NASA Contractor Report 3328

Environmental Protection Requirements for Scout/Shuttle Auxiliary Stages

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FOREWORD

This study provides recommendations for enabling the Scout upper stages to endure the expected temperature, mechanical shock, acoustical and mechanical vibration environments during a specified shuttle mission.

The study effort consisted of the following five tasks:

(I) Determination of Shuttle-Launched Mission Trajectory for a 545 kilogram (1200 pound) payload
(II) Compilation of Environmental Conditions in the Shuttle
(III) Determination of Scout Upper Stages Environments in Space Shuttle Launched Missions
(IV) Compilation of Scout Upper Stages Environmental Qualification Criteria and Comparison to Shuttle Mission Expected Environments
(V) Recommendations for Enabling Scout Upper Stages to Endure the Expected Shuttle Mission Environments.

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GLOSSARY OF TERMS

ABBREVIATIONS

PSD	–	Power spectral density (expressed in g^2 per Hertz)
C_{TH}	–	Thermal capacity
C_P	–	Specific heat
t	–	Thickness
RMS	–	Root mean square
dB	–	Decibel
BTU	–	British thermal unit
V	–	Velocity
fps	–	feet per second
m	–	meter
kg	–	kilogram
^oC	–	degrees Celsius
^oF	–	degrees Fahrenheit
T/M	–	telemetry
K	–	Conductivity
RCS	–	Reaction control system
N_2	–	Nitrogen gas
EMI	–	Electromagnetic interference
N/m^2	–	Newtons per square meter

SYMBOLS

α_s	–	Solar absorptance
ϵ	–	Emittance
ρ	–	Material density
ΔV	–	Small change in velocity
γ	–	Path angle
ψ	–	Inclination angle

NOMENCLATURE

Scout upper stages – The Scout third and fourth stage motors and associated interstages.

1.0 SUMMARY

This study used a typical trajectory whose derivation was based upon the Scout upper stages, Figure 1–1, launching a 545 kilogram (1200 pound) payload from the Space Shuttle. Deployment of the Scout upper stages and the payload occurred from a typical 296 kilometer (160 nautical mile) circular orbit for the Space Shuttle. For the Scout upper stages trajectory, a maximum altitude, Hohmann transfer type mission was used. The environmental conditions encountered during this mission and the conditions resulting from an abort situation, i.e., re-entry and landing, were identified. These conditions and their effects upon the equipment listed in Table 1–I were evaluated.

Thermal and dynamic analyses were conducted to determine the effects on the Scout upper stages during Shuttle buildup, launch and orbit conditions. Similar analyses were conducted for the periods of upper stage deployment, burn and coast phases of operation.

The thermal analysis defines the thermal protection requirements for the Scout auxiliary stages for the total mission duration, including the twenty-four hour on-station orbit with the Space Shuttle payload bay doors open. This analysis resulted in two recommendations; (1) add thermal protective coatings and (2) maintain the pre-launch temperature of the Space Shuttle payload bay between 10° to 32°C (50° to 90°F) to assure that the temperature of the Antares motor is within its specified ignition temperature limits.

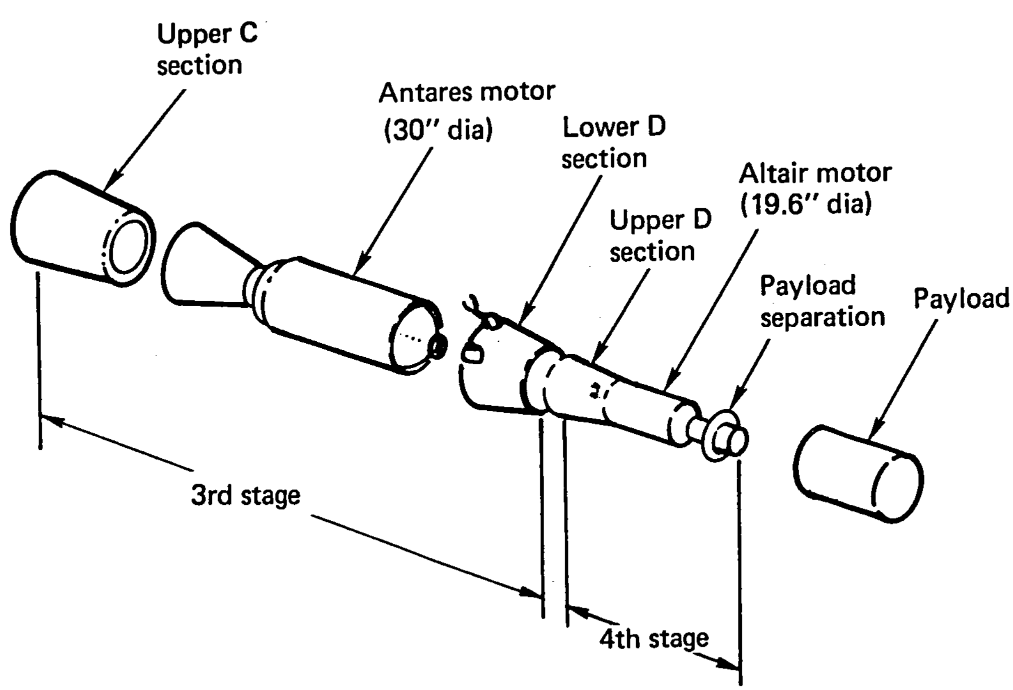


FIGURE 1-1.– SCOUT UPPER STAGES

TABLE 1-I.– EQUIPMENT EVALUATED IN THE ENVIRONMENTAL PROTECTION – SCOUT/SHUTTLE AUXILIARY STAGES STUDY

Vehicle transition sections:	
C section	
D section	
E section	
Rocket motors:	
* Altair IIIA	
* Antares IIB	
Components:	
Guidance & Control	Poppet valve electronics Rate gyro unit Inertial reference unit Yardney battery pack
Instrumentation	Fourth stage T/M transmitter
Reaction control	Thruster valves [267 newtons and 8.9 newtons (60 pound and 2 pound motors)] Relief valve (H_2O_2) Quick disconnects (regulated N_2) Hydrogen peroxide tanks Pressure regulator

* Referred to as Altair or Antares in the text for brevity.

The dynamic analysis used the baseline pallet design described in Reference 1 and shown in Figure 1–2. The analysis was performed taking into account mechanical shock, mechanical vibration and acoustical vibration. The mechanical shock and vibration analysis resulted in determination of vibrational modes of the Scout/pallet system and the maximum vibrational and shock loads on the Scout induced by the Space Shuttle. From these, the recommendations that (1) the E Section be redesigned to withstand the Space Shuttle induced loads, (2) no vibration isolators be used between the Space Shuttle sill supports and the pallet or between the pallet and the Scout, and (3) the Scout Standard Environmental Test vibration spectrum be extended to include the 10 to 20 Hertz region, were made. The Scout environmental qualification criteria do not include an acoustical vibration test. Consequently, it is recommended that the Shuttle payload bay acoustical levels, modified by an appropriate safety factor, be established as a qualification test for Scout upper stages to be launched from the Shuttle.

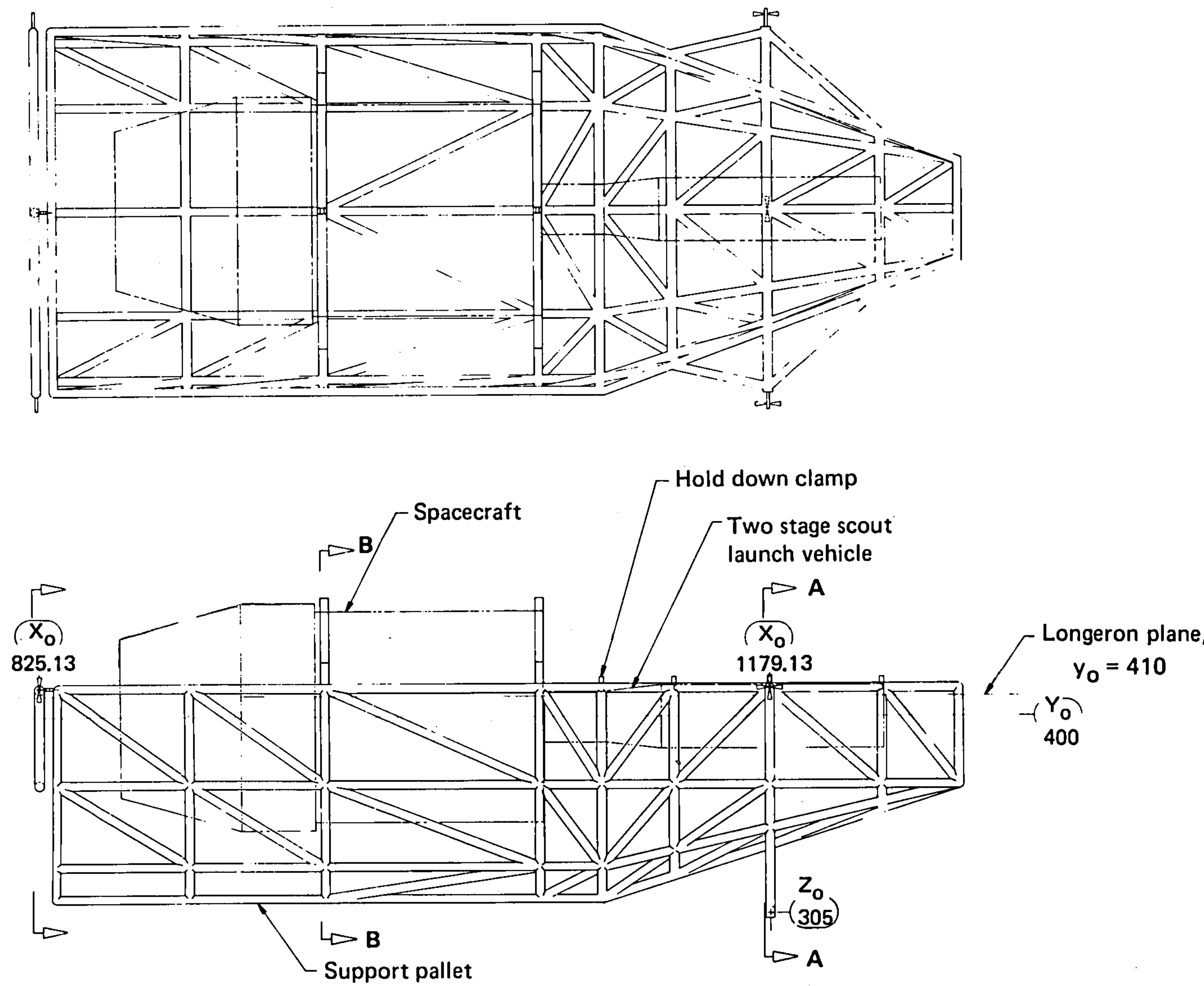
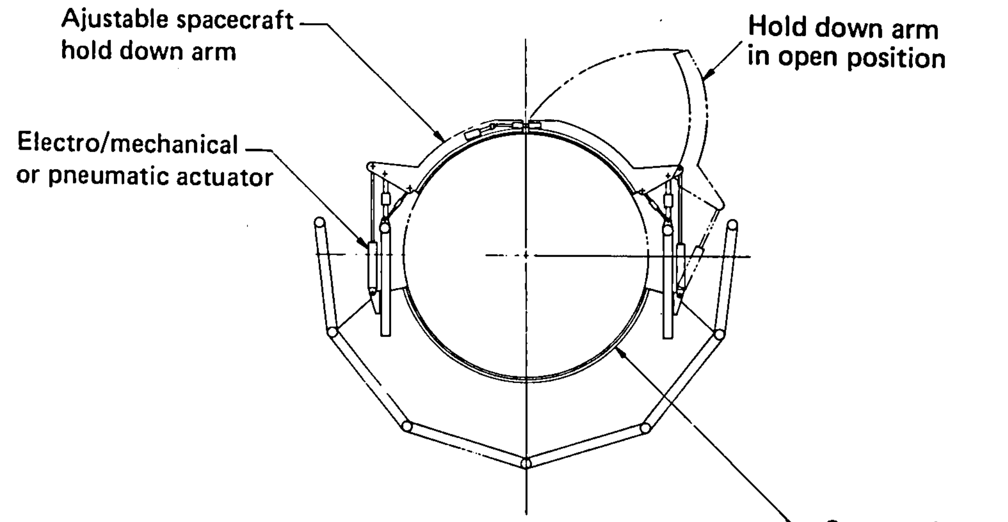
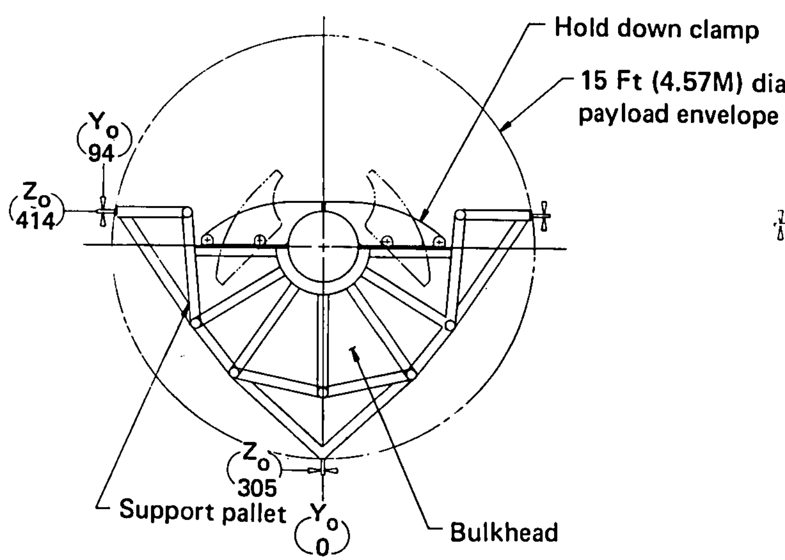


FIGURE 1-2.— SCOUT UPPER STAGES AND PAYLOAD SUPPORT PALLET



SECT. B–B
Typical spacecraft cradle & hold down



SECT. A–A
Typical hold down clamp & bulkhead arrangement

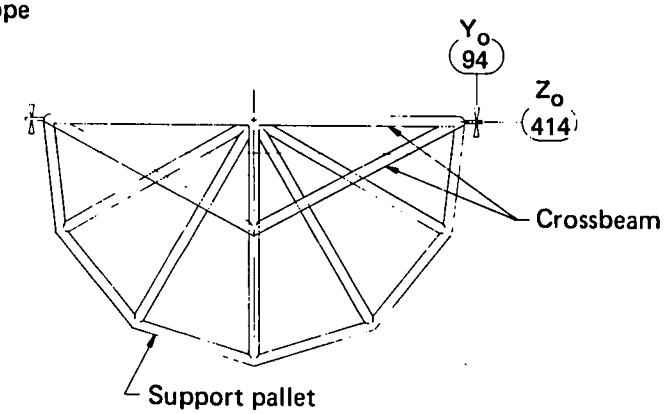


FIGURE 1-2.–SCOUT UPPER STAGES AND PAYLOAD SUPPORT PALLET (Continued)

2.0 INTRODUCTION

The potential utilization of the Scout third and fourth stage motors and associated interstage sections as auxiliary stages for Space Shuttle applications will expose the Scout to environmental conditions not previously encountered. Thermal conditions in space will be more severe because of (1) potentially longer coast times between stage burns and (2) space orientation of the Shuttle with the payload bay doors opened and closed, and with the payload bay oriented toward or away from the sun. New mechanical dynamic and thermal environments will also be encountered by the Scout stages during launch of the Shuttle and, in the event of a mission abort, when the Shuttle may return to Earth with the Scout stages still in the payload bay.

At the start of this study, the Scout F–1, with the Antares IIB motor as the third stage, was one of the Scout standard configurations. Subsequently, the Antares IIB motor was deleted, resulting in a slight decrease in vehicle performance. The effect of this reduction on the environmental conditions determined in the study, is negligible and the recommendations are valid for Scout upper stages using the Antares IIA motor.

This study was accomplished under a series of five tasks, Table 2–I. The study guidelines are described in the following paragraphs.

TABLE 2-I.– STUDY TASKS

Task I	Determination of Shuttle-Launched Mission Trajectory
Task II	Compilation of Environmental Conditions in the Shuttle
Task III	Determination of Scout Environments in Shuttle Launched Missions
Task IV	Compilation of Scout Upper Stages Environmental Qualification Criteria and Comparison to Shuttle Mission Expected Environments
Task V	Recommendations for Enabling Scout Upper Stages to Endure the Expected Shuttle Mission Environments

The two upper stages (less the heatshield) of Scout were used as configured by the Scout Phase VII procurement. The interface between the Scout upper stages and the Shuttle payload bay was taken as the baseline pallet design, Figure 1–2.

The Shuttle payload bay worst case environmental characteristics were summarized from the Shuttle payload accomodations document, Reference 2. The conditions of normal launch along with abort conditions of re-entry, landing and crash were taken into consideration.

A trajectory analysis was performed to develop a mission timeline as the basis for predicting the environmental conditions encountered by the Scout after launch from the Shuttle. The developed trajectory produces an orbit with an apogee of 15,726 kilometers (8,492 nautical miles), a perigee of 10,522 kilometers (5,682 nautical miles), and an inclination of 28.5 degrees with a 545 kilogram (1200 pound) payload based on operating from the Shuttle in a circular orbit of 296 kilometers (160 nautical miles) at 28.5 degrees inclination. This trajectory provides approximately 2.4 hours coast time between Antares burnout and Altair ignition.

Subsequent to the identification of the Shuttle environmentally induced characteristics upon the Scout upper stages, and the establishment of a nominal trajectory, an environmental profile was developed for the Scout upper stages. This profile began with the Shuttle payload bay doors open and the Shuttle starting an on-orbit phase of twenty-four hours. The on-orbit phase was followed by Scout/Spacecraft check-out and countdown. The nominal mission trajectory began at this point with Scout deployment and separation from the Shuttle. The environmental conditions associated with the total mission timeline, the twenty-four hour on-orbit phase with the Scout exposed in the Shuttle, and the Scout mission from deployment through the spacecraft separation are presented in Section 5. All pertinent environmental conditions were reviewed and those considered significant were identified and evaluated with the exception of EMI which is awaiting definition in Reference 2, paragraph 4.2.2.8. A preliminary analysis of potential micrometeoroid damage was performed. The analysis used the meteoroid environment model given in Reference 3 and was performed only upon the two rocket motor cases. This damage probability to the two-motor subsystem was assessed at .0036 (99.64% probability of no damage).

After the significant environments were established for the Shuttle launched mission, the land launched Scout mission environments were compiled and a comparison made between the two missions. Incompatibilities exist in the thermal, mechanical shock, vibration and acoustic environments and are discussed in Section 6. Results of the analyses concerning pre-launch restrictions, thermal insulation, "E" section redesign and design verification testing to overcome the incompatibilities are presented in Section 7. Section 8 presents the conclusions derived from the analyses and recommendations for enabling the Scout upper stages to endure the environment of a Shuttle launched mission. Appendix A defines changes in the predicted Shuttle environmental conditions, compiled from Reference 2, which have occurred since completion of the effort associated with Section 3.

3.0 PREDICTED SPACE SHUTTLE PAYLOAD BAY ENVIRONMENTAL CONDITIONS

Reference 2 was reviewed and analyzed to determine the most severe environmental conditions in the Shuttle payload bay. A profile of these conditions, Table 3-I, is provided for the Shuttle launch, on-orbit, Scout deployment, and re-entry and landing (abort) mission phases. A twenty-four hour Shuttle on-orbit time with the payload doors open was assumed to provide deep-space soak conditions and is covered in a subsequent profile, Table 5-II. The applicable environmental levels are described in the following paragraphs.

3.1 Pressure/Altitude
(Reference 2, para. 4.2.2.1)

The pressure/altitude environment affects the mission flight phases of launch, on-orbit, Scout deployment, and re-entry and landing (abort). The launch pressure will be local ambient. The payload bay is vented during boost to the desired 296 kilometer (160 nautical mile) orbit and depressurizes in 120 seconds to 0.02 millimeters of mercury. The pressure remains at space vacuum unless an abort situation is encountered. When this occurs, the pressure during re-entry and landing increases from space vacuum to local ambient in 350 seconds. These pressures and variations are within the ranges encountered in a typical Scout land launched mission and present no problem for the Scout upper stages in a Shuttle launched mission.

