NSTS 07700, Volume XIV,

Appendix 2

System Description and Design Data -

Thermal

DESCRIPTION OF CHANGES TO

SYSTEM DESCRIPTION AND DESIGN DATA - THERMAL
NSTS 07700, VOLUME XIV, APPENDIX 2

CHANGE NO.	DESCRIPTION/AUTHORITY	DATE	PAGES AFFECTED
REV J	Complete revision; replaces and supersedes the thermal sections to Revision I of NSTS 07700, Volume XIV (reference CR D07700-014-002-01). The following CR's are included: D07700-014-002-02, D07700-014-002-03, D07700-014-002-04.	02/23/88	ALL
1	The following CR's are included: D07700-014-002-05, D07700-014-002-07, D07700-014-002-08.	6/14/89	1, 2-6, 3-1, 3-3
	Reformat Word for Windows.	7/96	ALL
REV K	Complete revision; replaces and supercedes the thermal sections to Revision J of NSTS 00770, Volume XIV. The following CR is included: D07700-014-002-0014	06/22/00	ALL
1	The following CR is included: DO7700-014-002-0015	09/27/00	Preface

Preface

This document is designed to be used in conjunction with the series of documents illustrated in 1. Information on the thermal accommodations available in the Orbiter payload bay and cabin is presented herein.

Specific agreements for thermal design must be specified in the individual payload integration plans.

Effective with the publication of this revision, configuration control of this document will be accomplished through the application of the procedures contained in NSTS 07700, Vol. IV, Configuration Management Requirements.

Questions and recommendations concerning this document should be addressed to:

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Space Shuttle Program

NSTS 07700 VOLUME XIV
SPACE SHUTTLE SYSTEM PAYLOAD ACCOMMODATIONS

NSTS 21492 PAYLOAD BAY
PAYLOAD USER'S GUIDE

SAFETY
- 45 SPW HB S-100/KHB 1700.7
- NSTS 1700.7B
- NSTS/ISS 13830C
- NSTS 14046
- NSTS 16879
- NSTS/ISS 18798
- NSTS 22648

SHUTTLE/PAYLOAD
STANDARD INTEGRATION
PLANS (SIP's)

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NSTS 21000-SIP-ATT
ATTACHED PAYLOADS

NSTS 21000-SIP-DRP
DEPLOYABLE/RETRIEVABLE
PAYLOADS

NSTS 21000-SIP-GAS
GET AWAY SPECIAL
PAYLOADS

NSTS 21000-SIP-MDK
MIDDECK PAYLOADS

NSTS 21000-SIP-ISS
INTERNATIONAL SPACE
STATION

ORBITER/PAYLOAD
INTERFACES

ICD 2-19001:
VOL. XIV,
ATTACHMENT 1 -
SHUTTLE
ORBITER/
CARGO STANDARD
INTERFACES

NSTS 21000-IDD-SML
SMALL PAYLOADS

NSTS 21000-IDD-ISS
INTERNATIONAL SPACE
STATION

NSTS 21000-IDD-MDK
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AND DESIGN DATA

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1.1 Scope

This document provides information for effective utilization of Space Shuttle thermal accommodations. The information provided will aid the customer in planning the design of the payload-to-Orbiter interfaces. Thermal accommodations consist of controlled thermal environments and heat rejection capability for the various mission phases when the payload is in the Orbiter. Actual thermal environments and heat rejection capability depend on payload mission, design, and thermal characteristics; and on the Orbiter's operational requirements, attitude hold capability, and thermal interactions with the payload.

Information on Space Shuttle thermal accommodations is provided in this document to aid the customer in the thermal design and analysis and in understanding the thermal integration process. This information should aid in ensuring that the payload will be thermally compatible with Orbiter thermal accommodations.

The customer is responsible for the payload thermal design consistent with Space Shuttle Program (SSP) requirements and for providing data to the SSP for use in conducting the compatibility assessment as shown in Figure 1-1. Also, payload thermal math models shall be provided to the SSP for use in conducting a thermal verification analysis/ assessment. The customer is responsible for providing payload thermal data for the Integration Plan (IP), IP annexes, and the Interface Control Document (ICD). The schedule for these activities is specified in the Standard Integration Plan.

The SSP role in the thermal integration process, as summarized in Figure 1-1, includes providing the documentation on SSP thermal requirements and accommodations. The SSP will supply Orbiter thermal math models to be used for payload thermal design analysis. The SSP and the customer will jointly develop the IP, IP annexes, and the ICD. As mentioned previously, the SSP will conduct a compatibility assessment prior to the Cargo Integration Review. The SSP will conduct a verification thermal analysis/ assessment to assure payload compatibility with the flight design.

1.2 Payload Thermal Design Considerations

In addition to the design considerations associated with completion of payload mission objectives, special considerations associated with Space Shuttle safety and mission compatibility are required.

The customer is responsible for investigating the effect of unplanned events that may occur to ensure that no thermal limit violations exist which could endanger the crew or compromise the flight during any mission phase. There are two types of considerations: design requirements for contingency operation and analyses defining limitations during contingency operations.

1) Contingency Design Requirements

   - Payloads must be designed to be thermally compatible with abort during any mission phase:

     During powered ascent, abort can occur as either a return to launch site (RTLS) or abort to an alternate landing site such as a transatlantic landing site. On-orbit aborts can occur prior to or subsequent to payload bay door opening. Prior to door opening, abort-once-around (AOA) represents the minimum orbit time while the maximum time depends on the orbit inclination. The payload bay doors are normally opened 1 to 1 1/4 hours after liftoff; however, customers must design

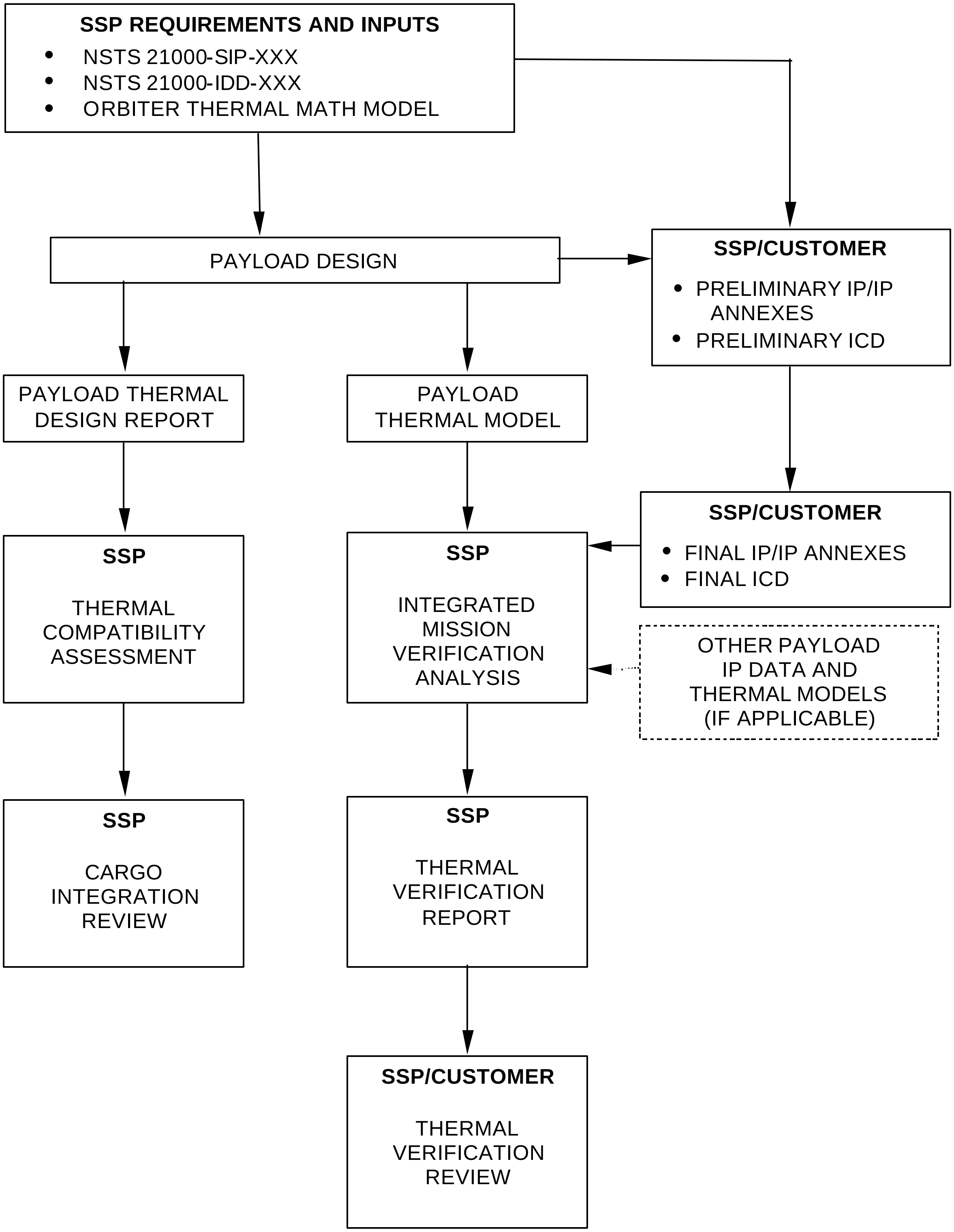


Figure 1-1.- SSP/payload thermal integration.

for a maximum time for door opening of 3 hours. If the doors are not opened by 3 hours, an abort will be declared and landing will occur by liftoff plus 6.5 hours for 28.5-degree inclination missions or 11.5 hours for 57-degree inclination. Following the 3-hour abort time, special Orbiter contingency operations may be required necessitating curtailment of standard payload services; i.e., power, cooling, etc. Following payload bay door opening, aborts can occur at any time; therefore, payloads must be compatible with an abort from the worst hot or cold condition that could be encountered for that particular mission.

- Payloads must be designed to not present a hazard to the Orbiter for flights ending at contingency landing sites; i.e., where ground services (such as payload bay purge or active cooling) are not available.

- Payloads using Orbiter-provided heat rejection provisions must be designed to not present a hazard to the Orbiter for reduced or loss of heat rejection.

- Payloads using Orbiter-provided electrical energy for thermal control must not present a hazard in the event of loss of power.

- Payloads must be designed to prevent a hazard in the event of a failed open Orbiter payload bay vent door during entry and in the event any Orbiter payload bay floodlight fails on.

2) Contingency Analyses Defining Limitations

Data must be provided to the SSP to support contingency planning:

- Long term (off nominal) exposure to worst hot or cold mission environments must be analyzed and temperature limits affecting safety must be identified.

- For deployable payloads, limitations associated with delay in the deployment sequence or restow of erectable spacecraft (if applicable) and delayed deployment must be identified and thermal recovery periods defined.

Additional contingencies may exist due to payload-peculiar characteristics and these contingencies as well as the contingencies noted above will be defined and documented in the applicable IP or IP annex.

Also, payload operational constraints associated with implementation of payload objectives should be established by conducting appropriate thermal analyses of the payload design.

Payloads which share flights with other payloads and utilize the standard accommodations (as defined in <u>ICD 2-19000, Shuttle Orbiter/Cargo Standard Interfaces</u> must incorporate into the payload design a minimum thermal capability common to all users of a particular flight. To ensure this mixed cargo compatibility, the SSP has defined a set of on-orbit Orbiter attitude requirements with which (as a minimum) all payloads sharing a flight must be compatible. All mixed payloads must be able to accommodate a selected attitude continuously; i.e., an attitude which can be maintained without interruption. For missions with beta angles (beta angle and Orbiter coordinate axis system are defined in Table 2-I) less than 60 degrees, the selected attitude is with the Orbiter payload bay continuously facing the Earth (+ZLV). For beta angles greater than 60 degrees, the selected attitude is specified as the Orbiter X-axis perpendicular to the solar vector within 20 degrees and rolling about the X-axis at a rate of two to five revolutions per hour. (This attitude is called passive thermal control, or PTC.) The continuous attitude will be maintained during Orbiter crew sleep periods as well as long duration coast periods such as between deployment opportunities for deployable spacecraft. Short term deviations from the continuous attitude are required to allow for the deployment of deployable spacecraft. As a minimum, all mixed payloads are required to be able to incur 30 minutes of Orbiter +Z-axis directed toward the sun, as well as 90 minutes of +Z-axis directed toward deep space. Thermal recovery from the short term solar or deep space attitudes will be made in the applicable continuous attitudes; i.e., +ZLV or PTC.

It should be recognized that the Orbiter has, in general, considerably greater attitude capability than has been required of mixed payloads. For this reason, on mixed payload missions, deployable payload airborne support equipment (ASE - equipment remaining in the payload bay after deployment) is required to have attitude capability equivalent to that of the Orbiter. ASE that does not constrain Orbiter attitudes allows for manifesting deployable-type payloads with nondeployable types, performing the deployments in the early mission phase, and thus subsequently having the ability to accommodate attitudes required for nondeployable payloads. Nondeployable requirements are generally more demanding than required by deployable payloads. Similarly, nondeployable payloads must have, as a minimum, the capability to accommodate the mixed payload criteria in order to not constrain requirements of deployable payloads. SSP experience has shown that mission objectives associated with deployment attitude requirements have been satisfied by use of the preceding mixed cargo criteria.

For mixed cargo missions, the SSP is responsible for determination of actual payload location in the payload bay and for determination of the order of deployment of deployable payloads. Payload thermal design must provide for these considerations. If a payload is particularly sensitive to being located immediately adjacent to a bulkhead or another large payload, consideration for this must be given in the design. Similarly, thermal design for deployable payloads must not assume first-day deployment. Attention to these considerations will maximize manifesting opportunities.

For mixed cargo missions, the specific Orbiter attitude constraints consistent with SSP and payload requirements will be agreed to and documented in the applicable payload IP. These attitude requirements will be used in determining compatible manifests and will be included in planning the mission attitude timeline. The resulting nominal mission profile will then be used by the SSP for the integrated mission verification analyses as shown in Figure 1-1.

For dedicated payload missions (i.e., nonmixed payloads) specific attitude constraints consistent with the Orbiter attitude hold capability as defined in ICD 2-19001 will generally be acceptable; however, analysis must provide sufficient data to plan for contingencies. Specific thermal attitude constraints will be agreed to and documented in the applicable payload IP and will be included in planning the mission attitude timeline. The nominal mission profile then will be used by the SSP for conduct of the integrated mission verification analyses as shown in Figure 1-1.

Small payloads utilizing the requirements in Shuttle/Payload Interface Definition Document for Small Payload Accommodations, NSTS 21000-IDD-SML, and Get Away Special (GAS) payloads are required to have thermal attitude capability equivalent to the Orbiter and thereby not present mission attitude constraints to the primary payloads.

Payload Bay Thermal Accommodations

2

2.1 Thermal Control Interfaces

This section provides supplemental information to further aid the customer in establishing a payload thermal design compatible with the Orbiter and the expected thermal environments.

2.1.1 Payload Bay Wall Temperatures

Payload bay wall temperature ranges (Figure 2-1) for various mission phases given in ICD 2-19001, apply to many payloads and mission conditions. Actual temperatures are expected to fall between these extremes and depend upon payload design, thermal characteristics, and flight conditions. During the prelaunch and ascent phases when the payload bay doors are closed, temperatures are relatively moderate. After the Orbiter reaches orbit and the payload bay doors are opened, temperatures can vary over a wide range, depending on flight attitudes and the payload/cargo configuration.

Significant solar entrapment may occur on orbit when there is direct solar radiation into the payload bay and the gap between the cargo and the payload bay surface or adjacent payload is small. This phenomenon is illustrated in Figure 2-2, which is based on an integrated thermal analysis of the Spacelab module and pallet cargo. Local temperatures can approach 324 degrees F and exceed the 200 degrees F maximum reached in the empty payload bay case (as specified in the IDD).

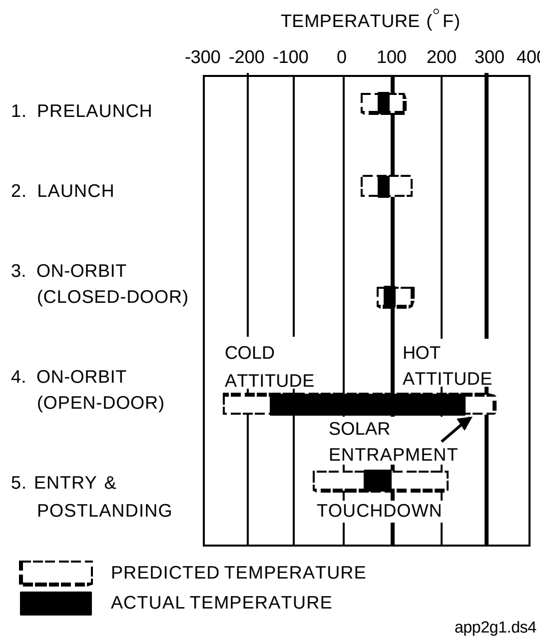


Figure 2-1.- Payload bay temperatures.

Another situation which can result in excessive high temperature is the “greenhouse effect” that can occur when material (such as beta cloth) which transmits solar energy is used on the payload surface and is exposed to direct solar radiation. Solar energy is transmitted through the beta cloth or similar material and is trapped, thereby creating relatively high temperatures.

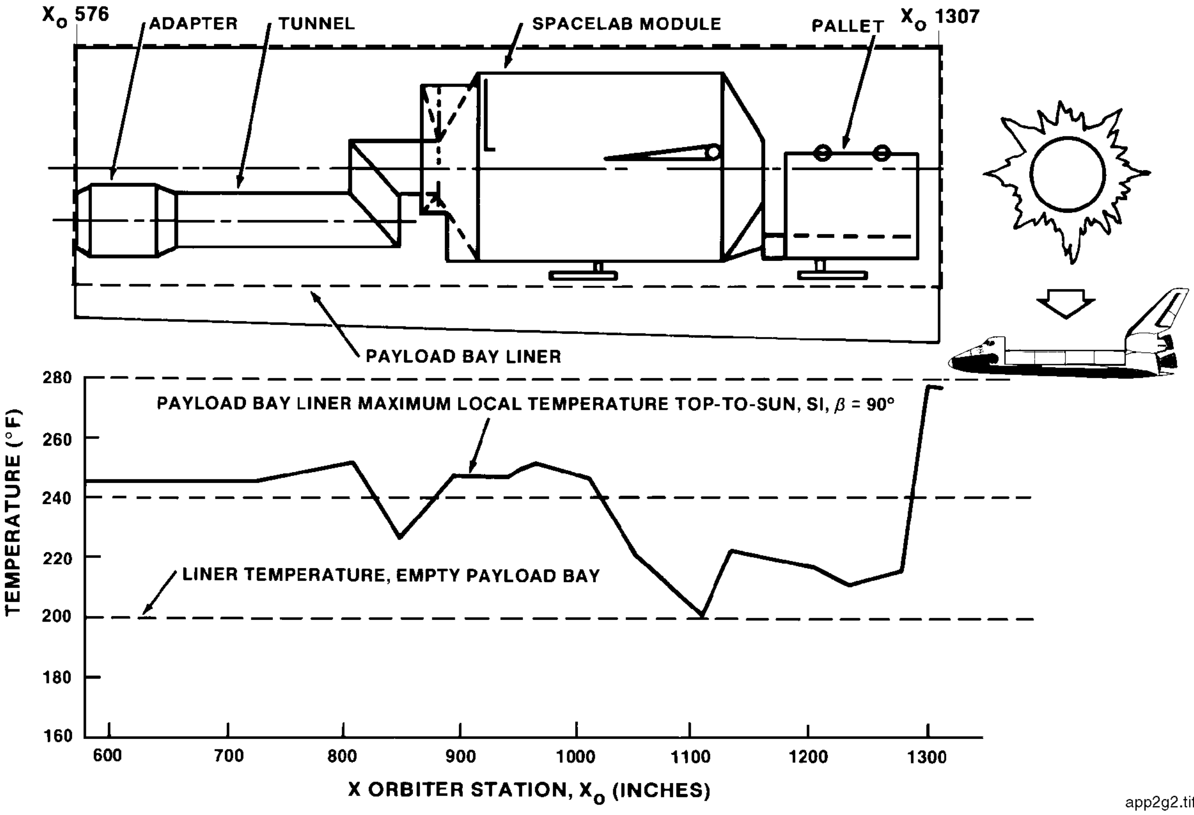


Figure 2-2.- Payload bay linear temperature with solar entrapment.

The temperature ranges given in ICD 2-19001 and reproduced in Figure 2-1 can be used to estimate the payload bay thermal environment to initiate the payload thermal design. Table 2-I can be used for estimating the payload bay thermal environment on orbit when the payload bay doors are open. It gives analytical predictions of steady-state liner temperatures for various flight attitudes and beta angles. The influence of a payload in the bay on payload bay liner temperatures should be noted. The payload bay liner is assumed to be insulated and the cylindrical payload is assumed to be adiabatic.

Empty payload bay liner temperatures can be used in the thermal design for payload diameters up to 90 inches (for a payload whose centerline coincides with the longitudinal axis (X- axis) of the payload bay). For payload diameters between 90 and 120 inches, liner temperatures can be estimated by interpolating between the empty payload bay temperature and the temperature with cylindrical payload in the payload bay.

During entry and postlanding phases, the temperature environment is influenced by the initial condition (that is, the pre-entry condition), entry heating and subsequent heat conduction inward, ground purge (if any) and weather conditions at the landing site. Generally, the maximum temperature is reached after landing as a result of heat soak-back through the Orbiter structure and air entering the payload bay through the vent doors.

TABLE 2-I.- STEADY-STATE LINER TEMPERATURE FOR PRELIMINARY DESIGN APPLICATION

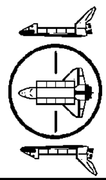
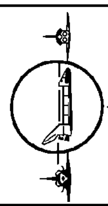
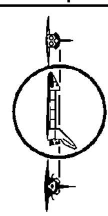
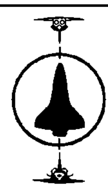
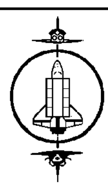
CASE DESCRIPTION	EMPTY PAYLOAD BAY (← LINER) LINER TEMPERATURE (°F)		CYLINDRICAL PAYLOAD (← LINER) LINER TEMPERATURE (°F)	
	MAXIMUM	MINIMUM	MAXIMUM	MINIMUM
1  ← SUN -ZLV, XPOP, $\beta = 90°$ *SEE NOTE	-160	-204	-45	-124
2  ← SUN +ZLV, XPOP, $\beta = 90°$	5	-9	6	-26
3  ← SUN -YLV, -X$\overrightarrow{OV}$, $\beta = 90°$ *SEE NOTE	-94	-114	20	-25
4  ← SUN +YLV, -X$\overrightarrow{OV}$, $\beta = 90°$	201	135	324	213
5  ← SUN +ZLV, -X$\overrightarrow{OV}$, $\beta = 90°$	6	-10	106	23
6  ← SUN -ZLV, -X$\overrightarrow{OV}$, $\beta = 90°$	-151	-200	0	-94
7  ← SUN PTC (4 REV/HR) $\beta = 90°$ *SEE NOTE	––	15	––	75

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TABLE 2-I.- CONTINUED

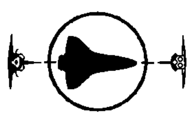
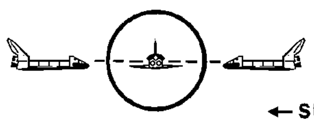
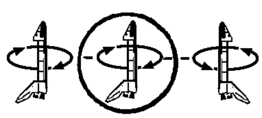
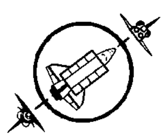
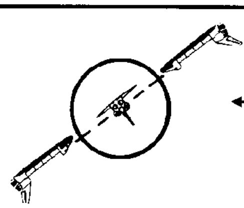
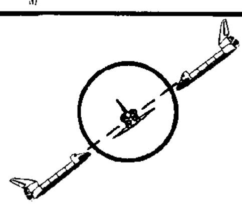
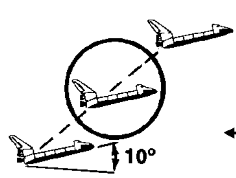
CASE DESCRIPTION	EMPTY PAYLOAD BAY ← LINER LINER TEMPERATURE (°F)		CYLINDRICAL PAYLOAD ← LINER LINER TEMPERATURE (°F)	
	MAXIMUM	MINIMUM	MAXIMUM	MINIMUM
8  ← SUN +ZLV, -XOV⃗, β = 0°	40	30	60	40
9  ← SUN -XLV, +YOV⃗, β = 0°	0	-10	13	-5
10  ← SUN PTC (4 REV/HR) β = 0°	——	5	——	60
11  ← SUN -ZLV, -XOV⃗, β = 45° *SEE NOTE	-61	-90	-20	-40
12  ← SUN -XLV, -YOV⃗, β = 60°	117	86	130	92
13  ← SUN -XLV, +YOV⃗, β = 60° *SEE NOTE	-28	-155	5	-30
14  ← SUN -XSI NOSE UP 10° β = 45° *SEE NOTE	70	-92	-20	-45

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TABLE 2-I.- CONCLUDED

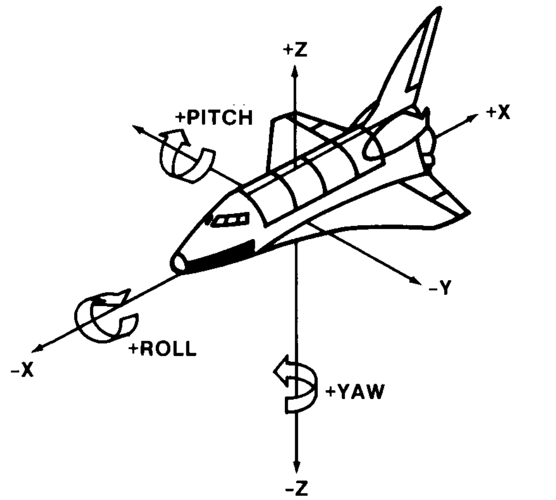
KEY TO TABLE 2-I

ORBITER AXIS:
+X = TAIL
−X = NOSE
+Y = RIGHT WING
−Y = LEFT WING
+Z = TOP (UP)
−Z = BOTTOM (DOWN)

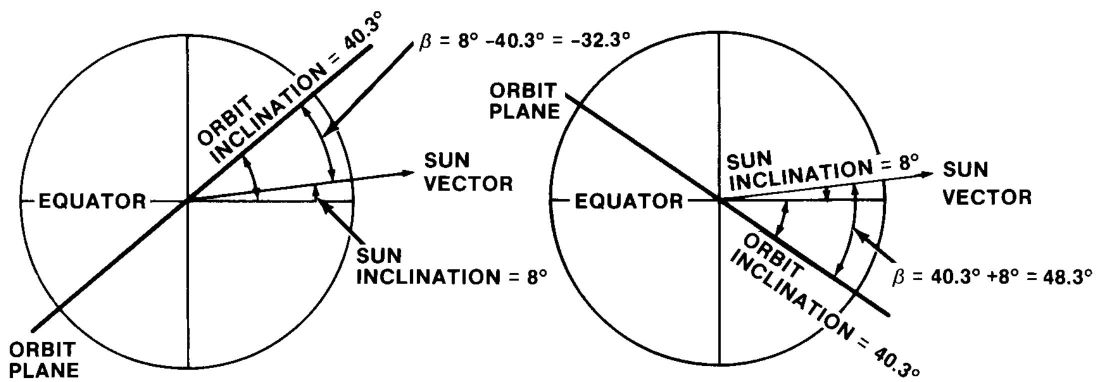
DIRECTION OF AXIS:
LH = LOCAL HORIZONTAL
LV = LOCAL VERTICAL
OV = ON VELOCITY VECTOR
POP = PERPENDICULAR TO ORBIT PLANE
SI = SOLAR INERTIAL

NOMENCLATURE:
ORBITER AXIS + DIRECTION OF AXIS

EXAMPLE:
+ZLV = TOP LOCAL VERTICAL
−YPOP = LEFT WING PERPENDICULAR TO ORBIT PLANE



DEFINITION OF BETA (β) ANGLE:



(a) MAXIMUM NEGATIVE β ANGLE CONDITION FOR A GIVEN ORBIT PLANE (ASCENDING/ DESCENDING NODES PERPENDICULAR TO THE SUN VECTOR).

