SPACE SHUTTLE TECHNOLOGY FLIGHT INSTRUMENTATION

John Dunstan
Rockwell International
Space Systems Group
Space Shuttle Instrumentation
12214 Lakewood Blvd
Downey, CA 90241

ABSTRACT

The launch and orbital phase of the Shuttle is comparable to the Apollo flight. The entry phase, on the other hand, presents many new challenges to a reusable vehicle. To explore this area and provide more detailed data than that required for flight, the Shuttle technology flight instrumentation (TFI) system was proposed.

This paper discusses the TFI, which records flight data during the operational phase of the Space Shuttle. It also deals with pertinent background information, such as Shuttle operation, flight verification, and instrumentation provided for the developmental and operational phase.

INTRODUCTION

It launches like a rocket, hauls like a truck, and lands like an airplane—it is the Space Shuttle. Our future space transportation, the Shuttle vehicle is the key to opening up near space to productive and economic application of both manned and unmanned exploration. A quick look at the Space Shuttle and a typical mission will demonstrate the need for Rockwell International's instrumentation system.

PROFILE OF SHUTTLE MISSION (Figure 1)

The Space Shuttle consists of the orbiter, two solid rocket boosters (SRB's), and one expendable external tank (ET). At launch, the Shuttle weighs approximately four and one-half million pounds. With the five engines producing about six and one-half million pounds of thrust, the Shuttle starts its flight. On reaching an altitude of 28 miles it expends the two SRB's (5.2 million pounds of thrust for 2 minutes). The SRB's separate from the external tank at this point and parachute down to a safe water landing. The boosters are designed to be recovered, towed back to the launch facility, refurbished, and readied for the next flight within two weeks. The external tank provides liquid oxygen and hydrogen to the three main engines which are located on the orbiter. The ET separates just before the orbiter enters a normal orbit of about 100 nautical miles. The orbital maneuvering subsystem (OMS) engines, located in the OMS pods at the base of the vertical tail, provide about 3000 pounds of thrust each. After ET separation, the OMS fires, completing the orbital insertion. A nominal seven-day mission of space exploration in a zero-g and vacuum environment then follows. The mission can expand to as many as 30 days with the addition of more consumables. Upon completion of the mission, the OMS fires to deorbit the orbiter for entry and landing. The thermal protection system (TPS) is designed to act as a thermal blanket to protect the orbiter aluminum structure from exceeding 350°F as it re-enters the atmosphere. The orbiter lands at Kennedy Space Center or Vandenberg Air Force Base.

The Shuttle is made up of six primary systems consisting of: (1) structures, (2) propulsion, (3) control, (4) maneuvering, (5) crew environmental control, and (6) thermal protection. To verify each system, extensive ground testing, simulating flight environments and conditions, is being completed in special laboratories. Flight testing is scheduled where modeling or ground testing is impractical.

TESTING

Instrumentation has been developed in two phases, operational and developmental. Operational flight instrumentation (OFI) consists of approximately 3000 housekeeping-type measurements. These are mandatory system measurements to provide the flight and ground crew with the state, performance, and condition of the orbiter subsystems. Development flight instrumentation (DFI) consists of approximately 3500 measurements to verify that the OFI system provides sufficient data to confirm system performance and to verify that the assumptions made in developing the system models are valid. The Rockwell philosophy stressed maximum use of analytical modeling and ground tests, with recourse to flight testing only to verify the modeling.

The OFI system is located everywhere in the orbiter, except for the payload bay area. As shown in Figure 2, three avionic bays are in the crew module and three in the aft fuselage. The DFI system consists of one avionic rack in the lower crew module and three DFI containers mounted in the payload area. Both OFI and DFI measure thermal, dynamic, structural strain, hinge moments, and other primary subsystem parameters.

The DFI system is scheduled for the first four flights only because scheduled payloads occupy the full payload bay for subsequent operational flights. A typical mission timeline (Figure 3) shows that in less than 20 minutes the SRB and ET separate, and the orbiter enters an eliptical orbit. After OMS burn, the orbiter enters the planned circular orbit.

Entry and landing take about thirty minutes. This means that in four flights the instrument systems will obtain 80 minutes of launch data and 120 minutes of entry and landing data. These are the two phases of the mission where the instrument technology is critical. The launch and space environments will be similar to the Apollo and Skylab missions and should present no new problems. The entry phase (Figure 4) presents the most challenging phase for the recoverable orbiter. Many new questions are anticipated in this phase.

To resolve the many questions pertaining to vehicle aerodynamics, flight performance, stability, handling qualities, and weight distribution during re-entry, the OFI measurement system had to be either expanded or complimented with another DFI-type system. Rather than compromise the OFI system, the technology flight instrumentation (TFI) system was proposed to resolve this problem. The ground rules were simple—use existing qualified DFI equipment, keep it out of the payload area, keep the weight and power down, and record the data with no impact to the OFI system.

Technical Flight Instrumentation

The primary purpose of the TFI system is to support the unique orbiter-related experiments. Payloads are not usually considered orbiter related and will not be part of the TFI system. The payload bay environment, however, is orbiter related and will be measured by TFI for various payload configurations.

The baseline TFI system (Figure 5) consists of DFI sensors installed throughout the orbiter, DFI signal conditioners, two pulse code modulators-master units (PCM masters) with eight PCM slaves, a frequency division multiplexer (FDM), and experiments in the development stage. The system shown will handle about 1000 analog measurements and 60 wideband measurements. A 28-track modular airborne recording system (MARS) recorder will provide 2 hours of recording at 15 inches per second tape speed. The system can be controlled either by the crew or via uplink command using the orbiter processing system.

The proposed TFI equipment will be installed in the wing carry-through area and the forward nose wheel well (Figures 6, 7, 8 and 9).

Of the 3500 DFI measurements, over 1400 have been baselined for TFI. These are primarily the temperature- and pressure-related measurements to the thermal protection system (TPS). No orbiter subsystem measurements have been requested for TFI.

The 1400 measurements are in addition to the measurements directly added by each experiment. Since the TFI system will handle only 1000 analog and 60 wideband measurements, many will not be recorded on each flight. Measurements to be recorded first will be the active experiments and then the TFI measurements required to complement and support these experiments.

Orbiter Experiment Program (OEX)

The OEX experiments that are being developed for flight are designed to provide some of the answers in the area of uncertainty in a Shuttle mission — that is, entry heating. Four of the experiments are identified in the TFI block diagram (Figure 5).

Few questions deal with the eight to ten minute launch phase because the technologies developed for the Apollo and Skylab launches apply. The entry and landing, starting after the deorbit burn, present a new set of difficulties requiring detailed system verification. The temperatures that the orbiter will experience during the blackout area are shown in Figure 10. The TPS is designed to limit the orbiter structure maximum temperature to 350°F for 100 missions without replacement. The surface temperatures range from 600 to 2650°F.

Aerodynamic Coefficient Instrument Package (ACIP) — The ACIP is designed to provide high-resolution state data required for post-flight research quality aerodynamic analysis. (The OFI system accuracy will not satisfy this requirement.) The ACIP consists of the tri-axial linear and angular accelerometers and the tri-axial rate gyros. It is mounted in the wing root area of the mid fuselage. The instruments are aligned to a baseplate in the lab, and the baseplate is aligned to the orbiter axis during installation. (See Figures 11 and 12.) Flight data will be recorded on entry from 400,000 feet through roll out. The instrument parameters are shown in Table I. ACIP is installed on the orbiter for all flights.

Table I. ACIP Parameters

Sensor/Axis		Range	Resolution
Linear Accelerometers			
X-axis	(a_x)	±1.5 g	183 μg
Y-axis	(a_y)	±0.5 g	61 μg
Z-axis	(a_z)	±3.0 g	366 μg
Rate Gyros			
X-axis	(P)	±30 deg/sec	3.6 mdeg/sec
Y-axis	(Q)	±10 deg/sec	1.2 mdeg/sec
Z-axis	(R)	±10 deg/sec	1.2 mdeg/sec

Angular Accelerometers X-axis (P) Y-axis (Q) Z-axis (R)	 ±1.0 rad/sec^2 ±2.0 rad/sec^2 ±2.0 rad/sec^2	 122 μrad/sec^2 244 μrad/sec^2 244 μrad/sec^2

Shuttle Entry Air Data System (SEADS) — The air data parameters obtained from the operational air data system (Figure 13A), although accurate enough for flight, will not satisfy the research air data parameters. The data in Table II provides an example.