TABLE 3-I.– ENVIRONMENTAL PROFILE FOR SHUTTLE PAYLOAD (CARGO) BAY

Environment	Space shuttle mission phase			
	Shuttle launch	On-orbit station (doors closed)	Scout deployment (doors open)	Re-entry and landing (abort)
Natural:				
• Pressure (vacuum)	X	X	X	X
• Solar radiation	0	0	X	0
• Earth albedo	0	0	X	0
• Earth radiation	0	0	X	0
• Space sink temperature	0	0	X	0
• Meteoroids	0	0	X	0
Induced:				
• Vibration	X	ϕ	ϕ	X
• Acoustic	X	0	0	ϕ
• Mechanical shock	ϕ	0	ϕ	X
• Acceleration	X	X	ϕ	X
• EMI	X	X	X	X
• Temperature	X	X	X	X
• Zero "g"	0	X	X	0

Legend:

X – Applicable environment
ϕ – Applicable environment – negligible effect
0 – Not applicable

3.2 Solar Radiation, Earth Albedo
(Reference 2, para. 4.1.2.2)

Solar radiation, Earth albedo, Earth radiation, and space sink temperatures are applicable during the Scout deployment phase. The effects of these were evaluated starting with initial conditions created by prelaunch ground environmental controls. The ambient payload bay temperature will be between 4 and 49°C (40 and 120°F) as determined by the setting of the Shuttle cargo bay environmental control system. During boost the temperature will rise to between 4 and 65°C (40 and 150°F). Upon opening of the payload bay doors and starting with this temperature range as the initial temperature, the heat load will be affected by:

Solar radiation @ 1399 watts per square meter (444 BTU/ft^{2}hr)
Earth albedo of 30%
Earth radiation @ 243 watts per square meter (77 BTU/ft^{2}hr)
Space sink temperature of 0 Kelvin (0° Rankine)

This heat load will be incident upon the Scout upper stages depending upon Shuttle (orientation) attitude.

3.3 Meteoroid
(Reference 2, para. 4.1.2.4)

The meteoroid environment becomes significant after the Scout upper stages are deployed from the Shuttle and is discussed in Section 6.5.

3.4 Vibration
(Reference 2, para. 4.2.2.2)

The vibration environment affects the mission phases of launch, re-entry and landing, (abort), and aborted mode handling. The re-entry and landing vibration levels will be less than for the launch phase. Duration of the launch random vibration, Figure 3-1, is expected to be approximately 28 seconds per mission and exists at the Shuttle sill attach points.

After the landing (normal or abort), the Space Shuttle must be towed to the refurbishment area. Towing presents different loads than other phases of operation which is to be simulated by four sinusoidal sweeps at one half octave per minute at the levels and frequencies of:

2–5Hz, 2.54 cm (1 inch) double amplitude
5–26 Hz, 1.3 g peak
26–50 Hz, .09 cm (.036 inch) double amplitude
50–100 Hz, 5 g peak

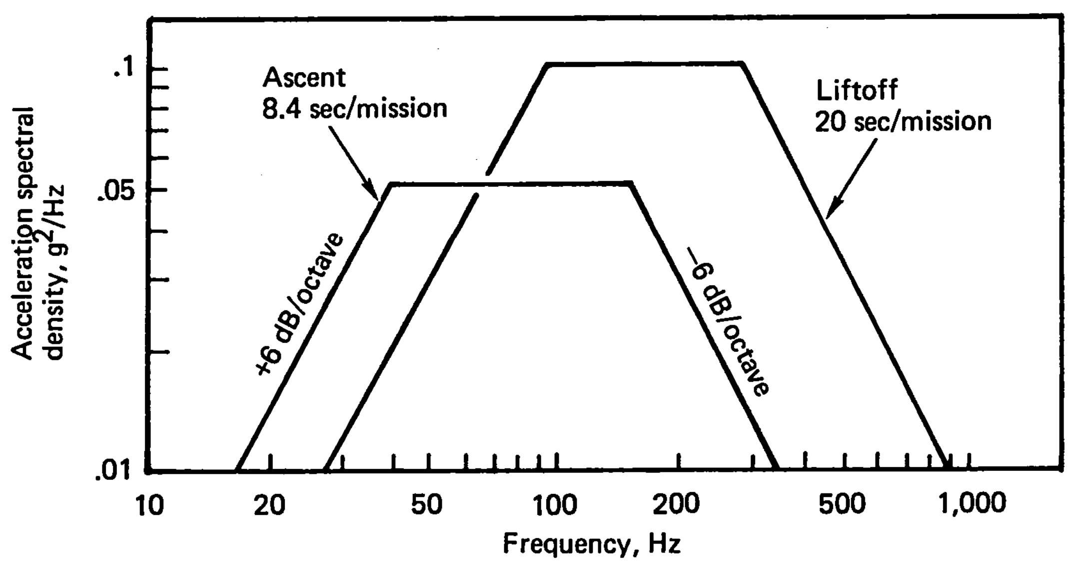


FIGURE 3-1.– SPACE SHUTTLE PAYLOAD BAY RANDOM VIBRATION CHARACTERISTICS

3.5 Acoustic
(Reference 2, para. 4.2.2.3)

An acoustic environment occurs in the payload bay during the launch and re-entry (abort) mission phases, Figure 3-2. The re-entry levels are considered negligible in comparison to the launch phase levels. The 1/3 octave band sound pressure level peaks at an approximate amplitude of 135 dB at 300 Hz over a broad band spectrum of 20 to 10,000 Hz. A transient maximum of approximately 145 dB occurs during the thrust build-up and lift-off for about 15 seconds. Another maximum of approximately 140 dB occurs at about 50 seconds.

3.6 Mechanical Shock
(Reference 2, para. 4.2.1.3)

The mechanical shock environment is most severe in the aborted mode handling. The requirement is for a 20 g terminal sawtooth pulse of 11 millisecond duration. One shock is required in each direction of each of the three orthogonal axes.

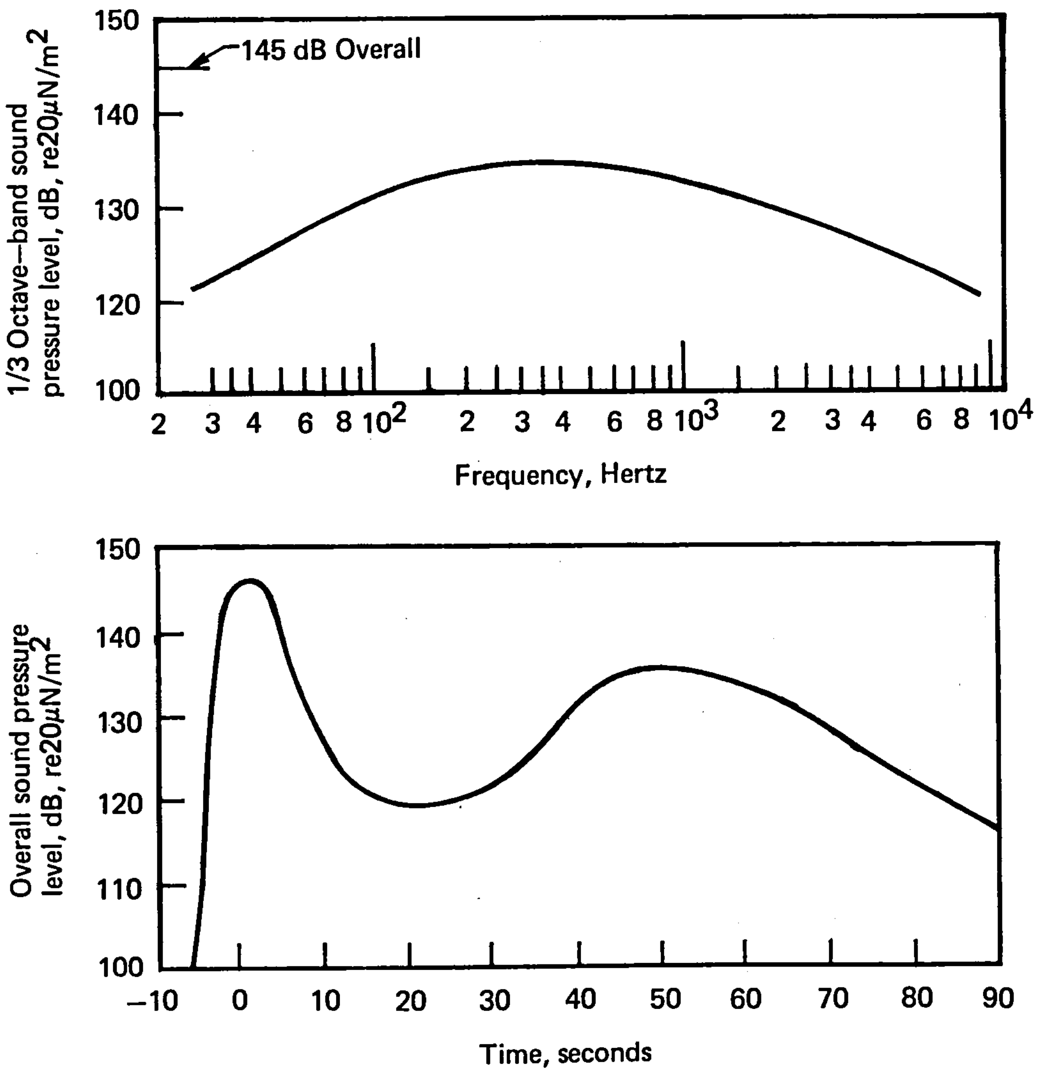


FIGURE 3-2.— SHUTTLE PAYLOAD BAY ACOUSTIC (LAUNCH) ENVIRONMENT CHARACTERISTICS

3.7 Acceleration
(Reference 2, para. 7.6)

The environment of zero "g" exists during the on-orbit Scout deployment mission phase with the only on-orbit accelerations being those induced by the Space Shuttle reaction control system. The aborted mode crash acceleration environment provides steady state levels of + 9.0 g and – 3.3 g in the (X) longitudinal axis, ± 1.5 g in the (Y) lateral axis, and + 4.5 g and – 2.0 g in the (Z) vertical axis. The X, Y, and Z coordinate system and sign convention follows that of the Shuttle. These are short duration accelerations; in the order of less than a second.

3.8 Temperature
(Reference 2, para. 4.2.2.7.1)

The maximum and minimum temperatures and heat fluxes are presented in Table 3–II for the various mission segments.

TABLE 3–II.– PAYLOAD BAY WALL THERMAL ENVIRONMENT

Mission flight phase	Payload bay wall thermal environment		
	Parameter	Design minimum	Design maximum
Prelaunch	Temperature, °C (°F)	+4 (+40)	+49 (+120)
Launch	Temperature, °C (°F)	+4 (+40)	+65 (+150)
On-orbit (door closed)	Total bay heat flux, Average watts per meter^2 (BTU/ft^2 hr)	⩽ 9.45 (Loss) (⩽ 3 (Loss)	⩽ 0 (Gain)
	Heat flux, local area, watts per meter^2 (BTU/ft^2 hr)	⩽ 12.51 (Loss) (⩽ 4 (Loss)	⩽ 9.45 (Gain) (⩽ 3 (Gain))
On-orbit (doors open, empty payload bay)	Temperature, °C (°F)	–182 (–296)	+98 (+209)
	Absorbed heat flux, watts per meter^2 (BTU/ft^2 hr)	0 (Tail to sun)	232 (+74) (Top to sun)
Abort: Entry and post landing	Temperature, °C (°F)	–73 (–100)	93 (+200)

4.0 MISSION TRAJECTORY DETERMINATION

The design trajectory selected for this study was based on the following:

(a) Stages used were the Antares and Altair.

(b) Payload weight of 545 kilograms (1200 pounds)

(c) Shuttle parking orbit of 296 kilometers (160 nautical miles) circular, inclination of 28.5 degrees

(d) Spacecraft final orbit to be the maximum average apogee-perigee achievable consistent with items (a) through (c).

The weights break-down for the Scout upper stages, modified for the Shuttle launched mission, is presented in Table 4—I. The Scout F-1 weights, shown for comparison purposes, are from Vought Corporation Report No. 2-53492/4R-23000, "Scout Vehicle S-193 and Sub. Weight Report" dated 31 January 1974.

After orbital injection, the Shuttle will be orbiting the Earth in any of several modes, i.e., rotisserie mode, fixed orientation to Earth, fixed orientation to Sun, etc., while it is performing its routine functions. However, when preparing to deploy a launch vehicle, the Shuttle must be re-oriented so that the vehicle will be in the proper orientation to enter its mission. For the Scout upper stages, the required orientation would be such that it will be deployed at an angle of 135 degrees relative to the Shuttle velocity vector as shown in Table 4—II and the inset of Figure 4-1. None of the published information for the Shuttle defines the required separation distance to ensure Shuttle safety at rocket motor ignition of the launch vehicle. The required separation will be a function of rocket motor size and was beyond the scope of this study. However, in a previous study, Reference 1, a nominal separation of 1.85 kilometers (1 nautical mile) was established as a safe separation and was used in this study. Using the above deployment angle and separation distance, and a deployment velocity of 1.5 meters per second (5 feet per second), the deployment trajectory, Table 4—II, will place the Scout upper stages approximately 1.85 kilometers (1 nautical mile) below (toward Earth) and 0.74 kilometer (0.4 nautical mile) ahead of the Shuttle in 950 seconds and the Antares motor can be fired to boost the upper stages into the transfer orbit, Figure 4—1. The upper stages are then reoriented through 180 degrees for Altair firing. Following a coast of 2.37 hours, the upper stages will be at apogee of the transfer orbit and the Altair is fired to place the payload in the final orbit. Trajectory parameters and separation distances are presented in Table 4—III.

TABLE 4–I.– SCOUT UPPER STAGES WEIGHT SUMMARY

Item description	Scout F–1	Baseline study stages
Altair stage burnout	[92.84]	[119.34]
Motor and hardware	(79.57)	(79.57)
Pressure transducer	.36	.36
Motor inert	55.42	55.42
Ignition harness	.88	.88
Tape – installation ignition harness	.52	.52
TM ring module (T/M & IGN)	20.39	20.39
Dynamic balance weight	2.00	2.00
Upper D	(13.27)	(13.27)
Hardware upper D to motor	.18	.18
Upper D structural and harness	13.09	13.09
Change to basic Scout		(26.50)
Altair ring mod. – component insul.		.60
Ring mod T/M package		5.65
Spacecraft adapter		20.00
Attach hardware – P/L to motor		.25
Antares stage burnout	[763.14]	[804.33]
Lower D spin items	(39.36)	(39.36)
Spin table struc. & comp.	24.79	24.79
Explosive bolts	.53	.53
Spin motors (4–1KS 75)	4.50	4.50
Inner bearing race	9.54	9.54
Lower D	(219.24)	(219.24)
Ring & hdw. – spin to lower D	6.20	6.20
Outer bearing race	11.97	11.97
Lower D & components	179.39	179.39
IRP installation & hardware	20.79	20.79
Tunnel covers and hardware	0.54	0.54
Hardware (lower D to motor)	0.35	0.35

TABLE 4–I.– SCOUT UPPER STAGES WEIGHT SUMMARY (Continued)

	Scout F–1	Baseline study stages
Change to basic Scout – lower D	(2.95)	(35.98)
Guidance battery (28V)		15.18
Guidance battery (37V)		7.71
TM battery		1.18
Radar beacon battery		4.51
T/M package & encoder		1.50
Brackets & instal. lrge. batt.		5.90
Electrolyte	2.95	
Motor section	(259.51)	(259.51)
Antares motor inert	223.10	223.10
Fillet	.35	.35
Headcap transducer	.48	.48
Nozzle tape	.70	.70
Dome tape	.32	.32
Motor tunnel and hdw. – TM	4.06	4.06
Motor tunnel & hdw. – guid.	4.07	4.07
Tunnel harness & hdw. – TM	6.07	6.07
Tunnel harness & hdw. – guid.	10.76	10.76
Nozzle shroud & hdw.	9.60	9.60
Changes to basic Scout motor sect.	(1.12)	(13.87)
Reflective tape		2.98
Cork (0.25")		10.89
Destruct charge and hdw.	1.12	
Upper C	(208.80)	(208.80)
Hardware upper C to motor	.86	.86
Upper C and components	192.73	192.73
Balance weight – 0°	3.65	3.65
Balance weight – 315°	2.90	2,90
N_2 remaining	1.00	1,00
Tunnel covers & hdw.	7.66	7.66

TABLE 4–I.– SCOUT UPPER STAGES WEIGHT SUMMARY (Concluded)

	Scout F–1	Baseline study stages
Changes to basic Scout upper C	(32.16)	(27.57)
Destruct system	17.96	
H_2O_2 tank bladder material change		.80
H_2O_2 tank		3.80
H_2O_2 brackets & tubes		3.00
Relay box & brackets		3.00
H_2O_2 tank and nozzle insulation		.50
H_2O_2 remaining	14.20	16.47
Weight Summary		
Altair burnout	92.84	119.34
Altair consumed	608.26	608.26
Altair ignition	701.10	727.60
Spin-up weight	740.46	766.96
Antares burnout	1,464.24	1,531.93
Antares consumed	2,581.24	2,581.24
H_2O_2 consumed	4.30	5.53
Antares ignition	4,049.78	4,118.70

TABLE 4-II.– DEPLOYMENT TRAJECTORY STATE

Space Shuttle

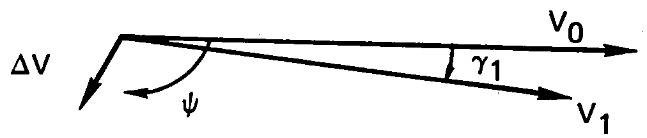
Orbit: Altitude = 296 km (160 n.mi.) circular
Inclination = 28.5 degrees; Period = 90.445 min

Altitude	Velocity (V_0)	Path angle (γ_0)
296 km (160 n.mi.)	7.73 km/sec (25354.04 fps)	0 degrees

Auxiliary stages

Deployment maneuver

ΔV = 1.52 m/sec (5 fps) ψ = –135 degrees



Orbit after deployment

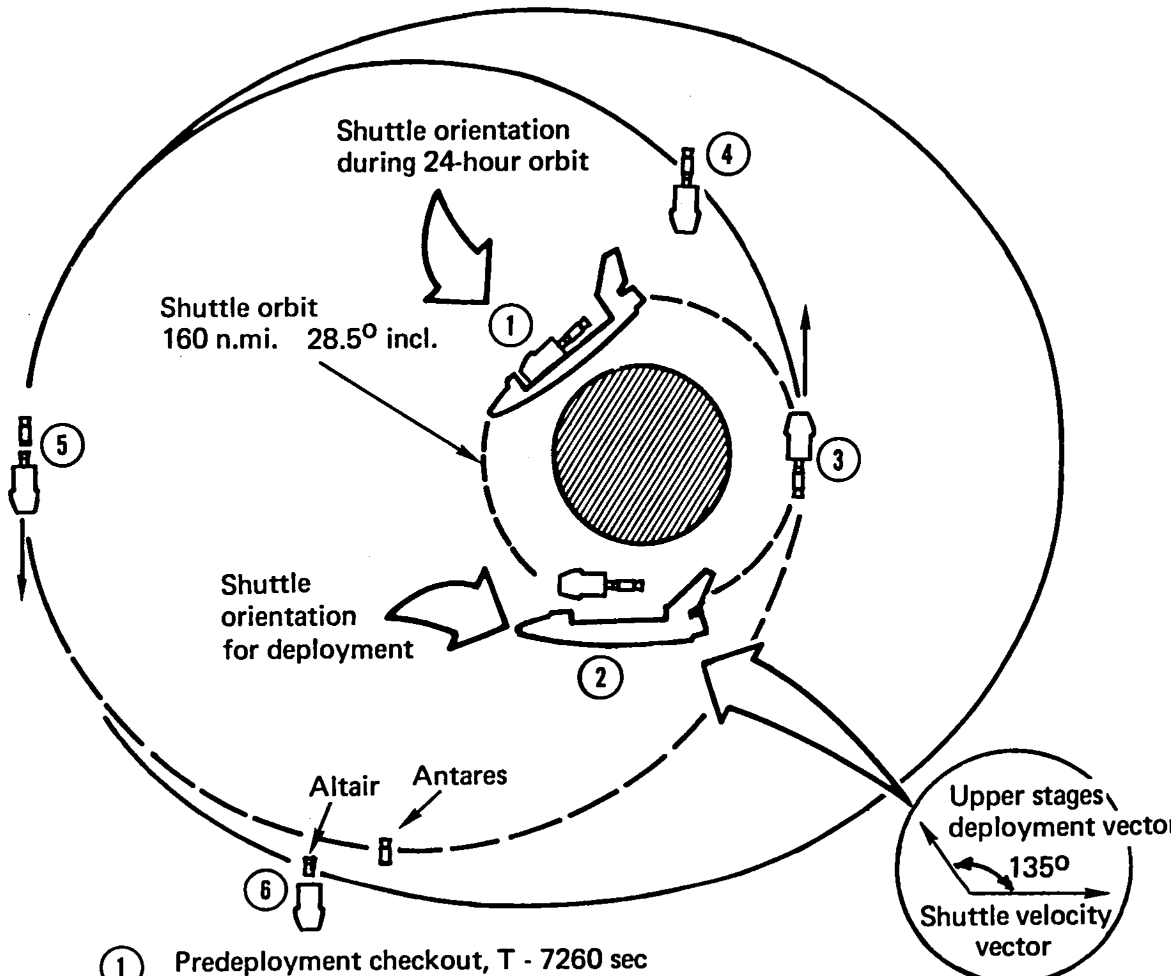
Perigee = 292 km (157.9 n.mi.) Apogee = 296 km (160 n.mi.)
Inclination = 28.5 degrees Period = 90.445 min

Trajectory state

Altitude	Velocity (V_1)	Path angle (γ_1)	Azimuth
196 km (160 n.mi.)	7.73 km/sec (25350.5 fps)	–0.008 degrees	102.103 degrees

		Vehicle attitude		
Latitude	Longitude	Roll	Pitch	Yaw
26.00 degrees	80.77 degrees	0 degrees	–62.4 degrees	101.5 degrees

Note: (1) All altitudes based on equatorial earth radius of 6378.17 km (3443.934 n.mi.)
(2) Latitude and longitude assumed, azimuth calculated based on latitude and inclination.



