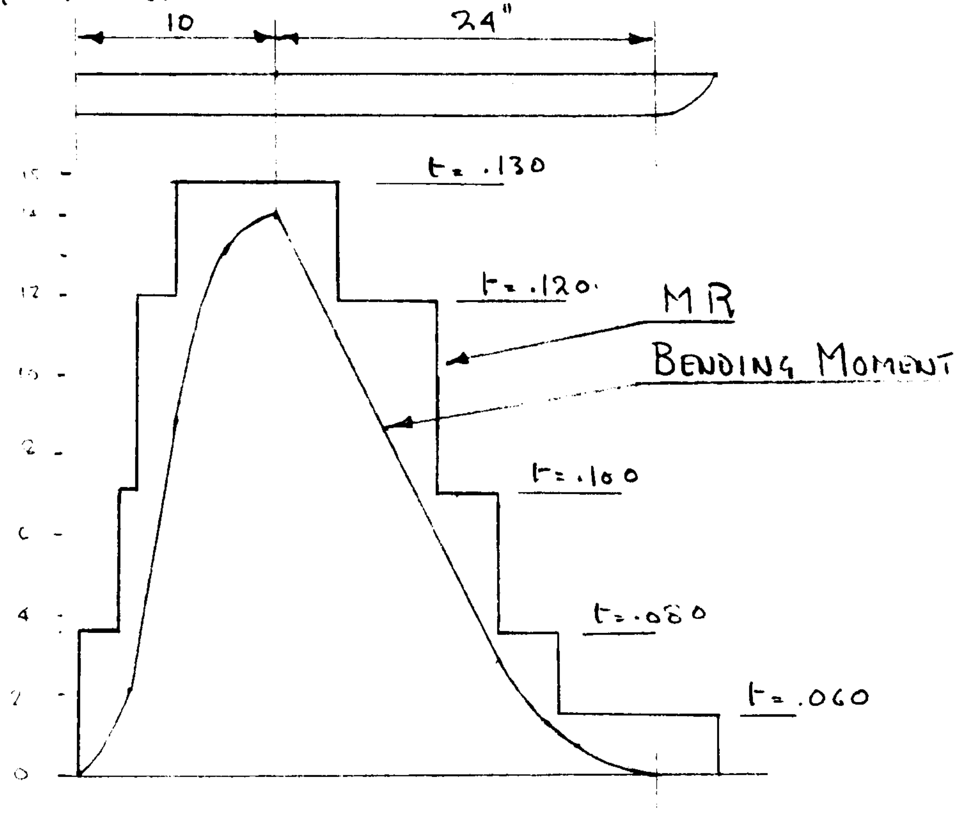
FOR t = .120

MR = 101,000 (1.170) = 118,170 LB INS.

FOR t = .130

MR = 118,000 (1.2525) = 149,000 LB INS.

REQUIRED SKID THICKNESS.



$$MS = \frac{36,600}{28,000} - 1 = 0.31$$

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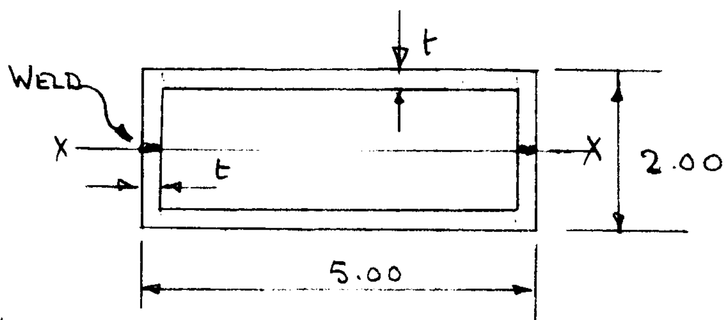
SKID SECTION PROPERTIES.



FOR $t = .06$

$I_{xx} = 4.88(.06)(.97)^2(2) + .120(2)^3/12 = 0.630$

FOR $t = .08$

$I_{xx} = 4.84(.08)(.96)^2(2) + .160(2)^3/12 = 0.820$

FOR $t = .100$

$I_{xx} = 4.80(.100)(.95)^2(2) + .200(2)^3/12 = 1.001$

FOR $t = .120$

$I_{xx} = 4.76(.120)(.94)^2(2) + .240(2)^3/12 = 1.170$

FOR $t = .130$

$I_{xx} = 4.74(.130)(.935)^2(2) + .260(2)^3/12 = 1.2525$

MATERIAL 14-8 PH STEEL

COMPRESSIVE BUCKLING ALLOWABLES AT 600°F.

t	σ_{CR}
0.060	25,200 PSI
0.080	44,600
0.100	70,000
0.120	101,000
0.130	118,000.

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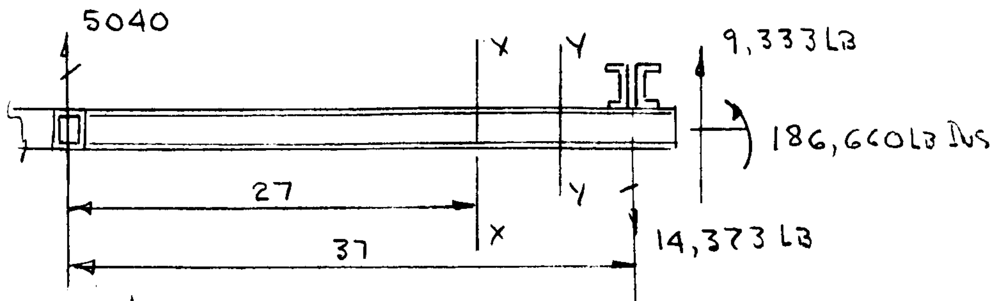
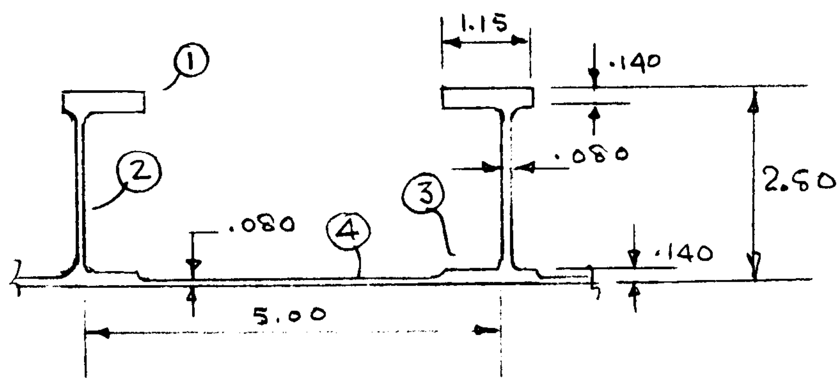
SKID HOUSING



BENDING AT XX

$M = 5040(27) = 136{,}080$ LB INS.

SECTION PROPERTIES (SECTION XX)



ITEM	AREA	Y_{XX}	AY_{XX}	Y_{NA}	AY_{NA}^2	I_o
1	.161	2.43	.392	1.430	.3300	.00026
2	.178	1.25	.222	.250	.0111	.07300
3	.161	.07	.011	.930	.1390	.00026
4	.128	.04	.005	.960	.1180	.00006
	.628		.630		.5981	.07358

$$Y_{NA} = \frac{.630}{.628} = 1.00$$

$$\begin{array}{r} .07358 \\ .5981 \\ \hline .67168 \end{array}$$

$$f_B = \frac{136{,}080\,(1.50)}{.67168\,(2)} = 152{,}000 \text{ PSI}$$

$$MS = \frac{156{,}000}{152{,}000} - 1 = 0.03$$

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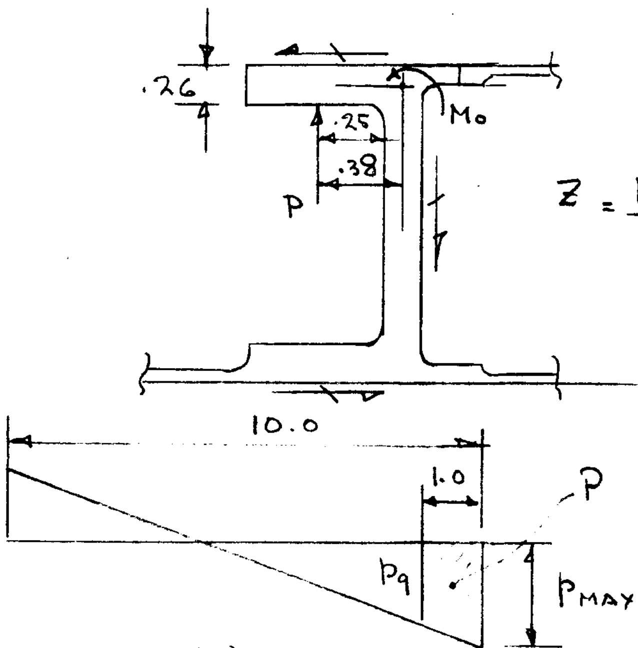
SKID HOUSING
SECTION YY FLANGE BENDING



$$Z = \frac{bd^2}{6} = \frac{.26^2}{6} = .01125$$

$P_{MAX} = 11,200$ LB (1.33)

$$P_q = \frac{10,500\,(4)}{5} + 700 = 9100 \text{ LB}$$

$$P = \frac{11,200 + 9100\,(1)}{2} = 10,150 \text{ LB.}$$

$$M_o = \frac{10,150\,(.38)}{2}\,(1.33) = 2560 \text{ LB INS}$$

$$f_B = \frac{2560}{.01125} = 228,000 \text{ PSI.}$$

ALLOWABLE AT 600°F WITH BENDING MODULUS = 230,000 P.S.I.

$$MS = \frac{230,000}{228,000} - 1 = 0.01.$$

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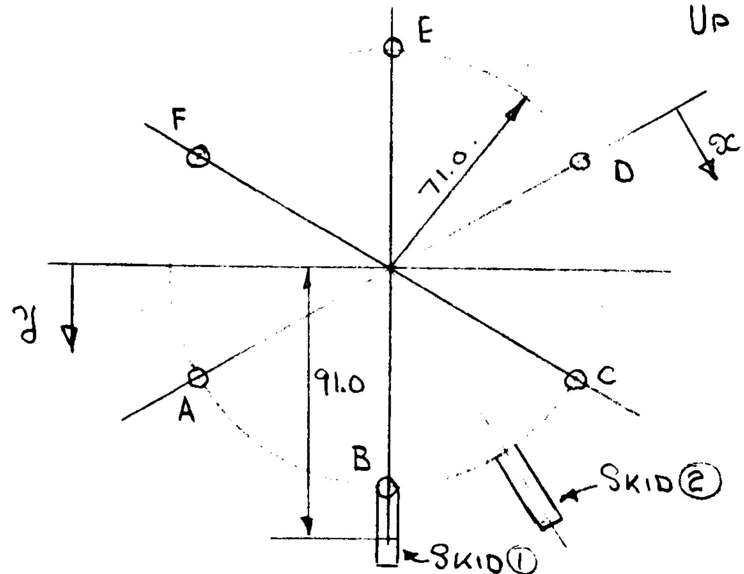
AFT HEAT SHIELD OUTER RING (71 RAD)
LOAD ON RING INDUCED BY SKIDS.

UP LOADS + VE



LOAD ON RING AT SKID ① = 9333 LB (REF PAGE 1.1)

TORQUE ABOUT CENTROID = 9333(91) = 849,000 LB INS

$\Sigma y^2 = 2[71^2 + 2(35.5)^2] = 15,122$

REACTIONS A AND C

$= -\dfrac{849,000(35.5)}{15,122} - \dfrac{9333}{6}$

$= -1990 - 1555 = -3545$ LB.

REACTION B $= -\dfrac{849,000(71)}{15,122} - \dfrac{9333}{6}$

$= -3970 - 1555 = -5525$ LB.

REACTIONS D AND F

$= 1990 - 1555 = 435$ LB.

REACTION E

$= 3970 - 1555 = 2415$ LB.

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LOAD AT SKID (2) - 9333 LB.

TORQUE ABOUT CENTROID = 9333(91) = 849,000 LB INS

$\Sigma x^2 = 4(61.5)^2 = 15150$

REACTIONS A AND D

$= -\frac{9333}{6} = -1555$ LB

REACTIONS B AND C

$= -\frac{849,000(61.5)}{15,150} - 1555$

$= -3440 - 1555 = -4995$ LB

REACTIONS F AND E

$= 3440 - 1555 = 1885$ LB.

TOTAL REACTIONS

A = -3545 - 1555 = -5100 LB
B = -5525 - 4995 = -10,520 LB
C = -3545 - 4995 = -8,540 LB
D = 435 - 1555 = -1120 LB
E = 2415 + 1885 = 4300 LB
F = 435 + 1885 = 2320 LB

CONSIDER RING CUT AT A AND DETERMINE STATIC MOMENT

MOMENT AT "B" = -2550(61.5) = -157,000 LB INS.

MOMENT AT SKID (2)

= -2550(71) - 10,520(35.5) + 9333(45.5)

= -181,000 - 373,000 + 424,000 = 130,000 LB INS

MOMENT AT C

= -2550(61.5) - 10,520(61.5) + 9333(78.5) + 9333(45.5)

= -157,000 - 648,000 + 732,000 + 424,000

= 351,000 LB INS.

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STATIC MOMENT ON AFT HEAT SHIELD RING (71" RAD.)

MOMENT AT D

$= -10{,}520\,(61.5) + 9333\,(78.5) + 9333\,(91) - 8540\,(61.5)$

$= -648{,}000 + 732{,}000 + 847{,}000 - 525{,}000$

$= 406{,}000$ LB INS.

MOMENT AT E

$= -2550\,(-61.5) + 9333\,(45.5) - 8540\,(61.5) - 1120\,(61.5)$

$= 157{,}000 + 425{,}000 - 525{,}000 - 68{,}500$

$= -11{,}500$ LB INS

MOMENT AT F

$= -2550\,(-61.5) - 10{,}520\,(-61.5) + 9333\,(-78.5)$

$+ 9333\,(-45.5) - 1120\,(61.5) + 4330\,(61.5)$

$= 157{,}000 + 648{,}000 - 732{,}000 - 425{,}000$

$- 68{,}500 + 264{,}000$

$= -156{,}500$ LB INS.

MOMENT AT A

$= -10{,}520\,(-61.5) + 9333\,(-78.5) + 9333\,(-91)$

$- 8540\,(-61.5) + 4300\,(61.5) + 2320\,(61.5)$

$= 648{,}000 - 732{,}000 - 849{,}500 + 525{,}000$

$+ 264{,}000 + 142{,}500$

$= 0.$

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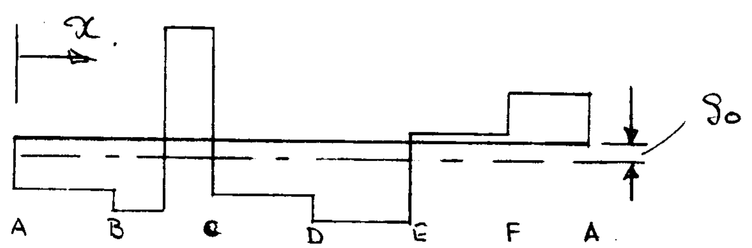
SHEAR ON AFT HEAT SHIELD RING (71 RAD)

A = ± 2550
B = − 2550 − 10,520 + 9333 = − 3,733
2 = − 3733 + 9333 = 5,600
C = 5600 − 8540 = − 2940
D = − 2940 − 1120 = − 4060
E = − 4060 + 4300 = 240
F = 240 + 2320 = 2560



SHEAR DIAGRAM

$$\int S\,dx = -2550x - 1866x + 2800x - 2940x - 4060x + 240x + 2550x$$
$$= -6366x$$

$$S_o = \int S\,dx / x = -1061 \text{ LB}$$

MOMENT DUE TO REDUNDANT SHEAR (m_o)

AT A AND D = 0

AT B AND C = −1061 (61.5) = +65200 LB INS
AT SKID 2 = −1061 (71) = +75,300 LB INS.
AT E AND F = −1061 (−61.5) = −65,200

$$\int m_o\,dx = -75,300(1.5x) + 75,300(1.5x)$$
$$= 0.$$

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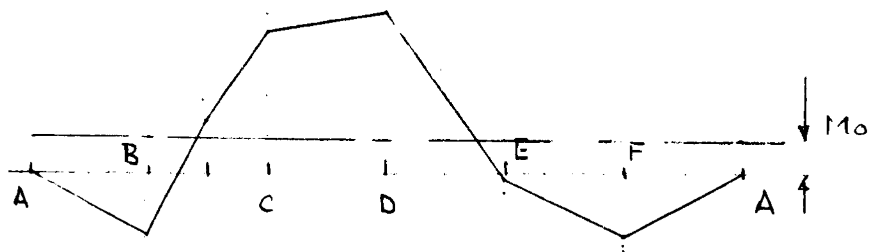
REDUNDANT MOMENT ON AFT HEAT SHIELD RING (71 RAD)



$$\int M_s\,dx = -157{,}000(.5x) + 130{,}000(.5x) + 221{,}000(.25x) + 351{,}000(x) + 55000(.5x) + 406{,}000(.5x) - 156{,}500(x) = 466{,}750x$$

$$M_o = 466{,}750/6 = 77{,}790 \text{ LB INS}$$

$$\int M_s\,dx + \int M_o\,dx + \int m_o\,dx = 0.$$

TOTAL MOMENT

A =	0	−77,790	+ 0	−77,790 LB INS
B =	−157,000	−77,790	+65,200	= −169,590
2 =	130,000	−77,790	+75,300	= 127,510
C =	351,000	−77,790	+65,200	= 338,410
D =	406,000	−77,790	+ 0	= 328,210
E =	−11,500	−77,790	−65,200	= −154,490
F =	−156,500	−77,790	−65,200	= −299,490

TORQUE ON RING

ASSUMING SKID HOUSING REACTS, THE TORQUE AND THE RING ARE FREE TO TWIST BETWEEN HOUSINGS

THEN MAX TORQUE = 14,373 (9.5)
= 136,000 LB INS.

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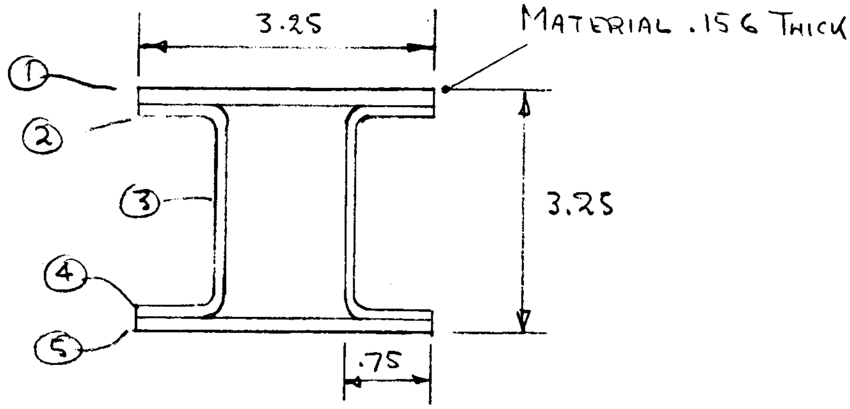
AFT HEAT SHIELD RING (71 RAD)

SECTION PROPERTIES



ITEM	AREA	Y_{NA}	$A\,Y_{NA}^2$	I_o
1	.506	1.547	1.210	.00103
2	.234	1.391	.453	.00057
3	.740	0	0	.47
4	.234	1.391	.453	.00057
5	.506	1.547	1.210	.00103
			3.326	.47320

$$
\begin{array}{r} .47320 \\ \underline{3.326} \\ 3.79920 \end{array}
$$

STRESS IN RING DUE TO BENDING.

$$f = \frac{338,410\,(1.625)}{3.7992} = 145,000 \text{ P.S.I.}$$

ALLOWABLE STRESS AT 600° F = 156,000 PSI

$$MS = \frac{156,000}{145,000} - 1 = 0.08.$$

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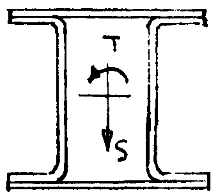
AFT HEAT SHIELD RING (71 RAD)

SHEAR STRESS



TORQUE = 136,000 LB
SHEAR = 5,600 LB

$$q = \frac{T}{2A} = \frac{136,000}{2(1.75)(3.1)} = 12,500 \text{ LB/IN.}$$

$$f_s = \frac{12,500}{.156} = 80,000 \text{ P.S.I}$$

DIRECT SHEAR

$$q = \frac{VQ}{I} = \frac{5600(1.351)}{3.799} = 2000 \text{ LB/IN.}$$

$$f_s = \frac{2000}{.156} = 12,800 \text{ PSI}$$

TOTAL SHEAR STRESS = 80,000 + 12,800 = 92,800 PSI.

ALLOWABLE SHEAR STRESS AT 600°F = 105,000 P.S.I.

$$MS = \frac{105,000}{92,800} - 1 = 0.13$$

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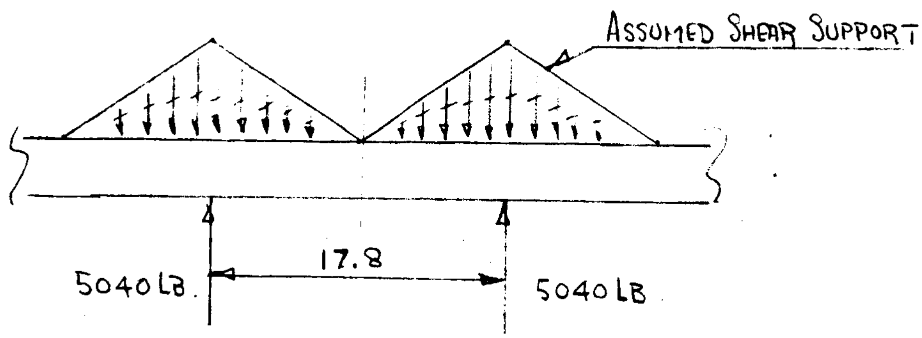
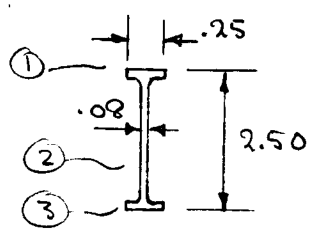
AFT HEAT SHIELD INNER RING (34" RAD)



MAX SUPPORTING SHEAR $= \frac{5040}{12.8(.5)} = 567$ LB/IN.

RING BENDING $= \frac{W\ell}{6} = \frac{5040(17.8)}{6} = 14950$ LB INS.

SECTION PROPERTIES.



ITEM	AREA	Y_{NA}	AY_{NA}^2	I_o
①	.0136	1.21	.0199	.00007
②	.2000	0	0	.1040
③	.0136	1.21	.0199	.00007
	.2272		.0398	.10414
				.0398
				.14394

$$f_B = \frac{14,950(1.25)}{.14394} = 130,000 \text{ PSI}$$

$$MS = \frac{156,000}{130,000} - 1 = 0.20$$

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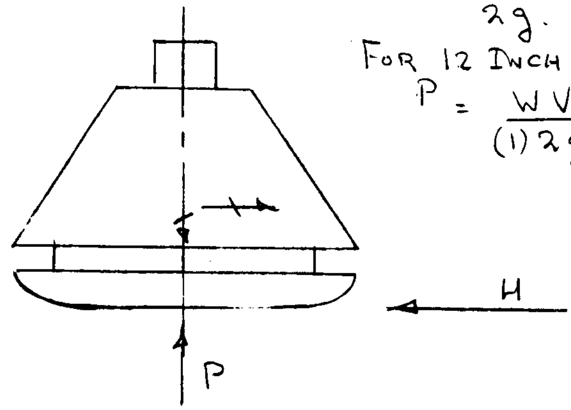
GROUND IMPACT CONDITION (VERTICAL)

$$KE = \frac{W V^2}{2g}$$

FOR 12 INCH STRUT TRAVEL

$$P = \frac{W V^2}{(1) 2g}$$



IMPACT LOAD

$$P = \frac{14{,}000 (15)^2 (1.33)}{2 \ (32.2)} = 65{,}000 \text{ LB ULT.}$$

$$H = .35 V = .35 (65{,}000) = 22{,}750 \text{ LB}$$

ASSUME GROUND CONTACT = 34" RAD.

AREA $\pi (34)^2 = 3640 \text{ INS}^2$

PRESSURE ON AFT H/S $= 65000/3640 = 17.90$ P.S.I.

MIN SKIN THICKNESS = .022

HOOP STRESS IN CENTER PANEL $= \frac{PR}{2t}$

$$= \frac{17.90 (175)}{2(2)(.022)} = 35{,}500 \text{ PSI}$$

HIGH MARGIN.

CORE SHEAR STRESS AT 34" RAD

$$f_s = \frac{65{,}000}{34(2)\pi(2.5)} = 122 \text{ P.S.I.}$$

HIGH MARGIN.

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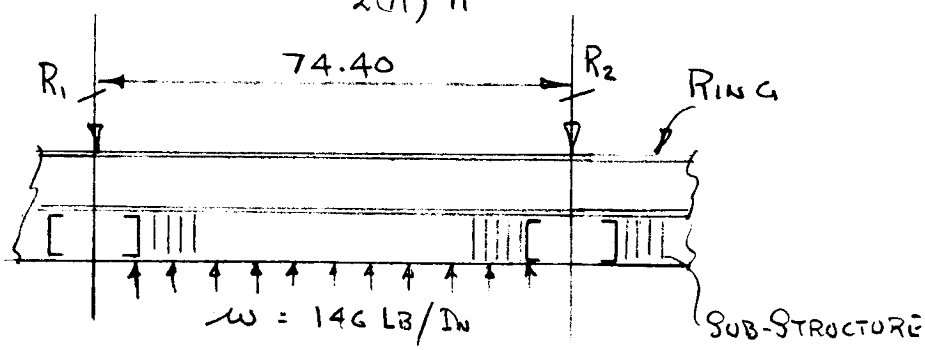
GROUND IMPACT CONDITION (VERTICAL)

BENDING ON AFT HEAT SHIELD RING AT 71" RAD.

SHEAR AT 71" RAD $= \dfrac{65000}{2(\pi)71} = 146$ LB/IN.



$R_1 = R_2 = 74.4(146) = 10800$ LB

$M = \dfrac{w\ell^2}{12} = \dfrac{146(74.4)^2}{12} = 67,300$ LB INS.

$f_B = \dfrac{67,300}{3.7992}(1.625) = 28,806$ P.S.I

HIGH MARGIN.

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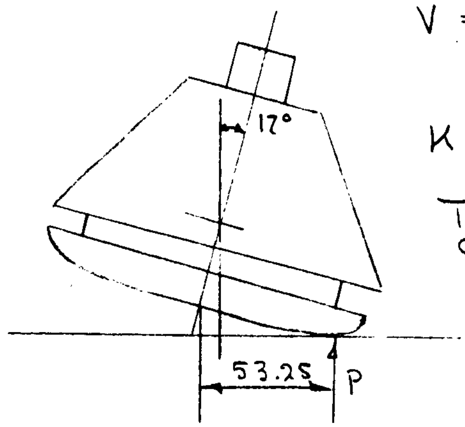
GROUND IMPACT CONDITION (17°)



RESULTANT VERTICAL VELOCITY

$V = 15 \cos 5° + 80 \sin 5°$

$= 15(.99756) + 80(.08716)$

$= 21.936$ FT / SEC.

$KE = \dfrac{mV^2}{2}$

THEN FOR 12 SHOCK STRUT STROKE

$P = \dfrac{WV^2}{2(32.2)(1)}$.

$$P = \frac{14{,}000(21.936)^2(1.33)}{2(32.2)} = 139{,}000 \text{ LB.}$$

DISTRIBUTING THIS LOAD TO THE OUTER RING AT 71" RAD. EXPRESSED IN LB / IN.

$$\text{MEAN LOAD} = \frac{139{,}000}{71(2)(\pi)} = 312 \text{ LB./IN}$$

$$\text{MAX LOAD} = \frac{312(71+53.25)}{71} = 546 \text{ LB / IN}$$

$$\text{MIN LOAD} = \frac{312(71-53.25)}{71} = 74.6 \text{ LB / IN}$$

RATE OF CHANGE OF LOAD PER DEGREE

$$= \frac{546-74.6}{180} = 2.62 \text{ LB / IN.}$$

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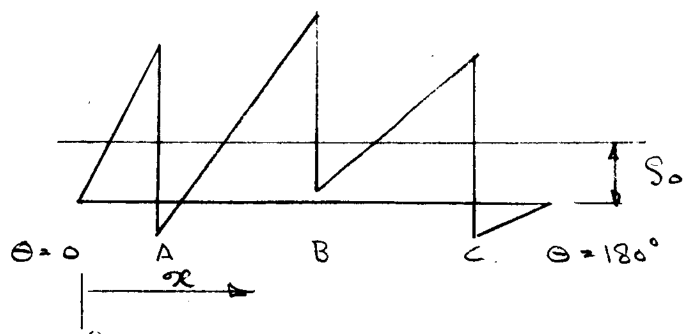
GROUND IMPACT CONDITION (17°)
SHEAR ON AFT HEAT SHIELD RING AT 71" RAD

A = 18,800 AND −4,366 LB
B = 24,734 AND 1568 LB
C = 18,918 AND −4248 LB



$$\int S\,dx = 9400(.5x) + 12,367(x) + 9,459(x) - 2124(.5x) = 25,464x$$

$$S_o = \int S\,dx/x = 8,488 \text{ LB.}$$

MOMENT DUE TO REDUNDANT SHEAR (m_s)

AT $\Theta = 0$ = 0

AT A = −8488(35.5) = −301,000

AT B = −8488(71) = −602,000

AT C = −8488(35.5) = −301,000

AT $\Theta = 180°$ = 0

$$\int m_s\,dx = -150,500(.5x) - 451,500(2x) - 150,500(.5x) = -1,053,500x.$$

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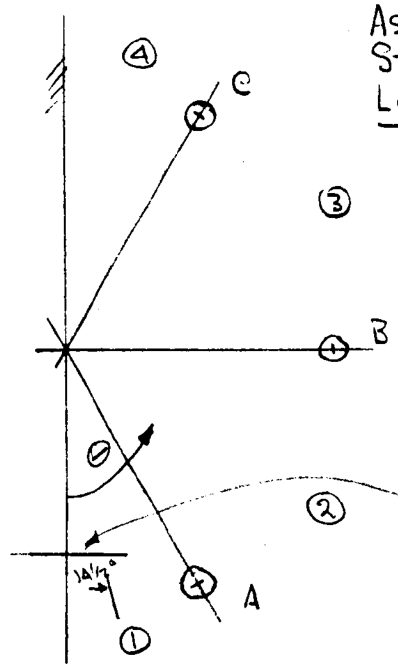
GROUND IMPACT CONDITION (17°)
AFT HEAT SHEILD RING AT 71" RAD.



ASSUME ALL SHOCK STRUTS ARE STROKING AND SUPPORT EQUAL LOADS

THEN:- LOADS ON STRUTS A, B AND C

$$= \frac{139{,}000}{6}$$

$= -23{,}166$ LB.

UP LOADS ARE +VE.

LOAD ON BAY ①

546 — 467.4 LB/IN — 37.2 $= 18{,}800$ LB

LOAD ON BAY ②

467.4 — 312 LB/IN — 74.4 $= 29{,}100$ LB

LOAD ON BAY ③

312 — 154 LB/IN $= 17{,}350$ LB

LOAD ON BAY ④

154 — 74.6 LB/IN $= 4250$ LB

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GROUND IMPACT CONDITION (17°)

STATIC MOMENT ON AFT HEAT SHIELD RING AT 71" RAD.

MOMENT AT A

$= 18,800(.267)71 = 357,000$ LB INS.

MOMENT AT B

$= 18,800(.968)71 - 23,166(61.5) + 29,100(.5299)71$

$= 1,291,000 - 1,422,000 + 1091,000$

$= 960,000$ LB INS

MOMENT AT C

$= 18,800(.709)71 - 1,422,000 + 29,100(.999)71$
$\quad - 1,422,000 + 17,350(.616)71$

$= 949,000 - 1,422,000 + 2,060,000 - 1,422,000$
$\quad + 759,000$

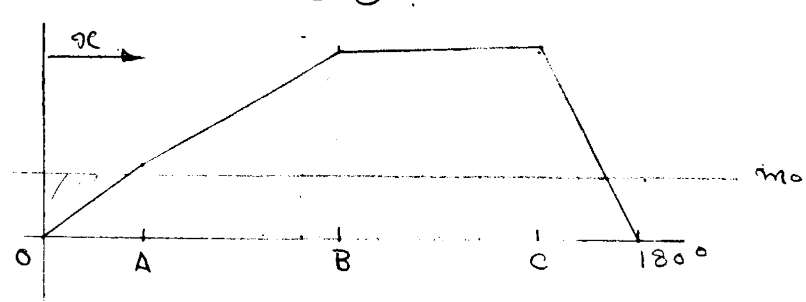
$= 924,000$ LB INS

MOMENT AT $\theta = 180$

$= 18,800(.242)71 - 23,166(35.5) + 29,100(.848)71$
$- 23,166(71) + 17350(.927)71 - 23,166(35.5)$
$+ 4250(20.8)$

$= 322,000 - 821,000 + 1,736,000 - 1,642,000$
$+ 1,139,000 - 821,000 + 87,000$

$= 0.$



$$\int M_s\, dx = 178,500(.5x) + 658,500(x) + 942,000(x) + 462,000(.5x) = 1,920,750x.$$

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GROUND IMPACT CONDITION (17°)

TOTAL MOMENT ON AFT HEAT SHIELD RING AT 71" RAD.

$$\int M_s\,dx + \int m_s\,dx + \int m_o\,dx = 0$$

$$m_o = \int M_s\,dx + \int m_s\,dx \Big/ x$$

$$= 1{,}920{,}750x - 1053{,}500x \big/ 3x$$

$$= 289{,}080 \text{ LB INS.}$$

LOCATION	M_s	m_s	m_o	TOTAL
$\Theta = 0$	0	0	-289,080	-289,080
$\Theta = 30°$ A	357,000	-301,000	-289,080	-233,080
$\Theta = 90°$ B	960,000	-602,000	-289,080	68,920
$\Theta = 150°$ C	924,000	-301,000	-289,080	333,920
$\Theta = 180°$	0	0	-289,080	-289080

STRESS DUE TO BENDING

$$f_B = \frac{333{,}920\ (1.625)}{3.7992} = 143{,}500 \text{ P.S.I}$$

ALLOWABLE STRESS AT 600°F = 156,000 PSI

$$MS = \frac{156{,}000}{143{,}500} - 1 = 0.09$$

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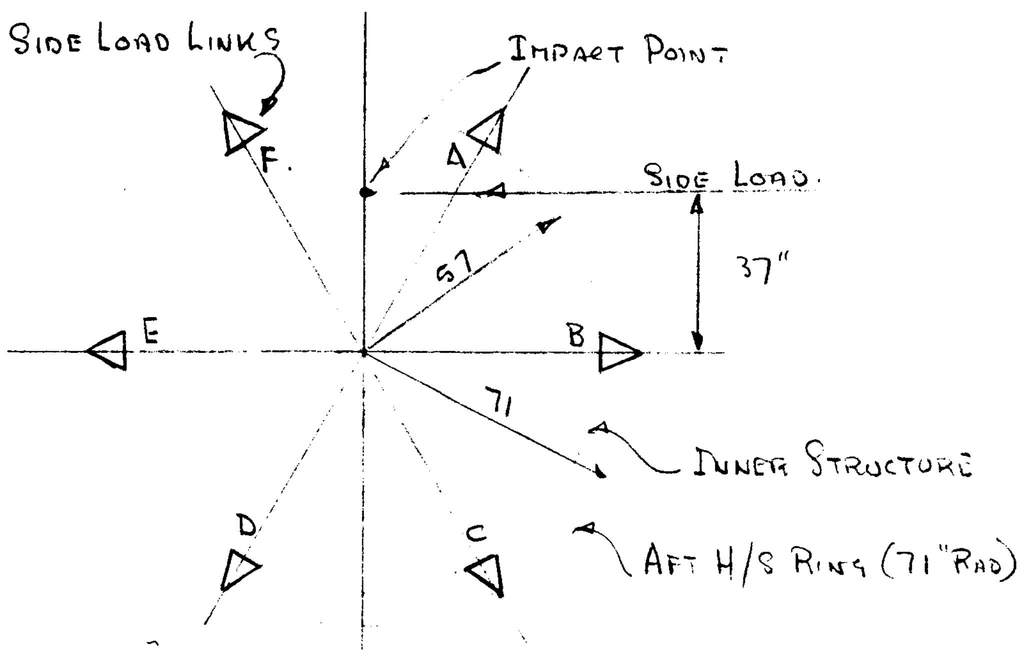
GROUND IMPACT CONDITION 17° (WITH 12° YAW)

EFFECT OF SIDE LOAD

LOAD = .35 (139,000) = 48,700 LB (REF PG 2.3)



TORQUE = 37 (48,700) = $1.8 (10)^6$ LB INS

LOAD PER LINK DUE TO TORQUE $= \frac{1.8 (10)^6}{71 (6)} = 4220$ LB

DIRECT LOAD PER LINK $= \frac{48,700}{6} =$ 8,116 LB.

LOAD ON LINKS A AND F

= 8,116 (.866) + 4220

= 7030 + 4220 = 11,250 LB.

LOAD ON LINKS E AND B

= 0 + 4220 = 4220 LB.

LOAD ON LINKS C AND D

= 7030 − 4220 = 2810 LB.

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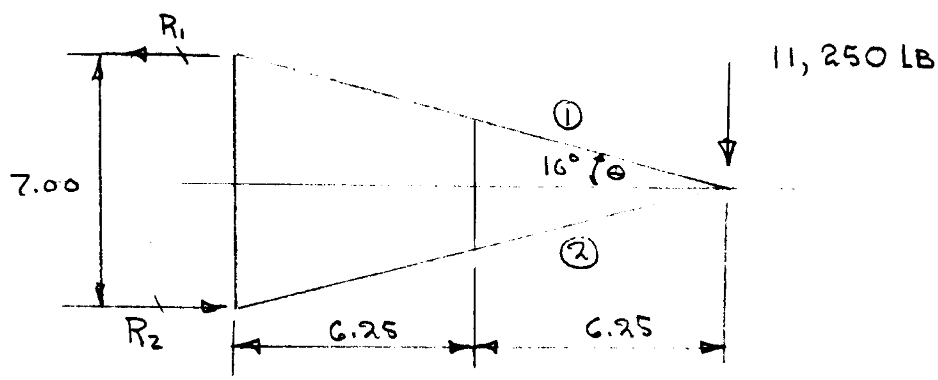
GROUND IMPACT CONDITION 17° (WITH 12° YAW)

SIDE LOAD ON LINKS.

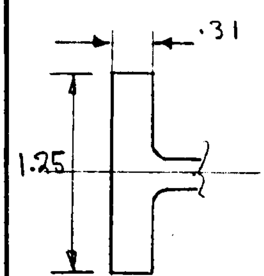


$R_1 = R_2 = 11{,}250\,(12.5)/7 = 20{,}100$ LB.

LOADS IN LINK ① AND ②

$= \dfrac{R}{\cos\theta} = \dfrac{20{,}100}{.961} = 20{,}950$ LB.

LINK SECTION (LOWER)



$A = .31(1.25) = .388$ INS^2

$f_c = \dfrac{20{,}950}{.388} = 54{,}500$ P.S.I.

MATERIAL 7075-T6

COMPRESSIVE ALLOWABLE AT 200° F = 60,000 PSI

$MS = \dfrac{60\,000}{54{,}600} - 1 = 0.10$.

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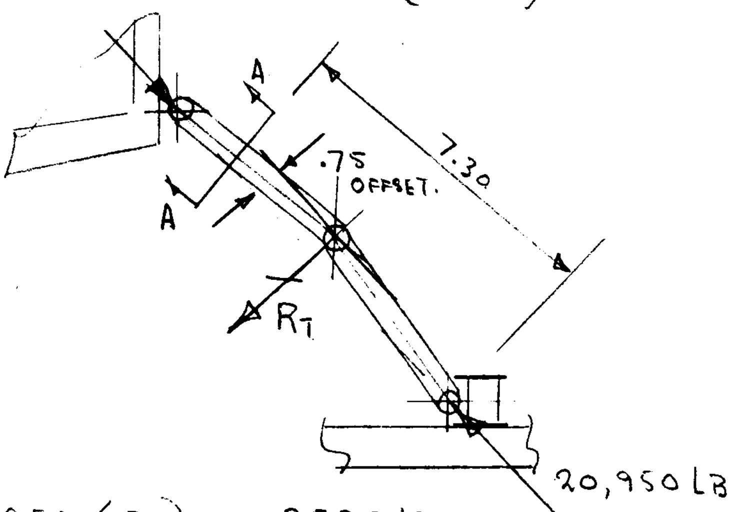
GROUND IMPACT CONDITION 17° (WITH 12° YAW)

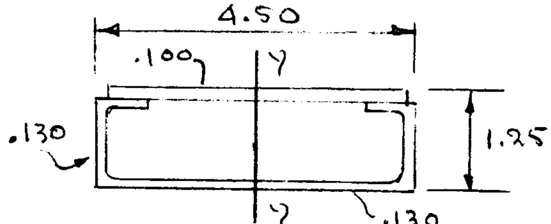
TORQUE ON SIDE LOAD LINKS (UPPER)



$R_T = \frac{20,950}{6.25}(.75) = 2520 \text{ LB}$

TORQUE $= 2520\,(3.5) = 8810$ LB INS.

SECTION A A



$I_{YY} = 3.295$

$q = \frac{T}{2A} = \frac{8810}{2(4.5)(1.25)} = 784$ LB / IN.

$f_s = \frac{784}{.10} = 7840$ P.S.I

BENDING ON SECTION $= 11,250\,(7.30) = 82,200$ LB INS

$f_B = \frac{82,200\,(2.25)}{3.295} = 56,100$ P.S.I.

COMPRESSIVE ALLOWABLE AT 200°F = 60,000 P.S.I.

$MS = \frac{60,000}{56,100} - 1 = 0.07$.

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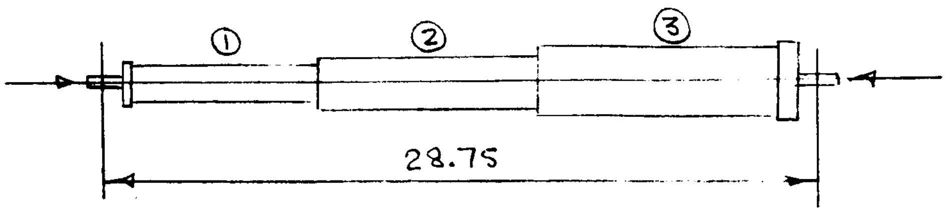
SHOCK STRUT

LOAD = 31,000 (1.32) = 41,000 LB (ULT.)

BASED ON THE DYNAMIC ANALYSIS FOR A 10,600 LB VEHICLE INCREASED IN THE RATIO OF 10,600 TO 14,000 LB.



ITEM	THICKNESS	DIAM	AREA	I	ρ	LENGTH
①	.100	1.50	.439	.108	.496	9.5
②	.080	2.00	.481	.223	.683	8.4
③	.080	2.50	.608	.446	.857	10.8

$$\frac{\ell}{\rho} = \frac{9.5}{.496} + \frac{8.4}{.683} + \frac{10.8}{.857} = 44.$$

180,000 H.T. STEEL AT 600°F.

COLUMN ALLOWABLE 95,500 P.S.I

$$f_c = \frac{41,000}{.439} = 93,500$$

$$MS = \frac{95,500}{93,500} - 1 = 0.02$$

WORKING PRESSURE

PISTON AREA $= (1.17)^2 \pi = 4.30$ INS^2

PRESSURE $= \frac{41,000}{4.30} = 9550$ P.S.I. (ULT)

$$f_T = \frac{PR}{t} = \frac{9550\,(1.17)}{.080} = 140,000 \text{ P.S.I}$$

$$MS = \frac{156,000}{140,000} - 1 = 0.11$$

NOTE: —

LIMIT STRUT LOAD $= 41,000 / 1.33 = 30,756$ LB.

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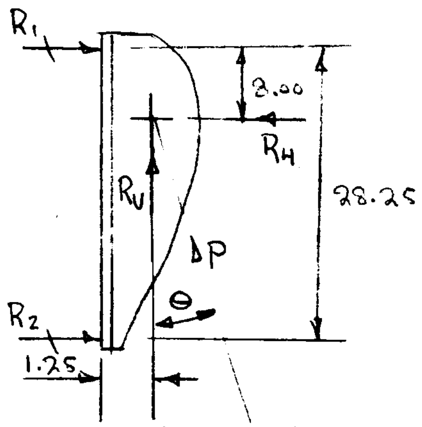
SIDEWALL FITTING – SHOCK STRUT TO INNER STRUCTURE ATTACHMENT.



$\theta = 28°$
SIN = .46947
COS = .88295

P = 41,000 LB.

$R_H = .46947(41{,}000) = 19{,}200$ LB
$R_V = .88295(41{,}000) = 36{,}100$ LB

$$R_2 = \frac{8(19{,}200) - 1.25(36{,}100)}{28.25} = 3860 \text{ LB}$$

$R_1 = 19{,}200 - 3860 = 15{,}340$ LB

LOAD ON BOND (FITTING TO SIDEWALL)

$$q = \frac{36{,}100}{29} = 1245 \text{ LB/IN (AVERAGE)}$$

ASSUME TRIANGULAR SHEAR DISTRIBUTION.

$q_{MAX} = 2(1245) = 2490$ LB/IN

BASE OF FITTING IS 4.00 INCHES WIDE

$$\text{BOND STRESS} = \frac{2490}{4} = 622 \text{ P.S.I.}$$

BOND ALLOWABLE AT 200°F = 1320 PSI

$$MS = \frac{1320}{622} - 1 = 1.12$$

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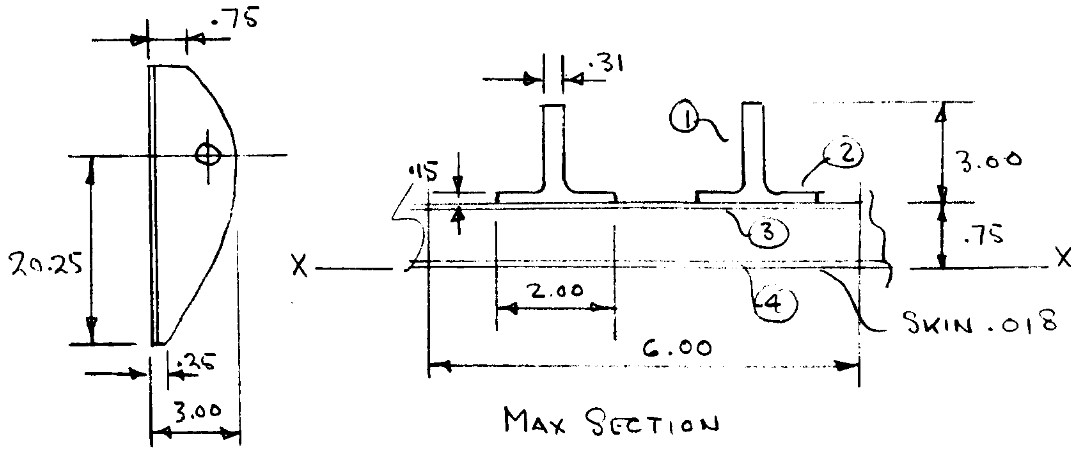
SIDEWALL FITTING – SECTION PROPERTIES



MAX SECTION

ITEM	AREA	Y_{XX}	$A\,Y_{XX}$	Y_{NA}	$A\,Y_{NA}^2$	I_o
①	1.770	2.325	4.115	.515	.470	1.199
②	.600	.825	.494	.985	.582	.001
③	.108	.741	.080	1.069	.124	
④	.108	.009	.001	1.801	.350	
	2.586		4.690		1.526	1.200
						1.526
						2.726

$$Y_{NA} = \frac{4.690}{2.586} = 1.810$$

$M = (20.25)\,3860 = 78{,}100$ LB INS

END LOAD $= \dfrac{36{,}100}{2} = 18{,}050$ LB

$$f_T = \frac{78{,}100\,(1.810)}{2.726} + \frac{18{,}050}{2.586}$$

$$51{,}800 + 7000 = 58{,}800 \text{ P.S.I}$$

INNER STRUCTURE INNER SKIN ALLOWABLE = 60,000 PSI

$$MS = \frac{60{,}000}{58{,}800} - 1 = 0.02$$

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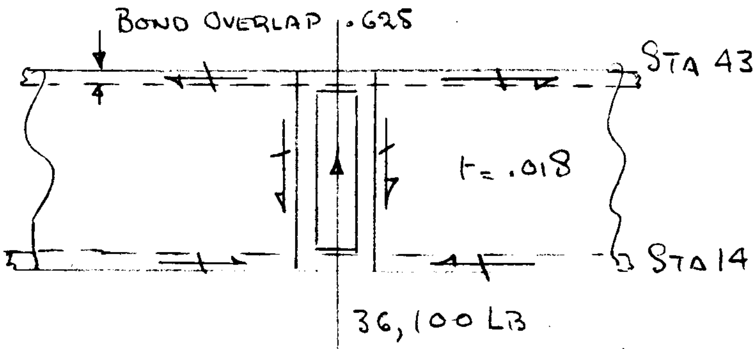
COMMAND MODULE INNER STRUCTURE AFT SIDEWALL SKIN

SKIN SHEAR.



$$q = \frac{36,100\,(2)}{29\,(2)} = 1245 \text{ LB/IN (TOTAL FOR TWO SKINS)}$$

$$f = \frac{1245}{(2)\,.018} = 34,600 \text{ P.S.I.}$$

SHEAR ALLOWABLE OF HONEYCOMB PANEL = 38,000 P.S.I.

$$MS = \frac{38,000}{34,600} - 1 = 0.10$$

BOND STRESS AT STA 43.

$$f_B = \frac{1245}{(4)\,.625} = 499 \text{ PSI}$$

BOND ALLOWABLE AT 200°F = 1320 P.S.I.

$$MS = \frac{1320}{499} - 1 = 1.64$$

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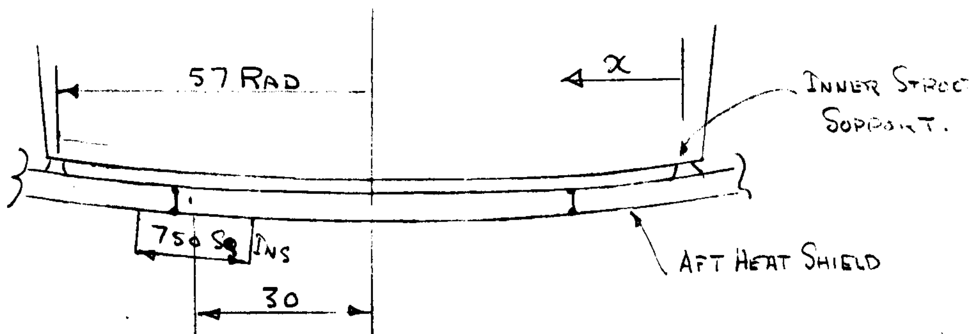
WATER IMPACT CONDITION.