(b) MAXIMUM POSITIVE β ANGLE CONDITION FOR A GIVEN ORBIT PLANE (ASCENDING/ DESCENDING NODES PERPENDICULAR TO THE SUN VECTOR).

***NOTE: FOR THIS CASE, LINER TEMPERATURE IS FOR INFORMATION ONLY; ORBITER TEMPERATURE LIMITS ARE EXCEEDED UNDER STEADY STATE CONDITIONS.**

app2g5.tif

The payload bay wall temperature data given in ICD 2-19001 were established initially from thermal analyses conducted for Orbiter thermal design and were updated as data from the integrated payload/cargo analyses became available. In addition, the flight test temperature data were used to refine the Orbiter thermal math models for Orbiter design and mission analysis, and for payload/cargo integrated thermal analyses and temperature predictions.

2.1.2 Payload Bay Floodlight Analysis

Payload surfaces or elements which may be located near one or more payload bay floodlights should be analyzed to determine if a temperature violation could result (from the operation of the floodlight). If a temperature violation could occur and a suitable redesign is not feasible or practical, the floodlight operational constraint should be specified in the payload-unique IP and analysis results supplied to the SSP for evaluation and planning purposes.

To conduct the analysis, the payload bay floodlight locations and thermal characteristics given in ICD 2-19001, should be used. In special situations that require a more detailed analysis SSP can provide a floodlight thermal math model.

The payload should not be designed to utilize payload bay floodlights for thermal control.

Floodlight circuitry is such that a single failure could cause a floodlight to fail on; therefore, the payload must be designed to be safe with any floodlight failed on.

2.1.3 Payload Bay Purge

The payload bay purge system supplies conditioned air or gaseous nitrogen (GN_2) to the payload bay with payload bay doors closed during prelaunch operations and conditioned air during the postlanding period at primary and alternate landing sites. The primary function of the payload bay purge system is to inert the payload bay; the purge produces only limited thermal conditioning. The customer should consider the use of alternate services (such as spigot cooling with purge gas or active cooling by utilizing the payload heat exchanger) for payloads that require close temperature control and/or large heat rejection capacity.

Purge air is normally provided to the payload bay by mobile/facility equipment during closed payload bay door operations except during:

- Mobile ground support equipment (GSE) facility/mobile GSE transfer
- Towing of the Orbiter
- Orbiter mate/demate
- Orbiter test or purge system line replaceable unit (LRU) replacement/test
- GSE periodic maintenance at the Orbiter Processing Facility (OPF), Vertical Assembly Building (VAB), and pad

The purge gas is conditioned air except during cryogenic servicing of the Orbiter power reactant storage and distribution subsystem and during final launch countdown from just before external tank loading until launch (or through detanking, when necessary). During these periods, temperature-conditioned GN_2 is provided as the purge gas for inerting purposes.

All gas used to purge the payload bay, whether air or GN_2, is filtered using high efficiency particulate air (HEPA) filters (Class 5000). The resulting purge gas contains 15 or fewer parts per million of hydrocarbons based on methane equivalent.

The purge gas inlet temperature can be set between 45 and 100 degrees F at the pad, nominally controllable to ± 5 degrees F (under steady flow conditions, a tolerance of ± 2 degrees F with excursions to ± 5 degrees F for 1 hour over a period of 12 hours is negotiable for temperature-sensitive payloads. The standard purge gas inlet temperature is set at 65 degrees F and can vary between 60 and 70 degrees F.

For payloads sharing a mission that require something other than the standard purge temperature, they must negotiate a different purge temperature with the other payloads. The temperature control point is on the facility side (upstream of the Orbiter T-0 umbilical) and payload bay temperatures may vary depending on ambient conditions. Orbiter payload bay thermal analytical models (discussed further in section 5) include capability for determination of the payload bay environment, and integrated analyses can be performed to determine resulting payload thermal conditions if required.

Additional characteristics of the purge gas (including flow rates) are given in ICD 2-19001. For payloads sharing a mission, special consideration of flow rate is required. The purge gas flow enters the payload bay at the forward bulkhead location (X_o 576) and exits at the aft bulkhead (X_o 1307). Due to leakage through the payload bay doors and flow to the lower mid-fuselage (the volume beneath the payload bay) through payload bay vents the local flow rate may be less than the inlet flow. Additionally, three spigots are available to provide supplemental flow through special ducting to meet unique payload requirements. Use of the spigots is a nonstandard service and is further discussed in section 6. Manifests for shared missions may include payloads using the spigots. The supplemental spigot flow is introduced into the payload bay as it exits the using payload. Therefore, the local purge flow rate may vary considerably, especially for shared missions. Customers whose payloads share a flight must design for both the maximum and minimum flow rates specified in ICD 2-19001 since the location in the payload bay will be determined by the SSP.

Payload bay purge is normally provided at the planned primary and alternate landing sites, starting approximately 45 minutes after touchdown at the primary site and 90 minutes after touchdown at the alternate site. Payload bay purge will be provided within 72 hours at any landing site. The payload bay purge shall not be used to satisfy the technical requirements contained in Safety Policy and Requirements for Payloads using the Space Transportation System, NSTS 1700.7B. Payload requirements for special postlanding services shall be negotiated with the SSP and documented in the IP. Emergency landing site environmental conditions are in ICD 2-19001. Purge at ferry flight stopover sites can be provided as a nonstandard service.

2.1.4 Reflected Solar Energy

Cargo elements that extend above the payload bay door hinge line or are deployed transversely over the Orbiter radiators may experience reflected solar radiation from the Orbiter radiators. The radiators have moderately specular reflective surfaces.

The magnitude of the local fluxes and thermal effect is a function of cargo location, Orbiter orientation relative to the sun, and duration of the exposure. In most cases, except for solar inertial attitude, if reflected solar radiation does occur, it can be expected to be brief, nearly instantaneous exposure at a given payload surface due to the continuously changing solar angle. The possibility that reflected solar radiation may occur is limited to periods when the forward radiators are deployed during the daylight period of the orbit (Figure 2-3). Normally, while on orbit, the forward radiators are not deployed unless maximum heat rejection is required.

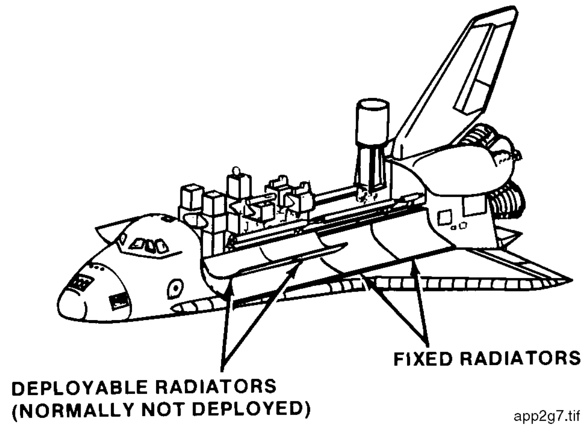


Figure 2-3.- Orbiter radiator configuration during on-orbit operations.

The SSP and other organizations have conducted analytical studies of the solar focusing phenomenon from Orbiter radiator panels. Solar ray tracing for various sun angles and radiator panel geometry has been developed. Figure 2-4 illustrates ray tracing for various sun angles for a deployed forward radiator.

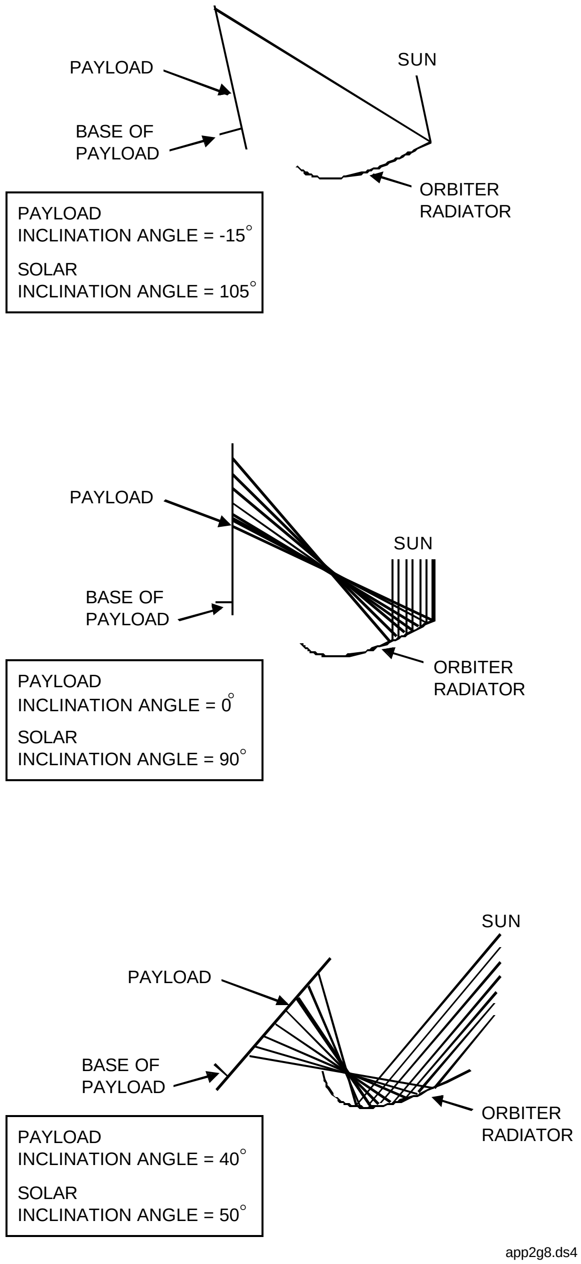


Figure 2-4.- Reflected solar energy ray tracing from deployed orbiter radiator.

Solar energy reflected from the radiators during payload bay door opening is precluded by opening the doors with the payload bay facing the earth (+ZLV).

2.1.5 Entry Air Inlet Conditions

The temperature, mass flow rate of the repressurizing air entering the payload bay, and the payload bay pressure during entry given in ICD 2-19001, are the maximum or worst conditions that occur at or near the payload bay vents (Figure 2-5). Thermally sensitive payload surfaces that may be located near a payload bay vent should be analyzed to determine the impact of being exposed to hot entry air after the vent doors are opened. As given in the ICD, the entry air temperature declines rapidly from approximately 400 degrees F (low density air) at vent door opening to 100 degrees F in approximately 60 seconds.

As the distance from a vent increases, the effect of entry air on a payload surface decreases rapidly.

Normally, payload bay vent doors are closed at the start of entry and do not open until after peak aerodynamic heating has occurred. However, customers must conduct thermal assessments to confirm that no hazards are presented to either the payload or its integration hardware if one or more vent doors should fail in the open position and remain open during reentry. The methodology for performing these assessments is presented in ICD 2-19001.

2.2 Orbiter Attitude Hold Capabilities

Orbiter attitude hold capabilities (attitude and attitude hold durations) given in ICD 2-19001 have been established to preclude Orbiter temperature limit violations and to satisfy the heat rejection requirements imposed by the Orbiter systems, crew, and payloads heat rejection accommodations. These attitude hold capabilities are based on analyses, tests, and actual flight experience. (Section 8 has illustrations of flight attitudes.)

The attitude hold times vary from 5 hours up to 160 hours and upon the beta angle and the payload bay orientation. These attitude hold capabilities are representative of Orbiter capability and are considered suitable or applicable for most payload missions.

The Orbiter pre-entry thermal conditioning attitude and duration requirement is established during the mission based upon real-time temperature measurements. The thermal conditioning duration may range from 0 to 12 hours (ICD 2-19001). For normal entry, the pre-entry thermal

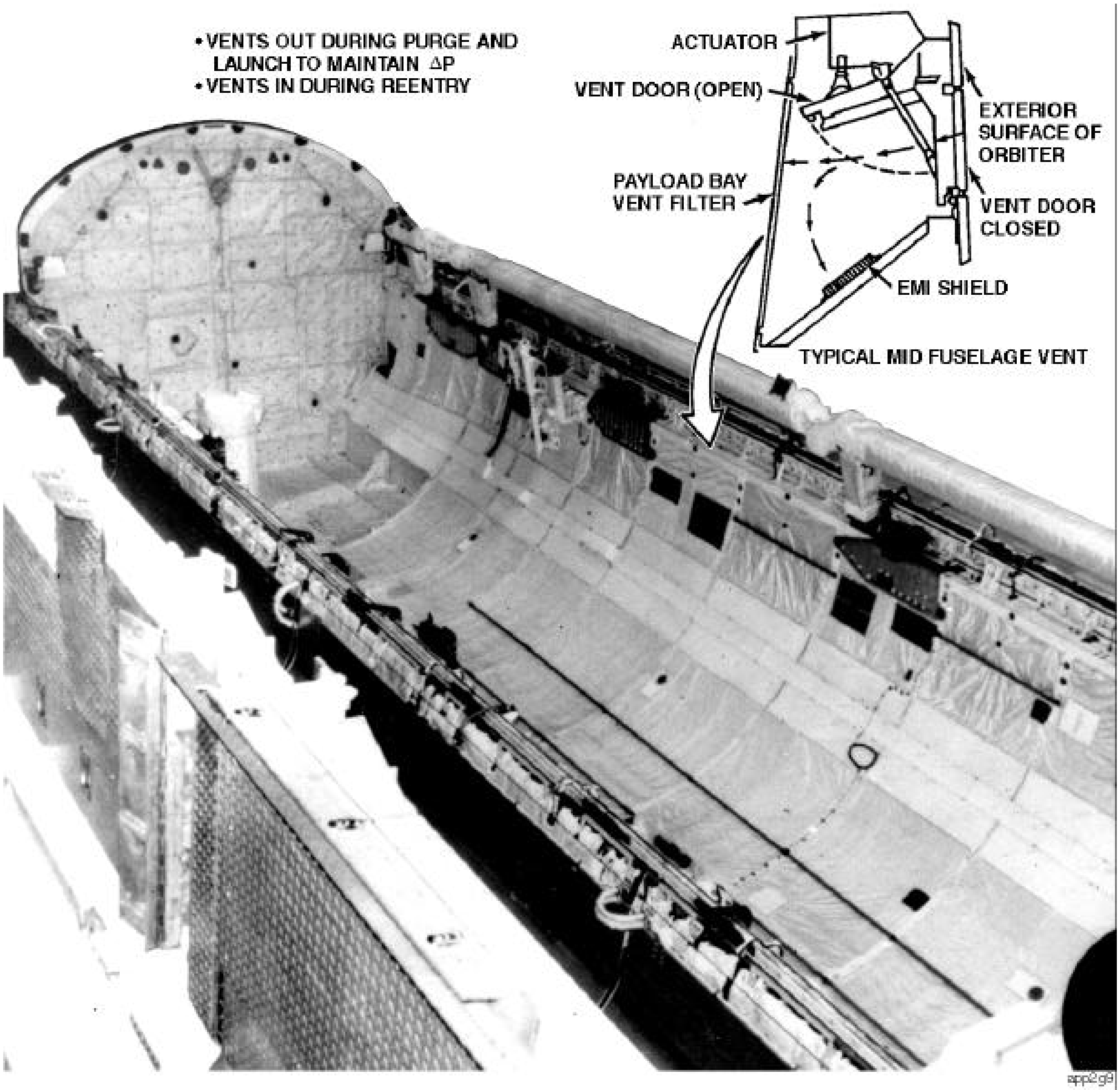


Figure 2-5.- Payload bay vent ports.

conditioning attitude and duration are selected to be compatible with both Orbiter and payload operational or refurbishment requirements. As stated in ICD 2-19001, if mutually compatible requirements cannot be established, pre-entry conditioning will be accomplished by passive thermal conditioning (PTC). PTC will be assumed to be the rotation of the Orbiter at two to five revolutions per hour about the Orbiter X-axis with the orientation of this axis within ±20 degrees of the perpendicular-to-the-sun vector.

In the event of an anomaly, the SSP will observe the payload operational attitude constraints to the extent possible. In the event these constraints must be violated, payload safety constraints will be observed. Payload flight safety constraints and operational or refurbishment attitude hold constraints are established by the customer and defined in the payload-unique IP and IP annexes.

Middeck Payload Accommodations

3

This section provides thermal information and data for customers who plan to locate a payload in the Orbiter middeck.

3.1 Standard Middeck Accommodations

Accommodations for payloads located in the Orbiter middeck are provided either by use of standard Orbiter lockers or by use of adapter plates mounted to standard locker attachment provisions. Shuttle/Payload Interface Definition Document for Middeck Accommodations, NSTS 21000-IDD-MDK, specifies the standard thermal interfaces for middeck payloads. Standard middeck payloads are passively cooled; i.e., no active cooling (liquid or air) is provided as a standard service (active cooling can be provided as a nonstandard service - see section 6). Payloads which generate waste heat and cannot reject the heat to the cabin air (using a fan of similar means) are limited to a continuous heat load of 60 watts. Cooling requirements above 60 watts continuous must be negotiated with the SSP.

Figure 3-1 shows an overview of the middeck area and stowage locker locations. Figures 3-2 and 3-3 show an experiment apparatus container (EAC)-type payload and available locations for mounting. Figure 3-4 depicts a fan-cooled-type payload. Inlet and outlet filtration are recommended for fan-cooled payloads.

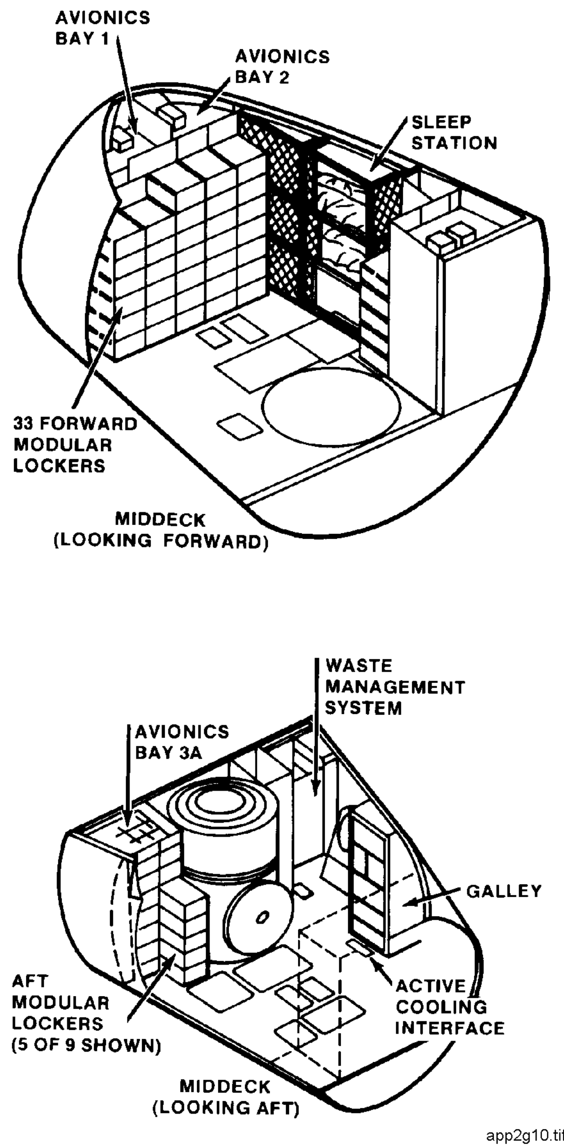


Figure 3-1.- Middeck stowage lockers.

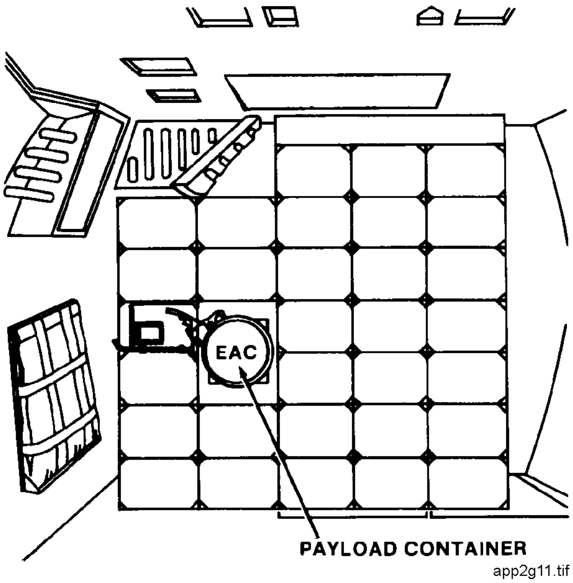


Figure 3-2.- Typical passive cooled payload (without fan).

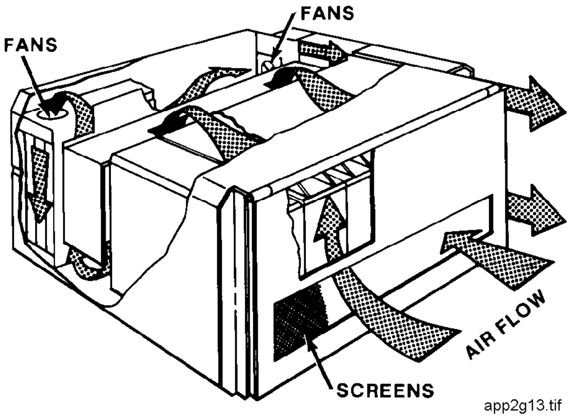


Figure 3-4.- Typical payload with internal fans.