(1) Predeployment checkout, T - 7260 sec

(2) Orient Shuttle to deployment attitude
Deploy upper stages, T—60 sec

(3) Antares burn
293 x 15,792 km (158 x 8,527 n.mi.) orbit, T + 950 sec

(4) Reorientation maneuver, T + 979 sec

(5) Antares separation/Altair burn
10,522 x 15,726 km (5,682 x 8,492 n.mi.) orbit, T + 9,525 sec

(6) Spacecraft/Altair in orbit, T + 9,824 sec
Altair separation

Coast time = 2.37 hr
between (3) and (5)

FIGURE 4-1.— SHUTTLE LAUNCHED SCOUT MISSION TRAJECTORY PROFILE

TABLE 4-III.– TRAJECTORY PARAMETERS AT EVENT TIMES

Time sec	Event	Altitude* km	n.mi.	Velocity km/sec	(fsp)	Path angle degree	Azimuth degree	Apogee/perigee km	n.mi.
0	Deploy	296	(160)	7.73	(25350.5)	–0.008	121.500	296/292	(160/158)
950	Antares ignition	289	(156)	7.74	(25375.0)	–0.059	118.482	307/289	(116/156)
978	Antares burnout	292	(158)	9.59	(31446.9)	0.370	118.601	15,790/292	(8527/158)
5220	Coast midpoint	11,467	(6,192)	4.12	(13515.4)	29.598	67.288	15,726/293	(8492/159)
9525	Altair ignition	15,726	(8,492)	2.89	(9488.1)	0.252	61.427	15,725/296	(8491/160)
9559	Altair burnout	15,726	(8,492)	3.95	(12969.3)	0	61.330	15,725/10,522	(8492/5682)

*Altitude based on equatorial radius of 6377.65 km (3443.934 n.mi.)

Time sec	Event	Separation Horizontal km	n.mi.	Vertical km	n.mi.	Total km	n.mi.
0	Start deployment	0	(0)	0	0	0	
0	Clear shuttle bay	0	(0)	.002	(-0.001)	.002	(0.001)
950.0	Antares ignition	+.78	(+0.419)	-1.849	(-0.998)	2.000	(1.081)
978.9	Antares burnout	+28.95	(+15.634)	-1.367	(-0.738)	28.985	(15.652)

5.0 ENVIRONMENTAL PROFILE FOR A SHUTTLE LAUNCHED SCOUT ORBITAL MISSION

The trajectory analysis mission times of Section 3.0 and typical Scout event times were combined to form a detail mission timeline for the Shuttle launched mission, Table 5-1. A profile of environmental levels, expected durations, and mission phases for this mission is presented in Table 5-2.

TABLE 5-1.– SEQUENCE OF EVENTS–NOMINAL TRAJECTORY

Relative time (seconds)	Δt (sec)	Mission event
		(Assume a Shuttle on-orbit time of 24 hours before initiation of Scout mission.)
–7260	6300	Start Scout/spacecraft checkout and countdown.
– 960	900	Scout terminal countdown
– 60	60	Initiate Scout deployment and separation.
00	10	Separation from Orbiter
10		Activate RCS
	940	Coast
950	29	Antares ignition and burn
979	8540	Close deadband and coast
9519	1	Spin motor ignition
9520	2	Altair/spacecraft separation from Antares
9522	3	Retro Antares
9525	34	Altair ignition and burn
9559	265	Minimum time to P/L separation
9824		Separate P/L

TABLE 5-II.– ENVIRONMENTAL PROFILE FOR A SHUTTLE LAUNCHED SCOUT MISSION

Mission phase / Environment	Shuttle on-orbit for T — 24 hours doors open	Scout/spacecraft deployment and separation	Scout/spacecraft deployment and separation from orbiter T — 1 min.	Coast	Antares Burn	Coast	Coast	Altair Burn	Coast
Time line				00 Separate from orbiter; 10 Activate RCS	950 Antares ignition	979 Antares burn-out	9519 Spin motor ignition; 9520 Antares Sep; 9522 Antares Ret	9525 Altair ignition	9559 Altair burn-out; 9824 Minimum time to payload sep.
Pressure (vacuum)	← Deep space vacuum; use 13 x 10^{-9} newtons/meter^2 (1 x 10^{-10} torr) for design considerations →								
Solar radiation	← Exposed to 1399 watt/meter^2 (444 btu/ft^2/hr) on the side facing the sun →								
Earth albedo	←		Use 30% for spectrum areas of concern →						
Earth radiation	← Exposed to 243 watt/meter^2 (77 btu/ft^2/hr) on the side facing the earth →								
P/L Bay temperature	← −182°C (−296°F) design minimum, 98°C (+209°F) for design maximum →								
Zero "g"	← Gravitational field is negligible; use zero "g" for design consideration →								
Meteoroid	←		An analysis was performed using the meteoroid environment model of Reference 3. Results of the analysis yielded a probability of survival of 0.9964. The analysis was performed on only the two uninsulated rocket motors (Antares and Altair). →						
Vibration	← None →			Negligible control motor firings	Less than 0.3 grms random — no discrete	Negligible control motor firings	None	Less than 0.3 grms random — no discrete	None
Mechanical shock	← None →				Less than ± 60 g.	← None →		Less than ± 60 g.	None
Acceleration	← Negligible →				Thrust accel. of 6.9 g	None	8.8 rad/min (1.40) rpm imparted to vehicle above "D" section spin bearing (4th stage and payload), 0 < A_N < 15 g Thrust accel. of 4.5 g		
EMI	To be provided as stated by JSC 07700 Vol. IV Rev. D			← Negligible →					
Temperature			Thermal considerations, in addition to environment temperature, account for (1) electrical power dissipation, (2) RCS valve temperature dissipation, and (3) rocket motor nozzle heat radiation. These occur in localized areas and will be treated at the individual transition section and/or component level.						

Notes:
(1) Vibration and mechanical shock levels are enveloped for the aft and forward motor shoulders.
(2) Temperatures given are for the surface of the vehicle.
(3) Unless otherwise noted time is in seconds.

6.0 COMPILATION OF SCOUT UPPER STAGES ENVIRONMENTAL QUALIFICATION CRITERIA AND COMPARISON TO SPACE SHUTTLE MISSION EXPECTED ENVIRONMENTS

A comparison of the Shuttle launched Scout upper stages mission environment to the present Scout mission environmental qualification requirements was performed to identify their incompatibilities. Recommendations for resolving these incompatibilities are presented in Section 8.0.

The environments were grouped into the three categories of dynamics, meteoroid, and thermal and are discussed in the following paragraphs. These data also include the environmental testing that has been performed on the Scout components and is included in summary form in Table 6-I.

A comparison of the differences between Scout qualification test levels and Scout/Shuttle expected levels is contained in the following sub-sections.

6.1 Vibration

The Scout upper stages, during transportation in the Shuttle, will encounter different random vibration spectra than are used in the Scout qualification tests, Figure 6-1. The Shuttle spectra, with a total duration of 28.4 seconds, exist at the payload bay sill support points and are transmitted to the Scout upper stages through the support pallet, Figure 1-2.

Sinusoidal vibration tests were made early in the Scout program. However, analysis of flight data indicated that all vibration data was random. Consequently, sinusoidal testing was stopped.

6.2 Mechanical Shock

Mechanical shock qualification levels for the Scout upper stages are:

C Section: 68 g. terminal sawtooth, 6 milliseconds duration
D Section: 60 g. terminal sawtooth, 6 milliseconds duration
E Section: 75 g. terminal sawtooth, 6 milliseconds duration

The most severe mechanical shock during flight of the Scout upper stages occurs at Antares ignition and is shown in Figure 6–2.

The Shuttle mechanical shock environment is 20 g. terminal sawtooth, 11 milliseconds duration, plus several rectangular pulses of 0.23 g. to 1.5 g. with durations ranging between 170 to 350 milliseconds. The differences between these spectra are negligible; consequently, no further qualification of Scout upper stages in mechanical shock is considered necessary.

TABLE 6-I.– LIST OF SCOUT EQUIPMENT FOR ENVIRONMENT COMPARISON AND SUMMARY OF ENVIRONMENTAL TESTING PERFORMED

	Tested to Scout qual levels	Scout environment evaluation tests	Environmental flight acceptance
Vehicle sections:			
"C" section (upper)		T-A	
"D" section			
Contractor supplied separation system ("E" section)	V	V	
Rocket motors:			
Antares	V,T		
Altair	T		
Guidance and control components:			
Poppet valve electronics		T-S, V, MS	V, T-A
Rate gyro unit		T-A	V, T-A
Inertial reference platform			V, T-A
Yardney battery pack			
Instrumentation:			
4th Stage T/M transmitter	MS, V		T-A, V, MS
Reaction control components:			
Thruster valves (60#, & 2# motors)		T-A	
Relief valves (H_2O_2)		T-A, T, V	
Quick disconnect (unregulated N_2)	MS, A	T-A	
Hydrogen peroxide tanks		T-A	
Pressure regulator, N_2		T-A	

Legend:

T	Temperature	MS	Mechanical shock
V	Vibration	T-A	Temperature-altitude
A	Acceleration	T-S	Temperature-shock

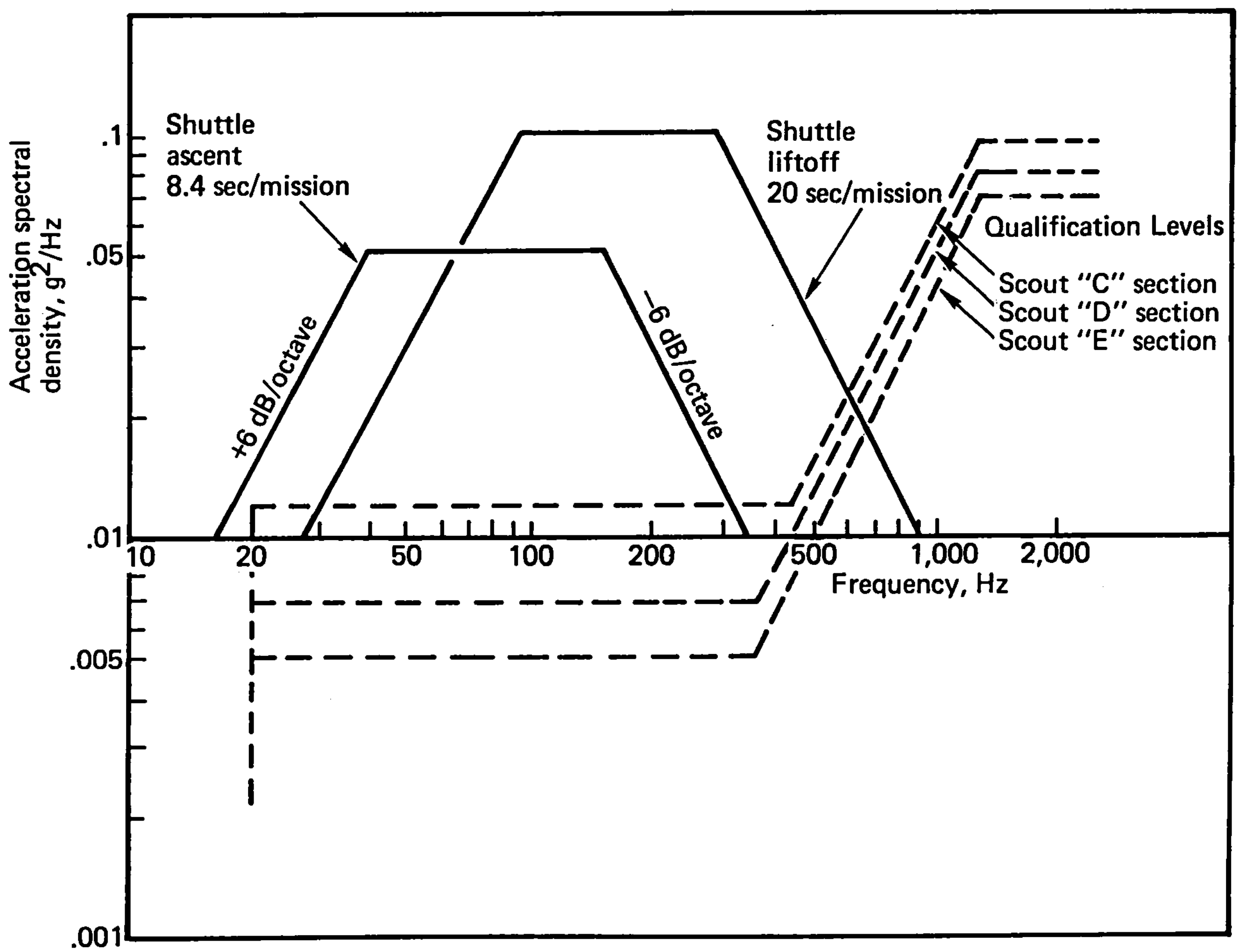


FIGURE 6-1.– RANDOM VIBRATIONS OF SCOUT QUALIFICATION TESTS AND SPACE SHUTTLE PAYLOAD BAY

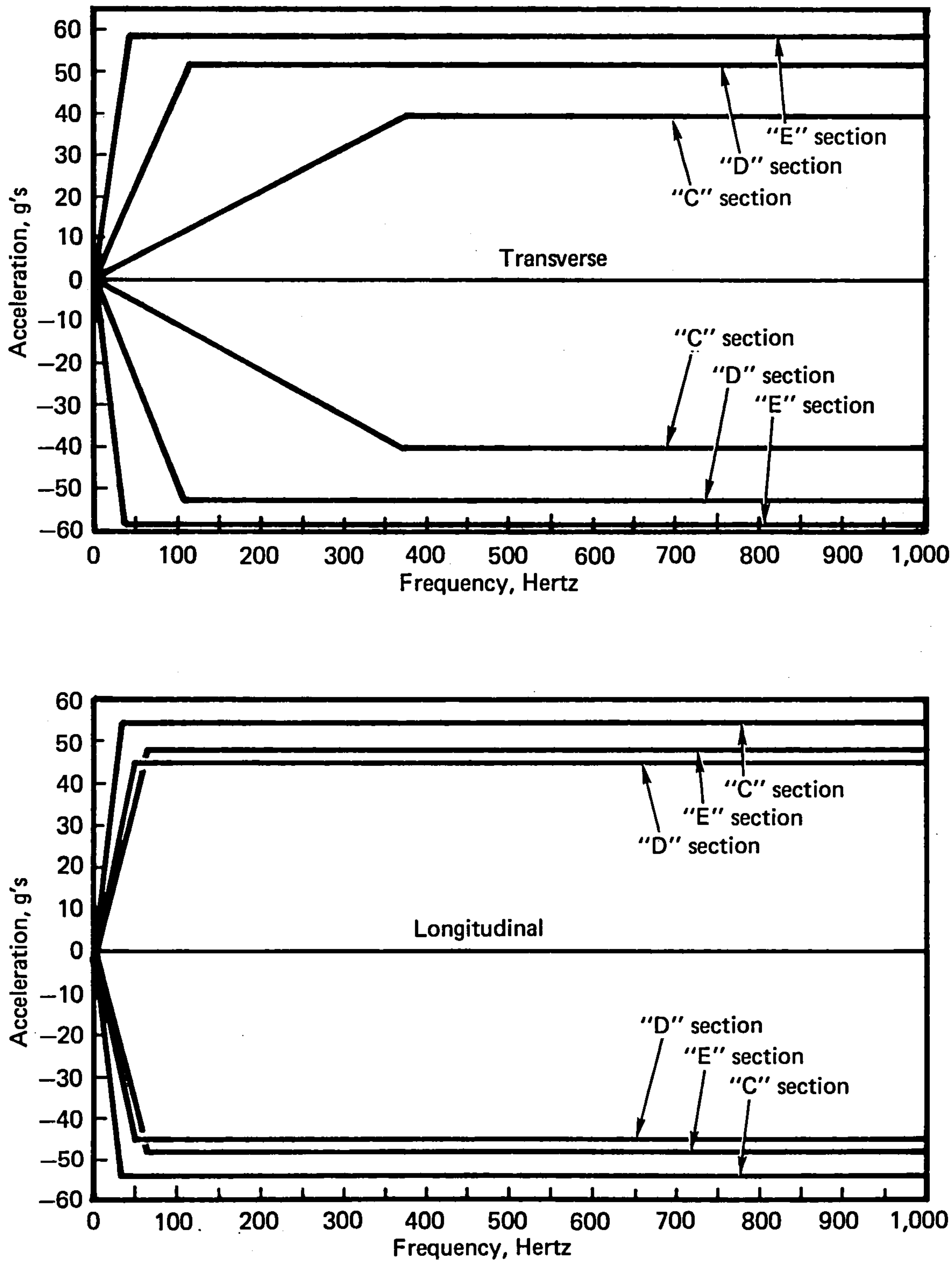


FIGURE 6-2.– SCOUT MECHANICAL SHOCK LEVELS
(MAXIMUM SHOCK ENVELOPE – ANTARES MOTOR)

6.3 Acceleration

The expected mission acceleration levels are lower than the Scout environmental test levels; therefore, no incompatibility exists. However, the Scout support pallet must be capable of withstanding 15 g's in the shuttle Z axis and 10 g's in the X and Y axes.

6.4 Acoustic

For the acoustic environment, no Scout test levels are required. However, the Scout vibration test levels include the effects of vibrations induced by sound. The reverberant sound field within the Shuttle will be different in character from the sound field generated during flight of a Scout through the atmosphere. The overall sound pressure levels for the Shuttle payload bay and the flight of a Scout through the atmosphere are comparable; however, at portions of the frequency range the Shuttle levels will exceed the Scout flight levels and are so noted in Figure 6-3.

It has to be assumed that during the period that acoustics are encountered, they are applied uniformly over the entire Scout upper stages and support pallet. The design of the pallet to the levels presented in Figure 6-3 is required.