NOTE:- FOR THIS CONDITION THE AFT HEAT SHIELD IS CONSIDERED IN THE CLOSED POSITION, WHICH IS MORE CONSERVATIVE. WITH THE AFT HEAT SHIELD DEPLOYED THE LOAD WOULD BE ABSORBED BY THE SHOCK ABSORBERS.



PRESSURE ON 630 SQ INS = 178 PSI (REF PAGE 2.1-6 LEG CONCEPT)

LINE LOAD AT 57" RAD (INNER STRUCTURE SUPPORT)

MEAN LOAD $= \dfrac{178\ (630)}{\pi\ (114)} = 313$ LB/IN.

MAX LOAD $= \dfrac{313\,(87)}{57} = 478$ LB/IN

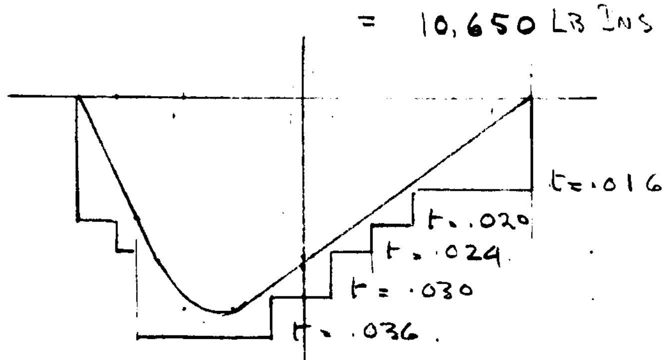
MIN LOAD $= \dfrac{313\,(27)}{57} = 147.5$ LB/IN.

BENDING AT CENTER OF H/S $= 147.5\,(57) = 8450$ LB INS

BENDING $x = 72.86 \quad = 147.5\,(72.86) = 10750$ LB INS

BENDING $x = 87 \quad = 147.5\,(87) - (478 + 147.5)\,\dfrac{7.07}{2}$

$= 10,650$ LB INS



BM DIAGRAM (ALONG ℄ OF H/S)

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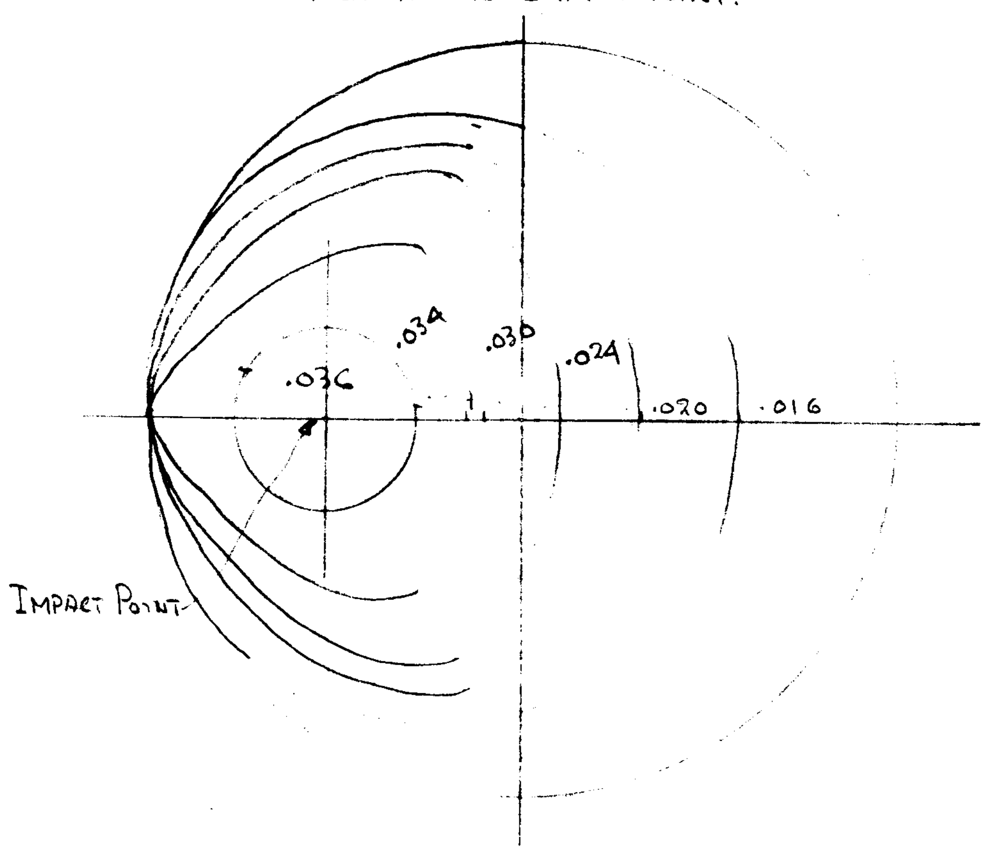
WATER IMPACT CONDITION
AFT HEAT SHIELD SKIN THICKNESS

THICKNESS	ALLOWABLE STRESS	MOMENT OF RESISTANCE
.016	120,000 PSI	4800 LB INS
.020	125,000	6250
.024	130,000	7800
.030	135,000	10,100
.034	135,000	11,400
.036	135,000	12,200

MOMENT OF RESISTANCE = ALLOWABLE × Z. $Z = \frac{I}{y}$.

SKIN PROFILE RELATIVE TO IMPACT POINT.



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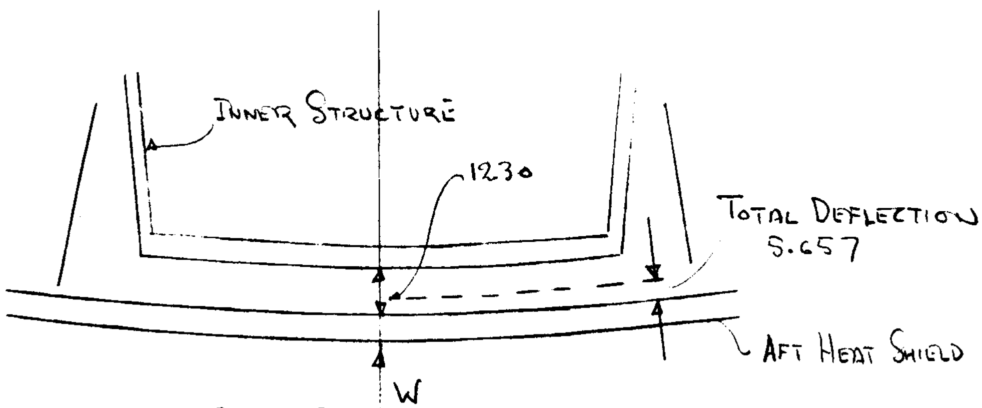
DEFLECTIONS
VERTICAL GROUND CONTACT CONDITION.



CONSIDER 4 INCH SHOCK STRUT TRAVEL.

$$W = \frac{14000\,(15)^2(12)}{2(32.2)(4)} = 146{,}500 \text{ LB.}$$

DEFLECTION OF AFT HEAT SHIELD CENTER (34" RAD) $= \dfrac{96\,W R^2}{144\pi E t^3} = \delta_C$

EQUIV. $t^3 = 24(1.25)^2 t = 37.5(.030) = 1.125$

$$\delta_c = \frac{96\,(146{,}500)(34)^2}{144\pi(25)(10)^6(1.125)} = 1.27 \text{ INS.}$$

DEFLECTION OF HOUSING $= \dfrac{W\ell^3}{48EI} = \delta_H$

$$\delta_H = \frac{146{,}000\,(37)^3}{12(48)\,25(10)^6(1.34336)} = .383 \text{ INS}$$

TOTAL DEFLECTION $= 4.00 + .383 + 1.27 = 5.657$ INS.

FOR THIS CONDITION THE AFT HEAT SHIELD WILL NOT CONTACT THE INNER STRUCTURE. WATER IMPACT WITH H/S DEPLOYED GIVES A SMALLER DEFLECTION.

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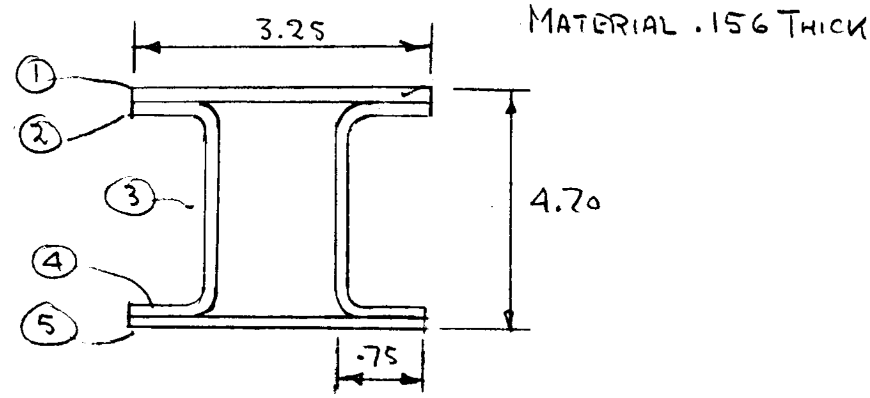
W = 14,000 LB V = 20 FT/SEC μ = .35

AFT HEAT SHIELD RING AT 71" RAD.

GROUND IMPACT CONDITION (17°) REF PAGE 2.7

MAXIMUM BENDING = (1.78) 333,920 = 603,000 LB INS.

RING SECTION (REF PAGE 1.12)



ITEM	AREA	Y_{NA}	$A\,Y_{NA}^2$	I_o
1	.506	2.272	2.605	.001
2	.234	2.116	1.048	.0006
3	1.100	0	0	1.76
4	.234	2.116	1.048	.0006
5	.506	2.272	2.605	.001
			7.306	1.7632

7.306

9.0692

$$f_B = \frac{603,000\,(2.35)}{9.0692} = 156,000$$

$$MS = \frac{156,000}{156,000} - 1 = \text{ZERO.}$$

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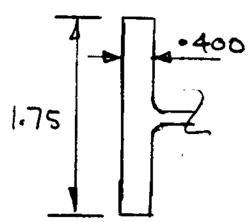
$W = 14{,}000$ LB $V = 20$ FT/SEC $\mu = .35$

GROUND IMPACT CONDITION 17° (WITH 12° YAW)

SIDE LOAD ON LINKS

LOWER LINK (REF PAGE 2.9)

LOAD ON LINK $= 20{,}950(1.78) = 37{,}400$ LB



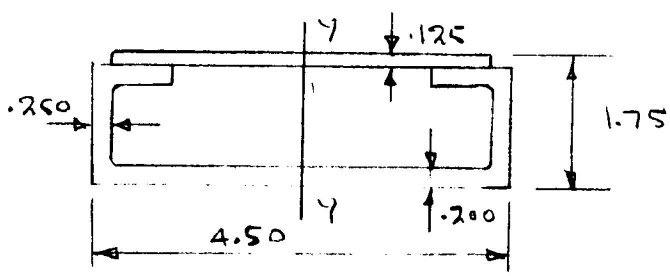
$A = .40(1.75) = .700$ INS^2

$f_c = \dfrac{37{,}400}{.700} = 53{,}400$ P.S.I

$MS = \dfrac{60{,}000}{53{,}400} - 1 = 0.12$.

UPPER LINK (REF PAGE 2.10)

BENDING ON SECTION $= 82{,}200(1.78) = 146{,}000$ LB INS



$I_{yy} = .325(4.5)^3/12 + 1.425(.50)(2.125)^2 = 5.69$ INS^4.

$f_B = \dfrac{146{,}000(2.25)}{5.69} = 57{,}700$ P.S.I.

$MS = \dfrac{60{,}000}{57{,}700} - 1 = 0.04$.

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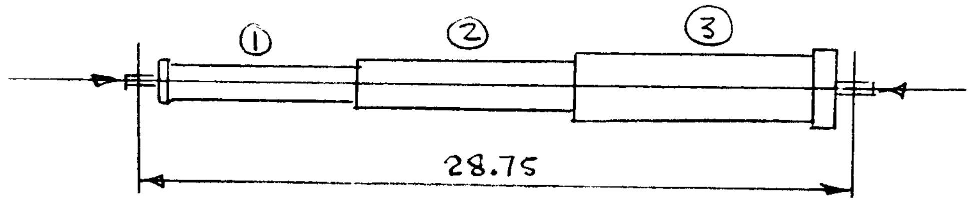
SHOCK STRUT $W = 14{,}000$ LB $V = 20$ FT/SEC $\mu = .35$

LOAD $= 41{,}000\ (1.78) = 73{,}000$ LB (ULT)

REF PAGE 2.11.



ITEM	THICKNESS	DIAM	AREA	I	ρ	LENGTH
1	.090	2.25	.611	.375	.765	9.5
2	.100	2.75	.834	.732	.936	8.4
3	.110	3.25	.986	1.335	1.165	10.8

$$\frac{l}{\rho} = \frac{9.5}{.765} + \frac{8.4}{.936} + \frac{10.8}{1.165}$$

$$12.5 + 9.0 + 9.25 = 30.75$$

COLUMN ALLOWABLE $= 121{,}000$ PSI

$$f_c = \frac{73{,}000}{.611} = 119{,}000 \text{ P.S I}$$

$$MS = \frac{121{,}000}{119{,}000} - 1 = 0.02$$

INTERNAL PRESSURE $= \dfrac{73000}{\pi (1.51)^2} = 10{,}100$ PSI

WALL STRESS ITEM 3 $= \dfrac{10{,}100\ (1.570)}{.110} = 144{,}000$ PSI

$$MS = \frac{156000}{144{,}000} - 1 = 0.08.$$

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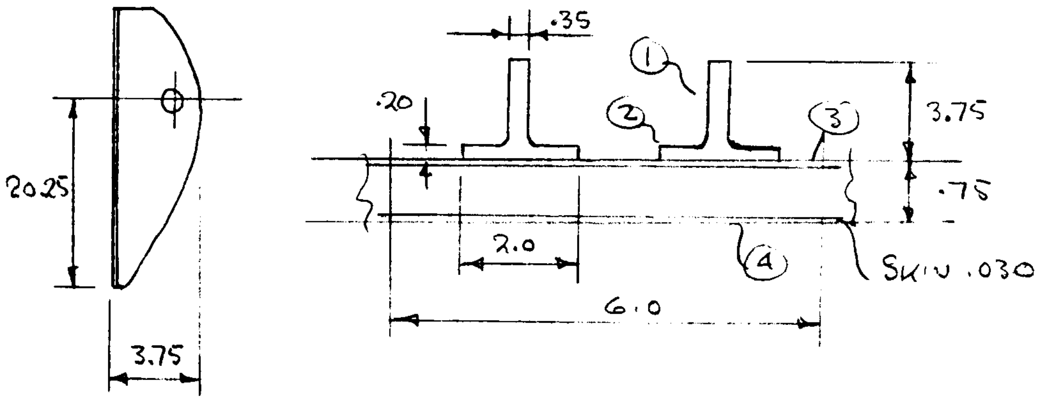
SIDEWALL FITTING - SHOCK STRUT TO INNER STRUCTURE ATTACHMENT. W = 14000 LB V = 20 FT/SEC μ = .35

MAX BENDING MOMENT = 78,100 (1.78) = 138,500 LB INS.
" END LOAD = 18,050 (1.78) = 32,200 LB.
REF PAGE 2.13



ITEM	AREA	Y_{XX}	AY_{XX}	Y_{NA}	AY_{NA}^2	I_o
①	2.480	2.725	6.750	.645	1.030	2.62
②	.800	.850	.680	1.230	1.210	.003
③	.180	.735	.132	1.345	.326	
④	.180	.015	.003	2.065	.767	
	3.640		7.565		3.333	2.623

$$Y_{NA} = \frac{7.565}{3.640} = 2.08$$

$$\begin{array}{r} 2.623 \\ 3.333 \\ \hline 5.956 \end{array}$$

$$f_T = \frac{138,500\,(2.08)}{5.956} + \frac{32,200}{3.640}$$

$$= 48,400 + 8850 = 57,250 \text{ PSI}$$

$$MS = \frac{60,000}{57,250} - 1 \quad 0.05$$

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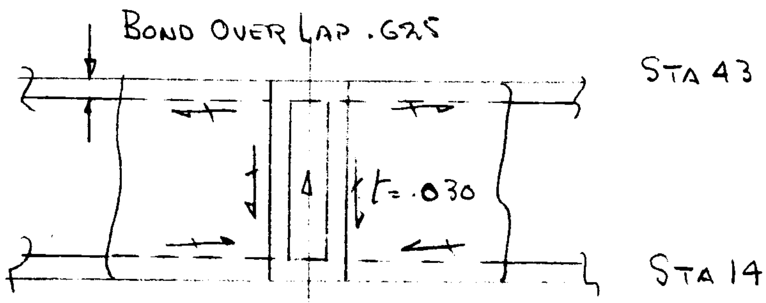
COMMAND MODULE INNER STRUCTURE AFT SIDEWALL SKIN

$W = 14{,}000 \quad V = 20\ \text{FT/SEC} \quad \mu = .35$

SKIN SHEAR (REF PAGE 2.14)



$36{,}100\,(1.78) = 64{,}100\ \text{LB}$

$$q_{MAX} = \frac{64{,}100\,(2)}{29\,(2)} = 2210\ \text{LB/IN}$$

SHEAR STRESS IN SKIN $t = .030$

$$f_s = \frac{2210}{.030\,(2)} = 36{,}800\ \text{PSI}$$

$$MS = \frac{38{,}000}{36{,}800} - 1 = 0.03$$

BOND STRESS AT STA 43

$$\text{SHEAR ON BOND} = q_B = \frac{2210}{4} = 552\ \text{LB/IN}$$

$$f_B = \frac{552}{.625} = 885\ \text{PSI}$$

$$MS = \frac{1320}{885} - 1 = 0.49$$

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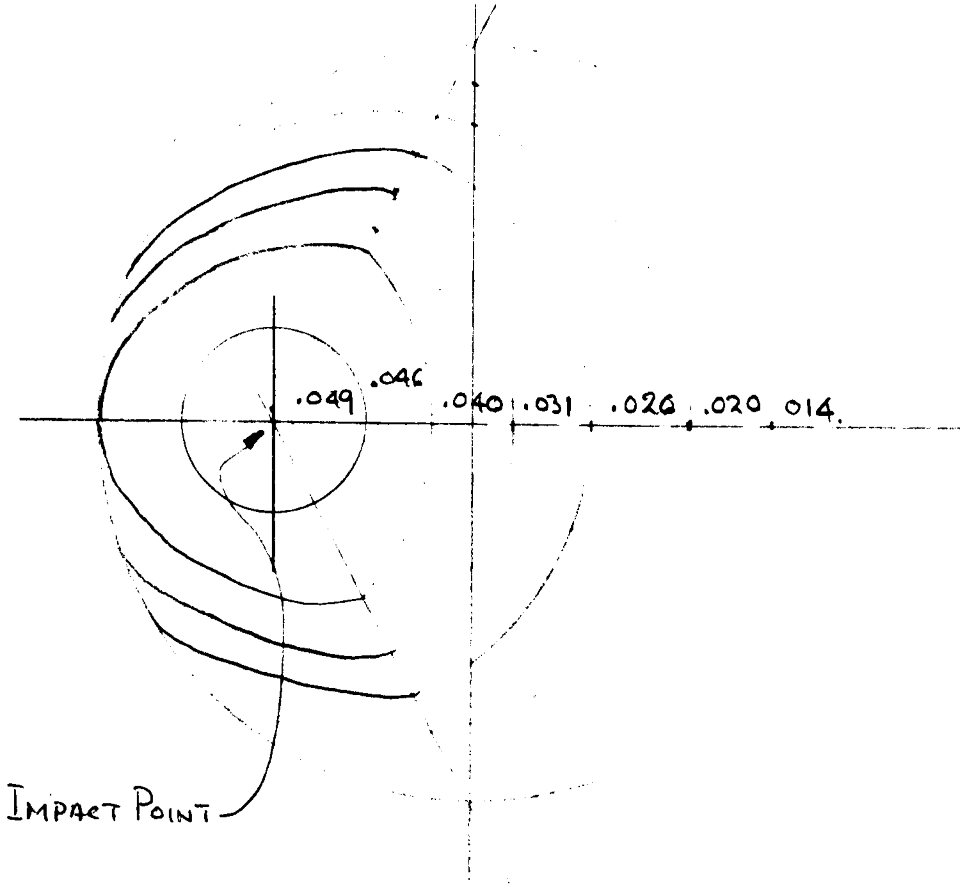
WATER IMPACT CONDITION W = 14,000 LB V = 20 FT/SEC μ = .35

REF PAGE 3.2.

LOAD FACTOR INCREASE $= \frac{12.5g}{8.0g} = 1.56$

SKIN PROFILE RELATIVE TO IMPACT POINT.



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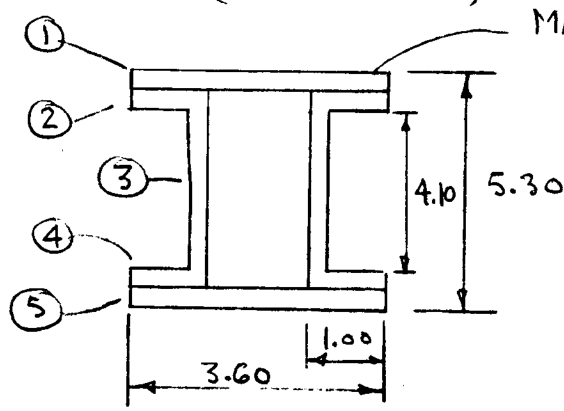
W = 14,000 LB V = 30 FT/SEC μ = .35
AFT HEAT SHIELD RING AT 71" RAD.
GROUND IMPACT CONDITION (17°) REF PAGE 2.7.

MAXIMUM BENDING = 333,920(40) = 1,335,680 LB INS

RING SECTION (REF PAGE 1.12)



ITEM	AREA	y_{NA}	Ay_{NA}^2	I_o
1	1.080	2.500	6.780	.008
2	.600	2.200	2.900	.004
3	2.460	0	0	3.450
4	.600	2.200	2.900	.004
5	1.080	2.500	6.780	.008
			19.360	3.474
				19.360
				22.834

$$f_B = \frac{1,335,680(2.65)}{22.834} = 155,000 \text{ P.S.I.}$$

MS = ZERO.

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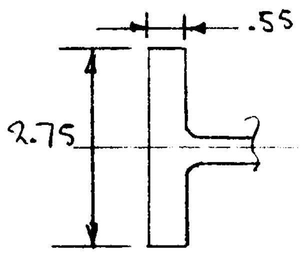
$W = 14{,}000$ LB $V = 30$ FT/SEC $\mu = .35$

GROUND IMPACT CONDITION 17° (WITH 12° YAW)

SIDE LOAD ON LINKS

LOWER LINK (REF PAGE 2.9)

LOAD ON LINK = 20,950 (4) = 83,800 LB.



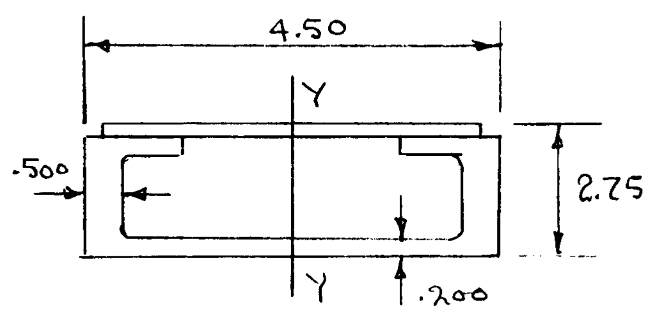
$A = .55(2.75) = 1.51$

$$f_c = \frac{83{,}800}{1.51} = 55{,}500 \text{ PSI}$$

$$MS = \frac{60{,}000}{55{,}500} - 1 = 0.08.$$

UPPER LINK (REF PAGE 2.10)

BENDING ON SECTION = 82,200 (4) = 328,800 LB INS.



$$I_{yy} = .325(4.5)^3/12 + 2.485(1.00)(2)^2 = 12.42 \text{ INS}^4$$

$$f_B = \frac{328{,}800\,(2.25)}{12.42} = 59{,}500 \text{ PSI}$$

$$MS = \frac{60{,}000}{59{,}500} - 1 = \text{ZERO}.$$

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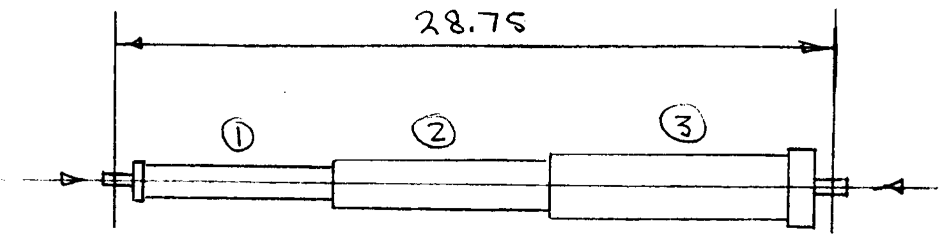
SHOCK STRUT W = 14,000 LB V = 30 FT/SEC $\mu = .35$

LOAD = 41,000 (4.0) = 164,000 LB. (ULT)

REF PAGE 2.11



ITEM	THICKNESS	DIA	AREA	I	ρ	LENGTH
1	.125	3.875	1.410	2.585	1.355	9.5
2	.140	4.375	1.855	4.140	1.492	8.4
3	.160	4.875	2.365	6.570	1.672	10.8

$$\frac{l}{\rho} = \frac{9.5}{1.355} + \frac{8.4}{1.492} + \frac{10.8}{1.672}$$

$$= 7.0 + 5.63 + 6.45 = 19.07$$

COLUMN ALLOWABLE = 156,000 P.S.I

$$f_c = \frac{164,000}{1.410} = 116,300 \text{ P.S.I.}$$

$$MS = \frac{156,000}{116,300} - 1 = 0.34$$

$$\text{PRESSURE} = \frac{164,000}{\pi(2.277)^2} = 10,100 \text{ P.S.I}$$

$$\text{WALL STRESS ITEM 1} = \frac{10,100(1.875)}{.125} = 151,500 \text{ P.S.I}$$

$$\text{ITEM 2} = \frac{10,100(2.117)}{.140} = 152,500 \text{ P.S.I}$$

$$\text{ITEM 3} = \frac{10,100(2.357)}{.160} = 148,500 \text{ P.S.I.}$$

$$MS = \frac{156,000}{152,000} - 1 = 0.02$$

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SIDEWALL FITTING - SHOCK STRUT TO INNER STRUCTURE

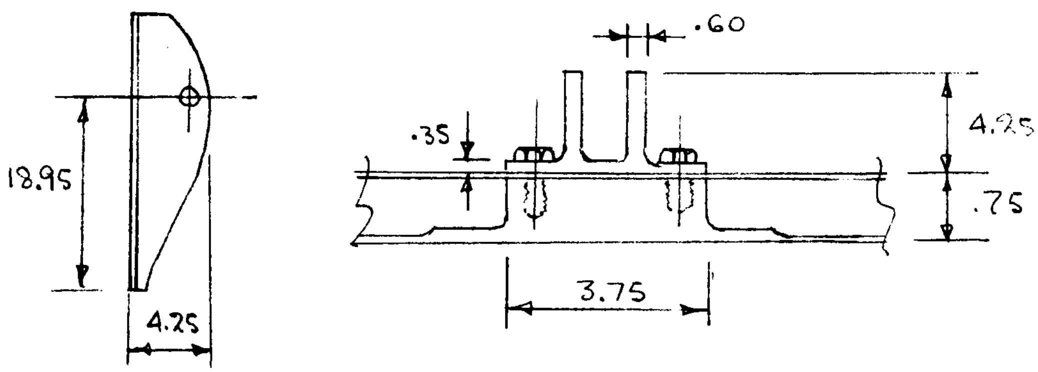
W = 14,000 LB V = 30 FT/SEC μ = .35

MAX BENDING MOMENT = 78,100 (4.0) = 312,400 LB INS

" END LOAD = 18,050 (4.0) = 72,200 LB

REF PAGE 2.13

SECTION PROPERTIES (MAX SECTION)



ITEM	AREA	y_{xx}	Ay_{xx}	y_{NA}	Ay_{NA}^2	I_o
①	4.680	3.05	14.25	1.17	6.40	5.93
②	4.120	.55	2.26	1.33	7.29	.42
	8.800		16.51		13.69	6.35

$$Y_{NA} = \frac{16.51}{8.80} = 1.880 \qquad \frac{13.69}{20.04}$$

$$f_c = \frac{312,400(3.12)}{20.04} + \frac{72,200}{8.80}$$

$$= 48,800 + 8,200 = 57,000 \text{ PSI}$$

$$MS = \frac{60,000}{57,000} - 1 = 0.05$$

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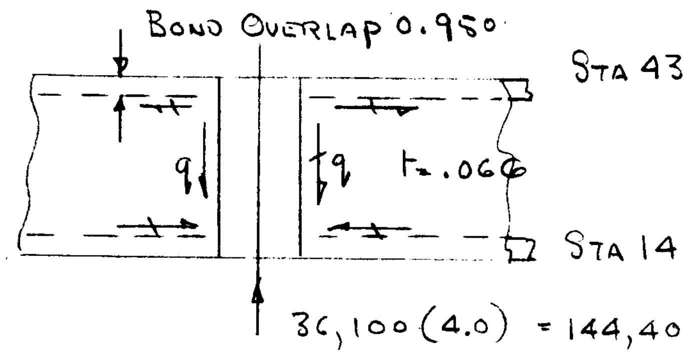
COMMAND MODULE INNER STRUCTURE AFT SIDEWALL SKIN.

W = 14,000 LB V = 30 FT/SEC $\mu = .35$

SKIN SHEAR (REF PAGE 2.14)



36,100 (4.0) = 144,400 LB.

$$q_{MAX} = \frac{144{,}400\,(2)}{29\,(2)} = 5000 \text{ LB/IN}$$

SHEAR STRESS IN SKIN t = .066

$$f_s = \frac{5000}{.066\,(2)} = 38{,}000 \text{ PSI}$$

MS = ZERO

RING TO SKIN BOND STRESS

$$f_{BOND} = \frac{5000}{(4)(0.95)} = 1320 \text{ PSI}$$

MS = ZERO

NOTE DEPTH OF RING AT STA X_c 43 INCREASED 0.33 INS

STRESS ON WELD AT STA 14 AND 43

$$f_s = \frac{5000}{2(.066+.100)} = 15{,}000 \text{ PSI}$$

MS = ZERO.

REQUIRED WELD LAND THICKNESS = .100 ON RINGS AND LONGERONS TO ACHIEVE ZERO MARGIN.

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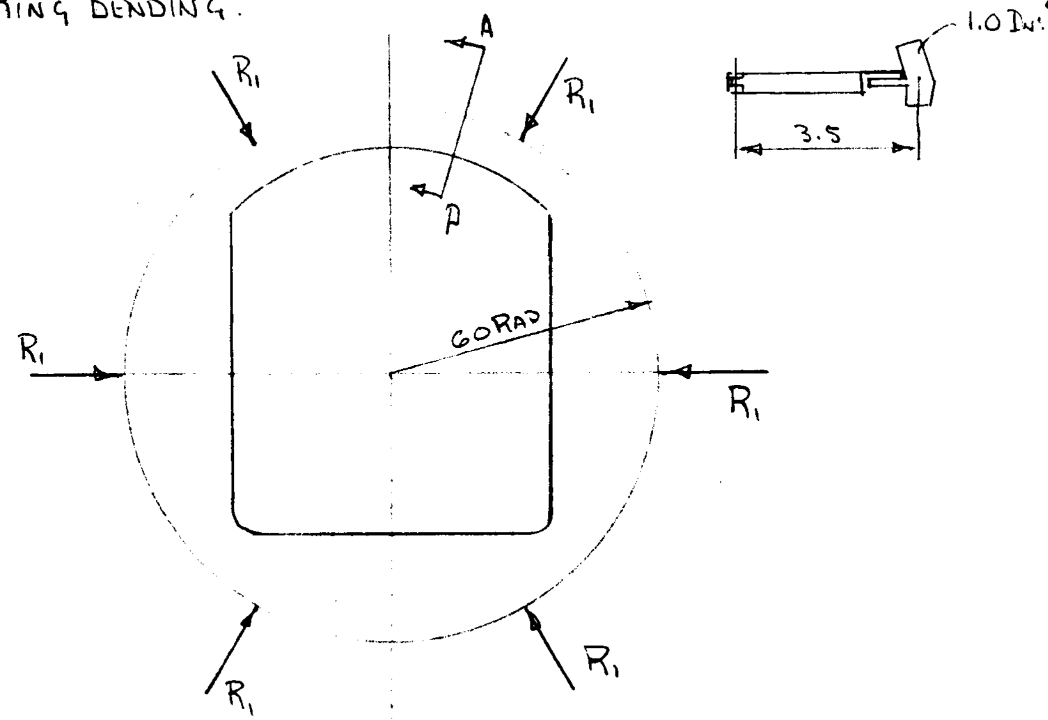
COMMAND MODULE INNER STRUCTURE GIRTH RING STA. Xc 43.

$W = 14000$ LB $V = 30$ FT/SEC $\mu = .35$

REF PAGE 2.12

$R_1 = 15,340\ (4.0) = 61,360$ LB.

RING BENDING.



APPROX BM = $K_B R_1 r$ (ASSUMING RING SECTION CONSTANT)

$= .16\ (61,360)\ 60 = 587,000$ LB INS

$$f_B = \frac{589,000}{3.5} = 168,000 \text{ P.S.I.}$$

MIN RING SECTION WILL REQUIRE INCREASING BY.

$$\frac{168,000}{60,000} = 2.80 \qquad 180\%.$$

THIS CHANGE IS ASSUMED NOT TO AFFECT THE RING WIDTH.

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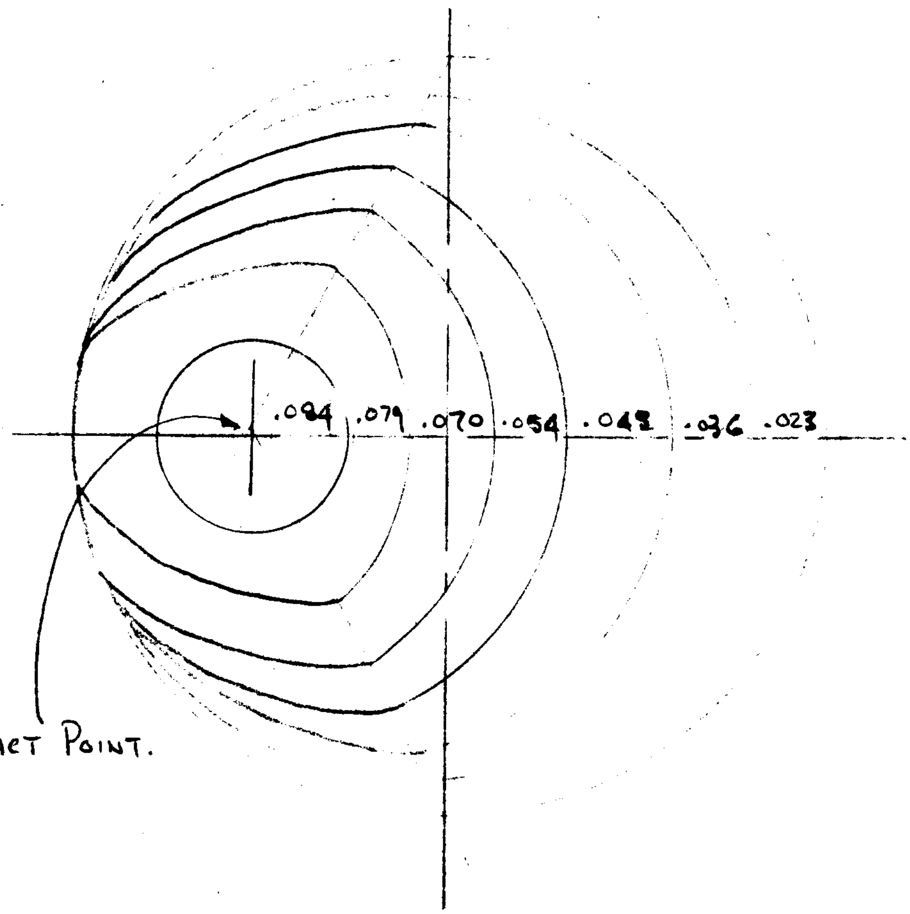
WATER IMPACT CONDITION

W = 14,000 LB V = 30 FT/SEC μ = .35

IMPACT FORCE FROM WATER IMPACT CRITERIA = 21.5g.
REF PAGE 3.2.

LOAD FACTOR INCREASE = $\frac{21.5}{8.0}$ = 2.69.

SKIN PROFILE RELATIVE TO IMPACT POINT.



IMPACT POINT.

APPENDIX B

MATERIALS EVALUATION

The materials requirements for the MISDAS application are derived from the Apollo mission and the operational and loading requirements of the landing impact attenuation system. The structural components that form part of the aft heat shield (landing legs, skids, skid housings, and associated fittings) were designed for a temperature range of -150 F to +600 F. These values, which represent the extreme temperatures at the ablator/heat shield interface, are somewhat conservative for structural design. Structural components attached to the inner capsule are designed for its anticipated temperature range of -150 F to +200 F. In general, the materials used for similar applications to Apollo are satisfactory for the MISDAS system, and no material development programs are required for the structural members.

The parameters of major importance with respect to materials selection for a land landing system are strength (F_{tu}, F_{ty}), density (ρ), toughness (notch strength, impact resistance), rigidity, producibility, and corrosion resistance. The high-strength aluminum alloys, corrosion resistant steels, and titanium alloys all possess these characteristics to the degrees shown in the data presented in Table 14.

The structural members of the heat shield, landing legs, skids, skid housings and associated supports and the shock struts could be fabricated of a high-strength corrosion-resistant steel, such as the PH 14-8 Mo material used for the Apollo heat shield. This alloy is readily weldable and affords a desirable combination of strength, toughness, rigidity, and corrosion resistance. The use of PH 14-8 Mo or equivalent high temperature metallic heat shield structure provides thermal protection in case of a premature failure of the ablator. The corrosion-resistant steels are favored for these parts over the high-strength titanium alloys because of superior fabrication and welding characteristics and greater ductility and toughness.

A superalloy such as Inconel 718 may be used for the skid thruster of the radially extended skid system. This material provides a significant combination of high-impact resistance, notch toughness and strength at cryogenic, ambient, and elevated temperatures. It readily welded and brazed to it self and to other materials such as the type 18-8 stainless steels (304L, 321, 347, etc.).

Item	NAA-Apo Temperat Limitatio
Stainless Steels	
PH 15-7 Mo (RH 1050)	-150 F
PH 14-8 Mo (BCHT 1050)	-300 F
A-286	-423 F
Aluminum Alloys	
2014 T6	-300 F
6061 T6	-423 F
7075 T6	-100 F
Nickel Base Alloys	
Inconel 718	-423 F
Steel Alloys	
4140 (180 ksi)	-65 F
18-8 Mar-Aging	New
Titanium Alloys	
Ti 5A1 - 2.5 Sn	-300
Ti 6A1 - 4 V	-300

*Reference 5
**Reference 10
***Reference 11

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Table 14. N
Char

lo re n	ρ (lb/in.^{2})	Room Temperature Properties						300 F Properties				600 F Properties			
		F_{ty} (ksi)	F_{ty} (ksi)	F_{ty}/ρ (10^3)	e (%)	Impact (Charpy V)	Ec (10^6)	F_{ty} (ksi)	F_{ty} (ksi)	F_{ty}/ρ (10^3)	e (%)	F_{ty} (ksi)	F_{ty} (ksi)	F_{ty}/ρ (10^3)	e (%)
	0.277	190*	175*	686	2*	4	30.0*	175*	158*	632	2*	160*	135*	578	3*
	0.277	185**	175**	668	11**	6.5	29.0**	172**	158**	621	4**	162**	138**	585	3.5**
	0.286	140*	95*	490	26*	56	29.0*	131*	90*	458	21*	126*	87*	441	19*
	0.101	67*	59*	663	6*	2.4	10.7	57*	49*	564	6*	12*	9*	119	14*
	0.098	42*	35*	428	9*	8.5	10.1	35*	28*	357	10*	8.6	6.3	98	
	0.101	77*	66*	762	7*	4	10.5	55*	47*	544	12.7*				
	0.296	180*	150*	608	16*	12	29.5*	172*	144*	581	16*	167*	139*	564	19*
	0.283	180*	165*	636	16*	7.5	29*	173*	146*	611	9*	158*	124*	558	13*
lloy	0.289	240***	230***	830	12***	18	28.2***	232***	204***	803	10.8***	212***	186***	733	11***
F F	0.161 0.160	115* 155*	110* 145*	714 969	10* 5*	10 17	15.5* 16.3*	94 136	87 119	584 850	10* 5*	74* 122*	66* 98*	460 762	13* 4.5*

MISDAS Study Project Material Properties and General
acteristics of Candidate Alloys, -150 to 600 F

-150 F Properties					
ty (ksi)	F_{ty} (ksi)	F_{ty}/ρ (10^3)	e (%)	Impact (Charpy v)	Other Characteristics
11*	195*	761	2*	2*	1. Good metals joining characteristics 2. Good corrosion resistance
95	189	704	12		
63*	102*	567	30*	56*	1. Poor weldability, good brazing characteristics 2. Excellent corrosion resistance
70	63	693	10	3.5	1. Good metals joining characteristics 2. Acceptable corrosion resistance
47	37	479	10.5	9	1. Excellent metals joining characteristics 2. Good corrosion resistance
82	71	812	10.8	4.5	1. Poor metals joining characteristics 2. Acceptable corrosion resistance
196*	161*	662	15*		1. Excellent metals joining characteristics 2. Excellent corrosion resistance
187	178	660		5	1. Good metals joining characteristics 2. Requires protective coating against the atmosphere
264	253	913		21	1. Good metals joining characteristics 2. Good corrosion resistance 3. Low temperature thermal (900 F aging) treatment facilitates ease of fabrication 4. Requires protective coating against the atmosphere
140	136	869	8.5	10	1. Coefficient of thermal expansion varies significantly from PH 14-8 Mo, the Apollo heat shield material. 2. Titanium welding requires special equipment. An inert atmosphere weld chamber is preferred. Welding most MISDAS components in a chamber would be impractical. 3. Good corrosion resistance against the elements.
216	198	1350		11	

- [redacted] -

The fasteners and threaded members should be fabricated from steels of high strength toughness and corrosion resistance in the temperature range previously noted. An alloy that meets these requirements is A-286, the standard material used for Apollo fasteners.

The thin-walled bellows around the rocket nozzles and shock struts may be subjected to high temperatures and corrosive gases from the retrorockets. These members must be very flexible, thin-walled, weldable items. Depending on actual temperature requirements, stainless steels, such as Types 304L, 321, and 347, or superalloys, such as Inconel 718, can be utilized.

Aluminum alloys, such as those used in Apollo bracketry, reinforcements, and attachments to the inner structure, are considered satisfactory for similar applications with the MISDAS installation.

The requirements for heat shield ablator and ablative edge members at the interfaces between leg segments and fixed heat shield are identical to the Apollo and AES heat shield criteria. The ablator must provide thermal protection; joints must be sealed against aerodynamic entry heating; and movable legs must be extendable after entry. The Avcoat 5026-39 basic ablator developed for Apollo is applicable to the MISDAS installation. Seal materials require chemical and physical compatibility with the basic ablator during cold soak and entry conditions.

Figure 40 illustrates a feasible approach to a hatch seal concept. This concept involves use of a molded seal bonded to the fairing, a faired seal compound, and a release film. The molded seal offers a more precise fit, and the troweled or sprayed faired seal acts mainly as the abrasion resistant exterior seal. General Electric RTV560, a material already qualified to AVCO and NAA S&ID specifications, or Dow Corning DC 950 could be used to fabricate the molded seal. (Reference 12)

Larodyne 3310-23-4 is a promising material for an easy to finish and repair seal fairing that can be troweled or sprayed on, to be used in conjunction with a molded seal to fill plugholes and pop plug voids and joints. Among its properties are (1) low density of 30 pounds per cubic foot, (2) excellent dimensional stability during ablation, (3) easily repaired, and (4) easily bonded to structures using cold or hot bonding agents specially developed for use with Larodyne.

Two materials are proposed for use as release films: Teflon, which ablates with a clean, no-char surface, and Kapton polyimide. Both materials are able to withstand temperatures of up to 600 F. These films can be obtained in thicknesses varying from 0.001 to 0.010 inches, with or without pressure sensitive adhesives.

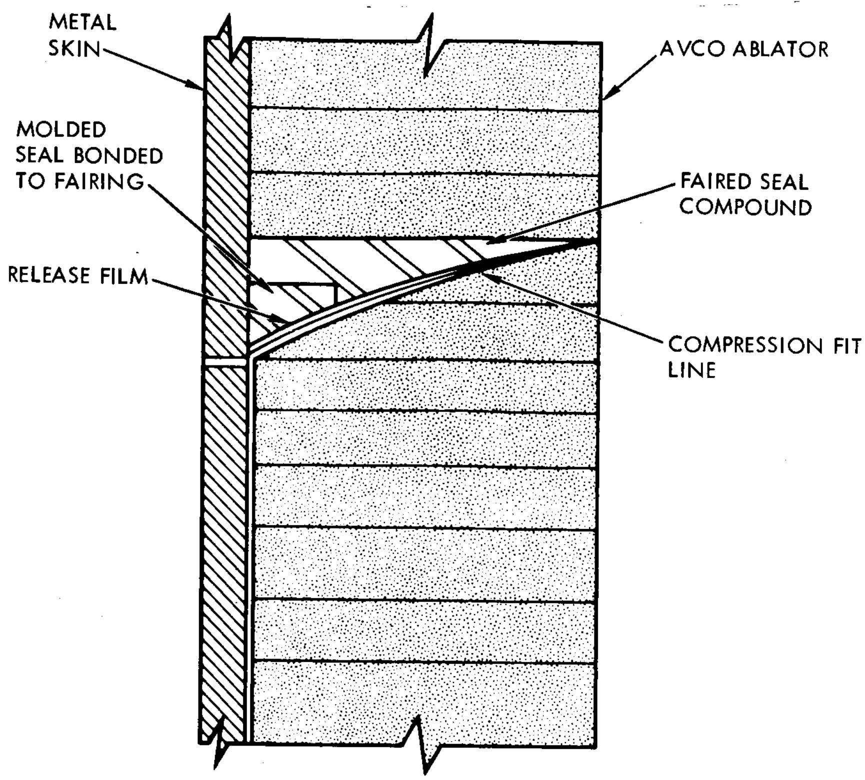

Figure 40. Hatch Seal Concept

All of these materials require limited investigation of their compatibility with Avcoat 5026-39, volatility, shape, and volume stability under entry conditions, fusion and bonding to adjacent surfaces after being exposed to entry heat, and shear strength of the remaining material after entry to determine the force required to deploy MISDAS.

APPENDIX C

LEGGED - A FORTRAN IV COMPUTER PROGRAM FOR THE SOLUTION OF LEGGED VEHICLE IMPACT DYNAMICS

Accession No.

SID 66-278

LEGGED
A FORTRAN IV COMPUTER PROGRAM FOR THE SOLUTION OF LEGGED VEHICLE IMPACT DYNAMICS

MAY 1966

by

D. N. Herting

and

J. R. Partin

Approved

L. A. Harris, Director
Structures and Dynamics

NORTH AMERICAN AVIATION, INC.
SPACE and INFORMATION SYSTEMS DIVISION

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

FOREWORD

LEGGED is a FORTRAN IV language computer program developed by the Structures and Dynamics Department of North American Aviation Inc. /Space and Information Systems Division, for National Aeronautics and Space Administation, Manned Spacecraft Center, under Contract NAS9-4915, "Mechanical Impact Design for Advanced Spacecraft. The program can be utilized to analyze the dynamic stability and impact attenuation requirements of vehicles landing on separate legs. It was developed by D. N. Herting and J. R. Partin. The Project Manager for MISDAS has been A. I. Bernstein and the Project Engineer has been A. S. Musicman.

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ILLUSTRATIONS

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INTRODUCTION

LEGGED is a FORTRAN IV computer program which is effectively a three-dimensional mathematical model of a legged spacecraft. When initial conditions, i.e., landing parameters, are properly loaded, the program simulates the dynamics of a real spacecraft making an earth landing. The action of the earth on strut tips produces forces and torques on the spacecraft. The laws of motion are integrated using small time increments to produce linear and angular acceleration, velocity, and displacement time histories.

The program has very flexible input sequencing since it uses the FORTRAN IV feature, NAMELIST. It is therefore useful for making parameter studies. Loading time for the object deck is about 30 seconds and computer time per landing case is on the order of 10 to 15 seconds.

The geometry of essential points on the spacecraft is described by the coordinates of each point in a coordinate system fixed to the spacecraft (capsule initial system). For example, the center of gravity is located by loading in its three coordinates in the capsule initial system. The same approach is used to establish the location of each strut end. Any number of struts are allowed and each may have different stroking properties. However, once a strut is located on the vehicle, the strut tip deforms (moves) in a straight line toward the strut end attached to the spacecraft.

The properties of each strut must be expressible as a load-stroke "curve" which can be formed by a series of straight lines. The principal strut property is plastic deformation, but provisions are made for the inclusion of velocity damping and elasticity. The struts (legs) are considered to be massless.

The ground is considered as a rigid plane having a constant friction coefficient with the spacecraft's legs. The ground may have a slope and a direction of slope.

A partial list vehicle input data for the program includes:

1. Number of legs

2. Acceleration of gravity

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3. Coordinates of c.g.