Table II. Example Air Data Parameters

		Accuracy (percent)		
Quantity	Fit Phase	Desired	Min Accep	Operational Sys
Mach number	Entry	1	2	±10
	TAEM	1	2	±7
	A/L	5	10	±10
Dynamic pressure	Entry	1	5	-
	TAEM	1	5	±7
	A/L	1	5	±10
Note: Other parameters involved include pressure, altitude, true air speed, angle of attack, air density, and temperature.				

The purpose of the SEADS is to improve the air data measurements by providing the freestream condition across the entry speed profile. To provide the required system accuracy with the nose cap's non-symetrical geometry and large angle of attack, 10 to 40 degrees, 14 pressure ports were added, as shown in Figure 13B. Pressure measurements of 0 to 20 and 0 to 2 pounds per square inch (absolute pressure) are made at each port. This dual pressure transducer configuration provides better than 5 percent data. Six radiometers (Figure 13C) are used to measure the nose cone temperature in the port areas. Design problems are numerous, and a cross section of the nose cone area (Figure 13D) identifies a few.

The 3000°F temperature imposed on the tubes aft of the ports requires an expansion coil before the support manifold. The dynamic environment has dictated the coil shape and tube size, which is 0.25 inch outside diameter with a 0.015 inch wall. The problems are being resolved, and SEADS is scheduled to fly in 1981.

<u>Shuttle Upper Air Mass Spectrometer (SUMS)</u> — The SUMS is designed to provide freestream environmental data at pressure levels below the lower SEADS range (above altitude 80 ft). SUMS provides a measurement of atmospheric mass density using a mass spectrometer. The inlet port (Figures 8 and 13E) is just aft of the nose cap and close to the centerline of the orbiter. The instrument is under vacuum until approximately 30 minutes prior to entry. The entrance port valve will be activated, opening the mass spectrometer to atmosphere. Pressure measurements desired range from 20 to 10^{-4} Torr. The system will be deactivated by closing the entry port valve upon reaching 80,000 feet and/or 10^{-3} Torr. SUMS is scheduled to fly in 1981.

<u>Shuttle Infrared Leeside Temperature Sensing (SILTS)</u> — The SILTS experiment consists of an infrared scanner mounted on top of the orbiter vertical fin. Its purpose is to obtain detailed temperature maps of the upper wing area and upper mid body surface area. (See Figures 14 and 15.)

The infrared camera scans a 40° surface area through two silicon windows. The windows are cooled by flowing gaseous nitrogen to approximately 200°F during entry. The camera pointing system provides for a 2.3 second view through the left window, a 2.3 second view of a reference black body located between the wondows, and then a 2.3 second view through the right window. The scan continues left to right and right to left. The SILTS is activated 5 minutes prior to entry and records data for 30 minutes.

Nineteen temperature measurements located within the TPS in the scanned area provide additional data. Temperature, pressure,and sound pressure level sensors typical of those 19 are installed in the TPS as shown in Figures 16, 17 and 18.

CONCLUSION

The four scheduled development flights will provide approximately 80 minutes of launch data and 120 minutes of entry and landing data. The instrumentation will provide the measurement data necessary to verify that the assumptions made in modeling were sufficient to verify subsystem mission performance. To resolve what happens when deviations from a normal launch and entry occur, additional experiments, as well as a flight measurement system, will be flown. The technology flight instrumentation system will provide approximately 1000 analog measurements and 60 wideband (dynamics) measurements.