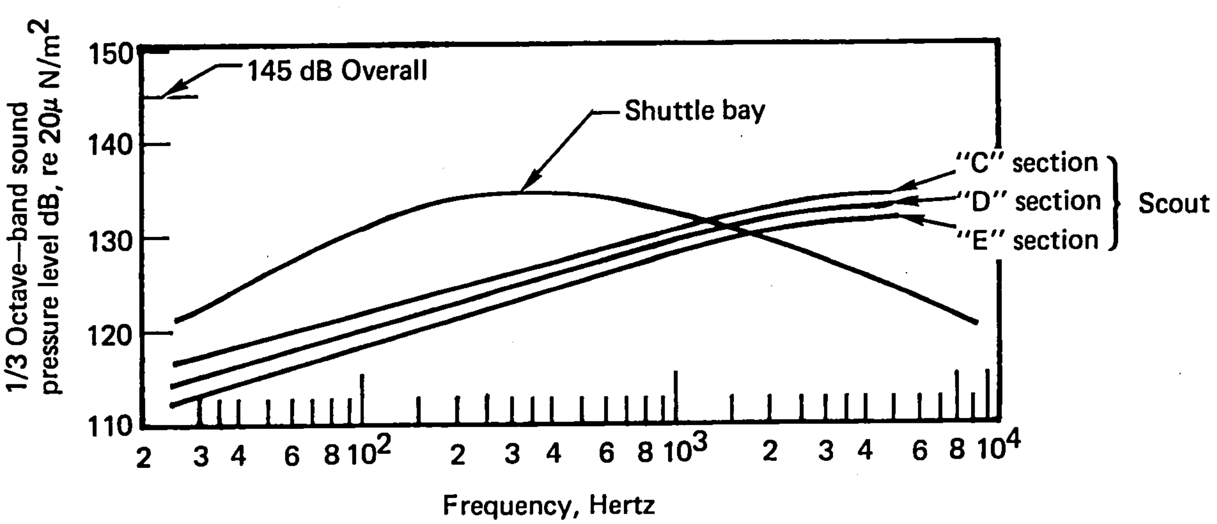


FIGURE 6-3.— ACOUSTICAL ENVIRONMENT CHARACTERISTICS OF SPACE SHUTTLE AND PRESENT SCOUT

6.5 Meteoroid

The land launched Scout mission, because of its relatively short duration, has not been concerned with meteoroid damage. In the Shuttle launched mission, the Scout upper stages will be exposed to the deep space environment for approximately three hours after deployment from the Shuttle. Using the method of Reference 3, the probability of meteoroid damage was assessed as 0.00364, or a 99.64% probability of no damage. This is considered an acceptable probability for purposes of this study.

6.6 Thermal

During Shuttle prelaunch operations, temperatures in the payload bay can be set between 4° and 49°C (40° and 120°F), Reference 2, Table 4—1. The Antares motor ignition temperature minimum and maximum limits are 10° and 32°C (50° and 90°F), respectively. For the Altair the limits are 4° and 38°C (40° and 100°F). Consequently, during prelaunch operations with the Scout upper stages in the Shuttle, the payload bay temperature must be held within the motor ignition temperature limits, with the Antares being the more critical.

For the post launch conditions, a layer of white paint on the outside of all motors and vehicle sections was assumed as a starting point for all thermal analyses. Under that condition, the maximum allowable temperatures were never approached in space and all further analyses were restricted to the minimum temperature condition.

For analysis, the Scout vehicle was considered as 5 major sections. The thermal capacities for these sections is listed below:

Upper "C" Skin	$C_{TH} = \rho C_p t$ = 5104 joule/meter^2 °C (.2495 BTU/ft^2 °F)
Antares Motor Case	C_{TH} = 9328 joule/meter^2 °C (.4560 BTU/ft^2 °F)
Lower "D" Skin	C_{TH} = 6683 joule/meter^2 °C (.3267 BTU/ft^2 °F)
Upper "D" Skin	C_{TH} = 3717 joule/meter^2 °C (.1817 BTU/ft^2 °F)
Altair Motor Case	C_{TH} = 3964 joule/meter^2 °C (.1938 BTU/ft^2 °F)

C_{TH} = Thermal Capacity ρ = Material Density
C_p = Specific Heat   t = Thickness

Since the thermal eapacity is a direct indication of the speed at which a section will change temperature, only the minimum thermal change (Antares motor case) and maximum thermal change (Upper "D" section skin) conditions were considered. All other sections listed above will have temperature variations which will lie between these two extremes.

The results of these analyses are seen in Figures 6-4 through 6-6. Figure 6-4 shows the maximum Scout temperatures reached during the Shuttle launch-to-orbit segment of the mission, for an initial payload bay temperature of 49°C (120°F), to be 54°C (128°F) for the Upper "D" skin and 51°C (124°F) for the Antares motor case. Temperatures for the Antares motor case further indicate that insulation or pre-launch bay temperature limitations will be required to keep motor temperatures within acceptable limits. Figure 6-5 shows the minimum steady-state temperature distribution throughout the Shuttle earth orbit phase of the mission. With the white paint coating on the outer skin surfaces, minimum temperatures of —100°C (—148°F) and —76°C (—105°F) will exist for upper

"D" section skin and Antares motor case, respectively. These temperatures are unacceptable and new thermal protection will have to be defined to protect motors and section components. Figure 6-6 illustrates minimum temperatures during the Scout orbit segment of the mission after Antares ignition. An unacceptable Upper "D" skin minimum temperature of −108°C (−163°F) will exist while other Scout sections will have minimum temperatures below this value and are also unacceptable. Again, thermal protection of vehicle sections will be required to bring temperatures up to specified motor and component minimums. The acceptable temperature ranges for the present Scout components and rocket motors are given in Table 6-II.

(OUTSIDE SURFACES OF SCOUT COATED WITH WHITE PAINT)

Note 1: Upper "D" represents maximum temperature rise, Antares motor represents minimum temperature rise, all other sections will have temperature rises which lie between these two extremes.

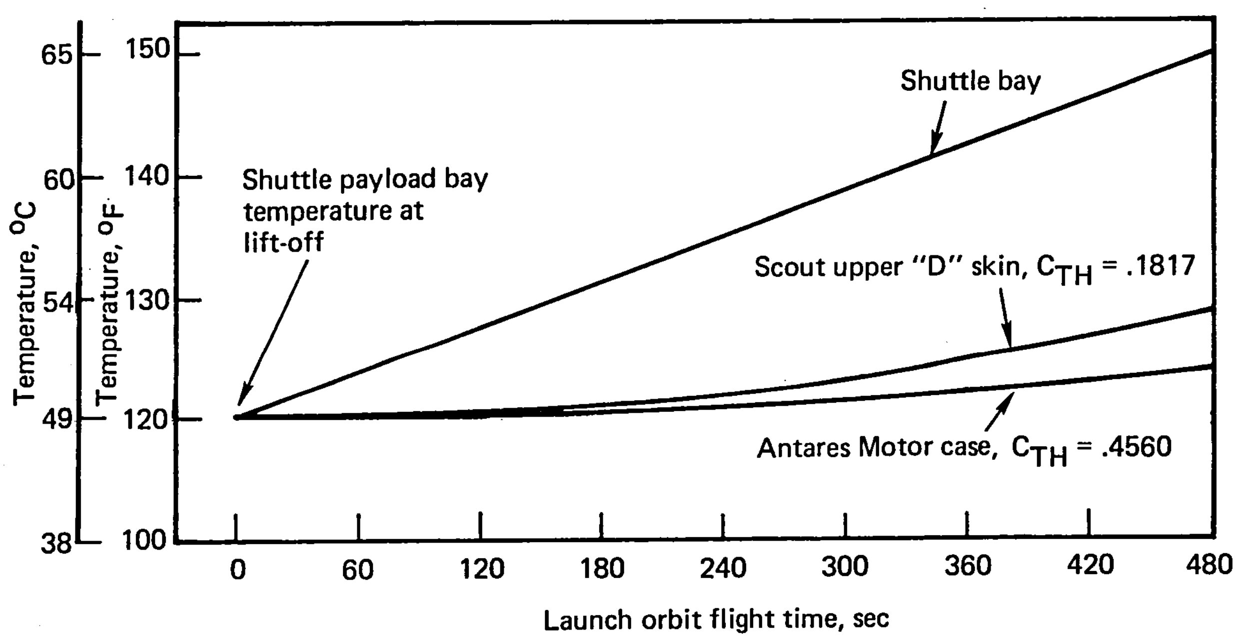


FIGURE 6-4.– MAXIMUM TEMPERATURE DURING SHUTTLE LAUNCH

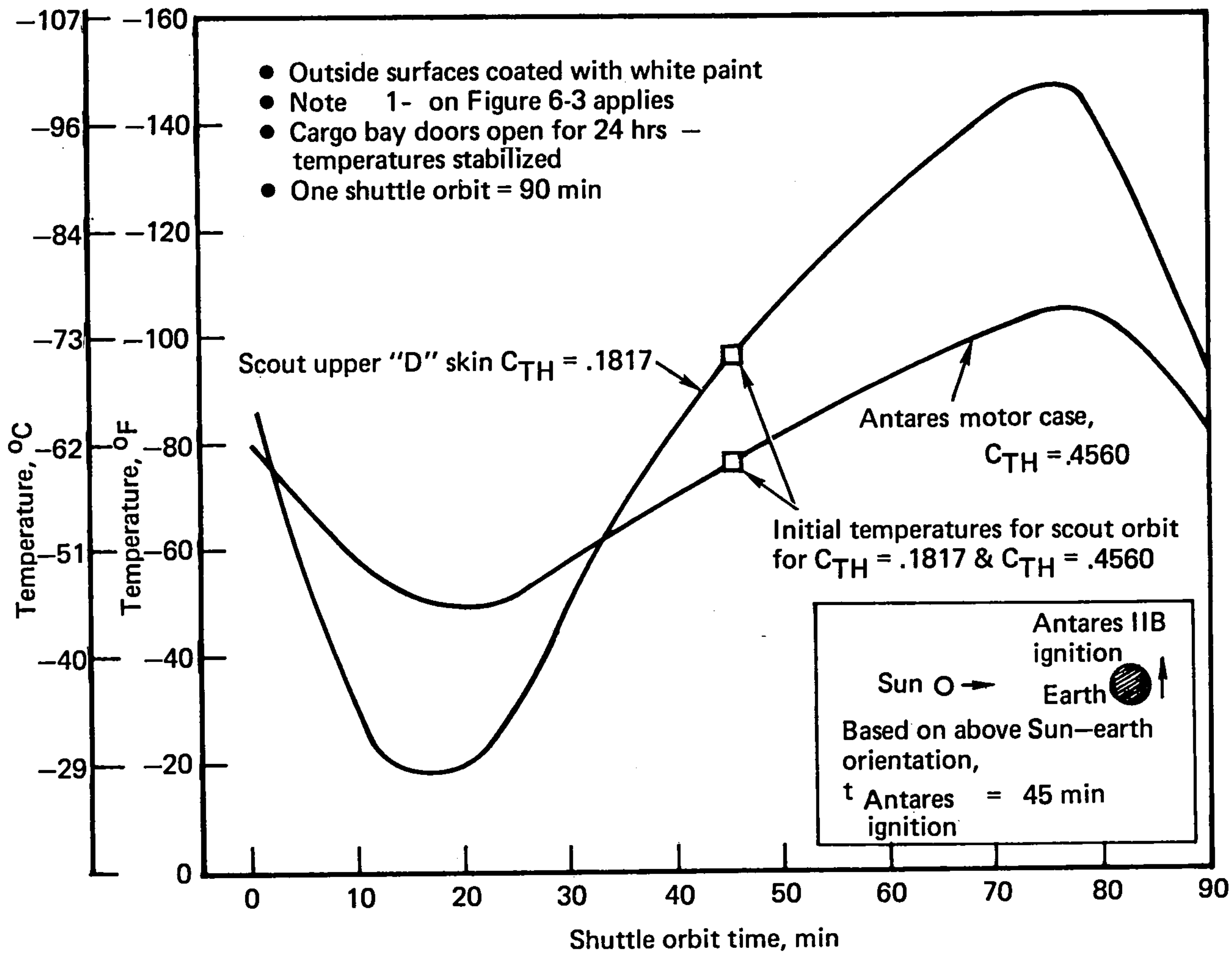


FIGURE 6-5.– MINIMUM TEMPERATURE DURING SPACE SHUTTLE ORBIT

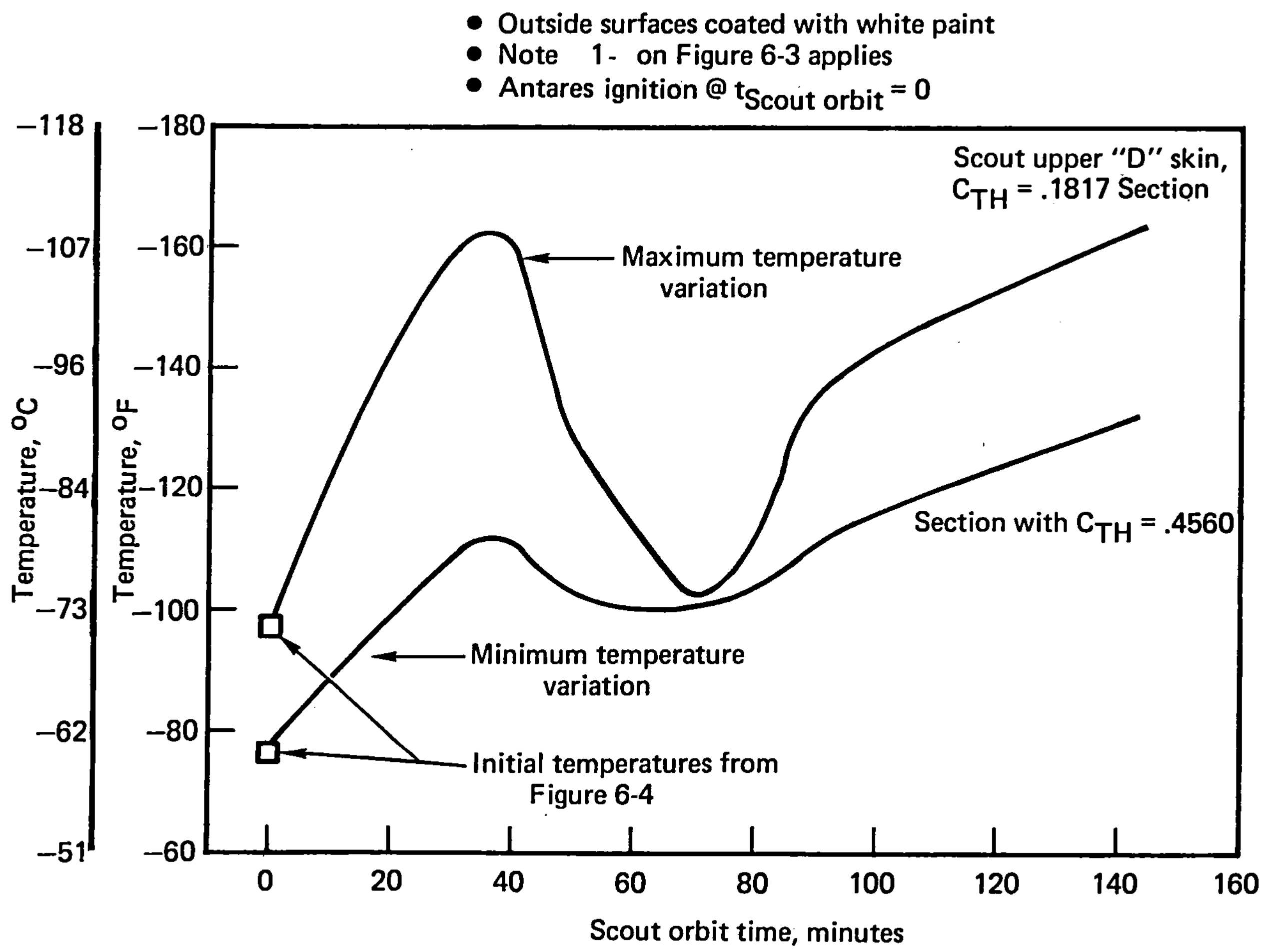


FIGURE 6-6.– MINIMUM TEMPERATURE DURING SCOUT ORBIT

TABLE 6-II.– TEMPERATURE RANGES FOR PRESENT SCOUT COMPONENTS AND ROCKET MOTORS

COMPONENTS:	Temperature range	
	Min ^oC (^oF)	Max ^oC (^oF)
Reaction control system		
Operating:	4 (40)	49 (120)
Non-operating:	– 7 (20)	71 (160)
Guidance electronics	–40 (–40)	66 (150)
T/M Transmitter	–18 (0)	80 (176)
Batteries	–18 (0)	49 (120)
MOTORS:		
Antares	Case bond temperature limits have been established at 4^oC (40^oF) minimum and 38^oC (100^oF) maximum.	
Altair	Case bond temperature limits have been established at 2^oC (35^oF) minimum and 41^oC (105^oF) maximum.	

7.0 RESULTS OF ANALYSES FOR ENABLING SCOUT UPPER STAGES TO ENDURE THE EXPECTED SHUTTLE MISSION ENVIRONMENTS

Analyses were performed on the dynamic, meteoroid and thermal conditions identified in Section 6.0, with the results presented in this Section. Section 8.0 presents recommendations, based on the analytical results, to enable the Scout upper stages to endure the Shuttle launched mission environments.

Differences were found between the Scout vibration test levels and the predicted dynamic environment during all phases of Shuttle operation. Also, a thermal incompatibility exists from the time the Space Shuttle payload bay doors are open until separation of the Scout upper stages from its payload.

7.1 Dynamic Analyses

Analyses were performed to determine the compatibility of the Shuttle launched Scout upper stages in the dynamic environment imposed by the Shuttle mission as defined in Section 6.0. The following items were determined in support of these analyses:

(1) Modes of vibration in the axial, lateral, and vertical directions of the Scout/pallet dynamic system.
(2) Maximum RMS flight loads and acceleration spectral densities imposed on the Scout by the Shuttle random vibration environment.
(3) Maximum loads imposed on the Scout by the Shuttle mechanical shock environment.
(4) Maximum loads imposed on the Scout by the Shuttle sinusoidal vibration environment.

The Scout upper stages and the Shuttle pallet were mathematically modeled using finite element techniques. A typical spacecraft envelope was used as the payload configuration. The physical properties of the Scout vehicle were taken from Vought Corporation Report No. 23.392 "Scout Structural Dynamics Design Data Report" Revision B dated 14 February 1976 and those of the spacecraft and pallet from Reference 1. The nodal locations of the Scout/pallet finite element model are presented in Scout station coordinates in Table 7–I. For the analysis the model was cantilevered at the appropriate support points as shown in Figure 7–1.

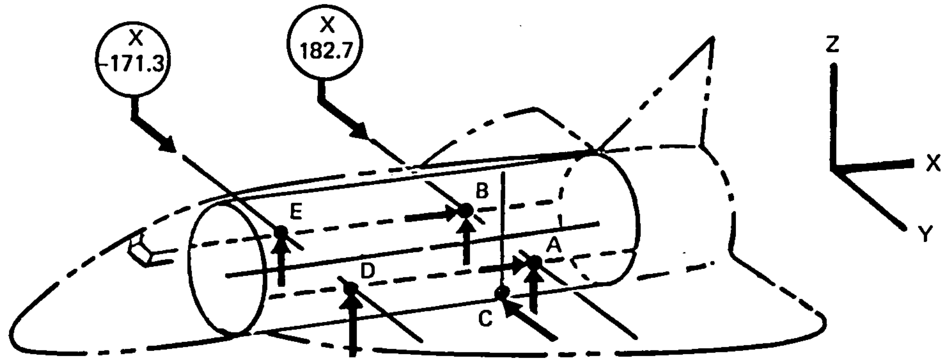
The first 12 cantilevered modes of the Scout/pallet system with rigid attachment members are presented in Table 7–II for the axial (X direction), lateral (Y direction), and vertical (Z direction) models. As noted in Table 7–II, the nature of the mounting system and the relatively large mass and moment of the Scout/pallet system result in very low frequency fundamental modes in all three axes.

The random vibration spectra representative of the Shuttle lift-off and ascent environment are shown in Figure 3–1. These spectra were analytically imposed on the Scout/pallet model and the RMS loads and acceleration spectral densities determined at various Scout stations. The maximum axial loads, and lateral and vertical bending moments are presented in RMS values in Table 7–III. Acceleration spectral densities for locations in the Scout "D" and "E" sections are plotted in Figure 7–2 and compared with current Scout 95% confidence limits at these locations. Figure 7–2 shows that a lateral acceleration spike at 19 Hz exceeds the current Scout limit for both the "D" and "E" sections but is not considered a problem to the structural integrity of the Sections or of any component. The limit was not exceeded at any other location in any other axis over the frequency range of interest.