4. Mass properties

5. Coordinates of each end of each strut

6. Load-stroke properties of each strut

The initial value (landing parameter) data includes:

1. Horizontal and vertical velocities

2. Roll, pitch, and yaw

3. Angular velocities

4. Ground slope and direction of slope

5. Friction coefficient with ground

6. Parachute swing angle and direction of swing

The programs output is principally in the form of CRT plotting. Time histories are plotted from the instant of impact for the following quantities:

1. Acceleration, velocity, displacement of the c.g. in a direction normal to the earth.

2. Roll, pitch, and yaw measured relative to the earth (earth y-z coordinate axes from plane of ground)

3. Stroke of each strut (versus time)

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SYMBOLS AND DEFINITIONS

Variable Code

1) Input Variable
2) Stored vs Time for CRT
3) Not used in this program version

Symbol	Code	Definition
A		Dummy scale factor
ACMAX		Maximum acceleration on capsule, ft/sec^2
AGE(I)		Acceleration vector of c.g. in earth coordinate system, ft/sec^2
AGES(I, J)	2	Acceleration, ft/sec^2 vs time, sec
AGT		Total acceleration, ft/sec^2
ANG(I)		Capsule angles relative to earth coordinates, deg
ANGS(I, J)	2	Angles, deg vs time, sec
ARG1		Dummy argument
ARG2		Dummy argument
ARG3		Dummy argument
ARG4		Dummy argument
ARG5		Dummy argument
ARG6		Dummy argument
ARG7		Dummy argument
ARG8		Dummy argument
ARMV(I)	3	Not used in this program version

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Symbol	Code	Definition
AXMAX		Max angle x axis makes with ground normal, deg
CPHI		cos (phi)
CPSI		cos (psi)
CTHT		cos (theta)
DAMP(I)	1	Damping constant for each strut, lb-sec/ft
DE(I)	1	Elastic constant for each strut, ft
DELT		Total strut deflection, ft
DMIN		Dummy variable
DSLP	1	Direction of ground slope (angle from absolute z axis), deg
DSTS(I, J)	2	Strut strokes, ft vs time, sec
DSWG	1	Direction of parachute swing (angle from absolute z axis), deg
DT		Time increment used in program, seconds
DTCE(I, J)		Transfer matrix increment of TCE
DTO	1	Real time increment used as input, seconds
DVPC(I)		Change in velocity at strut tip - capsule system
DVPE(I)		Change in velocity at strut tip - earth system
DWGC(I)		Change in angular velocity at c.g. in capsule system
ELF(I)	3	Not used in this program version
EL2		Length of strut-squared
EMU		Friction coefficient computed by subroutine FRIC

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Symbol	Code	Definition
ENTA(I)	1	Principle moments of inertia of vehicle about three axes, slug-ft^2
ETA(I, J)	3	Not used in this version
FE		Strut force modified by elasticity and damping
FGE(I)		Force on capsule c.g. - earth coordinates
FMAX(J)		Maximum force from each strut
FORC(J)		Actual force from each strut at any time
FORS(I, J)	1	Force magnitudes defining the load-stroke curve of leg j, lb
FRC(J)	1	Friction magnitudes which define the coefficient of friction EMU, dimensionless
FS		Force in strut along motion vector
FSC(I)		Force vectors on strut tip in capsule coordinate system
FSE(I)		Force vectors on strut tip in earth coordinate system
FSTS(I, J)	2	Force magnitudes, lb vs time, sec
FV		Force on strut due to velocity
G	1	Gravitational constant, ft/sec^2
GV(I)		Gravity vectors in earth coordinate system
I		Subscript index
IP		Index for plotting prints
IPRINT	1	Input-output control parameter
IPT		Integer increment used for spacing plotting points
J		Subscript index

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Symbol	Code	Definition
K		Subscript index
N		Subscript index
NDP		Number of iterations, IPT, between plotting
NS	1	Number of struts on vehicle
PCH	1	Parachute pitch hang angle, deg
PSI		Angle psi about z axis
PSTR(J)		Total amount of plastic stroking, ft
PTEST(I)	1	Plotting control variables
QGC(I)		Angular velocity vectors of capsule, rad/sec
QGCS(I, J)	2	Angular velocity vectors of capsule, rad/sec
RAT		Dummy variable
RATIO		Dummy variable
RBCI(I, J)	3	Vectors locating body point j in capsule initial system, in.
RGA(I)		Vectors locating the c.g. in absolute coordinate system
RGAS(I, J)	2	Vectors locating the c.g. in absolute coordinate system, ft vs time
RGCI(I)	1	Vectors locating the c.g. in capsule initial system, in.
RGE(I)		Vectors locating the c.g. in earth coordinate system
RGES(I, J)	2	Vectors locating the c.g. in earth coordinate system, ft vs time
ROL	1	Roll angle used as input - about vertical axis, deg
RPC(I)		Location vector of a deformed strut point in capsule system

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Symbol	Code	Definition
RSC(I, J)		Vectors locating strut tip j in capsule coordinate system, ft
RSCI(I, J)	1	Vectors locating strut tip j in capsule initial system, in.
RSCL(I)		Vectors locating strut tip j relative to capsule origin in earth coordinates
RSE(I)		Vectors locating strut tip in earth coordinate system, ft
RSFC(I, J)		Vectors locating fixed strut tip in capsule coordinate system, in.
RSFCI(I, J)	1	Vectors locating fixed strut tip in capsule initial system, in.
SLP	1	Ground slope angle measured from ground normal to absolute x axis, deg
SMAX		Dummy variable for GRAPH
SPHI		Sin (phi), dummy variable
SPSI		Sin (psi), dummy variable
STHT		Sin (theta), dummy variable
STRK(I, J)	1	Stroke magnitudes defining the load-stroke curve of leg j, ft
STROK(J)		Present stroke magnitudes at any time
SWG	1	Parachute swing angle (measured from absolute x axis), deg
TAE(I, J)		Absolute system to earth system transfer matrix
TCA(I, J)		Capsule system to absolute system transfer matrix
TCE(I, J)		Capsule system to earth system transfer matrix
TCP(I, J)		Capsule system to parachute system transfer matrix

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Symbol	Code	Definition
TERM	3	Stability test parameter
TEST	3	Stability test parameter
TGC(I)		Torque vectors on capsule
THT		Angle θ about x
TIME		Real time - seconds
TP(I)		Estimated c.g. angular acceleration vector due to strut
TPA(I, J)		Parachute system to absolute system transfer matrix
TPLOT	1	Time interval between plotting points, sec
TSC(I)		Torque about c.g. due to each strut - capsule system
TTIME	1	Total real time limit per case, sec
TYM(I)		Times at each storage point
TYMJ(I)		Points in time for labeling strut strokes
USC(I, J)		Unit strut vectors along strut j in capsule system
USE(I)		Unit strut vectors along strut j in earth system
VGA(I)		Velocity vectors of c.g. in absolute coordinate system
VGC(I)		Velocity vectors of c.g. in capsule coordinate system
VGE(I)		Velocity vectors of c.g. in earth coordinate system
VGES(I, J)	2	Velocity vectors of c.g. in earth coordinate system, ft/sec vs time
VH	1	Initial horizontal vehicle velocity along absolute z axis, ft/sec
VL		Vector length
VPE(I)		Velocity vector of strut tip

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Symbol	Code	Definition
VS		Stroking velocity of strut
VSC(I)		Velocity vectors of strut tip in capsule coordinate system
VSE(I)		Velocity vectors of strut tip in earth coordinate system
VT		Tangential velocity at strut tip
VV	1	Initial vertical vehicle velocity along absolute x axis, ft/sec
WGC(I)		Angular velocity of capsule in capsule system
WGCS(I, J)	2	Angular velocity of capsule in capsule system rad/sec vs time, sec
WHOA		Test variable to print reason for stopping
WPCH	1	Capsule pitch angular velocity used as input, rad/sec
WROL	1	Capsule roll angular velocity used as input, rad/sec
WT	1	Weight of vehicle, lb
WYAW	1	Capsule yaw angular velocity, rad/sec
XANG		Angle between capsule x axis and earth normal
XLIM		Dummy for CRT plotting
YAW	1	Parachute yaw hang angle about z axis, deg

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ANGLE CONVENTIONS

The angle conventions used for input are selected to decouple the various random parameters from the fixed-hang angles. The capsule is rigged on parachute lines at nominal pitch and yaw, but the deviations are in terms of a parachute swing angle and a direction of the swing angle. In establishing the hang angles the order of rotation is pitch and then yaw. This order leaves the capsule z axis in the plane formed by the parachute z axis and the shroud line axis (chute x axis).

Roll angle was selected as the random parameter which defines vehicle orientation to the horizontal velocity. Horizontal velocity is always taken to be in the direction of absolute z and vertical velocity parallel to absolute x. These velocities then form the reference plane x-z from which roll angle is measured. Roll angle is seen in Figure 1 to be measured about a vertical line and from the velocity plane.

Parachute swing angle and direction of swing are shown in Figure 2. Swing is defined as the angle between the capsule x axis and vertical (absolute x). The direction of swing is the principle angle between two planes containing a vertical line (absolute x). One plane contains the capsule x axis and the other contains the capsule z axis. It should be noted that direction of swing is measured from a vertical plane containing the capsule z axis, but roll is measured from the velocity plane.

The landing surface may also have a slope and a slope direction, as defined in Figure 3. The dynamics of the vehicle are calculated relative to a fixed coordinate system placed on the surface. Like the swing angle convention, this system (earth coordinate system) does not rotate with the slope direction, but "wobbles" with its z axis always in a vertical plane. The initial capsule roll angle measured from the surface coordinate system is always nearly equal to the input roll angle.

The output angles of the program are measured between the capsule axes and the surface axes. The order of rotation is x-y-z or roll-pitch-yaw. The angular velocities, however, are vector components in the capsule system.

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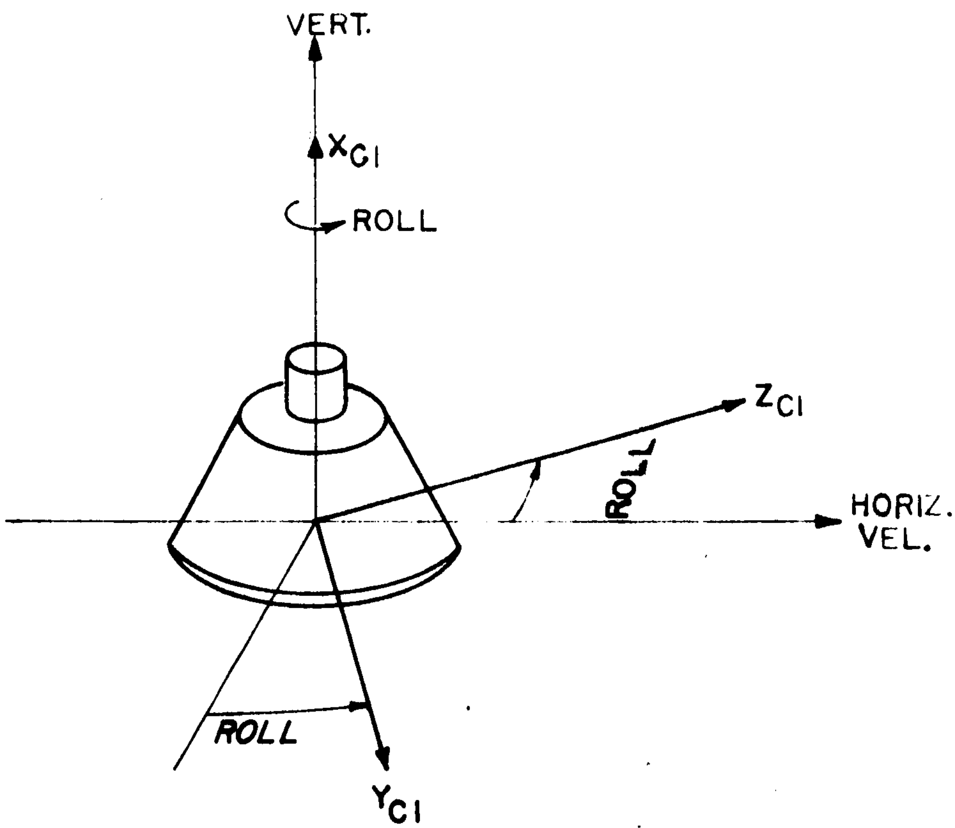

Figure 1. Roll Angle Definition

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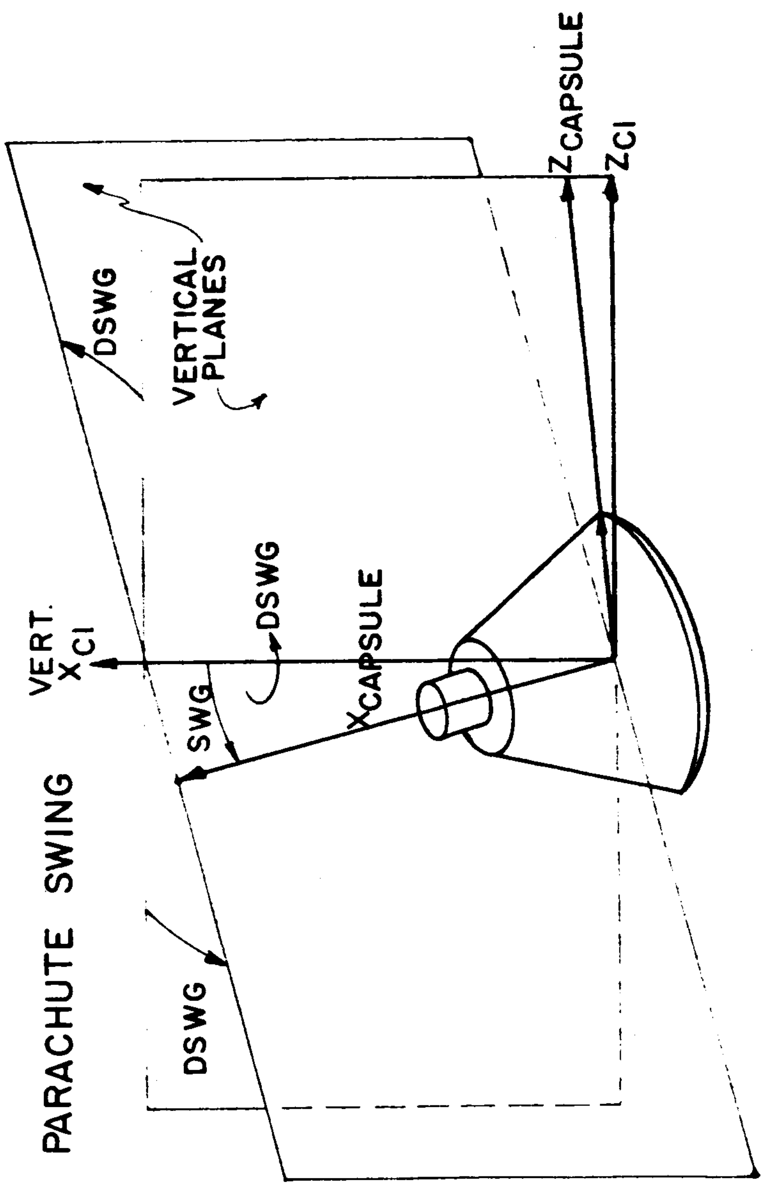

Notes: The capsule z axis is restrained to a vertical plane. Roll is angle between Z_{CI} and horizontal velocity. Z_{CI} is horizontal component of Z_c.

Figure 2. Definition of Swing Angle and Direction of Swing

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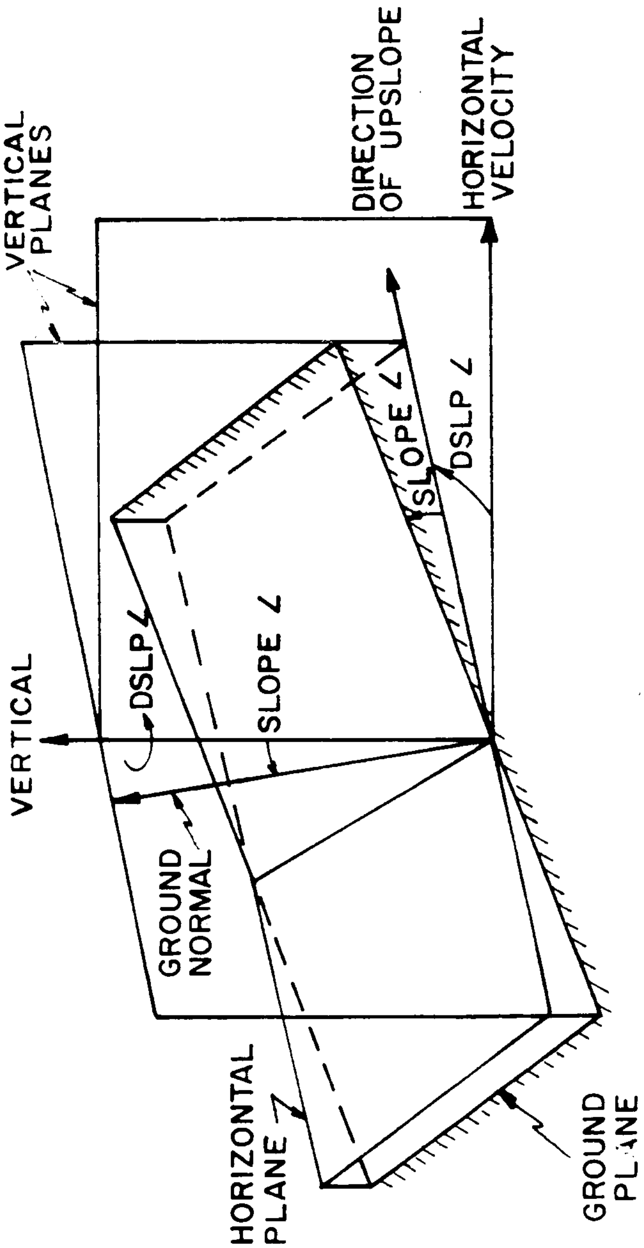

Figure 3. Definition of Ground Slope and Direction of Slope

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STRUT FORCE CALCULATIONS

The forces in the struts consist of a force $\vec{FS}$ along the direction of motion. This force is generated by the strut stroking properties and another force perpendicular to the stroking vector, which is implicitly known from the friction constraints. With a given friction coefficient and a sliding velocity, the force tangential to the ground is equal to the product of the normal force $\vec{FN}$ and the coefficient of friction μ, and its direction opposes the sliding velocity. The total force vector $\vec{FSE}$ on the strut tip due to the ground has a known direction and an unknown magnitude,

$$\vec{FSE} = \vec{FN} \begin{Bmatrix} 1 \\ -\mu V_y \\ -\mu V_z \end{Bmatrix},$$

where V_y and V_z are normalized velocity components.

The scalor product of the force vector $\vec{FSE}$ and a unit vector $\vec{USE}$ along the strut stroking motion is equal to the strut axis force

$$\vec{FSE} \cdot \vec{USE} = \vec{FS}$$

or

$$\frac{\vec{FS}}{\vec{FN}} = \vec{USE}_x - \mu . V_y . \vec{USE}_y - \mu . V_z . \vec{USE}_z$$

Since $\vec{FS}$ is known, $\vec{FN}$ and $\vec{FSE}$ are known. The force on the capsule at the strut tip may be resolved into forces and moments at the capsule c.g.

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VEHICLE INPUT DATA

All the data which describes a specific vehicle and program control parameters are read into the computer by subroutine INPUT through a single command, READ (5, DATA1). Variables which are read into the computer by this command appear in subroutine INPUT in NAMELIST statement, NAMELIST/DATA1. An example of vehicle and control data is given in Appendix B immediately following the listing of the complete FORTRAN IV program. Definitions of all program symbols are given in the List of Symbols with input variables designated by a code number.

The vehicle's center of gravity is located in the capsule initial coordinate system by the vector RGCI. Its three components are illustrated in Figure 4 and typical values of the components are given in the input data list, DATA1 in Appendix B.

Locations of each end of each strut on the vehicle are read in as vectors RSCI, movable strut tip locations in capsule initial system, and by RSFCI, locations of attachment points in capsule initial system. Refer to Figure 4 for a pictorial illustration and to Appendix B for input examples.

Inertias and vehicle weight are read in simply as ENTA(1), ENTA(2), ENTA(3), and WT. The inertias are about principle vehicle axes passing through the center of gravity.

Load-stroke properties for each vehicle strut are determined by a "curve" which is defined by a maximum of 10 points. An example is given in Figure 5 in which six points (1-2-3-4-5-6) define a plastic load versus stroke curve. Input data variables defining the curve are FØRS(I, J) and STRK(I, J), I = 1, 2, ... , 10, J = 1, 2, ... , NS, where NS is the number of struts.

The purely plastic stroking properties of the strut presented by the curve 1-2-3-4-5-6 can be modified to include elastic deformation. For strut J a distance DE(J) is defined as the amount of strut is elastically deformed (stroked) as it is loaded or unloaded. With DE(J) having a positive value, the load curve is specified (in Figure 5) by line A-B-2-3-4-5-6 where line A-B is elastic deformation. Assuming that the strut has been stroked to point C, the strut will unload elastically along line C-D. If a load is reapplied, the strut will assume the load by following line D-C-4-5-6. Setting DE(J) = 0, J = 1, 2, ... , NS will, of course, provide purely plastic struts.

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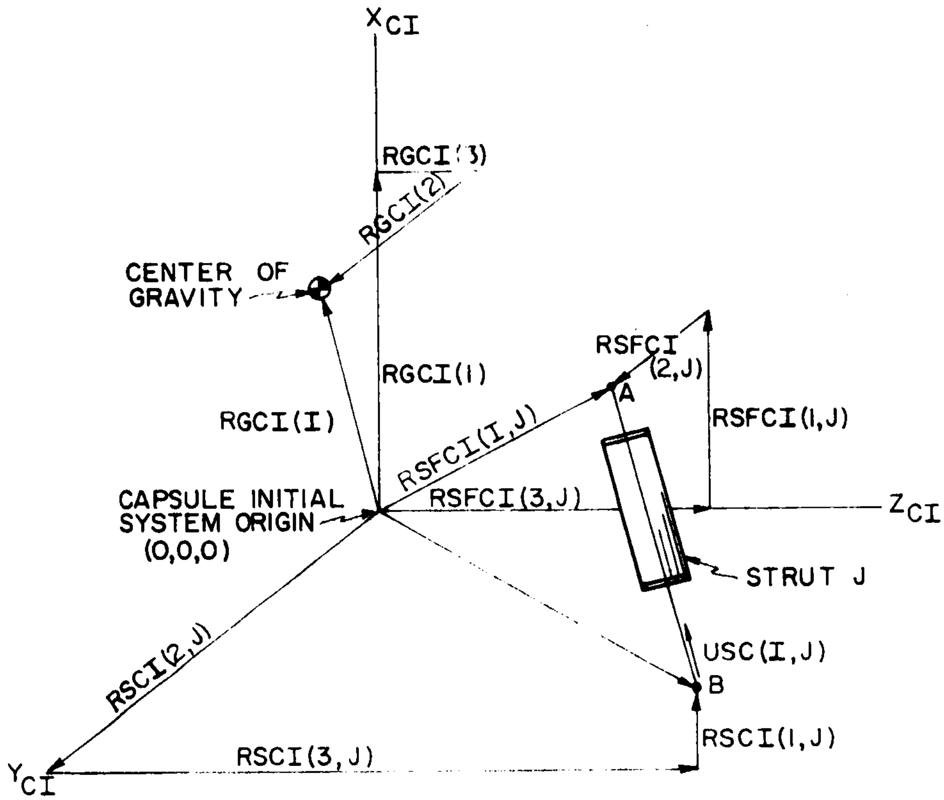

Notes: Point A is fixed to the vehicle. Point B contacts ground. Stoking is along original line AB with respect to vehicle.

Figure 4. Capsule Geometry in Capsule Initial System Coordinates

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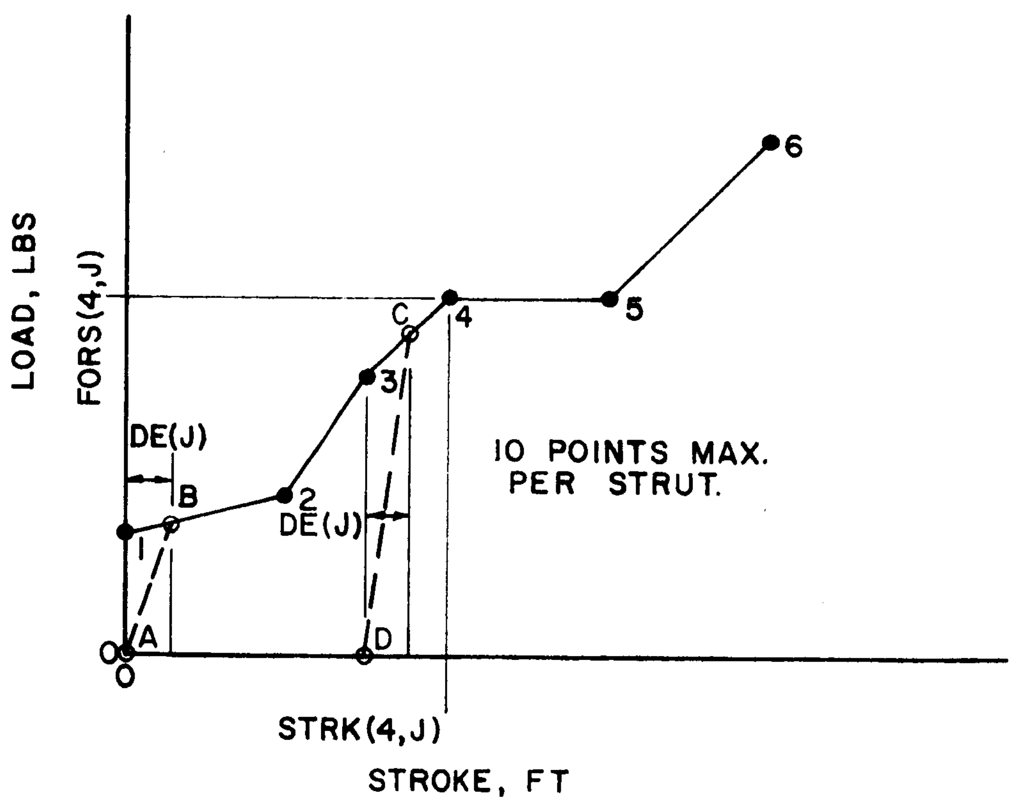

Figure 5. Load-Stroke Characteristic for Strut J Coordinates of Point I Given by STRK(I, J), FØRS(I, J)

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The strut elastic properties can be further modified through the use of damping proportional to stroking velocity. A coefficient DAMP(J), J = 1, 2, . . . , NS, is provided in the input data DATA2. A non-zero, positive value of DAMP(J) will cause a strut load proportional to stroking velocity and to DAMP(J), opposing the stroking velocity. (This velocity load will not exceed the plastic load, FØRS). Again, a purely elastic strut is obtained by setting DAMP(J) to zero.

Several miscellaneous constants must be read in with the vehicle input data. They are the gravitational constant G, the real time increment DTØ, the total real program execution time TTIME, time increment between plotting points TPLØT (preferably a multiple of DTØ), and the number of vehicle struts NS.

The CRT plotting may be omitted (or included) by assigning zero (or non-zero) values to three variables PTEST(1), PTEST(2), and PTEST(3). PTEST(1) controls plotting of roll, pitch, and yaw. PTEST(2) controls plotting of acceleration, velocity, and displacement. PTEST(3) controls plotting of strut strokes. Setting all variables PTEST(I) to 1.0, for example, will cause three plates to be plotted for each landing. Setting all the variables to zero will cause omission of all plotting.

Refer to Appendix B for examples of typical vehicle and control parameter data.

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INITIAL VALUE DATA

All initial value data are read into the computer through a single statement, READ (5, DATA2). (Refer to subroutine INPUT, Appendix A). Variables which may be read in by this command are listed in the NAMELIST statement, NAMELIST/DATA2. Initial value data for twenty sets of vehicle landing conditions are given in Appendix C. Note that all landing conditions are initialized by the first set of data following the first appearance of the name DATA2. Subsequent sets of data reinitialize specific parameters, while all other parameters retain their original initial values. Initial value and other input parameters are identified in the List of Symbols.

A program control parameter IPRINT must appear in every set of initial values following the NAMELIST name DATA2. IPRINT must be assigned either the value of one (1) or two (2). Figure 6 illustrates program operation for allowable values of IPRINT.

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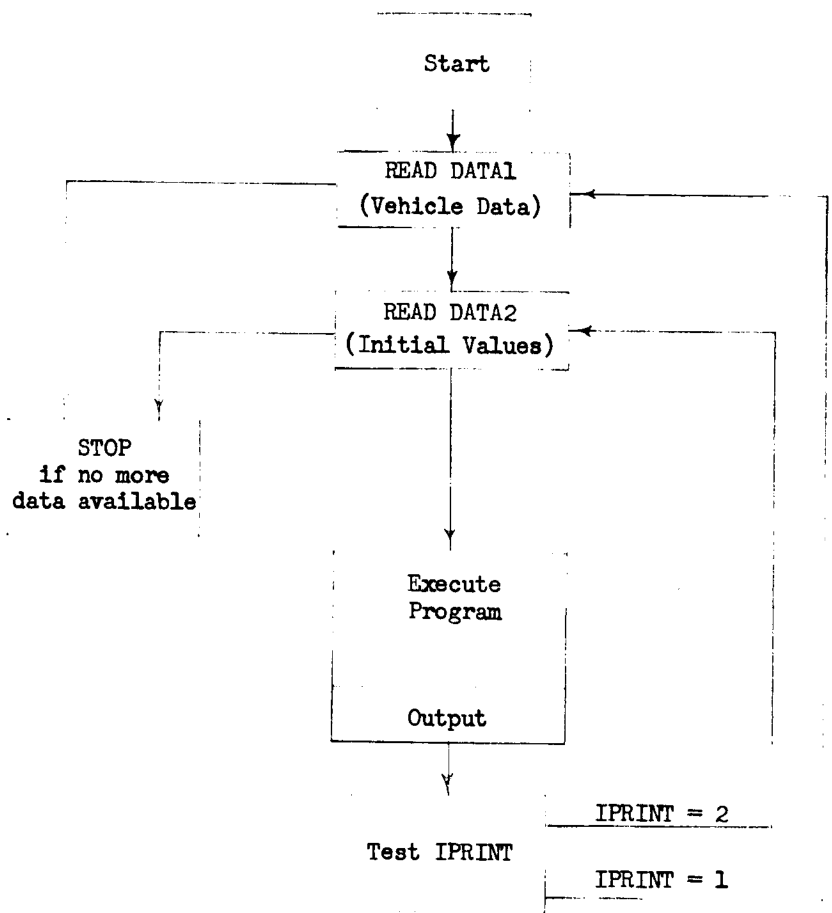

Figure 6. Program Operation for Allowable Values of IPRINT

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PROGRAM OUTPUT

The output of the program is controlled by subroutine ØUTPUT and consists of both printing and CRT plotting. Although a minimum of output is used in this program version, several blocks of data are stored in CØMMØN locations. A program user may select any combination of these variables for plotting by modifying subroutine ØUTPUT.

A sample of printed output from the program is shown in Appendix D. This output corresponds to the vehicle data in Appendix B and to the first set of input value data in Appendix C. The first line of printed output, following the initial values, describes the reason for stopping normal execution of the program. Three maxima are given for each vehicle landing. They are the total acceleration ft/sec^2 of the c.g., the angle the capsule x axis makes with a ground normal, deg, and strut loads lb and strokes ft. Final linear and angular displacements and velocities in the earth coordinate system are also printed in units of feet, ft/sec, degrees, and radians/sec.

Three plates of CRT plotting normally accompany the printed output of each set of landing conditions (initial values). These plates are time traces of several important parameters describing vehicle behavior. The first plate (Figure 13, Appendix D) contains plots of roll, pitch, and yaw in degrees, measured in ground coordinates. The second plate (Figure 14, Appendix D) contains c.g. acceleration ft/sec^2, velocity ft/sec, and displacement ft normal to the ground. A third plate (Figure 15, Appendix D) illustrates strut strokes ft as function of time.

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APPENDIX A

FLOW DIAGRAMS AND PROGRAM LISTING

The complete computer program, for the solution of legged vehicle landing dynamics, includes the following:

Main Program

LEGGED (Figure 7)

Subprograms

INPUT (Figure 8)
START (Figure 9)
STRUT2 (Figure 11)
MØVE (Figure 10)
ØUTPUT (Figure 12)
FRIC
ATUDE
TRAN
ITRAN
AXB
GRAPH*

*A NAA package for producing CRT plotting.

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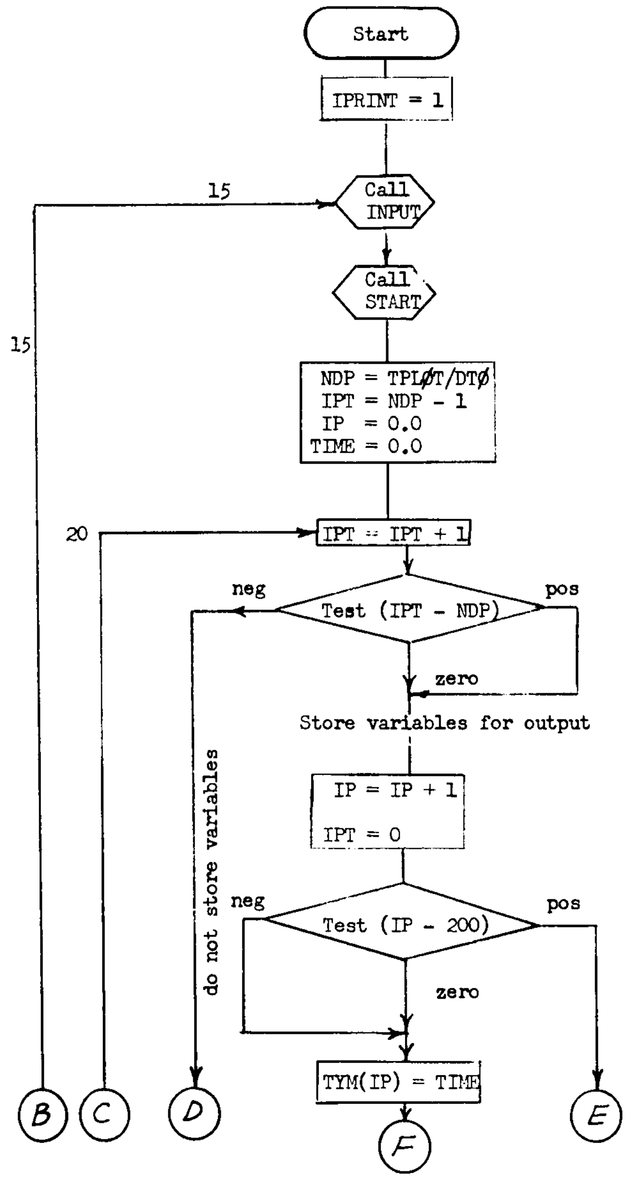

Figure 7. Flow Diagram of Program LEGGED (Sheet 1 of 3)

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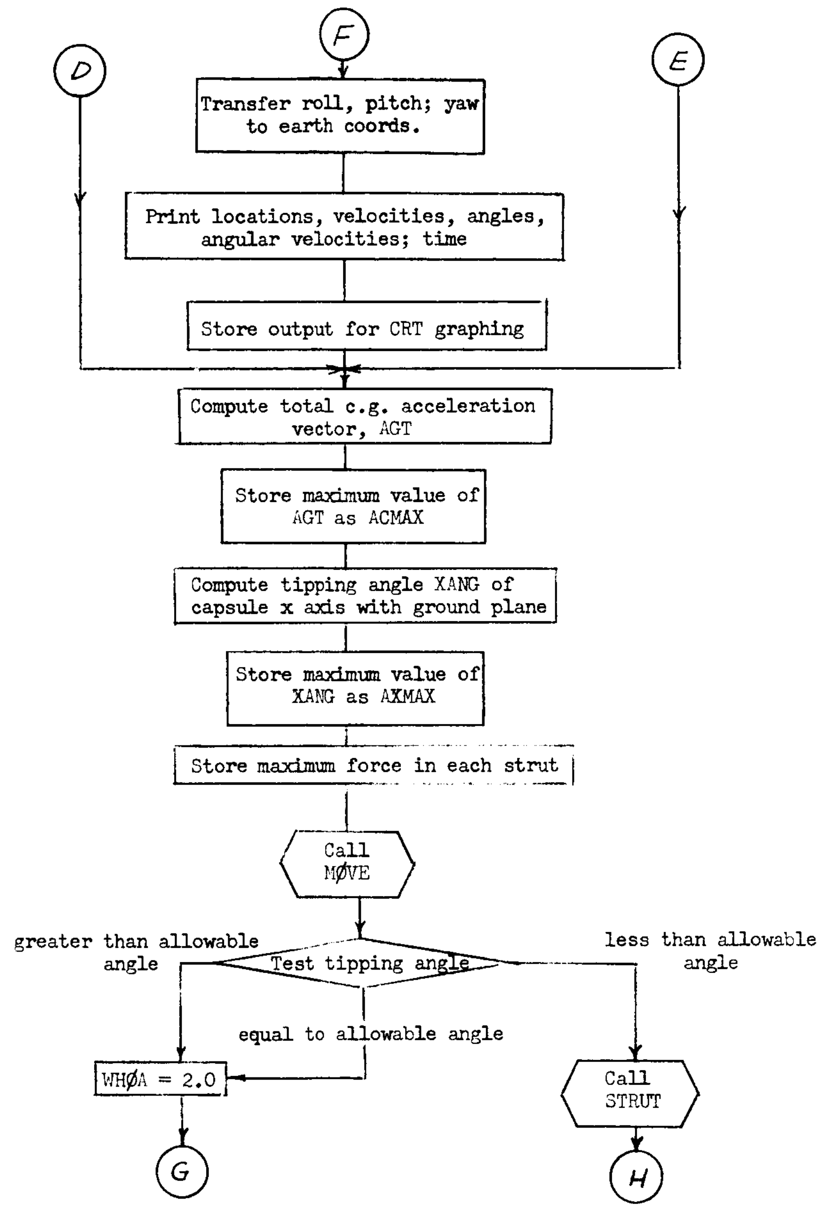

Figure 7. Flow Diagram of Program LEGGED (Sheet 2 of 3)

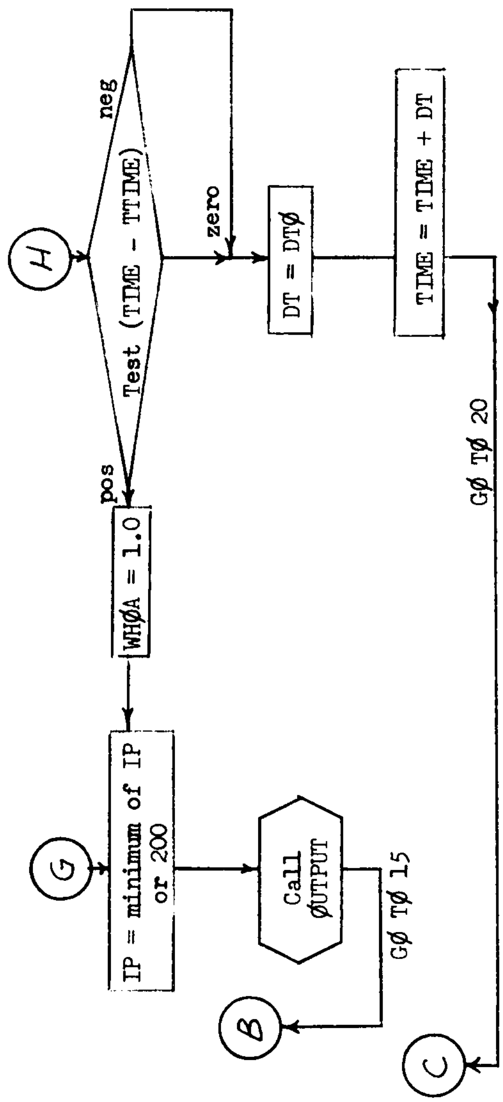

Figure 7. Flow Diagram of Program LEGGED (Sheet 3 of 3)

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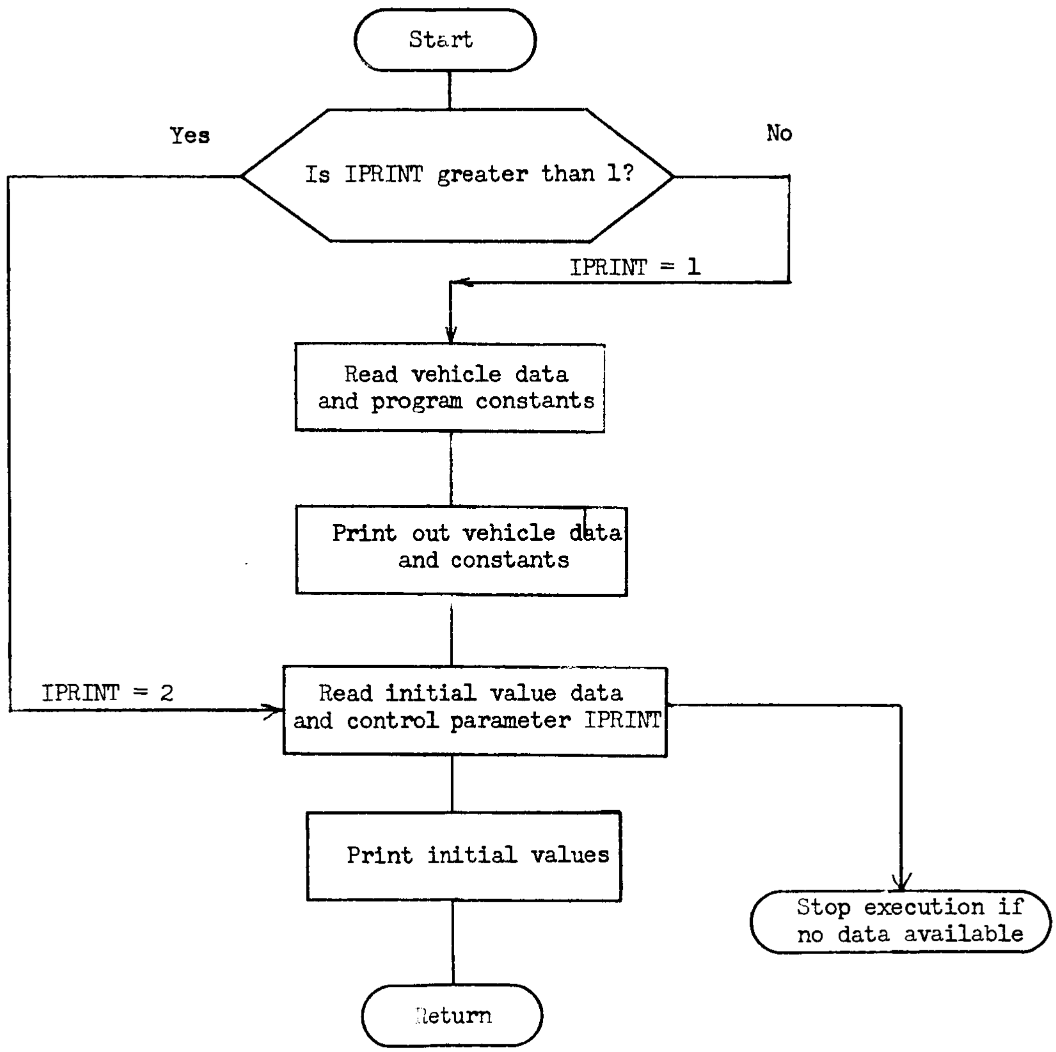

Figure 8. Flow Diagram of Subroutine INPUT

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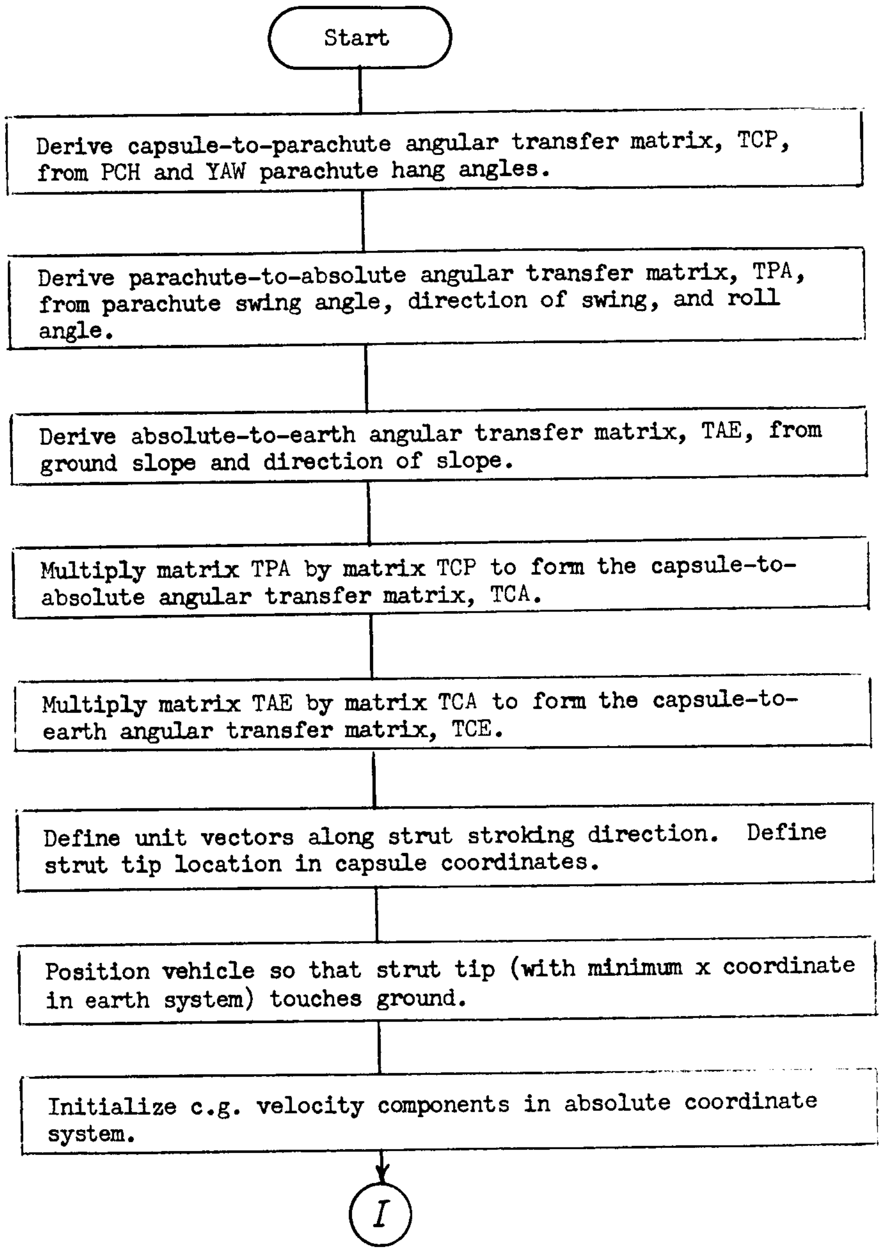

Figure 9. Flow Diagram of Subroutine START (Sheet 1 of 2)

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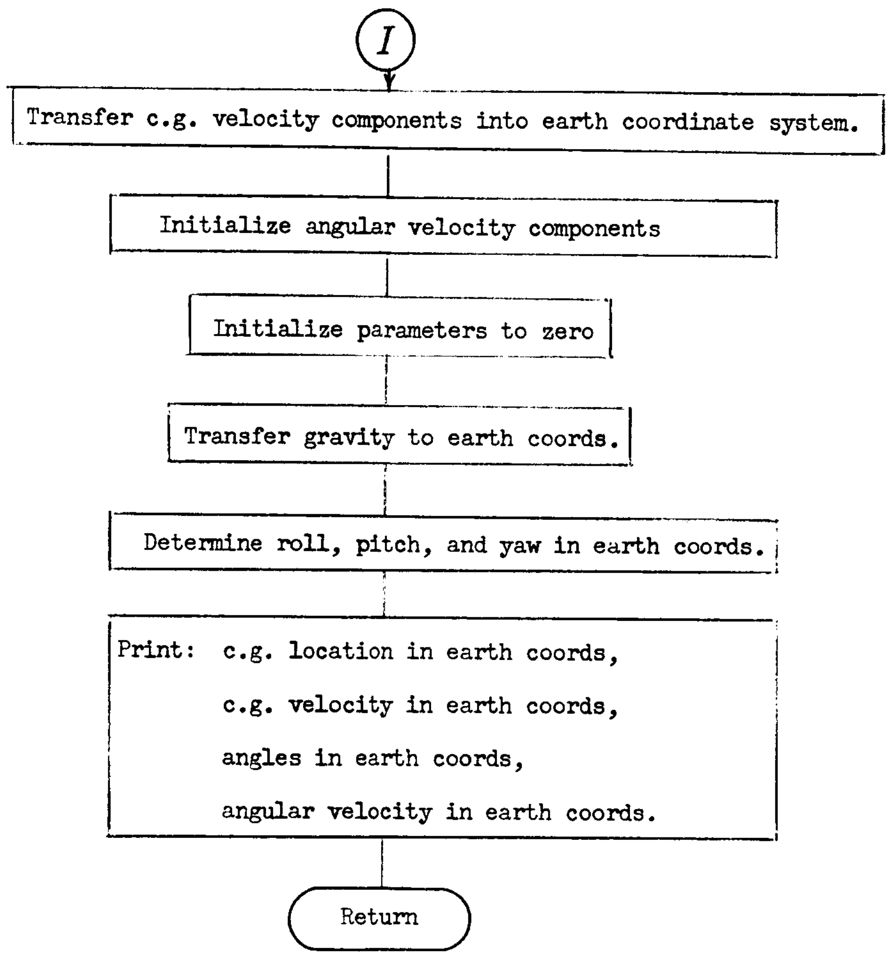

Figure 9. Flow Diagram of Subroutine START (Sheet 2 of 2)