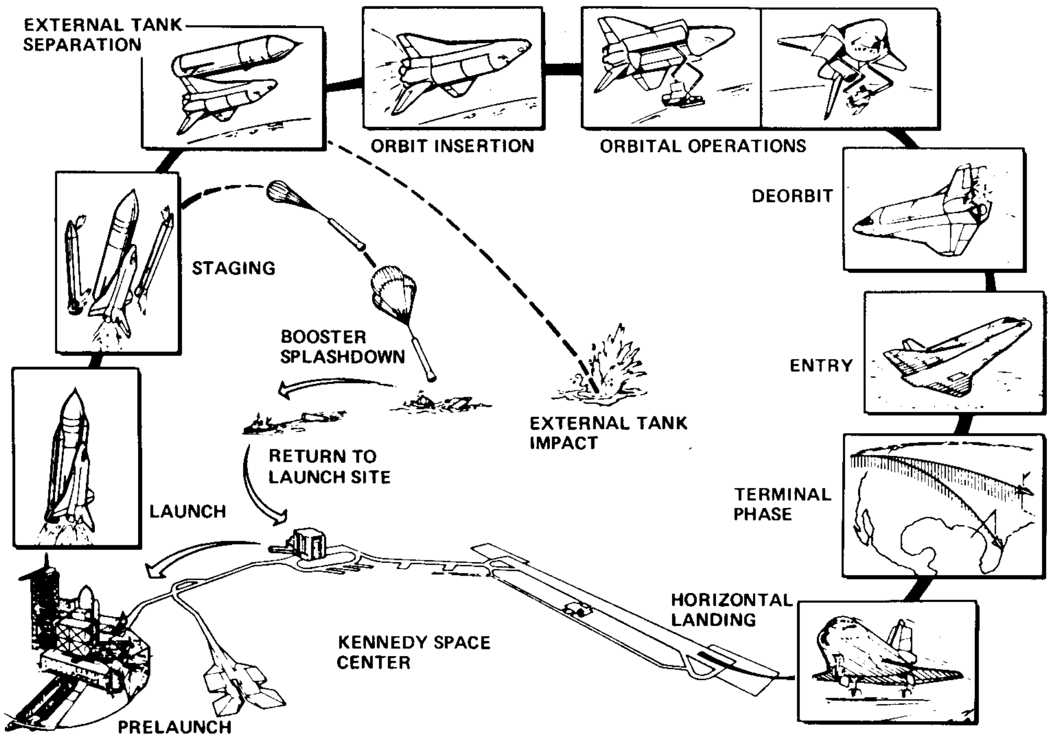


Figure 1. Typical Space Shuttle Mission Profile

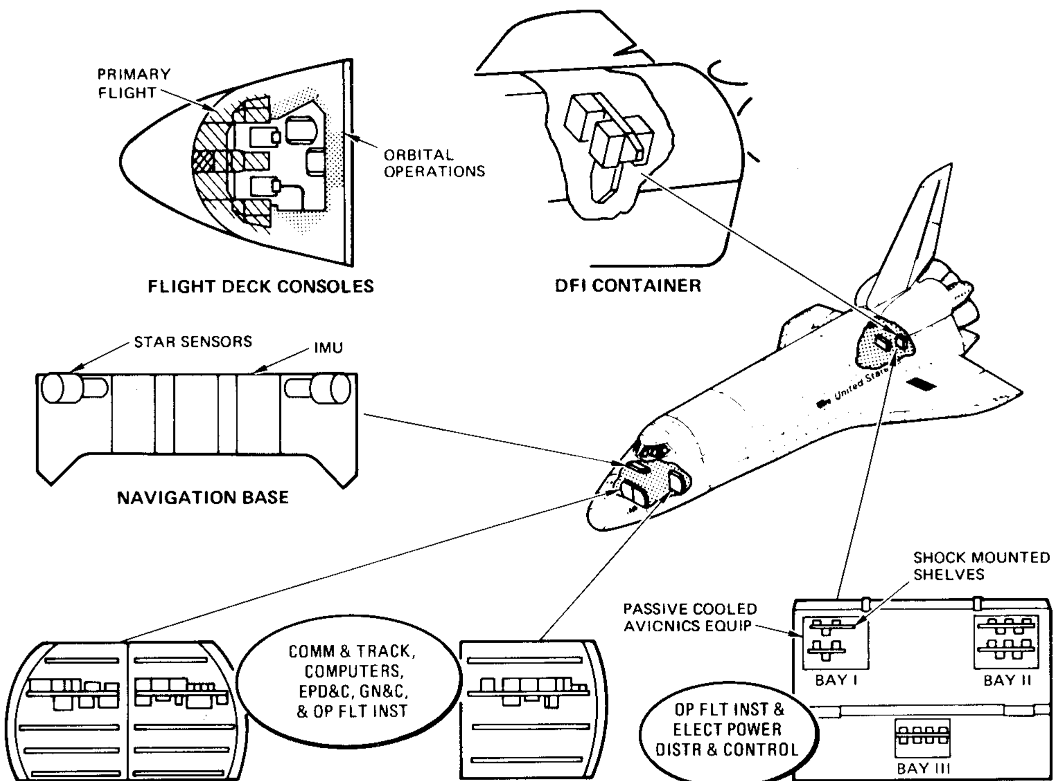


Figure 2. Orbiter Avionic System Installation Configuration

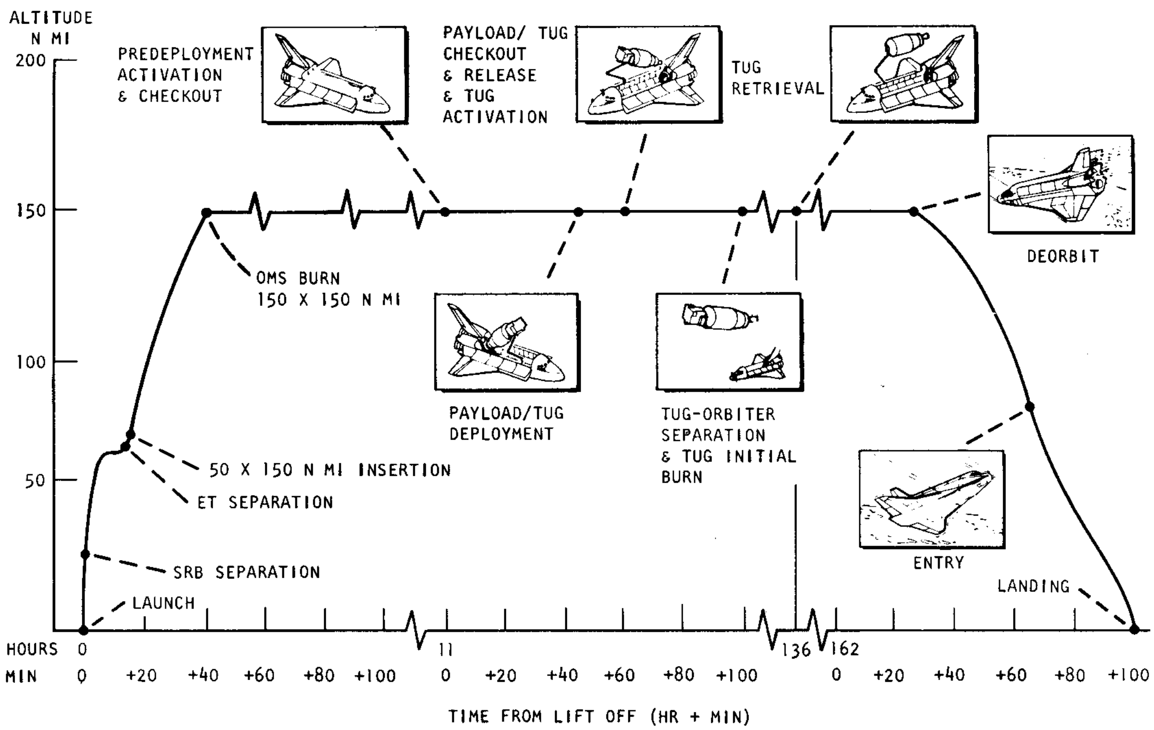


Figure 3. Typical Mission Timeline, Payload/Tug Deployment and Retrieval