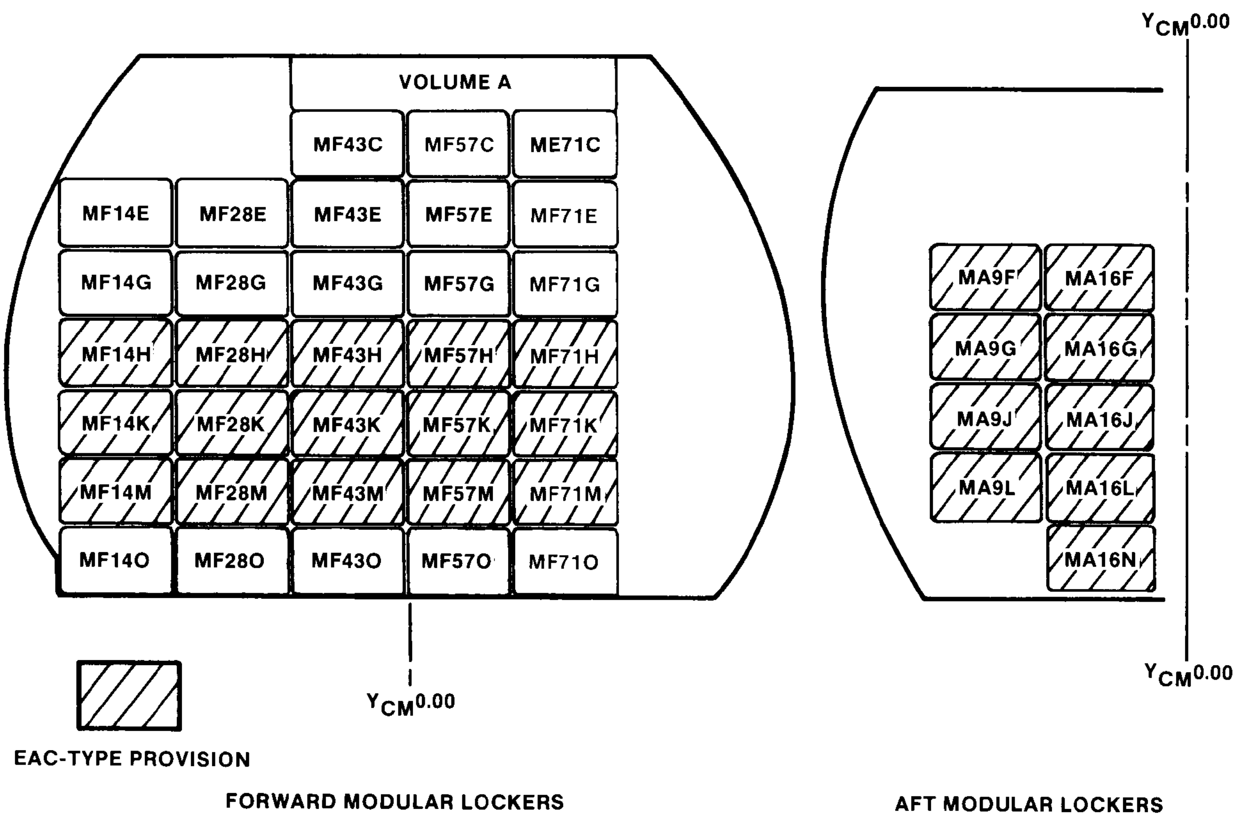


Figure 3-3.- Middeck locker locations for EAC-type provisions.

3.1.1 Maximum Temperature Limit

Middeck payloads should be designed so that external surface temperatures do not exceed 120 degrees F.

If the payload design incorporates a fan for enhanced heat rejection, the air outlet should not exceed 120 degrees F.

3.1.2 Middeck Environment

Heat generated by the payload is primarily rejected to the middeck air by means of convection resulting from the air movement in the middeck, or enhanced forced air convection by using an internal fan. During a nominal mission without any planned extravehicular activity (EVA), the cabin air temperature and pressure are at approximately 80 degrees F and 14.7 psia. For missions with planned EVA, the cabin pressure is normally reduced to 10.2 psia during the EVA and EVA prebreath periods. In both cases, the heat removal capability is low since air flow in the middeck locker area is minimal. The natural heat convection coefficient is normally low, approximately 0.25 Btu/hr/°F/sq ft for 14.7 psia cabin pressure and 0.17 Btu/hr/°F/sq ft for 10.2 psia cabin.

Additional heat generated by the payload is rejected by conduction and radiation to the adjacent structure such as the avionics closeout panels and surrounding lockers. The maximum structure temperature is at 120 degrees F, as defined in NSTS 21000-IDD-MDK. However, it is normally lower; approximately 80 to 90 degrees F provided there is no heat generation in the adjacent locker.

3.1.3 Thermal Analysis of Middeck Locker

The SSP has performed a parametric study of middeck lockers for various heat loads, payload locations, and single and multiple lockers. Air temperatures of 80 degrees F in the cabin and avionics bays 1, 2, and 3 were assumed in the study. The following are general observations from the study:

- No single 60-watt source will cause any exposed surface of any locker to exceed the 120 degree F limit.
- Within the range of heat sources of 30 to 60 watts, the temperature increase in the surrounding lockers is proportional to the source power. For example, if 60 watts heats an area to 90 degrees F (10 degrees F above cabin), then a 45-watt source will heat the same area to 87.5 degrees F (7.5 degrees F above cabin) and a 30-watt source will heat the area to 85 degrees F (5 degrees F above cabin).

3.2 Thermal Analysis Requirements

Each payload should be analyzed by the payload designer to ensure that adequate cooling is provided. The analysis must consider the worst-case environment (which is defined in NSTS 21000-IDD-MDK). Where warranted, the SSP will perform an integrated analysis based on a specific flight manifest. The manifest may include a combination of certain middeck payloads, not necessarily one single payload. The purpose of the integrated analysis is to determine if any external surfaces of the lockers or the payload containers exceed the touch temperature limit of 120 degrees F and that adjacent lockers and equipment do not exceed temperature limits.

Ferry Flight Accommodations

4

When the Shuttle flight ends at Edwards Air Force Base (EAFB), the payload (cargo) usually remains aboard the Orbiter, which is flown or ferried from EAFB to the launch site on the Shuttle carrier aircraft (SCA). Payloads and ASE should be designed to be compatible with ferry flight thermal environments.

During ferry flight operations, payloads within the payload bay are exposed to ambient conditions that are not controlled or monitored. Payloads normally are not powered, heated, or cooled. Customers should specify any unique requirements in the IP, Annex 8 and Operations and Maintenance Requirements and Specifications Document (OMRSD).

4.1 Flight Phase Thermal Environment

The maximum duration of any flight segment is limited to approximately 4 hours during which time the payload bay environment is not controlled. Based on temperature measurements recorded during several ferry flights, the temperature in the payload bay could range from about +35 degrees F to +86 degrees F.

Although the payload bay thermal environment is not controlled during flight, as nonstandard service the payload temperature range may be biased at takeoff within a reasonable range by conditioned air supplied to the Orbiter payload bay via the Orbiter purge system while the Orbiter and SCA are on the ground.

4.2 Ground Phase Thermal Environment

The interval on the ground at selected Air Force bases or NASA facilities varies from a few hours to 24 or more hours, and the payload bay temperature may vary from about +10 degrees F to about +125 degrees F as the result of diurnal and seasonal variations.

During stops in route, conditioned air can be made available to the payload in the payload bay. If a payload requires conditioned air, the requirement must be specified in the IP, Annex 8 and OMRSD. The specific temperature range and flow rate are negotiated with the SSP.

When determining conditioned air requirements, the customer should consider possible payload and payload bay temperatures at touchdown, minimum duration of the ground service available between flights, and the influence of the ground environment and the payload bay surface temperatures.

4.3 Payload with Active Cooling System

For payloads that utilize water cooling, it is necessary to prevent the water from freezing in the cooling system during the ferry flight.

To prevent freezing for middeck payloads, the SSP will provide electrical power to the Orbiter coolant pump for circulating the coolant during the flight and during intervals on the ground.

For payload bay payloads that utilize water cooling, freezing protection will be provided using methods described in sections 4.1 and 4.2.

Integrated Thermal Analysis Considerations

5

The payload thermal control design process must include an integrated thermal analysis to ensure that the design meets expected mission objectives and to define payload-unique thermal requirements for inputs to the IP and ICD. Integrated analysis can be an iterative process where the initial effort is directed toward defining the payload thermal control design. Subsequent analyses, after the payload design matures, should be directed toward establishing payload-unique requirements, particularly in orbit.

An integrated analysis may consist of several separate analyses, depending on the thermal interfaces involved with the particular payload. The following separate analyses should be performed:

1. Payload/Orbiter analysis for payloads and ASE located in the payload bay
2. Payload bay floodlight analysis for payloads in the payload bay (including failed-on floodlight analyses)
3. Failed payload bay vent door analysis
4. Heat rejection analysis for payloads utilizing the payload heat exchanger
5. Heat rejection analysis for payloads utilizing the spigot system
6. Ferry flight analysis for payloads and ASE located in the payload bay, middeck, or aft flight deck
7. Payload/grapple fixture/end effector analysis for payloads utilizing the remote manipulator system (RMS). Grapple fixture thermal data are given in System Description and Design Data - Payload Deployment and Retrieval System, NSTS 07700, Volume XIV, Appendix 8.

The integrated analysis for payload and ASE in the payload bay or payloads deployed from the payload bay is relatively complex. This procedure requires the use of suitable payload and Orbiter math models, development of relatively large integrated math models (several hundred nodes), and use of computer programs capable of analyzing them.

A flow chart of the integrated analysis task is presented in Figure 5-1. Analysis cases should consist of the worst hot, worst cold, and design or nominal conditions.

Thermal Interfaces	Payload Location/Category				
	Payload Bay			Middeck	Aft Flight Deck
	Deployable or Non-Deployable Payload Plus ASE	Small Payload	Get Away Special (GAS)	Stowage Locker and Galley Stowage	Mission Station and Payload Station
1) Thermal Environment					
a) Radiation Interchange with Payload Bay Surfaces	All Mission Phases	All Mission Phases	All Mission Phases	-	-
b) Radiation Interchange with Orbiter External Surfaces	On-Orbit Payload Bay Doors Open	On-Orbit Payload Bay Doors Open	-	-	-
c) Conduction at Attachments	All Mission Phases	All Mission Phases	All Mission Phases	-	-
d) Payload Bay Purge	Prelaunch and Postlanding Phases	Prelaunch and Postlanding Phases	-	-	-
e) Entry Air	Entry Phase	Entry Phase	-	-	-
f) Payload Bay Floodlights	On-Orbit Payload Bay Doors Open	On-Orbit Payload Bay Doors Open	-	-	-
2) Heat Rejection Via Orbiter Active Thermal Control System					
a) Payload Heat Exchanger	(Optional Service) All Mission Phases			(Optional Service) All Mission Phases	-
b) Cabin Air				All Mission Phases	All Mission Phases
3) Heat Rejection Utilizing Spigot System	(Optional Service) Prelaunch and Postlanding Phases	-	-	-	-
4) Ferry Flight Thermal Environment Airborne and Ground Environments	Payload Bay Temperatures	Payload Bay Temperatures	Payload Bay Temperatures	(TBD)	(TBD)

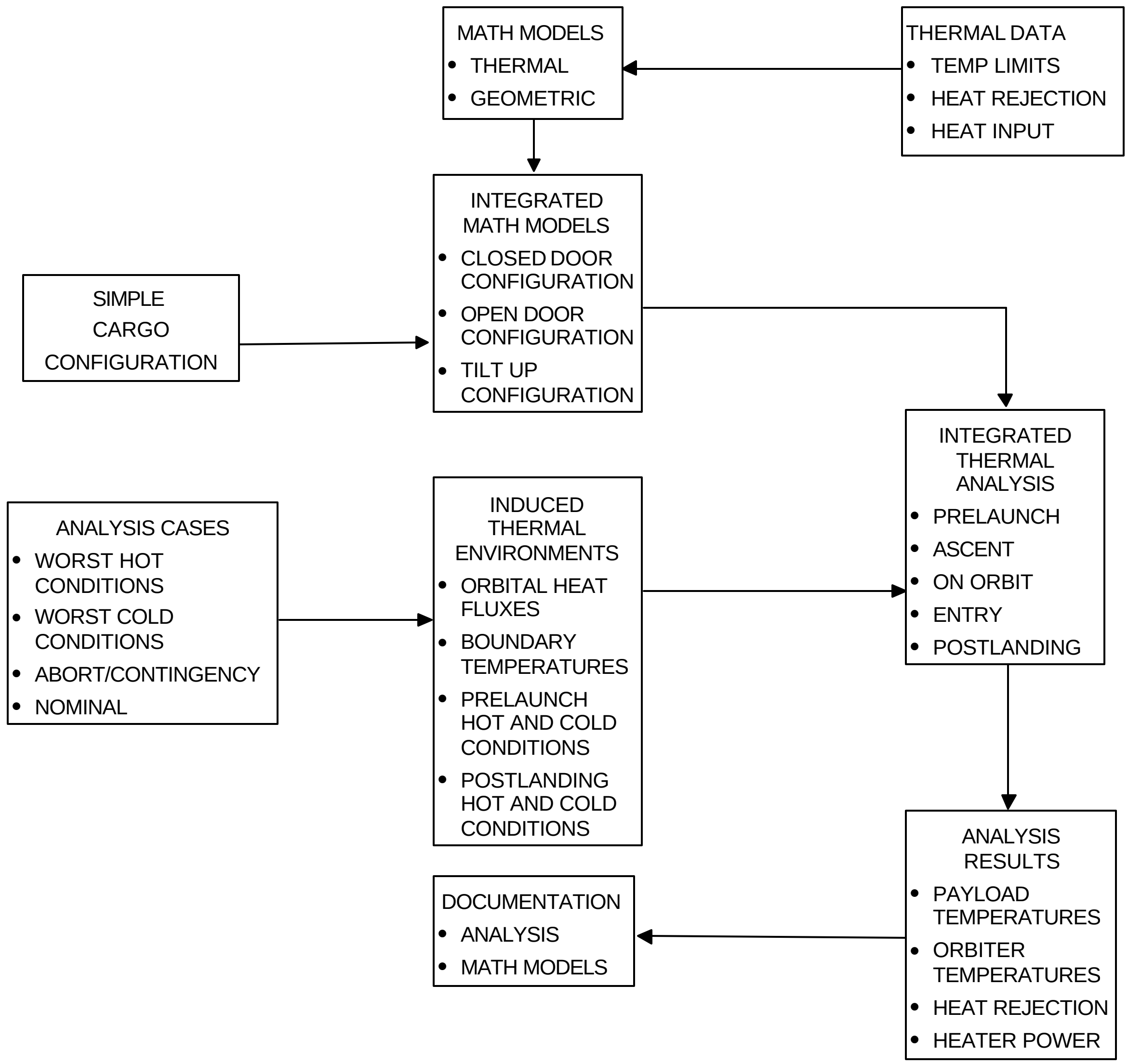


Figure 5-1.- Payload/Orbiter integrated thermal analysis flow diagram.

Design timelines for these conditions must be defined. The Orbiter geometric and thermal math models to be used in the integrated analysis are available from the SSP. A thermal analyzer computer program identified as SINDA and a companion computer program called TRASYS for computing view factors, radiation conductor values, and orbital heat fluxes are also available from the SSP.

Generally, integrated thermal math models and analysis cases are tailored specifically for the payload, its mission conditions, and the objective of the analysis. For example, if the integrated analysis is performed primarily in support of payload thermal control design, a detailed payload thermal model would be used in conjunction with the simplest interface models to represent the Orbiter and other adjoining payloads in the payload bay. These and other considerations that minimize the cost of integrated thermal analysis are discussed in subsequent sections.

5.1 On-Orbit Attitudes and Constraints

The Orbiter's attitude/duration constraints for thermal compatibility are defined in ICD 2-19001. Similar payload constraints must be defined in the payload-unique ICD. These payload constraints are determined by integrated analysis. Worst hot and worst cold attitudes are examined, as well as operational and nonoperational payload attitudes. The worst hot and cold attitudes normally are +ZSI (top sun inertial) and +XSI (tail sun inertial), respectively. A colder attitude would be +X sun orbital rate (tail to sun, one revolution per orbit about the X-axis), so that the payload bay is always facing deep space. Some other attitude may be locally coldest or hottest in special circumstances (e.g., unusual payload geometry or physical properties).

Among other factors, the beta angle (between the sun vector and the orbit plane) influences the thermal severity of these and other attitudes. Generally, the shortest time required to exceed the operating and nonoperating temperature limits of critical components is used to define constraints for the payload-unique ICD. Of course, if these constraints violate Orbiter constraints the latter must prevail.

In addition to the time to exceed a temperature limit, the time to recover from a limiting temperature to a nominal condition (e.g., to +ZLV, payload bay facing Earth) is also of interest. This time establishes the waiting period before commencing another hot or cold attitude excursion. Depending on whether a hot or cold extreme has been reached, the recovery attitude is generally +ZLV, PTC, +XSI, or +ZSI. The designation PTC (passive thermal control) is assumed for analysis purposes to be rotation of the Orbiter about its X-axis at two to five revolutions per hour with the X-axis within 20 degrees of perpendicular to the sun vector. This is sometimes called the barbecue mode.

The Orbiter attitudes referred to above are depicted in section 8. Note that other Orbiter orientations could also satisfy these attitude designations. The direction of at least one other Orbiter axis is needed to uniquely define the attitudes shown.

5.2 Prelaunch, Ascent, Entry, and Postlanding Mission Phases

These mission phases are of particular interest for AOA and contingency landing site conditions and for cryogenic and high-heat-generating payload components for which thermal compatibility with the closed-door Orbiter must be determined. Launch and landing sites, time of year, time of day, and Orbiter payload bay purge gas parameters and availability are variables that must be considered.

5.3 Analysis Approach

Typical approaches to integrated thermal analysis are shown in Tables 5-I and 5-II for hot and cold cases, respectively. Included are sample timelines (Figures 5-2 and 5-3) and methods of using temperature plots (Figures 5-4 and 5-5) to determine on-orbit attitude hold and recovery times, attitude hold times prior to entry, times to reach entry/postlanding temperature extremes, and refurbishment times. Examples of actual analysis timelines for determining payload attitude thermal constraints and verifying mission thermal

TABLE 5-I.- TYPICAL INTEGRATED THERMAL ANALYSIS APPROACH
FOR THE HOT CASE

- Perform hot excursion/recovery analysis to satisfy IP TBD's
  - Both Space Vehicle (SV)/ASE and ASE alone
  - Use hot-biased mission timeline and environments to generate initial conditions
- Perform hot entry/postlanding analysis to determine temperature rise for each component
  - Both SV/ASE and ASE alone (if required)
  - Use hottest point in timeline for initial conditions
  - Assume no purge at landing site and continue analysis until all temperatures begin decreasing
- Determine allowable excursion times prior to entry
  - Both SV/ASE and ASE alone (if required)
  - Use Δt's generated from excursion temperature curves to determine allowable times
  - Determine minimum allowable time for each excursion attitude
- Run entry/postlanding to verify minimum allowable times
- Refurbishment limits can be similarly established

TABLE 5-II.- TYPICAL INTEGRATED THERMAL ANALYSIS APPROACH FOR THE COLD CASE

- Perform cold excursion/recovery analysis to satisfy IP TBD's
  - Both SV/ASE and ASE alone (if required)
  - Use cold-biased mission timeline and environments to generate initial conditions
- Perform cold entry/postlanding analysis to determine allowable exposure time to cold postlanding environment
  - Both SV/ASE and ASE alone (if required)
  - Use coldest point in timeline for initial conditions
  - Assume no purge at landing site and continue analysis until cyclic steady state is reached
  - Cold safety limits eventually will be exceeded
  - Ground power or warm purge air is required
  - Establish length of time prior to power/warm air need

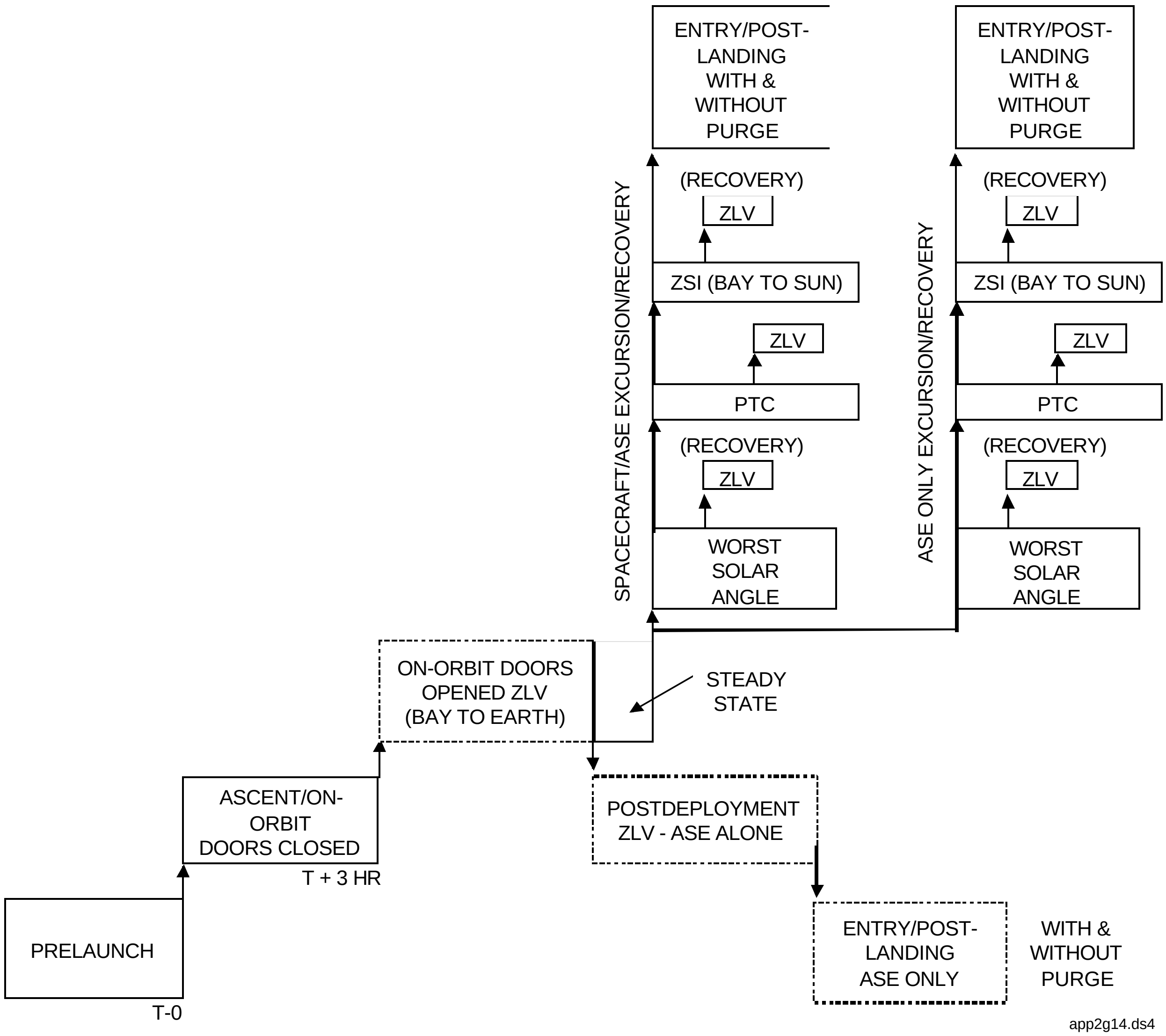


Figure 5-2.- Typical hot case thermal design timeline.

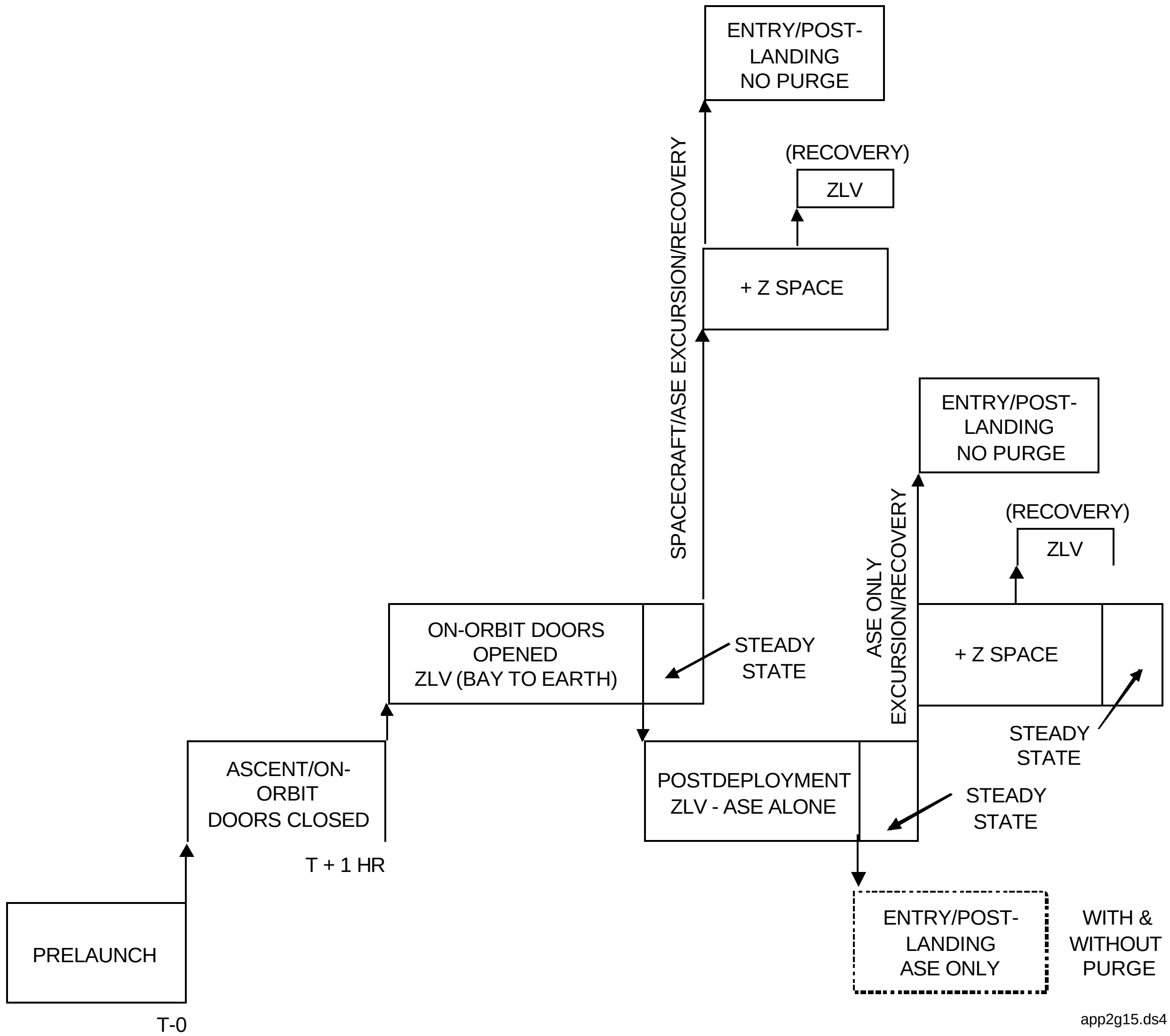


Figure 5-3.- Typical cold case thermal design timeline.