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

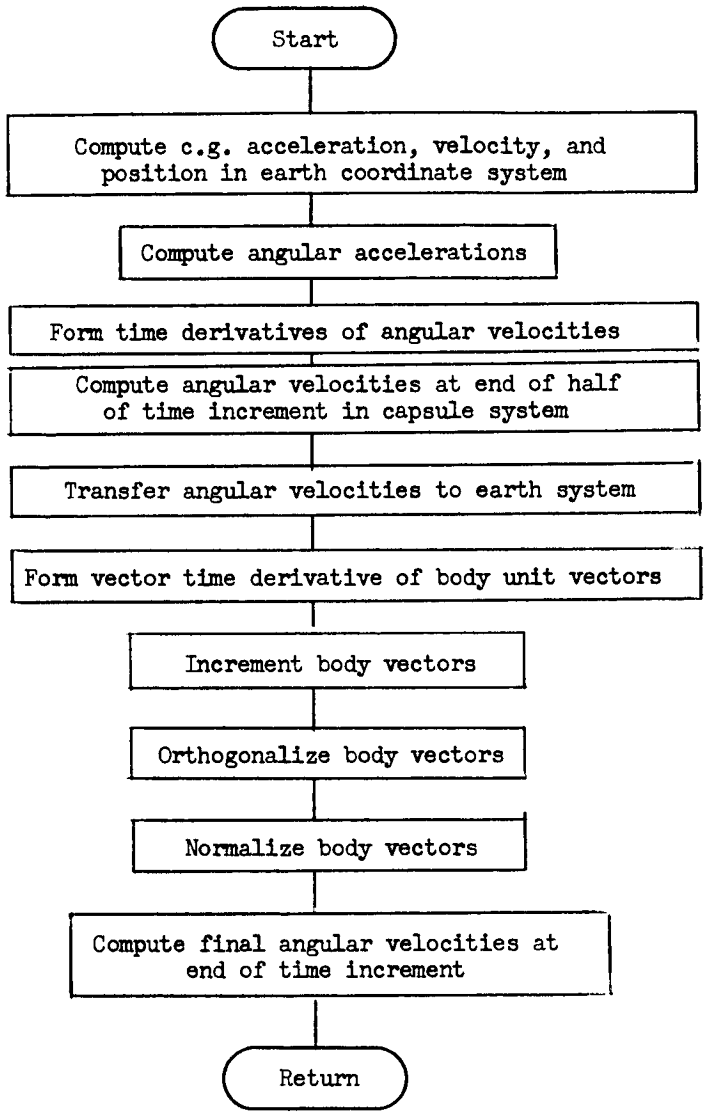

Figure 10. Flow Diagram of Subroutine MØVE

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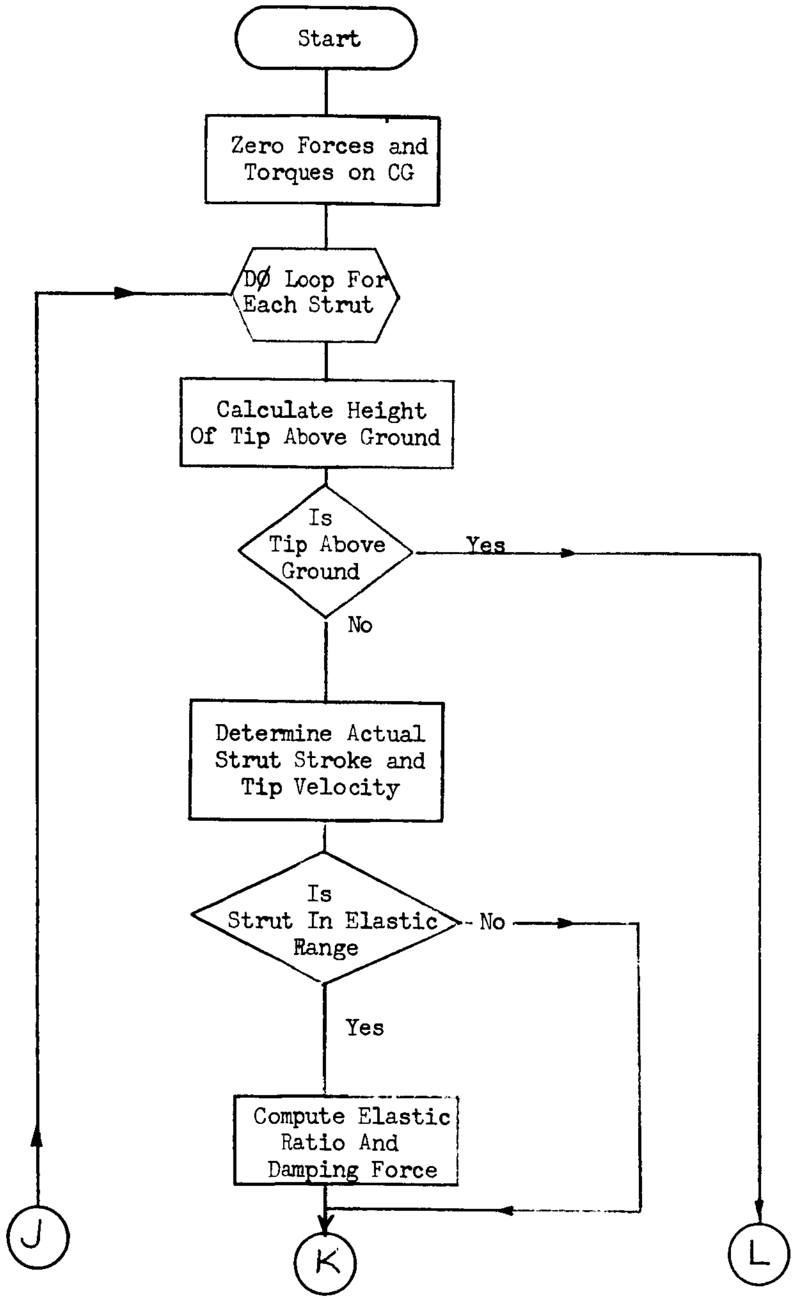

Figure 11. Flow Diagram of Subroutine STRUT (Sheet 1 of 2)

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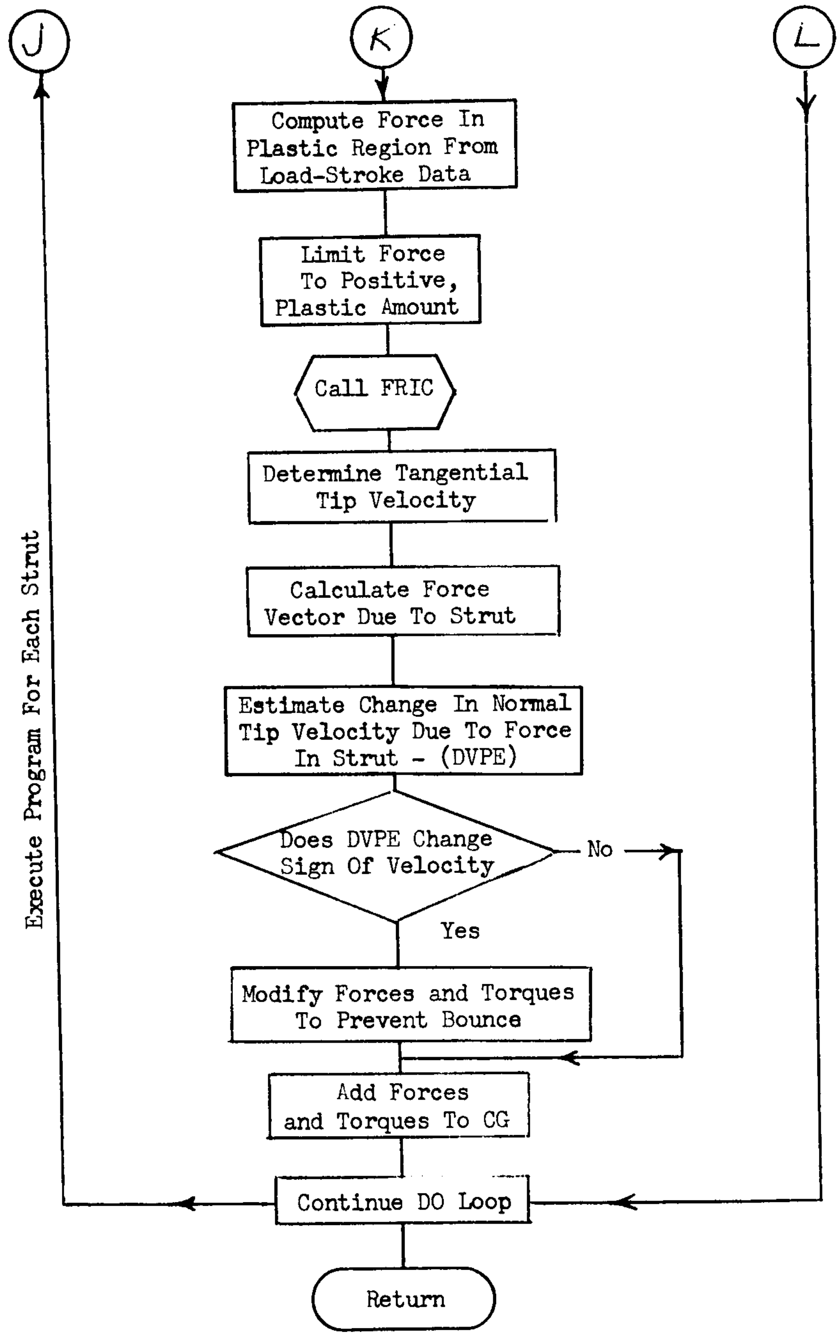

Figure 11. Flow Diagram of Subroutine STRUT (Sheet 2 of 2)

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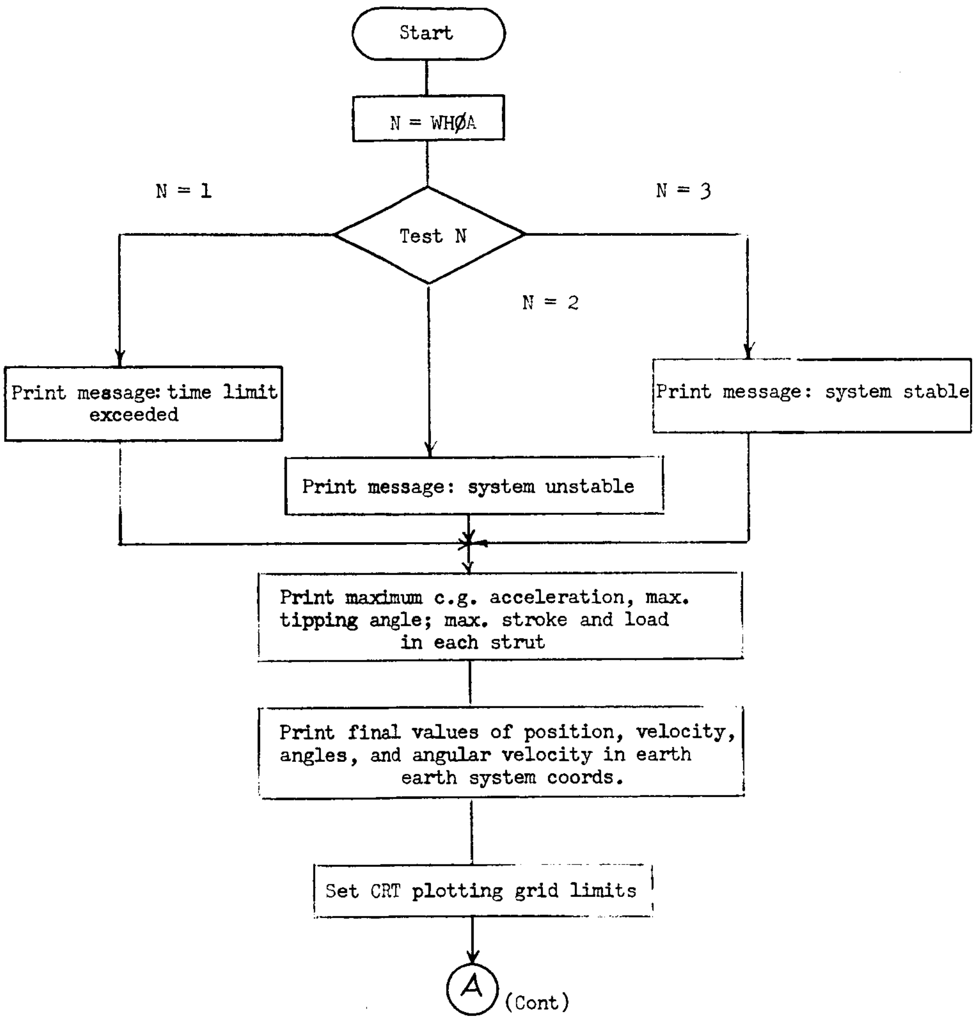

Figure 12. Flow Diagram of Subroutine ØUTPUT (Sheet 1 of 2)

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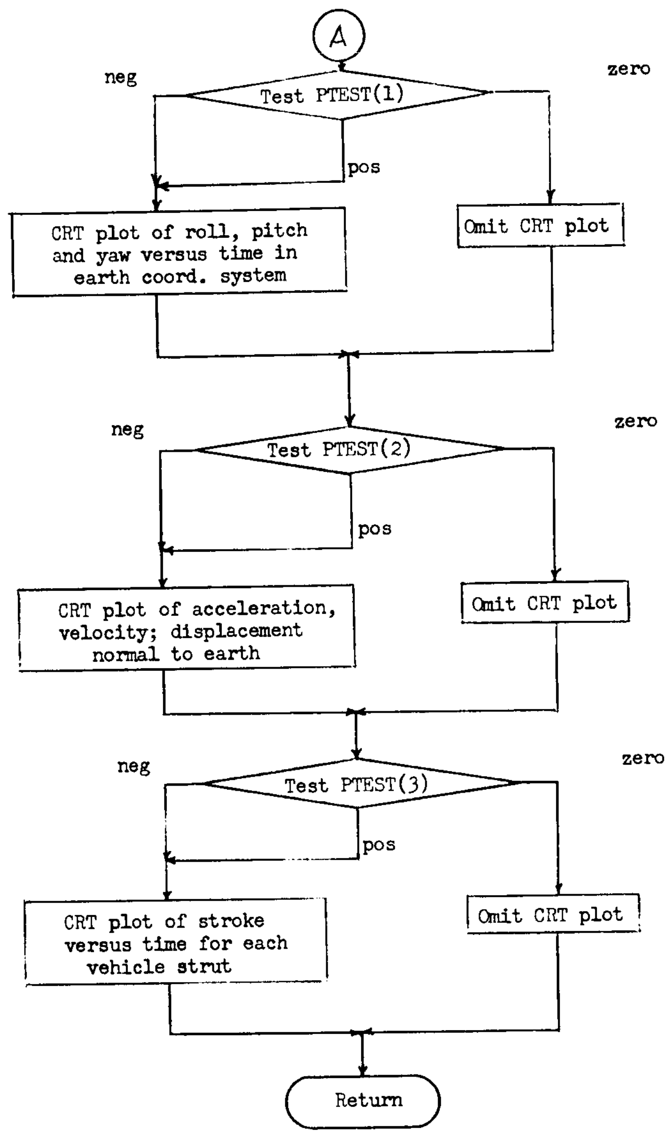

Figure 12. Flow Diagram of Subroutine ØUTPUT (Sheet 2 of 2)

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```
JOB 63                                                                   01/25/86
    LEGGED      -  EFN   SOURCE STATEMENT  -  IFN(S)  -

      COMMON       G,DTO,TTIME,TPLOT,VH,VV,ROL,PCH,YAW,WROL,WPCH,WYAW,SLP,00000020
     1             DSLP,SWG,DSWG,NS,IPRINT,FRC(10),RGCI(3),RSCI(3,10),     00000022
     2             RSFCI(3,10),RBCI(3,10),WT,ENTA(3),STRK(10,10),          00000024
     3             FORS(10,10),DF(10),DAMP(10),PTEST(10)                   00000026
      COMMON       DT,TIME,ACMAX,AXMAX,XANG,FMAX(10),ANG(3),RGE(3),VGE(3),00000030
     1             AGE(3),WGC(3),QGC(3), RGA(3),STROK(10),FORC (10),       00000032
     2             PSTR(10),FGE(3),TGC(3),DWGC(3),DTCE(3,3),RSC(3,10),     00000034
     3             USC(3,10),RSCL(3),RSE(3),VSC(3),USE(3),VSE(3),FSE(3),   00000036
     4             FSC(3),TSC(3),VGC(3), RPC(3),VPE(3),TCE(3,3),TAE(3,3),  00000038
     5             TCP(3,3),TPA(3,3),TCA(3,3),EMU,GV(3),VGA(3),WHOA        00000040
      COMMON       RSFC(3,10),ARMV(3),ETA(3,10),ELF(10),TYMJ(41),IP,TP(3),00000042
     1             DVPC(3),DVPE(3),WGE(3)                                  00000043
      COMMON       RGAS(200,3),RGES(200,3),VGES(200,3),AGES(200,3),        00000044
     1             WGCS(200,3),QGCS(200,3),ANGS(200,3),DSTS(200,10),       00000046
     2             FSTS(200,10),TYM(200)                                   00000048
   10 IPRINT =1                                                            00001000
   15 CALL INPUT                                                           00001010    3
      CALL START                                                           00001020    5
      TEST =-1.0                                                           00001025
      WRITE (6,90)                                                                     7
   90 FORMAT  (1H1,9X,33H       POSITIONS IN SURFACE SYSTEM / 6X,12HDISPL
     1ACEMENT ,12X,10HVELOCITIES ,14X6HANGLES ,16X,13HANG. VELOCITY  /
     2 6X1HX7X1HY7X1HZ7X1HX7X1HY7X1HZ, 6X4HROLL3X5HPITCH4X3HYAW 6X1HX
     3             7X1HY 7X1HZ  / )
      NDP = TPLOT/DTO+.0001                                                00001030
      IPT = NDP -1                                                         00001040
      IP =0.0                                                              00001050
      TIMF =0.0                                                            00001060
   20 IPT = IPT +1                                                         00001070
      IF (IPT -NDP) 100,30,30                                              00001080
   30 IP =IP +1
      IPT =0
      IF(IP -200) 35,35,100
   35 TYM(IP) =TIME
      CALL ATUDE(TCE,ANG)                                                              20
      WRITE (6,95) RGE ,VGE,ANG ,WGC,TYM(IP)                                           21
```

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```
  JOB 63                                                      01/25/86
      LEGGED      -  EFN   SOURCE STATEMENT  -  IFN(S)  -

 95 FORMAT (12F8.2,1F8.4)
    DO 40 I=1,3
    ANGS(IP,I) =ANG(I)
    RGES(IP,I) =RGE(I)
    VGES(IP,I) =VGE(I)
    AGES(IP,I) =AGE(I)
    WGCS(IP,I) =WGC(I)
    QGCS(IP,I) = DWGC(I)
 40 CONTINUE
    DO 50 K =1,NS                                              00001090
    DSTS(IP,K) =STROK(K)                                       00001100
 50 FSTS(IP,K) =FORC(K)                                        00001110
    CALL INTRAN(TAE,RGE,RGA)                                   00001120    55
    DO 60 I=1,3                                                00001130
 60 RGAS(IP,I) =RGA(I)                                         00001140
100 AGT = SQRT(AGE(1)**2 +AGE(2)**2 +AGE(3)**2 )               00001150    66
    ACMAX  = AMAX1(ACMAX,AGT)                                  00001160
    XANG = ATAND(SQRT(1.0 -TCE(1,1)**2) , TCE(1,1)  )          00001170    67    68
    AXMAX= AMAX1(AXMAX,XANG)                                   00001180
    DO 110 K=1,NS                                              00001190
110 FMAX(K) =AMAX1(FMAX(K),FORC(K))                            00001200
118 CALL MOVE                                                              79
    IF(TCE(1,1)-0.5 ) 120,120,130                              0C001212
120 WHOA =2.0                                                  00C01214
     GO TO 300                                                 00001216
130 CALL STRUT                                                 0C001220    85
    IF (TIME - TTIME) 180,180,200                              00001230
180 DT = DTO                                                   00001240
    TIME = TIME +DT                                            00001250
    GO  TO  20                                                 00001260
200 WHOA = 1.0                                                 00001265
300 IP = MINO(IP ,200)                                         00001990
    CALL OUTPUT                                                00002000    93
    GO TO 15                                                   00002100
    END                                                        00003000
```

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```
       JOB 63                                                            01/25/86
          INPUT*      -  EFN   SOURCE STATEMENT  -  IFN(S)  -

      SUBROUTINE INPUT                                                  INPU0011
      COMMON      G,DTO,TTIME,TPLOT,VH,VV,ROL,PCH,YAW,WROL,WPCH,WYAW,SLP,00000020
     1            DSLP,SWG,DSWG,NS,IPRINT,FRC(10),RGCI(3),RSCI(3,10),    00000022
     2            RSFCI(3,10),RBCI(3,10),WT,ENTA(3),STRK(10,10),         00000024
     3            FORS(10,10),DE(10),DAMP(10),PTEST(10)                  00000026
      COMMON      DT,TIME,ACMAX,AXMAX,XANG,FMAX(10),ANG(3),RGE(3),VGE(3),00000030
     1            AGE(3),WGC(3),QGC(3), RGA(3),STROK(10),FORC (10),      00000032
     2            PSTR(10),FGE(3),TGC(3),DWGC(3),DTCE(3,3),RSC(3,10),    00000034
     3            USC(3,10),RSCL(3),RSE(3),VSC(3),USE(3),VSE(3),FSE(3),  00000036
     4            FSC(3),TSC(3),VGC(3), RPC(3),VPE(3),TCE(3,3),TAE(3,3), 00000038
     5            TCP(3,3),TPA(3,3),TCA(3,3),EMU,GV(3),VGA(3),WHOA       00000040
      COMMON      RSFC(3,10),ARMV(3),ETA(3,10),ELF(10),TYMJ(41),IP,TP(3),00000042
     1            DVPC(3),DVPE(3),WGE(3)                                 00000043
      COMMON      RGAS(200,3),RGES(200,3),VGES(200,3),AGES(200,3),       00000044
     1            WGCS(200,3),QGCS(200,3),ANGS(200,3),DSTS(200,10),      00000046
     2            FSTS(200,10),TYM(200)                                  00000048
      NAMELIST/DATA1/G,DTO,TTIME,TPLOT,NS,RGCI,RSCI,RSFCI,RBCI,          INPU0050
     1            WT,ENTA,STRK,FORS,DE,DAMP,PTEST                        INPU0055
      NAMELIST/DATA2/VH,VV,ROL,PCH,YAW,WROL,WPCH,WYAW,SLP,DSLP,FRC,SWG,  INPU0060
     1            DSWG,IPRINT                                            INPU0070
      IF(IPRINT.GT.1) GO TO 1                                            INPU0075
C     READ VEHICLE DATA                                                  INPU0080
      READ(5,DATA1)                                                      INPU0090
C     PRINT OUT VEHICLE DATA                                             INPU0140    4
    2 FORMAT (1H1)                                                       INPU0150
      WRITE (6,2)                                                        INPU0160    5
    3 FORMAT (10X,12HVEHICLE DATA)                                       INPU0170
      WRITE (6,3)                                                        INPU0180    6
    4 FORMAT (/,10X, 4HWT =,E12.5,5X,4HIXX=,E12.5,5X,4HIYY=,E12.5,5X4HIZZINPU0190
     1Z=,E12.5)                                                          INPU0200
      WRITE(6,4) WT,ENTA(1),ENTA(2),ENTA(3)                              INPU0210    7
    5 FORMAT (/,10X,15HNUMBER OF LEGS=,I4,2X,4HG=   ,E12.5,5X,4HDT= ,    INPU0220
     1E12.5)                                                             INPU0221
      WRITE (6,5) NS,G,DTO                                               INPU0230    8
    6 FORMAT (/,10X,34HGEOMETRY IN CAPSULE INITIAL SYSTEM)               INPU0240
      WRITE (6,6)                                                        INPU0250    9
```

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```
JOB 63                                                                01/25/86
      INPUT*      -  EFN   SOURCE STATEMENT  -  IFN(S)  -

   7 FORMAT (/,36X,1HX,16X,1HY,16X,1HZ)                                INPU0260
     WRITE (6,7)                                                       INPU0270    10
   8 FORMAT (10X,20HCENTER OF GRAVITY    ,E12.5,5X,E12.5,5X,E12.5)     INPU0280
     WRITE (6,8) RGCI(1),RGCI(2),RGCI(3)                               INPU0290    11
   9 FORMAT (10X,20HMOVABLE STRUT TIPS   )                             INPU0300
     WRITE (6,9)                                                       INPU0310    12
     DO 11 J=1,NS                                                      INPU0320
  10 FORMAT (10X,6X,4HLEG ,I3,7X,E12.5,5X,E12.5,5X,E12.5)              INPU0330
  11 WRITE (6,10)   J,RSCI(1,J),RSCI(2,J),RSCI(3,J)                    INPU0340    16
  12 FORMAT (10X,16HFIXED STRUT TIPS)                                  INPU0350
     WRITE (6,12)                                                      INPU0355    21
     DO 13 J=1,NS                                                      INPU0360
  13 WRITE (6,10)   J,RSFCI(1,J),RSFCI(2,J),RSFCI(3,J)                 INPU0370
C    PRINT LOAD-STROKE DATA                                            INPU0380    25
  16 FORMAT (/,10X,22HSTRUT LOAD-STROKE DATA)                          INPU0390
     WRITE (6,16)                                                      INPU0400    30
     DO 20 J=1,NS                                                      INPU0410
  17 FORMAT (/,10X,4HLEG ,I3)                                          INPU0420
     WRITE (6,17) J                                                    INPU0430    33
  18 FORMAT (10X,5HPOINT, 9X, 4HLOAD,12X,6HSTROKE,7X,7HELAST= ,E12.5,5XINPU0440
    1,6HDAMP= ,E12.5)                                                  INPU0441
     WRITE (6,18) DE(J),DAMP(J)                                        INPU0450    34
     DO 20 I=1,10                                                      INPU0460
  19 FORMAT (12X,I2, 5X,E12.5, 5X,E12.5)                               INPU0470
  20 WRITE (6,19) I,FORS(I,J),STRK(I,J)                                INPU0480
C    READ INITIAL VALUE DATA                                           INPU0490    39
   1 READ (5,DATA2)                                                    INPU0500
C    PRINT OUT INITIAL VALUES                                          INPU0510    45
     WRITE (6,2)                                                       INPU0520    46
  22 FORMAT (10X,14HINITIAL VALUES)                                    INPU0530
     WRITE (6,22)                                                      INPU0540    47
  23 FORMAT (/,10X,20HVERTICAL VELOCITY=   ,E12.5,8X,20HHORIZONTAL VELOCINPU0550
    1ITY=,E12.5)                                                       INPU0560
     WRITE (6,23) VV,VH                                                INPU0570    48
  24 FORMAT (/,10X,20HCHUTE ROLL ANGLE=    ,E12.5,8X,20HPITCH HANG ANGLEINPU0580
    1=    ,F12.5,    //,10X,20HYAW HANG ANGLE=      ,E12.5)            INPU0590
     WRITE (6,24) ROL,PCH,YAW                                          INPU0600    49
```

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```
     JOB 63                                                                01/25/86
         INPUT*      -  EFN   SOURCE STATEMENT  -  IFN(S)  -

  25 FORMAT (/,10X,20HROLL VELOCITY=       ,E12.5,8X,20HPITCH VELOCITY= INPU0610
   1     ,E12.5,    //,10X,20HYAW VELOCITY=       ,E12.5)                INPU0620
     WRITE(6,25)WROL,WPCH,WYAW                                           INPU0625     50
  26 FORMAT (/,10X,20HGROUND SLOPE=       ,E12.5,8X,20HSLOPE DIRECTION=INPU0630
   1     ,E12.5)                                                         INPU0640
     WRITE (6,26) SLP,DSLP                                               INPU0650     51
  27 FORMAT (/,10X,20HCHUTE SWING ANGLE=  ,E12.5,8X,20HSWING DIRECTION=INPU0660
   1     ,E12.5)                                                         INPU0670
     WRITE (6,27) SWG,DSWG                                               INPU0680     52
  28 FORMAT (/,10X,24HCOEFFICIENTS OF FRICTION)                          INPU0690
     WRITE (6,28)                                                        INPU0700     53
     DO 21 J=1,10                                                        INPU0710
  21 WRITE (6,19) J,FRC(J)                                               INPU0720     57
     RETURN                                                              INPU0740
     END                                                                 INPU0750
```

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```
JOB 63                                                                     01/25/86
     START*      -  EFN   SOURCE STATEMENT  -  IFN(S)  -

      SUBROUTINE START                                                  STAR0015
      COMMON     G,DTO,TTIME,TPLOT,VH,VV,ROL,PCH,YAW,WROL,WPCH,WYAW,SLP,00000020
     1           DSLP,SWG,DSWG,NS,IPRINT,FRC(10),RGCI(3),RSCI(3,10),     00000022
     2           RSFCI(3,10),RBCI(3,10),WT,ENTA(3),STRK(10,10),          00000024
     3           FORS(10,10),DE(10),DAMP(10),PTEST(10)                   00000026
      COMMON     DT,TIME,ACMAX,AXMAX,XANG,FMAX(10),ANG(3),RGE(3),VGE(3),00000030
     1           AGE(3),WGC(3),QGC(3), RGA(3),STROK(10),FORC (10),       00000032
     2           PSTR(10),FGE(3),TGC(3),DWGC(3),DTCE(3,3),RSC(3,10),     00000034
     3           USC(3,10),RSCL(3),RSE(3),VSC(3),USE(3),VSE(3),FSE(3),   00000036
     4           FSC(3),TSC(3),VGC(3), RPC(3),VPE(3),TCE(3,3),TAE(3,3),  00000038
     5           TCP(3,3),TPA(3,3),TCA(3,3),EMU,GV(3),VGA(3),WHOA        00000040
      COMMON     RSFC(3,10),ARMV(3),ETA(3,10),ELF(10),TYMJ(41),IP,TP(3),00000042
     1           DVPC(3),DVPE(3),WGE(3)                                  00000043
      COMMON     RGAS(200,3),RGES(200,3),VGES(200,3),AGES(200,3),        00000044
     1           WGCS(200,3),QGCS(200,3),ANGS(200,3),DSTS(200,10),       00000046
     2           FSTS(200,10),TYM(200)                                   00000048
C     DERIVE ELEMENTS OF MATRIX TCP FROM PITCH AND YAW                  STARC079
      CTHT=COSD(PCH)                                                    STAR0080     2
      STHT=SIND(PCH)                                                    STAR0090     3
      CPSI=COSD(YAW)                                                    STAR0100     4
      SPSI=SIND(YAW)                                                    STAR0105
C     FORM MATRIX TCP                                                   STAR0110     5
      TCP(1,1) = CTHT*CPSI                                              STAR0120
      TCP(1,2) =-CTHT*SPSI                                              STAR0130
      TCP(1,3) = STHT                                                   STAR0140
      TCP(2,1) = SPSI                                                   STAR0150
      TCP(2,2) = CPSI                                                   STAR0160
      TCP(2,3) = 0.0                                                    STAR0170
      TCP(3,1) =-STHT*CPSI                                              STAR0180
      TCP(3,2) = STHT*SPSI                                              STAR0190
      TCP(3,3) = CTHT                                                   STAR0200
C                                                                       STAR0208
C     CONVERT CHUTE SWING ANGLE AND DIRECTION OF SWING TO PITCH AND YAW STAR0210
C     DERIVE ELEMENTS OF MATRIX TPA                                     STAR0212
      ARG1 =SIND(SWG)*COSD(DSWG)                                        STAR0250     6       7
      ARG2 =COSD(SWG)                                                   STAR0260     8
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```
 JOB 63                                                                   01/25/86
      START*      -  EFN   SOURCE STATEMENT  -  IFN(S)  -

       THT = ATAN(ARG1,ARG2)                                               STAR0270   9
       ARG3 = SIND(SWG)*SIND(DSWG)*COS (THT)                               STAR0280   10    11    12
       ARG4 =COSD(SWG)                                                     STAR0290   13
       PSI = ATAN(ARG3,ARG4)                                               STAR0300   14
       CPHI=COSD(ROL)                                                      STAR0310   15
       SPHI=SIND(ROL)                                                      STAR0320   16
       CPSI=COS(PSI)                                                       STAR0330   17
       SPSI=SIN(PSI)                                                       STAR0340   18
       CTHT=COS(THT)                                                       STAR0350   19
       STHT=SIN(THT)                                                       STAR0360
C      FORM MATRIX TPA                                                     STAR0370   20
       TPA(1,1)=  CTHT*CPSI                                                STAR0380
       TPA(1,2)= -CTHT*SPSI                                                STAR0390
       TPA(1,3)=  STHT                                                     STAR0400
       TPA(2,1)=  SPHI*STHT*CPSI + CPHI*SPSI                               STAR0410
       TPA(2,2)= -SPHI*STHT*SPSI + CPHI*CPSI                               STAR0420
       TPA(2,3)= -SPHI*CTHT                                                STAR0430
       TPA(3,1)= -CPHI*STHT*CPSI + SPHI*SPSI                               STAR0440
       TPA(3,2)=  CPHI*STHT*SPSI + SPHI*CPSI                               STAR0450
       TPA(3,3)=  CPHI*CTHT                                                STAR0460
C                                                                          STAR0465
C      CONVERT GROUND SLOPE AND DIRECTION OF SLOPE TO PITCH AND YAW        STAR0470
C      DERIVE ELEMENTS OF MATRIX TAE                                       STAR0472
       ARG5 = SIND(SLP)*COSD(DSLP)                                         STAR0500   21    22
       ARG6 =COSD(SLP)                                                     STAR0510   23
       THT = ATAN(ARG5,ARG6)                                               STAR0520   24
       ARG7 = SIND(SLP)*SIND(DSLP)* COS(THT)                               STAR0530   25    26    27
       ARG8 =COSD(SLP)                                                     STAR0540   28
       PSI = ATAN(ARG7,ARG8)                                               STAR0550   29
       CTHT=COS(THT)                                                       STAR0560   30
       STHT=SIN(THT)                                                       STAR0570   31
       CPSI=COS(PSI)                                                       STAR0580   32
       SPSI=SIN(PSI)                                                       STAR0590
C      FORM MATRIX TAE                                                     STAR0600   33
       TAE(1,1) = CTHT*CPSI                                                STAR0610
       TAE(1,2) = SPSI                                                     STAR0620
       TAE(1,3) =-STHT*CPSI                                                STAR0630
```

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```
 JOB 63                                                         01/25/86
      START*      -  EFN   SOURCE STATEMENT  -  IFN(S)  -

       TAE(2,1) =-CTHT*SPSI                                      STAR0640
       TAE(2,2) = CPSI                                           STAR0650
       TAE(2,3) = STHT*SPSI                                      STAR0660
       TAE(3,1) = STHT                                           STAR0670
       TAE(3,2) = 0.0                                            STAR0680
       TAE(3,3) = CTHT                                           STAR0690
C                                                                STAR0695
C      MULTIPLY TPA BY TCP TO FORM TCA                           STAR0700
       DO 2 I=1,3                                                STAR0710
       DO 2 J=1,3                                                STAR0720
       TCA(I,J)= 0.0                                             STAR0730
       DO 2 K=1,3                                                STAR0740
     2 TCA(I,J)= TPA(I,K) * TCP(K,J) +TCA(I,J)                   STAR0750
C                                                                STAR0755
C      MULTIPLY TAE BY TCA TO FORM TCE                           STAR0760
       DO 3 I=1,3                                                STAR0770
       DO 3 J=1,3                                                STAR0780
       TCE(I,J)= 0.0                                             STAR0790
       DO 3 K=1,3                                                STAR0800
     3 TCE(I,J)= TAE(I,K) * TCA(K,J) +TCE(I,J)                   STAR0810
C                                                                STAR0815
C      GENERATE STRUT DATA                                       STAR0820
       DO 120 J =1,NS                                            STAR0830
       VL =0.0                                                   STAR0840
       DO 100 I =1,3                                             STAR0850
       USC(I,J) = RSFCI(I,J) -RSCI(I,J)                          STAR0860
       VL = VL + USC(I,J)**2                                     STAR0870
   100 CONTINUE                                                  STAR0880
       VL = SQRT(VL)                                             STAR0890    80
       DO 110 I =1,3                                             STAR0900
       USC(I,J) = USC(I,J)/VL                                    STAR0910
   110 RSC(I,J) =(RSCI(I,J) -RGCI(I))/12.0                       STAR0920
   120 CONTINUE                                                  STAR0930
C                                                                STAR0935
C      POSITION CAPSULE ON GROUND                                STAR0940
       DMIN = 0.0                                                STAR0950
       DO 130 J =1,NS                                            STAR0960
```

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```
      JOB 63                                                       01/25/86
          START*     -  EFN   SOURCE STATEMENT  -  IFN(S)  -

        CALL TRAN(TCE,RSC(1,J),RSE)                                STAR0970     97
    130 DMIN = AMIN1(RSE(1),DMIN)                                  STAR0980
        RGE(1)=-DMIN                                               STAR0990
        RGE(2) =0.0                                                STAR1000
        RGE(3) =0.0                                                STAR1010
C                                                                  STAR1015
C       SET INITIAL VELOCITY COMPONENTS IN ABSOLUTE SYSTEM         STAR1017
        VGA(1) =-ABS(VV)                                           STAR1020
        VGA(3) = ABS(VH)                                           STAR1030
        VGA(2) = 0.0                                               STAR1040
C                                                                  STAR1045
C       TRANSFER VELOCITY COMPONENTS TO EARTH SYSTEM               STAR1046
        CALL TRAN  (TAE,VGA,VGE)                                   STAR1050
C                                                                  STAR1055
C       SET INITIAL ANGULAR VELOCITY COMPONENTS                    STAR1056     101
        WGC(1) = WROL*.017453                                      STAR1060
        WGC(2) = WPCH*.017453                                      STAR1070
        WGC(3) = WYAW*.017453                                      STAR1080
C                                                                  STAR1085
C       INITIALIZE PARAMETERS                                      STAR1086
        DO 140 I =1,3                                              STAR1090
        AGE(I) =0.0                                                STAR1100
    140 DWGC(I) =0.0                                               STAR1110
        ACMAX = 0.0                                                STAR1120
        AXMAX = 0.0                                                STAR1130
        DO 150 J=1,NS                                              STAR1140
        PSTR(J) =0.0                                               STAR1142
        STROK(J) =0.0                                              STAR1144
    150 FMAX(J) =0.0                                               STAR1150
        WHOA = 0.0                                                 STAR1160
C                                                                  STAR1165
C       TRANSFER GRAVITY TO EARTH SYSTEM                           STAR1166
        USE(1)= G                                                  STAR1170
        USE(2)= 0.0                                                STAR1171
        USE(3)= 0.0                                                STAR1172
        CALL TRAN(TAE,USE,GV)                                      STAR1173
C                                                                  STAR1174
```

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```
   JOB 63                                                               01/25/86
       START*      -  EFN   SOURCE STATEMENT  -  IFN(S)  -

C      FIND CAPSULE ROLL, PITCH, AND YAW IN EARTH SYSTEM                STAR1176     120
       CALL ATUDE(TCE,ANG)                                              STAR1180     122
       WRITE (6,90) RGE ,VGE,ANG ,WGC                                   STAR1190     123
    90 FORMAT(1H-,9X,35HINITIAL POSITIONS IN SURFACE SYSTEM /10X,12HDISPLSTAR1200
      1ACEMENT ,12X,10HVELOCITIES ,14X6HANGLES ,16X,13HANG. VELOCITY  /  STAR1210
      2 6X1HX7X1HY7X1HZ7X1HX7X1HY7X1HZ, 5X4HROLL4X5HPITCH4X3HYAW 6X1HX   STAR1220
      3          7X1HY 7X1HZ  / 12F8.2  )                               STAR1230
       RETURN                                                           STAR2000
       END                                                              STAR2010
```

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```
      JOB 63                                                                          01/25/86
         STRUT2      -  EFN    SOURCE STATEMENT  -  IFN(S)  -

      SUBROUTINE STRUT                                                         00000020
      COMMON      G,DTO,TTIME,TPLOT,VH,VV,ROL,PCH,YAW,WROL,WPCH,WYAW,SLP,00000020
     1            DSLP,SWG,DSWG,NS,IPRINT,FRC(10),RGCI(3),RSCI(3,10),      00000022
     2            RSFCI(3,10),RBCI(3,10),WT,ENTA(3),STRK(10,10),           00000024
     3            FORS(10,10),DE(10),DAMP(10),PTEST(10)                    00000026
      COMMON      DT,TIME,ACMAX,AXMAX,XANG,FMAX(10),ANG(3),RGE(3),VGE(3),C0000030
     1            AGE(3),WGC(3),QGC(3), RGA(3),STROK(10),FORC (10),        00000032
     2            PSTR(10),FGE(3),TGC(3),DWGC(3),DTCE(3,3),RSC(3,10),      00000034
     3            USC(3,10),RSCL(3),RSE(3),VSC(3),USE(3),VSE(3),FSE(3),    00000036
     4            FSC(3),TSC(3),VGC(3), RPC(3),VPE(3),TCE(3,3),TAE(3,3),   00000038
     5            TCP(3,3),TPA(3,3),TCA(3,3),EMU,GV(3),VGA(3),WHOA         0000004
      COMMON      RSFC(3,10),ARMV(3),ETA(3,10),ELF(10),TYMJ(41),IP,TP(3),00000042
     1            DVPC(3),DVPE(3),WGE(3)                                   00000043
      COMMON      RGAS(200,3),RGES(200,3),VGES(200,3),AGES(200,3),         00000044
     1            WGCS(200,3),QGCS(200,3),ANGS(200,3),DSTS(200,10),        00000046
     2            FSTS(200,10),TYM(200)                                    00000048
C     SET FORCES AND TORQUES ON CAPSULE TO ZERO                            00000995
      DO 10 I =1,3                                                         00001000
      FGE(I) = 0.0                                                         00001010
   10 TGC(I) = 0.0                                                         00C01020
C     THESE  ARE TOTAL STRUT FORCES                                        00001030
C                                                                          00001035
C     START OF STRUT LOOP                                                  00001040
      DO 200 J = 1,NS                                                      00001050
      FORC(J) =0.0                                                         00001055
C                                                                          00001057
C     FIND HEIGHT OF STRUT FROM GROUND IN EARTH SYSTEM                     00001058
      CALL TRAN( TCE,RSC(1,J),RSCL)                                        00C01060     15
      RSE  = RGE(1) +RSCL(1)                                               00001070
C     RSE IS THE HEIGHT ABOVE THE GROUND                                   00001080
C                                                                          00001090
C     STOP COMPUTATION FOR THIS STRUT IF STRUT IS OFF GROUND               00001095
      IF(RSE) 20,200,200                                                   00001100
C                                                                          00001105
C     FIND CG VELOCITY IN SYSTEM PARALLEL TO CAPSULE SYSTEM                00001107
   20 CALL INTRAN(TCE,VGE,VGC)                                             00001110
```

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```
     JOB 63                                                          01/25/86
        STRUT2     -  EFN   SOURCE STATEMENT  -  IFN(S)  -
C                                                                   00001115
C        TRANSFER UNIT STRUT VECTOR FROM CAPSULE TO EARTH SYSTEM    00001116   19
         CALL TRAN( TCE,USC(1,J),USE)                               00001120
C                                                                   00001125   22
         DELT = -RSE(1)/ USE(1)                                     00001130
C        DELT IS STRUT DEFORMATION                                  00001135
C                                                                   00001136
C        DETERMINE NEW STRUT TIP LOCATION AFTER STROKE INCREMENT    00001138
         DO 25  I =1,3                                              00001140
      25 RPC(I) = RSC(I,J) + DELT*USC(I,J)                          00001150
C                                                                   00001155
C        DETERMINE STRUT TIP VELOCITY IN CAPSULE PARALLEL SYSTEM    00001157
         CALL AXB( WGC,RPC,VSC)                                     00001160   31
         DO 30 I =1,3                                               00001170
      30 VSC(I) = VSC(I) +VGC(I)                                    00001180
C        THIS IS THE VELOCITY OF THE STRUTPOINT                     00001190
C                                                                   00001195
C        STOP COMPUTATION IF TOTAL STROKE LESS THAN PREVIOUS PLASTIC STROKE00001197
         IF(DELT - PSTR(J)) 200,200,40                              00001200
C                                                                   00001205
C        DETERMINE IF STROKE IS IN PLASTIC OR ELASTIC RANGE         00001207
      40 IF (DELT - PSTR(J)-DE(J))60,50,50                          00001210
C        50 IS PLASTIC ,60 IS ELASTIC,200 IS NO FORCE               00001220
C                                                                   00001225
C        IF IN PLASTIC RANGE, COMPUTE PLASTIC STROKE, SET VELOCITY FORCE   00001227
C        TO ZERO, SET RATIO                                         00001228
      50 PSTR(J) = DELT  -DE(J)                                     00001230
         FV =0.0                                                    00001240
         RAT =1.0                                                   00001250
         GO TO 80                                                   00001260
C                                                                   00001265
C        IF IN ELASTIC RANGE, COMPUTE DAMPING FORCE AND ELASTIC FORCE RATIO00001267
      60 VS = 0.0                                                   00001270
         DO 7C I = 1,3                                              00001280
      70 VS = VS -VSC(I)*USC(I,J)                                   00001290
C        VS IS STROKING VELOCITY  + =INCREASING , - =DECREASING     00001300
      76 FV = DAMP(J)*VS                                            00001310
```

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```
  JOB 63                                                          01/25/86
       STRUT2      -  EFN   SOURCE STATEMENT  -  IFN(S)  -

       RAT = (DELT -PSTR(J))/DE(J)                                00001320
C                                                                 00001330
C      DETERMINE STRUT FORCE FROM LOAD-STROKE DATA                00001490
   80 DO 100 K=2,10                                               00001500
       IF (PSTR(J) -STRK(K,J)) 90,90,100                          00001510
   90 K = K                                                       00001520
       GO TO 110                                                  00001530
  100 CONTINUE                                                    00001540
  110 FS =         FORS(K-1,J) + ( FORS(K,J) - FORS(K-1,J))       00001550
     1             /(STRK(K,J)-STRK(K-1,J)) *(PSTR(J) -STRK(K-1,J))  00001560
C                                                                 00001565
C      SET STRUT LOAD EQUAL TO THE MIN OF PLASTIC FORCE OR ELASTIC PLUS  00001567
C      DAMPING FORCES                                             00001568
       FE= FS*RAT + FV                                            00001570
       FS = AMIN1(FS,FE)                                          00001571
C      LIMIT STRUT LOAD TO POSITIVE VALUES                        00001572
       FS=AMAX1(FS,0.0)                                           00001573
C                                                                 00001574
C      SET FORCE ALONG STRUT AXIS                                 00001575
       FORC(J)= FS                                                00001577
C      SET STRUT STROKE                                           00001580
       STROK(J)=DELT                                              00001585
C                                                                 00001590
C      DETERMINE PRESENT FRICTION COEFFICIENT                     00001595
       CALL FRIC(J)                                               00001600
C                                                                 00001605
C      TRANSFER STRUT TIP VELOCITY FROM CAPSULE TO EARTH SYSTEM   00001607   81
       CALL TRAN( TCE,VSC,VSE)                                    00001610
C                                                                 00001615
C      OBTAIN STRUT TIP VELOCITY WITH RESPECT TO GROUND           00001617   83
       VT = SQRT (VSE(2)**2 +VSE(3)**2) +.0001                    00001620
C                                                                 00001625   85
       FSE(1) =1.0                                                00001630
       FSE(2) =-VSE(2)/VT * EMU                                   00001640
       FSE(3) =-VSE(3)/VT * EMU                                   00001650
       A = 0.0                                                    00001660
       DO 120 I =1,3                                              00001670
```

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```
      JOB 63                                                              01/25/86
          STRUT2      -  EFN   SOURCE STATEMENT  -  IFN(S)  -

  120 A = A + FSE(I) *USE(I)                                               00001680
C     A IS THE RATIO BETWEEN FS AND F NORMAL                               00001690
C                                                                          00001695
C     IF A IS LESS THAN OR EQUAL TO ZERO, PRINT WARNING                    00001697
      IF (A) 130 ,130,150                                                  00001700
  130 WRITE (6,140) TIME, J                                                00001710     93
  140 FORMAT(1H  10X 9HAT TIME = ,F7.5,  10HSTRUT NO. ,I13 ,               00001720
    1  22H IS PERP TO THE FORCE )                                          00001730
C                                                                          00001735
C     SET LOWER LIMIT OF A                                                 00001740
  150 A =AMAX1(A,0.5)                                                      00001755
      DO 160 I = 1,3                                                       00001760
      FSE(I) = FSE(I)/A *FS                                                00001770
  160 CONTINUE                                                             00001780
      CALL INTRAN( TCE,FSE,FSC)                                            00001800    101
      CALL AXB(RPC,FSC,TSC)                                                00001810
C                                                                          00001812
C                                                                          00001813
C     PREDICTOR  ---  USED ONLY WHEN NORMAL STRUT VELOCITY IS SMALL        00001814    103
      IF ( ABS(VSE(1))-1000.0*DT)162,190,190                               00001820
  162 DO 164 I =1,3                                                        00001825
  164 TP(I) = TSC(I)/ENTA(I)                                               00001830
      CALL AXB(TP,RPC,DVPC)                                                00001840    114
      DO 170 I =1,3                                                        00001850
  170 DVPC(I) =(DVPC(I) +  FSC(I)/WT*G -GV(I))*DT                          00001855
      CALL TRAN( TCE ,DVPC,DVPE)                                           00001860    124
      IF(VSE(1)) 172,175,172                                               00001865
  172 IF((VSE(1) +DVPE(1))/ VSE(1))175,190,190                             00001870
  175 RATIO  =(ABS(VSE(1)) +GV(1) *DT   )/(ABS(DVPE(1)) +GV(1)*DT )        00001880
      DO 180 I =1,3                                                        00001890
      FSE(I) = FSE(I)*RATIO                                                00001900
  180 TSC(I) = TSC(I)*RATIO                                                00001910
C                                                                          00001915
C                                                                          00001916
C     SUM UP FORCES AND TORQUES ON CAPSULE                                 00001918
  190 DO 195 I =1,3                                                        00001920
      FGE(I) = FGE(I) +FSE(I)                                              00001930
```

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

```
   JOB 63                                                              01/25/86
       STRUT2      -  EFN   SOURCE STATEMENT  -  IFN(S)  -

 195 TGC(I) = TGC(I) +TSC(I)                                            00001940
 200 CONTINUE                                                           00002040
     RETURN                                                             00002050
     END                                                                00010C00


     SUBROUTINE MOVE                                                    00000020
     COMMON     G,DTO,TTIME,TPLOT,VH,VV,ROL,PCH,YAW,WROL,WPCH,WYAW,SLP,00000020
    1           DSLP,SWG,DSWG,NS,IPRINT,FRC(10),RGCI(3),RSCI(3,10),     00C00022
    2           RSFCI(3,10),RBCI(3,10),WT,ENTA(3),STRK(10,10),          00000024
    3           FORS(10,10),DE(10),DAMP(10),PTEST(10)                   00000026
     COMMON     DT,TIME,ACMAX,AXMAX,XANG,FMAX(10),ANG(3),RGE(3),VGE(3),00000030
    1           AGE(3),WGC(3),QGC(3), RGA(3),STROK(10),FORC (10),       00000032
    2           PSTR(10),FGE(3),TGC(3),DWGC(3),DTCE(3,3),RSC(3,10),     00000034
    3           USC(3,10),RSCL(3),RSE(3),VSC(3),USE(3),VSE(3),FSE(3),   00000036
    4           FSC(3),TSC(3),VGC(3), RPC(3),VPE(3),TCE(3,3),TAE(3,3),  00000038
    5           TCP(3,3),TPA(3,3),TCA(3,3),EMU,GV(3),VGA(3),WHOA        C0000040
     COMMON     RSFC(3,10),ARMV(3),ETA(3,10),ELF(10),TYMJ(41),IP,TP(3),00000042
    1           DVPC(3),DVPE(3),WGE(3)                                  00000043
     COMMON     RGAS(200,3),RGES(200,3),VGES(200,3),AGES(200,3),        00000044
    1           WGCS(200,3),QGCS(200,3),ANGS(200,3),DSTS(200,10),       00000046
    2           FSTS(200,10),TYM(200)                                   00000048
C    COMPUTE CG ACCELERATION, VELOCITY, AND POSITION IN EARTH SYSTEM    00000990
     DO 10 I=1,3                                                        00001000
     AGE(I) = FGE(I)/WT*G -GV(I)                                        0C001010
     VGE(I) = VGE(I) +AGE(I)*DT                                         C0001020
     RGE(I) = RGE(I) +(VGE(I)-0.5*AGE(I)*DT )*DT                        00001030
C                                                                       00001034
C    COMPUTE ANGULAR ACCELERATION                                       00001035
     QGC(I) =TGC(I)/ENTA(I)                                             00001040
  10 CONTINUE                                                           00001050
C                                                                       00001051
C    FORM TIME DERIVATIVES OF ANGULAR VELOCITIES                        C0001055
     DWGC(1)= QGC(1) -(ENTA(3)-ENTA(2)) /ENTA(1) *WGC(2)*WGC(3)         00001060
     DWGC(2)= QGC(2) -(ENTA(1)-ENTA(3)) /ENTA(2) *WGC(1)*WGC(3)         00001070
     DWGC(3)= QGC(3) -(ENTA(2)-ENTA(1)) /ENTA(3) *WGC(1)*WGC(2)         00001080
C                                                                       00001085
C    COMPUTE INTERMEDIATE ANGULAR VELOCITIES                            00001090
     DO 20 I =1,3                                                       00001100
  20 WGC(I) = WGC(I)+DWGC(I)*DT/2.0                                     00001110
C                                                                       00001115
     CALL TRAN(TCE,WGC,WGE)                                             00001116     30
```

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```
   JOB 63                                                                01/25/86
       MOVE*      -  EFN   SOURCE STATEMENT  -  IFN(S)  -

      DO 30 J =1,3                                                       00001120
   30 CALL AXB(WGE,TCE(1,J),DTCE(1,J))                                   00001130
C     DTCE IS THE VECTOR TIME DERIVATIVE OF THE BODY UNIT VECTORS        00001140
C                                                                        00001145
C     INCREMENT BODY VECTORS                                             00001150   38
      DO 40 J=1,3                                                        00001160
      DO 40 I=1,3                                                        00001170
   40 TCE(I,J) =TCE(I,J) +DTCE(I,J)*DT                                   00001180
C     ORTHOGANALIZE                                                      00001190
      CALL AXB(TCE(1,1),TCE(1,2),TCE(1,3) )                              00001200   54
      CALL AXB(TCE(1,2),TCE(1,3),TCE(1,1) )                              00001210   56
      CALL AXB(TCE(1,3),TCE(1,1),TCE(1,2) )                              00001220
C                                                                        00001230
C     NORMALIZE                                                          00001240   58
      DO 60 J=1,3                                                        00001250
      EL2=0.0                                                            00001260
      DO 50 I=1,3                                                        00001270
   50 EL2= EL2 +TCE(I,J)**2                                              00001280
      EL2= SQRT(EL2)                                                     00001290   69
      DO 55 I=1,3                                                        00001300
   55 TCE(I,J)= TCE(I,J)/EL2                                             00001310
   60 CONTINUE                                                           00001320
C                                                                        00001330
C     COMPUTE FINAL ANGULAR VELOCITIES AT END OF TIME INCREMENT          00001335
      DO 70 I=1,3                                                        00001340
   70 WGC(I) =WGC(I) +DWGC(I)*DT/2.0                                     00001350
C                                                                        00001990
      RETURN                                                             00002000
      END                                                                00003000
```