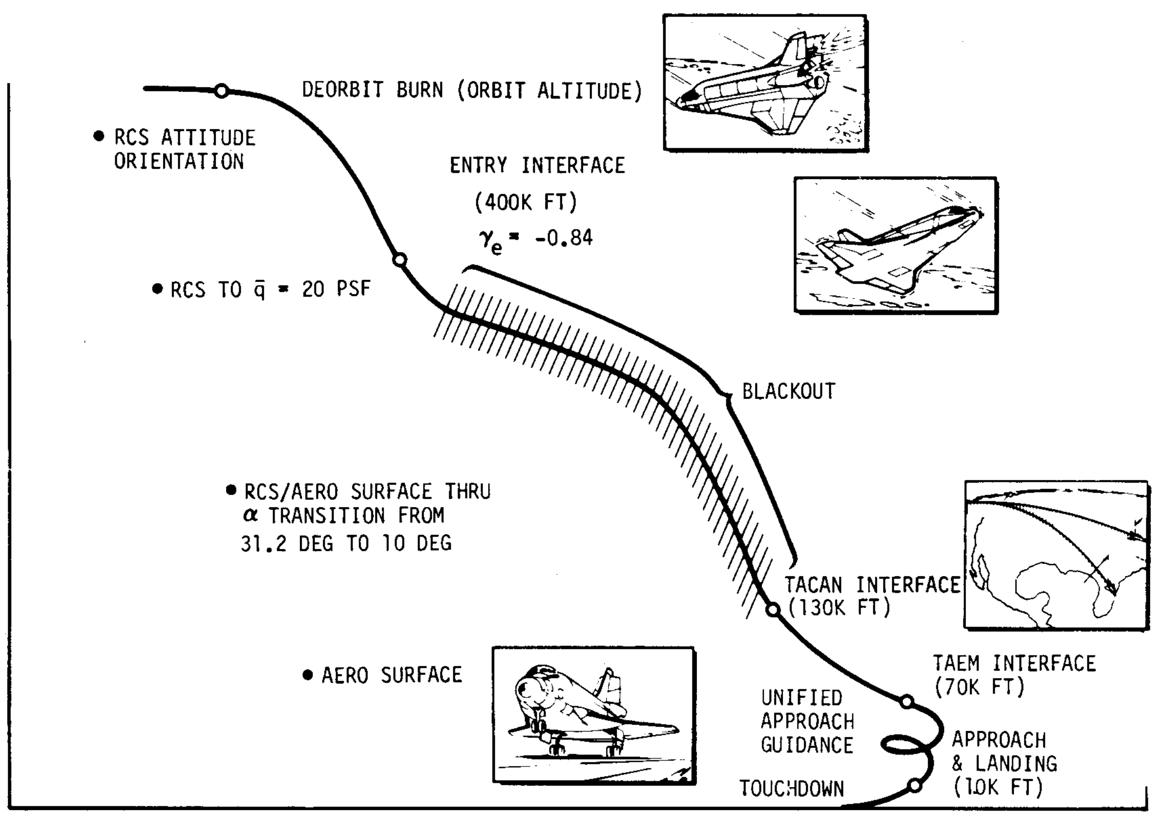


Figure 4. Orbiter Entry and Return Flight Profile

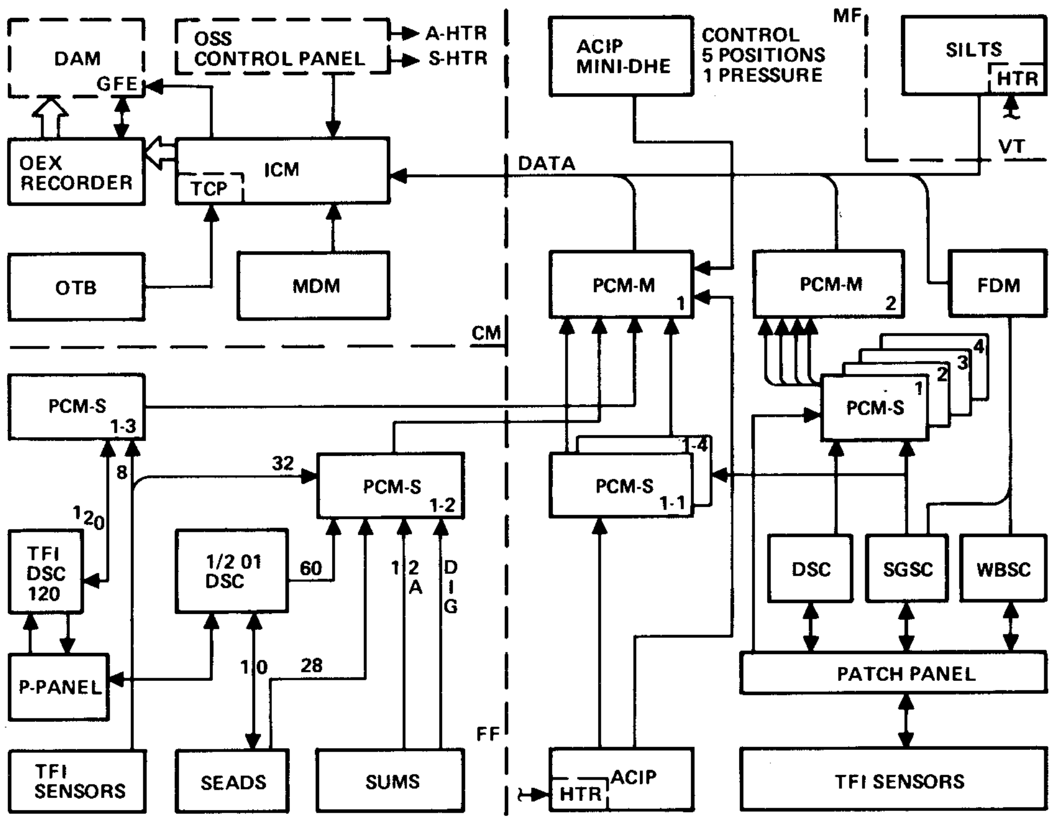


Figure 5. OEX/TFI

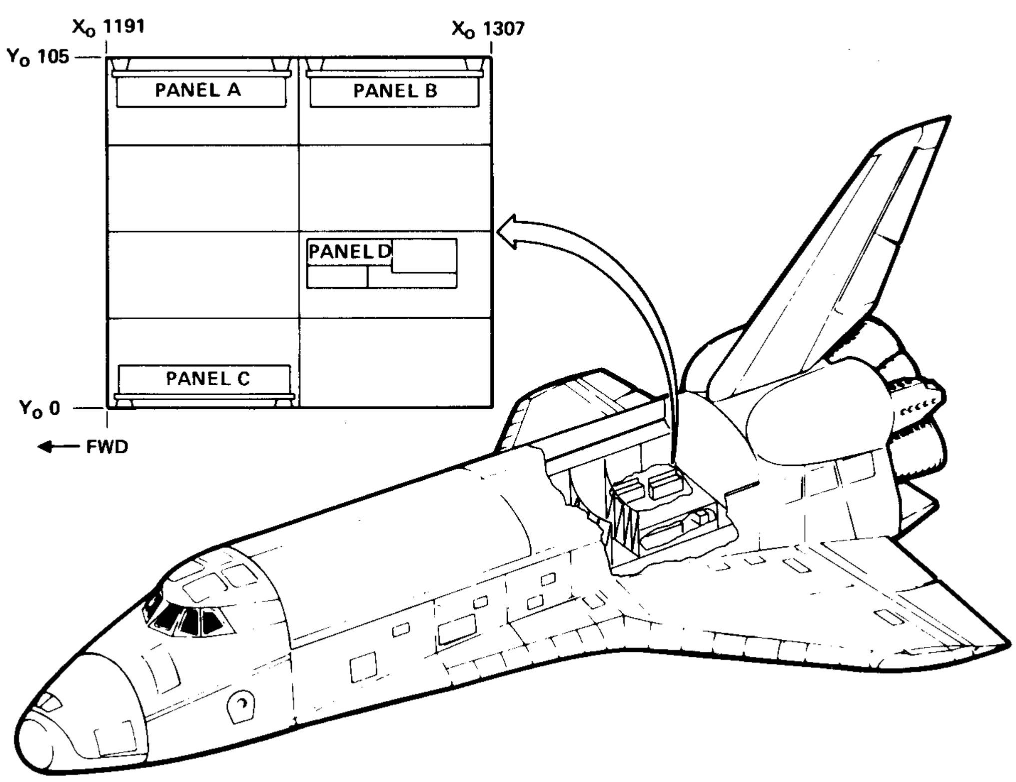


Figure 6. TFI Equipment Location