The most severe mechanical shock condition of the Shuttle environment is the aborted-mode handling requirement of a 20g terminal sawtooth pulse of 11 milliseconds duration. This shock forcing function was applied to the Scout/pallet model and maximum axial loads, lateral bending moments, and vertical bending moments determined at various Scout stations. These maximum loads and moments are presented in Table 7–III. It appears that the magnitude of these loads would not be appreciably reduced by the installation of isolators. All loads shown in Table 7–III are within the current structural capability of the Scout vehicle except those at Station 47.8 for the "E" Transition Section.

TABLE 7-I.– SCOUT/SHUTTLE PALLET COORDINATES

Axial (X direction) cantilevered at (X = 182.7, Y = 88, Z = 414) and (X = 182.7, Y = 88, Z = 414) Lateral (Y direction) cantilevered at (X = 182.7, Y = 0, Z = 305) Vertical (Z direction) cantilevered at (X = 171.3, Y = 88, Z = 414 X = 171.3, Y = -88, Z = 414 X = 182.7, Y = 88, Z = 414 X = 182.7, Y = -88, Z = 414)	
Scout station	Coord. no.
– 31.3	1
37.27	2
47.77	3
65.9	4
72.7	5
84.5	6
99.8	7
102.7	8
103.7	9
124.1	10
131.1	11
137.7	12
161.5	13
182.7	14
191.9	15
218.6	16
238.18	17



		Scout coordinates
Axial restraints	A	(X = 182.7, Y = 88, Z = 414)
	B	(X = 182.7, Y = -88, Z = 414)
Lateral restraint	C	(X = 182.7, Y = 0, Z = 305)
Vertical restraints	A	(X = 182.7, Y = 88, Z = 414)
	B	(X = 182.7, Y = -88, Z = 414)
	D	(X = -171.3, Y = 88, Z = 414)
	E	(X = -171.3, Y = -88, Z = 414)

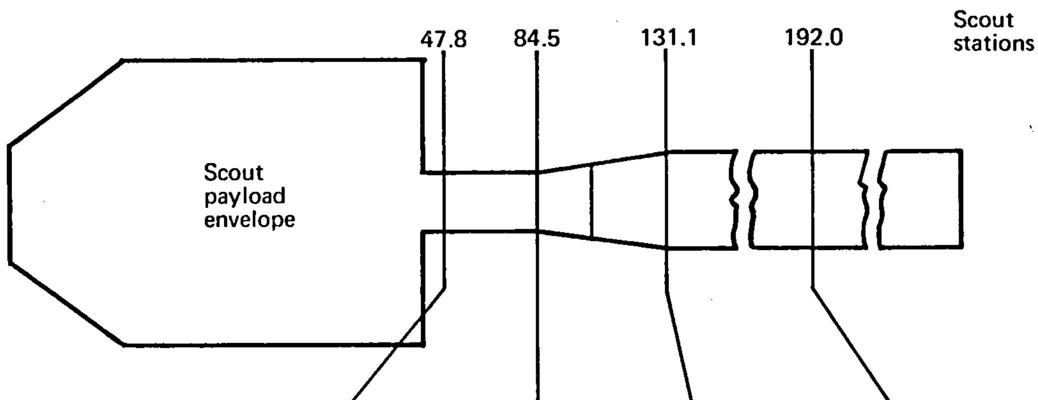
FIGURE 7-1.– SCOUT/SHUTTLE PALLET RESTRAINT SYSTEM

TABLE 7-II. – SCOUT/SHUTTLE PALLET CANTILEVERED MODAL FREQUENCIES

Mode no.	Axial (X direction)	Lateral (Y direction)	Vertical (Z direction)
1	2.1	0.7	2.0
2	39.4	10.6	3.4
3	88.5	13.7	7.4
4	115.3	19.3	23.3
5	136.4	33.0	42.4
6	179.9	44.3	66.4
7	258.3	67.9	80.9
8	349.6	115.8	108.1
9	381.6	137.2	144.6
10	411.6	152.9	150.6
11	609.9	215.2	214.8
12	635.9	224.4	239.3

The most severe sinusoidal vibration environment imposed by the Shuttle is that for the aborted-mode handling. The input vibration spectrum for this condition is given in Section 3.4. This spectrum was analytically applied to the Scout/pallet model and resulting maximum loads and moments are presented in Table 7–III. The loads resulting from this sinusoidal input are excessive. The sinusoidal test spectrum defined for this condition is unrealistic when applied to heavy structural elements and should not be considered as a part of the dynamic environment imposed by the Shuttle mission.

TABLE 7-III.– SCOUT/SHUTTLE PALLET DYNAMIC RESPONSE LOADS



Scout stations	47.8	84.5	131.1	192.0	
Max. axial rms load (X direction) newtons (lbs)	371.9 (83.6)	399.0 (89.7)	358.0 (80.5)	96.0 (21.6)	Response loads from random vibration
Max. lateral rms bending moment (Y direction) joules (in.-lbs.)	904 (8000)	370 (3274)	138 (1221)	491 (4342)	
Max. vertical rms bending moment (Z direction) joules (in.-lbs.)	8.61 (76.2)	7.21 (63.8)	21.47 (190)	18.98 (168)	
Max. axial load (X direction) newtons (lbs.)	23,237 (5,224)	18,771 (4,220)	15,035 (3,380)	1,121(252)	Response loads from mechanical shock
Max. lateral bending moment (Y direction joules (in.-lbs.)	15,634 (138,370)	4,420 (39,120)	14,972 (132,510)	11,175 (98,910)	
Max. vertical bending moment (Z direction) joules (in.-lbs.)	12,777 (113,090)	2,626 (23,240)	6,601 (58,420)	1,456 (12,890)	
Max. axial load (X direction) newtons (lbs.)	62,053 (13,950)	66,545 (14,960)	79,979 (17,980)	155,287 (34,910)	Response loads from sinusoidal vibration
Max. lateral bending moment (Y direction) joules (in.-lbs.)	116,826 (1,034,000)	125,187 (1,108,000)	140,101 (1,240,000)	190,718 (1,688,000)	
Max. vertical bending moment (Z direction) joules (in.-lbs.)	182,922 (1,619,000)	234,217 (2,073,000)	308,675 (2,732,000)	534,644 (4,732,000)	

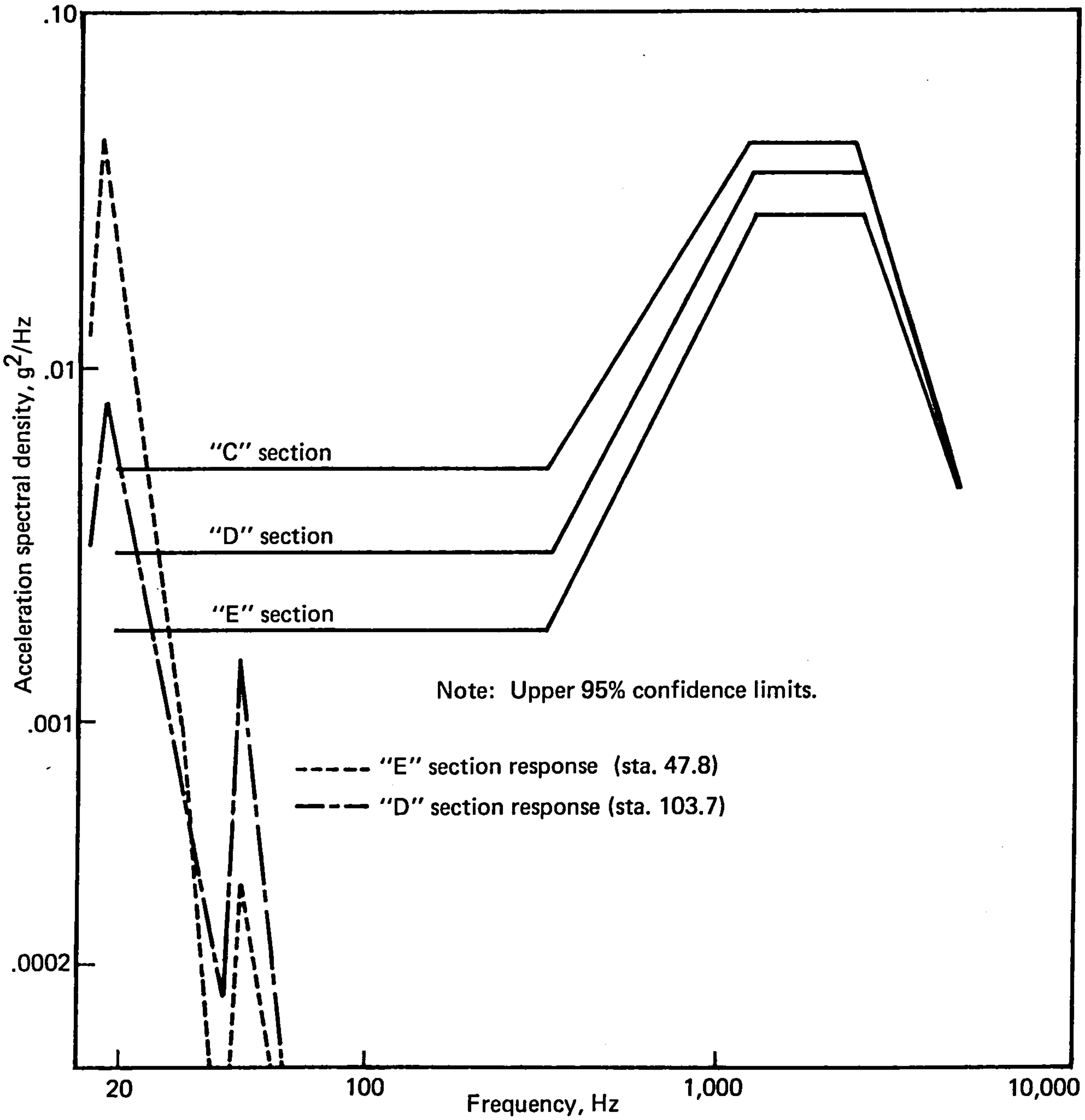


FIGURE 7-2.– ACCELERATION SPECTRAL DENSITY DUE TO RANDOM VIBRATION INPUT SPECTRA

Spectral levels of acoustic noise within Shuttle cargo bay during launch of Shuttle are expected to be over ten decibels higher than spectral levels of acoustic noise at the surface of an air-launched Scout as shown in Figure 6–2. Therefore, Scout is underqualified to Shuttle noise levels, regardless of any modifications of Scout attachment to Shuttle. Acoustical testing will be required to qualify the Scout vehicle for Shuttle launches.

7.2 Thermal Analysis

Thermal analyses were performed on the Scout upper stages vehicle for the Shuttle launched mission environment. The analyses were done following the thermal study discussed in Section 6.6 which indicated that components of the Scout upper stages vehicle, with its outside surface painted white, would be subjected to temperatures below their minimum limits, Table 6–II. These analyses were done to define the thermal protection requirements for the Scout upper stages for this mission, and to recommend coatings and/or insulation necessary to insure proper Scout operation.

The phases of the Scout mission and their corresponding thermal environments are seen in Figures 4–1 and 7–3. Figure 4–1 illustrates the Scout mission phases and timeline. For this investigation, a 24-hour Shuttle Earth Orbit, with bay doors continuously open, was assumed. The assumed Shuttle-Earth orientation is also shown in Figure 4–1. Other Shuttle-Earth orientations were considered; however, the orientation used was felt to be the extreme case. Based on the mission trajectory

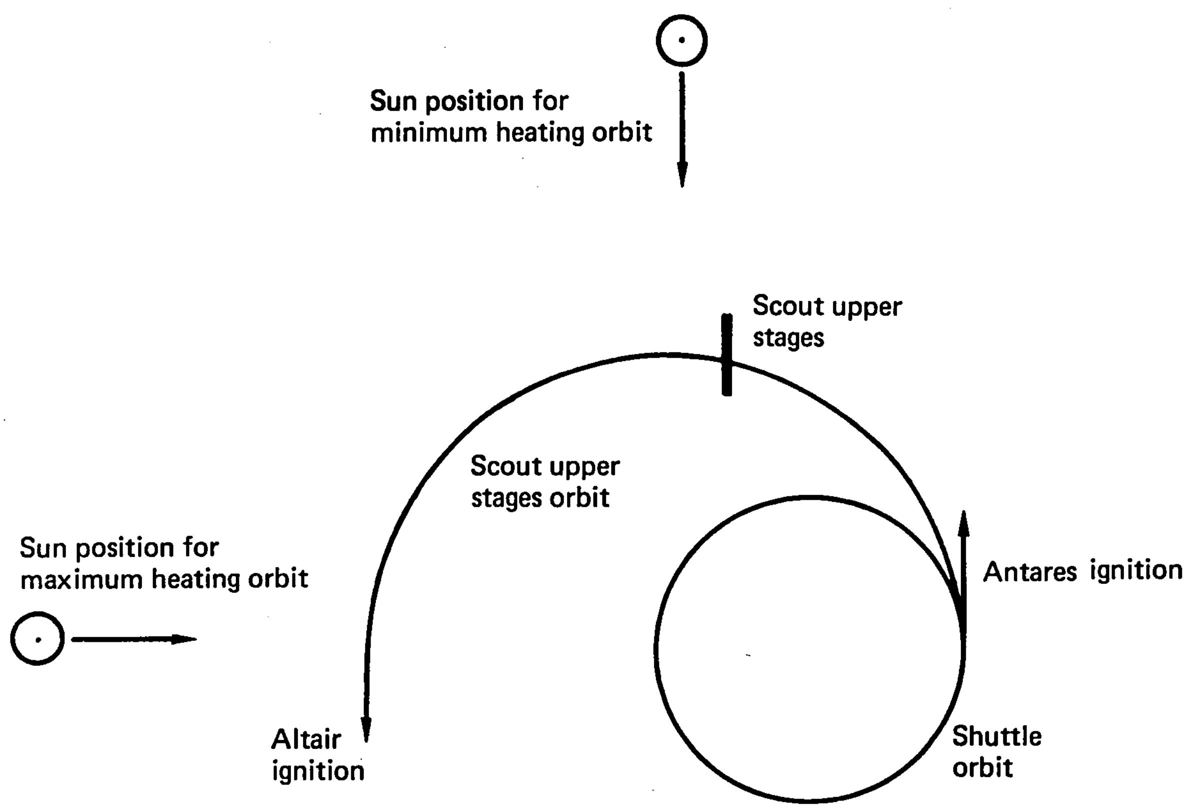


FIGURE 7-3.– SUN-TO-VEHICLE ORIENTATION FOR MINIMUM AND MAXIMUM HEATING

described in Section 3.0, orbital characteristics for the Scout vehicle after Antares ignition were calculated using methods described in References 4 and 5. Figure 7–3 indicates the vehicle orientation for maximum and minimum solar thermal environments seen by the Scout upper stages vehicle during this orbit. Other Sun-Earth positions were considered; however, the two cases presented in Figure 7–3 will be the extremes seen by the vehicle. Earth radiation and albedo heating inputs were also estimated. The methods and charts used are found in Reference 8.

The thermal models used in these analyses are described in the following paragraphs and are pictorially displayed in Figures 7–4 through 7–6. The skin and component materials and properties are given in Table IV.

Figure 7–5 shows a cross-section sketch of the Upper "C" Section without a component attached to the skin and with the Scout rate gyro attached to the skin. "D" and "E" section final models with superinsulation are seen in Figure 7–6.

Throughout these analyses, all transient nodal temperatures were calculated using methods described in Reference 6. Antares nozzle outer wall temperature decay was estimated by assuming heat loss through radiation to the aluminum radiation shields which make the double wall shroud around the nozzle. Initial temperatures were found in Vought Corporation Report 23.124 "Scout "C" Section Thermal Control Study" dated 15 June 1964. The results of these analyses follow in the order of rocket motors, Upper "C" section, and "D" and "E" sections.

Temperatures at nodes 1, 2, and 3, Figure 7–4, for the Antares and Altair were computed for all mission phases assuming an outside motor case thermal coating consisting of aluminum tape to white paint in a ratio of ten parts aluminum tape to one part white paint. Figure 7–7 illustrates the temperature rise experienced by both motors at the specified minimum and maximum temperature limits of the Shuttle bay environmental control system. The temperature rise incurred is a result of aerodynamic heating on the Space Shuttle bay door outside surfaces, Reference 2. Heat is then transferred to the Scout upper stages through thermal radiation and free convection. Figure 7–8 shows the stabilized Antares nodal temperatures achieved after the Shuttle has been in orbit for 24 hours with the cargo bay doors open continuously. It is apparent that, at an initial prelaunch cargo bay temperature of 49°C (120°F), the Antares motor will not be sufficiently cooled to meet the specified upper firing limit of 32°C (90°F). However, for an initial temperature of 21°C (70°F), the motor will have stabilized at a temperature well within the allowable ignition range of 10° to 32°C (50° to 90°F). Figure 7–9 shows the Altair temperature variation in the Shuttle orbit for cargo bay pre-launch temperatures of 5°C (40°F) and 21°C (70°F). Figure 7–10 illustrates Altair temperature distributions for maximum and minimum Scout heating orbits as defined in Figure 7–3. These results indicate that the Altair motor temperatures will lie well within the 4° to 43°C (40° to 110°F) ignition temperature limits of the motor using recommended thermal protection.

The results of the Upper "C" section thermal analysis, where Upper "C" outside skin is covered with .13 cm (.05 inch) cork coated with six to one ratio of aluminum tape to white paint are presented in Figures 7–11 through 7–14. Figure 7–11 shows the Upper "C" inside skin and rate gyro temperature variations while in the last Shuttle orbit prior to Antares ignition. Figure 7–12 illustrates the estimated Antares nozzle outer wall and corresponding radiation shield temperatures after motor ignition. Figure 7–13 shows the inside skin and rate gyro temperatures achieved during the maximum Scout heating orbit. Figure 7–14 shows the same for the minimum Scout heating orbit. Both Figures 7–13 and 7–14 include the Antares nozzle and solar heating inputs. These figures indicate that the thermal protection presently utilized for the rate gyro will be adequate for this mission. The other components in Upper "C" section are influenced less by temperature change than the gyro and are, therefore, also adequately protected.