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```
 JOB 63                                                                01/25/86
       OUTPT*      -  EFN   SOURCE STATEMENT  -  IFN(S)  -

      SUBROUTINE OUTPUT                                                 OUTP0015
      COMMON     G,DTO,TTIME,TPLOT,VH,VV,ROL,PCH,YAW,WROL,WPCH,WYAW,SLP,00000020
     1           DSLP,SWG,DSWG,NS,IPRINT,FRC(10),RGCI(3),RSCI(3,10),    00000022
     2           RSFCI(3,10),RBCI(3,10),WT,ENTA(3),STRK(10,10),         00000024
     3           FORS(10,10),DE(10),DAMP(10),PTEST(10)                  00000026
      COMMON     DT,TIME,ACMAX,AXMAX,XANG,FMAX(10),ANG(3),RGE(3),VGE(3),00000030
     1           AGE(3),WGC(3),QGC(3), RGA(3),STROK(10),FORC (10),      00000032
     2           PSTR(10),FGE(3),TGC(3),DWGC(3),DTCE(3,3),RSC(3,10),    00000034
     3           USC(3,10),RSCL(3),RSE(3),VSC(3),USE(3),VSE(3),FSE(3),  00000036
     4           FSC(3),TSC(3),VGC(3), RPC(3),VPE(3),TCE(3,3),TAE(3,3), 00000038
     5           TCP(3,3),TPA(3,3),TCA(3,3),EMU,GV(3),VGA(3),WHOA       00000040
      COMMON     RSFC(3,10),ARMV(3),ETA(3,10),ELF(10),TYMJ(41),IP,TP(3),00000042
     1           DVPC(3),DVPE(3),WGE(3)                                 00000043
      COMMON     RGAS(200,3),RGES(200,3),VGES(200,3),AGES(200,3),       00000044
     1           WGCS(200,3),QGCS(200,3),ANGS(200,3),DSTS(200,10),      00000046
     2           FSTS(200,10),TYM(200)                                  00000048
      N = WHOA                                                          OUTP0100
      GO TO (10,30,50),N                                                OUTP0110
   10 WRITE(6,20) TIME                                                  OUTP0120       3
   20 FORMAT (1H1,10X,26HTIME LIMIT IS EXCEEDED AT ,F7.4 , 8H SECONDS ) OUTP0130
      GO TO 70                                                          OUTP0140
   30 WRITE(6,40) TIME                                                  OUTP0150       5
   40 FORMAT (1H1,10X27H SYSTEM UNSTABLE - TIME IS  ,F7.4, 8H SECONDS ) OUTP0160
      GO TO 70                                                          OUTP0170
   50 WRITE(6,60)                                                       OUTP0180       7
   60 FORMAT (1H1,10X25H SYSTEM STABLE - TIME IS  ,F7.4, 8H SECONDS )   OUTP0190
   70 WRITE (6,80) ACMAX,AXMAX,( J,FMAX(J), PSTR(J) ,J=1,NS )           OUTP0200       8
   80 FORMAT(1H  ,10X, 6HMAXIMA  /12X,21HTOTAL ACCEL. VECTOR =  F8.3,/  OUTP0210
     1 12X18HANGLE OF CAPSULE = F8.3,/ 12X,42HSTRUT FORCES - NUMBER FORCOUTP0220
     2E LBS  STROKE FT  //  (28X,1I4,2F12.3 )     /     )               OUTP0230
      WRITE (6,90) RGE ,VGE,ANG ,WGC                                    OUTP0240      16
   90 FORMAT  (1H-,9X,33HFINAL POSITIONS IN SURFACE SYSTEM /10X,12HDISPLOUTP0250
     1ACEMENT ,12X,10HVELOCITIES ,14X6HANGLES ,16X,13HANG. VELOCITY  /  OUTP0260
     2 6X1HX7X1HY7X1HZ7X1HX7X1HY7X1HZ, 5X4HROLL4X5HPITCH4X3HYAW 6X1HX   OUTP0270
     3           7X1HY 7X1HZ  / 12F8.2  )                               OUTP0280
C                                                                       OUTP0290
```

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```
      JOB 63                                                            01/25/86
          OUTPT*      -  EFN   SOURCE STATEMENT  -  IFN(S)  -
C                                                                      OUTP0300
C                                                                      OUTP0310
C     CRT PLOTTING                                                     OUTP0320
      CALL SCOUTV                                                      OUTP0330    21
      XLIM = TYM(IP)                                                   OUTP0334
      CALL LIMITI(0.0,XLIM,0.0,0.0,0.0)                                OUTP0336    24
      IF(PTEST(1))100,110,100                                          OUTP0340
  100 CALL GRAPH(3, 42,-IP,TYM,ANGS(1,1) , 1H ,1H ,1H    )             OUTP0350    28
      CALL GRAPH(3,42,-IP,TYM,ANGS(1,2),1H ,              71H ROLL     OUTP0360
     1 *CAPSULE ANGLES*       PITCH          *IN DEGREES*        YAW,1H )OUTP0370  30
      CALL GRAPH(3,42,-IP,TYM,ANGS(1,3),15H TIME - SECONDS,1H ,1H )    OUTP0380
C                                                                      OUTP0390    32
  110 IF(PTEST(2))120,130,120                                          OUTP0400
  120 CALL GRAPH(3,42,-IP,TYM,AGES(1,1), 1H ,1H ,1H )                  OUTP0410    36
      CALL GRAPH(3,42,-IP,TYM,VGES(1,1),1H ,              81H ACCELERATOUTP0420
     1ION   *CG PARAMETERS*      VELOCITY        *NORMAL*         DISPLACOUTP0430
     2EMENT ,1H )                                                      OUTP0440
C                                                                      OUTP0450    38
      CALL GRAPH(3,42,-IP,TYM,RGES(1,1),15H TIME - SECONDS,1H ,1H )    OUTP0460
C                                                                      OUTP0470
C                                                                      OUTP0480    40
  130 IF(PTEST(3))140,300,140                                          OUTP0490
  140 SMAX =0.0                                                        OUTP0500
      DO 150 J=1,NS                                                    OUTP0510
      DO 150 I=1,IP                                                    OUTP0520
  150 SMAX =AMAX1(SMAX,DSTS(I,J))                                      OUTP0530
C                                                                      OUTP0540
C                                                                      OUTP0550
      CALL LIMITI(0.0,XLIM,0.0,SMAX)                                   OUTP0560    54
      CALL GRAPH (1 ,42,-IP,TYM,DSTS(1,1) ,14H TIME -SECONDS , 20H STRUTOUTP0570
     1 STROKES -FEET , 1H  )                                           OUTP0580    56
      DO 160 J =2,NS                                                   OUTP0590
      CALL GRAPH(0 ,42,-IP,TYM,DSTS(1,J) ,1H ,1H ,1H )                 OUTP0600    62
  160 CONTINUE                                                         OUTP0610
      DO 170 I =1,IP,5                                                 OUTP0630
      K =(I-1)/5  +1                                                   OUTP0640
      TYMJ(K)   = TYM(I)                                               OUTP0660
```

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```
 JOB 63                                                          01/25/86
      OUTPT*      -  EFN    SOURCE STATEMENT  -  IFN(S)  -

      DO 170 J =1,NS                                              OUTP0620
      DSTS(K,J) =DSTS(I,J)                                        OUTP0650
  170 CONTINUE                                                    OUTP0670
      GO TO(270,260,250,240,230,220,210,200,190,180 ),NS          OUTP0680
  180 CALL GRAPH(0,1H0,K,TYMJ,DSTS(1,10),1H ,1H ,1H )             OUTP0690     82
  190 CALL GRAPH(0,1H9,K,TYMJ,DSTS(1,9),1H ,1H ,1H )              OUTP0700     84
  200 CALL GRAPH(0,1H8,K,TYMJ,DSTS(1,8),1H ,1H ,1H )              OUTP0710     86
  210 CALL GRAPH(0,1H7,K,TYMJ,DSTS(1,7),1H ,1H ,1H )              OUTP0720     88
  220 CALL GRAPH(0,1H6,K,TYMJ,DSTS(1,6),1H ,1H ,1H )              OUTP0730     90
  230 CALL GRAPH(0,1H5,K,TYMJ,DSTS(1,5),1H ,1H ,1H )              OUTP0740     92
  240 CALL GRAPH(0,1H4,K,TYMJ,DSTS(1,4),1H ,1H ,1H )              OUTP0750     94
  250 CALL GRAPH(0,1H3,K,TYMJ,DSTS(1,3),1H ,1H ,1H )              OUTP0760     96
  260 CALL GRAPH(0,1H2,K,TYMJ,DSTS(1,2),1H ,1H ,1H )              OUTP0770     98
  270 CALL GRAPH(0,1H1,K,TYMJ,DSTS(1,1),1H ,1H ,1H )              OUTP0780
C                                                                 OUTP0790    100
      CALL LIMITI(0.0,0.0,0.0,0.0)                                OUTP0800    102
  300 RETURN                                                      OUTP1000
      END                                                         OUTP2000

      FRIC*       -  EFN    SOURCE STATEMENT  -  IFN(S)  -

      SUBROUTINE FRIC(J)                                          FRIC0020
      COMMON      G,DTO,TTIME,TPLOT,VH,VV,ROL,PCH,YAW,WROL,WPCH,WYAW,SLP,00000020
     1            DSLP,SWG,DSWG,NS,IPRINT,FRC(10),RGCI(3),RSCI(3,10),    00000022
     2            RSFCI(3,10),RBCI(3,10),WT,ENTA(3),STRK(10,10),         00000024
     3            FORS(10,10),DE(10),DAMP(10),PTEST(10)                  00000026
      COMMON      DT,TIME,ACMAX,AXMAX,XANG,FMAX(10),ANG(3),RGE(3),VGE(3),00000030
     1            AGE(3),WGC(3),QGC(3), RGA(3),STROK(10),FORC (10),      00000032
     2            PSTR(10),FGE(3),TGC(3),DWGC(3),DTCE(3,3),RSC(3,10),    00000034
     3            USC(3,10),RSCL(3),RSE(3),VSC(3),USE(3),VSE(3),FSE(3),  00000036
     4            FSC(3),TSC(3),VGC(3), RPC(3),VPE(3),TCE(3,3),TAE(3,3), 00000038
     5            TCP(3,3),TPA(3,3),TCA(3,3),EMU,GV(3),VGA(3),WHOA       00000040
      COMMON      RSFC(3,10),ARMV(3),ETA(3,10),ELF(10),TYMJ(41),IP,TP(3),00000042
     1            DVPC(3),DVPE(3),WGE(3)                                 00000043
      COMMON      RGAS(200,3),RGES(200,3),VGES(200,3),AGES(200,3),       00000044
     1            WGCS(200,3),QGCS(200,3),ANGS(200,3),DSTS(200,10),      00000046
     2            FSTS(200,10),TYM(200)                                  00000048
      EMU=FRC(1)                                                  FRIC0060
      RETURN                                                      FRIC1000
      END                                                         FRIC1010
```

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

```
 JOB 63                                                      01/25/86
     ATUDE*      -  EFN    SOURCE STATEMENT  -  IFN(S)  -

        SUBROUTINE ATUDE(TMAT,ANG)                            ATUD0020
        DIMENSION TMAT(3,3),ANG(3)                            ATUD0030
C       COMPUTES ROLL, PITCH, AND YAW FROM MATRIX TMAT        ATUD0040
        ANG(3) = ATAND(-TMAT(1,2),TMAT(1,1))                  ATUD0050    2
        ARG1 = TMAT(1,3)*COSD(ANG(3))                         ATUD0060    3
        ANG(2) = ATAND(ARG1,TMAT(1,1))                        ATUD0070    4
        ANG(1) = ATAND(-TMAT(2,3),TMAT(3,3))                  ATUD0080    5
        RETURN                                                ATUD0090
        END                                                   ATUD0100
                                                             11/08/85
     TRAN*       -  EFN    SOURCE STATEMENT  -  IFN(S)  -

        SUBROUTINE TRAN(TMAT,VIN,VOUT)                        TRAN0020
        DIMENSION TMAT(3,3),VIN(3),VOUT(3)                    TRAN0030
        DO 1 I=1,3                                            TRAN0040
        VOUT(I) = 0.0                                         TRAN0050
        DO 1 K=1,3                                            TRAN0060
      1 VOUT(I)= TMAT(I,K)*VIN(K) + VOUT(I)                   TRAN0070
        RETURN                                                TRAN0080
        END                                                   TRAN0090

        SUBROUTINE INTRAN(TMAT,VIN,VOUT)                      INTR0020
        DIMENSION TMAT(3,3),VIN(3),VOUT(3)                    INTR0030
        DO 2 I=1,3                                            INTR0040
        VOUT(I) =0.0                                          INTR0050
        DO 2 K=1,3                                            INTR0060
      2 VOUT(I)= TMAT(K,I)*VIN(K) + VOUT(I)                   INTR0070
        RETURN                                                INTR0080
        END                                                   INTR0090

     AXB*        -  EFN    SOURCE STATEMENT  -  IFN(S)  -

        SUBROUTINE AXB(A,B,C)                                 AXB00020
        DIMENSION A(3),B(3),C(3)                              AXB00030
        C(1)= A(2)*B(3) -A(3)*B(2)                            AXB00040
        C(2)= A(3)*B(1) -A(1)*B(3)                            AXB00050
        C(3)= A(1)*B(2) -A(2)*B(1)                            AXB00060
        RETURN                                                AXB00070
        END                                                   AXB00080
```

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

APPENDIX B

LISTING OF VEHICLE INPUT DATA

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

```
$DATA1        G=32.2      , DT0=.005   , TTIME=1.0  , TPLOT=.005, NS=6          ,
RGCI=36.9    ,  -1.79    ,   6.24     ,
RBCI= 30*0.0,  WT=10600.0,   ENIA= 5204.0,    3941.0,    3662.0,
RSCI= -15.0,     -34.67,     60.05,     -15.0,    -69.34,    0.0,
 -15.0,     -34.67,     -60.05,     -15.0,     34.67,     -60.05,
   -15.0,     69.34,     0.0,     -15.0,     34.67,     60.05,
RSFCI= 40.0,     -34.67,     60.05,     40.0,    -69.34,     0.0,
   40.0,     -34.67,     -60.05,     40.0,     34.67,     -60.05,
   40.0,     69.34,     0.0,     40.0,     34.67,     60.05,
FORS=100*30033.0        , FORS(1,1)=  0.0        , FORS(1,2)=  0.0          ,
FORS(1,3)=  0.0         , FORS(1,4)=  0.0        , FORS(1,5)=  0.0          ,
FORS(1,6)=  0.0         ,
STRK=100*0, STRK(2,1)=  0.5,10.0   , STRK(2,2)=  0.5,10.0   ,
STRK(2,3)=  0.5,10.0   , STRK(2,4)=  0.5,10.0   , STRK(2,5)=  0.5,10.0   ,
STRK(2,6)=  0.5,10.0   ,
DF=10*0.0    ,    DAMP=10*0.0    ,
PTEST=10*1.0                            $
```

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

APPENDIX C

LISTING OF INITIAL VALUE INPUT DATA

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

```
$DATA2      VH=  30.C.    VV= 15.0.    ROL=0.0.     PCH= 0.0.    YAW= 0.0.
     WROL= 0.0.    WPCH=0.0.    WYAW= 0.0.    SLP=  -5.0.    DSLP=0.0.
     FRC=0.35.    SWG=12.0.    DSWG=0.0.    IPRINT=2.
$
$DATA2      IPRINT=2.
   ROL=22.5.    DSLP=22.5.
$
$DATA2      IPRINT=2.
   ROL=45.0.    DSLP=45.0.
$
$DATA2      IPRINT=2.
   ROL=67.5.    DSLP=67.5.
$
$DATA2      IPRINT=2.
   ROL=90.0.    DSLP=90.C.
$
$DATA2      IPRINT=2.
   ROL=30.0.    DSLP=0.0.
    DSWG=-30.0.
$
$DATA2      IPRINT=2.
   ROL=52.5.    DSLP=22.5.
$
$DATA2      IPRINT=2.
   ROL=75.0.    DSLP=45.0.
$
$DATA2      IPRINT=2.
   ROL=97.5.    DSLP=67.5.
$
$DATA2      IPRINT=2.
   ROL=120.0.    DSLP=90.0.
$
$DATA2      IPRINT=2.
   ROL=0.0.    DSLP=0.0.
   VV=20.0.    DSWG=0.0.
$
$DATA2      IPRINT=2.
   ROL=22.5.    DSLP=22.5.
$
$DATA2      IPRINT=2.
   ROL=45.0.    DSLP=45.0.
$
$DATA2      IPRINT=2.
```

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

```
    ROL=67.5.    DSLP=67.5.
$
$DATA2      IPRINT=2.
    ROL=90.0.    DSLP=90.0.
$
$DATA2      IPRINT=2.
    DSWG=-30.0.
   ROL=30.0.    DSLP=0.0.
$
$DATA2      IPRINT=2.
   ROL=52.5.    DSLP=22.5.
$
$DATA2      IPRINT=2.
   ROL=75.0.    DSLP=45.0.
$
$DATA2      IPRINT=2.
   ROL=97.5.    DSLP=67.5.
$
$DATA2      IPRINT=2.
   ROL=120.0.    DSLP=90.0.
$
```

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

APPENDIX D

SAMPLE OUTPUT

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

VEHICLE DATA

WT = 0.10600E 05 IXX= 0.52040E 04 IYY= 0.39410E 04 IZZ= 0.36620E 04

NUMBER OF LEGS= 6 G= 0.32200E 02 DT= 0.50000E-02

GEOMETRY IN CAPSULE INITIAL SYSTEM

	X	Y	Z
CENTER OF GRAVITY	0.36900E 02	-0.17900E 01	0.62400E 01
MOVABLE STRUT TIPS			
LEG 1	-0.15000E 02	-0.34670E 02	0.60050E 02
LEG 2	-0.15000E 02	-0.69340E 02	0.00000E-38
LEG 3	-0.15000E 02	-0.34670E 02	-0.60050E 02
LEG 4	-0.15000E 02	0.34670E 02	-0.60050E 02
LEG 5	-0.15000E 02	0.69340E 02	0.00000E-38
LEG 6	-0.15000E 02	0.34670E 02	0.60050E 02
FIXED STRUT TIPS			
LEG 1	0.40000E 02	-0.34670E 02	0.60050E 02
LEG 2	0.40000E 02	-0.69340E 02	0.00000E-38
LEG 3	0.40000E 02	-0.34670E 02	-0.60050E 02
LEG 4	0.40000E 02	0.34670E 02	-0.60050E 02
LEG 5	0.40000E 02	0.69340E 02	0.00000E-38
LEG 6	0.40000E 02	0.34670E 02	0.60050E 02

STRUT LOAD-STROKE DATA

LEG 1

ELAST= 0.00000E-38 DAMP= 0.00000E-38

POINT	LOAD	STROKE
1	0.00000E-38	0.00000E-38
2	0.30033E 05	0.50000E 00
3	0.30033E 05	0.10000E 02
4	0.30033E 05	0.00000E-38
5	0.30033E 05	0.00000E-38
6	0.30033E 05	0.00000E-38
7	0.30033E 05	0.00000E-38
8	0.30033E 05	0.00000E-38
9	0.30033E 05	0.00000E-38
10	0.30033E 05	0.00000E-38

LEG 2

POINT LOAD STROKE ELAST= 0.00000E-38 DAMP= 0.00000E-38

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1	0.00000E-38	0.00000E-38
2	0.30033E 05	0.50000E 00
3	0.30033E 05	0.10000E 02
4	0.30033E 05	0.00000E-38
5	0.30033E 05	0.00000E-38
6	0.30033E 05	0.00000E-38
7	0.30033E 05	0.00000E-38
8	0.30033E 05	0.00000E-38
9	0.30033E 05	0.00000E-38
10	0.30033E 05	0.00000E-38

LEG 3

POINT	LOAD	STROKE
1	0.00000E-38	0.00000E-38
2	0.30033E 05	0.50000E 00
3	0.30033E 05	0.10000E 02
4	0.30033E 05	0.00000E-38
5	0.30033E 05	0.00000E-38
6	0.30033E 05	0.00000E-38
7	0.30033E 05	0.00000E-38
8	0.30033E 05	0.00000E-38
9	0.30033E 05	0.00000E-38
10	0.30033E 05	0.00000E-38

ELAST= 0.00000E-38 DAMP= 0.00000E-38

LEG 4

POINT	LOAD	STROKE
1	0.00000E-38	0.00000E-38
2	0.30033E 05	0.50000E 00
3	0.30033E 05	0.10000E 02
4	0.30033E 05	0.00000E-38
5	0.30033E 05	0.00000E-38
6	0.30033E 05	0.00000E-38
7	0.30033E 05	0.00000E-38
8	0.30033E 05	0.00000E-38
9	0.30033E 05	0.00000E-38
10	0.30033E 05	0.00000E-38

ELAST= 0.00000E-38 DAMP= 0.00000E-38

LEG 5

POINT	LOAD	STROKE
1	0.00000E-38	0.00000E-38
2	0.30033E 05	0.50000E 00
3	0.30033E 05	0.10000E 02
4	0.30033E 05	0.00000E-38

ELAST= 0.00000E-38 DAMP= 0.00000E-38

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```
INITIAL VALUES

VERTICAL VELOCITY=    0.15000E 02       HORIZONTAL VELOCITY= 0.30000E 02

CHUTE ROLL ANGLE=     0.00000E-38       PITCH HANG ANGLE=    0.00000E-38

YAW HANG ANGLE=       0.00000E-38

ROLL VELOCITY=        0.00000E-38       PITCH VELOCITY=      0.00000E-38

YAW VELOCITY=         0.00000E-38

GROUND SLOPE=        -0.50000E 01       SLOPE DIRECTION=     0.00000E-38

CHUTE SWING ANGLE=    0.12000E 02       SWING DIRECTION=     0.00000E-38

COEFFICIENTS OF FRICTION
   1     0.35000E 00
   2          ......
   3          ......
   4          ......
   5          ......
   6          ......
   7          ......
   8          ......
   9          ......
  10          ......

INITIAL POSITIONS IN SURFACE SYSTEM
DISPLACEMENT                VELOCITIES                 ANGLES                  ANG. VELOCITY
   X       Y       Z       X       Y       Z      ROLL   PITCH    YAW      X       Y       Z
 5.75    0.00    0.00  -12.33    0.00   31.19   -0.00   17.00   -0.00    0.00    0.00    0.00
```

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5	0.30033E 05	0.00000E-38
6	0.30033F 05	0.00000F-38
7	0.30033E 05	0.00000E-38
8	0.30033E 05	0.00000E-38
9	0.30033E 05	0.00000E-38
10	0.30033E 05	0.00000F-38

LEG 6

ELAST= 0.00000E-38 DAMP= 0.00000E-38

POINT	LOAD	STROKE
1	0.00000E-38	0.00000E-38
2	0.30033E 05	0.50000E 00
3	0.30033E 05	0.10000E 02
4	0.30033E 05	0.00000E-38
5	0.30033E 05	0.00000F-38
6	0.30033E 05	0.00000E-38
7	0.30033E 05	0.00000E-38
8	0.30033E 05	0.00000E-38
9	0.30033E 05	0.00000F-38
10	0.30033E 05	0.00000E-38

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```
TIME LIMIT IS EXCEEDED AT  1.0050 SECONDS
MAXIMA
 TOTAL ACCEL. VECTOR = 333.292
 ANGLE OF CAPSULE =  17.000
 STRUT FORCES - NUMBER FORCE LBS  STROKE FT