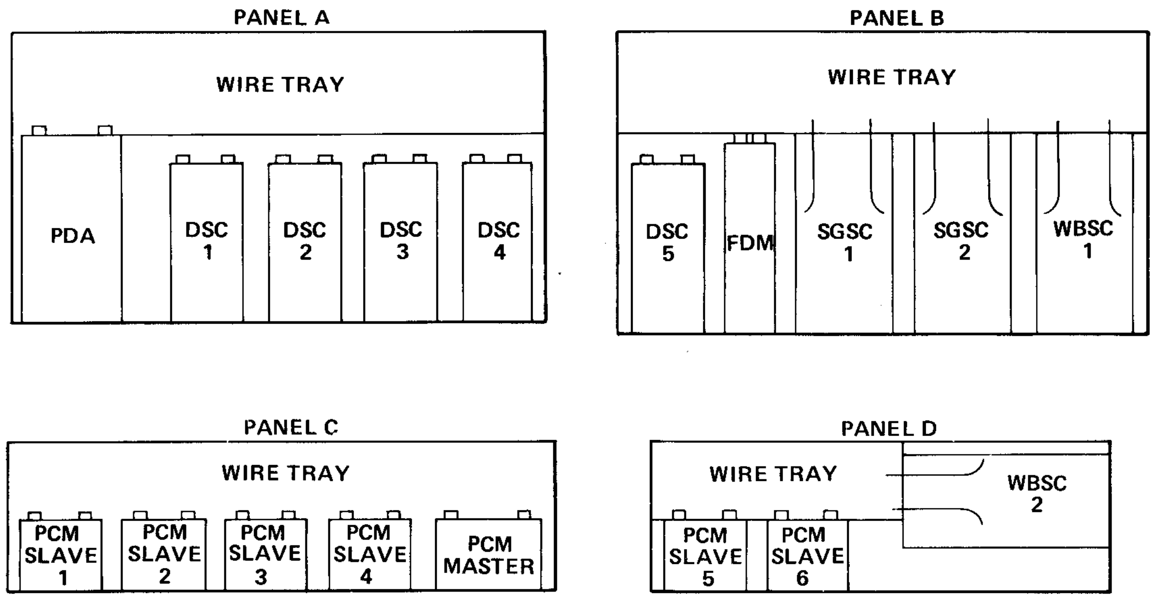


Figure 7. TFI Equipment Panels

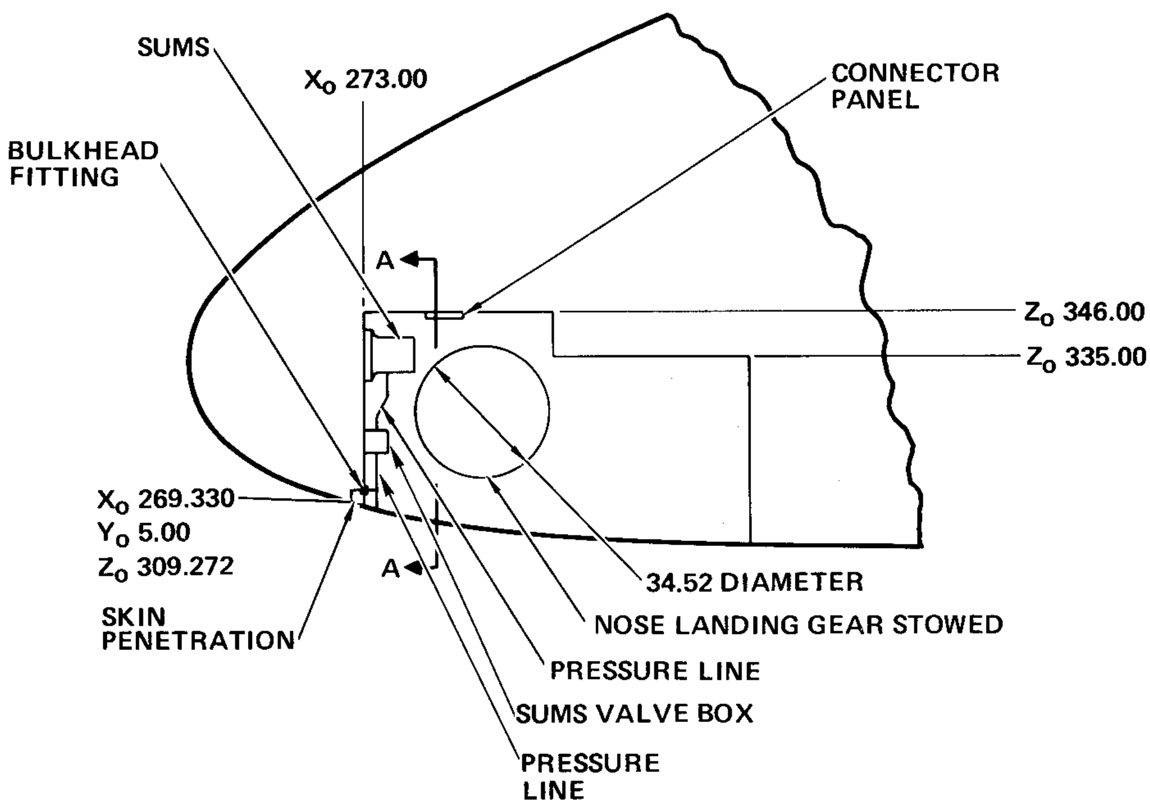


Figure 8. Shuttle Upper Atmosphere Mass Spectrometer, Orientation View

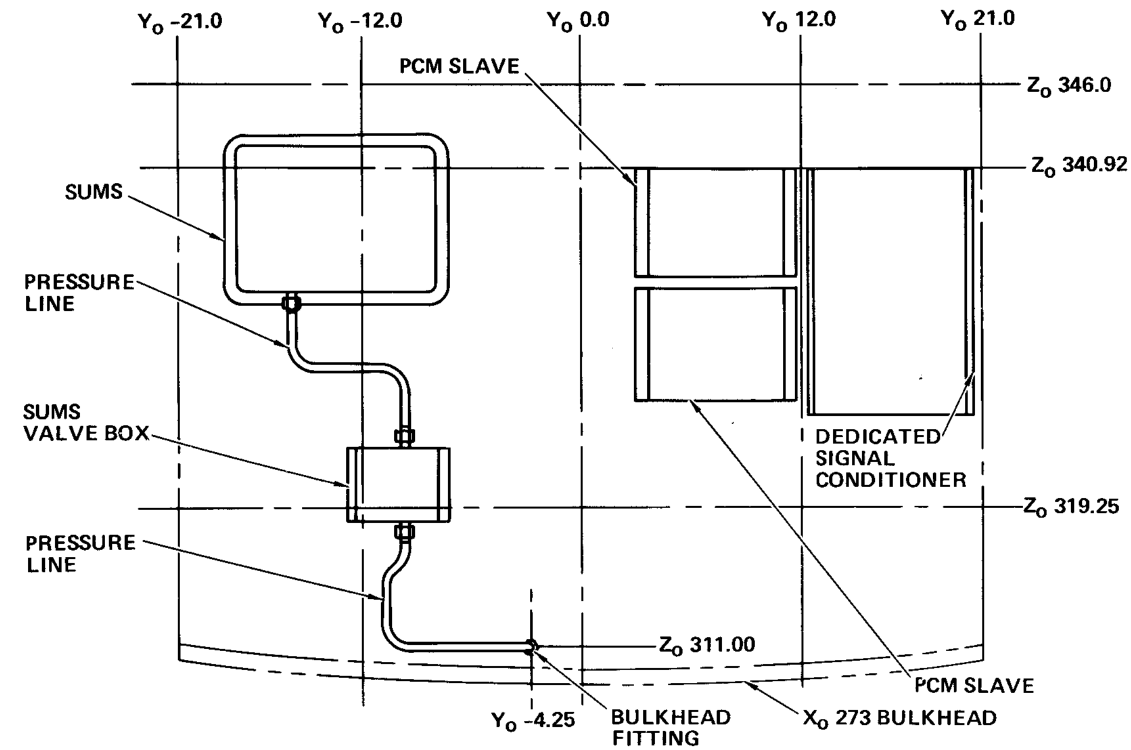


Figure 9. Shuttle Upper Atmosphere Mass Spectrometer, Schematic View