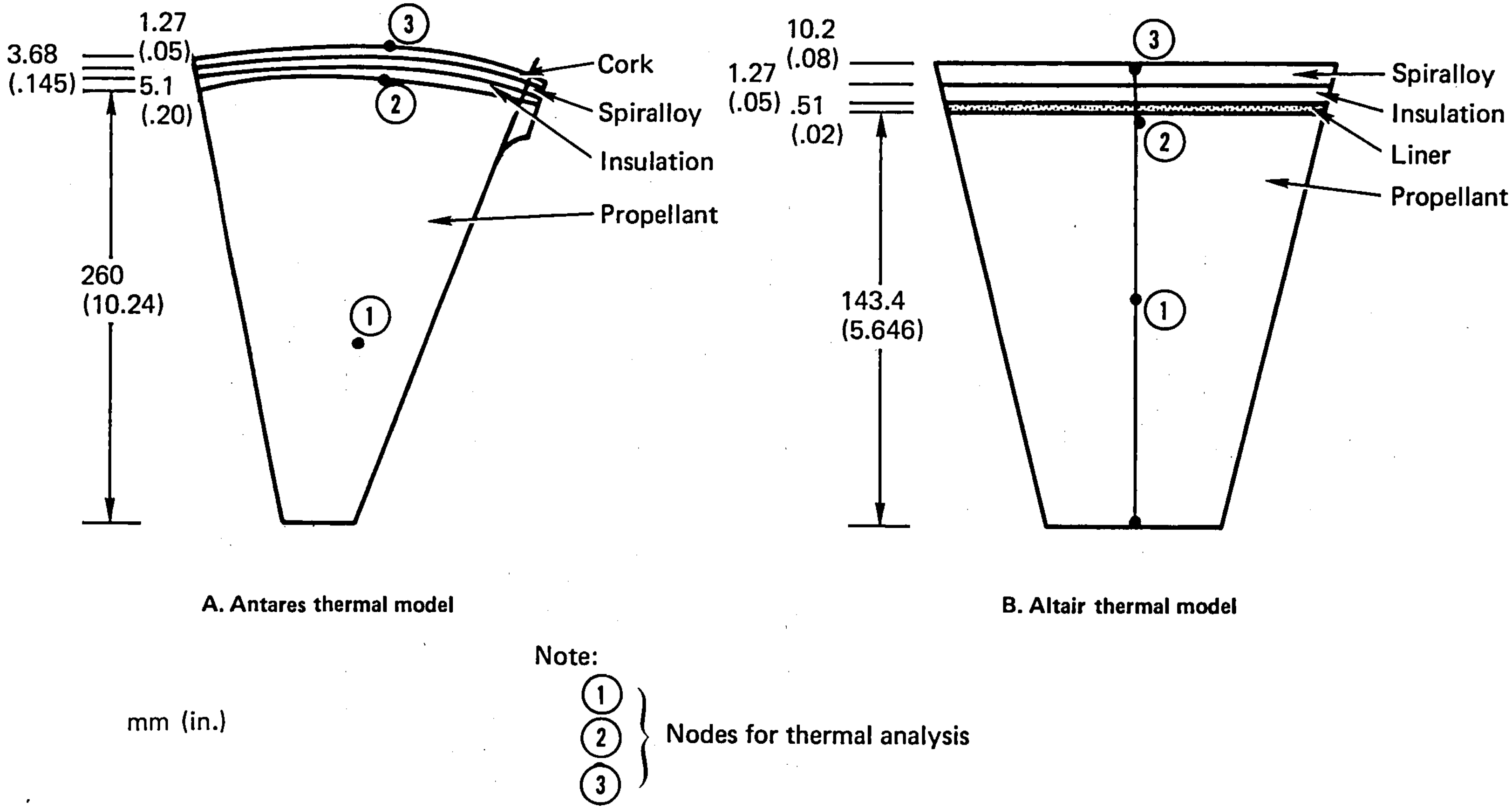
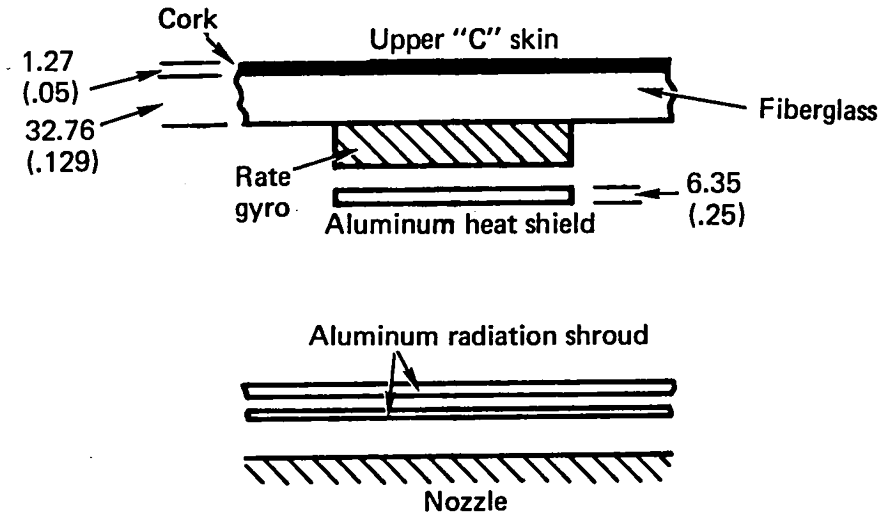
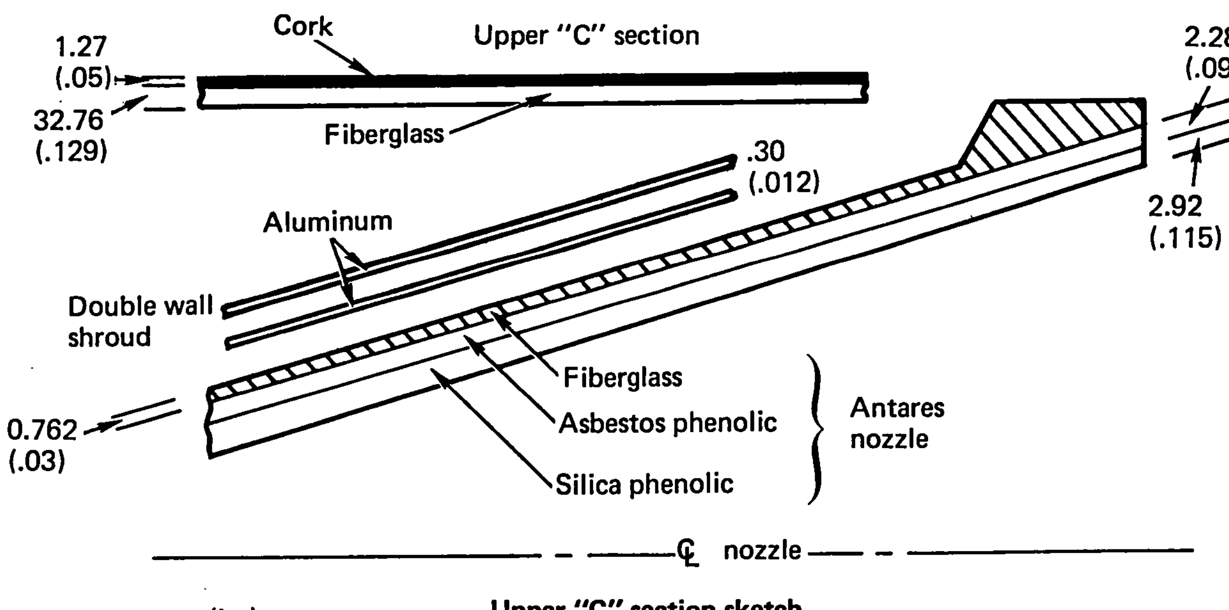


FIGURE 7-4.– ANTARES AND ALTAIR IIIA MOTOR THERMAL MODELS



Upper "C" section thermal model with rate gyro



Upper "C" section sketch

FIGURE 7-5.– UPPER "C" SECTION THERMAL MODEL

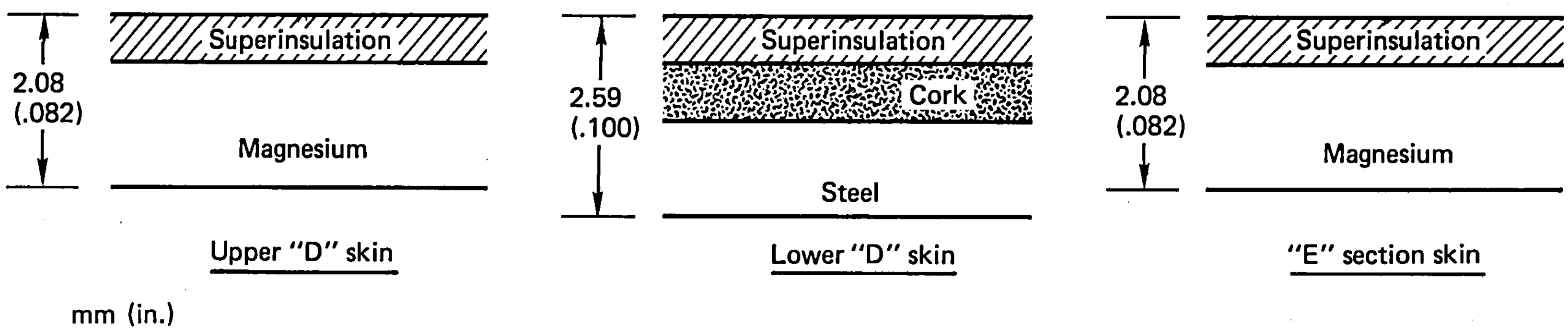


FIGURE 7-6.– "D" AND "E" SECTION THERMAL MODELS

TABLE 7-IV.– SCOUT UPPER STAGES MATERIALS AND PROPERTIES

Material		t		Density		C_p		K	
		mm	(ft)	Kg/m^3	(lb/ft^3)	Joules/Kg^{o}C	BTU/lb^{o}F	Joules/hr^{o}C m	BTU/hr ft^{o}F
Upper "C" Section Skin and Components									
Skin	Fiberglass	3.3	(.0108)	1762	(110)	880	(.21)	603	(.0967)
Nozzle	Fiberglass	.8	(.0025)	1842	(115)	1592	(.38)	1497	(.2401)
	Asbestos phenolic	3	(.010)	1473	(92)	1843	(.44)	1347	(.2160)
	Silica phenolic	4.9	(.0162)	1473	(92)	880	(.21)	898	(.1440)
Radiation shield	Aluminum	.3 6.4	(.0010) (.021)	2659	(166)	896	(.214)	729,547	(117)
Rate gyro	Aluminum			2659	(166)	896	(.214)	729,547	(117)
Antares Motor									
Skin	Cork	1.28	(.0042)	480	(30)	1969	(.47)	156	(.025)
	Spiralloy	3.9	(.0128)	1986	(124)	1047	(.25)	1247	(.200)
	Insulation	4.4	(.0146)	1794	(112)	1437	(.343)	823	(.132)
Propellant	(Rubber base)	264.4	(.8675)	1794	(112)	1248	(.298)	1640	(.263)
Lower "D" Section									
Skin	Cork	1.3	(.0042)	480	(30)	1969	(.47)	156	(.025)
	Steel	1.3	(.0042)	7849	(490)	544	(.13)	46,142	(7.4)
Altair Motor									
Skin	Spiralloy	2.0	(.0067)	1986	(124)	1047	(.25)	1247	(.200)
	Insulation	1.3	(.0042)	1794	(112)	1437	(.343)	823	(.132)
	Liner	.5	(.00167)	961	(60)	1437	(.343)	823	(.132)
Propellant	(Rubber base)	135.6	(.445)	1794	(112)	1248	(.298)	1640	(.263)
"E" and Upper "D" Section									
Skin	Magnesium	2.0	(.0067)	1810	(113)	1005	(.24)	236,947	(38.)