                   1    30033.000        1.023
                   2    30033.000        0.558
                   3    26761.068        0.446
                   4    26417.467        0.440
                   5    30033.000        0.536
                   6    30033.000        1.007
```

FINAL POSITIONS IN SURFACE SYSTEM

DISPLACEMENT			VELOCITIES			ANGLES			ANG. VELOCITY		
X	Y	Z	X	Y	Z	ROLL	PITCH	YAW	X	Y	Z
3.78	0.16	23.46	-0.40	0.22	18.57	-0.42	-5.30	0.14	-0.06	0.03	-0.14

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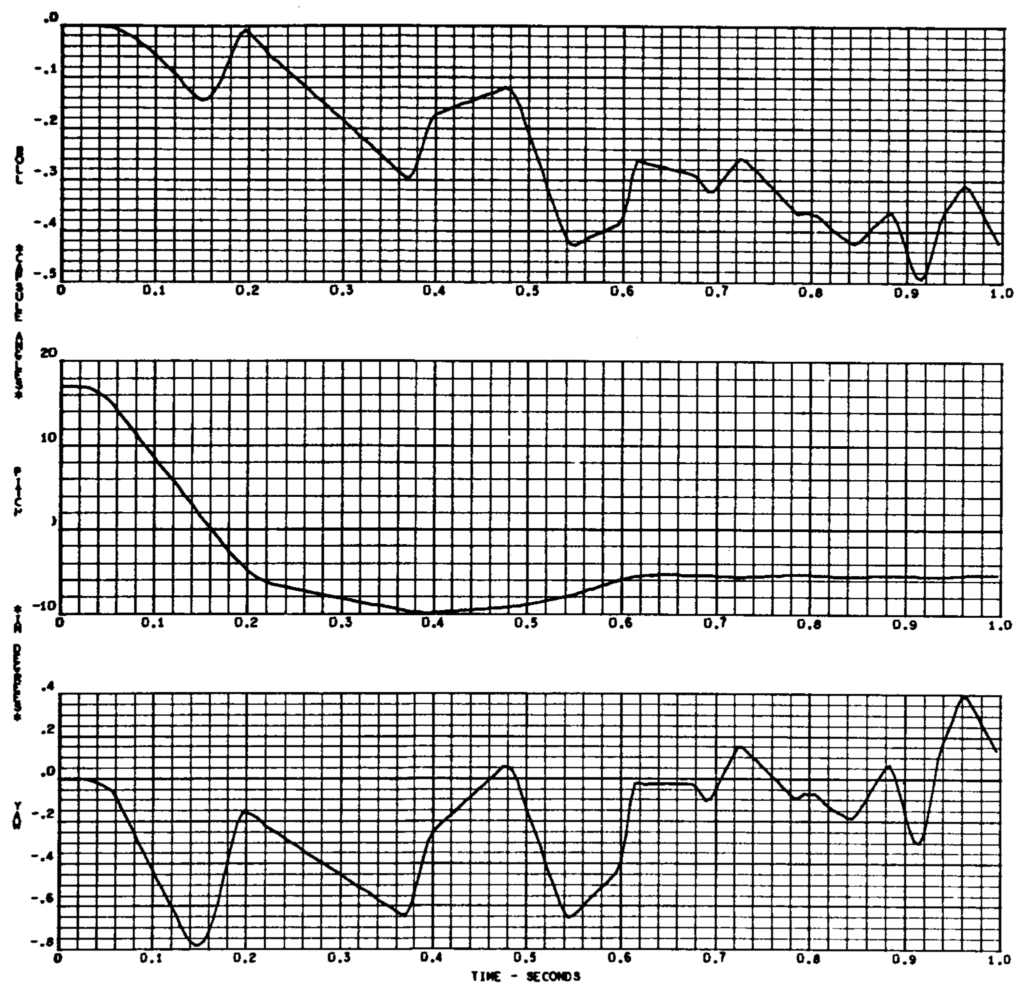

Figure 13. Roll, Pitch, and Yaw in Degrees Measured in Earth Coordinates Versus Time, Seconds

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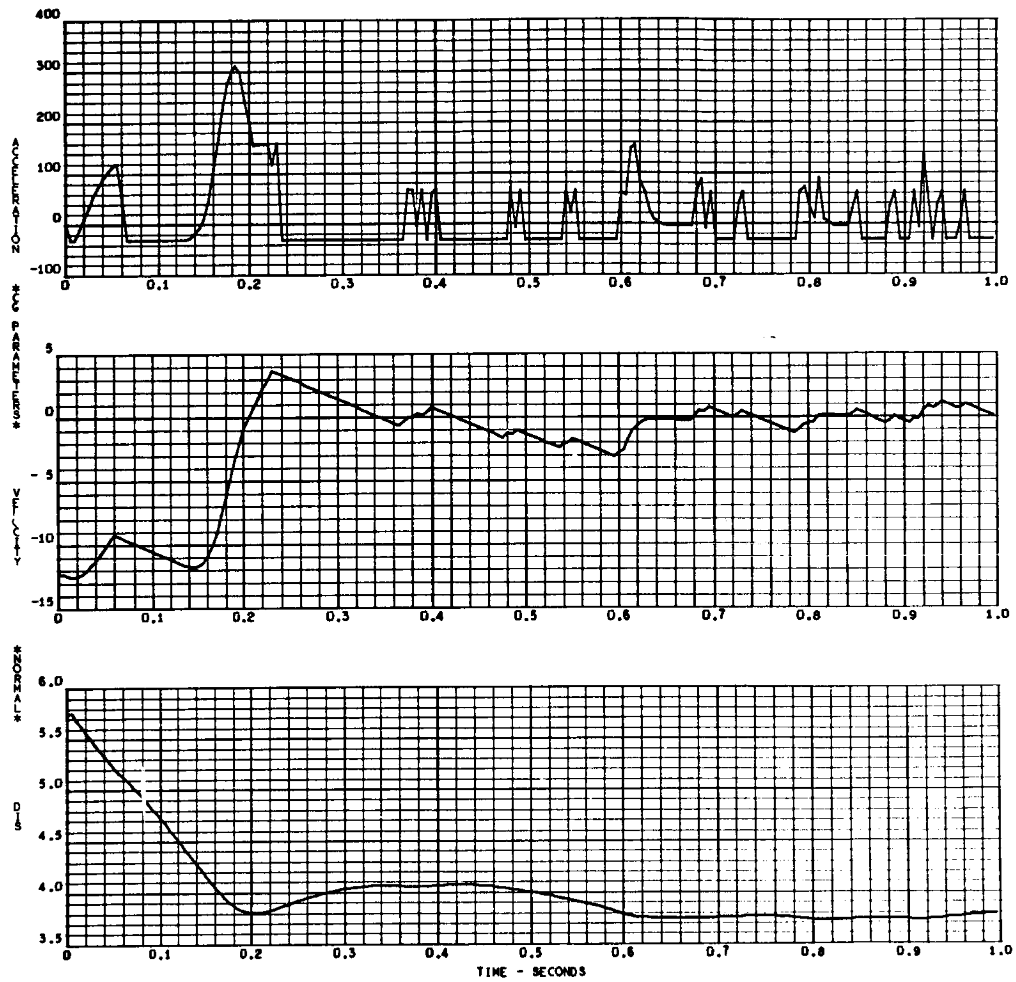

Figure 14. Acceleration, Ft/Sec^2; Velocity, Ft/Sec; and Displacement, Ft Normal to the Earth Versus Time, Seconds

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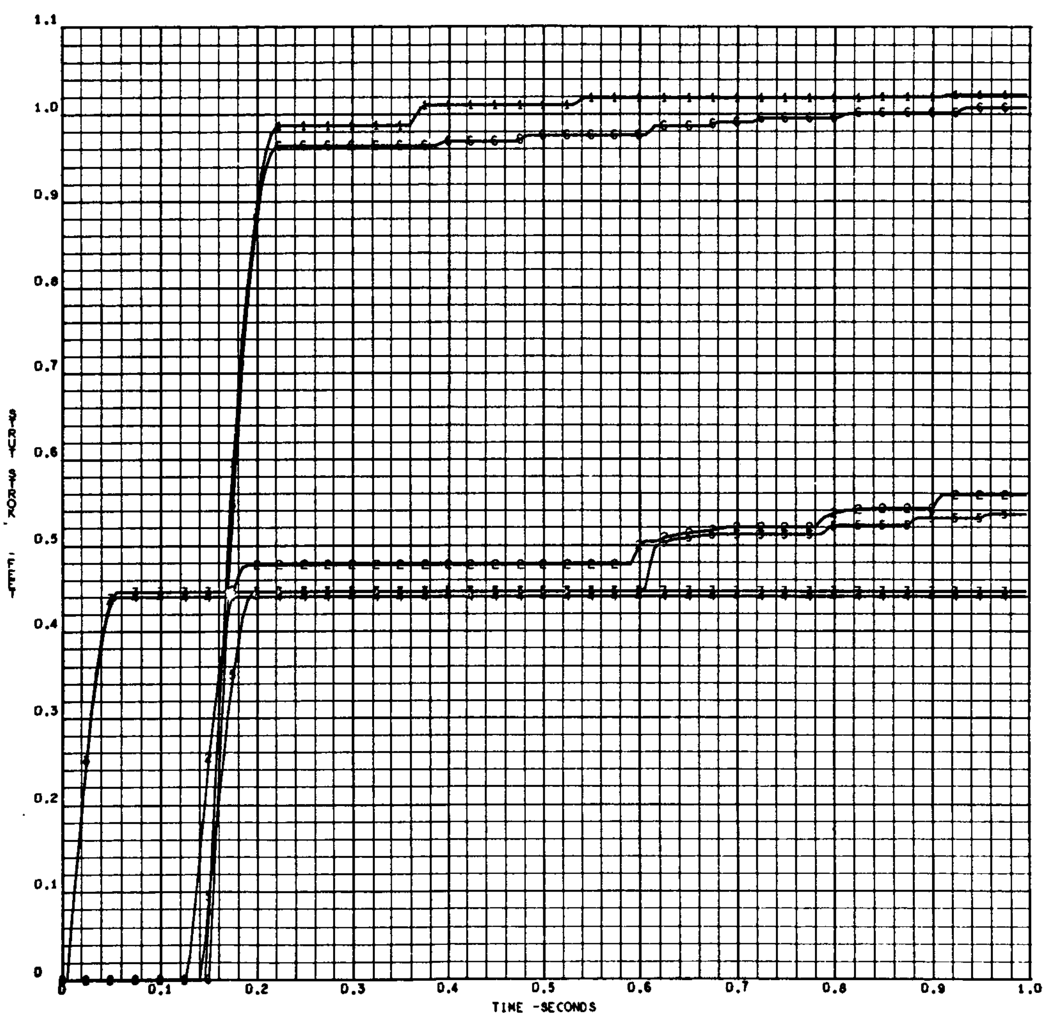

Figure 15. Strut Strokes, Ft, Versus Time, Seconds
(Numbers on Traces are Strut Numbers)

APPENDIX D

A USER'S GUIDE FOR 6DØF, A FORTRAN COMPUTER PROGRAM FOR THE SOLUTION OF APOLLO VEHICLE IMPACT DYNAMICS

Accession No.

SID 66-279

A USER'S GUIDE FOR 6DØF
A FORTRAN COMPUTER PROGRAM FOR THE SOLUTION OF APOLLO VEHICLE IMPACT DYNAMICS

MAY 1966

By

D.N. Herting

and

J.R. Partin

Approved

L.A. Harris, Director
Structures and Dynamics

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FOREWORD

This user's guide has been prepared by the Structures and Dynamics Department of North American Aviation Inc. /Space and Information Systems Division for NASA/MSC under Contract NAS9-4915, "Mechanical Impact System Design for Advanced Spacecraft. The program was developed by D. N. Herting and J. R. Partin. This guide is intended as documentation of a FORTRAN IV computer program "6DØF" developed by Systems Dynamics in 1963. A report, SID 63-851, "Mathematical Analysis of Landing Dynamics," June 1963, may be consulted for further information on the analysis. The Project Manager for MISDAS has been A. I. Bernstein and the Project Engineer has been A. S. Musicman.

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INTRODUCTION

The specific need for an analytic tool in the Apollo landing problem was the impetus for the development of this program. Although the basic mechanics are general enough for other applications, the terminology and angle conventions remain geared to Apollo. The dynamics of two rigid bodies are calculated in three dimensions. Two bodies "COUCH" and "HULL" are subject to applied forces from interconnecting, pin jointed, plastic stroking, struts. One body "HULL" is subject to forces applied by the earth to deformable points on its surface. Figure 1 may assist in visualizing the two bodies.

Although this program has existed since 1963, complete documentation has not been accomplished. The program, however, is well checked out and may be used with a minimum knowledge of its inner mechanics. General flow diagrams and a program listing are included in Appendix C.

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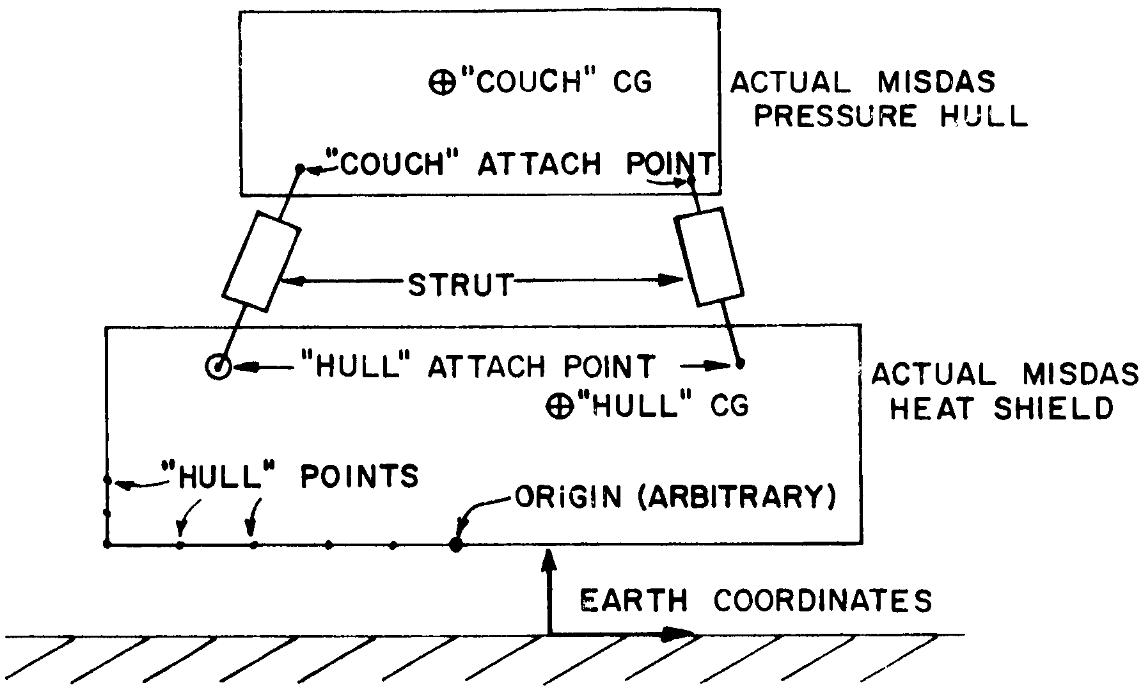

Figure 1. A Two-Dimensional Representation of Two-Body, Three-Dimensional Landing Impact Program Variables Showing Adaptation to MISDAS Design

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INPUT DATA

The method of loading input data is with "DECRD," a standard IBM subroutine. Locations for all necessary variables are given in the sample data section, Appendix A. Each input variable is assigned a location number. The location of the first variable on a card is punched, followed by up to five sequential decimal variables. Any order of cards may be used with the exception of the last card in each case, which must have a (-) in the first column. Any number of variables may be changed in each subsequent case, with other input variables remaining unchanged by execution.

FORCE-STROKE FUNCTIONS

Both the struts and heat shield points use a similar format for defining a force-stroke function. A sample is shown in Figure 2. The force in the strut is approximated by straight lines valid between discrete stroke points. The stroke points are stored in the array, STRØK. The constant forces between these strokes are stored in the array, FØRS. If a slope or ramp in the force is needed, it is stored in the array, RAMP.

The forces generated by this method are purely plastic and when the strut reverses motion at a point it generates no force. Any future travel in the original direction will cause no force until the reversal point is reached, at which the force-stroke curve is picked up again.

The struts have forces, strokes, and ramps in tension and compression. On the tension side they are FØRST, STRØKT, and RAMPT, and on the compression side they are FØRSC, STRØKC, and RAMPC.

The struts have an added coulomb friction in both directions to provide forces at all possible positions. These are stored in the arrays FMUC and FMUT.

The heat shield points have the added feature of allowing some elasticity. The first stroke and ramp are purely elastic and are carried along until the point reverses in motion. The point then unloads along the original elastic ramp. The first FØRCE location is not used.

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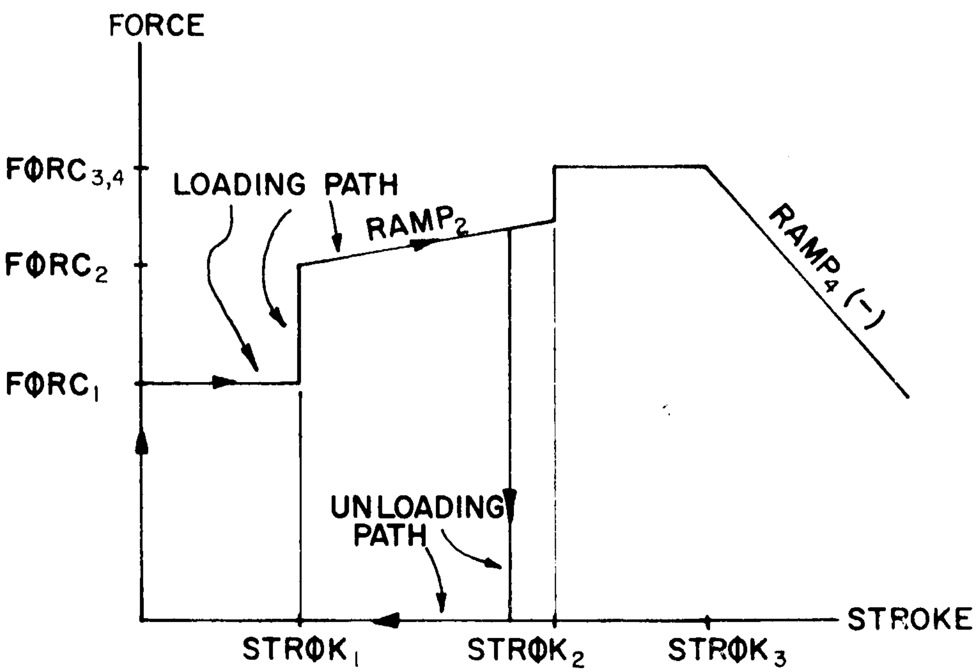

Figure 2. Sample Force-Stroke Function

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ANGLE CONVENTIONS

The angles used as input to the program are roll, pitch, yaw, slope, and direction of slope. These angles are all measured by right-hand rule relative to an absolute coordinate system fixed along the vertical and horizontal velocities. Figures 3 and 4 describe these angles. To produce a given attitude, the capsule is placed upright with its z axis aligned with the horizontal velocity, its x axis pointing vertically upward, and its y axis pointing according to the right-hand rule. It is first rolled about x_1 (vertical), then pitched about y_2 (in the horizontal plane), then yawed about z_c (the actual capsule axis).

The slope angle is the maximum slope of the earth; the direction of slope is the angle, measured in the horizontal plane, from the horizontal velocity to the maximum upslope.

Output angles are also roll, pitch, and yaw except that they are measured relative to the earth axis system. The earth z axis is in the plane of horizontal and vertical velocities, the earth y and z axes in the ground plane, and the earth x axis normal to the ground plane.

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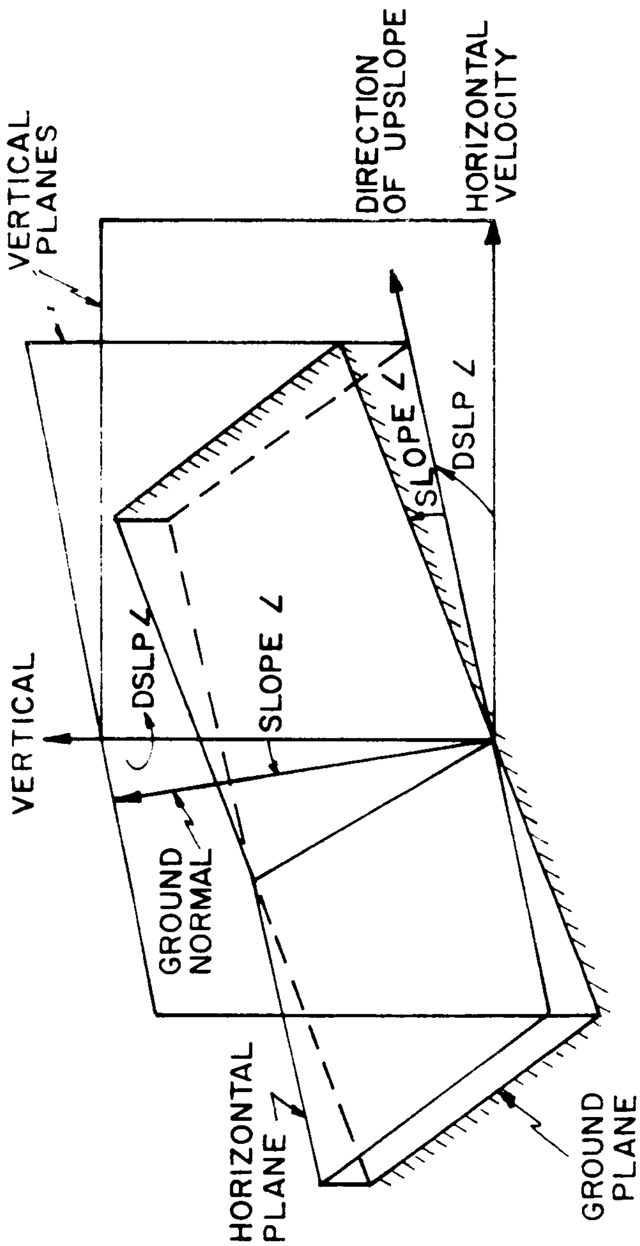

Figure 3. Definition of Ground Slope and Direction of Slope

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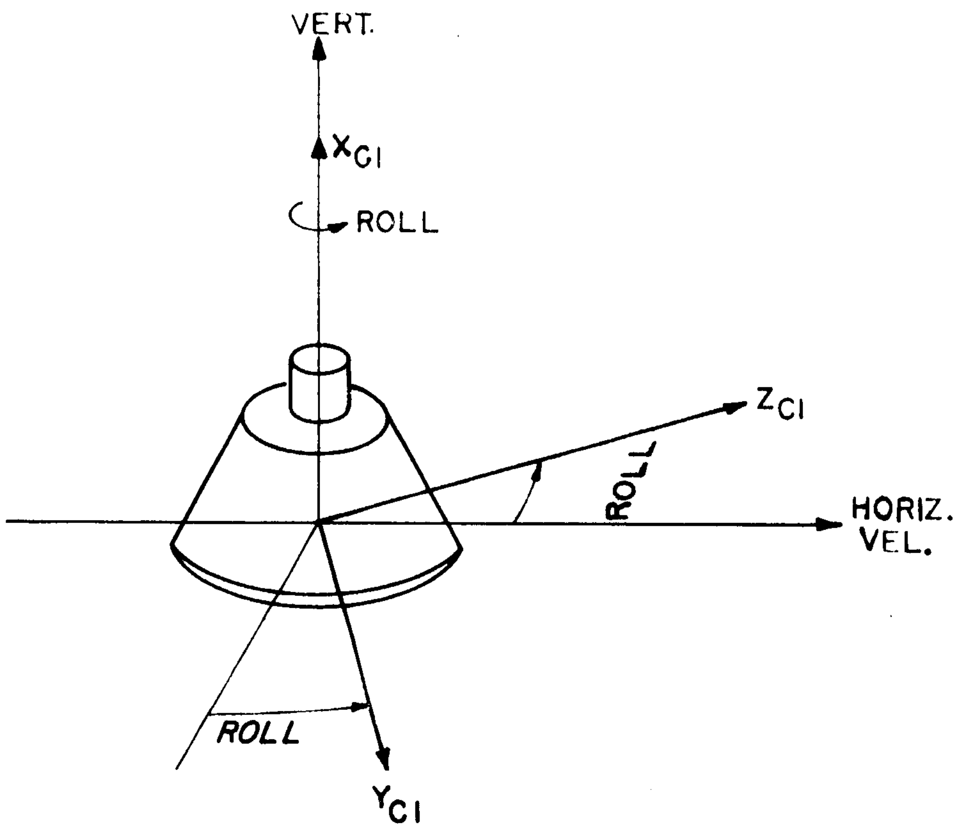

Figure 4. Roll Angle Definition

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OUTPUT

The output of the program consists of a page of general data, optioned printing of pertinent variables versus time and optioned CRT plotting of the same variables. Since the program was initially developed for the solution of the Apollo impact problem, the first mass is named "Pressure Hull" or "P.H." and the second mass is labeled "Couch." A sample output is given in Appendix B.

The first printed page of output for each case consists of the initial impact conditions, the mass and c.g. data, the maximum accelerations, strut strokes and forces, and final parameters. The three numbers under coefficient of friction are initial friction, second friction, stroke at which first friction ends and stroke at which second friction starts acting, with a ramp in between. The number under "CSS HULL" is an identification number and is not used by the program. Maximum accelerations are along the capsule axes with maximum yz plane acceleration and maximum total acceleration printed below the axes numbers. The rotational accelerations are in G's per foot and may be converted to radians per second squared by multiplying by 32.2. The strut attenuator lengths and loads are self-explanatory except that they are labeled for the Apollo system. The struts are in order, however, from strut No. 1 on the left to strut No. 8 on the right. The final parameters are relative to the earth coordinate system with the attitude measured from the earth system to the capsule and couch axes.

The output variables for both printing and plotting are stored corresponding to points in a time array. Test numbers in the input determine which variables are to be plotted or printed. Accelerations and angular velocities are measured in the body axis system. Pressure hull linear velocities and positions are measured from the earth system. Couch relative velocities are measured in the pressure hull system. Strut strokes are given in inches. In the CRT plots the initial starting point is the strut number. Actual stroke is the difference from the starting point.

The variable CRT plotting is much easier to interpret than the printing and most of the work should be done with the CRT. The printing options were used only as the program developed and are only recommended when accurate numbers are desired.

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APPENDIX A

SAMPLE INPUT DATA SHEETS

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 1 of ______ JOB NO. ______

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	1		
13			Horizontal velocity, ft/sec
25			Vertical velocity, ft/sec
37			Friction coefficient, dimensionless
49		73 80	Roll angle, degrees — CØMMØN Locations 4-8:
61			Pitch angle, degrees — Refer to angle conventions.
1	6		In this order
13			Yaw angle, degrees
25			Slope of ground-deg.
37			Direction of upslope, deg (from V_H)
49		73 80	Mass of hull, slugs
61			Mass of couch, slugs
1	1 1		
13			XX Inertia of hull, slug-ft^2
25			YY Inertia of hull, slug-ft^2
37			ZZ Inertia of hull, slug-ft^2
49		73 80	XX Inertia of couch, slug-ft^2
61			YY Inertia of couch, slug-ft^2
1	1 6		
13			ZZ Inertia of couch, slug-ft^2
25			Gravitational constant, ft/sec^2
37			Minimum energy of vehicle, ft-lbs (program stops if less)
49		73 80	
61			12

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 2 of ______ JOB NO. ______

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH	
1	1 9			
13			Print command-strut strokes	CØMMØN Locations 19-34:
25			Print command-couch accelerations	If number ≠ 0, variables are plotted or printed, if zero NO plot or print occurs.
37			Print command-hull accelerations	
49		73 80	Print command-hull velocities	
61			Print command-couch velocities	
1	2 4		(Note: 0 don't print, ± x print)	
13			Print command-hull positions	
25			Identification No. (css, hull)	
37			Not used	
49		73 80	Print command-transfer matrices	
61			(Should be 1.0) Friction change w/total G's	
1	2 9			
13			Plot command-strut strokes	
25			Plot command-couch accelerations	
37			Plot command-hull accelerations	
49		73 80	Plot command-hull velocities	
61			Plot command-couch velocities	
1	3 4			
13			Plot command-hull positions	
25			(same as printing commands)	
37				
49		73 80		
61				13

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 3 of ______ JOB NO. ______

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	35	73–80	
13			Delta time, sec (total real time = #35 x #36)
25			Number of time iterations
37			Number of iterations between plotted points
49			Number of hull points
61			
1	39	73–80	Note: All positions in inches relative to arbitrary origin
13			X } Hull C.G. position
25			Y } Hull C.G. position — CØMMØN Locations 42-44:
37			Z } Hull C.G. position — This vector is added to both the couch GB and the strut attach points on the couch. (Used for repositioning couch relative to hull).
49			X } Change in couch C.G., inches
61			Y } Change in couch C.G., inches
1	44	73–80	
13			Z } Change in couch C.G., inches
25			X } Couch C.G. position (Moves strut attach points also)
37			Y } Couch C.G. position
49			Z } Couch C.G. position
61			
1	48	73–80	
13			X Coord. of strut #1 attach PT on hull, inches
25			Y 1
37			Z 1
49			X 2
61			Y 2

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 4 of ______ JOB NO. ______

Col.	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	53		
13			Z Coord. of strut #2 attach PT on hull, inches
25			X 3
37			Y 3
49		73 80	Z 3
61			X 4
1	58		
13			Y 4
25			Z 4
37			X 5
49		73 80	Y 5
61			Z 5
1	63		
13			X Coord. of strut #6 attach point on hull
25			Y 6
37			Z 6
49		73 80	X 7
61			Y 7
1	68		
13			Z 7
25			X 8
37			Y 8
49		73 80	Z 8
61			15

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 5 of ______ JOB NO. ______

	NUMBER	IDENTIFICATION (73–80)	DESCRIPTION DO NOT KEY PUNCH
1	7 2		
13			X Coord. of strut #1 attach point on couch
25			Y 1
37			Z 1
49			X 2
61			Y 2
1	7 7		
13			Z 2
25			X 3
37			Y 3
49			Z 3
61			X 4
1	8 2		
13			Y Coord. of strut #4 attach point on couch
25			Z 4
37			X 5
49			Y 5
61			Z 5
1	8 7		
13			X 6
25			Y 6
37			Z 6
49			X 7
61			Y 7

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 6 of ______ JOB NO. ______

	NUMBER	IDENTIFICATION (73–80)	DESCRIPTION DO NOT KEY PUNCH
1	9 2		
13			Z Coord. of strut #7 attach point on couch
25			X 8
37			Y 8
49			Z 8
61			
1	9 6		
13			X Coord. of hull PT #1 — CØMMØN Locations 96-695:
25			Y 1 — Locations of hull outer
37			Z 1 — boundary points; storage
49			X 2 — for 200 points is available.
61			Y 2 up to a max. of 200 points
1	6 9 6		Force-Stroke Data Compression Strokes
13			Δ_1 strut #1
25			Δ_2 strut #1 — CØMMØN Locations 696-3951:
37			Δ_3 strut #1 — Refer to force-stroke function
49			Δ_4 strut #1 — description.
61			Δ_5 strut #1
1	7 0 1		
13			Δ_1 strut #2
25			Δ_2 strut #2
37			Δ_3 strut #2
49			Δ_4 strut #2
61			Δ_5 strut #2

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 7 of ______ JOB NO. ______

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	7 0 6		
13			Δ_1
25			Δ_2
37			Δ_3 strut #3 (compression)
49		73 … 80	Δ_4
61			Δ_5
1	7 1 1		
13			Δ_1
25			Δ_2
37			Δ_3 strut #4 (compression)
49		73 … 80	Δ_4
61			Δ_5
1	7 1 6		
13			Δ_1
25			Δ_2
37			Δ_3 strut #5 (compression)
49		73 … 80	Δ_4
61			Δ_5
1	7 2 1		
13			Δ_1
25			Δ_2
37			Δ_3 strut #6 (compression)
49		73 … 80	Δ_4
61			Δ_5 18

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 8 of ______ JOB NO. ______

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	726		
13			Δ_1
25			Δ_2
37			Δ_3 strut #7 (compression)
49		73 80	Δ_4
61			Δ_5
1	731		
13			Δ_1
25			Δ_2
37			Δ_3 strut #8 (compression)
49		73 80	Δ_4
61			Δ_5
1	736		Compression Forces
13			F_1
25			F_2
37			F_3 strut #1
49		73 80	F_4
61			F_5
1	741		
13			F_1
25			F_2
37			F_3 strut #2
49		73 80	F_4
61			F_5 19

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NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 9 of ______ JOB NO. ______

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	746	73–80	Compression Forces (Cont)
13			F_1
25			F_2
37			F_3 strut #3
49			F_4
61			F_5
1	751	73–80	
13			F_1
25			F_2
37			F_3 strut #4
49			F_4
61			F_5
1	756	73–80	
13			F_1
25			F_2
37			F_3 strut #5
49			F_4
61			F_5
1	761	73–80	
13			F_1
25			F_2
37			F_3 strut #6
49			F_4
61			F_5 20

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NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 10 of ______ JOB NO. ______

	NUMBER	IDENTIFICATION (73–80)	DESCRIPTION DO NOT KEY PUNCH
1	766		Compression Forces (cont)
13			F_1
25			F_2
37			F_3 strut #7
49			F_4
61			F_5
1	771		
13			F_1
25			F_2
37			F_3 strut #8
49			F_4
61			F_5
1	776		Compression Ramps
13			R_{11}
25			R_{21}
37			R_{31} strut #1
49			R_{41}
61			R_{51}
1	781		
13			R_{12}
25			R_{22}
37			R_{32} strut #2
49			R_{42}
61			R_{52} 21

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NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 11 of ______ JOB NO. ______

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	7.86		Compression Ramps (cont)
13			R_{13}
25			R_{23}
37			R_{33} strut #3
49		73 80	R_{43}
61			R_{53}
1	79.1		
13			R_{14}
25			R_{24}
37			R_{34} strut #4
49		73 80	R_{44}
61			R_{54}
1	79.6		
13			R_{15}
25			R_{25}
37			R_{35} strut #5
49		73 80	R_{45}
61			R_{55}
1	80.1		
13			R_{16}
25			R_{26}
37			R_{36} strut #6
49		73 80	R_{46}
61			R_{56} 22

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NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 12 of ______ JOB NO. ______

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	806		Compression Ramps (cont)
13			R_{17}
25			R_{27}
37			R_{37} strut #7
49		73 80	R_{47}
61			R_{57}
1	811		
13			R_{18}
25			R_{28}
37			R_{38} strut #8
49		73 80	R_{48}
61			R_{58}
1	816		Tension Strokes
13			Δ_{11}
25			Δ_{21}
37			Δ_{31} strut #1
49		73 80	Δ_{41}
61			Δ_{51}
1	821		
13			Δ_{12}
25			Δ_{22}
37			Δ_{32} strut #2
49		73 80	Δ_{42}
61			Δ_{52} 23

FORM 114-C-17 REV. 7-58- VELLUM

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 13 of ______ JOB NO. ______

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	826		Tension Strokes (cont)
13			Δ_{13}
25			Δ_{23}
37			Δ_{33} strut #3
49		73 80	Δ_{43}
61			Δ_{53}
1	831		
13			Δ_{14}
25			Δ_{24}
37			Δ_{34} strut #4
49		73 80	Δ_{44}
61			Δ_{54}
1	836		
13			Δ_{15}
25			Δ_{25}
37			Δ_{35} strut #5
49		73 80	Δ_{45}
61			Δ_{55}
1	841		
13			Δ_{16}
25			Δ_{26}
37			Δ_{36} strut #6
49		73 80	Δ_{46}
61			Δ_{56} 24

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NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 14 of ______ JOB NO. ______

	NUMBER	IDENTIFICATION (73–80)	DESCRIPTION DO NOT KEY PUNCH
1	846		Tension Strokes (cont)
13			Δ_{17}
25			Δ_{27}
37			Δ_{37} strut #7
49			Δ_{47}
61			Δ_{57}
1	851		
13			Δ_{18}
25			Δ_{28}
37			Δ_{38} strut #8
49			Δ_{48}
61			Δ_{58}
1	856		Tension Forces
13			F_{11}
25			F_{21}
37			F_{31} strut #1
49			F_{41}
61			F_{51}
1	861		
13			F_{12}
25			F_{22}
37			F_{32} strut #2
49			F_{42}
61			F_{52}

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NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 15 of ______ JOB NO. ______

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	866		Tension Forces (cont)
13			F_{13}
25			F_{23}
37			F_{33} strut #3
49		73 80	F_{43}
61			F_{53}
1	871		
13			F_{14}
25			F_{24}
37			F_{34} strut #4
49		73 80	F_{44}
61			F_{54}
1	876		
13			F_{15}
25			F_{25}
37			F_{35} strut #5
49		73 80	F_{45}
61			F_{55}
1	881		
13			F_{16}
25			F_{26}
37			F_{36} strut #6
49		73 80	F_{46}
61			F_{56} 26

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NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 16 of ______ JOB NO. ______

	NUMBER	IDENTIFICATION (73–80)	DESCRIPTION DO NOT KEY PUNCH
1	886		Tension Forces (cont)
13			F_{17}
25			F_{27}
37			F_{37} strut #7
49			F_{47}
61			F_{57}
1	891		
13			F_{18}
25			F_{28}
37			F_{38} strut #8
49			F_{48}
61			F_{58}
1	896		Tension Ramps
13			R_{11}
25			R_{21}
37			R_{31} strut #1
49			R_{41}
61			R_{51}
1	901		
13			R_{12}
25			R_{22}
37			R_{32} strut #2
49			R_{42}
61			R_{52}

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NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ____ PROGRAMMER ____ DATE ____ PAGE 17 of ____ JOB NO. ____

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NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
906		Tension Ramps (cont)
		R_{13}
		R_{23}
		R_{33} strut #3
		R_{43}
		R_{53}
911		R_{14}
		R_{24}
		R_{34} strut #4
		R_{44}
		R_{54}
916		R_{15}
		R_{25}
		R_{35} strut #5
		R_{45}
		R_{55}
921		R_{16}
		R_{26}
		R_{36} strut #6
		R_{46}
		R_{56}

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NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 18 of ______ JOB NO. ______

Card col.	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	926	73–80	Tension Ramps (cont)
13			R_{17}
25			R_{27}
37			R_{37} strut #7
49			R_{47}
61			R_{57}
1	931	73–80	
13			R_{18}
25			R_{28}
37			R_{38} strut #8
49			R_{48}
61			R_{58}
1	936	73–80	Friction Forces (added to strut forces)
13			Strut #1, compression
25			2
37			3
49			4
61			5
1	941	73–80	
13			6
25			7
37			8
49			
61			29

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NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 19 of ______ JOB NO. ______

	NUMBER	IDENTIFICATION (73–80)	DESCRIPTION DO NOT KEY PUNCH
1	944		Friction Forces (cont)
13			Strut #1, tension
25			2
37			3
49			4
61			5
1	949		
13			6
25			7
37			8
49			
61			
1	952		Hull Force-Stroke Values
13			Stroke #1 at point #1
25			" 2 " " 1
37			" 3 " " 1
49			
61			(Note: Stroke #1 is elastic)
1	957		
13			Stroke #1 at point #2
25			" 2 " " 2
37			" 3 " " 2 etc.
49			
61			30

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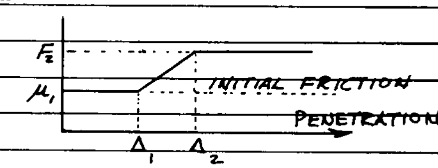
NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 20 of ______ JOB NO. ______

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1952		
		Force #1 on point #1
		(Note: Force #1 is not used for any hull point)
		etc.
2952		
		Ramp #1 on point #1
		(Note: Ramp #1 is elastic for all hull points)
		etc
3952		Variable Surface Friction
		Δ_1
		Δ_2
		F_2



CØMMØN Locations 3952-3954:

The initial friction valve in location 3 is used until a hull point displaces Δ_1 feet. The friction then is a function of penetration as shown in the figure.

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NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

APPENDIX B

SAMPLE OUTPUT CASE

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

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THE TIME LIMIT HAS BEEN EXCEEDED, TIME ELAPSED IS 0.9990 SECONDS.

INITIAL CONDITIONS

VELOCITY (FPS) VERTICAL	VELOCITY (FPS) HORIZONTAL	ATTITUDE (DEG) ROLL	PITCH	YAW	SLOPE (DEG) ANGLE	UP-DIRECTION	COEFFICIENT OF FRICTION			
25.00	30.00	22.5	12.0	0.0	-5.0	0.0	0.35	0.00	10.00	0.00

	MASS (SLUGS)	MOMENT OF INERTIA (SLUG-FT2) X-X	Y-Y	Z-Z
PRESSURE HULL	86.2	1710.0	860.0	860.0
COUCH	255.5	3455.0	2540.0	2280.0

DELTA TIME (SEC)	CSS HULL
0.0010	0.0000

MAXIMUM ACCELERATIONS

	LINEAR (G-S) X		Y		Z		ROTATIONAL (G-S/FOOT) X-X		Y-Y		Z-Z	
P. H.	-24.66	53.96	-3.86	0.96	-15.42	5.22	-0.41	0.49	-11.50	6.90	-2.09	2.47
COUCH	-4.18	8.79	-2.23	0.29	-6.83	3.53	-0.45	0.35	-3.38	1.82	-0.65	0.62

7.171

9.400

COUCH ATTENUATOR LENGTHS (FT) AND LOADS (LBS)

	FOOT LEFT	FOOT RIGHT	HEAD LEFT	HEAD RIGHT	Z-Z LEFT	Z-Z RIGHT	Y-Y LEFT	Y-Y RIGHT
MAXIMUM	2.591	2.565	2.565	2.565	8.728	8.665	8.638	8.611
INITIAL	2.565	2.565	2.565	2.565	8.603	8.603	8.603	8.603
MINIMUM	1.672	1.991	1.792	1.609	8.602	8.602	8.603	8.580
TENSION	34900.0	711.9	33029.2	333.9	30012.4	17296.1	13444.1	10933.0
COMPRSN	-34900.0	-31008.4	-34900.0	-34900.0	-4373.2	-3068.4	-2570.2	-4956.7

FINAL PARAMETERS

	VELOCITY (FPS) X	Y	Z	DISPLACEMENT (FT) X	Y	Z	ATTITUDE (DEGREES) ROLL	PITCH	YAW
PRESSURE HULL	-0.425	-1.241	16.127	5.541	-0.912	16.657	29.0	-51.8	19.2
COUCH	-0.194	-1.090	16.040	6.803	-1.269	19.846	29.4	-52.8	21.3

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

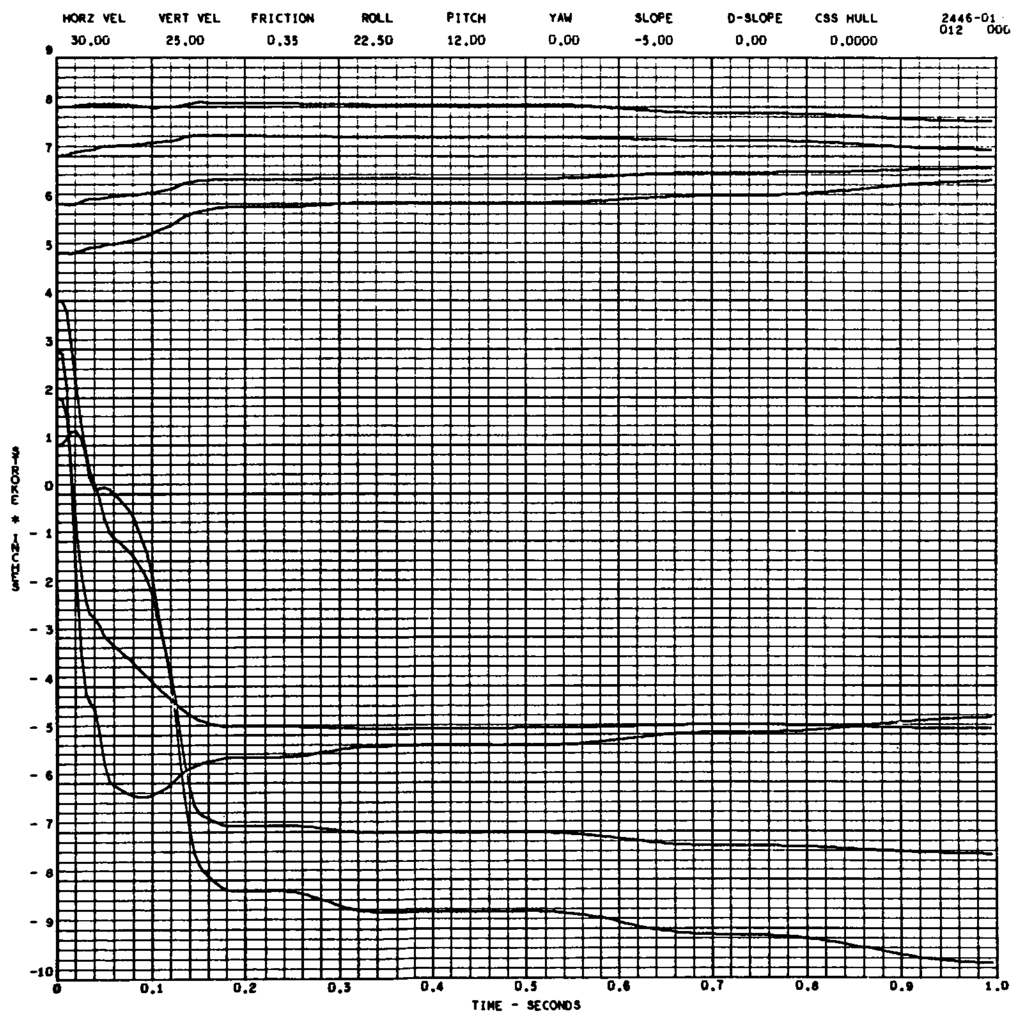

Figure 5. Stroke Versus Time

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

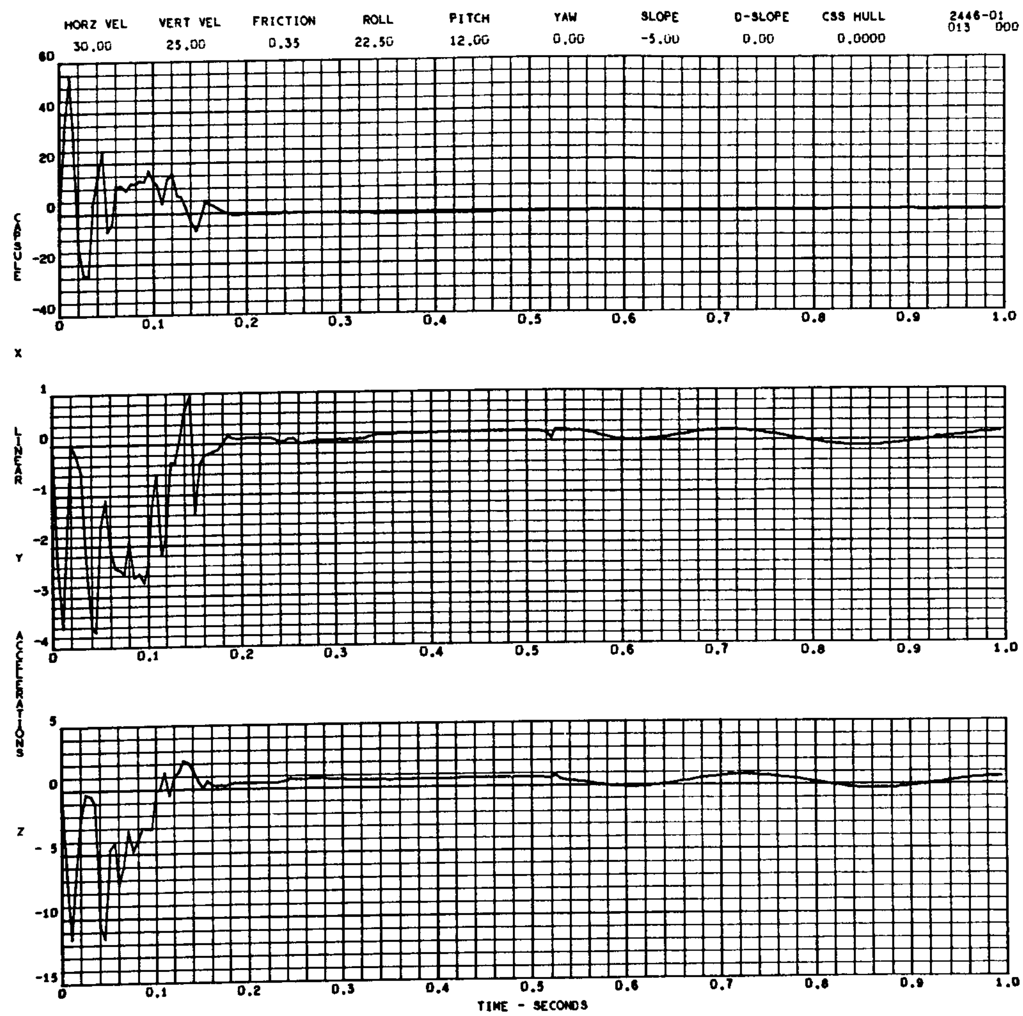

Figure 6. Capsule Linear Acceleration Versus Time

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

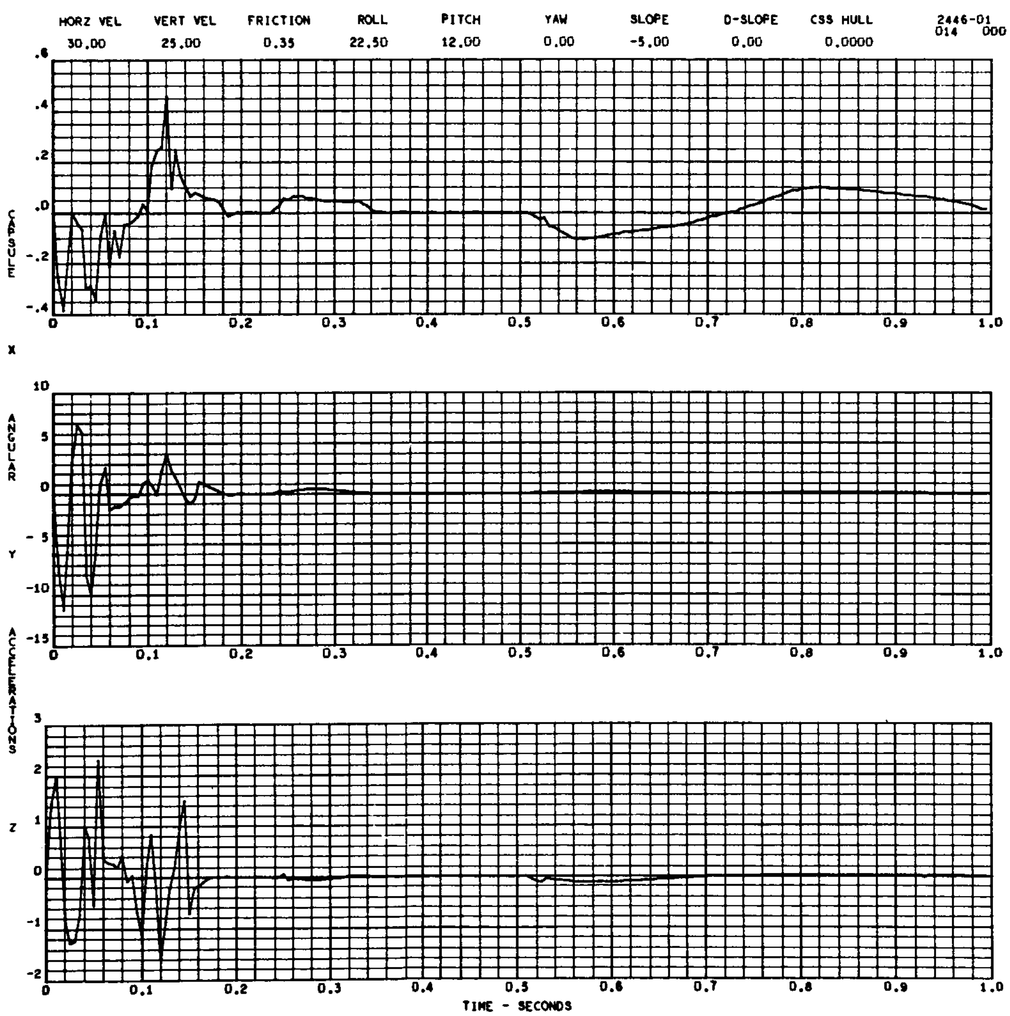

Figure 7. Capsule Angular Acceleration Versus Time

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

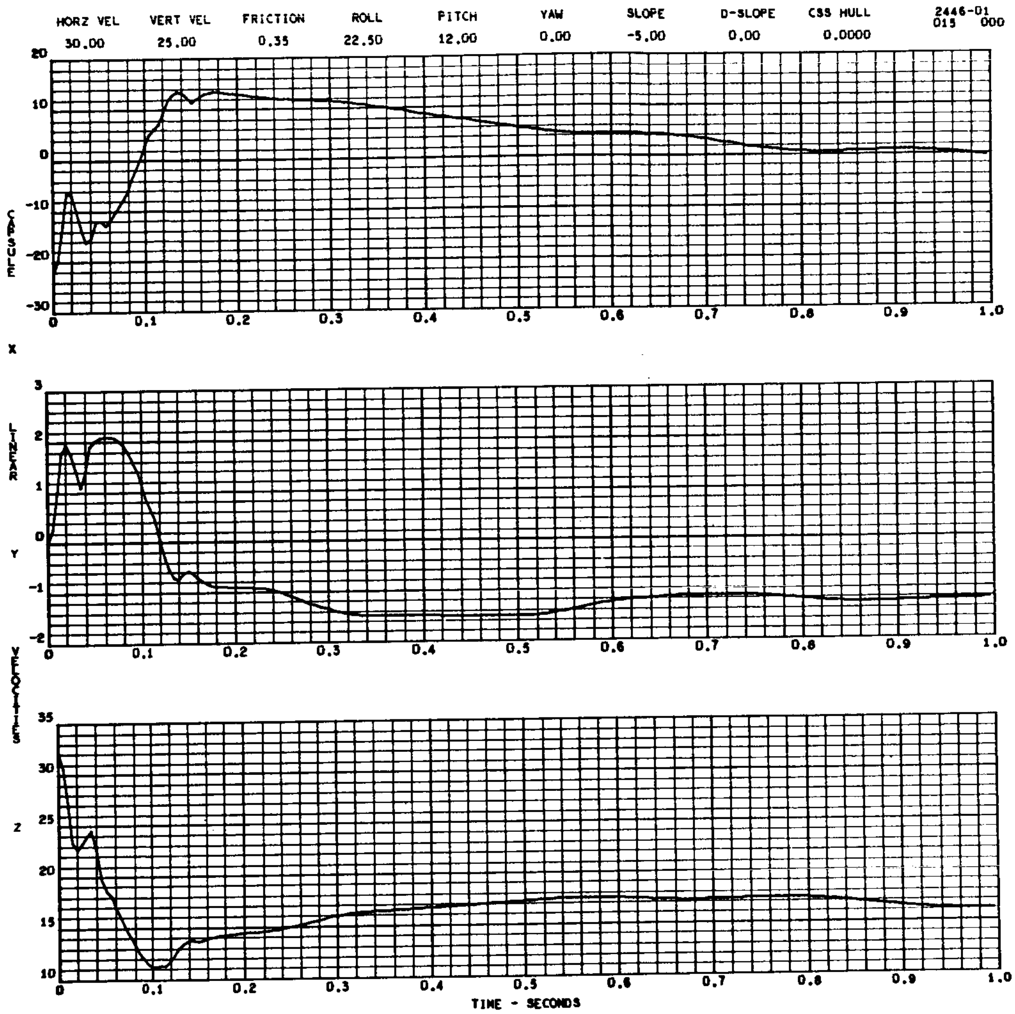

Figure 8. Capsule Linear Velocities Versus Time

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

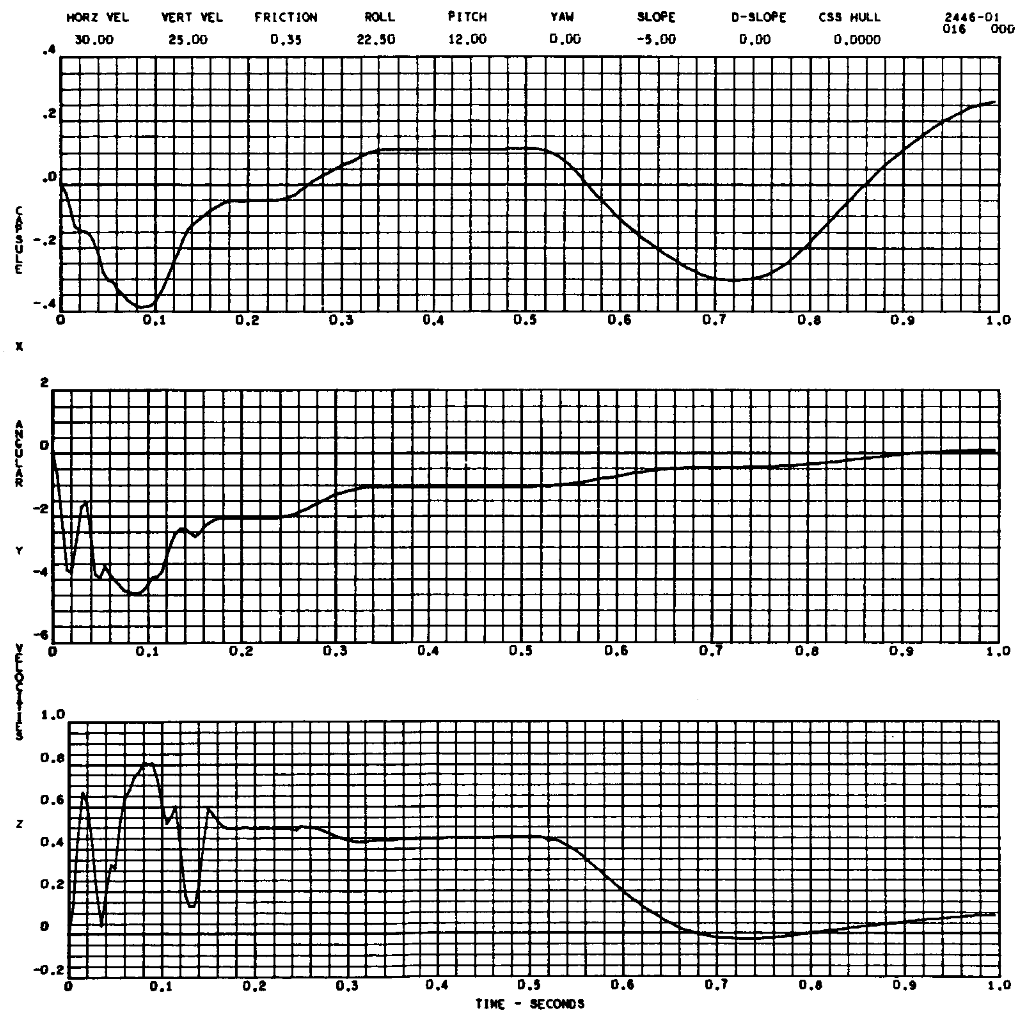

Figure 9. Capsule Angular Velocities Versus Time

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

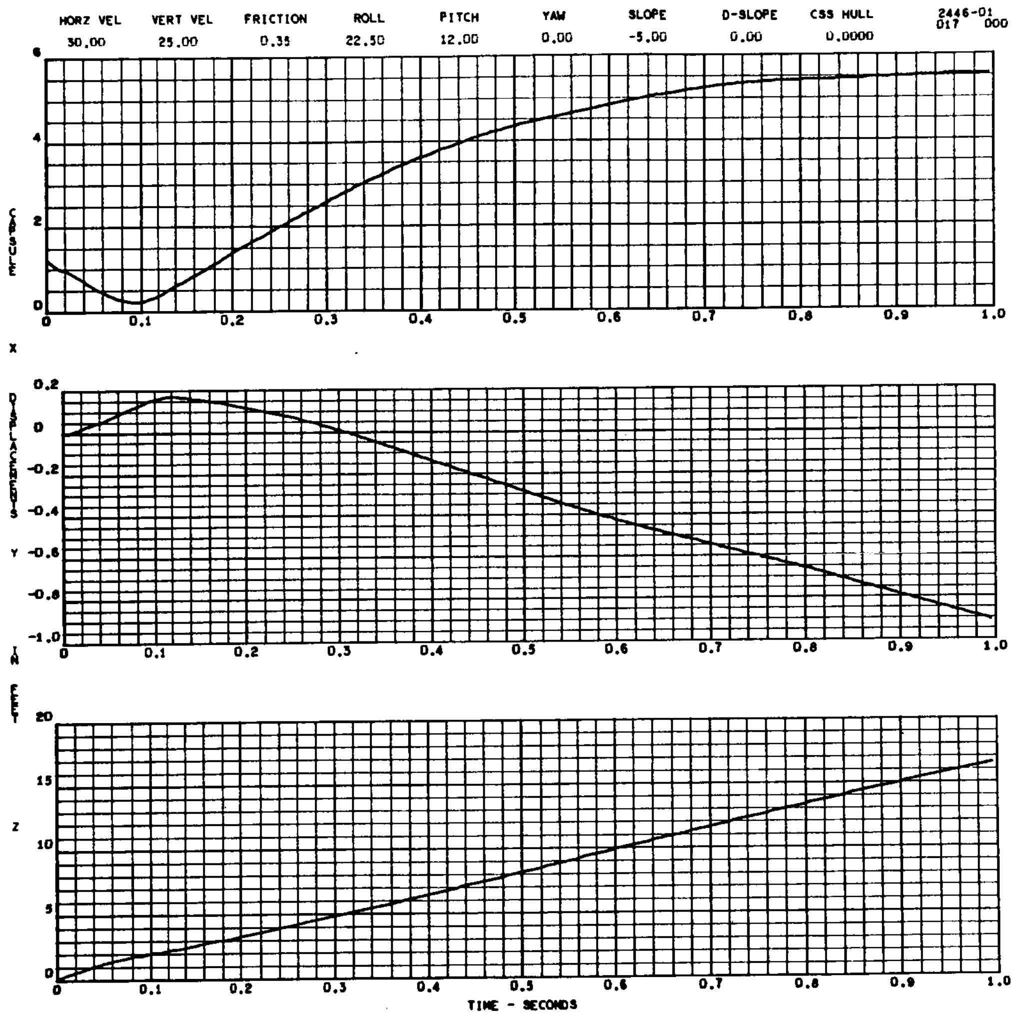

Figure 10. Capsule Displacement Versus Time

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

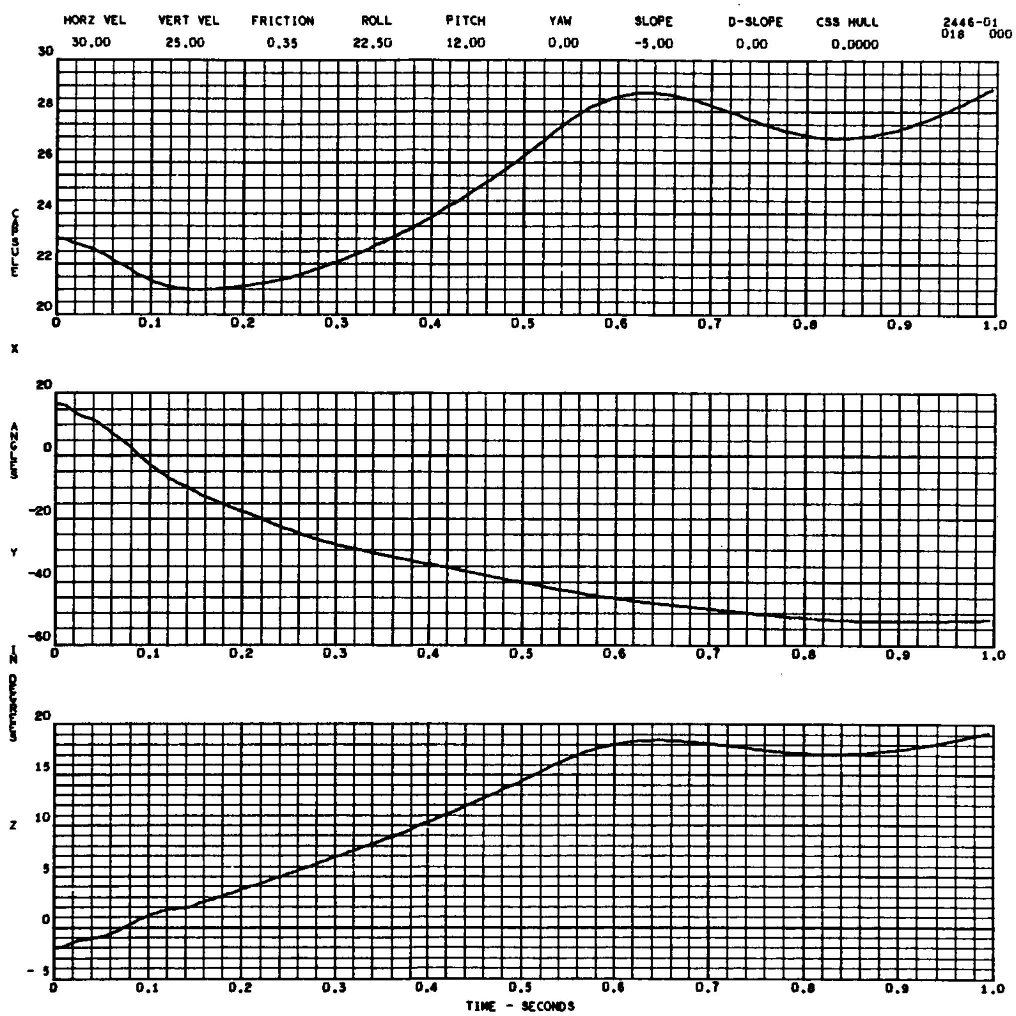

Figure 11. Capsule Angles Versus Time

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

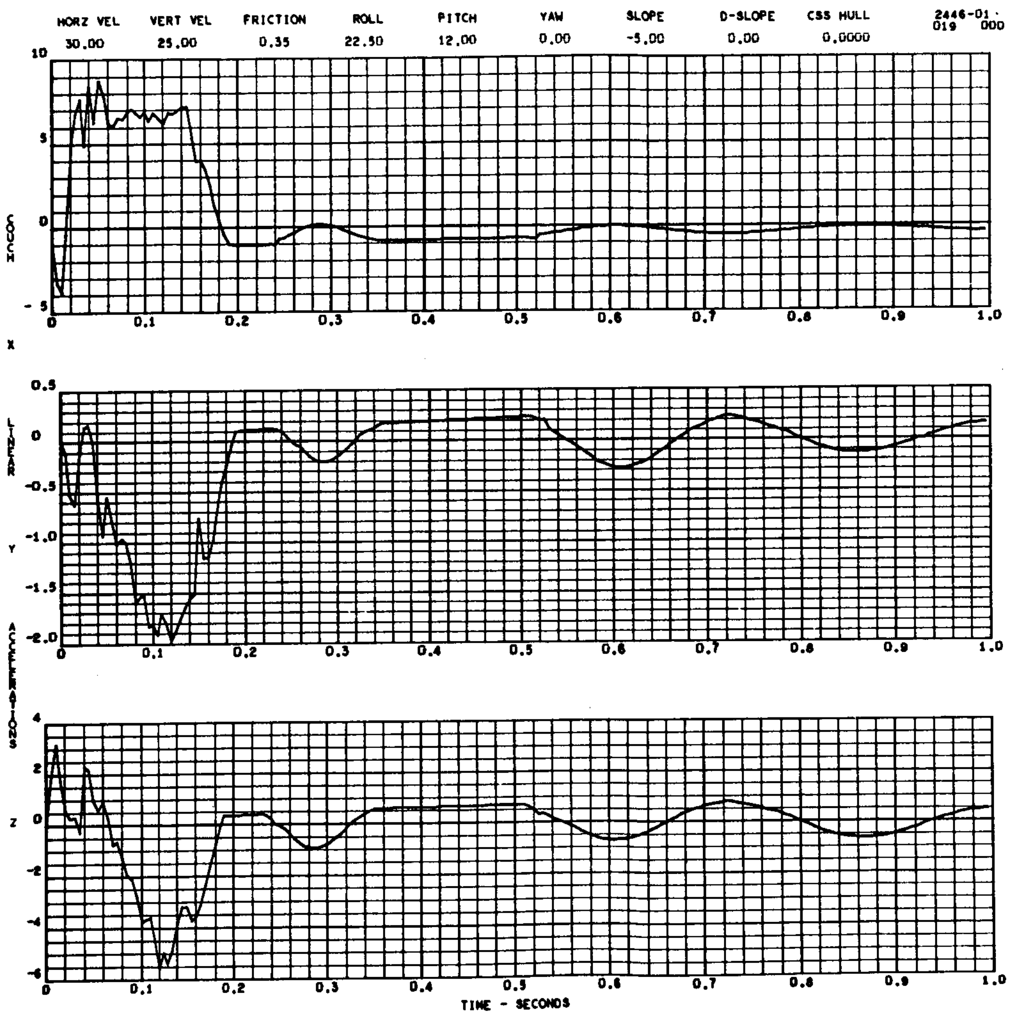

Figure 12. Couch Linear Accelerations Versus Time

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

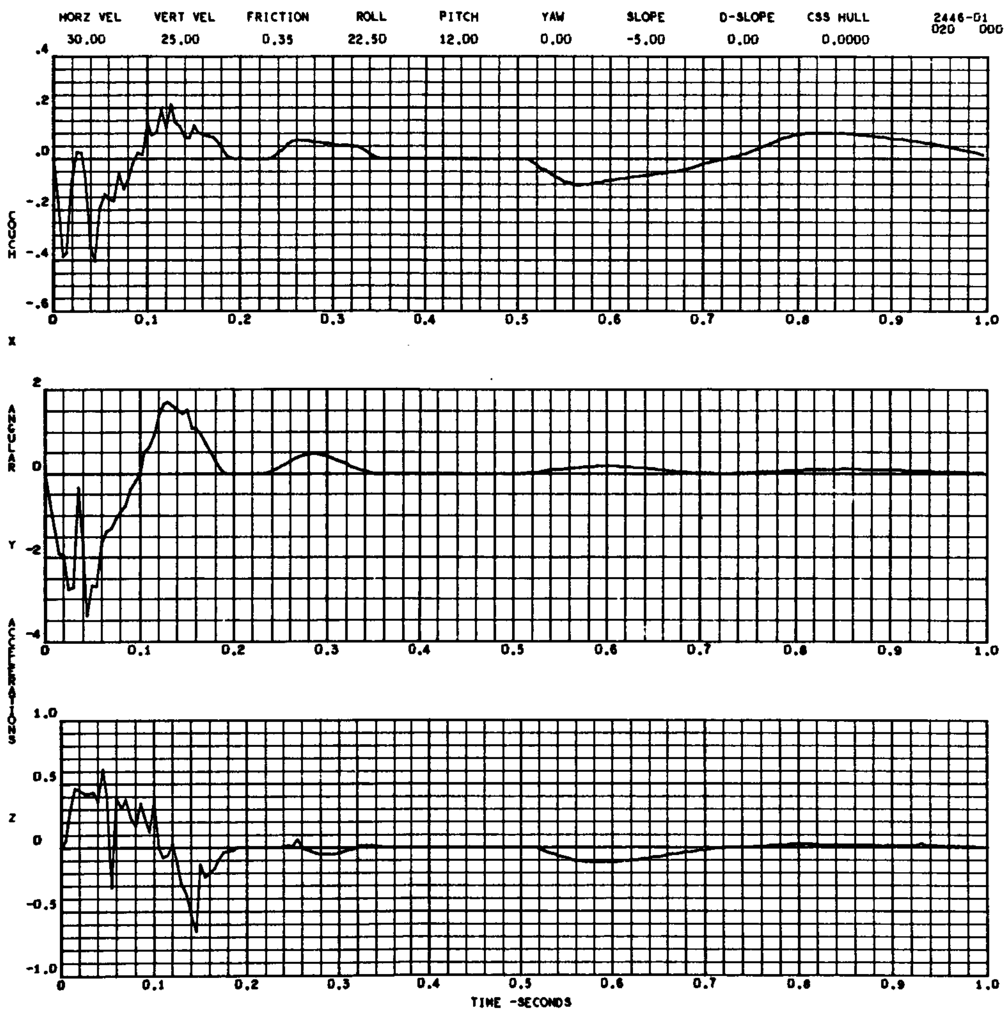

Figure 13. Couch Angular Accelerations Versus Time

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

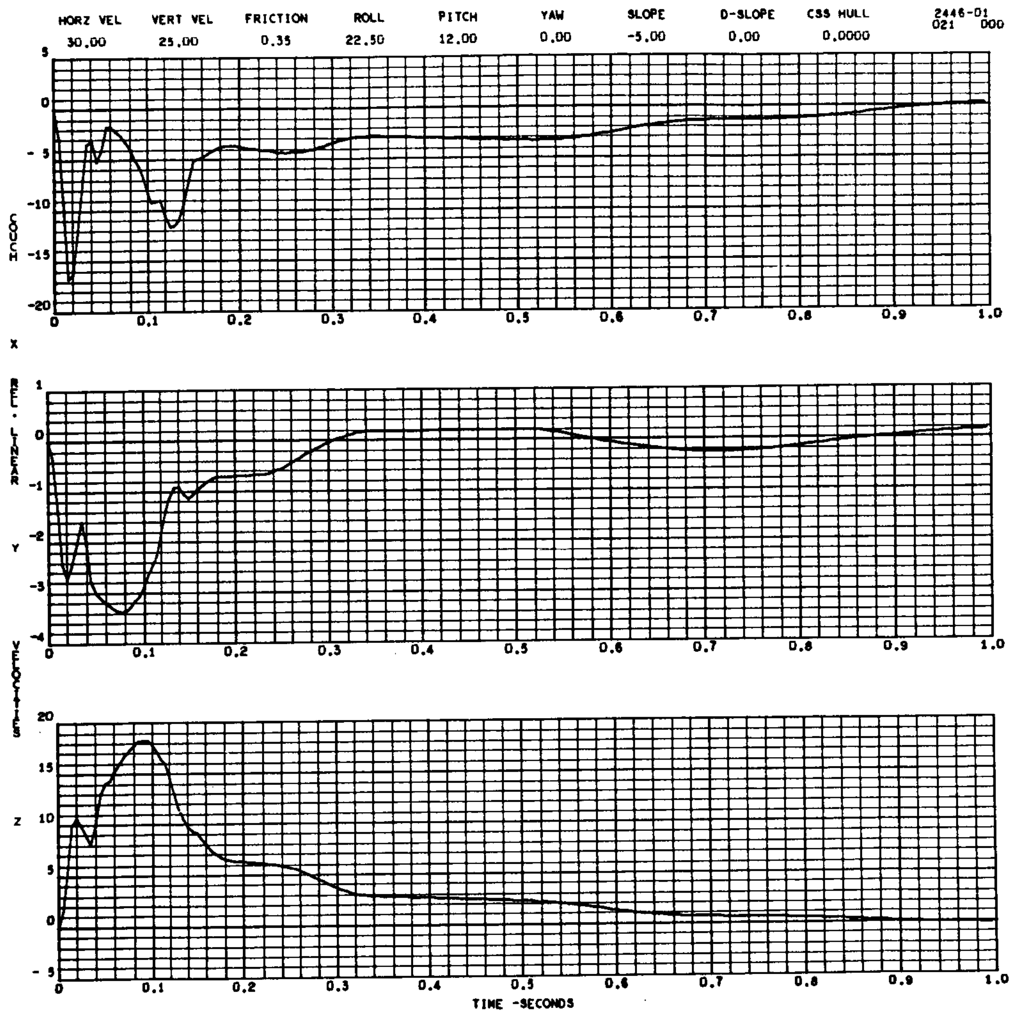

Figure 14. Couch Reliable Linear Velocities Versus Time

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

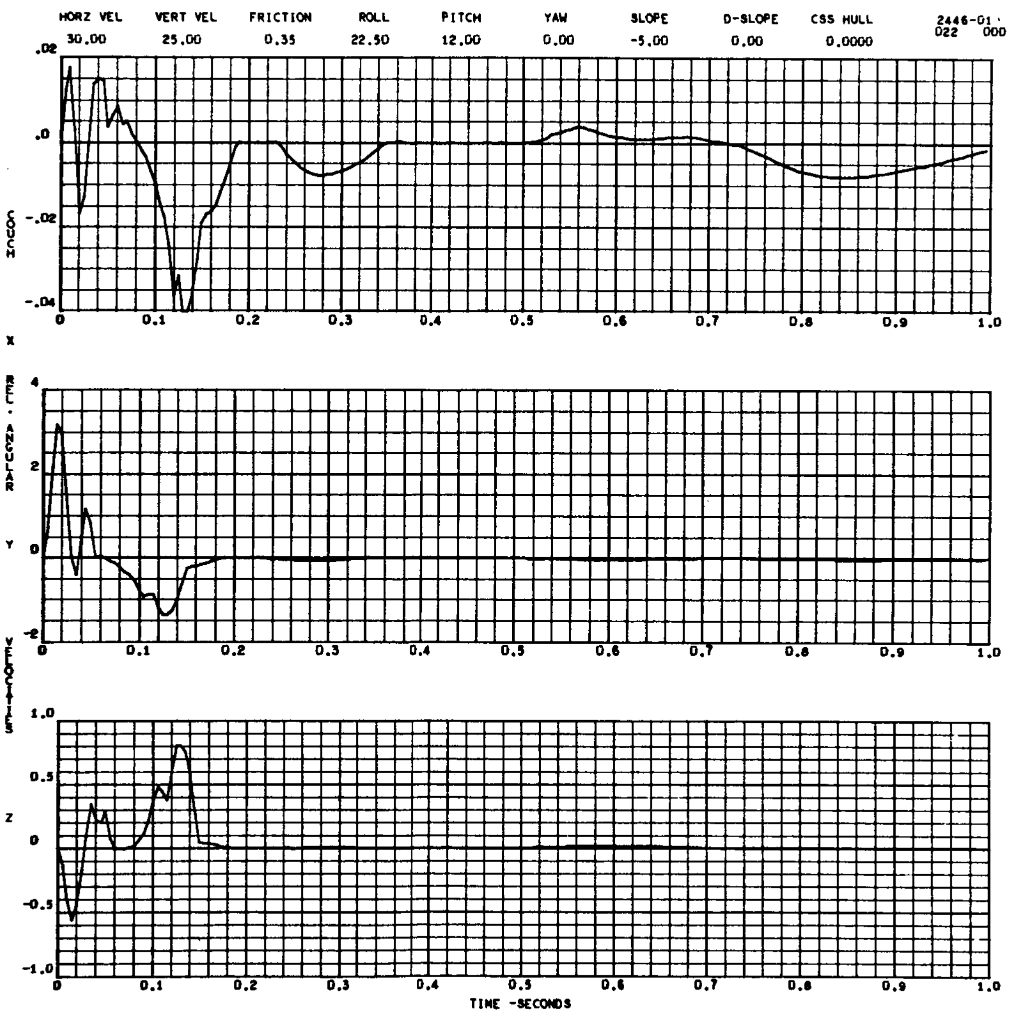

Figure 15. Couch Reliable Angular Velocities Versus Time

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

APPENDIX C

FLOW DIAGRAMS AND PROGRAM LISTING

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

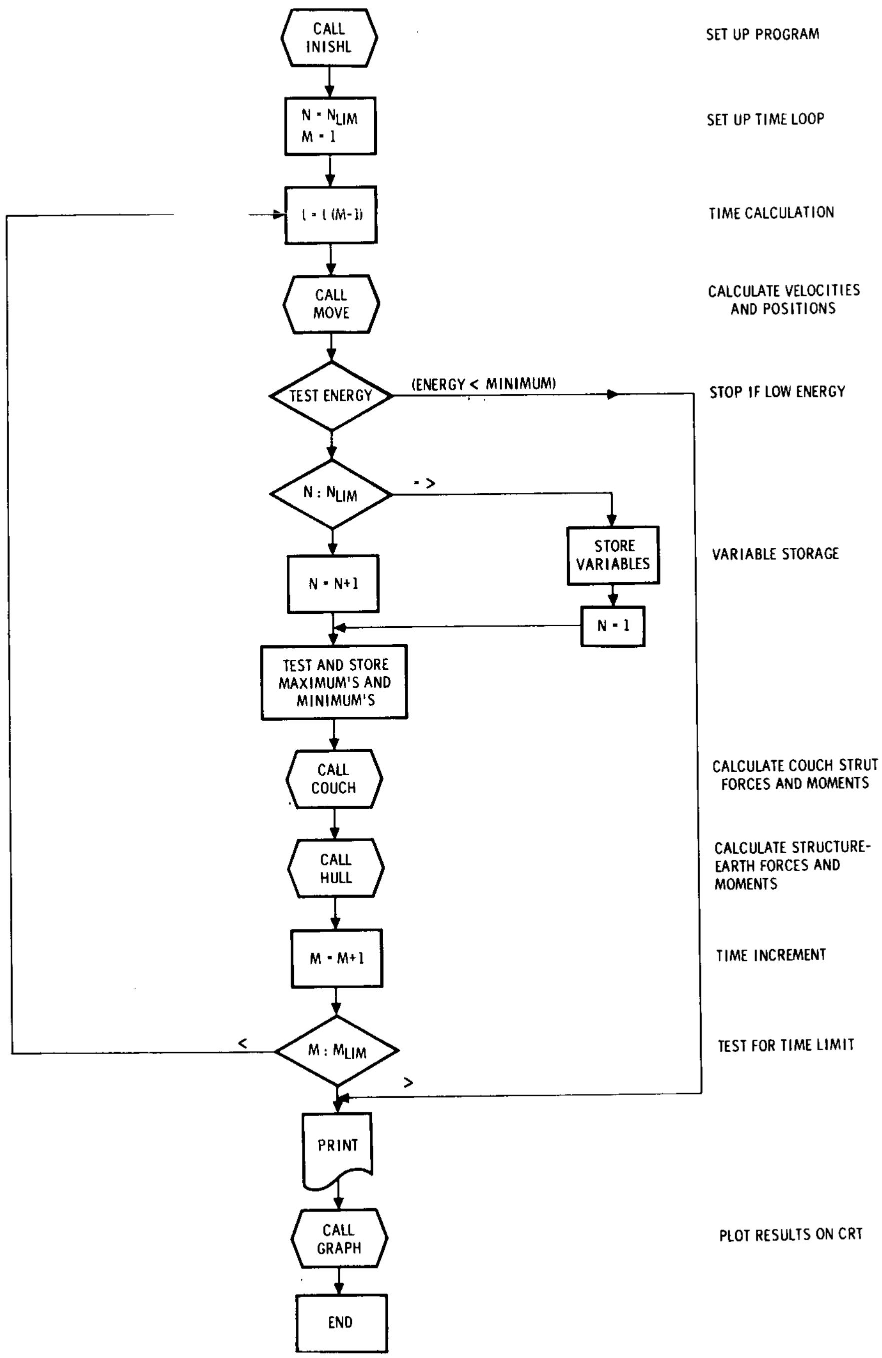

Figure 16. Main Program

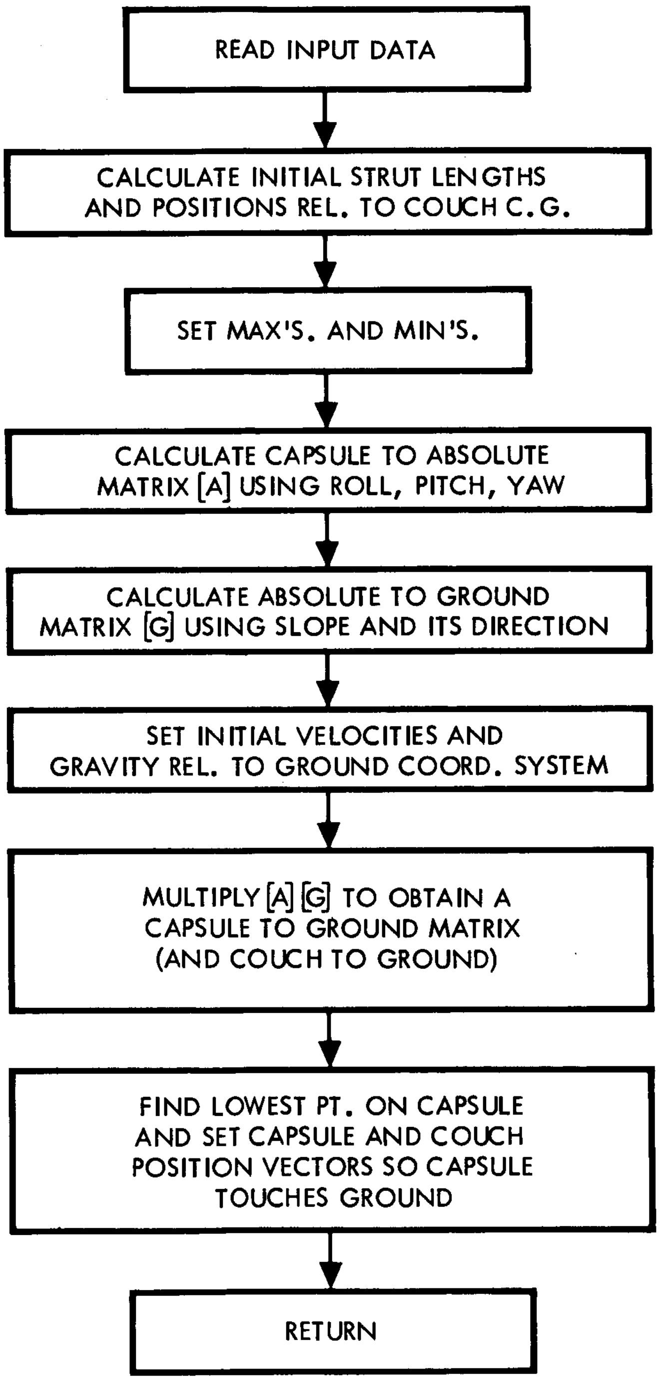

Figure 17. INISHL Subroutine

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

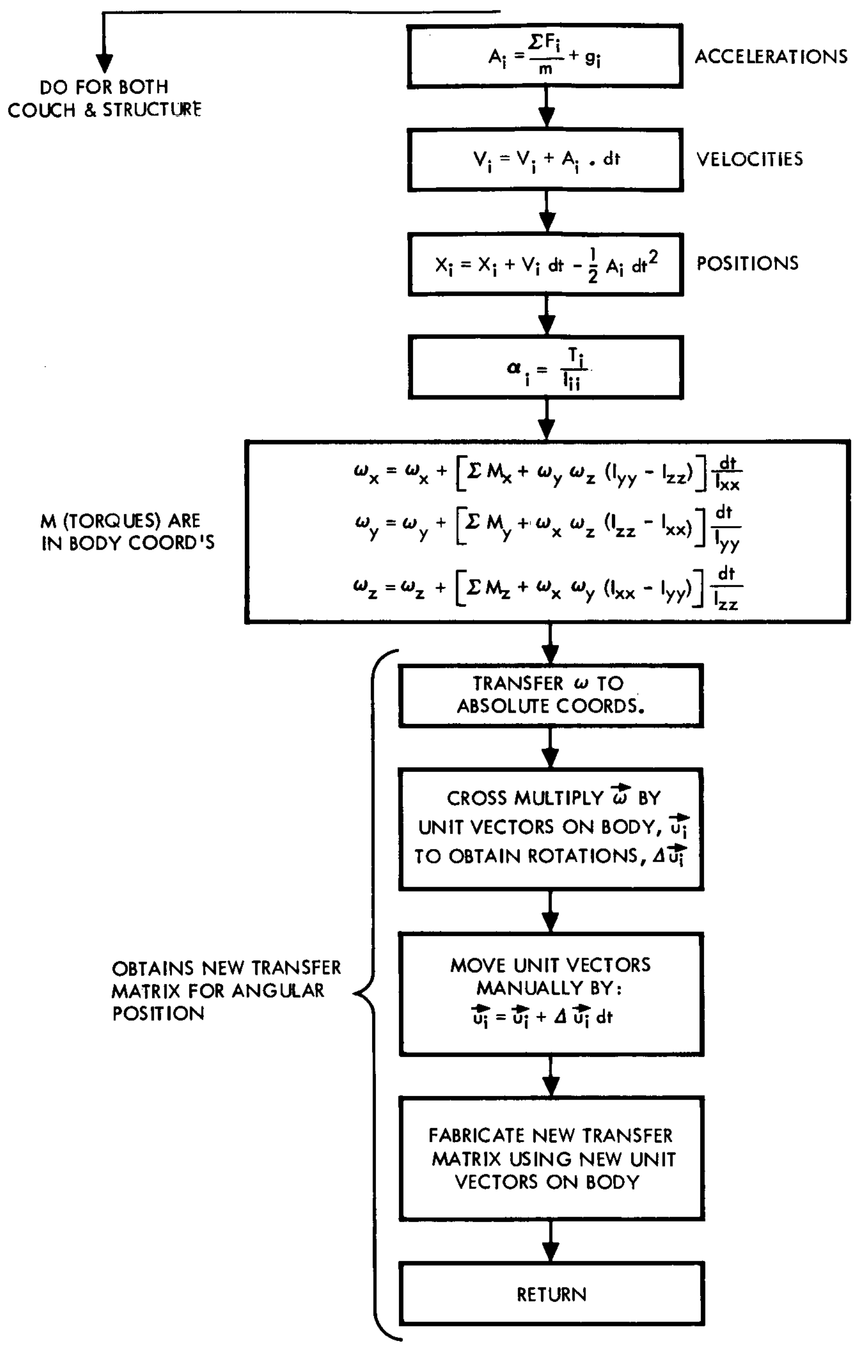

Figure 18. MØVE Subroutine

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

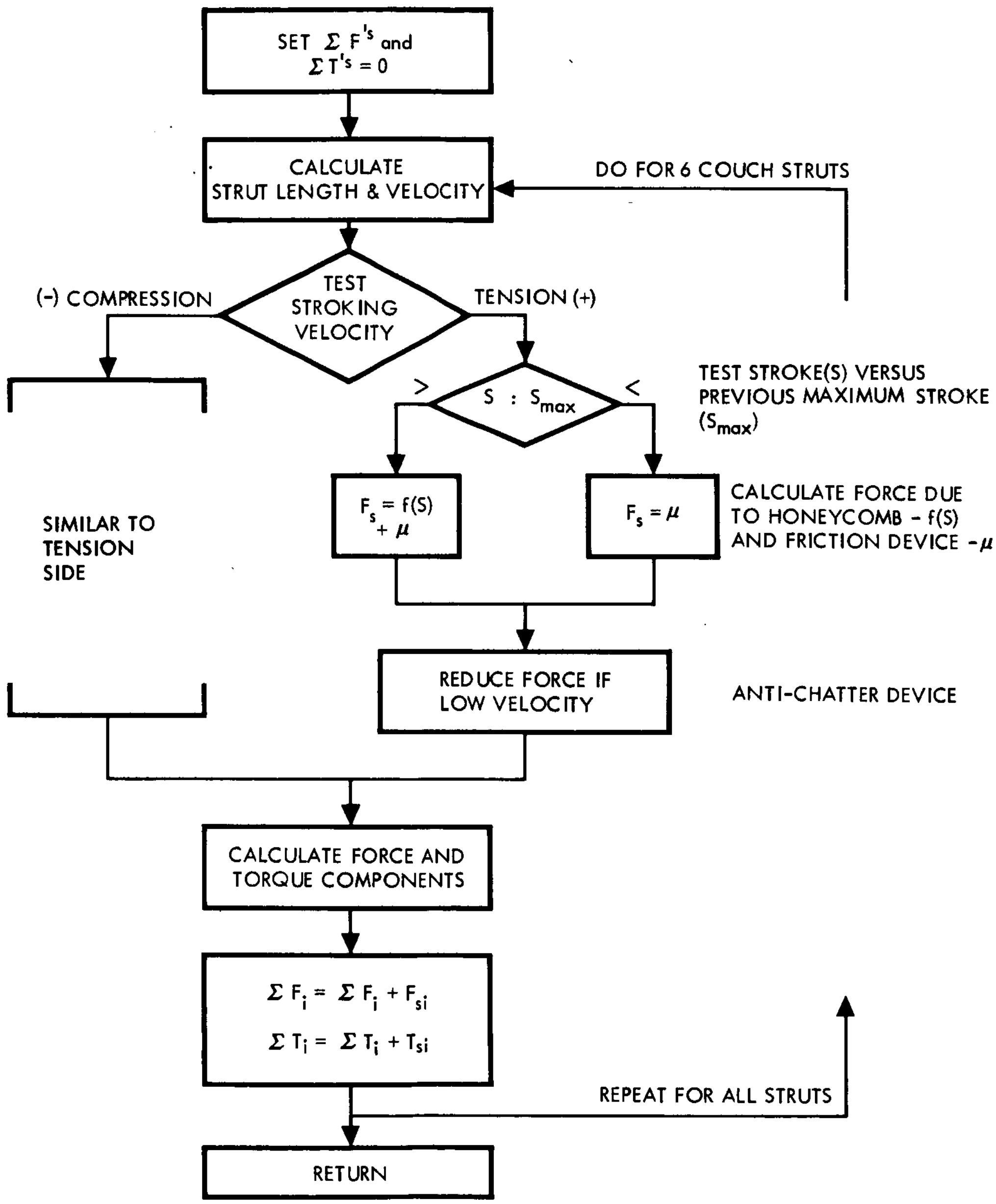

Figure 19. COUCH Subroutine

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

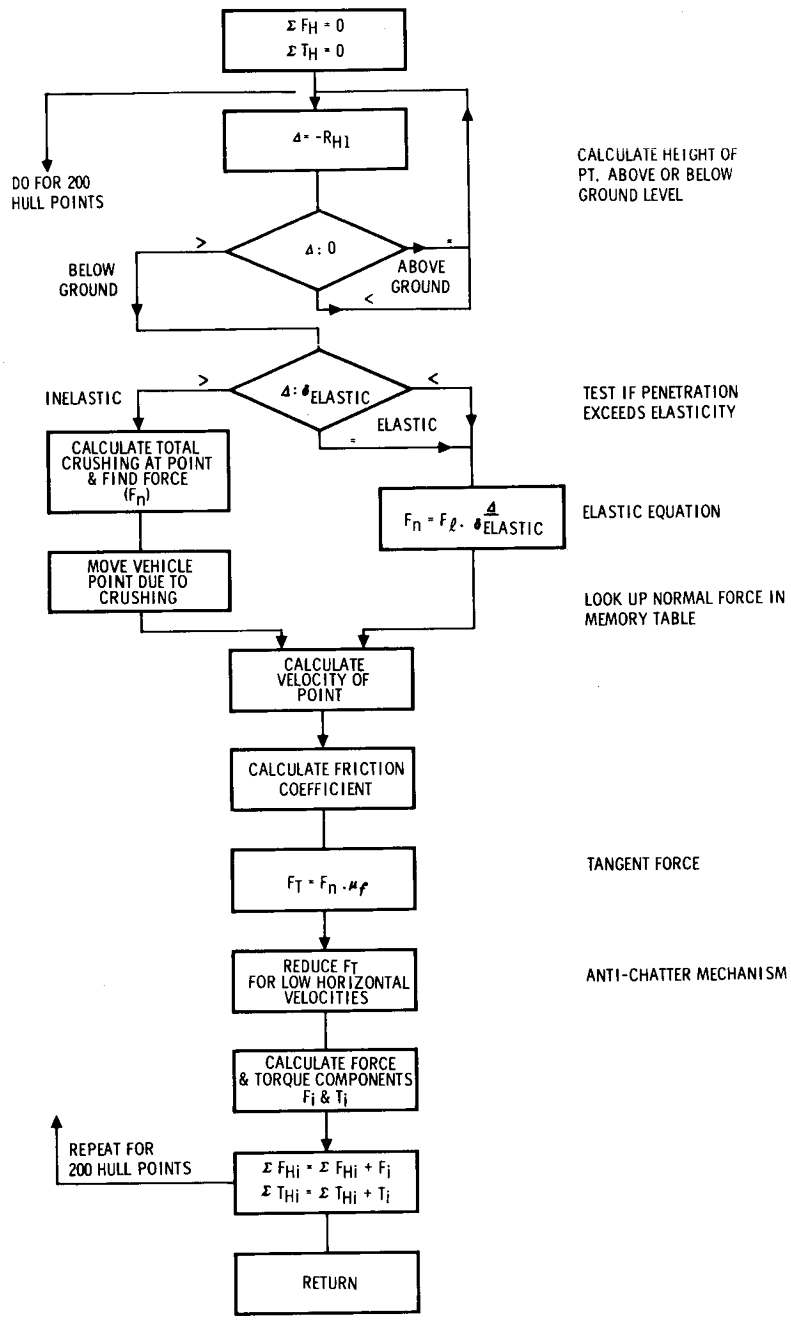

Figure 20. HULL Subroutine

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