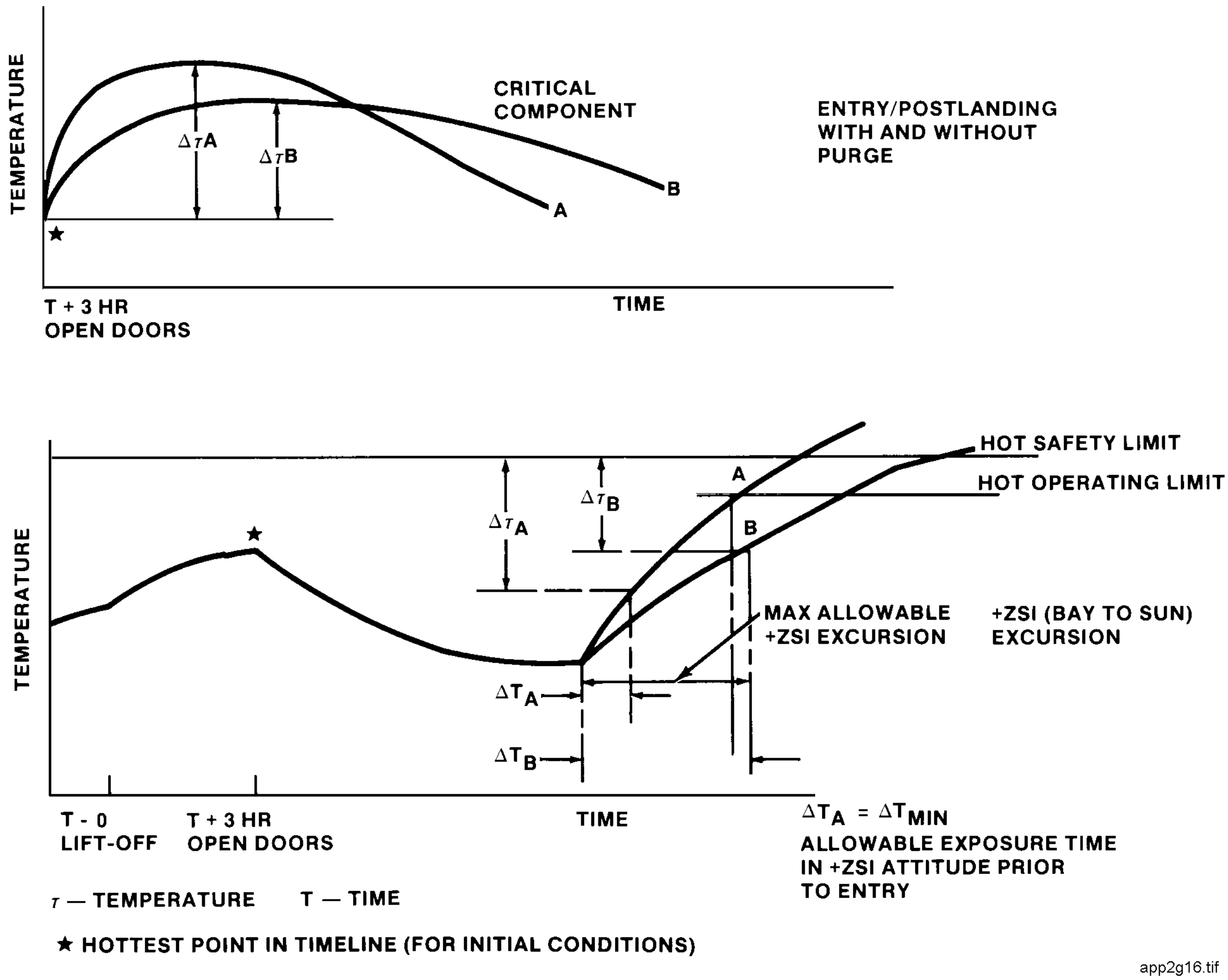


Figure 5-4.- Hot case temperature profiles for determining safety and operating limits.

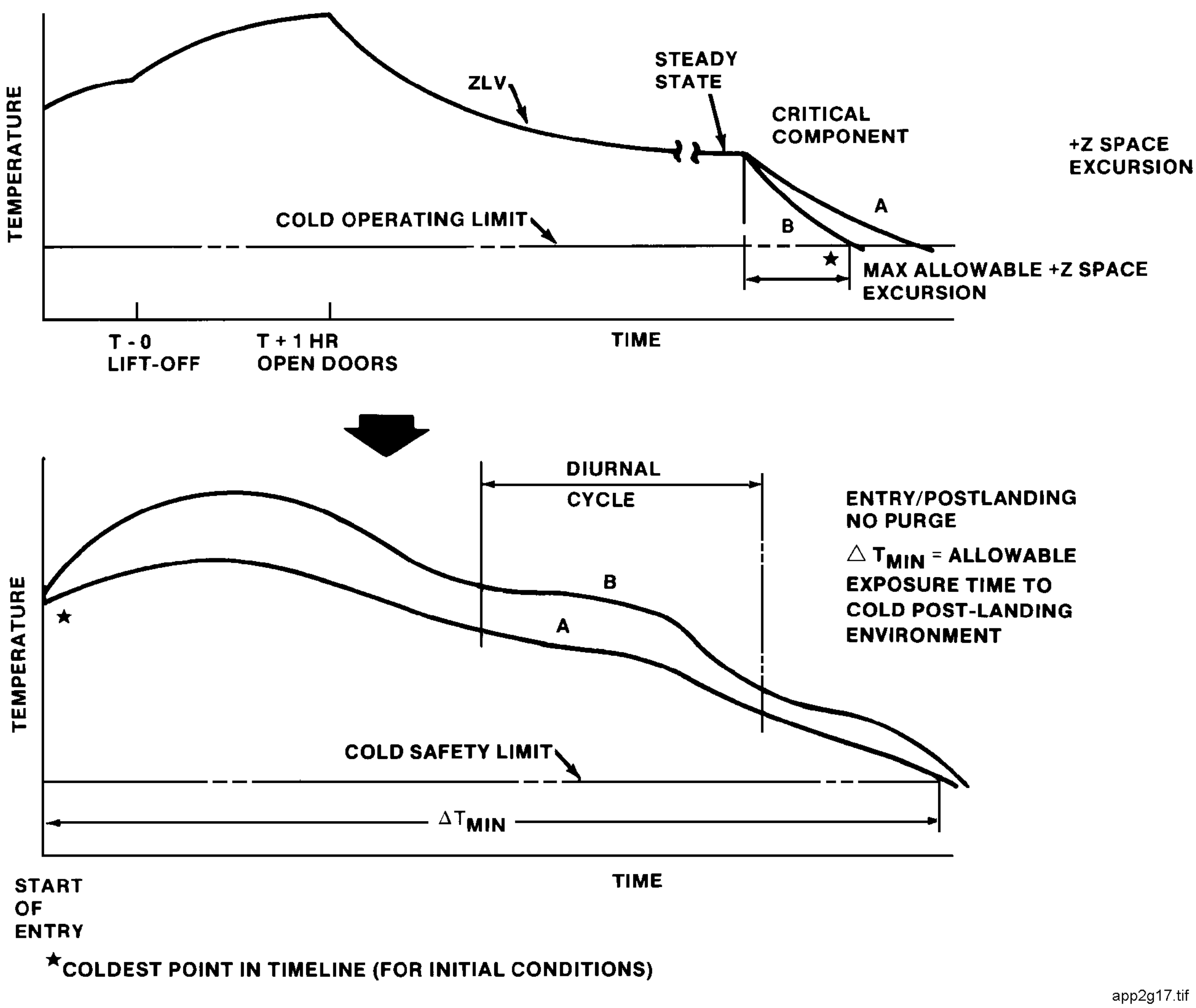


Figure 5-5.- Cold case temperature profiles for determining safety and operating limits.

compatibility are presented in Figure 5-6 for the hot condition, Figure 5-7 for the cold condition, and Figure 5-8 for the ASE-only configuration.

5.4 Example of Integrated Analysis Results

Integrated thermal analysis results consist primarily of plots of integrated thermal math mode (ITMM) node temperatures versus time for the various attitudes and payload configurations analyzed. Auxiliary data can include tables of maximum and minimum temperatures for all and/or selected nodes, tables of temperature limit exceedances for affected nodes, plots and tables of heater power and electronics power dissipations, plots and tables of heat transfer coefficients, etc. Some of these may require adding a special code to the ITMM's and using auxiliary computer programs.

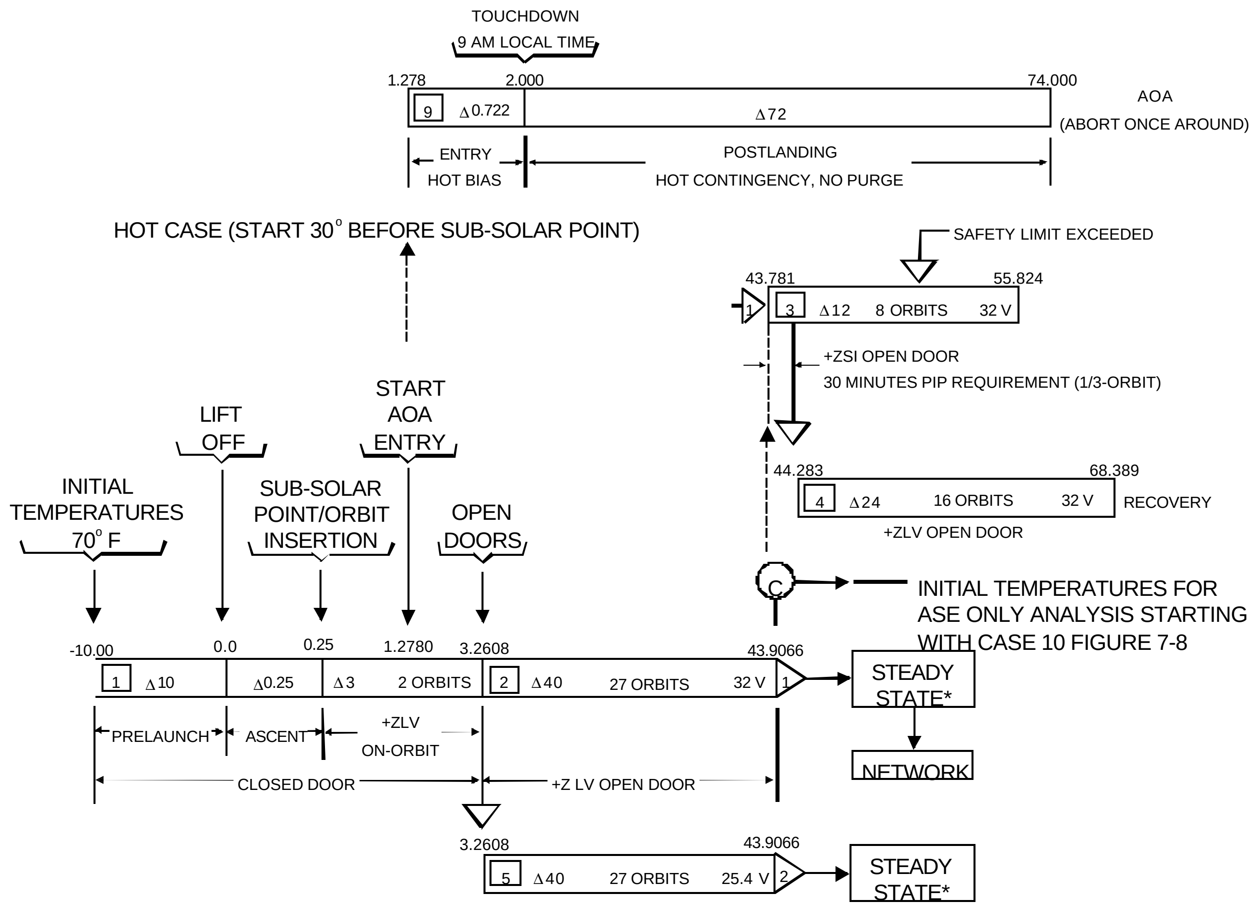
Samples of these kinds of results are presented in Figures 5-9 through 5-13. These were taken from the analysis timelines and cases indicated in Figures 5-6, 5-7, and 5-8. In that analysis, a 390 node spacecraft and ASE model was integrated with the Orbiter model. Because the spacecraft was deployable, the analysis included an ASE-only and a spacecraft/ASE integrated model. A number of components had specific temperature limits and several had thermostatically controlled heaters.

Figure 5-9 shows the temperature response for one of the nodes that had a heater. The heater power is plotted in Figure 5-10. A tradeoff between the allowable minimum calculation time interval and the steep heater-caused temperature gradients results in average thermostat overshoots of approximately 0.5 degrees C and 2.0 degrees C at the ON and OFF thermostat setpoints, which were 25 degrees C and 40 degrees C, respectively. In Figure 5-11, two nodes exceeded the upper temperature limits of 30 degrees C after about 1 hour in the +ZSI top-to-sun attitude.

Figure 5-12 provides the temperature extremes and time of occurrence during the same top-to-sun case for a subset of the payload nodes of special interest. Again, for the same case, all the nodes that exceeded the upper temperature limits and the first time of occurrence are given in Figure 5-13. Note that a 30-minute attitude hold constraint was barely violated by one node.

5.5 Payload Thermal Math Models

Among the first details to be considered by a thermal analyst in preparing a payload thermal math model (TMM) are those associated with its eventual inclusion in an Orbiter TMM. The resulting ITMM is required for an integrated analysis to confirm payload thermal compatibility with the Orbiter and with its mission environment.



LEGEND: ONE ORBIT = 1.5054 HOURS AT 160 NMI ALTITUDE
VOLTAGE: 32 V MAXIMUM, 28 V NOMINAL, 25.4 V MINIMUM

* USING ORBITAL AVERAGE HEAT RATES AND CONSTANT ADJUSTED HEATER POWERS

[1] CASE NO. (TYPICAL)

▷1 CONTINUE AT

▷1 WITH SAME OR EARLIER TEMPERATURES (TYPICAL)

MET IS IN HOURS

SPACECRAFT AND ASE
TIMES IN HOURS UNLESS NOTED OTHERWISE
(Δ TIMES ARE NOMINAL REQUESTED VALUES)

app2g18.ds4

Figure 5-6.- Examples of thermal design analysis timelines and cases for spacecraft (deployable) and ASE for hot condition.

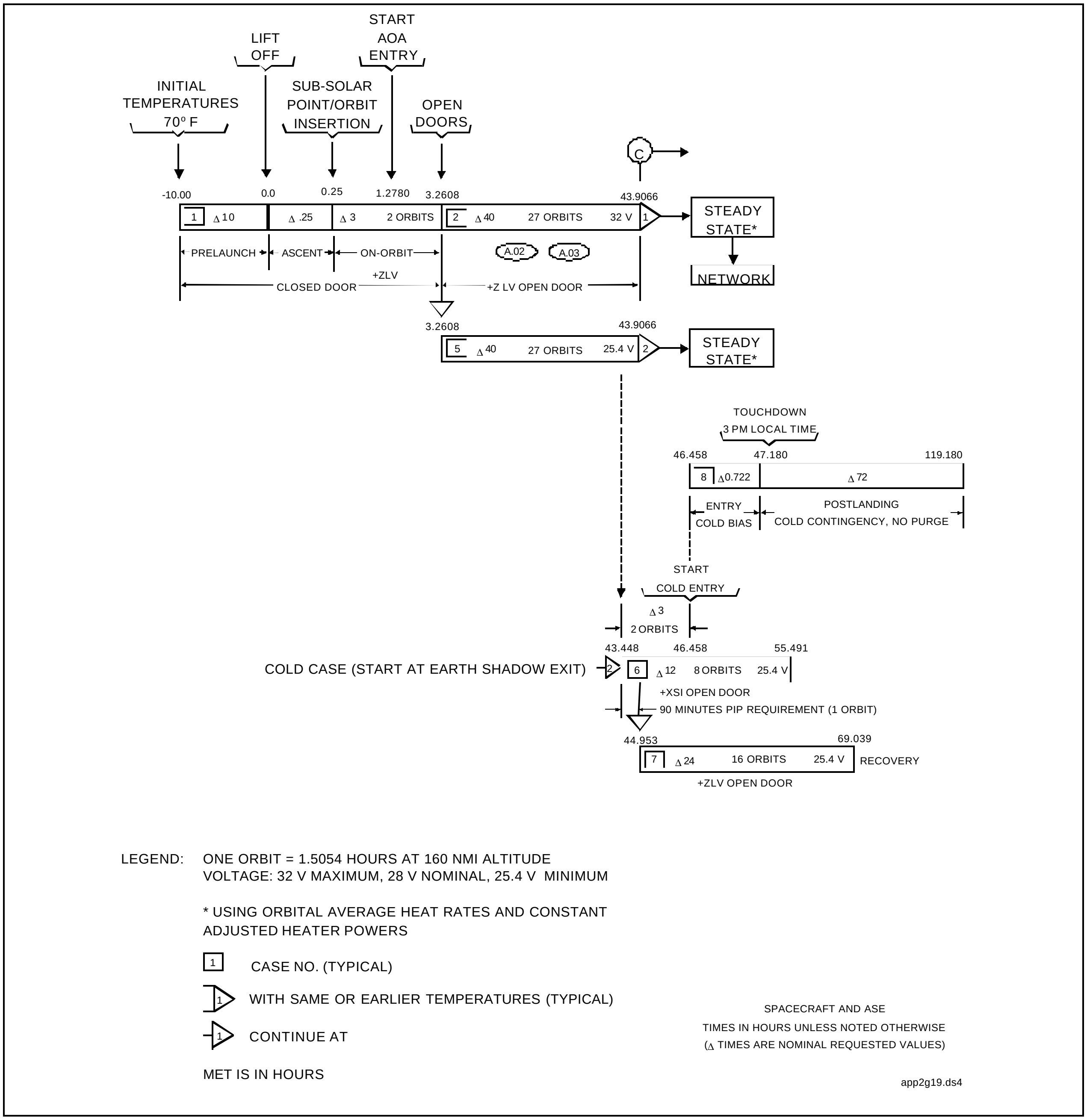
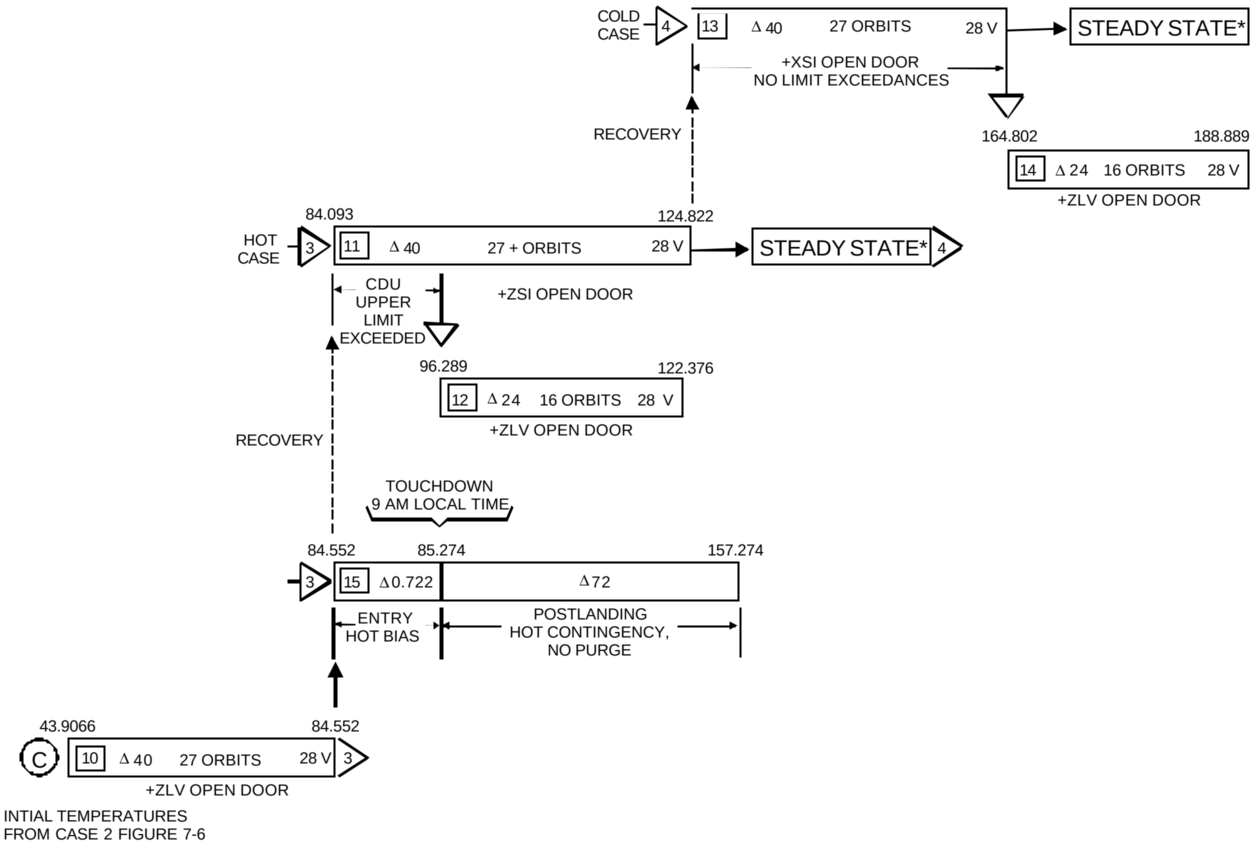


Figure 5-7.- Examples of thermal design analysis timelines and cases for spacecraft (deployable) and ASE for cold condition.



LEGEND: ONE ORBIT = 1.5054 HOURS AT 160 NMI ALTITUDE
VOLTAGE: 32 V MAXIMUM, 28 V NOMINAL, 25.4 V MINIMUM

* USING ORBITAL AVERAGE HEAT RATES AND CONSTANT ADJUSTED HEATER POWERS

1 CASE NO. (TYPICAL)

1 CONTINUE AT

1 WITH SAME OR EARLIER TEMPERATURES (TYPICAL)

MET IS IN HOURS

ASE ONLY
TIMES IN HOURS UNLESS NOTED OTHERWISE
(Δ TIMES ARE NOMINAL REQUESTED VALUES)

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Figure 5-8.- Examples of thermal design analysis timelines and cases for ASE only.