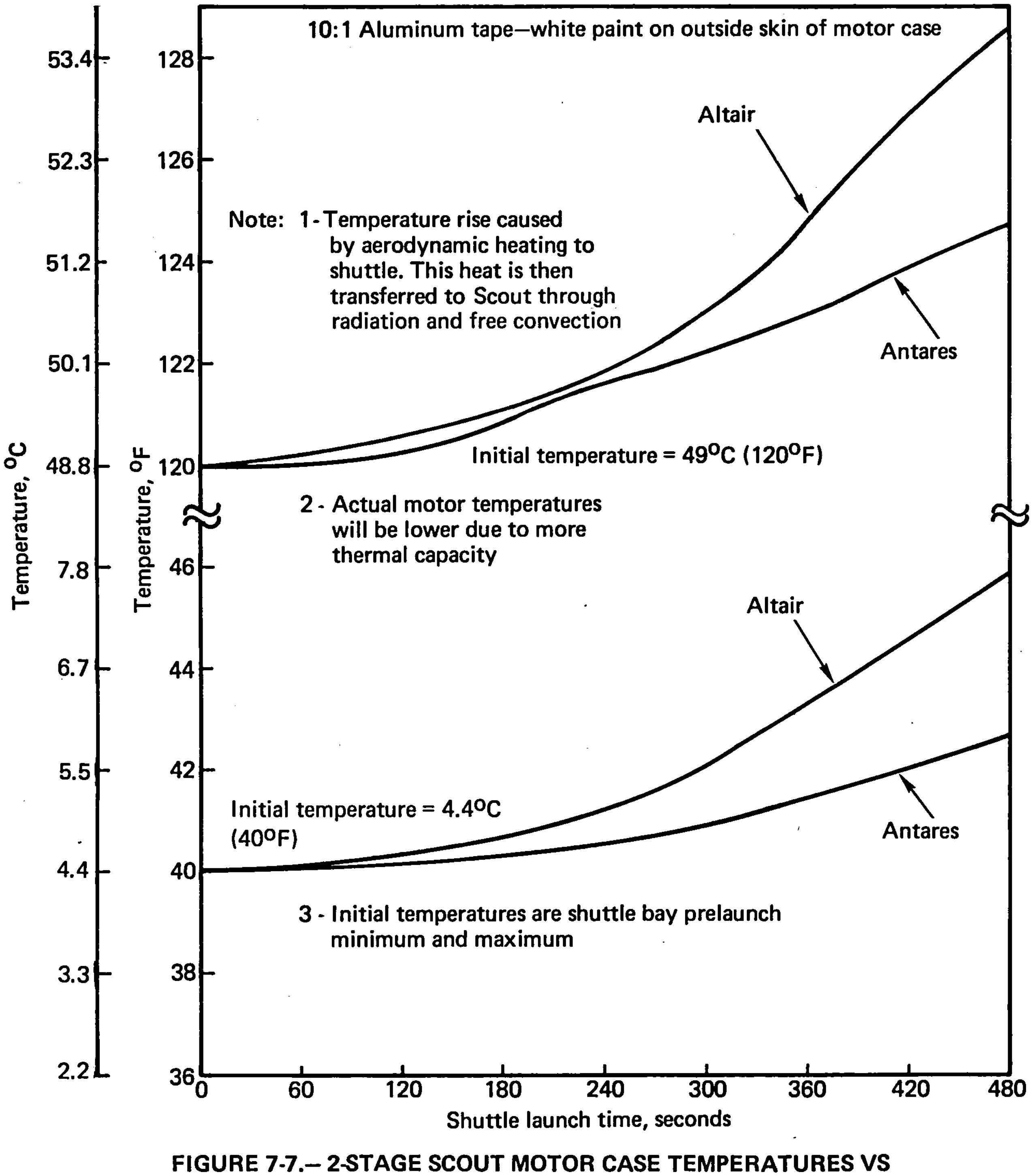


FIGURE 7-7.— 2-STAGE SCOUT MOTOR CASE TEMPERATURES VS SHUTTLE LAUNCH TIME

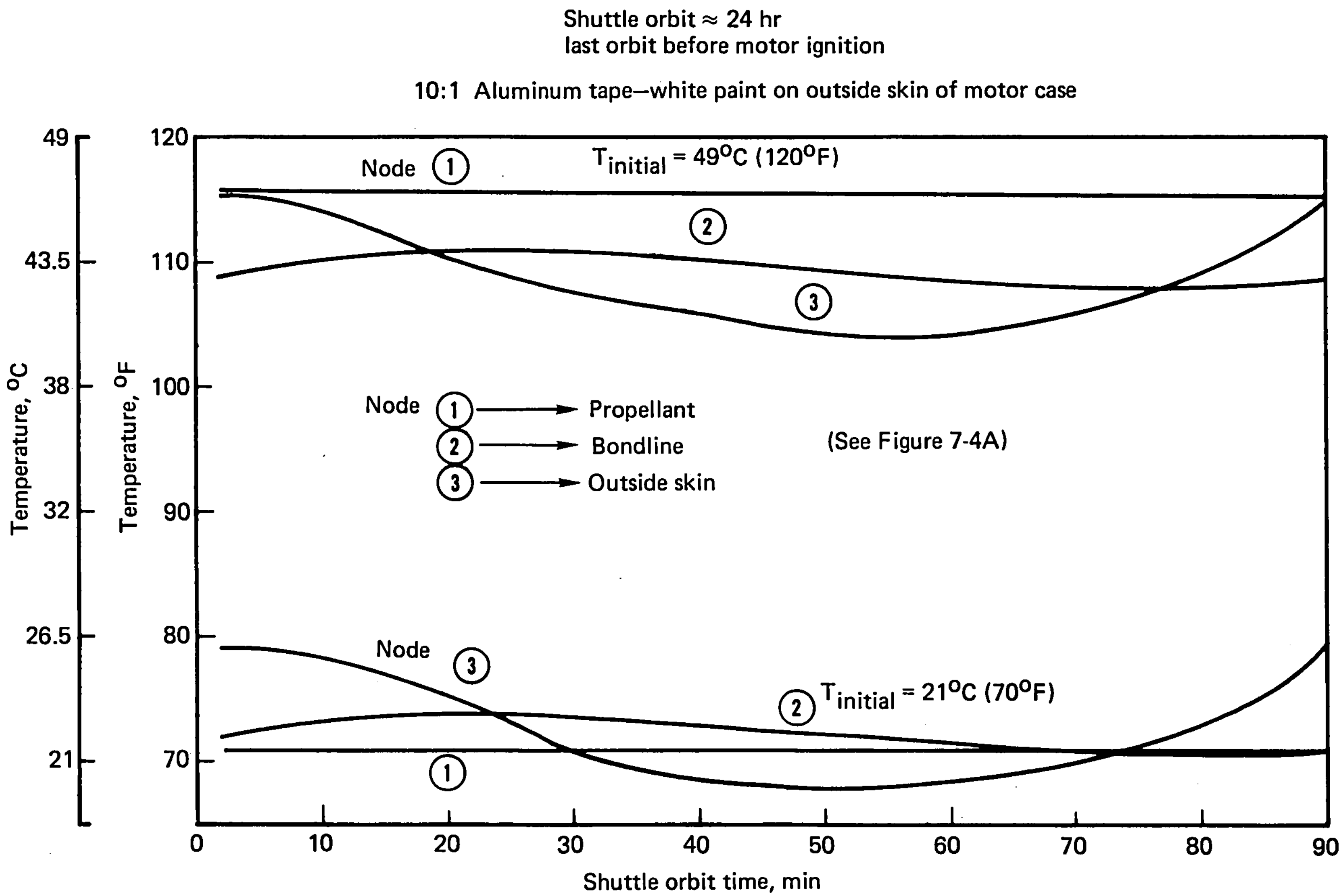


FIGURE 7-8.– ANTARES MOTOR NODAL TEMPERATURES VS SHUTTLE ORBIT TIME

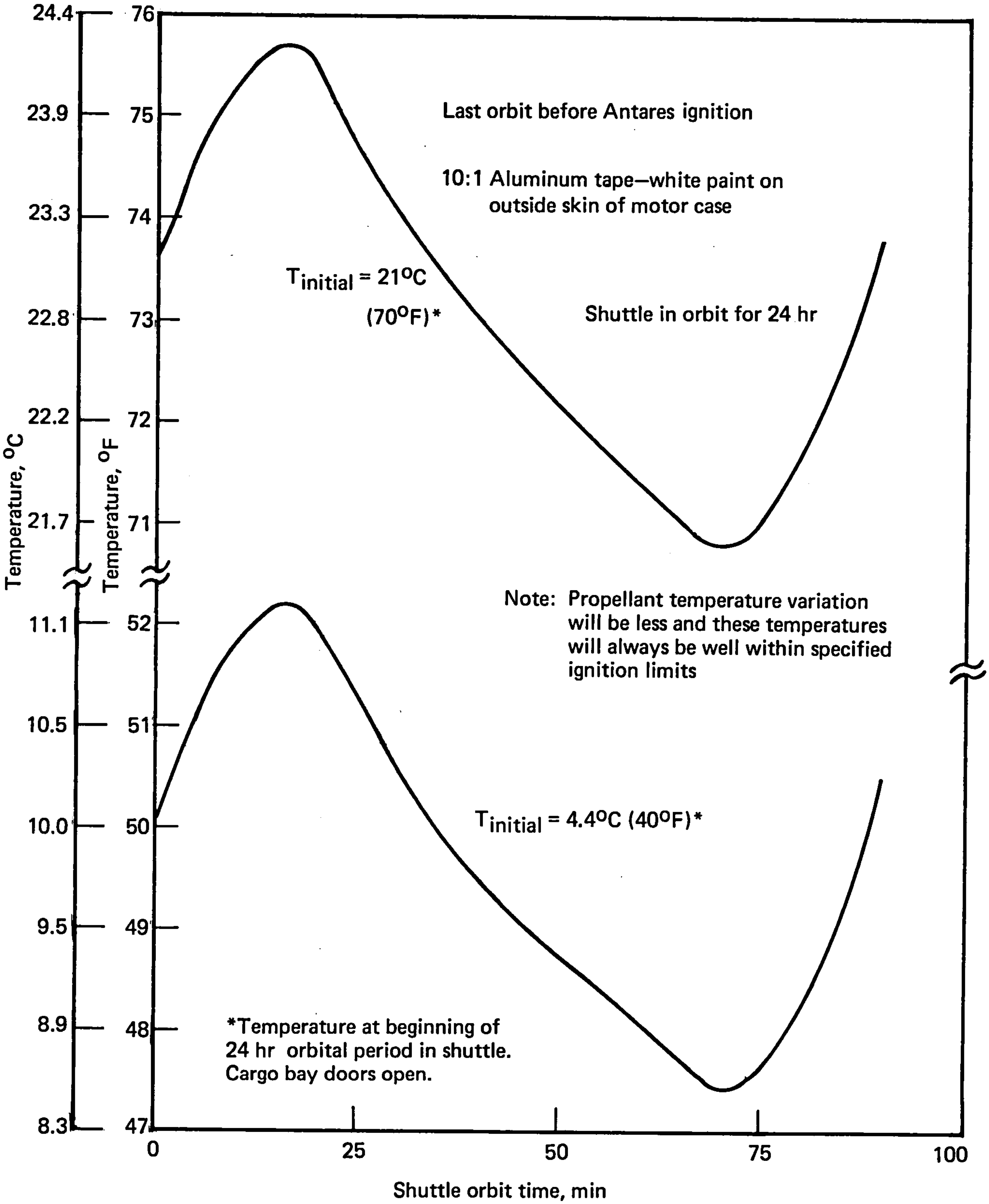


FIGURE 7-9.– ALTAIR BONDLINE (NODE 2) TEMPERATURE VS SHUTTLE ORBIT TIME

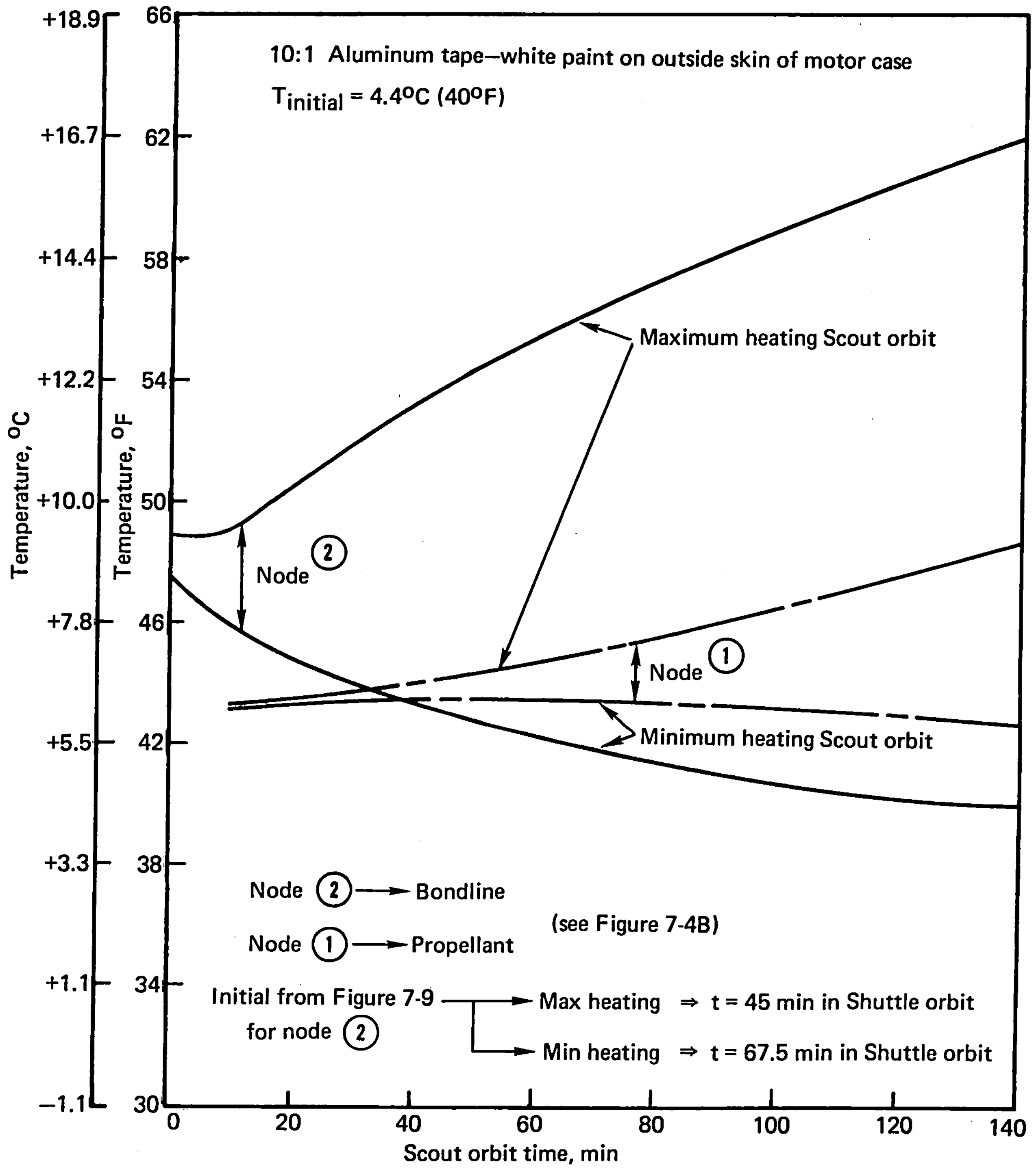


FIGURE 7-10.– ALTAIR PROPELLANT AND BONDLINE TEMPERATURE VS SCOUT ORBIT TIME

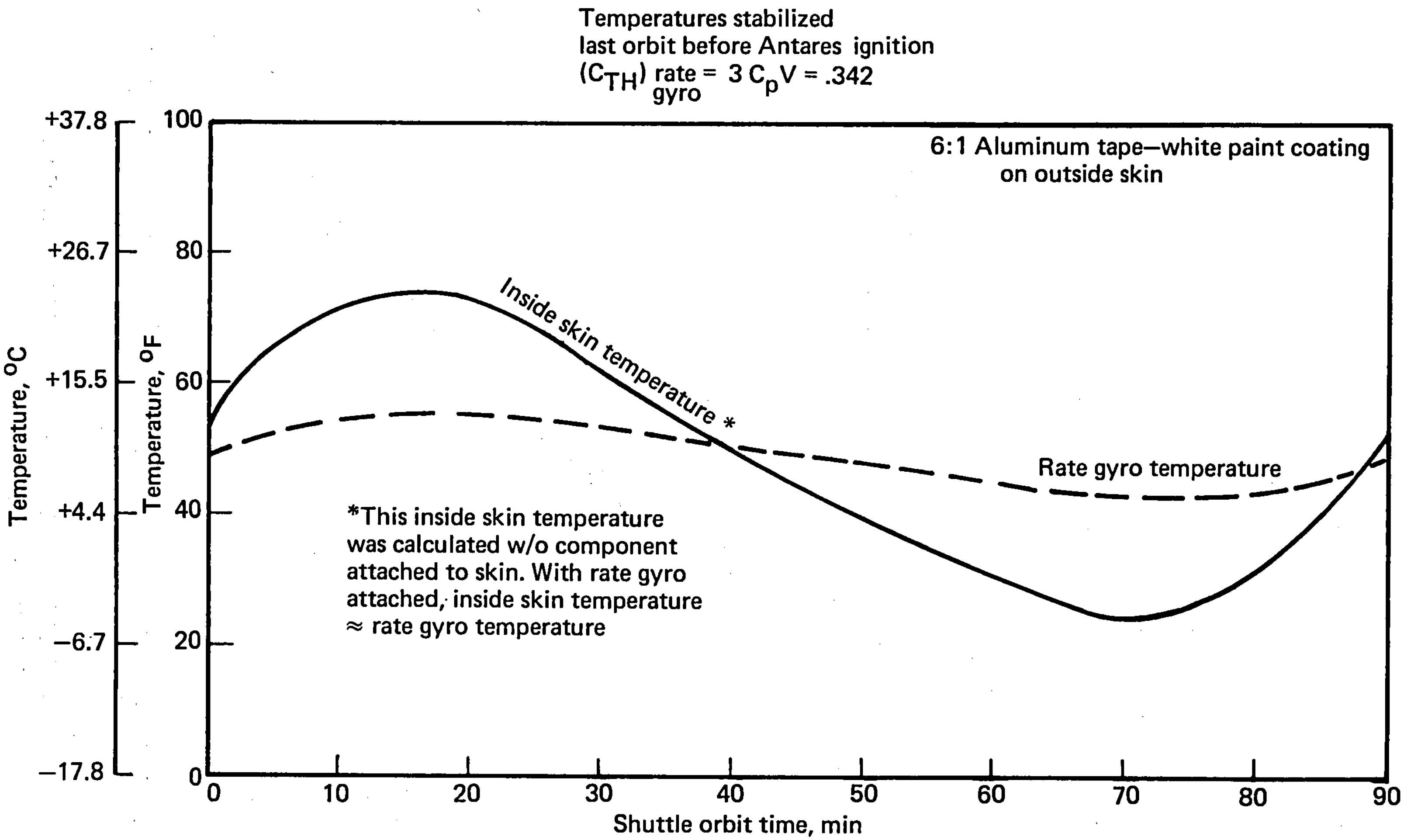


FIGURE 7-11.– UPPER "C" TEMPERATURE VS SHUTTLE ORBIT TIME

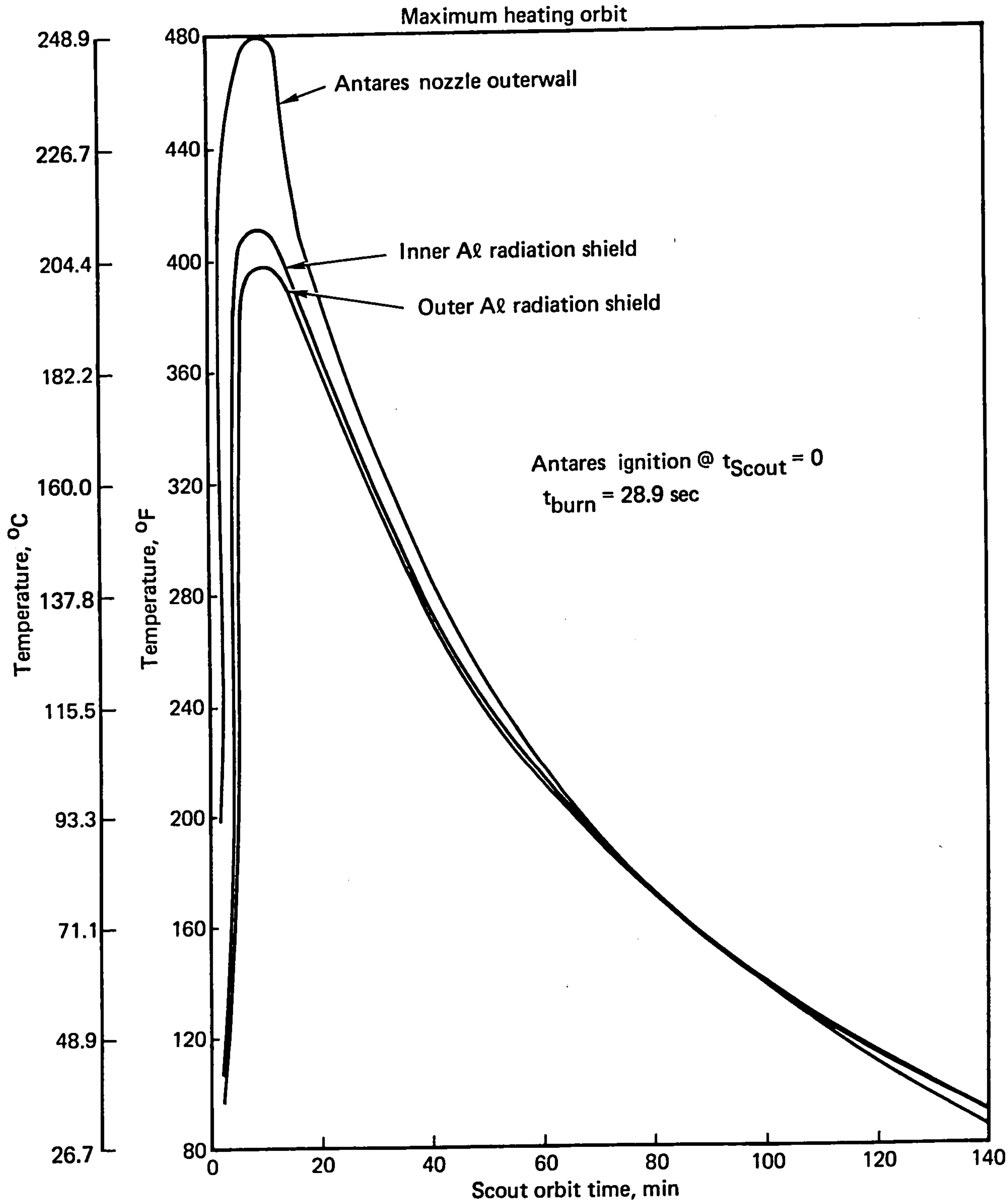


FIGURE 7-12.– ANTARES NOZZLE & SHROUD TEMPERATURES VS SCOUT ORBIT TIME

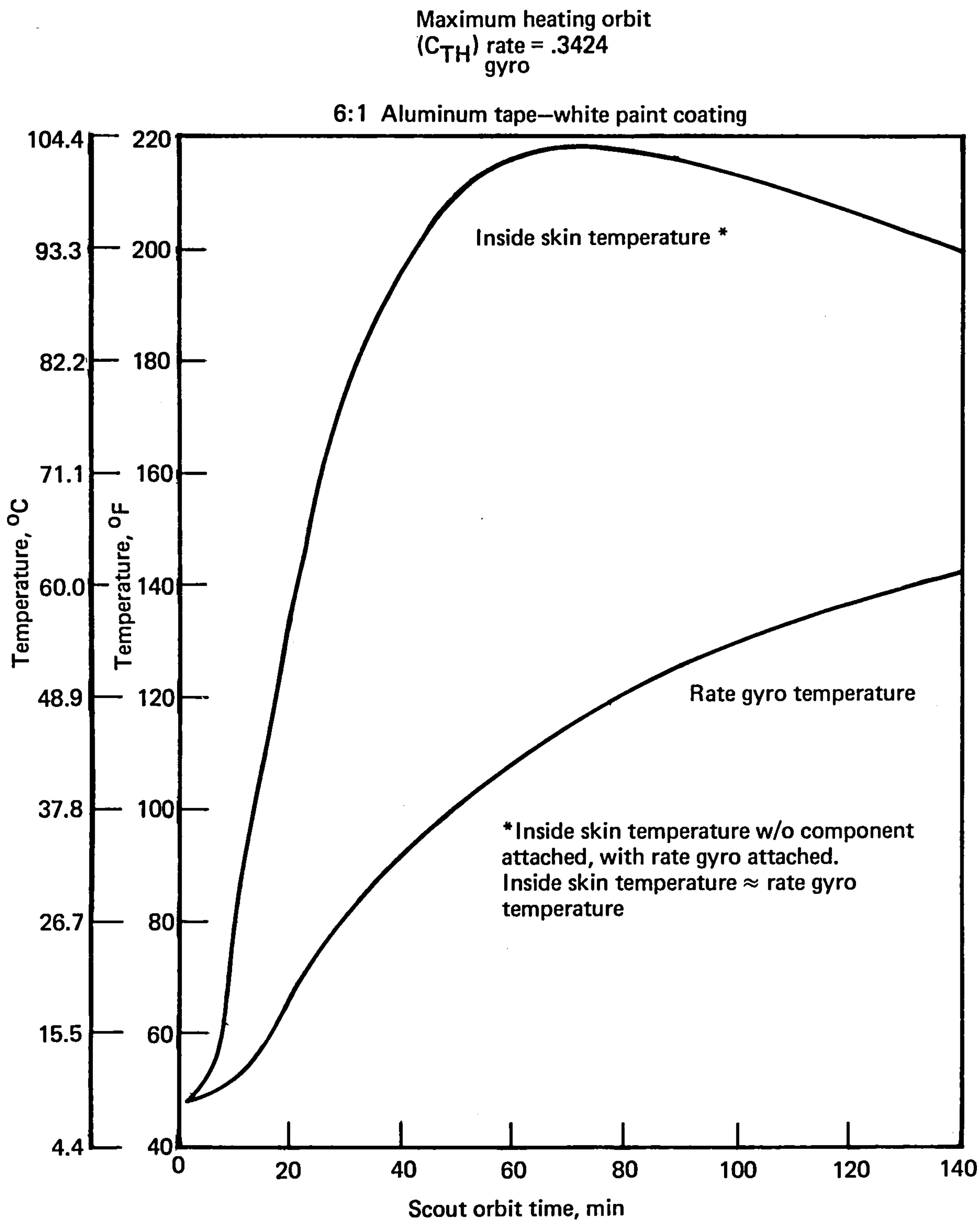


FIGURE 7-13.— UPPER "C" TEMPERATURE VS SCOUT ORBIT TIME — MAXIMUM HEATING ORBIT

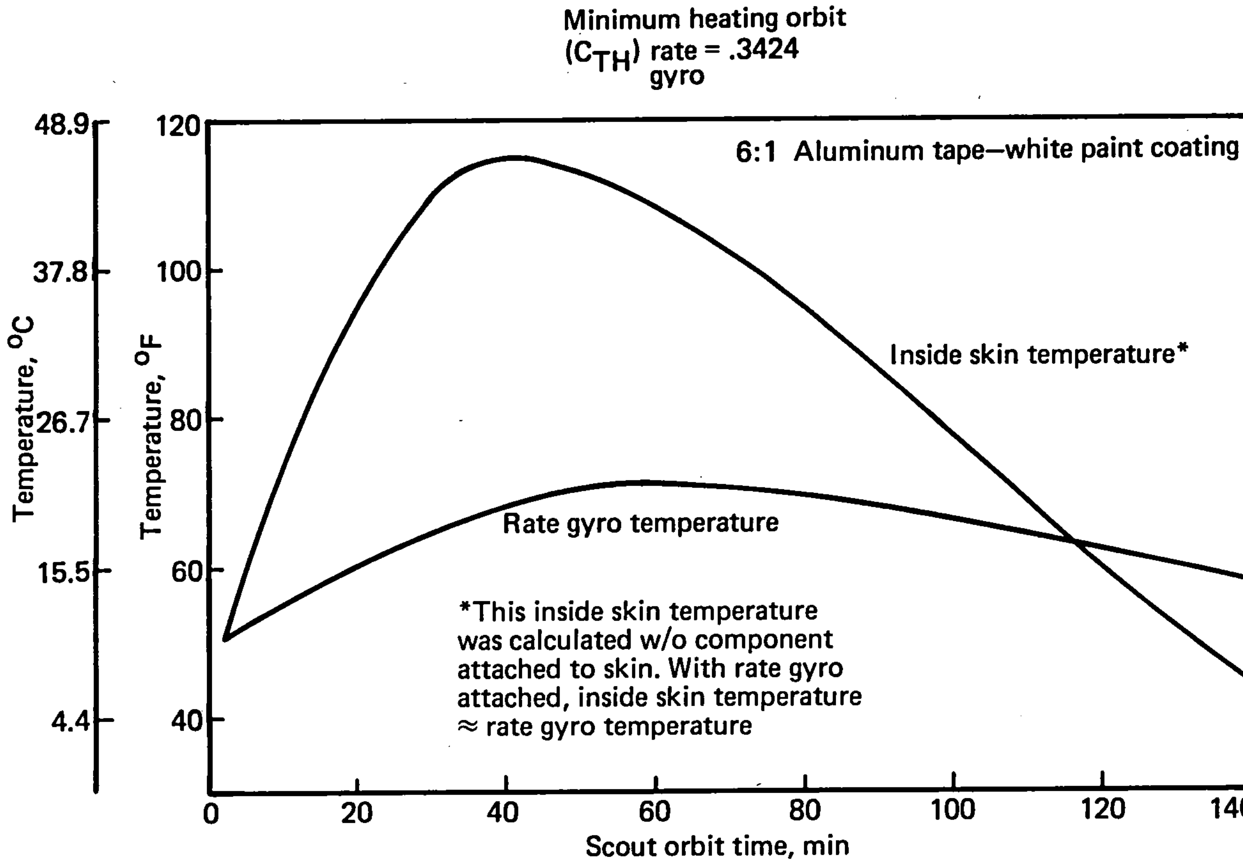


FIGURE 7-14.— UPPER "C" TEMPERATURE VS SCOUT ORBIT TIME — MINIMUM HEATING ORBIT

The "D" and "E" Section outside skins wrapped with 7-layer superinsulation were analyzed to determine their thermal characteristics. Superinsulation was used for these sections rather than tape and paint because of the section material's rapid response to temperature change. The rocket motors and the Upper "C" Section with the motor nozzle did not require this type of insulation because of their much slower response to change in solar environments. Figures 7–15 and 7–16 show the results of the "D"and "E" Section thermal analyses. Figure 7–15 indicates the inside skin temperature variation as a function of orbit time for the maximum heating Scout orbit while Figure 7–16 illustrates the same for the minimum heating orbit. It should be noted that the skin coating called out for Upper "D" section may be conservative. Superinsulation was used to protect the Altair nozzle because of the long (2.4 hour) exposure to deep space environment during the coast phase between Antares burn-out and Altair ignition.