```
$IBFTC MAIN    SDD
C        9J - 341 --  SIX DEGREE OF FREEDOM
      COMMON      VH,VV,FRIC,ROLL,PITCH,YAW,SLOPE,DSLOPE,EMP,EMC,EIP,EIC,
     1            GE,ERGMIN,P,TV,DT,TT,TLIM,TLH,RGPPI,DRGCI ,RGCPI,RAPPI,
     2            RACPI,RHPPI,STROKC,FCC,RAMPC,STROKT,FCT,RAMPT,FMUC,
     3            FMUT,STROKH,FH,RAMPH
      COMMON      DMU1,DMU2,FMU2
C
      COMMON      LH,NT,NTLIM,L,M,N,NP,ELI,RAPP,RACC,ELMAX,ELMIN,FAMAX,
     1            FAMIN,GCMAX,GCMIN,GPMAX,GPMIN,ALFACX,ALFACN,ALFAPX,
     2            ALFAPN,CRUSHT,CRUSHC,SLAT,SLAC,ELS,RGPE,RGCE,VGPE,VGCE,
     3            AGPE,AGCE,G,TMATP,TMATC,RHPP,DELTA,SFAPE,STAPE,SFACE,ST
     4            ACE,SFHPE,STHPE,WGPP,WGPE,WGCC,WGCE,RHPPL,RACE,RAPE,EL,
     5            RACCL,ELDOT,FACE,FAPE,FACC,FAPP,TACC,TAPP,RACPL,RACP,
     6            FACP,VHPPL,VHPE,FHPE,THPP,GRDM,ATUDM,VI,DGCC,DGPP
     7            ,TIME,STAPP,STACC,STHPP,AGCC,AGPP,RAPPL,FHPP,RGCPL
      COMMON      TYMH,TYM,ELPLOT,GP,ALFAP,VP,OP,RPP,TPP,GC,ALFAC,VC,OC
      DIMENSION   EIP(3),EIC(3),P(10),TV(6),RGPPI(3),DRGCI (3),RGCPI(3),
     1            RAPPI(3,8),RACPI(3,8),RHPPI(3,200),STROKC(5,8),FCC(5,8)
     2            ,RAMPC(5,8),STROKT(5,8),FCT(5,8),RAMPT(5,8),FMUC(8),
     3            FMUT(8),STROKH(5,200),FH(5,200),RAMPH(5,200)
      DIMENSION   ELI(8),RAPP(3,8),RACC(3,8),ELMAX(8),ELMIN(8),FAMAX(8),
     1            FAMIN(8),GCMAX(3),GCMIN(3),GPMAX(3),GPMIN(3),ALFACX(3),
     2            ALFACN(3),ALFAPX(3),ALFAPN(3),CRUSHC(8),CRUSHT(8),
     3            SLAC(8),SLAT(8),ELS(8),RGPE(3),RGCE(3),VGPE(3),VGCE(3),
     4            AGPE(3),AGCE(3),G(3),TMATP(3,3),TMATC(3,3),RHPP(3,200),
     5            DELTA(200),SFAPE(3),STAPP(3),SFACE(3),STACC(3),SFHPE(3)
     6            ,STHPP(3),WGPP(3),WGPE(3),WGCC(3),WGCE(3),RHPPL(3),
     7            RACE(3),RAPE(3),EL(8),RACCL(3),ELDOT(8),FACE(3)
     7            RACE(3),RAPE(3),EL(8),RACCL(3),ELDOT(8),FACE(3)
      DIMENSION   FAPE(3),FACC(3),FAPP(3),TACC(3),TAPP(3),RACPL(3),
     1            RACP(3,8),FACP(3),VHPPL(3),VHPE(3),FHPE(3),THPP(3),
     2            GRDM(3,3),ATUDM(3,3), VI(3),DGCC(3),DGPP(3)
     3            ,AGCC(3),AGPP(3),RAPPL(3),FHPP(3),RGCPL(3)
      DIMENSION   TYM(200),ELPLOT(8,200),ALFAP(3,200),ALFAC(3,200),
     1            GP(3,200),GC(3,200),RPP(3,200),TPP(3,200 ),
     2            VP(3,200),VC(3,200),OP(3,200),OC(3,200),TYMH(200)
      DIMENSION   EC(3)
      DIMENSION   VH(1)
C     ZERO THE COMMON REGEON BEFORE READING IN DATA
      DO 5 I=1,3954
    5 VH(I) = 0.
   10 CALL INISHL
```

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```
      N = NTLIM
      NP = 0
      M = 1
      ACPM = 0.0
      ACVM = 0.0
   20 TIME =   FLOAT(M-1)*DT
      CALL MOVE
      ENERGY = 0.0
      DO 40 I = 1,3
      ENERGY = ENERGY + 0.5*(EMP*VGPE(I)**2+EMC*VGCE(I)**2
     1                       +EIP(I)*WGPP(I)**2+EIC(I)*WGCC(I)**2 )
   40 CONTINUE
      IF(ENERGY - ERGMIN) 320,50,50
   50 CALL TRAN (TMATP,AGPE,AGPP)
      CALL TRAN (TMATC,AGCE,AGCC)
      IF (NP - 200)  60,160,160
   60 IF (N -NTLIM) 150,70,70
   70 N = 0
      NP = NP + 1
      DO 80 L = 1,8
      ELPLOT(L,NP) =(ELS(L) -ELI(L))*12.0
   80 CONTINUE
      TYM(NP) = TIME
      DO 90 I = 1,3
      ALFAP(I,NP) = DGPP(I)/GE
      ALFAC(I,NP) = DGCC(I)/GE
      GP(I,NP) = AGPP(I)/GE
      GC(I,NP) = AGCC(I)/GE
      RPP(I,NP) = RGPE(I)
      OP(I,NP) = WGPP(I)
      VP(I,NP) = VGPE(I)
      VC(I,NP) = VGCE(I)-VGPE(I)
      EC(I) = WGCE(I)-WGPE(I)
   90 CONTINUE
C
      CALL TRAN (TMATC,EC,OC(1,NP)    )
C
C
      CALL ATITUD (TMATP,TPP(2,NP),TPP(1,NP),TPP(3,NP) )
  150 N = N + 1
C
  160 DO 170 I = 1,3
      GPMAX(I)  = AMAX1(GPMAX(I),AGPP(I)/GE)
      GPMIN(I)  = AMIN1(GPMIN(I),AGPP(I)/GE)
```

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```
      GCMAX(I)  = AMAX1(GCMAX(I),AGCC(I)/GE)
      GCMIN(I)  = AMIN1(GCMIN(I),AGCC(I)/GE)
      ALFAPX(I) = AMAX1(ALFAPX(I),DGPP(I)/GE)
      ALFAPN(I) = AMIN1(ALFAPN(I),DGPP(I)/GE)
      ALFACX(I) = AMAX1(ALFACX(I),DGCC(I)/GE)
      ALFACN(I) = AMIN1(ALFACN(I),DGCC(I)/GE)
  170 CONTINUE
C
      ACP =  SQRT(AGCC(2)**2+ AGCC(3)**2)/GE
      ACPM= AMAX1(ACP,ACPM)
      ACV =  SQRT(AGCC(1)**2+AGCC(2)**2+AGCC(3)**2)/GE
      ACVM= AMAX1(ACV,ACVM)
      CALL COUCH
      CALL HULL
C
      IF (N-1)  300,175,300
  175 IF (P(9)) 180,300,180
  180 WRITE (6,191) (TMATP(1,K),K=1,3),(TMATC(1,K),K=1,3), TIME,((TMAT
     1P(I,K),K=1,3),(TMATC(I,K),K=1,3),I=2,3)
  191 FORMAT(1HO 5X 15HTMATP AND TMATC 3F10.4,F15.4,2F10.4/ 6X 5H(TIME
     1F9.4,1H),3F10.4,F15.4,2F10.4/F31.4,2F10.4,F15.4,2F10.4)
  300 M = M + 1
      IF (M - NT) 20,20,305
  305 WRITE
     0  (6, 311) TIME
  311 FORMAT (1H1,16X,   49HTHE TIME LIMIT HAS BEEN EXCEEDED, TIME ELAPS
     1ED IS F7.4, 9H SECONDS.)
      GO TO 350
  320 WRITE
     0  (6, 321)ERGMIN,TIME
  321 FORMAT (1H1,  6X , 52HTHE TOTAL KINETIC ENERGY OF THE SYSTEM WAS L
     1ESS THAN , F7.1 , 14H FT-LBS. AFTER , F7.4 , 9H SECONDS.)
C
C
  350 WRITE
     0  (6, 361)VV,VH,ROLL,PITCH,YAW,SLOPE,DSLOPE,FRIC,FMU2,DMU1,DMU2
C
  361 FORMAT (1H- 42X,18HINITIAL CONDITIONS / 9X14HVELOCITY (FPS)  9X
     114HATTITUDE (DEG)  9X 11HSLOPE (DEG) / 6X 94HVERTICAL  HORIZONTAL
     2    ROLL  PITCH   YAW    ANGLE  UP-DIRECTION      COEFFICIENT OF F
     3RICTION  / 2F12.2, F11.1,2F7.1,  F8.1,F11.1, F12.2 ,3F7.2)
C
      WRITE
```

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```
      Ø  (6, 371)DT,P(7),EMP,(EIP(I),I=1,3),EMC,(EIC(I),I=1,3)
  371 FØRMAT (1H- 19X  36HMASS    MOMENT ØF INERTIA (SLUG-FT2) 12X
     116HDELTA TIME (SEC)5X 8HCSS HULL/19X7H(SLUGS)5X3HX-X7X3HY-Y7X
     23HZ-Z 17X F7.4,F19.4/ 4X 13HPRESSURE HULL, F8.1,3F10.1 , /
     3 12X    5HCØUCH , F8.1, 3F10.1 )
C
      WRITE
      Ø  (6, 381)(GPMIN(I),GPMAX(I),I=1,3),(ALFAPN(I),ALFAPX(I),I=1,3)
C
  381 FØRMAT (1H- 41X 21HMAXIMUM ACCELERATIØNS / 27X 12HLINEAR (G-S)
     1 32X 21HRØTATIØNAL (G-S/FØØT)/18X1HX 15X 1HY 15X 1HZ 14X 3HX-X
     213X 3HY-Y 13X 3HZ-Z / 4X 5HP. H.   6(F9.2,F7.2))
C
      WRITE
      Ø  (6, 382)(GCMIN(I),GCMAX(I),I=1,3),(ALFACN(I),ALFACX(I),I=1,3)
C
  382 FØRMAT ( 9H    CØUCH  6(F9.2,F7.2))
      WRITE
      Ø  (6, 383) ACPM,ACVM
  383 FØRMAT (1F46.3 /1F 38.3)
C
      WRITE
      Ø  (6, 391)  (ELMAX(L),L=1,8)
C
  391 FØRMAT (1H- 29X, 45HCØUCH ATTENUATØR LENGTHS (FT) AND LØADS (LBS)/
     1 22X  4HFØØT 18X  4HHEAD 19X   3HZ-Z  19X  3HY-Y / 18X 4HLEFT  5X
     2 5HRIGHT  8X  4HLEFT  5X  5HRIGHT  8X  4HLEFT  5X  5HRIGHT   8X
     3 4HLEFT  5X  5HRIGHT / 4X  7HMAXIMUM,F11.3,F10.3,3(F12.3,F10.3))
C
      WRITE
      Ø  (6, 392)  (ELI(L),L=1,8)
  392 FØRMAT (11H    INITIAL , F11.3, F10.3, 3(F12.3,F10.3) )
C
      WRITE
      Ø  (6, 393)  (ELMIN(L),L=1,8)
  393 FØRMAT (11H    MINIMUM , F11.3, F10.3 , 3(F12.3,F10.3) )
C
      WRITE
      Ø  (6, 394) (FAMAX(L),L=1,8)
  394 FØRMAT (11HO   TENSIØN  4(F12.1 , F10.1))
C
      WRITE
      Ø  (6, 395) (FAMIN(L),L=1,8)
  395 FØRMAT (11H    CØMPRSN  4(F12.1 , F10.1))
```

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```
      CALL ATITUD (TMATP,PP,RP,YP)
      CALL ATITUD (TMATC,PC,RC,YC)
      WRITE
     Ø  (6, 401)(VGPE(I),I=1,3),(RGPE(I),I=1,3),RP,PP,YP
     1          ,(VGCE(I),I=1,3),(RGCE(I),I=1,3),RC,PC,YC
  401 FØRMAT (1H- 45X 16HFINAL PARAMETERS / 25X 14HVELØCITY (FPS) 14X
     1 17HDISPLACEMENT (FT) 14X 18HATTITUDE (DEGREES) / 23X 1HX 8X 1HY
     2 8X 1HZ 11X 1HX 8X 1HY 8X 1HZ 11X 4HRØLL 4X 5HPITCH 5X 3HYAW /
     3 4X 13HPRESSURE HULL F10.3,2F9.3,F12.3,2F9.3,F12.1,2F9.1, /
     4 12X 5HCØUCH         F10.3,2F9.3,F12.3,2F9.3,F12.1,2F9.1 )
      KN = 0
      DØ 430 K = 1,LH
      IF(TYMH(K)) 410,430,410
  410 KN = KN + 1
      DELTA(KN) = DELTA(K)*12.0
      TYMH(KN) = TYMH(K)
      DØ 420 I = 1,3
      RHPP(I,KN) = RHPPI(I,K)
  420 CONTINUE
  430 CONTINUE
C
      WRITE
     Ø  (6, 441)(TYMH(K),RHPP(1,K),RHPP(2,K),RHPP(3,K),DELTA(K),K=1,KN)
  441 FØRMAT(1H1 //  8X64HTIME ØF CØNTACT, LØCATIØN ØF PØINT, AND AMØUNT
     1 CRUSHED IN INCHES/16X4HTIME10X1HX10X1HY10X1HZ 8X 5HDELTA/
     2 (F22.5,4F11.2))
      IF (P(1)) 450,470,450
  450 WRITE
     Ø  (6, 461) (TYM(I),(ELPLØT(L,I),L=1,8),I=1,NP)
  461 FØRMAT (1H1 // 33X 39HTIME HISTØRY ØF STRUT STRØKES IN INCHES/ 6X
     1 4HTIME 12X 4HFØØT 18X 4HHEAD 19X 3HZ-Z 19X 3HY-Y / 5X 5H(SEC) 8X
     2 4HLEFT 5X 5HRIGHT 8X 4HLEFT 5X 5HRIGHT 8X 4HLEFT 5X 5HRIGHT 8X
     3 4HLEFT 5X 5HRIGHT /  (F10.4,F12.3,F10.3,F12.3,F10.3,F12.3,F10.3,
     4 F12.3,F10.3) )
C
  470 IF (P(2))  480,500,480
  480 WRITE
     Ø  (6, 491)
      WRITE
     Ø  (6, 492) (TYM(I),(GC(J,I),J=1,3),(ALFAC(J,I),J=1,3),I=1,NP)
  491 FØRMAT (1H1,// 30X 31HCØUCH ACCELERATIØNS VERSUS TIME )
  492 FØRMAT (1H  5X  4HTIME       9X
     1 1HX 10X 1HY 10X 1HZ 12X 3HX-X 8X 3HY-Y 8X 3HZ-Z / (F12.4,3F11.3,
```

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```
      2 F13.3,2F11.3 ))
C
  500 IF (P(3)) 510,530,510
  510 WRITE
     Ø  (6, 521)
  521 FØRMAT (1H1 25X    39HPRESSURE HULL ACCELERATIØNS VERSUS TIME )
       WRITE
     Ø  (6, 492)(TYM(I),(GP(J,I),J=1,3),(ALFAP(J,I),J=1,3),I=1,NP)
C
  530 IF (P(4)) 540,560,540
  540 WRITE
     Ø  (6, 551)
  551 FØRMAT (1H1 20X 58HPRESSURE HULL VELØCITIES VERSUS TIME (FEET/SEC
     1AND RAD/SEC)
       WRITE
     Ø  (6, 492)(TYM(K),(VP(J,K),J=1,3),(ØP(J,K),J=1,3),K=1,NP)
  560 IF (P(5)) 570,590,570
  570 WRITE
     Ø  (6, 581)
  581 FØRMAT (1H1 10X  79HCØUCH VELØCITIES VERSUS TIME RELATIVE TØ THE P
     1RESSURE HULL (FT/SEC AND RAD/SEC) )
       WRITE
     Ø  (6, 492)(TYM(K),(VC(I,K),I=1,3),(ØC(I,K),I=1,3),K=1,NP)
  590 IF (P(6)) 600,620,600
  600 WRITE
     Ø  (6, 611)
  611 FØRMAT (1H1 25X 59HPRESSURE HULL DISPLACEMENTS IN FEET AND DEGREES
     1 VERSUS TIME )
       WRITE
     Ø  (6, 492)(TYM(K),(RPP(I,K),I=1,3),(TPP(I,K),I=1,3),K=1,NP)
  620 GØ TØ 1100
 1100 WRITE
     Ø  (6, 1111)
 1111 FØRMAT (1H1)
       IF (TV(1) + TV(2) + TV(3) + TV(4) + TV(5) + TV(6))  2000,10,2000
 2000 CALL GRAFIT
       GØ TØ 10
       END
```

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```
$IBFTC INISHL
C                   9J - 342 --- INISHL
      SUBROUTINE INISHL
C     RESETS ALL  INITIAL VALUES AND PLACES CAPULE ON GROUND
      COMMON      VH,VV,FRIC,ROLL,PITCH,YAW,SLOPE,DSLOPE,EMP,EMC,EIP,EIC,
     1            GE,ERGMIN,P,TV,DT,TT,TLIM,TLH,RGPPI,DRGCI ,RGCPI,RAPPI,
     2            RACPI,RHPPI,STROKC,FCC,RAMPC,STROKT,FCT,RAMPT,FMUC,
     3            FMUT,STROKH,FH,RAMPH
      COMMON      DMU1,DMU2,FMU2
C
      COMMON      LH,NT,NTLIM,L,M,N,NP,ELI,RAPP,RACC,ELMAX,ELMIN,FAMAX,
     1            FAMIN,GCMAX,GCMIN,GPMAX,GPMIN,ALFACX,ALFACN,ALFAPX,
     2            ALFAPN,CRUSHT,CRUSHC,SLAT,SLAC,ELS,RGPE,RGCE,VGPE,VGCE,
     3            AGPE,AGCE,G,TMATP,TMATC,RHPP,DELTA,SFAPE,STAPE,SFACE,ST
     4            ACE,SFHPE,STHPE,WGPP,WGPE,WGCC,WGCE,RHPPL,RACE,RAPE,EL,
     5            RACCL,ELDOT,FACE,FAPE,FACC,FAPP,TACC,TAPP,RACPL,RACP,
     6            FACP,VHPPL,VHPE,FHPE,THPP,GRDM,ATUDM,VI,DGCC,DGPP
     7            ,TIME,STAPP,STACC,STHPP,AGCC,AGPP,RAPPL,FHPP,RGCPL
      COMMON      TYMH,TYM,ELPLOT,GP,ALFAP,VP,OP,RPP,TPP,GC,ALFAC,VC,OC
      DIMENSION   EIP(3),EIC(3),P(10),TV(6),RGPPI(3),DRGCI (3),RGCPI(3),
     1            RAPPI(3,8),RACPI(3,8),RHPPI(3,200),STROKC(5,8),FCC(5,8)
     2            ,RAMPC(5,8),STROKT(5,8),FCT(5,8),RAMPT(5,8),FMUC(8),
     3            FMUT(8),STROKH(5,200),FH(5,200),RAMPH(5,200)
      DIMENSION   ELI(8),RAPP(3,8),RACC(3,8),ELMAX(8),ELMIN(8),FAMAX(8),
     1            FAMIN(8),GCMAX(3),GCMIN(3),GPMAX(3),GPMIN(3),ALFACX(3),
     2            ALFACN(3),ALFAPX(3),ALFAPN(3),CRUSHC(8),CRUSHT(8),
     3            SLAC(8),SLAT(8),ELS(8),RGPE(3),RGCE(3),VGPE(3),VGCE(3),
     4            AGPE(3),AGCE(3),G(3),TMATP(3,3),TMATC(3,3),RHPP(3,200),
     5            DELTA(200),SFAPE(3),STAPP(3),SFACE(3),STACC(3),SFHPE(3)
     6            ,STHPP(3),WGPP(3),WGPE(3),WGCC(3),WGCE(3),RHPPL(3),
     7            RACE(3),RAPE(3),EL(8),RACCL(3),ELDOT(8),FACE(3)
      DIMENSION   FAPE(3),FACC(3),FAPP(3),TACC(3),TAPP(3),RACPL(3),
     1            RACP(3,8),FACP(3),VHPPL(3),VHPE(3),FHPE(3),THPP(3),
     2            GRDM(3,3),ATUDM(3,3), VI(3),DGCC(3),DGPP(3)
     3            ,AGCC(3),AGPP(3),RAPPL(3),FHPP(3),RGCPL(3)
      DIMENSION   TYM(200),ELPLOT(8,200),ALFAP(3,200),ALFAC(3,200),
     1            GP(3,200),GC(3,200),RPP(3,200),TPP(3,200 ),
     2            VP(3,200),VC(3,200),CP(3,200),OC(3,200),TYMH(200)
      CALL  DECRD(VH)
      LH =TLH
      NT = TT
      NTLIM = TLIM
      DO 30 J= 1,8
```

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```
      ELI2 = 0.0
      DØ 20 I= 1,3
      RACC(I,J)=(RACPI(I,J)-RGCPI(I))/ 12.0
      RAPP(I,J)=(RAPPI(I,J)-RGPPI(I))/ 12.0
      DRAPI =(RACPI(I,J) + DRGCI(I)- RAPPI(I,J))/ 12.0
      ELI2 = ELI2+ DRAPI**2
   20 CØNTINUE
      ELI(J) =  SQRT(ELI2)
      ELMAX(J)=ELI(J)
      ELMIN(J)=ELI(J)
      FAMAX(J)=0.0
      FAMIN(J)=0.0
      CRUSHC(J)=0.0
      CRUSHT(J)=0.0
      SLAC  (J)= 0.0
      SLAT  (J)= 0.0
      ELS(J) = ELI(J)
   30 CØNTINUE
C
      DØ 40 I=1,3
      SFAPE(I)=0.0
      STAPP(I)=0.0
      SFACE(I)=0.0
      STACC(I)=0.0
      SFHPE(I)=0.0
      STHPP(I)=0.0
C
      GPMAX(I)= 0.0
      GPMIN(I)= 0.0
      GCMAX(I)= 0.0
      GCMIN(I)= 0.0
      ALFAPX(I)=0.0
      ALFAPN(I)=0.0
      ALFACX(I)=0.0
      ALFACN(I)=0.0
   40 CØNTINUE
C
      SPA =  SIND(PITCH)
      CPA =  CØSD(PITCH)
      SYA =  SIND(YAW)
      CYA =  CØSD(YAW)
      SRA =  SIND(RØLL)
      CRA =  CØSD(RØLL)
      ATUDM(1,1) = CPA*CYA
```

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```
      ATUDM(1,2) =-CPA*SYA
      ATUDM(1,3) =  SPA
      ATUDM(2,1) = SPA*CYA*SRA+ SYA*CRA
      ATUDM(2,2) =-SPA*SYA*SRA+ CYA*CRA
      ATUDM(2,3) =-CPA*SRA
      ATUDM(3,1) =-SPA*CYA*CRA+ SYA*SRA
      ATUDM(3,2) = SPA*SYA*CRA+ CYA*SRA
      ATUDM(3,3) = CPA*CRA
      SPGRD=  SIND( ATAND( SIND(SLØPE)/ CØSD(SLØPE)* CØSD(DSLØPE)))
      SYGRD=- SIND(SLØPE)* SIND(DSLØPE)
      CPGRD =  SQRT(1.0- SPGRD**2)
      CYGRD =  SQRT(1.0- SYGRD**2)
      GRDM(1,1) = CPGRD*CYGRD
      GRDM(1,2) =-CPGRD*SYGRD
      GRDM(1,3) =-SPGRD
      GRDM(2,1) =SYGRD
      GRDM(2,2) =CYGRD
      GRDM(2,3) =0.0
      GRDM(3,1) =SPGRD*CYGRD
      GRDM(3,2) =-SPGRD*SYGRD
      GRDM(3,3) = CPGRD
      VI(1)=- ABS(VV)
      VI(2)= 0.0
      VI(3)=  ABS(VH)
      CALL TRAN(GRDM,VI,VGPE)
      G(1) =-GE* CPGRD*CYGRD
      G(2) =-GE* SYGRD
      G(3) =-GE* SPGRD*CYGRD
C
      DØ 100 I=1,3
      DØ 100 J=1,3
      TMATP (J,I) = 0.0
      DØ 50  IS=1,3
      TMATP(J,I) = TMATP(J,I)+GRDM(I,IS)*ATUDM(IS,J)
   50 CØNTINUE
      TMATC(J,I)=TMATP(J,I)
  100 CØNTINUE
      DMIN = 500.0
      DØ 200 J=1,LH
      DØ 150 I=1,3
      RHPP(I,J)=(RHPPI(I,J)- RGPPI(I))/ 12.0
  150 CØNTINUE
      CALL INTRAN(TMATP,RHPP(1,J),RHPPL)
```

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```
      DMIN =AMIN1(DMIN,RHPPL(1))
      DELTA(J)=0.0
      TYMH(J) =0.0
  200 CONTINUE
      RGPE(1)= -DMIN
      RGPE(2)=0.0
      RGPE(3)=0.0
      DO 220 I=1,3
      RGCE(I) = (RGCPI(I)+ DRGCI(I) -   RGPPI(I))/12.0
  220 CONTINUE
                                        CALL INTRAN(TMATP,RGCE,RGCPL)
      DO 240 I=1,3
      RGCE(I) = RGPE(I)+RGCPL(I)
      VGCE(I)= VGPE(I)
      WGPP(I) = 0.0
      WGCC(I) = 0.0
      WGPE(I) = 0.0
      WGCE(I) = 0.0
  240 CONTINUE
      RETURN
      END
```

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```
$IBFTC HULL
C                9J - 343 --- HULL
      SUBROUTINE HULL
C     CALCULATES THE EARTH FORCES AND  MOMENTS ON THE  PRESSURE HULL
      COMMON     VH,VV,FRIC,ROLL,PITCH,YAW,SLOPE,DSLOPE,EMP,EMC,EIP,EIC,
     1           GE,ERGMIN,P,TV,DT,TT,TLIM,TLH,RGPPI,DRGCI ,RGCPI,RAPPI,
     2           RACPI,RHPPI,STROKC,FCC,RAMPC,STROKT,FCT,RAMPT,FMUC,
     3           FMUT,STROKH,FH,RAMPH
      COMMON     DMU1,DMU2,FMU2
C
      COMMON     LH,NT,NTLIM,L,M,N,NP,ELI,RAPP,RACC,ELMAX,ELMIN,FAMAX,
     1           FAMIN,GCMAX,GCMIN,GPMAX,GPMIN,ALFACX,ALFACN,ALFAPX,
     2           ALFAPN,CRUSHT,CRUSHC,SLAT,SLAC,ELS,RGPE,RGCE,VGPE,VGCE,
     3           AGPE,AGCE,G,TMATP,TMATC,RHPP,DELTA,SFAPE,STAPE,SFACE,ST
     4           ACE,SFHPE,STHPE,WGPP,WGPE,WGCC,WGCE,RHPPL,RACE,RAPE,EL,
     5           RACCL,ELDOT,FACE,FAPE,FACC,FAPP,TACC,TAPP,RACPL,RACP,
     6           FACP,VHPPL,VHPE,FHPE,THPP,GRDM,ATUDM,VI,DGCC,DGPP
     7           ,TIME,STAPP,STACC,STHPP,AGCC,AGPP,RAPPL,FHPP,RGCPL
      COMMON     TYMH,TYM,ELPLOT,GP,ALFAP,VP,OP,RPP,TPP,GC,ALFAC,VC,OC
      DIMENSION  EIP(3),EIC(3),P(10),TV(6),RGPPI(3),DRGCI (3),RGCPI(3),
     1           RAPPI(3,8),RACPI(3,8),RHPPI(3,200),STROKC(5,8),FCC(5,8)
     2           ,RAMPC(5,8),STROKT(5,8),FCT(5,8),RAMPT(5,8),FMUC(8),
     3           FMUT(8),STROKH(5,200),FH(5,200),RAMPH(5,200)
      DIMENSION  ELI(8),RAPP(3,8),RACC(3,8),ELMAX(8),ELMIN(8),FAMAX(8),
     1           FAMIN(8),GCMAX(3),GCMIN(3),GPMAX(3),GPMIN(3),ALFACX(3),
     2           ALFACN(3),ALFAPX(3),ALFAPN(3),CRUSHC(8),CRUSHT(8),
     3           SLAC(8),SLAT(8),ELS(8),RGPE(3),RGCE(3),VGPE(3),VGCE(3),
     4           AGPE(3),AGCE(3),G(3),TMATP(3,3),TMATC(3,3),RHPP(3,200),
     5           DELTA(200),SFAPE(3),STAPP(3),SFACE(3),STACC(3),SFHPE(3)
     6           ,STHPP(3),WGPP(3),WGPE(3),WGCC(3),WGCE(3),RHPPL(3),
     7           RACE(3),RAPE(3),EL(8),RACCL(3),ELDOT(8),FACE(3)
      DIMENSION  FAPE(3),FACC(3),FAPP(3),TACC(3),TAPP(3),RACPL(3),
     1           RACP(3,8),FACP(3),VHPPL(3),VHPE(3),FHPE(3),THPP(3),
     2           GRDM(3,3),ATUDM(3,3), VI(3),DGCC(3),DGPP(3)
     3           ,AGCC(3),AGPP(3),RAPPL(3),FHPP(3),RGCPL(3)
      DIMENSION  TYM(200),ELPLOT(8,200),ALFAP(3,200),ALFAC(3,200),
     1           GP(3,200),GC(3,200),RPP(3,200),TPP(3,200 ),
     2           VP(3,200),VC(3,200),OP(3,200),OC(3,200),TYMH(200)
      DO 5 I=1,3
      SFHPE(I)=0.0
      STHPP(I) = 0.0
    5 CONTINUE
      DO 500 J =1,LH
```

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```
      RHPPL(1) = TMATP(1,1)*RHPP(1,J)+ TMATP(2,1)*RHPP(2,J)+
     1 TMATP(3,1)*RHPP(3,J)
      IF (RHPPL+RGPE)10,500,500
   10 CALL INTRAN(TMATP,RHPP(1,J),RHPPL)
      IF(TYMH(J)) 15,14,15
   14 TYMH(J)= TIME
   15 DEL = -RHPPL -RGPE
      IF (DEL-STRØKH(1,J)) 20,20,30
   20 FHPE= RAMPH(1,J)*DEL
      GØ TØ 60
   30 DØ 40 K =2,5
      K = K
      IF(DEL +DELTA(J)-STRØKH(K,J)) 50,50,40
   40 CØNTINUE
   50 FHPE = FH(K,J)+RAMPH(K,J)*(DEL+CELTA(J)-STRØKH(K-1,J))
      DELTA(J)= DELTA(J) +DEL -STRØKH(1,J)
      RHPPL = RHPPL+DEL -STRØKH(1,J)
      CALL TRAN(TMATP,RHPPL,RHPP(1,J))
   60 CALL AXB(WGPE,RHPPL,VHPPL)
      DØ 70 I =2,3
      VHPE(I) =VGPE(I)+ VHPPL(I)
   70 CØNTINUE
      VH2 =  SQRT(VHPE(2)**2+VHPE(3)**2)
      IF (DELTA(J)-DMU1) 72,72,74
   72 FMU = FRIC
       GØ TØ 78
   74 IF(DELTA(J)-DMU2) 75,75,76
   75 FMU = FRIC+(FMU2-FRIC)/(DMU2-DMU1)*(DELTA(J)-DMU1)
       GØ TØ 78
   76 FMU= FMU2
   78 IF(VH2)500,140,80
   80 IF(VH2 -0.2) 90,110,110
   90 DØ 100 I =2,3
      FHPE(I) = -FHPE*FMU *VHPE(I)*5.0
  100 CØNTINUE
      GØ TØ 130
  110 DØ 120 I =2,3
      FHPE(I)= -FHPE*FMU *VHPE(I)/VH2
  120 CØNTINUE
  130 CALL TRAN(TMATP,FHPE,FHPP)
      CALL AXB (RHPP(1,J),FHPP,THPP)
  140 DØ 150 I =1,3
      SFHPE(I) = SFHPE(I) + FHPE(I)
      STHPP(I) = STHPP(I) + THPP(I)
  150 CØNTINUE
  500 CØNTINUE
  600 RETURN
      END
```