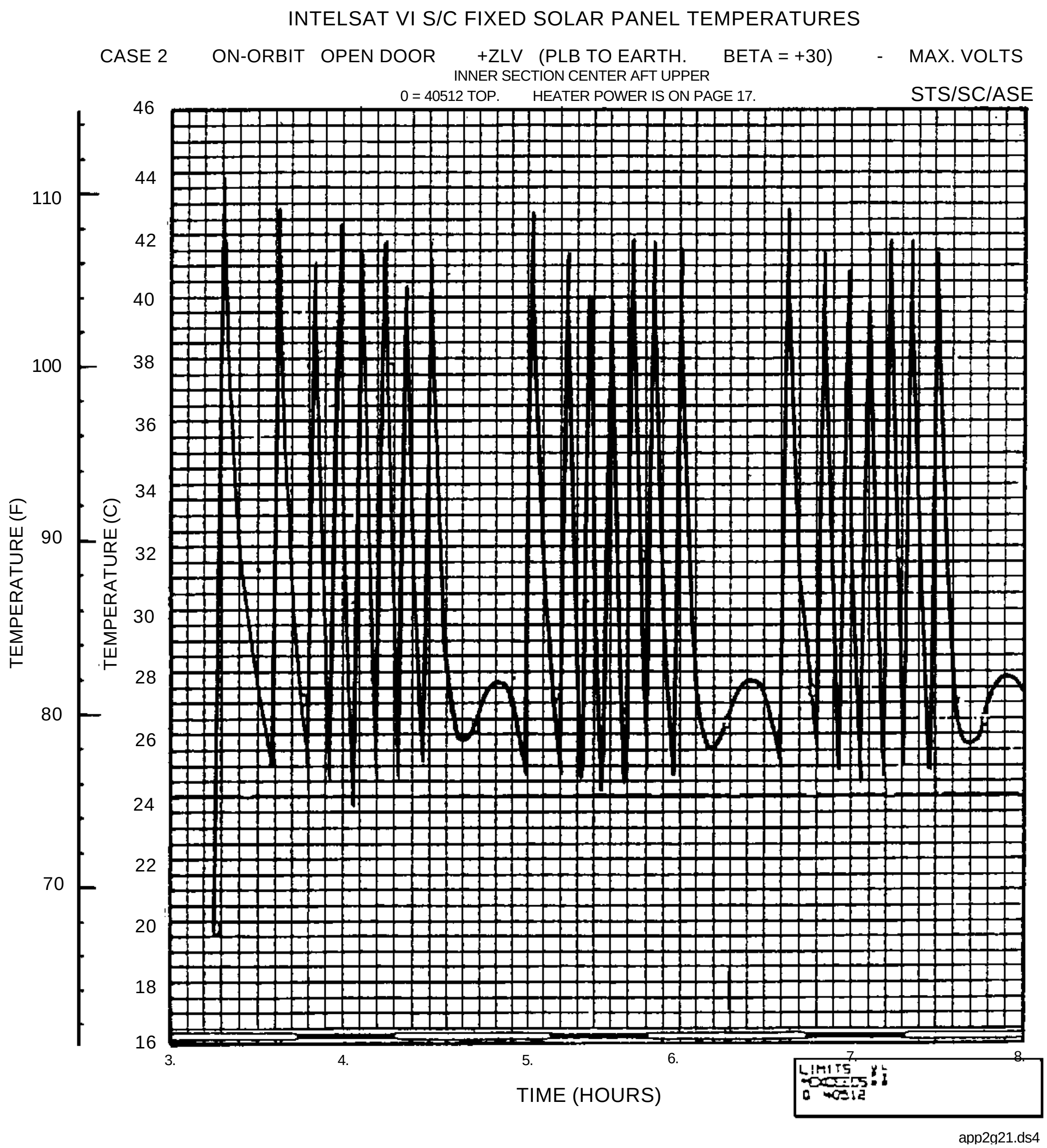

Figure 5-9.- Typical ITMM plot of a node with a heater (nominal case).

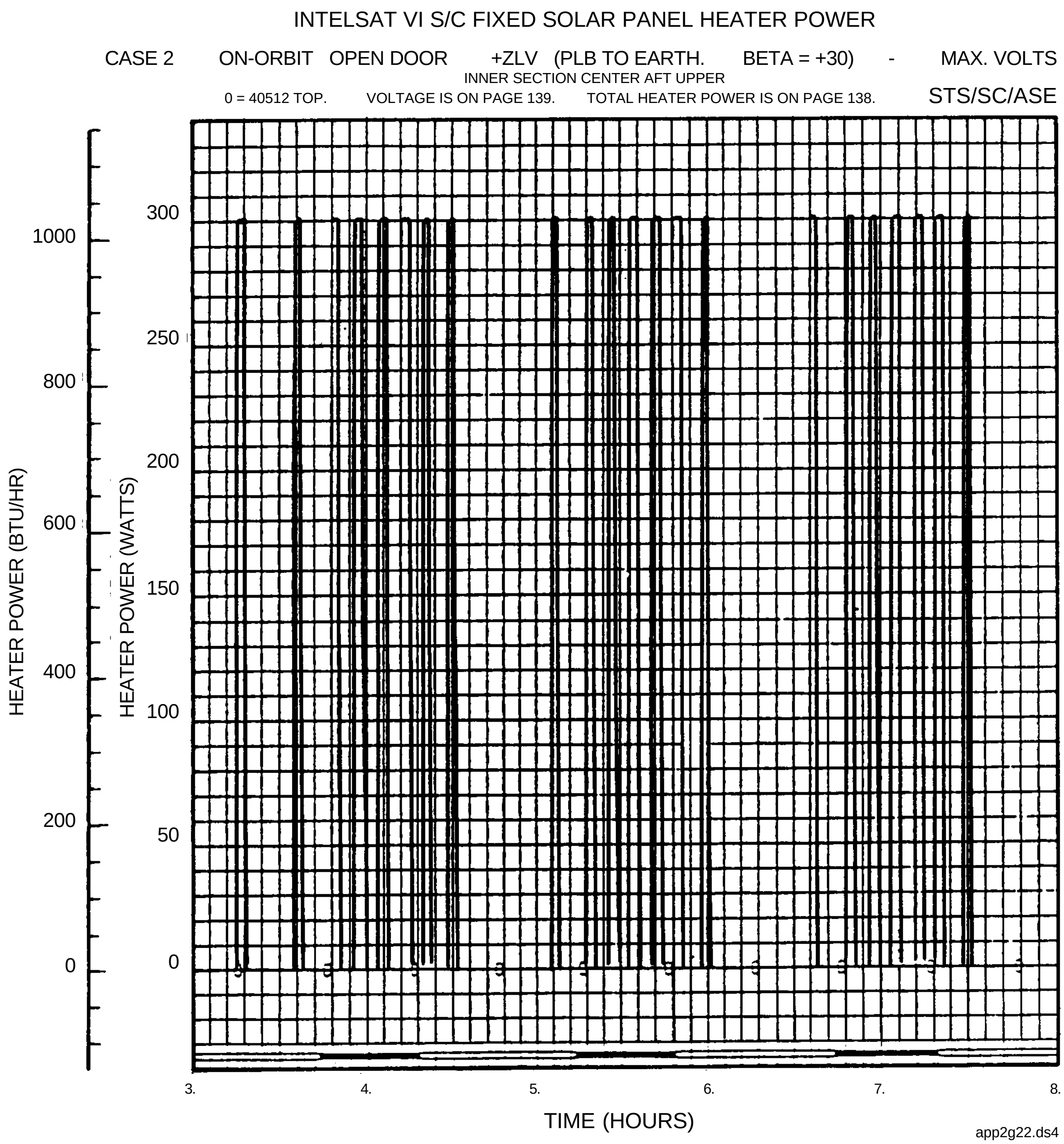

Figure 5-10.- Typical ITMM plot of heater power at a node.

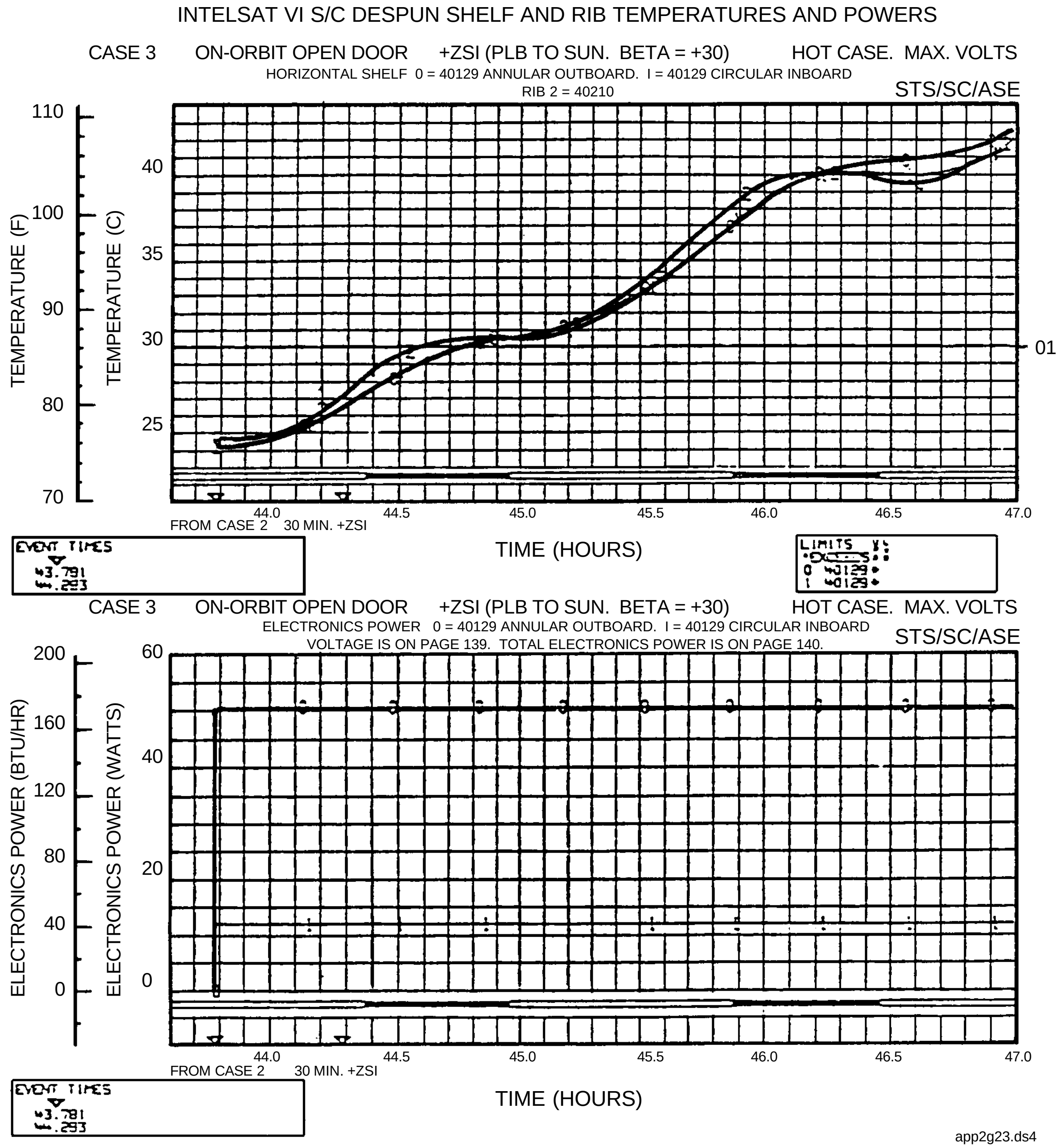

Figure 5-11.- Typical ITMM plots of temperature and heater power (hot case).

NODE MAXIMUM AND MINIMUM TEMPERATURES AND TIMES AT WHICH
THESE TEMPERATURES OCCUR FOR NODES OF SPECIAL INTEREST
CASE 3 INTELSAT VI SC/ASE/ORBITER - +Z SI OPEN DOOR, BETA = +30, 32 VOLTS
HOT CASE

NODE	MAXIMUM			MINIMUM			NODE	MAXIMUM			MINIMUM		
NUMBER	TEMP.-F	TEMP.-C	TIME-HR	TEMP.-F	TEMP.-C	TIME-HR	NUMBER	TEMP.-F	TEMP.-C	TIME-HR	TEMP.-F	TEMP.-C	TIME-HR
40116	135.9	57.7	55.70	8.1	-13.3	44.52	40117	161.5	71.9	54.90	36.0	2.2	44.95
40118	157.9	69.9	54.98	75.3	24.1	43.78	40119	159.0	70.5	54.95	74.1	23.4	43.78
40122	129.4	54.1	55.82	71.3	21.8	43.78	40123	153.8	67.7	55.05	75.1	24.0	43.79
40124	156.8	69.3	54.99	75.3	24.1	43.82	40125	156.8	69.4	54.95	74.5	23.6	43.78
40126	154.9	68.3	55.05	75.0	23.9	43.82	40127	154.8	68.2	54.98	73.8	23.2	43.78
40128	151.1	66.2	55.20	76.5	24.7	43.81	40129	150.0	65.5	55.15	75.6	24.2	43.79
40134	130.0	54.5	55.82	71.3	21.8	43.78	40406	203.9	95.5	54.90	38.9	3.6	44.96
40407	143.3	61.9	54.90	15.1	-9.4	44.95	40413	187.0	86.1	54.90	7.0	-13.9	44.95
40414	200.5	93.6	54.90	28.0	-2.2	44.95	40426	233.1	111.7	54.90	10.6	-11.9	44.95
40427	185.0	85.0	54.90	7.8	-13.4	44.95	40501	167.1	75.0	54.90	68.6	20.4	44.88
40502	190.2	87.9	54.90	69.3	20.7	44.93	40503	166.5	74.7	54.90	67.1	19.5	43.78
40504	174.1	78.9	54.91	72.4	22.4	43.79	40505	173.9	78.9	54.91	75.1	24.0	43.81
40506	166.0	74.4	54.90	59.6	15.3	44.96	40507	190.6	88.1	54.90	62.7	17.1	44.96
40508	165.1	74.0	54.90	58.4	14.7	43.78	40509	171.6	77.6	54.91	68.7	20.4	43.78
40510	171.8	77.7	54.91	66.7	19.3	43.78	40511	166.4	74.7	54.90	75.8	24.3	44.88
40512	191.8	88.8	54.90	75.7	24.3	44.93	40513	165.6	74.2	54.90	76.1	24.5	44.83
40514	171.1	77.3	54.90	78.0	25.6	44.97	40515	171.1	77.3	54.90	78.4	25.8	44.97
40516	168.5	75.8	54.90	51.0	10.6	44.95	40517	192.8	89.3	54.90	54.3	12.4	44.95
40518	167.7	75.4	54.90	56.3	13.5	43.78	40519	172.7	78.1	54.90	67.6	19.8	43.78
40520	172.5	78.1	54.90	65.8	18.8	43.78	40601	185.6	85.4	54.71	3.7	-15.7	44.95
40602	244.2	117.9	54.90	7.7	-13.5	44.95	40603	185.4	85.2	54.90	20.7	-6.3	44.95
40604	193.2	89.6	54.90	65.8	18.8	43.78	40605	193.3	89.6	54.90	63.9	17.7	43.78
40606	184.3	84.6	54.64	-3.6	-19.8	44.95	40607	245.6	118.7	54.90	3.4	-15.9	44.95
40608	183.3	84.1	54.90	16.0	-8.9	44.95	40609	189.7	87.6	54.90	63.3	17.4	43.78
40610	189.9	87.7	54.90	59.3	15.2	43.78	40611	183.3	84.1	54.61	8.9	-12.8	44.90
40612	245.6	118.7	54.90	11.7	-11.3	49.47	40613	181.5	83.1	54.90	23.0	-5.0	47.96
40614	186.5	85.8	54.90	67.2	19.5	44.95	40615	186.8	86.0	54.90	67.6	19.8	44.95
40616	181.9	83.3	54.61	-8.4	-22.5	44.95	40617	245.8	118.8	54.90	-0.2	-17.9	44.95
40618	180.7	82.6	54.90	12.0	-11.1	44.95	40619	185.9	85.5	54.90	62.6	17.0	43.78
40620	186.2	85.7	54.90	59.1	15.1	43.78	40621	217.8	103.2	54.90	-3.5	-19.7	44.95
40622	216.3	102.4	54.90	-3.6	-19.8	44.95	40623	221.2	105.1	54.90	37.5	3.0	44.95
40624	212.3	100.1	54.90	41.6	5.3	44.95	40703	122.0	50.0	55.82	68.1	20.1	43.78
40704	122.5	50.3	55.82	68.5	20.3	43.78	40720	215.7	102.1	54.90	42.0	5.6	43.78
40725	86.6	30.3	55.82	54.9	12.7	43.78	40726	83.0	28.3	55.82	51.5	10.9	43.78
40733	72.9	22.7	55.08	66.3	19.1	43.78	40734	70.5	21.4	55.82	67.7	19.8	43.92
40740	69.8	21.0	55.82	69.3	20.7	45.15	40742	69.7	21.0	43.78	69.6	20.9	49.56
40804	108.7	42.6	54.90	59.0	15.0	43.91	40810	105.0	40.6	54.90	54.0	12.2	44.95
40814	120.8	49.3	54.90	65.9	18.9	43.82	40819	114.4	45.8	54.90	63.9	17.7	43.84
40847	138.3	59.1	54.90	54.7	12.6	43.78	40860	173.0	78.3	54.90	50.4	10.2	43.78
40875	116.1	46.7	55.01	67.0	19.4	43.78	40876	120.2	49.0	55.82	67.0	19.4	43.78
40877	109.6	43.1	54.97	58.2	14.6	43.78	40878	131.4	55.2	55.82	79.9	26.6	43.78
40879	134.2	56.8	55.82	82.6	28.1	43.78							

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Figure 5-12.- Typical ITMM printout of several nodes (hot case).

SUMMARY OF NODES AND THEIR TEMPERATURE LIMITS AND
THE TIMES AT WHICH THESE LIMITS ARE FIRST REACHED OR EXCEEDED
CASE 3 INTELSAT VI SC/ASE/ORBITER - +Z SI OPEN DOOR, BETA = +30, 32 VOLTS
HOT CASE

	TEMPERATURE LIMITS DEGREES - F		DEGREES - C		TIMES AT WHICH LIMITS ARE REACHED AND/OR EXCEEDED (HRS)		MAXIMUM			MINIMUM		
NODE	LOW	HIGH	LOW	HIGH	UPPER LIMIT	LOWER LIMIT	TEMP.-F	TEMP.-C	TIME-HR	TEMP.-F	TEMP.-C	TIME-HR
40118	39.20	96.80	4.00	36.00	44.42	NOT EXCEEDED	157.90	69.94	54.98	75.33	24.07	43.78
40119	39.20	96.80	4.00	36.00	44.26*	NOT EXCEEDED	158.98	70.55	54.95	74.09	23.39	43.78
40122	5.00	95.00	-15.00	35.00	48.20	NOT EXCEEDED	129.38	54.10	55.82	71.29	21.83	43.78
40123	15.80	122.00	-9.00	50.00	47.37	NOT EXCEEDED	-153.78	67.66	55.05	75.14	23.97	43.79
40124	23.00	134.60	-5.00	57.00	48.83	NOT EXCEEDED	156.79	69.33	54.99	75.35	24.08	43.82
40125	23.00	134.60	-5.00	57.00	48.78	NOT EXCEEDED	156.84	69.35	54.95	74.52	23.62	43.78
40126	23.00	134.60	-5.00	57.00	48.94	NOT EXCEEDED	154.86	68.26	55.08	74.97	23.87	43.82
40127	23.00	134.60	-5.00	57.00	48.85	NOT EXCEEDED	154.82	68.23	54.98	73.77	23.20	43.78
40128	42.80	86.00	6.00	30.00	44.77	NOT EXCEEDED	151.10	66.17	55.20	76.48	24.71	43.81
40129	42.80	86.00	6.00	30.00	44.74	NOT EXCEEDED	149.97	65.54	55.15	75.58	24.21	43.79
40132	5.00	95.00	-15.00	35.00	48.64	NOT EXCEEDED	128.30	53.50	55.82	71.44	21.91	43.79
40133	5.00	95.00	-15.00	35.00	48.55	NOT EXCEEDED	128.60	53.67	55.82	71.51	21.95	43.79
40134	5.00	95.00	-15.00	35.00	48.08	NOT EXCEEDED	130.05	54.47	55.82	71.27	21.82	43.78
40135	5.00	95.00	-15.00	35.00	48.18	NOT EXCEEDED	128.87	53.82	55.82	70.96	21.65	43.78
40202	35.60	87.80	2.00	31.00	46.48	NOT EXCEEDED	141.32	60.73	55.82	75.85	24.38	43.83
40203	35.60	87.80	2.00	31.00	46.18	NOT EXCEEDED	148.80	64.89	55.02	75.55	24.20	43.79
40204	35.60	87.80	2.00	31.00	46.23	NOT EXCEEDED	148.03	64.46	55.03	75.59	24.22	43.79
40211	35.60	87.80	2.00	31.00	45.94	NOT EXCEEDED	142.51	61.40	55.42	75.81	24.34	43.89
40428	-173.20	222.80	-114.00	106.00	45.47	NOT EXCEEDED	310.68	154.82	54.90	106.98	41.66	43.78
40431	15.80	91.40	-9.00	33.00	46.67	NOT EXCEEDED	144.42	62.45	55.20	70.53	21.41	43.78
40432	-4.00	80.60	-20.00	27.00	45.34	NOT EXCEEDED	148.94	64.96	55.10	68.89	20.49	43.78
40433	-16.60	104.00	-27.00	40.00	47.13	NOT EXCEEDED	148.99	65.00	54.92	66.34	19.08	43.78
40434	-18.40	87.80	-28.00	31.00	45.38	NOT EXCEEDED	154.77	68.21	54.92	65.53	18.63	43.78
40703	14.00	93.20	-10.00	34.00	48.41	NOT EXCEEDED	122.00	50.00	55.82	68.11	20.06	43.78
40704	14.00	93.20	-10.00	34.00	48.37	NOT EXCEEDED	122.47	50.26	55.82	68.52	20.29	43.78
40876	5.00	95.00	-15.00	35.00	48.87	NOT EXCEEDED	120.16	48.98	55.82	67.00	19.44	43.78
40878	5.00	95.00	-15.00	35.00	47.18	NOT EXCEEDED	131.45	55.25	55.82	79.88	26.60	43.78
40879	5.00	95.00	-15.00	35.00	46.89	NOT EXCEEDED	134.17	56.76	55.82	82.58	28.10	43.78

NODE	Δ TIME (HRS) FROM START OF CASE TO EXCEEDANCE	NODE	Δ TIME (HRS) FROM START OF CASE TO EXCEEDANCE	NODE	Δ TIME (HRS) FROM START OF CASE TO EXCEEDANCE	NODE	Δ TIME (HRS) FROM START OF CASE TO EXCEEDANCE
40119	0.48*	40434	1.60	40878	3.40	40133	4.77
40118	0.64	40428	1.69	40123	3.59	40132	4.86
40129	0.96	40211	2.16	40134	4.30	40125	5.00
40128	0.99	40202	2.70	40135	4.40	40124	5.05
40203	1.40	40431	2.89	40122	4.42	40127	5.07
40204	1.45	40879	3.11	40704	4.59	40876	5.09
40432	1.56	40433	3.35	40703	4.63	40126	5.16

*Spun Shelf/Electronics Units Violates 30-minute PIP Requirement.

THIS CASE STARTED AT 43.78 HOURS

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Figure 5-13.- Typical ITMM summary printout of several nodes (hot case).

Specific payload TMM criteria and guidelines have been established (Criteria/Guidelines for Payload Thermal Math Models for Integration Analysis, JSC 14686) to assist the thermal analyst in this process. These requirements ensure TMM and supporting data consistency and adequacy for economic and reliable analysis and compatibility with SSP standard services. Among these requirements are payload TMM size restrictions (i.e., number of nodes, conductors, external surfaces), minimum allowable stable calculation time interval, payload/Orbiter interface considerations, and adequate documentation.

A complementary payload geometric math model (GMM) is required for each TMM for combining with an Orbiter GMM to produce an integrated geometric math model (IGMM) for use in calculating radiation interchange factors and orbital heat rates for external surfaces. Payload math model documentation should be referenced in the payload-unique ICD.

5.6 Orbiter Thermal Math Models

Several Orbiter midsection/payload bay TMM's are available for use in integrated thermal analyses and are authorized in the appropriate IDD or ICD. These models are listed in Table 5-III in order of decreasing detail, and major differences are noted.

Each Orbiter TMM is constructed in a manner that allows for renodalization of its payload bay liner and wire tray nodes (or zones) to provide additional and/or better distribution of nodes to attain the desired degree of accuracy for both the liner/wire trays and an included payload TMM. Renodalization of the payload bay liner should be considered when the sun's rays may shine directly into the payload bay parallel to the Orbiter Z-axis. (This is discussed in more detail in the next section.) The TMM references also describe how to add the optional payload retention fittings and RMS.

Input data for constant and diurnal prelaunch and postlanding environments, consisting of ambient air and surrounding boundary temperatures and solar heat rates for various conditions at the eastern test range (ETR). These data are included in the closed-door TMM documents, "390 Node" Atmospheric Orbiter Midsection/Payload Bay Thermal Math Model Description, ES3-77-3, ES3-76-7, and ES3-77-1.

While simpler Orbiter models may suffice for most applications, the capabilities and limitations of ES3-76-7 and ES3-77-1, should be understood before the models are used.

TABLE 5-III.- AVAILABLE THERMAL MATH MODELS

Orbiter TMM	Modeling of Payload Bay Liner and Outward Through Orbiter	Wire Trays, Frames, and Aft Fuselage	External Orbiter Heat Loads and Radiation Interchange	References
390 Node	Detailed	Included	Directly applied (must be calculated)	ES3-76-1 ES3-77-3
13	Less detailed than 390 node	May be added	Directly applied (must be calculated)	ES3-76-7
6-Node				ES3-77-1

5.7 Integrated Thermal Math Models

To aid in keeping the analysis cost down, the size (number of nodes) of the integrated thermal math models should be as small as practical and governed by the required accuracy of the results. For this reason, the integrated math model or models used primarily in support of payload design consist of a detailed payload thermal math model and the simplest Orbiter interface math model. The objective is to obtain accurate thermal results for the payload.