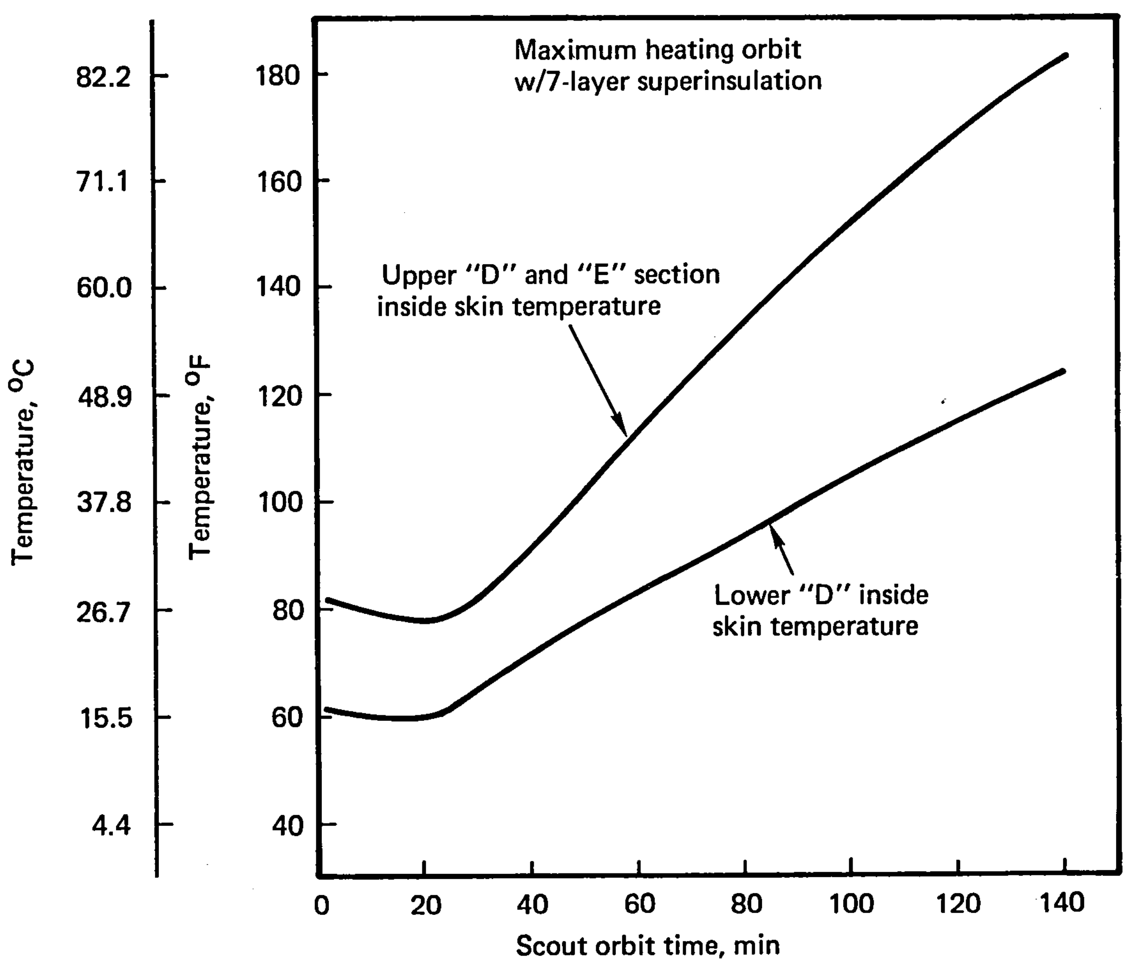


FIGURE 7-15.– "D" AND "E" SECTION TEMPERATURES VS SCOUT ORBIT TIME – MAXIMUM HEATING ORBIT

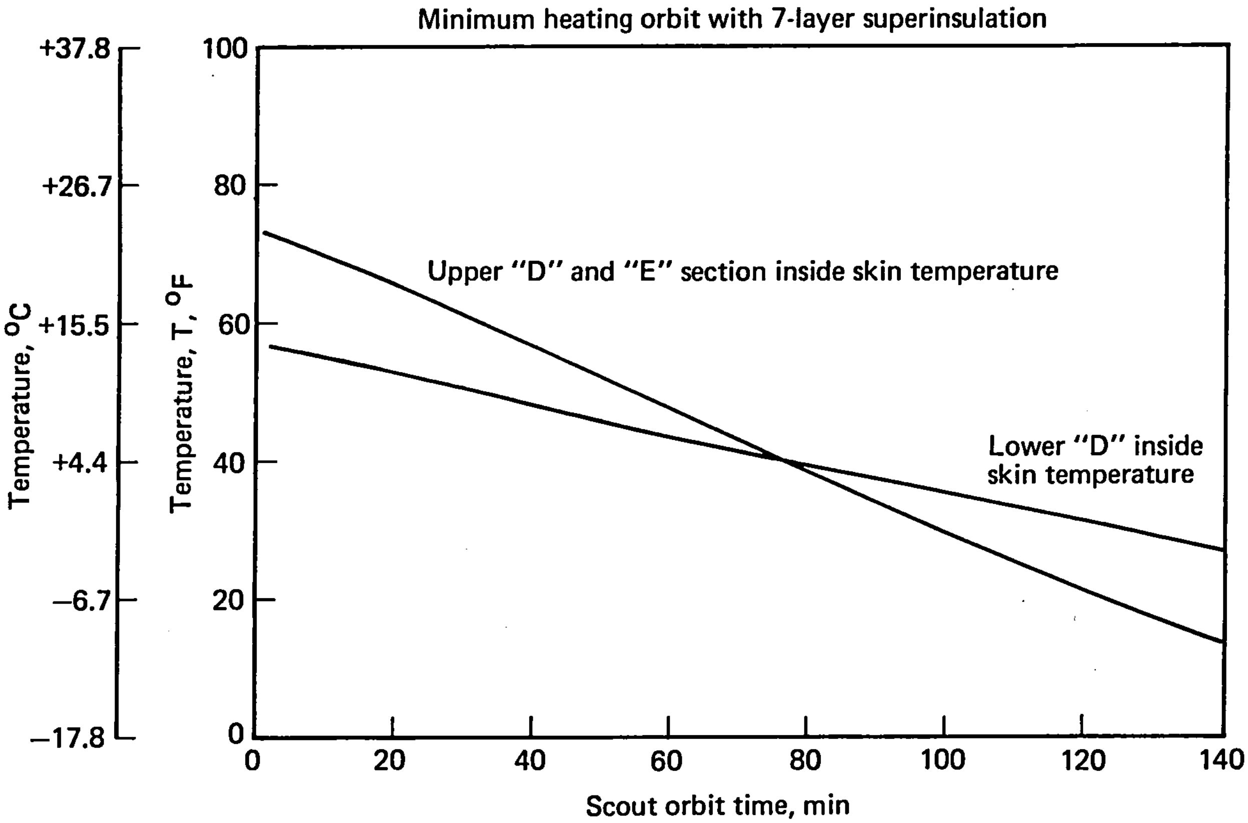


FIGURE 7-16.– "D" AND "E" SECTION TEMPERATURES VS SCOUT ORBIT TIME – MINIMUM HEATING ORBIT

The predicted temperatures of each vehicle section, insulated as recommended in this study, are compared with allowable temperature limits of the components within that section, Table 7–V. The component temperature limits are qualification levels except for the two motors which are restricted by the allowable propellant temperatures for proper ignition. This comparison shows that the allowable temperature limits are exceeded only in Upper "C" Section skin, without an attached component, in the maximum heating mission. The Upper "C" Section, condition can be corrected by (1) flying the minimum heating orbit or (2) reducing the 6:1 ratio of aluminum tape to white paint to reduce the heat absorption of the section. Consequently, it is concluded that the Scout upper stages can endure the thermal environment of a Shuttle launched mission.

TABLE 7–V.– SUMMARY OF THERMAL ANALYSES

Vehicle Section / Component	Component Temperature Limits °C (°F)		Predicted Temperatures in Vehicle Sections °C (°F)					
			Shuttle orbit (24 hr after launch)		Scout orbit			
					Minimum heating orbit		Maximum heating orbit	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Upper "C" section								
Rate gyro	−17.7 (0)	71.1 (160)	Skin only		Skin only		Skin only	
Thruster valves	− 6.7 (20)	71.1 (160)	− 4.4 (24)	23.3 (74)	6.7 (44)	46.1 (115)	9.4 (49)	103.3 (218)
Relief valves	−17.7 (0)	71.1 (160)						
Quick disconnects	−17.7 (0)	135.0 (275)	With component		With component		With component	
H_2O_2 tanks	− 6.7 (20)	71.1 (160)	Attached to skin		Attached to skin		Attached to skin	
H_2O_2	4.4 (40)	71.1 (160)	6.1 (43)	13.3 (56)	10.0 (50)	21.7 (71)	9.4 (49)	61.1 (142)
Pressure regulator	−12.2 (10)	80.0 (176)						
Lower "D" section								
Poppet valve elect.	−17.7 (0)	71.1 (160)	13.9 (57)	16.1 (61)	− 2.8 (27)	13.9 (57)	15.0 (59)	51.1 (124)
Inertial ref. unit	−17.7 (0)	62.8 (145)						
Guidance battery	−17.7 (0)	73.8 (165)						
Altair skin								
4th stage T/M xmtr	−17.7 (0)	80.0 (176)	8.3 (47)	11.1 (52)	3.9 (39)	8.9 (48)	9.4 (49)	16.7 (62)
Motor propellant								
Antares	10.0 (50)	32.2 (90)	22.2 (72)	22.2 (72)	N/A	N/A	N/A	N/A
Altair	4.4 (40)	37.8 (100)	6.1 (43)	6.1 (43)	6.1 (43)	6.1 (43)	6.1 (43)	8.9 (48)

Note: Predicted temperatures are based on pre-launch temperature of 4.4°C (40°F) in payload bay except for Antares propellant which is assumed to have initial temperature of 21.1°C (70°F) because of ignition temperature restriction.

8.0 CONCLUSIONS AND RECOMMENDATIONS

From the results of the structural dynamic, meteoroid damage, and thermal analyses discussed in the previous sections the following conclusions and recommendations are made.

(1) The low frequency response characteristics of the pallet to the Space Shuttle mounting system provide significant attenuation of vibration and shock inputs from the Space Shuttle. Vibration isolators will not be effective in further reducing the loads imposed on the Scout vehicle. Therefore, it is recommended that the Scout upper stages and payload be retained in a support pallet of tubular construction with rigid bulkheads at each clamping point. The clamping points are required to be at the aft end of the Upper "C" Section, each end of the Antares motor chamber, the aft end of the Altair motor chamber, and the aft end of the payload or the forward end of the Altair motor chamber. The payload requires at least one clamp. Recommended clamping points are shown in Figure 1-2.

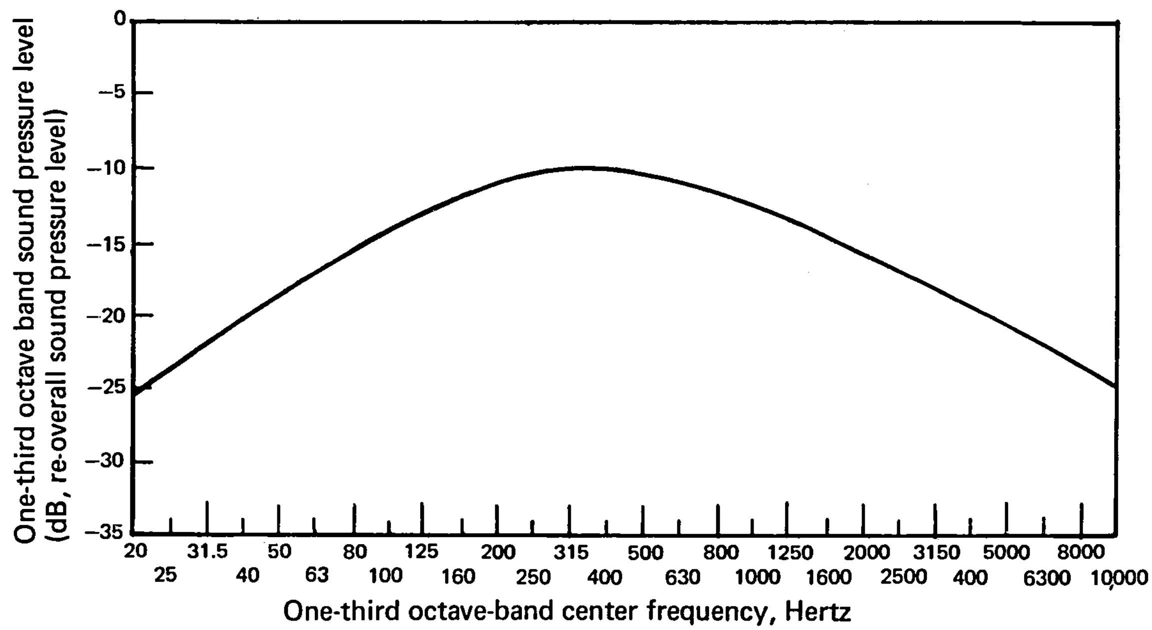
The pallet requires retention in the payload bay of the Space Shuttle by a five point attach. At the aft end of the Antares motor chamber, the pallet is fixed to the Space Shuttle payload bay longerons to react up and down loads as well as fore and aft loads. Also at the same station, the pallet is attached to the Space Shuttle payload bay keel to react side loads. The forward end of the pallet is fixed to the longerons to react the up and down loads.

(2) Lateral spectral density response at 19 Hz of the Scout "D" and "E" sections to the Shuttle random vibration spectrum was higher than the current Scout 95% confidence limits at that frequency. Based on previous experience with similar structures, it is concluded that addition of vibration isolators would not be effective in reducing this acceleration level. At all other locations the response levels were well below the Scout limits, It is concluded that the response at 19 Hz does not present a problem to the structural integrity or reliability of any component. However, to ensure the validity of this conclusion, it is recommended that the random vibration test spectrum defined for the Scout Standard Environmental Test be expanded to include the frequency range 10–20 Hz when applied to components of the Space Shuttle launched Scout upper stages.

(3) All response loads imposed on the Scout stages are within the present design limits except in the E Section (Station 47.8). A redesign of the section will be necessary.

(4) The sinusoidal test spectrum defined for the Shuttle aborted-mode handling condition is considered unrealistic when applied to heavy structural elements. The sinusoidal vibration should not be considered as part of the dynamic environment imposed by the Shuttle mission.

(5) The acoustical noise level of the Space Shuttle bay is higher than the present land launched Scout. However, the difference in level offers a minimal risk to the Scout upper stages vehicle. It is recommended that the risk be eliminated by performing acoustical qualification test on the Scout upper stages assembled vehicle to the spectrum given in Figure 8–1 with an appropriate safety factor to establish the test levels.



145 dB(re20μN/m^2) for 1 min

FIGURE 8-1.– SPECTRUM TO BE USED IN SCOUT ACOUSTICAL TESTS

(6) The micrometeoroid analysis yielded an assessed damage probability of .00364 (99.64% probability of no damage). This is on the rocket motor cases only and without any thermal protection. It is concluded that this probability is sufficiently small that it is of no consequence. It is recommended that this environment be neglected since the addition of thermal protection will further enhance the Scout upper stages survivability.

(7) For the Antares motor with an outside motor case coating of a ten to one ratio of aluminum tape to white paint, the bondline and propellant temperatures, for a prelaunch temperature of 49°C (120°F) will not be cooled to meet the upper firing limit temperature of 32°C (90°F). Therefore, it is recommended that ground controls maintain the prelaunch Shuttle bay temperature between 10°C and 32°C (50° to 90°F) to assure an Antares motor will remain within specified ignition temperature limits.

(8) For the Altair, with an outside motor case coating of a ten to one ratio of aluminum tape to white paint, the bondline and propellant temperatures will lie well within the firing limits of the motor for all mission conditions.

(9) It is concluded that the present thermal protection used on the rate gyro unit is adequate. No further thermal insulation is required.

(10) Upper "C" Section covered with .13 cm (.05 inch) cork coated with a six to one ratio of aluminum tape to white paint will maintain temperatures within operating ranges of the components. It is therefore recommended that this method of thermal protection be used.

(11) "D" and "E" Section outside skins wrapped with seven layer superinsulation will maintain temperatures within operating ranges of the components. It is recommended that this method of thermal protection be utilized.

With the completion of the design to incorporate these recommendations, the Scout upper stages will endure the environments imposed by the Space Shuttle mission.

UPDATING OF SHUTTLE PAYLOAD BAY ENVIRONMENTAL CONDITIONS

At the completion of Task II, Compilation of Environmental Conditions in the Shuttle, Change 13 was the latest revision to Reference 2. Subsequently, six more changes have been issued, with the most recent, Change 19, being released on 2 December 1976. This appendix will update the results of Task II to include the data through Change 19. These data could not be included in the study; however, in most cases, the revised data are less severe than used in the study so that the conclusions and recommendations are still valid. The referenced paragraph numbers are from Reference 2.

1. Electromagnetic Interference (EMI), paragraph 4.2.2.8.

   In Change 13, EMI was TBD and was subsequently defined in Change 18, released on 14 October 1976. A cursory review indicates no problems are anticipated.

2. Pressure Altitude, paragraph 4.2.2.1

   Figure 4–2, 4–3, and 4–4 were revised by Change 16 but the revisions have no effect on the results of this study.

3. Acceleration crash loads, paragraph 7.6.1

   Table 7–13 was added by Change 19 and revised the emergency landing design load factors in the + X direction from 9 g (Change 13) to 4.5 g (Change 19). The results of the study are still valid.

4. Ground Purge, paragraph 4.2.1.2.

   Change 13 stated that the ground air purge temperature is selectable over a range of 7.2° – 48.8°C (45 – 120°F). Change 18 revised the limits to 7.2 – 37.8°C (45 – 100°F). The results of the study are still valid.

REFERENCES

1. Scout/Shuttle Integration Study Final Report, NASA CR-121173, April 1973.

2. Space Shuttle Systems Payload Accommodations, JSC Report .07700, Volume XIV, Revision D, Change 13, 22 December 1975.

3. Micrometeoroid Environment Model (Near Earth to Lunar Surface), NASA SP-8013, March 1969.

4. Orbital Mechanics of Satellites, Article from Proceedings of the American Astronautical Society Western Region Meeting by G. S. Gedeon, 1958.

5. An Introduction to Celestial Mechanics, F. R. Moulton, MacMillan Company, N. Y., 2nd Edition, 1914.

6. Customer Utilization Instructions — Program Heat II, Computer Technology, Inc., April 1963.

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15. Supplementary Notes

Langley Technical Monitor: Thomas L. Owens

Final Report

16. Abstract

A study was conducted to determine the requirements for enabling the Scout upper stages to endure the expected temperature, mechanical shock, acoustical and mechanical vibration environments during a specified Shuttle mission. The study consisted of: determining a Shuttle mission trajectory for a 545 kilogram (1200 pound) Scout payload; compilation of Shuttle environmental conditions; determining of Scout upper stages environments in Shuttle missions; compilation of Scout upper stages environmental qualification criteria and comparison to Shuttle mission expected environments; and recommendations for enabling Scout upper stages to endure the expected Shuttle mission environments.

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