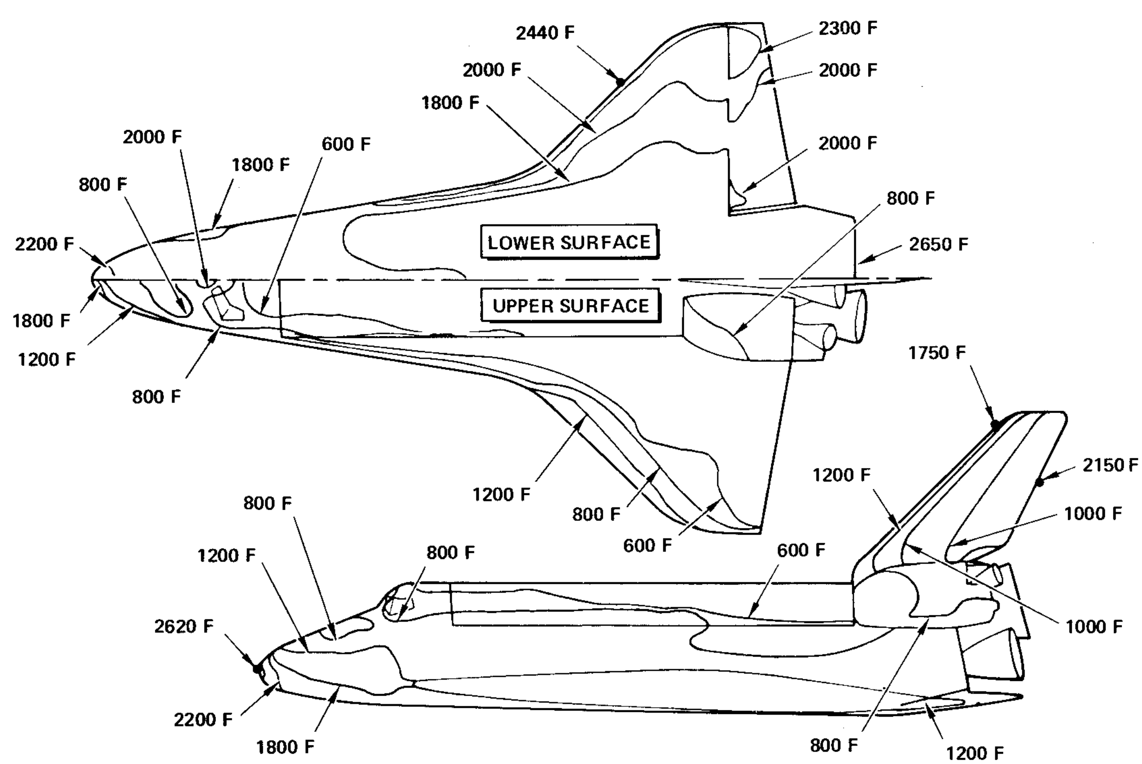


Figure 10. Maximum Temperatures for Entry Trajectory 14414.1

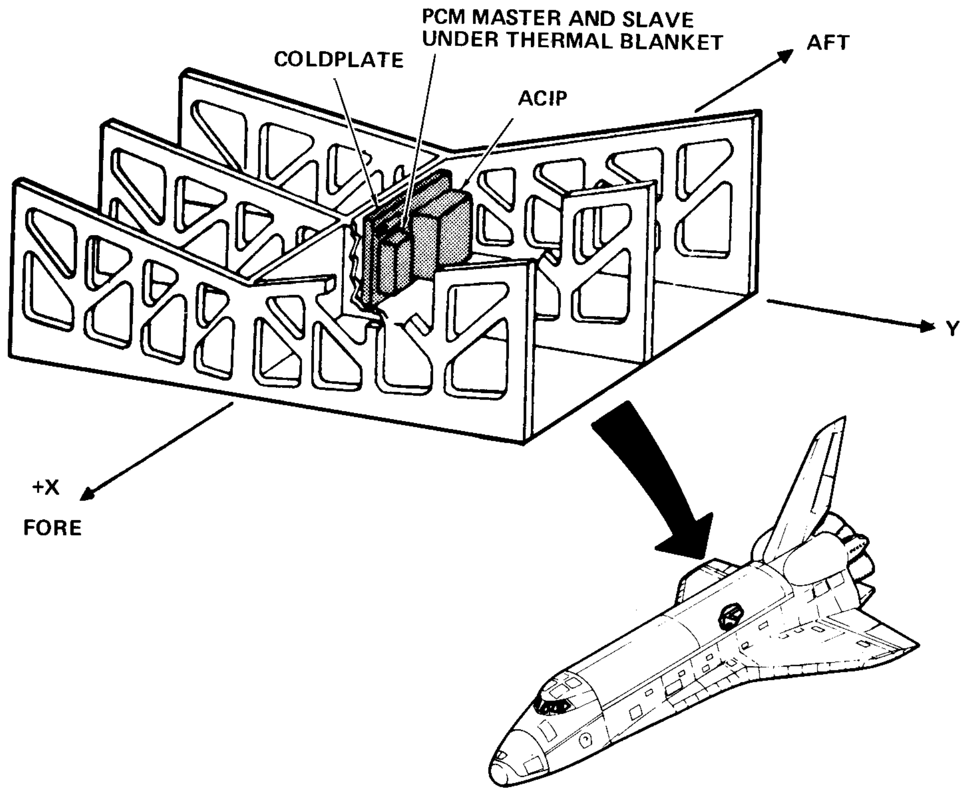


Figure 11. ACIP Installation

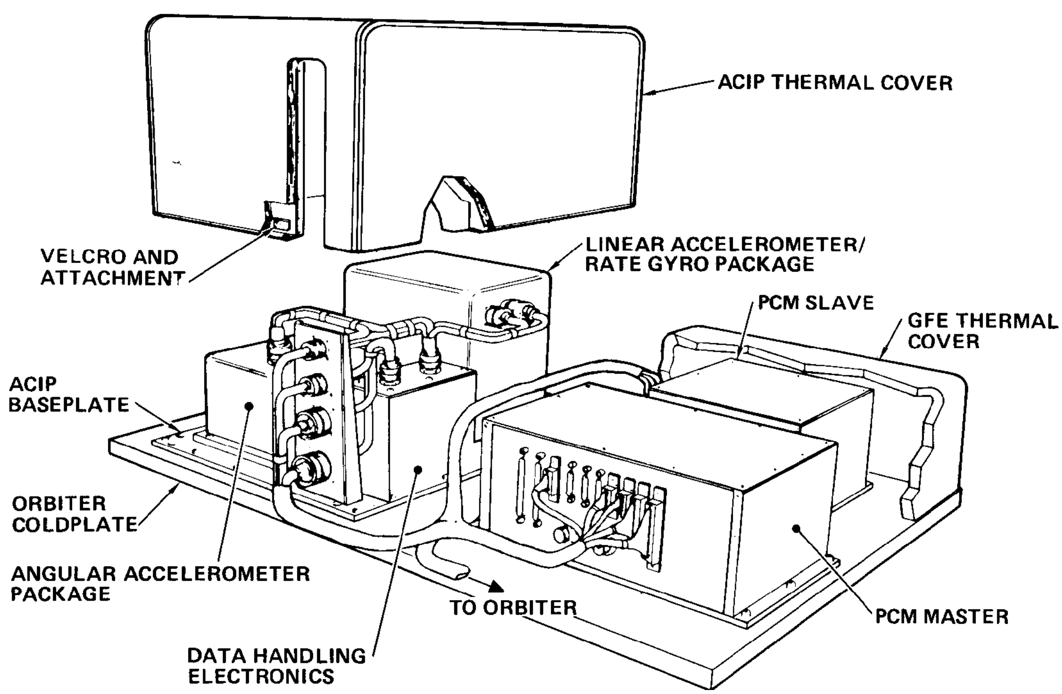
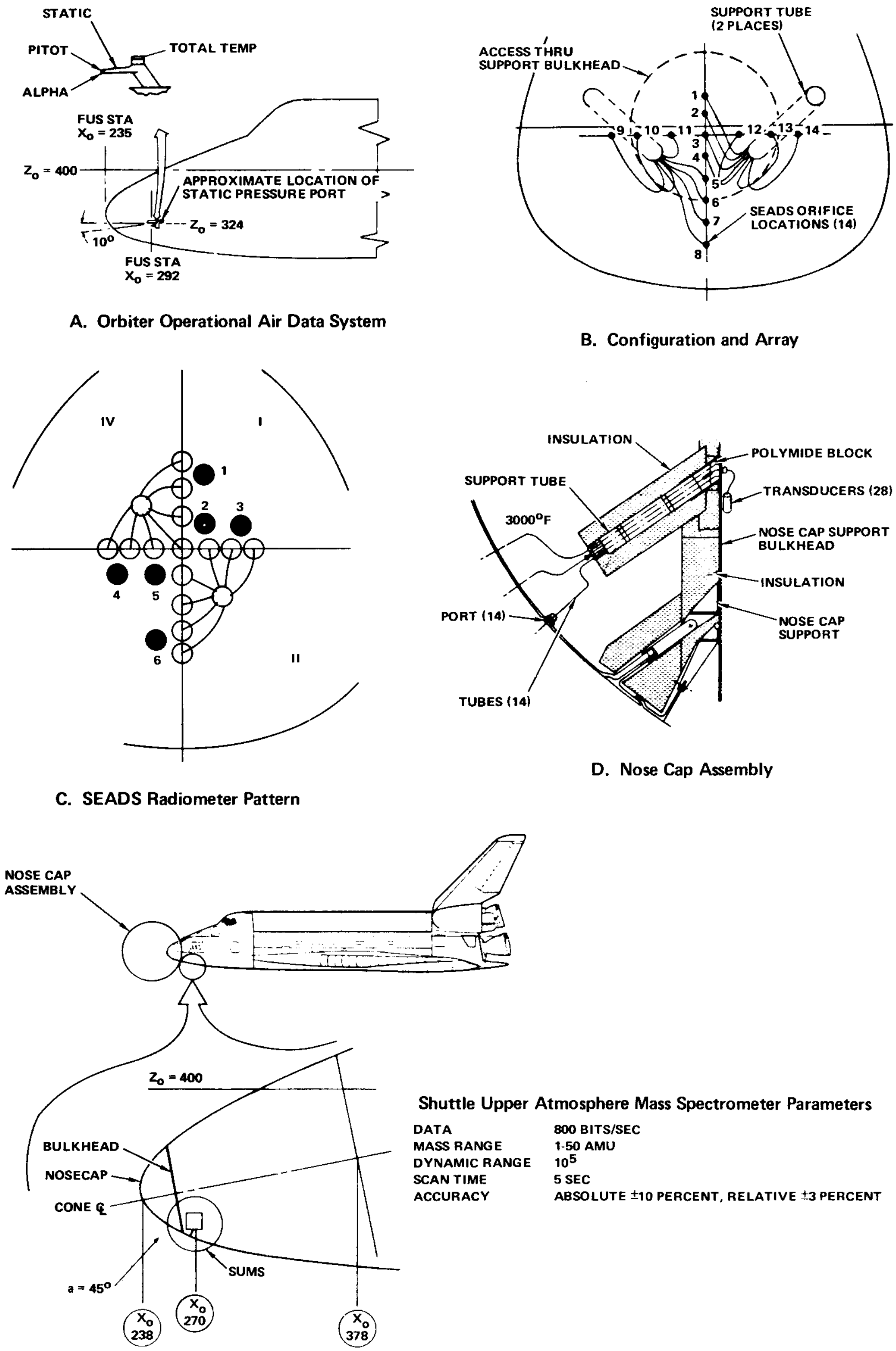