As the payload design matures, payload math models are finalized with emphasis on obtaining accurate temperatures at the payload and Orbiter interfaces; and a more detailed Orbiter interface math model is needed, particularly in the payload bay. To keep the overall integrated model size within reasonable range and cost to run, the payload math model may be reduced. The number of surface nodes has the maximum effect on the computer cost.

Generally, payload math model simplification should be directed toward the number of nodes that are "buried" or located within the payload or its components, which would have small effect on the payload interface temperatures, that is, the surface temperatures. For example, a payload component that is covered or enclosed by high-performance insulation could be represented by a single lumped node rather than several nodes, unless this element or component is sensitive to surface temperature or has a relatively strong influence on the surface temperature.

The simplified payload thermal math model should be checked by comparing the temperature results with those derived from the detailed or original model to ensure that the payload surface temperatures, i.e., the interface temperatures, are in agreement. Additional considerations in establishing the integrated thermal math models are discussed in the following paragraphs.

5.7.1 Node and Conductor Identification Numbers

To add a payload TMM to an Orbiter TMM, it is necessary to preclude duplicate node and conductor identification numbers. The preferred method to accomplish this is to use 5-digit node numbers greater than 20,000 and 6-digit conductor numbers when a payload TMM is first constructed. The payload GMM node or surface numbers should be treated similarly.

5.7.2 Convection Heat Transfer

When convection is required, the Orbiter TMM external surface convection code, which is built into the 390-node closed-door TMM (ES3-77-3) or provided for inclusion in the SOTS TMM's (JSC 22437), may be readily adapted to apply to the payload TMM external surfaces by making the associated payload conductors adhere to the format and placement in the model of Orbiter TMM convection conductors. Convection effects should be included in conductances across single-layer insulation blankets and multilayer insulation (MLI). For best results, these conductances should vary with pressure and temperature for ascent and entry mission phases. ES3-77-3 and JSC 22437 contain additional information regarding convection.

5.7.3 Other Effects

As noted in section 2, solar entrapment can prevent special problems. In a +ZSI (top-to-sun inertial) attitude, the sun's rays are parallel to the Orbiter Z-axis. In this attitude, Orbiter payload bay bulkhead and payload surfaces may be significantly hotter than anticipated in local areas near the payload bay liner where the view factor to space is small in the presence of direct or reflected solar energy. This solar entrapment can occur on payload surfaces which face the payload bay liner and have no direct view of the sun. If a few relatively large payload bay liner nodes are used in the analyses, this effect may not be discernible, especially if the payload shadow outline crosses a liner node. Therefore, to provide the needed accuracy, the payload bay liner in the vicinity of the payload should be renodalized. In general, new payload bay liner node boundaries are established at the edges of the projection (in the Z-direction) of the payload outline on the payload bay liner. Then fairly narrow nodes (6 to 10 inches) are established on either side of the projected payload outline. A before and after sample of payload bay liner renodalization in the presence of a payload is shown in Figures 5-14 and 5-15. The proximity of an adjacent payload can also result in solar entrapment by reducing the view factor to space.

In determining payload attitude thermal constraints, it may be sufficient to model this adjacent payload with a simulated blocking surface. For example, a large-diameter insulated adjacent payload can be simulated by employing two zero-capacitance back-to-back disks (or geometric shapes representing the projection of the adjacent payload on the Orbiter Y-Z plane) located at the end of the adjacent payload nearest the payload of interest. For accuracy, smaller nodes should be adiabatic on the sides that face each other. A mission verification integrated analysis, on the other hand, may require detailed modeling of both (all) payloads.

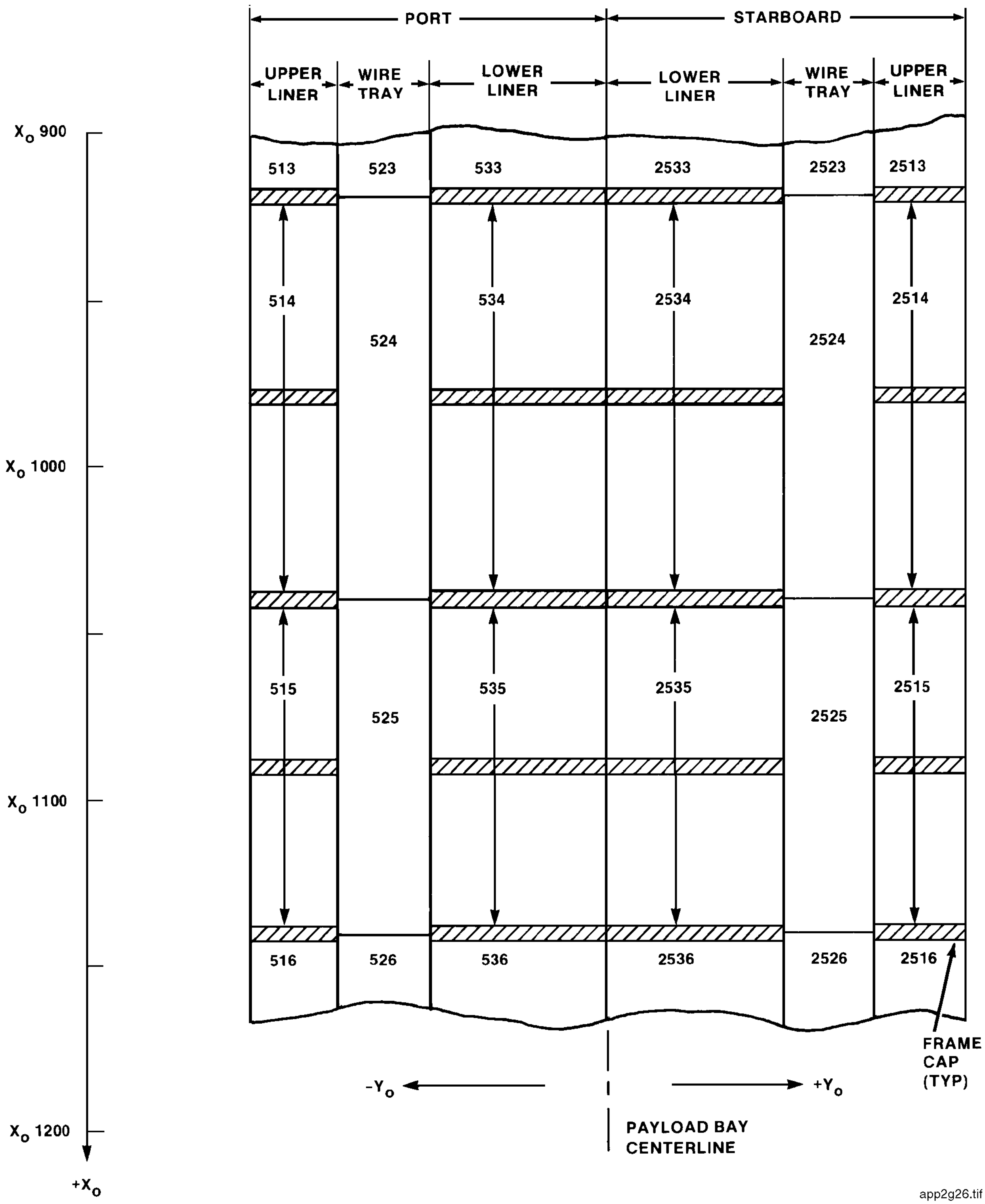


Figure 5-14.- Payload bay liner nodal pattern provided in the Orbiter thermal math model.

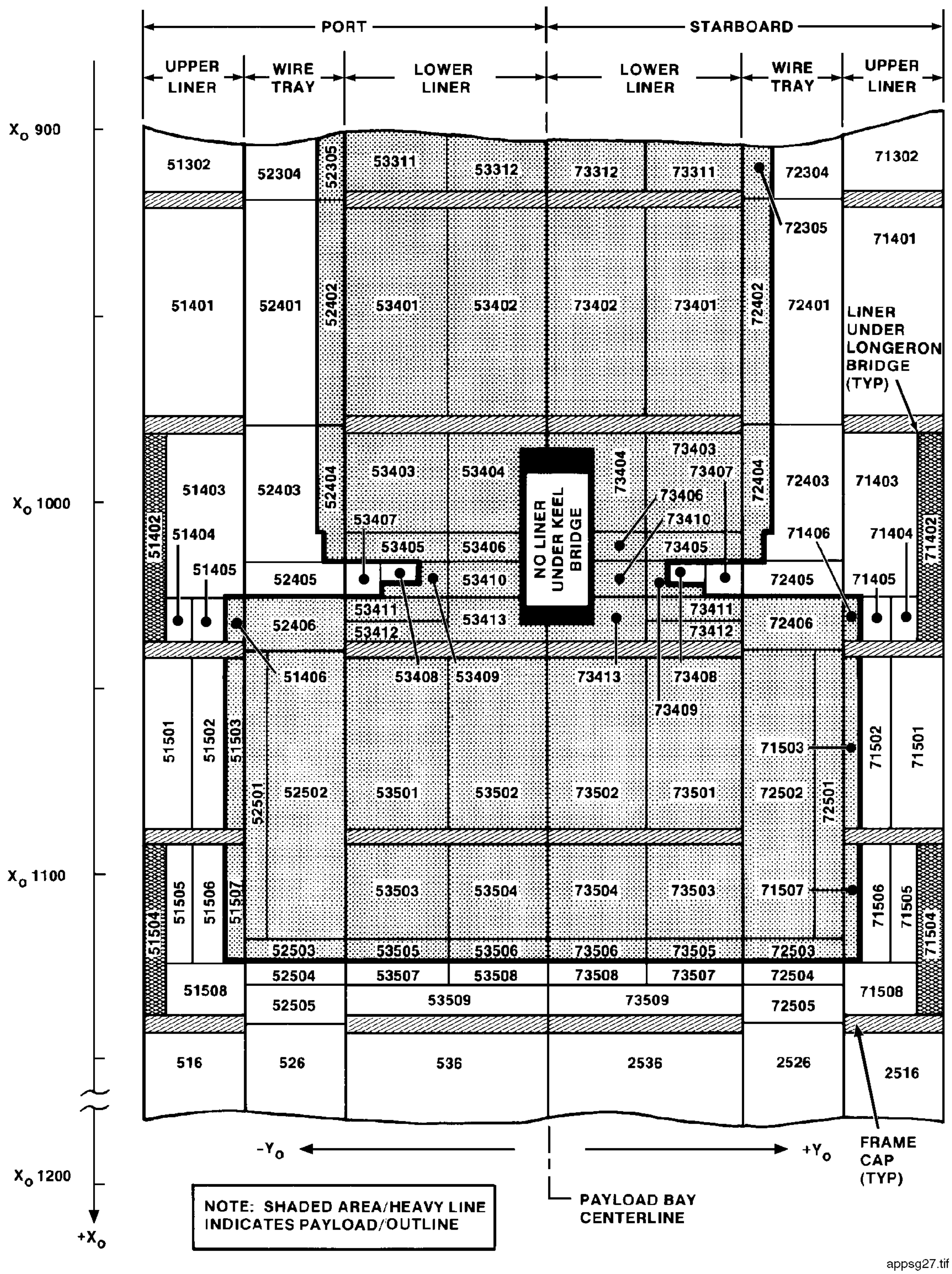


Figure 5-15.- Payload bay liner nodal pattern resulting from renodalization in the vicinity of a payload.

Nonstandard Services

6

This section provides information on the following nonstandard services:

- Active liquid cooling
- Prelaunch/postlanding spigot cooling in the payload bay
- Aft flight deck air cooling
- Orbiter-provided oxygen or nitrogen gas
- GSE prelaunch gas service

6.1 Active Liquid Cooling

Active liquid cooling is available to payloads located either in the payload bay or middeck. The cooling is accomplished by the payload heat exchanger which is a component of the Orbiter active thermal control system (ATCS). The payload heat load together with loads from the various Orbiter heat sources are absorbed into the Orbiter ATCS Freon-21 coolant loop as shown in Figure 6-1. The heat rejection from the ATCS is accomplished with the following sinks:

- GSE heat exchanger during prelaunch
- Flash evaporator during ascent and deorbit
- Radiator supplemented by flash evaporator during on orbit
- Radiators and ammonia boiler operation during descent and postlanding
- GSE heat exchanger approximately 45 minutes after landing

The payload heat exchanger has two passages available to payloads. One is normally provided to payloads in the middeck; the other is provided for payloads in the payload bay. However, both passages can be provided for payloads located in the payload bay. The supply temperature to the payload is a function of actual heat exchanger performance and should be determined based upon the effectiveness curves defined in ICD 2-19001. Dual use of the payload heat exchanger will reduce performance and the supply temperature will be determined by the SSP. The cooling capacity available at the payload heat exchanger varies as a function of mission phase. As indicated in ICD 2-19001, cooling during the prelaunch, ascent, descent, and postlanding phases is limited to 5200 Btu/hr. The on-orbit capacity is 29,000 Btu/hr after the payload bay doors are opened. For checkout purposes, the 29,000 Btu/hr capacity is available for limited time periods during prelaunch; however, this requires special negotiation with the SSP and is not available during the final hours of the countdown. In addition, the cooling capacity for middeck payloads will be limited to an amount not greater than the electrical power available to middeck payloads and to an amount that will not cause the cabin temperature limit to be exceeded during any mission phase.

The customer will provide a pump package with accumulator and will control coolant flow rate and pressure (200 psia maximum) on the payload side of the heat exchanger. In addition, the customer is responsible for freeze protection, filtration, and instrumentation. Freon 114 or water may be selected for use in the payload bay; however, Freon 114 is recommended to avoid potential freezing problems. The required coolant for middeck payloads is water and is not expected to have potential freezing problems as long as there are at least two Orbiter fuel cells operating at a total of 11kW. Water is also required for habitable modules in the payload bay.

Although lines are insulated, stagnant sections of water lines may require heaters when water is used as a coolant for payloads in the payload bay. Failure modes that preclude proper water flow rates can cause water freezing. When water is used as a coolant, ICD 2-19001 requires maintaining a minimum water flow rate of 100 lb/hr for all on-orbit periods to prevent freezing. Water line freezing can cause payload heat exchanger overpressurization and present a catastrophic hazard to the Orbiter if both Orbiter Freon loops are lost.

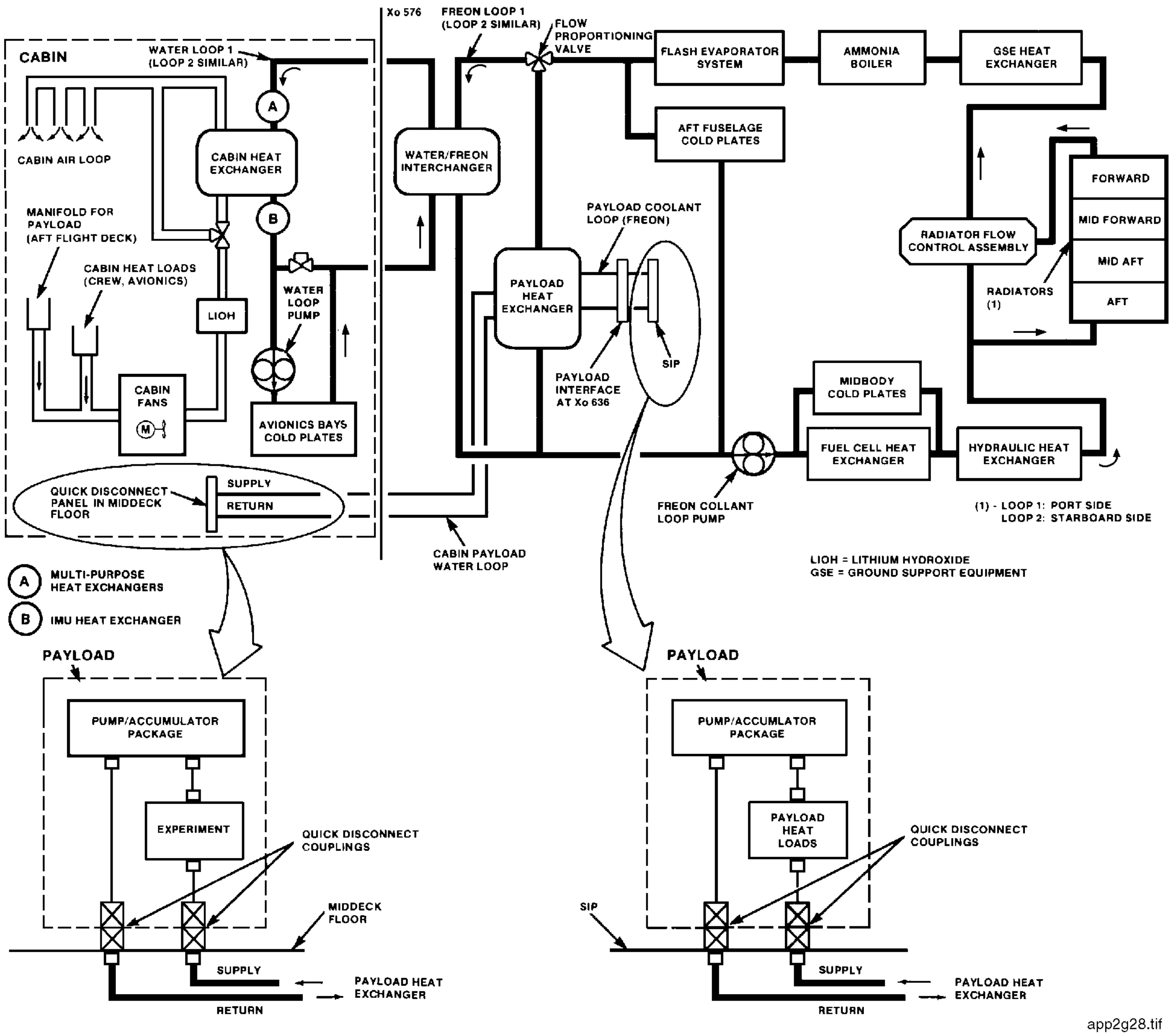


Figure 6-1.- Simplified Orbiter active cooling system.

In addition to limiting the maximum operating pressure to 180 psia, the payload must also withstand 180 psia on the payload side of the heat exchanger if a leak develops in the heat exchanger between the payload side and the Orbiter side.

6.1.1 Payload Active Cooling Kit

For payloads located in the payload bay a payload active cooling kit (PACK), Figure 6-2, is used to connect the payload to the Orbiter ATCS. The interconnecting plumbing between the PACK and the payload is furnished by the customer. The PACK interface is at a standard interface panel. The standard interface panel is located on the port side of the Orbiter at a longitudinal position specified in the payload-unique ICD. The PACK installation is designed for a wet mate (quick disconnect) interface and accommodates both OPF horizontal and launch pad vertical installation of payloads. The interfacing quick disconnects will be furnished by the SSP.

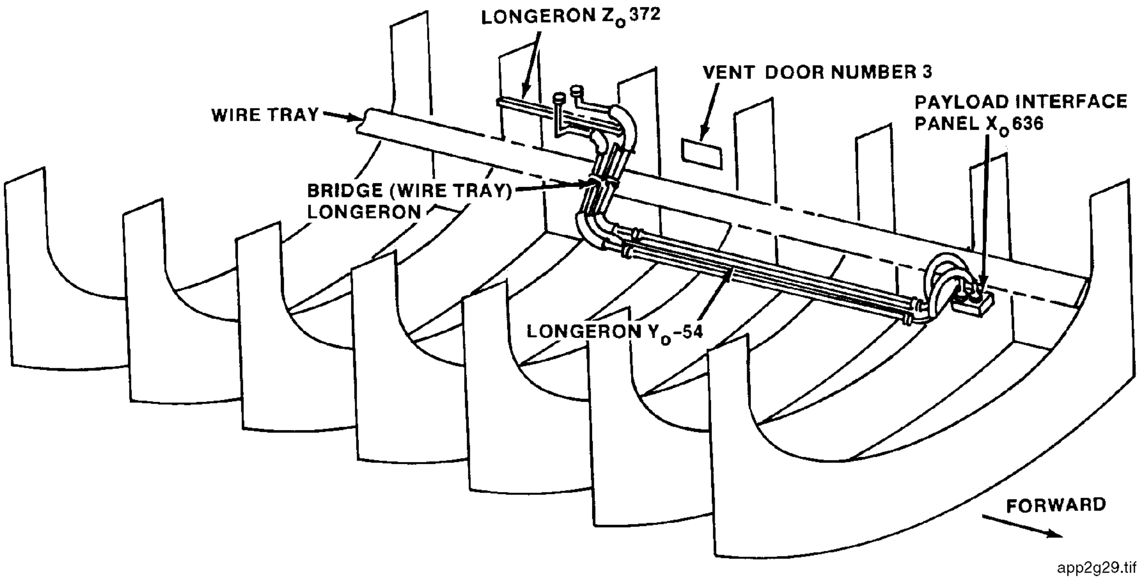


Figure 6-2.- Typical PACK installation.

6.1.2 PACK Leakage Rates

For payload system analyses, the PACK leakage rates in Table 6.1 shall be used. The ground conditions assume an internal pressure of 60 psia and an external pressure of 14.7 psia. The on-orbit condition assumes an internal pressure of 100 psia and a vacuum outside the lines.

TABLE 6-I

	Ground 1	On orbit 2
Water	0.1 cc/hr	0.2 cc/hr
Freon 114	0.2 cc/hr	0.5 cc/hr

6.1.3 Cabin Middeck Payloads

The interface for liquid cooling in the middeck is via quick disconnects located on the middeck floor as shown in Figure 6-3. The interfacing quick disconnects will be furnished by the SSP. The system is designed for wet mate installation. The coolant plumbing located in the cabin must be appropriately insulated to preclude condensation. In the case of an interchanging air cooling loop, water coolant temperature inlet to the air-to-water heat exchanger should be controlled so that water does not condense at the heat exchanger. Maximum cabin dew point is defined in Shuttle/Payload Interface Definition Document for Middeck Payload Accommodations, NSTS 21000-IDD-MDK.

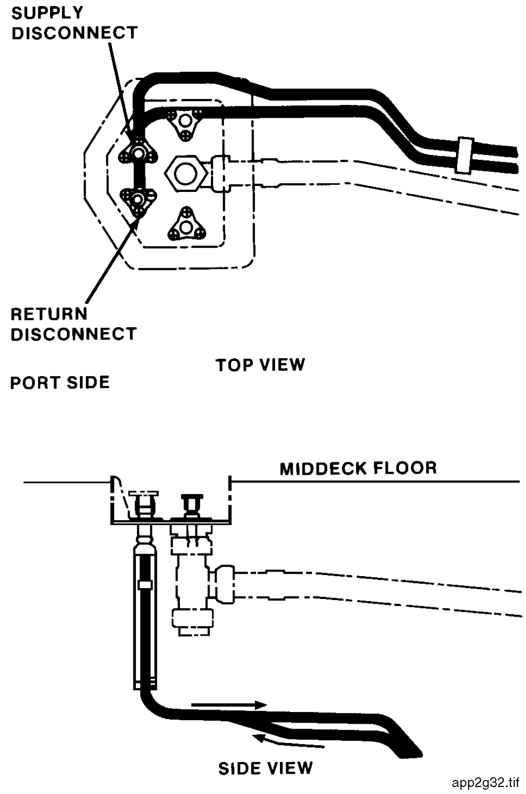


Figure 6-3.- Payload interface with the water loop in the Orbiter middeck.

6.2 Prelaunch/Postlanding Spigot Cooling

Purge gas spigot cooling is available to supplement the standard payload bay purge during prelaunch operations and the postlanding period at primary and alternate landing sites. Three spigots are available for payload use and are capped unless required.

If spigots are used , the SSP will design and fabricate the ducting and support fixtures from the negotiated payload interface to one or more spigots as required. The nominal flow of 50 pounds per minute is available from each spigot if all three spigots are utilized. If only one spigot is utilized, the maximum flow rate is 100 pounds per minute for that spigot.

Since the spigot system is part of the payload bay purge system, the conditioned gas is the same as the purge supply. Therefore, the gas conditions and flow rates must be negotiated to be compatible with other payloads that are manifested for the flight.

6.3 Aft Flight Deck Air Cooling

The Orbiter air ducting can provide air cooling for electronic boxes compatible with cooling by forced convection. Cabin air at 95 degrees F maximum will be drawn into the box and exit (via an orifice and interface duct) into the Orbiter manifold duct. The orifice and interface duct are provided by the SSP. The combined pressure drop for the avionics box, the orifice, and the interface ducting is limited to 1 inch of water at the design air flow of 0.406 lbm/hr/W. Therefore, the payload-unique ICD must define the pressure drop allocation for the payload. After completion of avionics box pressure drop testing (provided by the customer), the orifice will be sized so that the total pressure drop is 1 inch of water. The payload-unique ICD will then be updated, if required, to define the maximum pressure drop for the payload, as well as the other unique parameters (heat load, air flow requirement, and geometric and connection interface definition).