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```
$IBFTC COUCH   SDD
C                9J - 344 --- COUCH
      SUBROUTINE COUCH
      COMMON     VH,VV,FRIC,ROLL,PITCH,YAW,SLOPE,DSLOPE,EMP,EMC,EIP,EIC,
     1           GE,ERGMIN,P,TV,DT,TT,TLIM,TLH,RGPPI,DRGCI ,RGCPI,RAPPI,
     2           RACPI,RHPPI,STROKC,FCC,RAMPC,STROKT,FCT,RAMPT,FMUC,
     3           FMUT,STROKH,FH,RAMPH
      COMMON     DMU1,DMU2,FMU2
C
      COMMON     LH,NT,NTLIM,L,M,N,NP,ELI,RAPP,RACC,ELMAX,ELMIN,FAMAX,
     1           FAMIN,GCMAX,GCMIN,GPMAX,GPMIN,ALFACX,ALFACN,ALFAPX,
     2           ALFAPN,CRUSHT,CRUSHC,SLAT,SLAC,ELS,RGPE,RGCE,VGPE,VGCE,
     3           AGPE,AGCE,G,TMATP,TMATC,RHPP,DELTA,SFAPE,STAPE,SFACE,ST
     4           ACE,SFHPE,STHPE,WGPP,WGPE,WGCC,WGCE,RHPPL,RACE,RAPE,EL,
     5           RACCL,ELDOT,FACE,FAPE,FACC,FAPP,TACC,TAPP,RACPL,RACP,
     6           FACP,VHPPL,VHPE,FHPE,THPP,GRDM,ATUDM,VI,DGCC,DGPP
     7           ,TIME,STAPP,STACC,STHPP,AGCC,AGPP,RAPPL,FHPP,RGCPL
      COMMON     TYMH,TYM,ELPLOT,GP,ALFAP,VP,OP,RPP,TPP,GC,ALFAC,VC,OC
      DIMENSION  EIP(3),EIC(3),P(10),TV(6),RGPPI(3),DRGCI (3),RGCPI(3),
     1           RAPPI(3,8),RACPI(3,8),RHPPI(3,200),STROKC(5,8),FCC(5,8)
     2           ,RAMPC(5,8),STROKT(5,8),FCT(5,8),RAMPT(5,8),FMUC(8),
     3           FMUT(8),STROKH(5,200),FH(5,200),RAMPH(5,200)
      DIMENSION  ELI(8),RAPP(3,8),RACC(3,8),ELMAX(8),ELMIN(8),FAMAX(8),
     1           FAMIN(8),GCMAX(3),GCMIN(3),GPMAX(3),GPMIN(3),ALFACX(3),
     2           ALFACN(3),ALFAPX(3),ALFAPN(3),CRUSHC(8),CRUSHT(8),
     3           SLAC(8),SLAT(8),ELS(8),RGPE(3),RGCE(3),VGPE(3),VGCE(3),
     4           AGPE(3),AGCE(3),G(3),TMATP(3,3),TMATC(3,3),RHPP(3,200),
     5           DELTA(200),SFAPE(3),STAPP(3),SFACE(3),STACC(3),SFHPE(3)
     6           ,STHPP(3),WGPP(3),WGPE(3),WGCC(3),WGCE(3),RHPPL(3),
     7           RACE(3),RAPE(3),EL(8),RACCL(3),ELDOT(8),FACE(3)
      DIMENSION  FAPE(3),FACC(3),FAPP(3),TACC(3),TAPP(3),RACPL(3),
     1           RACP(3,8),FACP(3),VHPPL(3),VHPE(3),FHPE(3),THPP(3),
     2           GRDM(3,3),ATUDM(3,3), VI(3),DGCC(3),DGPP(3)
     3           ,AGCC(3),AGPP(3),RAPPL(3),FHPP(3),RGCPL(3)
      DIMENSION  TYM(200),ELPLOT(8,200),ALFAP(3,200),ALFAC(3,200),
     1           GP(3,200),GC(3,200),RPP(3,200),TPP(3,200 ),
     2           VP(3,200),VC(3,200),OP(3,200),OC(3,200),TYMH(200)
      DO 5 I = 1,3
      STAPP(I) = 0.0
      STACC(I) = 0.0
      SFACE(I) = 0.0
      SFAPE(I) = 0.0
    5 CONTINUE
      DO 300 L= 1,8
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      FA     = 0.0                                                      00000450
      CALL INTRAN (TMATP,RAPP(1,L),RAPPL)                               00000460
      DO 10 I = 1,3                                                     0C000470
      RAPE(I)    = RAPPL(I)+RGPE(I)                                     0C000480
   10 CONTINUE                                                          00000490
      CALL INTRAN (TMATC,RACC(1,L),RACCL)                               00000500
      DO 20 I = 1,3                                                     00000510
      RACE(I)    = RACCL(I)+RGCE(I)                                     00000520
   20 CONTINUE                                                          0C000530
      EL(L) =     SQRT(                    (RACE(1)  -  RAPE(1) ) **2   0C000540
     1                                   + (RACE(2)  -  RAPE(2) ) **2   0C000550
     2                                   + (RACE(3)  -  RAPE(3) ) **2)  00000560
      ELDOT(L) = (EL(L)-ELS(L))/DT                                      0C000570
      IF (ELDOT(L)) 40, 300, 150                                        00000580
C     40 STRUT IN COMPRESSION          150 STRUT IN TENSION             00000590
   40 IF (EL(L)+CRUSHC(L)- ELI(L)) 50, 120, 120                         00000600
   50 CRUSHC(L) = ELI(L) - EL(L)                                        0C000610
   55 DO 100 K =1, 4                                                    00000620
      IF (CRUSHC(L) - STROKC(K,L)) 60, 60, 100                          0C000630
   60 IF (K- 2) 70, 80, 80                                              00000640
   70 FA    =  -FCC(1,L) - RAMPC(1,L) *  CRUSHC(L)                      0C0C0650
      GO TO 120                                                         00000660
   80 FA    =  -FCC(K,L) - RAMPC(K,L)*  (CRUSHC(L) - STROKC(K-1,L))     00000670
      GO TO  120                                                        00000680
  100 CONTINUE                                                          00000690
C     STRUT BOTTOMED OUT                                                00000700
      FA = -FCC(5,L) - RAMPC(5,L) * (CRUSHC(L) - STROKC(5,L))           00000710
      IF (SLAC(L)) 130, 110, 130                                        0C000720
  110 SLAC(L) = 1.0                                                     0C000730
      WRITE                                                             0C000740
     0 (6, 111) L, TIME, ELDOT(L)                                       0C000750
  111 FORMAT (1H0,5X,15HCOUCH STRUT NO.    I12,26H HAS BOTTOMED OUT. TIM0000760
     1E = 1F7.4,21H SECS.  CLOSURE RATE= F8.3, 5H FPS.)                 0C000770
C                                                                       0C000780
      GO TO 130                                                         0C000790
  120 FA    =  FA - FMUC(L)                                             00000800
  130 IF(ELDOT(L) + 2000.0*DT) 145,145,140                              00000810
  140 FA=-FA*ELDOT(L)/2000.0/DT                                         CC000820
  145 ELMIN (L) =  AMIN1(ELMIN(L) ,EL(L))                               00000830
      FAMIN (L) =  AMIN1(FAMIN(L) , FA)                                 0C000840
      GO TO 250                                                         CC000850
  150 IF (EL(L) - CRUSHT(L) - ELI(L))  220, 220, 160                    00000860
  160 CRUSHT(L) = EL(L) - ELI(L)                                        00000870
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```
      DO 200 K= 1,4                                                     CCCC0880
      IF (CRUSHT(L) - STROKT(K,L)) 170, 170, 200                        CCC00890
  170 IF (K- 2) 180, 190, 190                                           CCCC0900
  180 FA    =  FCT(1,L)+RAMPT(1,L)* CRUSHT(L)                           CCCC0910
      GO TO 220                                                         CCCC0920
  190 FA    =  FCT(K,L) +RAMPT(K,L) * (CRUSHT(L) - STROKT(K-1,L))       00000930
      GO TO 220                                                         CCCC0940
  200 CONTINUE                                                          CCCC0950
C     STRUT TOPPED OUT                                                  0C000960
      FA =  FCT(5,L) + RAMPT(5,L) * (CRUSHT(L) - STROKT(5,L))           CCCC0970
      IF (SLAT(L)) 230, 210, 230                                        CCCC0980
  210 SLAT(L) = 1.0                                                     0C000990
      WRITE                                                             0CC01C00
     3  (6, 211) L, TIME, ELDOT(L)                                      CC001010
  211 FORMAT (1HO 5X 15HCOUCH STRUT NO. 112,23H HAS TOPPED OUT. TIME =  0C00102C
     1F7.3,23H SECS.  OPENING RATE = F8.3,5H FPS.)                      0C001030
      GO TO 230                                                         CCC01040
  220 FA    =  FA     + FMUT(L)                                         CC001050
  230 IF(ELDOT(L) - 2000.0*DT) 240,245,245                              CC001060
  240 FA= FA*ELDOT(L)/2000.0/DT                                         C0001070
  245 ELMAX(L) =  AMAX1(ELMAX(L),EL(L))                                 0C001080
      FAMAX (L) =  AMAX1(FAMAX(L) ,FA)                                  CCCC1C90
  250 DO 260  I = 1,3                                                   00001100
      FACE(I)  =  FA / EL(L) * (RAPE(I)  -   RACE(I)  )                 0C001110
      FAPE(I) =  -FACE(I)                                               CC001120
      SFACE(I) = SFACE(I) + FACE(I)                                     CCC01130
      SFAPE(I) = SFAPE(I) + FAPE(I)                                     0C001140
  260 CONTINUE                                                          CCC01150
      CALL TRAN(TMATC, FACE, FACC)                                      C0001160
      CALL TRAN(TMATP, FAPE, FAPP)                                      C0001170
      CALL AXB (RACC(1,L),FACC,TACC)                                    CC001180
      CALL AXB (RAPP(1,L),FAPP,TAPP)                                    CC001190
C                                                                       CC001200
      DO 270  I = 1,3                                                   0C001210
      STACC(I) = STACC(I) + TACC(I)                                     CC001220
      STAPP(I) = STAPP(I) + TAPP(I)                                     C0001230
  270 CONTINUE                                                          00001240
      ELS(L) = EL(L)                                                    00001250
  300 CONTINUE                                                          CC001260
      RETURN                                                            CC001850
      END                                                               0C001860
```

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```
$IBFTC MOVE
C              9J - 345 --- MOVE
      SUBROUTINE  MOVE
C     SUBROUTINE  MOVE                    DECK  NUMBER  345
      COMMON      VH,VV,FRIC,ROLL,PITCH,YAW,SLOPE,DSLOPE,EMP,EMC,EIP,EIC,
     1            GE,ERGMIN,P,TV,DT,TT,TLIM,TLH,RGPPI,DRGCI ,RGCPI,RAPPI,
     2            RACPI,RHPPI,STROKC,FCC,RAMPC,STROKT,FCT,RAMPT,FMUC,
     3            FMUT,STROKH,FH,RAMPH
      COMMON      DMU1,DMU2,FMU2
C
      COMMON      LH,NT,NTLIM,L,M,N,NP,ELI,RAPP,RACC,ELMAX,ELMIN,FAMAX,
     1            FAMIN,GCMAX,GCMIN,GPMAX,GPMIN,ALFACX,ALFACN,ALFAPX,
     2            ALFAPN,CRUSHT,CRUSHC,SLAT,SLAC,ELS,RGPE,RGCE,VGPE,VGCE,
     3            AGPE,AGCE,G,TMATP,TMATC,RHPP,DELTA,SFAPE,STAPE,SFACE,ST
     4            ACE,SFHPE,STHPE,WGPP,WGPE,WGCC,WGCE,RHPPL,RACE,RAPE,EL,
     5            RACCL,ELDOT,FACE,FAPE,FACC,FAPP,TACC,TAPP,RACPL,RACP,
     6            FACP,VHPPL,VHPE,FHPE,THPP,GRDM,ATUDM,VI,DGCC,DGPP
     7            ,TIME,STAPP,STACC,STHPP,AGCC,AGPP,RAPPL,FHPP,RGCPL
      COMMON      TYMH,TYM,ELPLOT,GP,ALFAP,VP,OP,RPP,TPP,GC,ALFAC,VC,OC
      DIMENSION   EIP(3),EIC(3),P(10),TV(6),RGPPI(3),DRGCI (3),RGCPI(3),
     1            RAPPI(3,8),RACPI(3,8),RHPPI(3,200),STROKC(5,8),FCC(5,8)
     2            ,RAMPC(5,8),STROKT(5,8),FCT(5,8),RAMPT(5,8),FMUC(8),
     3            FMUT(8),STROKH(5,200),FH(5,200),RAMPH(5,200)
      DIMENSION   ELI(8),RAPP(3,8),RACC(3,8),ELMAX(8),ELMIN(8),FAMAX(8),
     1            FAMIN(8),GCMAX(3),GCMIN(3),GPMAX(3),GPMIN(3),ALFACX(3),
     2            ALFACN(3),ALFAPX(3),ALFAPN(3),CRUSHC(8),CRUSHT(8),
     3            SLAC(8),SLAT(8),ELS(8),RGPE(3),RGCE(3),VGPE(3),VGCE(3),
     4            AGPE(3),AGCE(3),G(3),TMATP(3,3),TMATC(3,3),RHPP(3,200),
     5            DELTA(200),SFAPE(3),STAPP(3),SFACE(3),STACC(3),SFHPE(3)
     6            ,STHPP(3),WGPP(3),WGPE(3),WGCC(3),WGCE(3),RHPPL(3),
     7            RACE(3),RAPE(3),EL(8),RACCL(3),ELDOT(8),FACE(3)
      DIMENSION   FAPE(3),FACC(3),FAPP(3),TACC(3),TAPP(3),RACPL(3),
     1            RACP(3,8),FACP(3),VHPPL(3),VHPE(3),FHPE(3),THPP(3),
     2            GRDM(3,3),ATUDM(3,3), VI(3),DGCC(3),DGPP(3)
     3            ,AGCC(3),AGPP(3),RAPPL(3),FHPP(3),RGCPL(3)
      DIMENSION   TYM(200),ELPLOT(8,200),ALFAP(3,200),ALFAC(3,200),
     1            GP(3,200),GC(3,200),RPP(3,200),TPP(3,200 ),
     2            VP(3,200),VC(3,200),OP(3,200),OC(3,200),TYMH(200)
      IF(SFHPE(1)-EMP*GE*5.0) 2,2,5
    2 SFHPE(2) = P(10)*SFHPE(2)
      SFHPE(3) = P(10)*SFHPE(3)
      CALL  INTRAN(TMATP,STHPP,THPP)
C     THPP  ACTUALLY  TAPE
```

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```
      THPP(1) = THPP(1) *P(10)
      THPP(2) = THPP(2) - (P(10)-1.0)* SFHPE(3)*RGPE(1) /P(10)
      THPP(3) = THPP(3) + (P(10)-1.0)* SFHPE(2)*RGPE(1) /P(10)
      CALL TRAN(TMATP,THPP,STHPP)
    5 DØ 10 I = 1,3
      AGPE(I) = (SFAPE(I) + SFHPE(I)) / EMP     + G(I)
      VGPE(I) = VGPE(I) + AGPE(I) * DT
      RGPE(I) = RGPE(I) + VGPE(I) * DT - AGPE(I) * DT **2 / 2.0
   10 CØNTINUE
      DGPP(1) = (STAPP(1) + STHPP(1) - WGPP(2) * WGPP(3) * (EIP(2) - EIP
     1(3))) / EIP(1)
      DGPP(2) = (STAPP(2) + STHPP(2) - WGPP(3) * WGPP(1) * (EIP(3) - EIP
     1(1))) / EIP(2)
      DGPP(3) = (STAPP(3) + STHPP(3) - WGPP(1) * WGPP(2) * (EIP(1) - EIP
     1(2))) / EIP(3)
      DØ 20  I = 1, 3
      WGPP(I) = WGPP(I) + DGPP(I) * DT
   20 CØNTINUE
      CALL INTRAN(TMATP, WGPP, WGPE)
      CALL MATRIX(TMATP, WGPE, DT)
C     CØUCH
      DØ 30  I = 1, 3
      AGCE(I) =  SFACE(I) / EMC     + G(I)
      VGCE(I) =  VGCE(I) + AGCE(I) * DT
      RGCE(I) =  RGCE(I) + VGCE(I) * DT-  AGCE(I) * DT**2 / 2.0
   30 CØNTINUE
      DGCC(1) = (STACC(1) - WGCC(2) * WGCC(3) * (EIC(2) - EIC(3))) / EIC
     1(1)
      DGCC(2) = (STACC(2) - WGCC(3) * WGCC(1) * (EIC(3) - EIC(1))) / EIC
     1(2)
      DGCC(3) = (STACC(3) - WGCC(1) * WGCC(2) * (EIC(1) - EIC(2))) / EIC
     1(3)
      DØ 40  I = 1, 3
      WGCC(I) = WGCC(I) + DGCC(I) * DT
   40 CØNTINUE
      CALL INTRAN (TMATC, WGCC, WGCE)
      CALL MATRIX (TMATC, WGCE, DT)
      RETURN
      END
```

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```
$IBFTC GRAFIT
      SUBRØUTINE GRAFIT
      CØMMØN      VH,VV,FRIC,RØLL,PITCH,YAW,SLØPE,DSLØPE,EMP,EMC,EIP,EIC,
     1            GE,ERGMIN,P,TV,DT,TT,TLIM,TLH,RGPPI,DRGCI ,RGCPI,RAPPI,
     2            RACPI,RHPPI,STRØKC,FCC,RAMPC,STRØKT,FCT,RAMPT,FMUC,
     3            FMUT,STRØKH,FH,RAMPH
      CØMMØN      DMU1,DMU2,FMU2
C
      CØMMØN      LH,NT,NTLIM,L,M,N,NP,ELI,RAPP,RACC,ELMAX,ELMIN,FAMAX,
     1            FAMIN,GCMAX,GCMIN,GPMAX,GPMIN,ALFACX,ALFACN,ALFAPX,
     2            ALFAPN,CRUSHT,CRUSHC,SLAT,SLAC,ELS,RGPE,RGCE,VGPE,VGCE,
     3            AGPE,AGCE,G,TMATP,TMATC,RHPP,DELTA,SFAPE,STAPE,SFACE,ST
     4            ACE,SFHPE,STHPE,WGPP,WGPE,WGCC,WGCE,RHPPL,RACE,RAPE,EL,
     5            RACCL,ELDØT,FACE,FAPE,FACC,FAPP,TACC,TAPP,RACPL,RACP,
     6            FACP,VHPPL,VHPE,FHPE,THPP,GRDM,ATUDM,VI,DGCC,DGPP
     7            ,TIME,STAPP,STACC,STHPP,AGCC,AGPP,RAPPL,FHPP,RGCPL
      CØMMØN      TYMH,TYM,ELPLØT,GP,ALFAP,VP,ØP,RPP,TPP,GC,ALFAC,VC,ØC
      DIMENSIØN   EIP(3),EIC(3),P(10),TV(6),RGPPI(3),DRGCI (3),RGCPI(3),
     1            RAPPI(3,8),RACPI(3,8),RHPPI(3,200),STRØKC(5,8),FCC(5,8)
     2            ,RAMPC(5,8),STRØKT(5,8),FCT(5,8),RAMPT(5,8),FMUC(8),
     3            FMUT(8),STRØKH(5,200),FH(5,200),RAMPH(5,200)
      DIMENSIØN   ELI(8),RAPP(3,8),RACC(3,8),ELMAX(8),ELMIN(8),FAMAX(8),
     1            FAMIN(8),GCMAX(3),GCMIN(3),GPMAX(3),GPMIN(3),ALFACX(3),
     2            ALFACN(3),ALFAPX(3),ALFAPN(3),CRUSHC(8),CRUSHT(8),
     3            SLAC(8),SLAT(8),ELS(8),RGPE(3),RGCE(3),VGPE(3),VGCE(3),
     4            AGPE(3),AGCE(3),G(3),TMATP(3,3),TMATC(3,3),RHPP(3,200),
     5            DELTA(200),SFAPE(3),STAPP(3),SFACE(3),STACC(3),SFHPE(3)
     6            ,STHPP(3),WGPP(3),WGPE(3),WGCC(3),WGCE(3),RHPPL(3),
     7            RACE(3),RAPE(3),EL(8),RACCL(3),ELDØT(8),FACE(3)
      DIMENSIØN   FAPE(3),FACC(3),FAPP(3),TACC(3),TAPP(3),RACPL(3),
     1            RACP(3,8),FACP(3),VHPPL(3),VHPE(3),FHPE(3),THPP(3),
     2            GRDM(3,3),ATUDM(3,3), VI(3),DGCC(3),DGPP(3)
     3            ,AGCC(3),AGPP(3),RAPPL(3),FHPP(3),RGCPL(3)
      DIMENSIØN   TYM(200),ELPLØT(8,200),ALFAP(3,200),ALFAC(3,200),
     1            GP(3,200),GC(3,200),RPP(3,200),TPP(3,200 ),
     2            VP(3,200),VC(3,200),ØP(3,200),ØC(3,200),TYMH(200)
      M1 = TV(1)
      M2 = TV(2)
      M3 = TV(3)
      M4 = TV(4)
      M5 = TV(5)
      M6 = TV(6)
      NS = NP
```

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```
      TIMEP =   FLOAT(NP * NTLIM) * DT
      IF(TV(1))  20,80,20
   20 DO 40 NTV = 1,NP
      DO 30 L = 1,8
      ELPLOT(L,NTV) = ELPLOT(L,NTV) +  FLOAT(L)
   30 CONTINUE
   40 CONTINUE
      VALMIN = 0.0
      VALMAX = ELPLOT
      DO 45  MOE = 2,1600
      VALMIN  =  AMIN1(ELPLOT(MOE,1),VALMIN)
   45 VALMAX = AMAX1(ELPLOT(MOE,1),VALMAX)
      CALL INCRI (M1,M1*8)
      NP = NS / M1
      CALL LIMITI (0.0,TIMEP,VALMIN,VALMAX)
      CALL GRAPH (-1,42,-NP,TYM,ELPLOT,15H TIME - SECONDS , 16H STROKE *
     1 INCHES,  1H )
      CALL BLABEL
      DO 50 L = 2,8
      CALL GRAPH (0,42,-NP,TYM,ELPLOT(L,1))
   50 CONTINUE
   80 CALL LIMITI (0.0,TIMEP,0.0,0.0)
      IF (TV(3)) 90,180,90
   90 CALL INCRI (M3,M3*3)
      NP = NS / M3
      CALL GRAPH (-3,42,-NP,TYM,GP, 1H ,1H , 1H  )
      CALL GRAPH (3,42,-NP,TYM,GP(2,1),1H , 65H CAPSULE        X        LI
     1NEAR        Y         ACCELERATIONS        Z , 1H )
      CALL GRAPH (3,42,-NP,TYM,GP(3,1),15H TIME - SECONDS ,1H ,1H )
      CALL BLABEL
      CALL GRAPH (-3,42,-NP,TYM,ALFAP(1,1),1H ,1H ,1H )
      CALL GRAPH (3,42,-NP,TYM,ALFAP(2,1),1H , 65H CAPSULE        X
     1ANGULAR        Y        ACCELERATIONS        Z ,1H )
      CALL GRAPH (3,42,-NP,TYM,ALFAP(3,1), 15H TIME - SECONDS ,1H ,1H )
      CALL BLABEL
C
  180 IF (TV(4)) 190,280,190
  190 CALL INCRI (M4,M4*3)
      NP = NS / M4
      CALL GRAPH (-3,42,-NP,TYM,VP, 1H ,1H , 1H )
      CALL GRAPH (3,42,-NP, TYM,VP(2,1),1H ,65H CAPSULE        X        LI
     1NEAR        Y          VELOCITIES        Z  ,1H )
      CALL GRAPH (3,42,-NP, TYM,VP(3,1),15H TIME - SECONDS ,1H ,1H )
      CALL BLABEL
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```
      CALL GRAPH(-3,42,-NP, TYM,ØP, 1H ,1H ,1H )
      CALL GRAPH (3,42,-NP, TYM,ØP(2,1),1H ,65H CAPSULE        X         AN
     1GULAR      Y          VELØCITIES       Z  ,1H )
      CALL GRAPH (3,42,-NP, TYM,ØP(3,1),15H TIME - SECØNDS ,1H ,1H )
      CALL BLABEL
C
  280 IF (TV(6)) 290,380,290
  290 CALL INCRI (M6,M6*3)
      NP = NS / M6
      CALL GRAPH (-3,42,-NP,TYM,RPP,1H ,1H ,1H )
      CALL GRAPH (3,42,-NP,TYM,RPP(2,1),1H ,65H CAPSULE        X     DISPL
     1ACEMENTS   Y          IN  FEET         Z  ,1H )
      CALL GRAPH (3,42,-NP,TYM,RPP(3,1),15H TIME - SECØNDS ,1H ,1H )
      CALL BLABEL
      CALL GRAPH(-3,42,-NP,TYM,TPP, 1H ,1H ,1H )
      CALL GRAPH (3,42,-NP,TYM,TPP(2,1),1H ,65H CAPSULE        X         AN
     1GLES       Y          IN DEGREES       Z  ,1H )
      CALL GRAPH (3,42,-NP,TYM,TPP(3,1),15H TIME - SECØNDS ,1H ,1H )
      CALL BLABEL
C
  380 IF (TV(2)) 390,480,390
  390 CALL INCRI (M2,M2*3)
      NP = NS / M2
      CALL GRAPH (-3,42,-NP,TYM, GC,1H ,1H ,1H )
      CALL GRAPH (3,42,-NP, TYM,GC(2,1),1H ,65H  CØUCH         X         LI
     1NEAR       Y       ACCELERATIØNS       Z  ,1H )
      CALL GRAPH (3,42,-NP, TYM,GC(3,1),15H TIME - SECØNDS ,1H ,1H )
      CALL BLABEL
      CALL GRAPH(-3,42,-NP, TYM,ALFAC(1,1),1H ,1H ,1H )
      CALL GRAPH (3,42,-NP,TYM,ALFAC(2,1),1H , 65H  CØUCH          X
     1ANGULAR        Y        ACCELERATIØNS       Z ,1H )
      CALL GRAPH (3,42,-NP,TYM,ALFAC(3,1),15H TIME -SECØNDS ,1H ,1H )
      CALL BLABEL
C
  480 IF (TV(5)) 490,580,490
  490 CALL INCRI (M5,M5*3)
      NP = NS / M5
      CALL GRAPH (-3,42,-NP,TYM,VC, 1H ,1H ,1H )
      CALL GRAPH (3,42,-NP, TYM,VC(2,1),1H ,65H  CØUCH         X    REL. L
     1INEAR      Y          VELØCITIES       Z ,1H )
      CALL GRAPH (3,42,-NP, TYM,VC(3,1),15H TIME -SECØNDS ,1H ,1H )
      CALL BLABEL
      CALL GRAPH(-3,42,-NP, TYM,ØC,1H ,1H , 1H )
      CALL GRAPH (3,42,-NP, TYM,ØC(2,1),1H ,65H  CØUCH         X    REL. A
     1NGULAR     Y          VELØCITIES       Z  ,1H )
      CALL GRAPH (3,42,-NP, TYM,ØC(3,1),15H TIME -SECØNDS ,1H ,1H )
      CALL BLABEL
  580 RETURN
      END
```

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```
$IBFTC BLABEL
C      PUTS THE HEADING ON THE CRT ---BLABEL--- 9J-333
       SUBROUTINE BLABEL
       COMMON     VH,VV,FRIC,ROLL,PITCH,YAW,SLOPE,DSLOPE
       DIMENSION   VH(1)
       CALL SCOUTV (0)
       WRITE           ( 16,100)(VH(I),I=1,8),VH(25)
  100 FORMAT(6X8HHORZ VEL 4X 8HVERT VEL 4X  8HFRICTION 6X 4HROLL 7X
     1        5HPITCH 8X 3HYAW 8X 5HSLOPE 7X 7HD-SLOPE 4X 8HCSS HULL
     2 / 8F12.2,F14.4  )
       RETURN
       END
$IBFTC MATRIX
       SUBROUTINE  MATRIX (TM, OM, DT)
C      CONSTRUCT NEW  T MATRIX
       DIMENSION   TM(3,3), DTM(3,3),   OM(3), EN(3)
       DO 10 J = 1, 3
       DTM(J,1) = (OM(2) * TM(J,3) - OM(3) * TM(J,2)) * DT
       DTM(J,2) = (OM(3) * TM(J,1) - OM(1) * TM(J,3)) * DT
       DTM(J,3) = (OM(1) * TM(J,2) - OM(2) * TM(J,1)) * DT
   10 CONTINUE
       DO 20  J = 1, 2
       DO 15  I = 1, 3
       TM(J,I)  = TM(J,I) + DTM(J,I)
   15 CONTINUE
   20 CONTINUE
       TM(3,1) = TM(1,2) * TM(2,3) - TM(1,3) * TM(2,2)
       TM(3,2) = TM(1,3) * TM(2,1) - TM(1,1) * TM(2,3)
       TM(3,3) = TM(1,1) * TM(2,2) - TM(1,2) * TM(2,1)
       TM(2,1) = TM(3,2) * TM(1,3) - TM(3,3) * TM(1,2)
       TM(2,2) = TM(3,3) * TM(1,1) - TM(3,1) * TM(1,3)
       TM(2,3) = TM(3,1) * TM(1,2) - TM(3,2) * TM(1,1)
       DO 40 J= 1,3
       EN(J) = 0.0
       DO 30  I = 1, 3
       EN(J) = TM(J,I)**2 + EN(J)
   30 CONTINUE
   40 CONTINUE
       DO 50  J = 1, 3
       DO 50  I = 1, 3
       TM(J,I)  =  TM(J,I) /  SQRT(EN(J))
   50 CONTINUE
       RETURN
```

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```
       END
$IBFTC AXB
       SUBROUTINE   AXB (A, B, C)
C       C = A X B
       DIMENSION   A(3), B(3), C(3)
       C(1)   = A(2) * B(3) - A(3) * B(2)
       C(2)   = A(3) * B(1) - A(1) * B(3)
       C(3)   = A(1) * B(2) - A(2) * B(1)
       RETURN
       END
$IBFTC TRAN
       SUBROUTINE   TRAN (T, VIN, VOUT)
C      TRANSFORM A VECTOR FROM PARALLEL SYSTEM TO BODY SYSTEM.
       DIMENSION T(3,3), VIN(3), VOUT(3)
       DO 10  I = 1,3
       VOUT(I) = 0.0
       DO 5  J = 1,3
       VOUT(I) = T(I,J) * VIN(J) + VOUT(I)
     5 CONTINUE
    10 CONTINUE
       RETURN
       END
$IBFTC INTRAN
       SUBROUTINE  INTRAN (T, VIN, VOUT)
C      TRANSFORM A VECTOR FROM BODY SYSTEM TO PARALLEL SYSTEM.
       DIMENSION T(3,3), VIN(3), VOUT(3)
       DO 10  I = 1,3
       VOUT(I) =0.0
       DO 5 J = 1,3
       VOUT(I) = T(J,I) * VIN(J) + VOUT(I)
     5 CONTINUE
    10 CONTINUE
       RETURN
       END
$IBFTC ATITUD
       SUBROUTINE ATITUD(TM, PITCHE, ROLLE, YAWE )
C      COMPUTE ROLL, PITCH AND YAW ANGLES FROM DIRECTION COSINES.
       DIMENSION TM(3,3)
       SINP  = TM(3,1)
       COSP =  SQRT(1.0- SINP**2)
       IF (SINP) 10,300,10
    10 IF (COSP) 15,400,15
    15 PITCHE =   ATAND(SINP,COSP)
    20 IF (TM(3,2) ) 25,500,25
```

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```
 25 IF( TM(3,3) ) 30,600,30
 30 RØLLE =    ATAND(-TM(3,2),TM(3,3))
 40 IF(TM (2,1)) 5C,700,50
 50 IF ( TM(1,1)) 60,800,60
 60 YAWE =    ATAND(-TM(2,1),TM(1,1))
    GØ TØ 900
300 PITCHE =  0.0
    GØ TØ 20
400 IF(SINP) 410,420,420
410 PITCHE =  -90.0
    GØ TØ 20
420 PITCHE =  90.0
    GØ TØ 20
500 IF ( TM(3,3) ) 510,520,520
510 RØLLE =  180.0
    GØ TØ 40
520 RØLLE =  0.0
    GØ TØ 40
600 IF (TM(3,2))  610,620,620
610 RØLLE =  90.0
    GØ TØ 40
620 RØLLE = -90.0
    GØ TØ 40
700 IF ( TM(1,1) ) 710,720,720
710 YAWE =  180.0
    GØ TØ  900
720 YAWE  =  0.0
    GØ TØ 900
800 IF ( TM(2,1) ) 810,820,820
810 YAWE = 90.0
    GØ TØ 900
820 YAWE = -90.0
900 CØNTINUE
    RETURN
    END
```

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```
$DATA
   96 0.0        0.0        0.0        0.65       0.0       BP100130
  101 14.6       0.65      12.65       7.3        0.65      BP100140
  106 12.65     - 7.3       0.65       0.0      -14.6       BP100150
  111 0.65     -12.65     - 7.3        0.65     -12.65      BP100160
  116- 7.3       2.5        0.0       29.2        2.5       BP100170
  116 7.3
  121 14.6      25.3        2.5       25.3       14.6       BP100180
  126  2.5      29.2        0.0        2.5       25.3       BP100190
  131-14.6       2.5       14.6      -25.3        2.5       BP100200
  136  0.0     -29.2        2.5      -14.6      -25.3       BP100210
  141  2.5     -25.3      -14.6        2.5      -29.2       BP100220
  146  0.0       2.5      -25.3       14.6        2.5       BP100230
  151-14.6      25.3        5.5        0.0       43.8       BP100240
  156  5.5      15.0       41.2        5.5       28.2       BP100250
  161 33.6       5.5       37.9       21.9        5.5       BP100260
  166 43.1       7.61       5.5       43.1      - 7.61      BP100270
  171  5.5      37.9      -21.9        5.5       28.2       BP100280
  176-33.6       5.5       15.0      -41.2        5.5       BP100290
  181  0.0     -43.8        5.5      -15.0      -41.2       BP100300
  186  5.5     -28.2      -33.6        5.5      -37.9       BP100310
  191-21.9       5.5      -43.1      - 7.61       5.5       BP100320
  196-43.1       7.61       5.5      -37.9       21.9       BP100330
  201 5.5      -28.2       33.6        5.5      -15.0       BP100370
  206 41.2       9.9        0.0       58.4        9.9       BP100380
  211 15.64     56.4        9.9       29.2       50.5       BP100390
  216 9.9       41.3       41.3        9.9       50.5       BP100400
  221 29.2       9.9       56.4       15.64       9.9       BP100410
  226 58.4       0.0        9.9       56.4      -15.64      BP100420
  231 9.9       50.5      -29.2        9.9       41.3       BP100430
  236-41.3       9.9       29.2      -50.5        9.9       BP100440
  241 15.64    -56.4        9.9        0.0      -58.4       BP100450
  246 9.9      -15.64     -56.4        9.9      -29.2       BP100460
  251-50.5       9.9      -41.3      -41.3        9.9       BP100470
  256-50.5     -29.2        9.9      -56.4      -15.64      BP100480
  261 9.9      -58.4        0.0        9.9      -56.4       BP100490
  266 15.64      9.9      -50.5       29.2        9.9       BP100500
  271-41.3      41.3        9.9      -29.2       50.5       BP100510
  276 9.9      -15.64      56.4       21.0        0.0       BP100520
  952 0.0        0.41       0.82       1.23       2.5       27310001
  957 0.0        0.41       0.82       1.23       2.5       27310002
  962 0.0        0.41       0.82       1.23       2.5       27310003
  967 0.0        0.41       0.82       1.23       2.5       27310004
  972 0.0        0.41       0.82       1.23       2.5       27310005
```

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977	0.0	0.41	0.82	1.23	2.5	27310006
982	0.0	0.41	0.82	1.23	2.5	27310007
987	0.0	0.31	0.62	0.93	2.5	27310034
992	0.0	0.31	0.62	0.93	2.5	27310035
997	0.0	0.31	0.62	0.93	2.5	27310036
1002	0.0	0.31	0.62	0.93	2.5	27310037
1007	0.0	0.31	0.62	0.93	2.5	27310038
1012	0.0	0.31	0.62	0.93	2.5	27310039
1017	0.0	0.31	0.62	0.93	2.5	27310040
1022	0.0	0.31	0.62	0.93	2.5	27310041
1027	0.0	0.31	0.62	0.93	2.5	27310042
1032	0.0	0.31	0.62	0.93	2.5	27310043
1037	0.0	0.31	0.62	0.93	2.5	27310044
1042	0.0	0.31	0.62	0.93	2.5	27310045
1047	0.0	0.18	0.72	2.5		27310058
1052	0.0	0.18	0.72	2.5		27310059
1057	0.0	0.18	0.72	2.5		27310060
1062	0.0	0.18	0.72	2.5		27310061
1067	0.0	0.18	0.72	2.5		27310062
1072	0.0	0.18	0.72	2.5		27310063
1077	0.0	0.18	0.72	2.5		27310064
1082	0.0	0.18	0.72	2.5		27310065
1087	0.0	0.18	0.72	2.5		27310066
1092	0.0	0.18	0.72	2.5		27310067
1097	0.0	0.18	0.72	2.5		27310068
1102	0.0	0.18	0.72	2.5		27310069
1107	0.0	0.18	0.72	2.5		27310070
1112	0.0	0.18	0.72	2.5		27310071
1117	0.0	0.18	0.72	2.5		27310072
1122	0.0	0.18	0.72	2.5		27310073
1127	0.0	0.18	0.72	2.5		27310074
1132	0.0	0.18	0.72	2.5		27310075
1137	0.1	2.5				13080073
1142	0.1	2.5				13080074
1147	0.1	2.5				13080075
1152	0.1	2.5				13080076
1157	0.1	2.5				13080077
1162	0.1	2.5				13080078
1167	0.1	2.5				13080079
1172	0.1	2.5				13080080
1177	0.1	2.5				13080081
1182	0.1	2.5				13080082
1187	0.1	2.5				13080083

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1192	0.1	2.5				13080084
1197	0.1	2.5				13080085
1202	0.1	2.5				13080086
1207	0.1	2.5				13080087
1212	0.1	2.5				13080088
1217	0.1	2.5				13080089
1222	0.1	2.5				13080090
1227	0.1	2.5				13080091
1232	0.1	2.5				13080092
1237	0.1	2.5				13080093
1242	0.1	2.5				13080094
1247	0.1	2.5				13080095
1252	0.1	2.5				13080096
1952	0.0	0.0	10000.0	0.0	0.0	27310008
1957	0.0	0.0	10000.0	0.0	0.0	27310009
1962	0.0	0.0	10000.0	0.0	0.0	27310010
1967	0.0	0.0	10000.0	0.0	0.0	27310011
1972	0.0	0.0	10000.0	0.0	0.0	27310012
1977	0.0	0.0	10000.0	0.0	0.0	27310013
1982	0.0	0.0	10000.0	0.0	0.0	27310014
1987	0.0	0.0	10000.0	0.0	0.0	27310015
1992	0.0	0.0	10000.0	0.0	0.0	27310016
1997	0.0	0.0	10000.0	0.0	0.0	27310017
2002	0.0	0.0	10000.0	0.0	0.0	27310018
2007	0.0	0.0	10000.0	0.0	0.0	27310019
2012	0.0	0.0	10000.0	0.0	0.0	27310020
2017	0.0	0.0	10000.0	0.0	0.0	27310021
2022	0.0	0.0	10000.0	0.0	0.0	27310022
2027	0.0	0.0	10000.0	0.0	0.0	27310023
2032	0.0	0.0	10000.0	0.0	0.0	27310024
2037	0.0	0.0	10000.0	0.0	0.0	27310025
2042	0.0	0.0	10000.0	0.0	0.0	27310026
2047	0.0	0.0	10000.0	10000.0		27310076
2052	0.0	0.0	10000.0	10000.0		27310077
2057	0.0	0.0	10000.0	10000.0		27310078
2062	0.0	0.0	10000.0	10000.0		27310079
2067	0.0	0.0	10000.0	10000.0		27310080
2072	0.0	0.0	10000.0	10000.0		27310081
2077	0.0	0.0	10000.0	10000.0		27310082
2082	0.0	0.0	10000.0	10000.0		27310083
2087	0.0	0.0	10000.0	10000.0		27310084
2092	0.0	0.0	10000.0	10000.0		27310085
2097	0.0	0.0	10000.0	10000.0		27310086
2102	0.0	0.0	10000.0	10000.0		27310087

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2107	0.0	0.0	10000.0	10000.0		27310088
2112	0.0	0.0	10000.0	10000.0		27310089
2117	0.0	0.0	10000.0	10000.0		27310090
2122	0.0	0.0	10000.0	10000.0		27310091
2127	0.0	0.0	10000.0	10000.0		27310092
2132	0.0	0.0	10000.0	10000.0		27310093
2137	0.0	30000.0	0.0			38350381
2142	0.0	30000.0	0.0			38350382
2147	0.0	30000.0	0.0			38350383
2152	0.0	30000.0	0.0			38350384
2157	0.0	30000.0	0.0			38350385
2162	0.0	30000.0	0.0			38350386
2167	0.0	3C000.0	0.0			38350387
2172	0.0	30000.0	0.0			38350388
2177	0.0	30000.0	0.0			38350389
2182	0.0	30000.0	0.0			38350390
2187	0.0	30000.0	0.0			38350391
2192	0.0	30000.0	0.0			38350392
2197	0.0	3C000.0	0.0			38350393
2202	0.0	30000.0	0.0			38350394
2207	0.0	30000.0	0.0			38350395
2212	0.0	30000.0	0.0			38350396
2217	0.0	3C000.0	0.0			38350397
2222	0.0	30000.0	0.0			38350398
2227	0.0	30000.0	0.0			38350399
2232	0.0	30000.0	0.0			38350400
2237	0.0	3C000.0	0.0			38350401
2242	0.0	30000.0	0.0			38350402
2247	0.0	30000.0	0.0			38350403
2252	0.0	30000.0	0.0			38350404
2952	0.0	24390.0	-24390.0	0.0	24390.0	27310027
2957	0.0	24390.0	-24390.0	0.0	24390.0	27310028
2962	0.0	24390.0	-24390.0	0.0	24390.C	27310029
2967	0.0	24390.0	-24390.0	0.0	24390.0	27310030
2972	0.0	24390.0	-24390.0	0.0	24390.0	27310031
2977	0.0	24390.0	-24390.0	0.0	24390.0	27310032
2982	0.0	24390.0	-24390.0	0.0	24390.0	27310033
2987	0.0	32258.0	-32258.0	0.0	32258.0	27310046
2992	0.0	32258.0	-32258.0	0.0	32258.0	27310047
2997	0.0	32258.0	-32258.0	0.0	32258.C	27310048
3002	0.0	32258.0	-32258.0	0.0	32258.0	27310049
3007	0.0	32258.0	-32258.0	0.0	32258.0	27310050
3012	0.0	32258.0	-32258.0	0.0	32258.0	27310051

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3017	0.0	32258.0	-32258.0	0.0	32258.0	27310052
3022	0.0	32258.0	-32258.0	0.0	32258.0	27310053
3027	0.0	32258.0	-32258.0	0.0	32258.0	27310054
3032	0.0	32258.0	-32258.0	0.0	32258.0	27310055
3037	0.0	32258.0	-32258.0	0.0	32258.0	27310056
3042	0.0	32258.0	-32258.0	0.0	32258.0	27310057
3047	0.0	55556.0	0.0	55556.0		22390019
3052	0.0	55556.0	0.0	55556.0		22390020
3057	0.0	55556.0	0.0	55556.0		22390021
3062	0.0	55556.0	0.0	55556.0		22390022
3067	0.0	55556.0	0.0	55556.0		22390023
3072	0.0	55556.0	0.0	55556.0		22390024
3077	0.0	55556.0	0.0	55556.0		22390025
3082	0.0	55556.0	0.0	55556.0		22390026
3087	0.0	55556.0	0.0	55556.0		22390027
3092	0.0	55556.0	0.0	55556.0		22390028
3097	0.0	55556.0	0.0	55556.0		22390029
3102	0.0	55556.0	0.0	55556.0		22390030
3107	0.0	55556.0	0.0	55556.0		22390031
3112	0.0	55556.0	0.0	55556.0		22390032
3117	0.0	55556.0	0.0	55556.0		22390033
3122	0.0	55556.0	0.0	55556.0		22390034
3127	0.0	55556.0	0.0	55556.0		22390035
3132	0.0	55556.0	0.0	55556.0		22390036
3137	300000.0					38710025
3142	300000.0					38710026
3147	300000.0					38710027
3152	300000.0					38710028
3157	300000.0					38710029
3162	300000.0					38710030
3167	300000.0					38710031
3172	300000.0					38710032
3177	300000.0					38710033
3182	300000.0					38710034
3187	300000.0					38710035
3192	300000.0					38710036
3197	300000.0					38710037
3202	300000.0					38710038
3207	300000.0					38710039
3212	300000.0					38710040
3217	300000.0					38710041
3222	300000.0					38710042
3227	300000.0					38710043
3232	300000.0					38710044

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3237	300000.0					38710045
3242	300000.0					38710046
3247	300000.0					38710047
3252	300000.0					38710048
9	86.2	255.5	1710.0	860.0	860.0	
14	3455.0	2540.0	2280.0	32.2	0.0	
25	0.0	0.0	0.0	1.0	1.0	
30	1.0	1.0	1.0	1.0	1.0	
35	0.001	1000.0	5.0	73.0		
39	8.0	0.0	0.0	0.0	0.0	
44	0.0	58.7	0.0	8.7		
48	18.25	0.0	73.0	18.25	-73.0	
53	0.0	18.25	0.0	-73.0	18.25	
58	73.0	0.0	18.25	-73.0	0.0	
63	18.25	73.0	0.0	18.25	-73.0	
68	0.0	18.25	73.0	0.0		
72	46.6	0.0	61.0	46.6	-61.0	
77	0.0	46.6	0.0	-61.0	46.6	
82	61.0	0.0	18.25	0.0	73.0	
87	18.25	0.0	73.0	18.25	0.0	
92	-73.0	18.25	0.0	-73.0		
696	0.5	1.0			1.0	
701	0.5	1.0			1.0	
706	0.5	1.0			1.0	
711	0.5	1.0			1.0	
716	10.0					
721	10.0					
726	10.0					
731	10.0					
736	0.0	34900.0			34900.0	
741	0.0	34900.0			34900.0	
746	0.0	34900.0			34900.0	
751	0.0	34900.0			34900.0	
776	69800.0					
781	69800.0					
786	69800.0					
791	69800.0					
816	1.0					
821	1.0					
826	1.0					
831	1.0					
836	10.0					
841	10.0					

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 846 10.0
 851 10.0
 940 55000.0      55000.0      55000.0      55000.0      34900.0
 945 34900.0      34900.0      34900.0      55000.0      55000.0
 950 55000.0      55000.0
 279 22.7         0.0          96.0         22.7         -48.0
 284 83.3         22.7         -83.3        48.0         22.7
 289-96.0         0.0          22.7         -83.3        -48.0
 294 22.7         -48.0        -83.3        22.7         0.0
 299-96.0         22.7         48.0         -83.3        22.7
 304 83.3         -48.0        22.7         96.0         0.0
 309 22.7         83.3         48.0         22.7         48.0
 314 83.3
1257 0.25         2.0
1262 0.25         2.0
1267 0.25         2.0
1272 0.25         2.0
1277 0.25         2.0
1282 0.25         2.0
1287 0.25         2.0
1292 0.25         2.0
1297 0.25         2.0
1302 0.25         2.0
1307 0.25         2.0
1312 0.25         2.0
3257 80000.0
3262 80000.0
3267 80000.0
3272 80000.0
3277 80000.0
3282 80000.0
3287 80000.0
3292 80000.0
3297 80000.0
3302 80000.0
3307 80000.0
3312 80000.0
3952 10.0
   1 80.0         15.0         0.35         0.0          -12.2
   6 0.0          5.0          0.0
   2 20.0
   2 30.0
```