Figure 12. ACIP Configuration



A. Orbiter Operational Air Data System

B. Configuration and Array

C. SEADS Radiometer Pattern

D. Nose Cap Assembly

Shuttle Upper Atmosphere Mass Spectrometer Parameters

DATA	800 BITS/SEC
MASS RANGE	1-50 AMU
DYNAMIC RANGE	10^5
SCAN TIME	5 SEC
ACCURACY	ABSOLUTE ±10 PERCENT, RELATIVE ±3 PERCENT

E. Shuttle Upper Atmosphere Mass Spectrometer Location

Figure 13. SEADS Air Data System

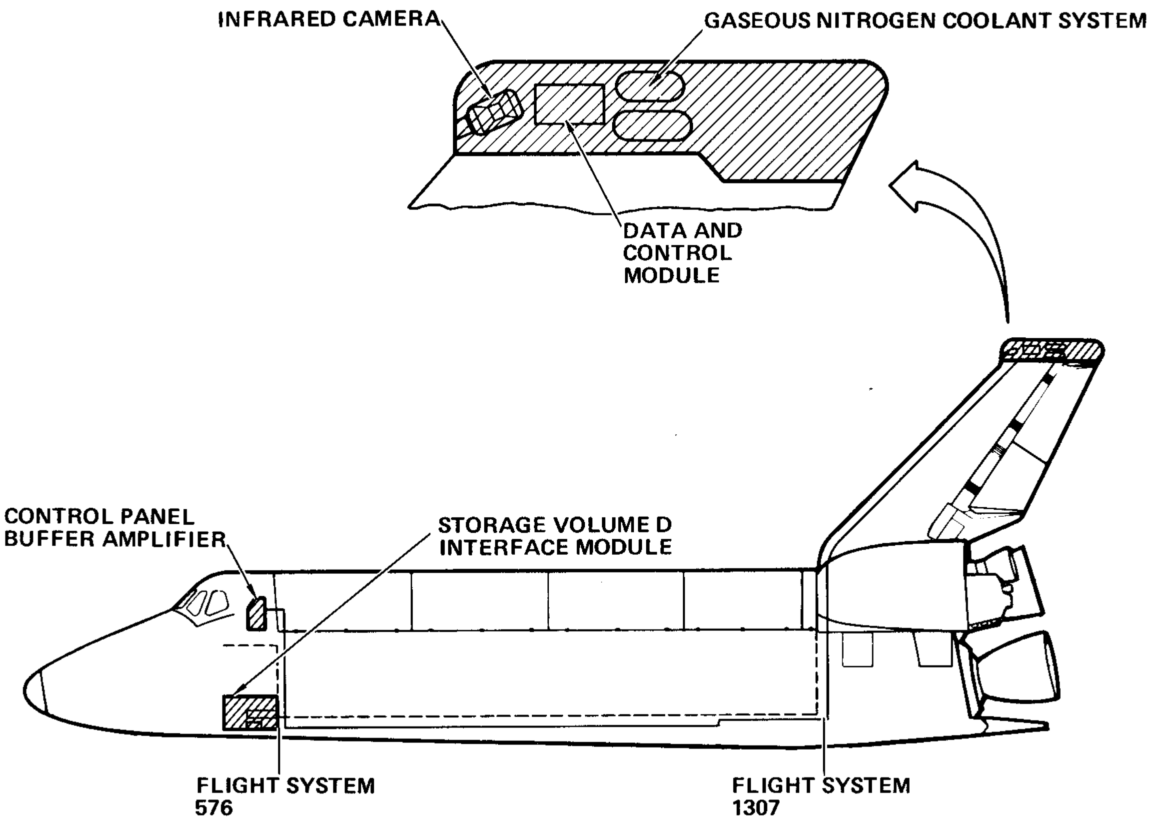