6.3.1 Payload Station and Mission Station Support (14.7-psia Cabin Pressure)

The Orbiter can provide cooling for the removal of a combined maximum of 2475 Btu/hr (725 watts) average from both stations during on-orbit operations. For prelaunch, ascent, descent, and postlanding, the air cooling is limited to 1193 Btu/hr. The above values include up to 341-Btu/hr (100 watts) cooling for aft flight deck payload equipment consuming small quantities of power (10 watts each) by direct radiation or convection to the cabin. Specific forced-air cooling will not be provided.

Total air flow available to the aft flight deck stations is approximately 300 lb/hr but is dependent on the flow distribution requirement between the payload and mission stations as defined in the IDD. Air cooled avionics air flow will be provided at a rate of 0.406 lb/hr/W of heat load, and therefore, cooling design will be based on an air temperature increase of 35 degrees F across each avionics box.

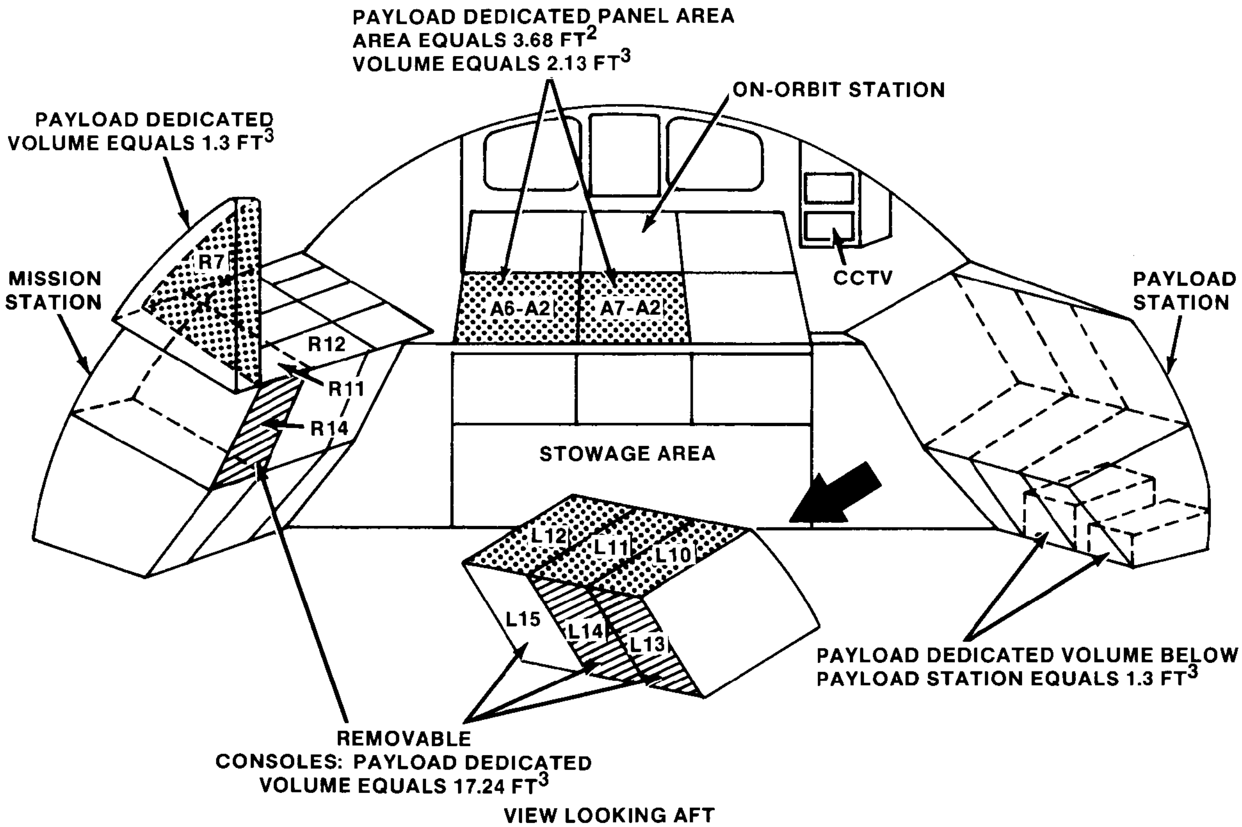
6.3.2 Physical Location and Ducting Installation

Payload areas in the aft flight deck are shown in Figure 6-4. Only compartments at L10, L11, L12, and R11 are dedicated for air-cooled payloads. Figure 6-5 depicts isometric views of the Orbiter manifold duct at both the Payload and Mission Stations. The available area for duct routing and connection accessibility is very limited due to wiring, connectors, and secondary structure; therefore, the SSP provides interface ducting (between the manifold and avionics box) and installs the required orifice discussed previously.

6.3.3 Operation at Reduced Cabin Pressure

All air-cooled equipment may be subjected to reduced air flow because of the reduction of cabin pressure from 14.7 to 10.2 psia. The 10.2-psia cabin condition is implemented to accommodate on-orbit pre-EVA (prebreathe) operations, and could last for the entire on-orbit duration for some missions. The resulting air flow is equal to the 14.7-psia air flow times the pressure ratio of the reduced cabin pressure (10.2 psia) to the normal cabin pressure (14.7 psia). The maximum air inlet temperature for this condition is 80 degrees F.

Another mode of reduced cabin pressure is the 8-psia contingency mode. This mode occurs in the event of a puncture in the pressure walls of the cabin and is considered an abort mode. All payload equipment will be powered off for the 8-psia cabin condition so that maximum heat rejection is available for Orbiter use.



NOTES:

1. LEGEND

   ▩ PAYLOAD DEDICATED PANEL AREA EQUALS 16.85 FT^2.

   ▨ ADDITIONAL PAYLOAD DEDICATED D&C PANELS ON INBOARD SURFACES OF THREE EQUIPMENT CONSOLES REQUIRE ALLOWANCE OF SIX (6) INCHES DEPTH OF NORMAL PANEL AREA. ALL COMPONENTS ON THESE SURFACES MUST BE FULLY RECESSED. ADDITIONAL PANEL SURFACE AREA IS 5.5 FT^2.

2. TOTAL PAYLOAD DEDICATED VOLUME IS 21.64 FT^3.

app2g36

Figure 6-4.- Shuttle Orbiter payload physical interface locations - aft flight deck general arrangement.

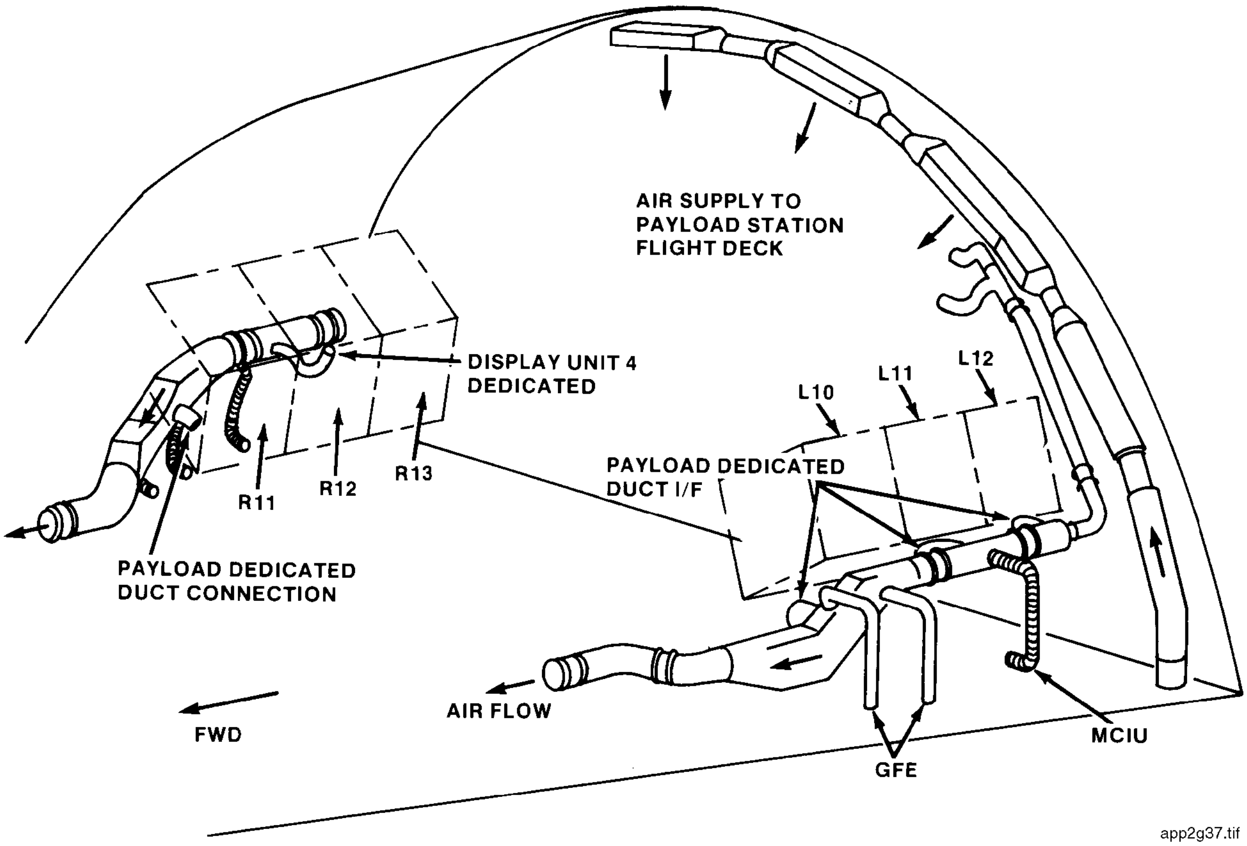


Figure 6-5.- Aft flight deck air duct interface locations.

6.4 Middeck Ducted Air Cooling

The ducted air cooling interface is defined in NSTS 21000-IDD-MDK for middeck locker payloads which require active cooling. Each locker payload shall provide its own circulation fan to draw air from the avionics bay volume and dump hot (return) air into the Orbiter return air duct. The avionics bay volume (supply) air temperature is nominally at 80 degrees F except during ascent/entry and certain mission phases. The supply air for these mission phases will be 85 degrees F nominally and up to 95 degrees F spike (10 minutes above 85 degrees F). The services are available in avionics bay 1, 2, and 3A. The locker locations with the cooling interface in each bay are also identified in NSTS 21000-IDD-MDK. Each location will have a dedicated air cooling flow rate of either 18 or 36 cubic feet per minute.

6.5 Middeck Accommodations Rack (MAR)

The MAR has been designed to permit the integration of small payloads and experiments into the middeck. It is meant to supplement the middeck lockers.

The payloads that use the MAR are required to meet the requirements specified in NSTS 21000-IDD-MDK, or as negotiated through the IP process. The thermal accommodations of the MAR are as defined in Section 4.2 in this document. The design and analysis requirements are in Section 6.6. The amount of heat that can be dissipated into the cabin environment or into the Orbiter coolant loop will be limited to values dependent upon specific mission capabilities. The maximum heat load that a payload will be permitted to dissipate into the cabin atmosphere will be as specified in NSTS 21000-IDD-MDK, or as negotiated through the IP process.

Thermal control for payloads or experiments installed in the MAR will be obtained through one of the following methods, which must be approved through the IP negotiation with the SSP:

Passive thermal control: All payload-generated heat will be conducted or radiated to the MAR structure for re-radiation to the middeck cabin environment. Convective circulation of cabin air past the MAR will serve to dissipate the heat. A thermal closeout panel will not be installed when this method of thermal control is used.

Active thermal control: A thermal control module, called the MAR Cooling Module, utilizing a water-to-air heat exchanger, is designed to dissipate heat loads of up to 1000 watts of payload-generated heat with 50°F coolant temperature change. An integral fan and system of ducting will create a closed system that will circulate payload-heated air through the heat exchanger and back past the payload components. A payload supplied thermal closeout panel will be installed when this method of thermal control is used.

Water circulating pumps only: The MAR Cooling Module is fabricated so that the circulating pumps and accumulator can be used alone. This is to accommodate users wanting water circulation through cold plates or a water jacket for thermal control. Using this system, a payload can get more than 1000 watts of cooling if the Orbiter payload cooling loop has enough reserve to allow it.

Payload-unique module: When dictated by design of a payload or experiment, a payload-unique thermal control module can be installed in the MAR for direct connection to the Orbiter heat exchange loop. All coolant lines and cold surfaces need insulation to prevent or minimize condensation. Installation of the thermal closeout panel will be optional when this method of thermal control is used.

Flight Data

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Following is a brief summary of the Orbiter flight thermal test program. A more comprehensive discussion and data are presented in Orbiter Payload Bay Flight Temperature Data, JSC 19956. It should be noted, however, that the flight temperature data reported are not necessarily the worst case maximum or minimum temperatures since the test flights were not necessarily performed to design conditions. As an example, the entry and postlanding temperatures as a result of a mission abort such as AOA or abort from on orbit with limited pre-entry conditioning can be expected to be significantly greater than the data presented herein for those mission phases. Results of the flight test program have confirmed that the payload bay thermal environment is within predicted ranges for the various mission phases. During the prelaunch, launch, and on-orbit (closed-door) phases, the flight data indicated relatively narrow and moderate temperature ranges. The purge air or gas, as it flows from the forward end of the payload bay to the aft end, does influence the prelaunch temperature. During the ascent phase, maximum temperatures are relatively moderate and generally about 5 to 10 degrees F greater than the value at lift-off. The minimum temperature value, which is about 15 to 20 degrees F less than the lift-off values, occurs during the early part of ascent when venting, or outflow, of the purge gas from the payload bay reduces the pressure and temperature in the payload bay.

Once the desired orbit is achieved and prior to opening the payload bay doors, the temperature in the payload bay is seen to increase as a result of heat soak-back from the exterior structure into the payload bay.

When the payload bay doors are opened, (normally performed with the payload bay facing Earth), subsequent flight attitudes and the space environment play dominant roles in defining the thermal environment in the payload bay, and may result in wide temperature ranges.

Temperatures at various locations within the payload bay are also influenced by the thermal characteristics of the surface or area. For example, the temperature response of the payload bay liner, which has low thermal capacitance, responded rapidly toward the forward end of the payload bay during the brief periods of the STS-1 flight when the payload bay was facing toward the sun. During the nominal or thermally benign flight attitude of payload bay toward the Earth (+ZLV), the liner temperature varied from about 15 to 80 degrees F during each orbit as the Orbiter passed from the shadow side to the sunlight side of the Earth.

In comparison, the development flight instrumentation (DFI) pallet attach fitting, which has a larger thermal capacitance, had a slower response rate and smaller temperature variation per orbit (Figure 7-1). Also the temperature continued to decay for more than 30 hours into the mission and began to stabilize during the second payload-bay-toward-Earth (+ZLV) flight attitude.

Selected payload bay temperatures for the +ZLV attitude (the major attitude flown for STS-2) are presented in Table 7-I for STS-1 and STS-2. Nominal temperatures are evident for the various regions within the payload bay, and good agreement between predicted and flight data is indicated. STS-1 was flown at a low beta angle ($\beta \simeq$ -30 degrees), resulting in temperatures of the port and starboard sides of the payload bay being about the same. However, at larger beta angles, such as those flown during STS-2 ($\beta \simeq$ -60 degrees), there is a difference between the temperatures of the port and starboard sides because the environmental heat fluxes impinging on the cargo are not symmetrical and are greater on the port side.

Mission timeline and flight attitudes for STS-3 and STS-4 were flown to achieve more severe thermal conditions. For STS-3, the temperature response of the DFI attach fitting is shown in Figure 7-2. Early in the mission, the 24 hours of Orbiter tail-

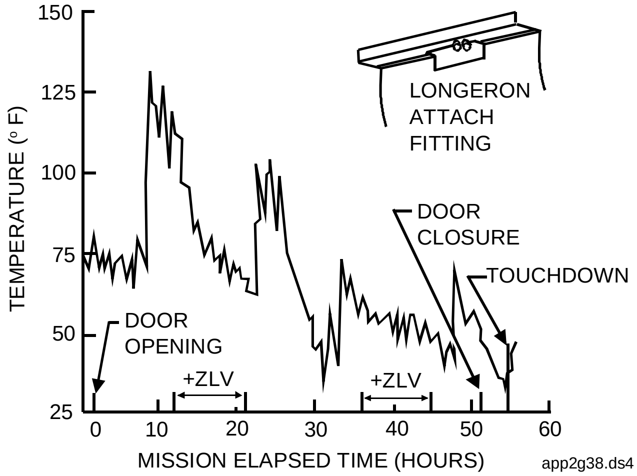

Figure 7-1.- STS-1 DFI pallet attach fitting temperature.

TABLE 7-I.- MINIMUM AND MAXIMUM PAYLOAD BAY ON-ORBIT TEMPERATURES FOR STS-1 AND STS-2

	STS-1 +ZLV, β ≈ -30°		STS-2 +ZLV, β ≈ -60°			
			Port		Starboard	
Location	Actual (°F) 5/80	Predicted (°F)	Actual (°F)	Predicted (°F)	Actual (°F)	Predicted (°F)
Liner	5/80	0/75	25/65	15/75	0/35	5/40
Longeron	15/20	18/30	40/45	35/50	15/20	15/30
Fitting	—	—	—	—	—	—
Bulkhead	0/ + 128	25/ + 120	0/100	-10/115	0/100	-10/115

to-sun and payload-bay-to-space attitude (the coldest attitude flown) resulted in a temperature drop from about 80 degrees F to less than -50 degrees F. The close agreement between predicted results and flight data is indicated until toward the end of this flight attitude period, when there is an increasing difference between the two. Both the flight data and the prediction indicate that an equilibrium temperature was not reached during the 24-hour period.

Following the cold attitude, the 10-hour passive thermal control (PTC) with the Orbiter rotating (rolling) at four revolutions per hour resulted in temperature recovery. This was followed by the 80-hour nose-to-sun attitude with the Orbiter rotating at two revolutions per orbit. During this period, an equilibrium temperature of -20 degrees F was reached (the predicted value was -35 degrees F). This was followed by the hottest attitude flown, a 27-hour period with the payload bay toward the sun (+ZSI). A maximum temperature of about 130 degrees F was reached (the predicted value approached 150 degrees F). It is evident the predictions exceeded the flight data for the hot and cold attitudes.

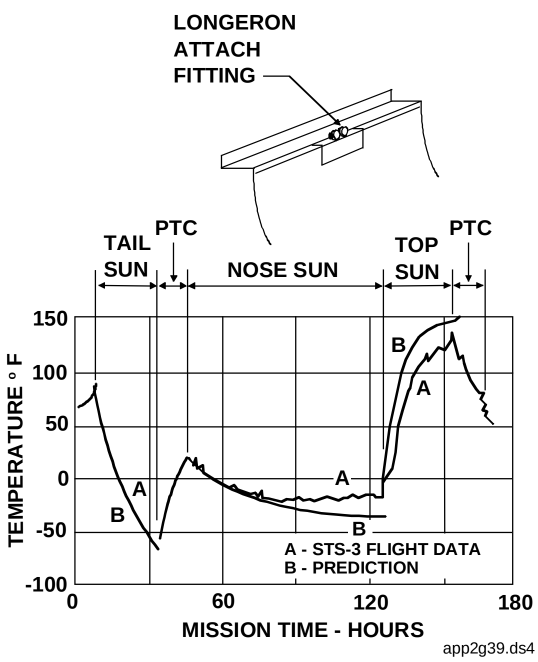

Figure 7-2.- STS-3 DFI pallet attach fitting temperature.

The temperature response of the DFI pallet attach fitting provides an example of the effect of the flight attitudes flown during STS-4 (Figure 7-3). STS-4 consisted principally of two periods of bottom-to-sun (-ZSI) attitude followed by 61 hours of tail-to-sun (+XSI) attitude. There were two short periods of payload-bay-to-sun (+ZSI) attitude and two periods of PTC. The maximum temperature was 110 degrees F and the minimum temperature was -35 degrees F. These maximum and minimum values were less than those reached during STS-3.

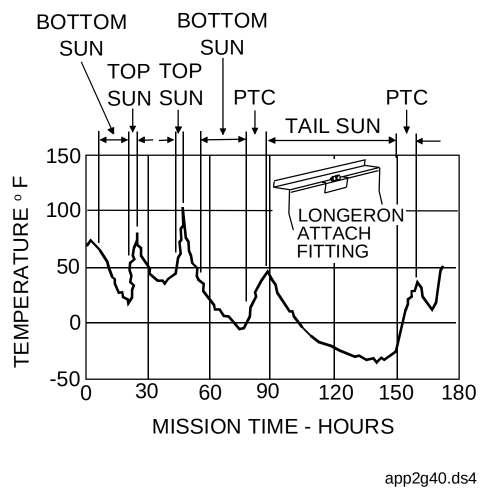

Figure 7-3.- STS-4 DFI pallet attach fitting temperature.

The maximum and minimum temperatures for other payload bay surfaces for STS-3 and STS-4 are given in Table 7-II, which includes the predicted values. The payload bay liner, with a small thermal capacitance, reached the lowest temperature of -153 degrees F during the tail-to-sun (+XSI, one revolution per orbit roll about the X-axis) flight attitude and the highest temperature of 260 degrees F during the payload-bay-to-sun (+ZSI) period. However, the maximum temperature value is the temperature of a layer of material below the semi-transparent liner (beta cloth) and not the temperature of the liner itself.

A summary of selected payload bay temperatures during nominal entry and post-landing phases is presented in Table 7-III. The maximum temperature during this phase, 85 degrees F, occurred after touchdown as a result of heat soak-back from the exterior structure into the payload bay. The minimum temperature of 10 to 20 degrees F occurred in all cases at the entry interface as a result of the end-of-mission attitude sequence, which consisted of two orbits tail-to-sun with payload bay doors open and two orbits top-to-sun with payload bay doors closed.

TABLE 7-II.- MINIMUM AND MAXIMUM PAYLOAD BAY ON-ORBIT TEMPERATURES FOR STS-3 AND STS-4

Location	STS-3						STS-4		
	Tail Sun/Orbit Rate		Nose Sun/ 2 Orbit Rate		Top Sun		Bottom Sun	Tail Sun	Top Sun
	Data (°F)	Prediction (°F)	Data (°F)	Prediction (°F)	Data (°F)	Prediction (°F)	Data (°F)	Data (°F)	Data (°F)
Liner	-153	-160	-100/50	-110/150	30/260*	0/200	-80/30	-100/20	210
Longeron	-95/-50**	-90/-60	-40/-20**	-54/-30	80/102	62/99	-20	-40	80
Fitting	-50	-60	-20	-35	125	140	-10	-35	110
Bulkhead	-120	-55	-100/20	-130/30	0/100	3/86	-80/0	-100/30	0/100

* Measurement suspect

** Forward/aft longeron temperature

Table 7-III.- PAYLOAD BAY ENTRY AND POSTLANDING TEMPERATURE

Location	Entry Interface/Touchdown/Maximum							
	STS-1		STS-2		STS-3		STS-4	
	Actual (°F)	Predicted (°F)	Actual (°F)	Predicted (°F)	Actual (°F)	Predicted (°F)	Actual (°F)	Predicted (°F)
Purge[a]	55/65		55/85		55/85		55/65	
Air[b]	-45/30	-150/66	-78/80	-105/105	-80/85	-105/105	-70/80	
Liner	28/60/70	20/48/74	20/55/70	20/68/90	15/55/70	15/55/76	-70/75	
Longeron	3/38/75	3/25/79	18/40/70	10/30/80	5/38/63	5/28/67	0/50/75	
Fitting	-	-	-	-	15/65/70	-	10/60/75	
Radiator	18/32/80[c]	18/35/108	15/30/85[d]	15/85/95	2/80/85[d]	20/85/95	-6/75/80[d]	
Bulkhead	28/58/85	28/42/87	20/80/85	15/55/68	15/80/70	15/55/78	0/65/75	

[a]Purge was 55° F initially, then increased to 65° F after a few hours.

[b]Air measurement appears to be environment temperature.

[c]Radiator flow from touchdown to touchdown +15 minutes.

[d]Radiator flow from touchdown -6 minutes to touchdown +15 minutes.

Illustrations of Flight Attitudes

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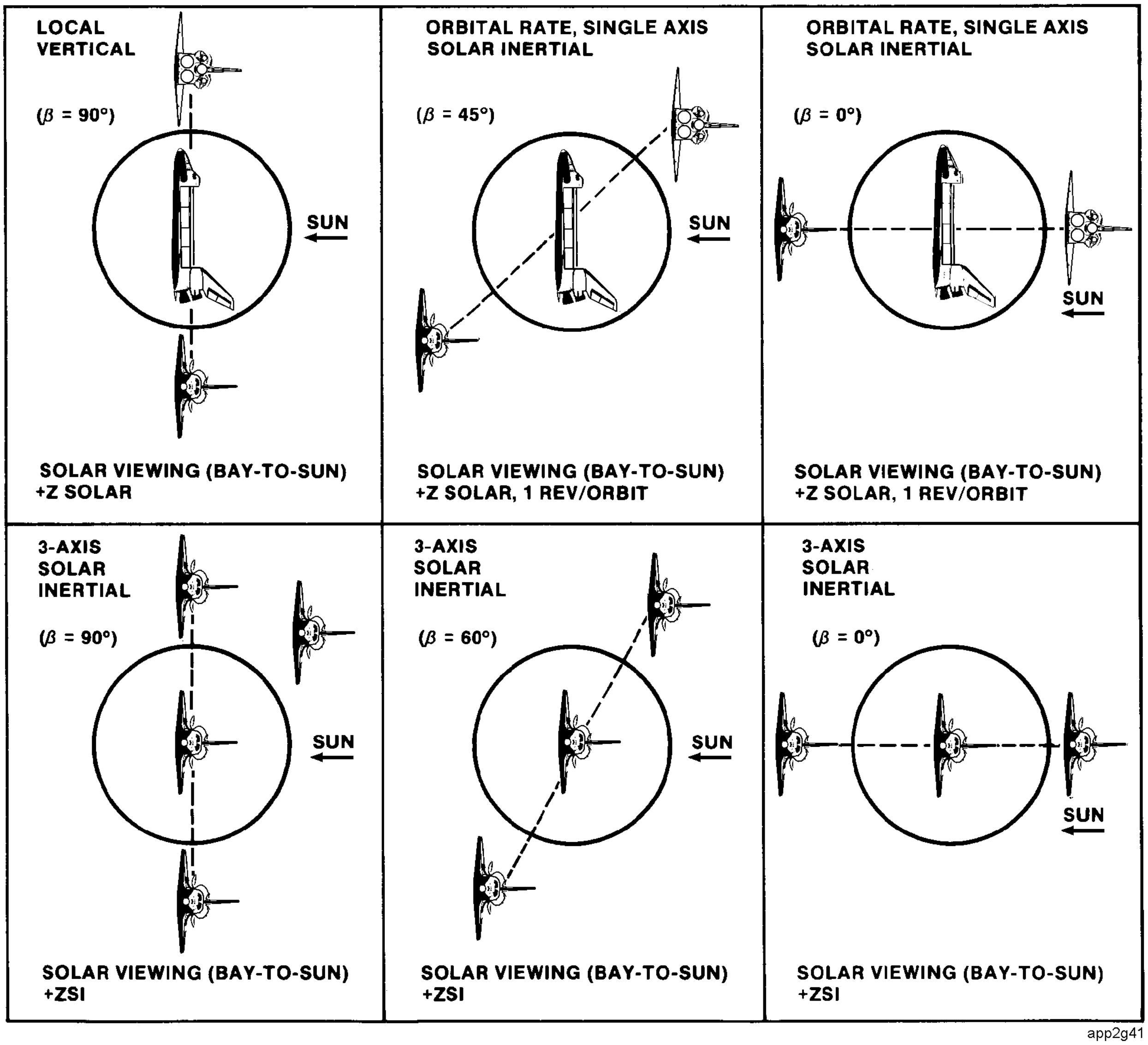

Figure 8-1.- Hot biased orientations (bay-to-sun) for worst hot case analysis.

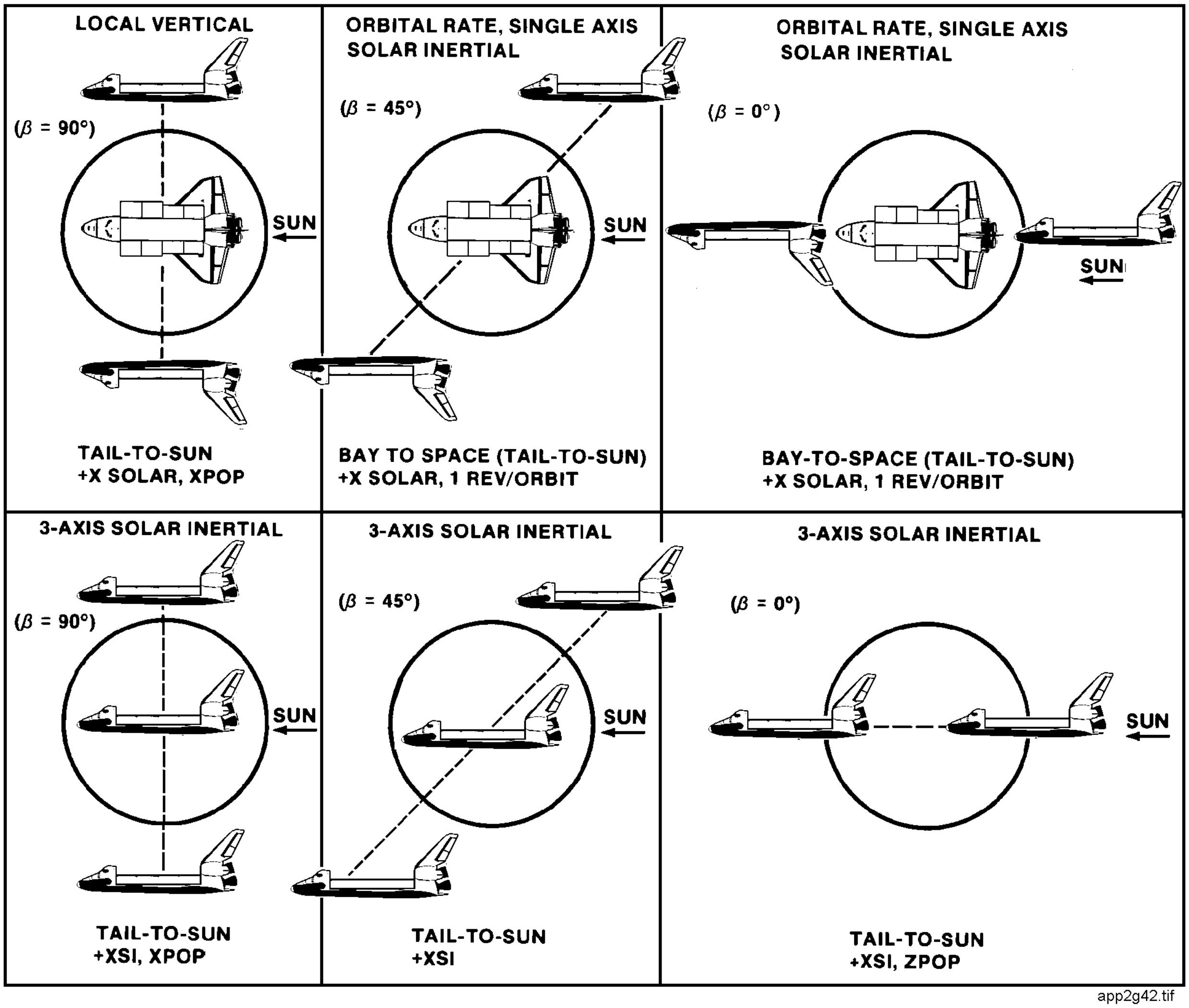

Figure 8-2.- Cold biased orientations (tail-to-sun) for worst cold case analysis.

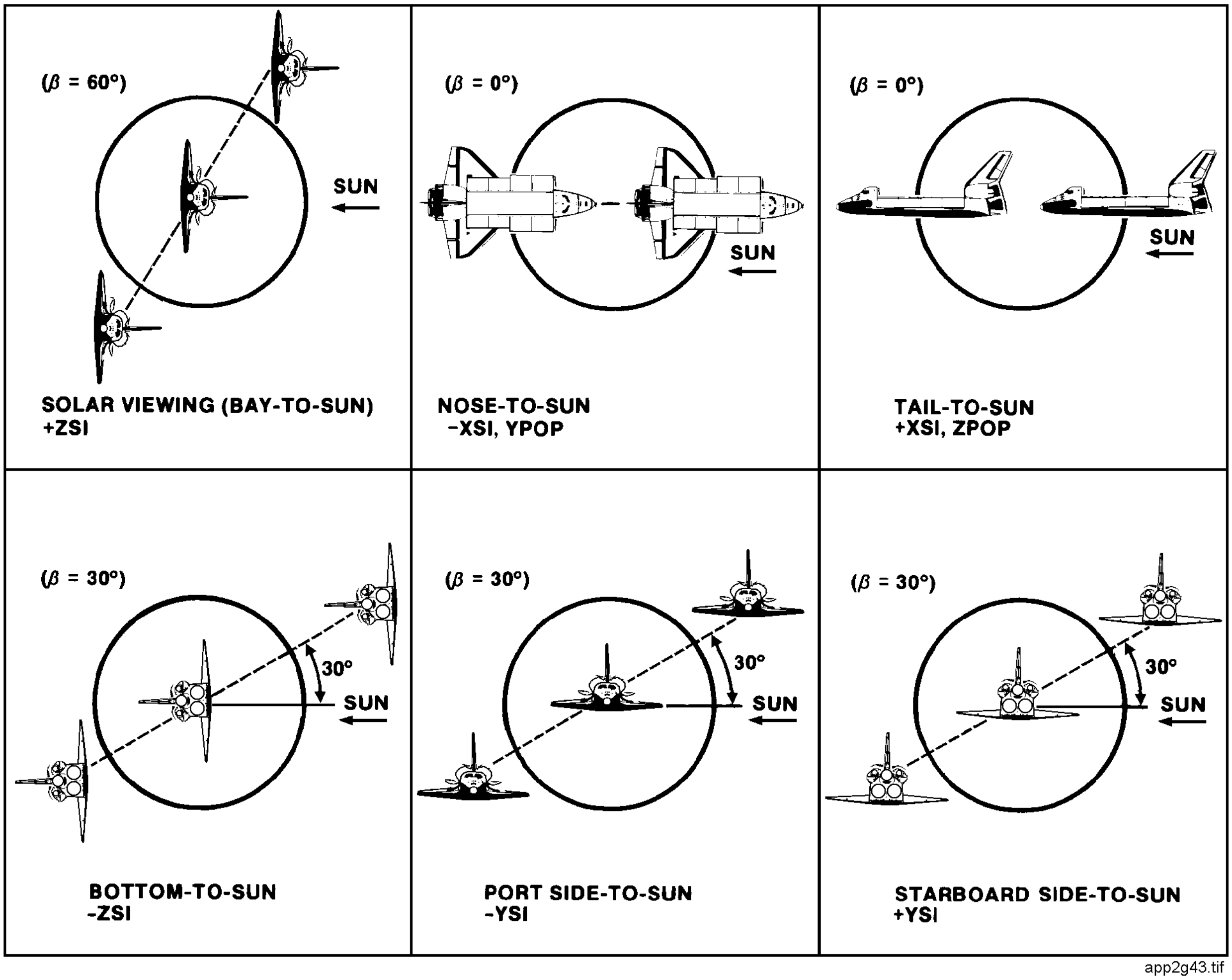

Figure 8-3.- Three-axis solar inertial attitudes.

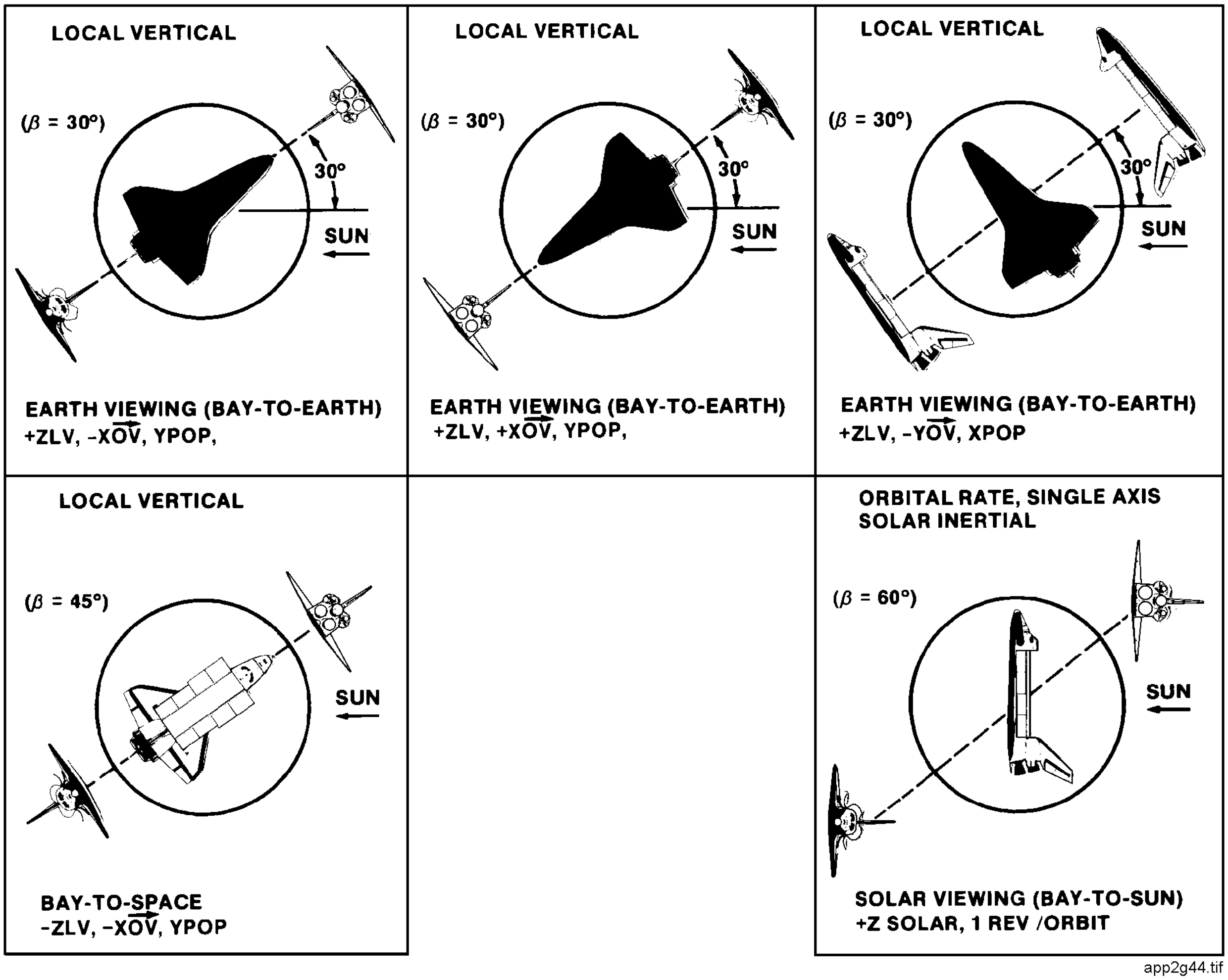

Figure 8-4.- Various flight attitudes.

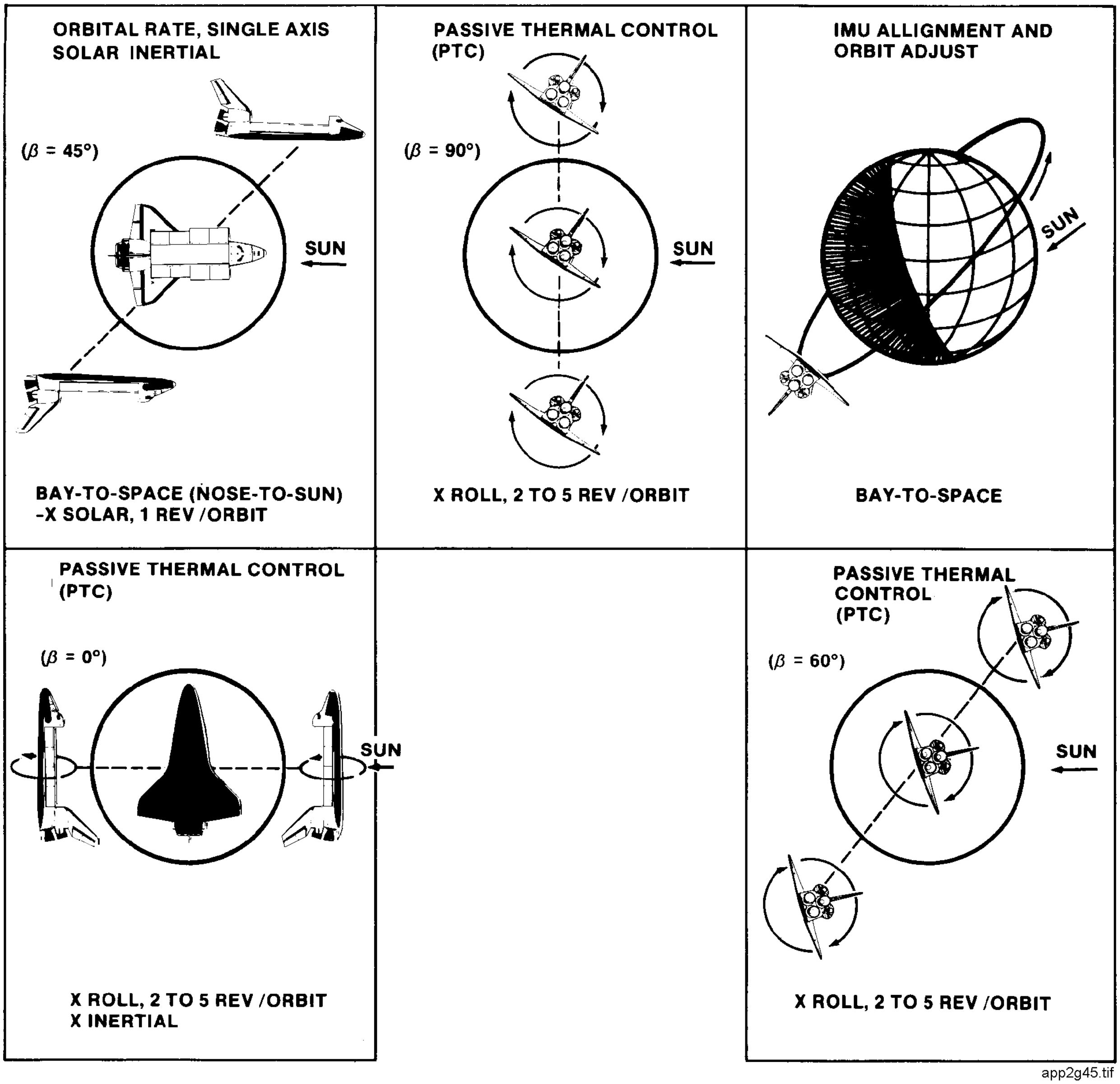

Figure 8-4.- Various flight attitudes (continued).

Acronyms and Abbreviations

9

AOA	abort-once-around
ASE	airborne support equipment
ATCS	active thermal cooling system
Btu	British thermal unit
CCTV	closed circuit television
CM	center of mass
DFI	development flight instrumentation
DIA	diameter
DOD	Department of Defense
EAC	experiment apparatus container
EAFB	Edwards Air Force Base
ETR	Eastern test range
EVA	extravehicular activity
F	Fahrenheit
FT	foot, feet
FWD	forward
GAS	Get Away Special
GMM	geometric math model
GN_2	gaseous nitrogen
GSE	ground support equipment
GSFC	Goddard Space Flight Center
HEPA	high efficiency particulate air
hr	hour
ICD	Interface Control Document
IDD	Interface Definition Document
I/F	interface
IGMM	integrated geometric math model
IP	Integration Plan
ITMM	integrated thermal math model
JSC	Lyndon B. Johnson Space Center
KSC	John F. Kennedy Space Center
kw	kilowatt(s)
kWh	kilowatt hour(s)
lb	pound(s)
LH	local horizontal
LiOH	lithium hydroxide
LV	local vertical
MAR	Middeck Accommodations Rack
MAX	maximum
MCIU	manipulator controller interface unit
MIN	minimum
MLI	multilayer insulation
NASA	National Aeronautics and Space Administration
NH_3	ammonia
NSTS	National Space Transportation System
OFT	orbital flight test
OPF	Orbiter Processing Facility
OV	on velocity vector
PACK	payload active cooling kit
PL	payload
POP	perpendicular to orbit plane
psia	pounds per square inch absolute
PTC	passive thermal control
QD	quick disconnect
REF	reference
REV/HR	revolutions per hour
RMS	remote manipulator system
RTLS	return to launch site
SCA	Shuttle carrier aircraft
SI	solar inertial
SIP	Standard Interface Panel
SOTS	Simplified Orbiter Thermal Simulator
sq ft	square foot (feet)
STA	station
SV	Space Vehicle
TBD	to be determined
TMM	thermal math model
TYP	typical
V	volt(s)
VAB	Vertical Assembly Building
WTR	Western test range

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10

1. NSTS 07700, Vol. IV, Configuration Management Requirements (current issue). Establishes detailed configuration management procedures for the control of program level requirements.

2. NSTS 21000-IDD-STD, Shuttle/Payload Interface Definition Document for Standard Accommodations. Space Shuttle Program, System Integration Office, Lyndon B. Johnson Space Center, Houston, Texas (current issue). Defines and controls the interfaces between the payload and the Orbiter payload bay and defines and controls all constraints.

3. NSTS 21000-IDD-SML, Shuttle/Payload Interface Definition Document for Small Payload Accommodations. Space Shuttle Program, System Integration Office, Lyndon B. Johnson Space Center, Houston, Texas (current issue). Defines and controls the interfaces between small payloads and the Orbiter payload bay and defines and controls all constraints.

4. NSTS 21000-IDD-MDK, Shuttle/Payload Interface Definition Document for Middeck Accommodations. Space Shuttle Program, System Integration Office, Lyndon B. Johnson Space Center, Houston, Texas (current issue). Defines and controls the interfaces between the payload and the Orbiter middeck area and defines and controls all constraints.

5a. K-DPM-XX.X, Launch Site Support Plan for (insert payload name) Annex 8 to Payload Integration Plan JSC-XXXXX. John F. Kennedy Space Center, Florida (current issue). Defines the format of the payload data required for KSC to integrate a deployable payload into the ground operations of the STS.

5b. K-STSM-11.0, Addendum B, Space Transportation System Horizontal Payload Boilerplate (mission) Launch Site Support Plan, Annex 8 to Payload Integration Plan JSC-XXXXX. John F. Kennedy Space Center, Florida (current issue). Contains information on payload processing flows and responsibilities, requirements and commitments, and facility-to-payload interfaces.

5c. K-DPM-11.3A, STS GAS Payloads LSSP, Annex 8 to PIP JSC 14021.

5d. K-SLM-11.89, STS Small Payload Accommodations Generic LSSP, Annex 8 to PIP JSC 21000-SIP-SML.

Note: The four documents listed above are Launch Site Support Plans (LSSP's). The purpose of the LSSP is to define the general and technical requirements for support needed to process and launch a payload as submitted to KSC by the payload owner/user and to document the KSC response. The LSSP, which is also Annex 8 to the PIP, is the official KSC launch site commitment for support and services to be provided.

5e. Operations, Maintenance and Requirements Specifications Document (OMRSD) (current issue). Identifies project level verification agreements, payload-to-STS ICD interfaces to be verified, the method of verification, and the location of verification.

6. NSTS 07700, Volume XIV, Appendix 8, System Description and Design Data - Payload Deployment and Retrieval System. Space Shuttle Program Customer and Flight Integration, Lyndon B. Johnson Space Center, Houston, Texas (current issue). Expands information concerning the Payload Deployment and Retrieval System.

7. 14690-H001-R0-00, Rev. 3, Systems Improved Numerical Differencing Analyzer (SINDA) User's Manual. Smith, J. P., TRW (March 1983). Contains a complete description of the input options and operational features of SINDA. SINDA is intended primarily for analyzing thermal systems represented in electrical analog, lumped parameter form.

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9. JSC 22437, Orbiter/Payload Thermal Integration Model Description. Structures and Mechanics Division, Lyndon B. Johnson Space Center, Houston, Texas (current issue). Provides the thermal data necessary to develop an Orbiter closed and open-door model in order to perform integrated Orbiter/payload thermal analysis.

10. ES3-76-1, Rev. D, Orbiter Midsection/Payload Bay Thermal Math Model Description (model no. SSX001D). Structures and Mechanics Division, Lyndon B. Johnson Space Center, Houston, Texas (July 1983). Provides documentation of the detailed Orbiter open-door midsection thermal math model (on-orbit).

11. ES3-77-3, Rev. D, "390 Node" Atmospheric Orbiter Midsection/Payload Bay Thermal Math Model Description (model no. SSX002D). Structures and Mechanics Division, Lyndon B. Johnson Space Center, Houston, Texas (September 1983). Provides documentation of the detailed Orbiter closed-door thermal math model (prelaunch, ascent, entry, and postlanding).

12. JSC 14686, Criteria/Guidelines for Payload Thermal Math Models for Integration Analysis (ES3-79-1). Structures and Mechanics Division, Lyndon B. Johnson Space Center, Houston, Texas (January 1979).

13. NSTS-07700, Volume XIV Attachment 1, ICD 2-19001, Shuttle Orbiter/Cargo Standard Interfaces. Space Shuttle Program, System Integration Office, and Flight Integration,, Lyndon B. Johnson Space Center, Houston, Texas (current issue). Defines and controls the Shuttle system interfaces and constraints.

14. JSC 19956, Orbiter Payload Bay Flight Temperature Data (Thermal Branch Report ES3-84-2). Structures and Mechanics Division, Lyndon B. Johnson Space Center, Houston, Texas (June 1984). Presents a summary of measured payload bay flight temperature data from the first eight flights of the Space Shuttle.

15. NSTS 1700.7B, Safety Policy and Requirements for Payloads Using the STS, (current issue), Space Shuttle Program, Payload Safety Panel.