Figure 14. SILTS Experiment and Support Hardware

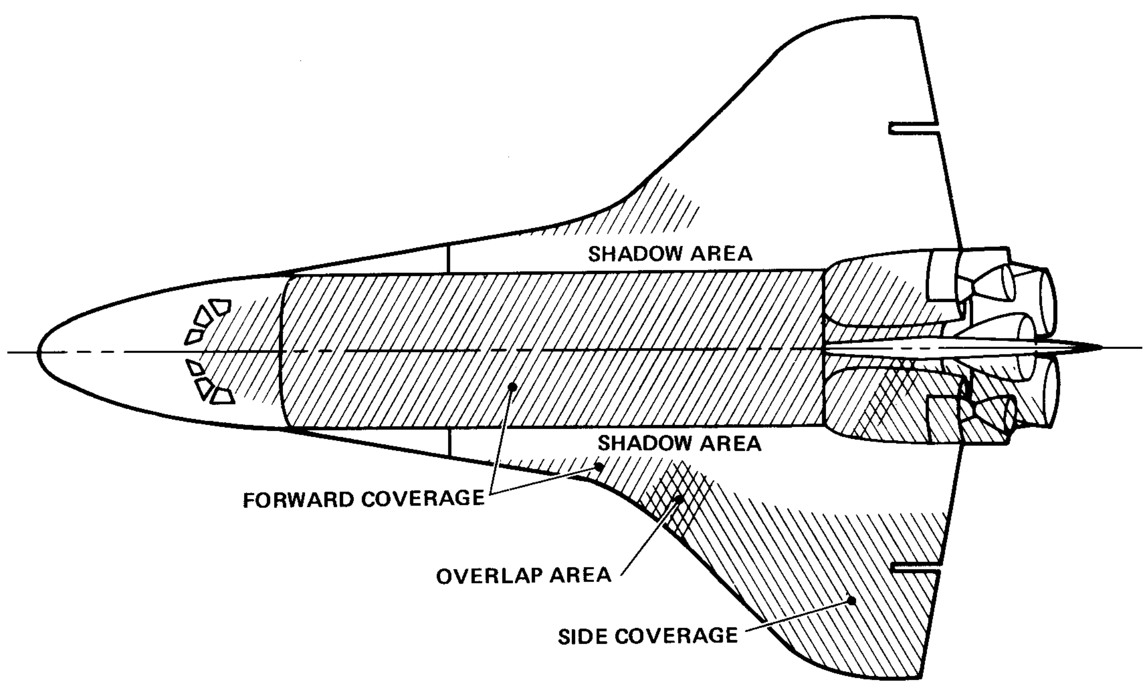


Figure 15. SILTS Experiment Infrared Camera Coverage

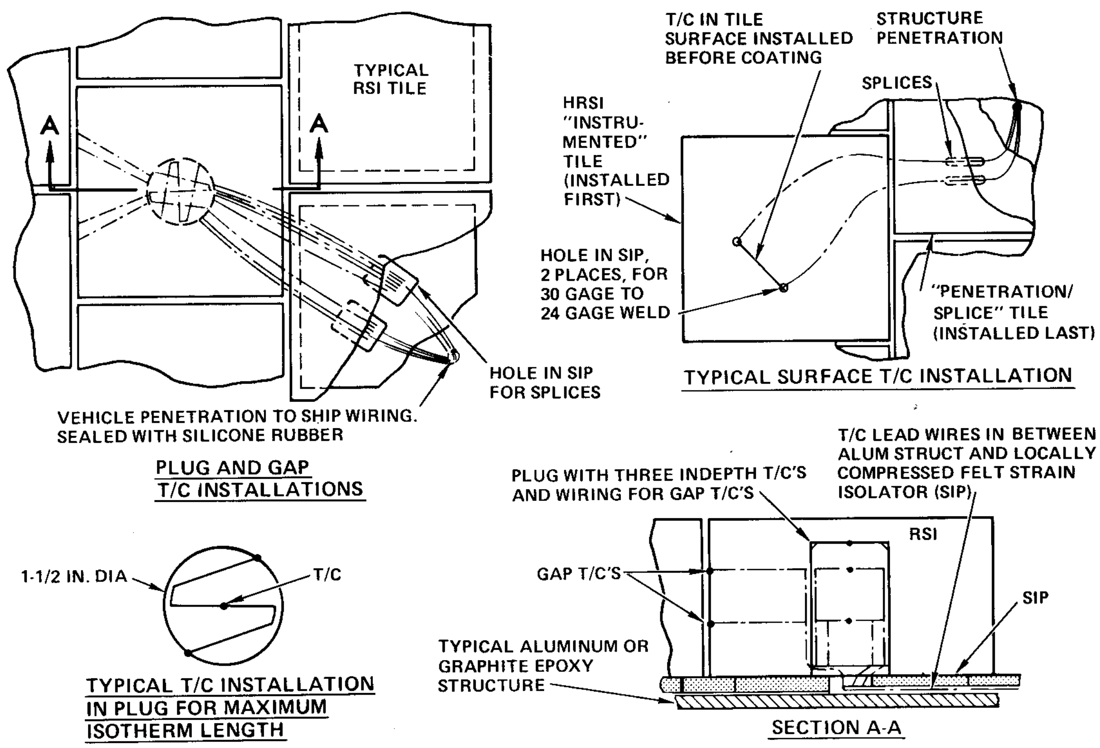


Figure 16. Typical TPS Thermocouple (T/C) Installation

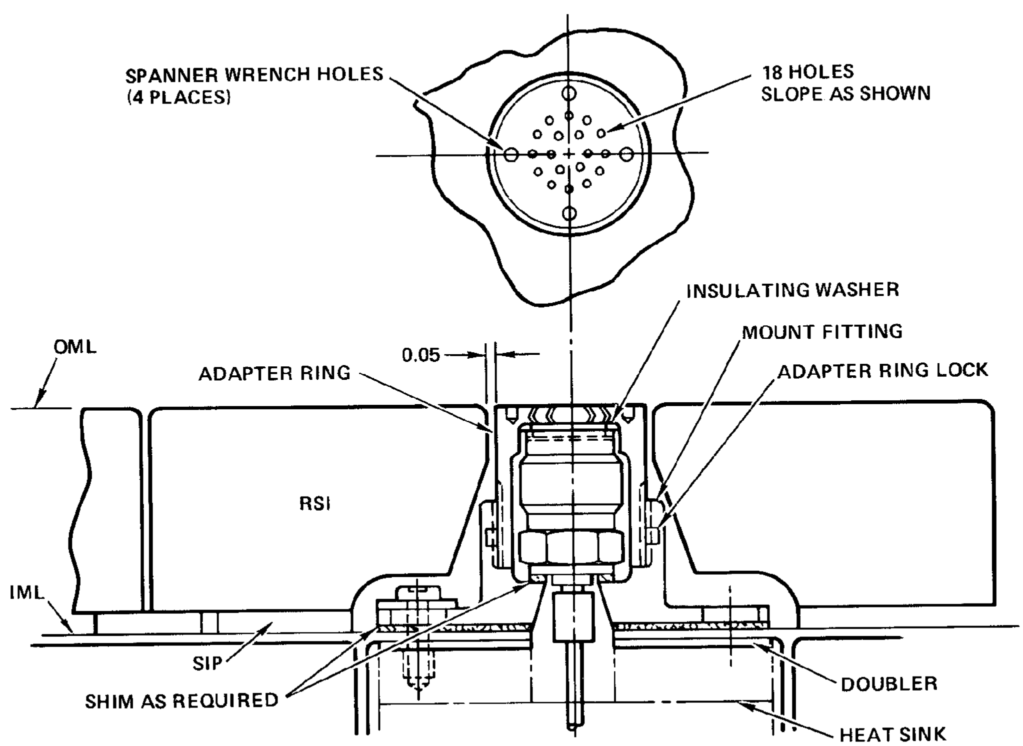


Figure 17. Typical Sound Pressure Installation in Aft TPS

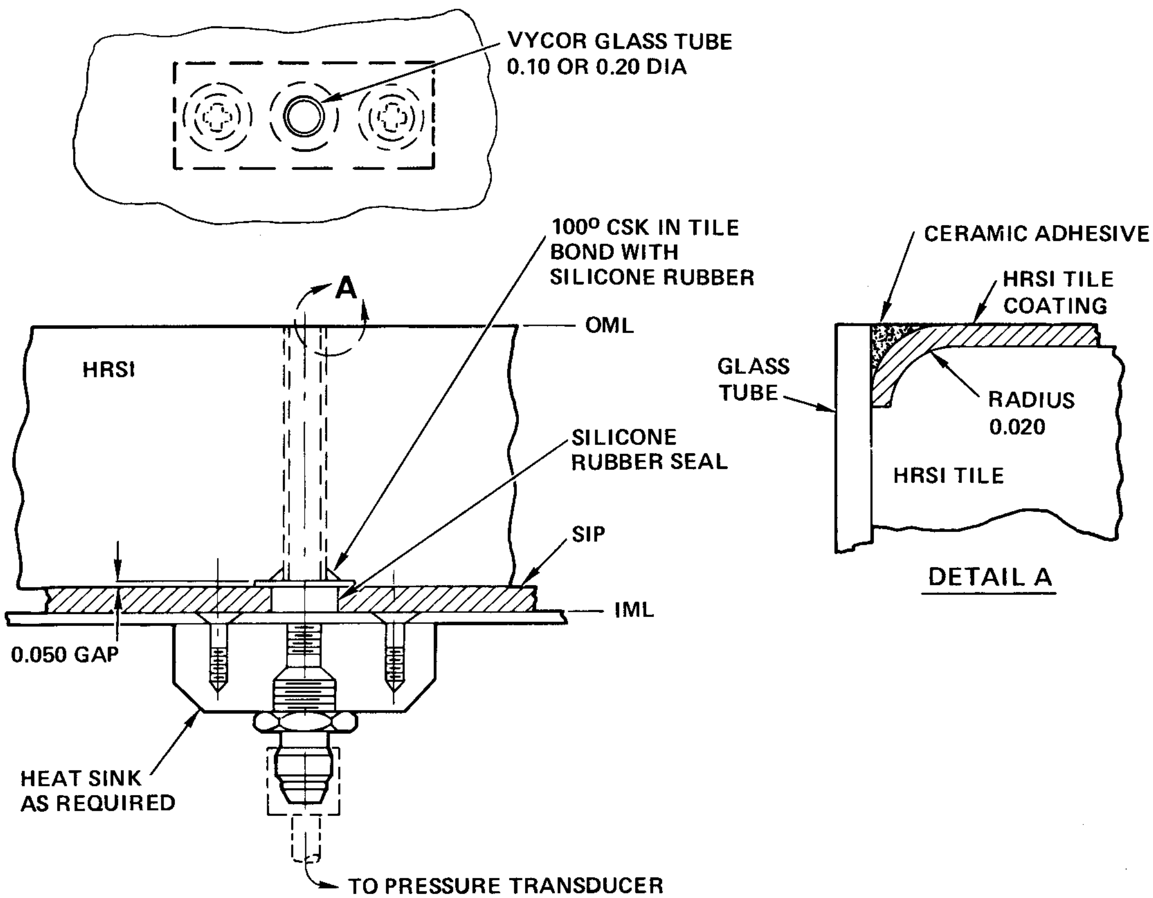


Figure 18. Pressure Ports in the TPS HRSI and FRSI