



Electromagnetic Compatibility for the Space Shuttle



Agenda

Introduction

Classic EMI

Electrostatic Charging

Electrical Bonding

Radar Monitoring

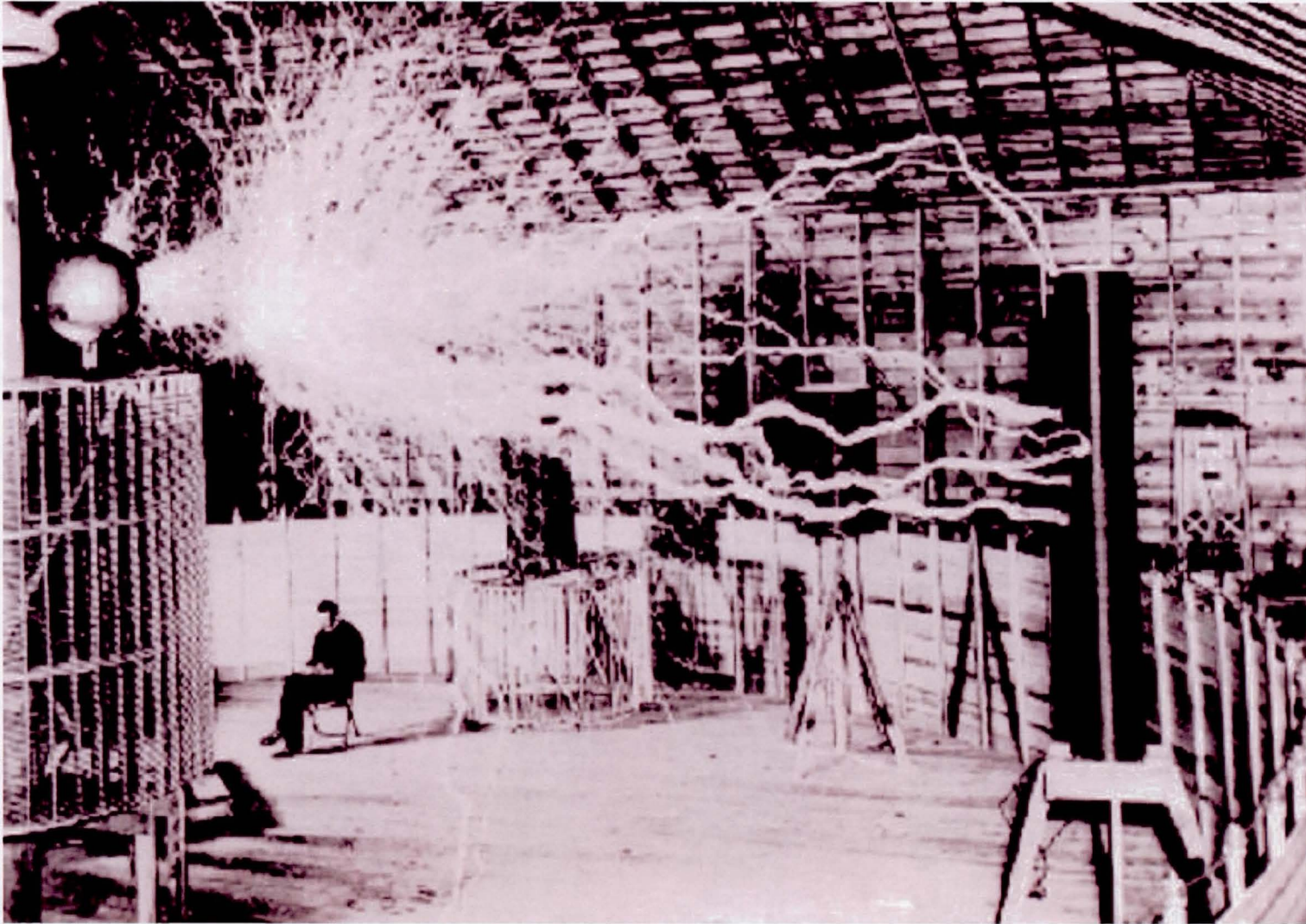
Lightning Protection

Future Work

Summary & Closing

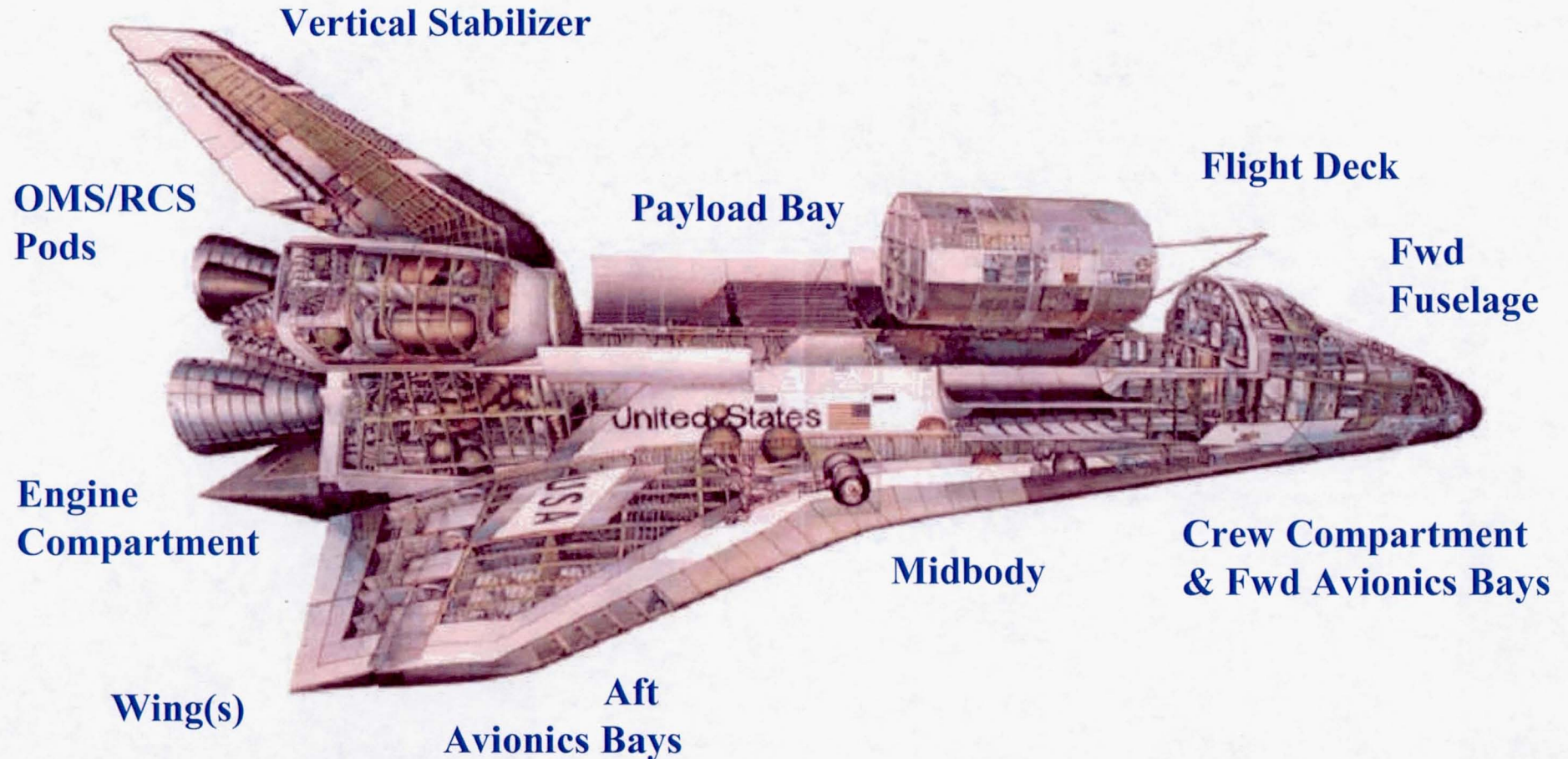


Introduction



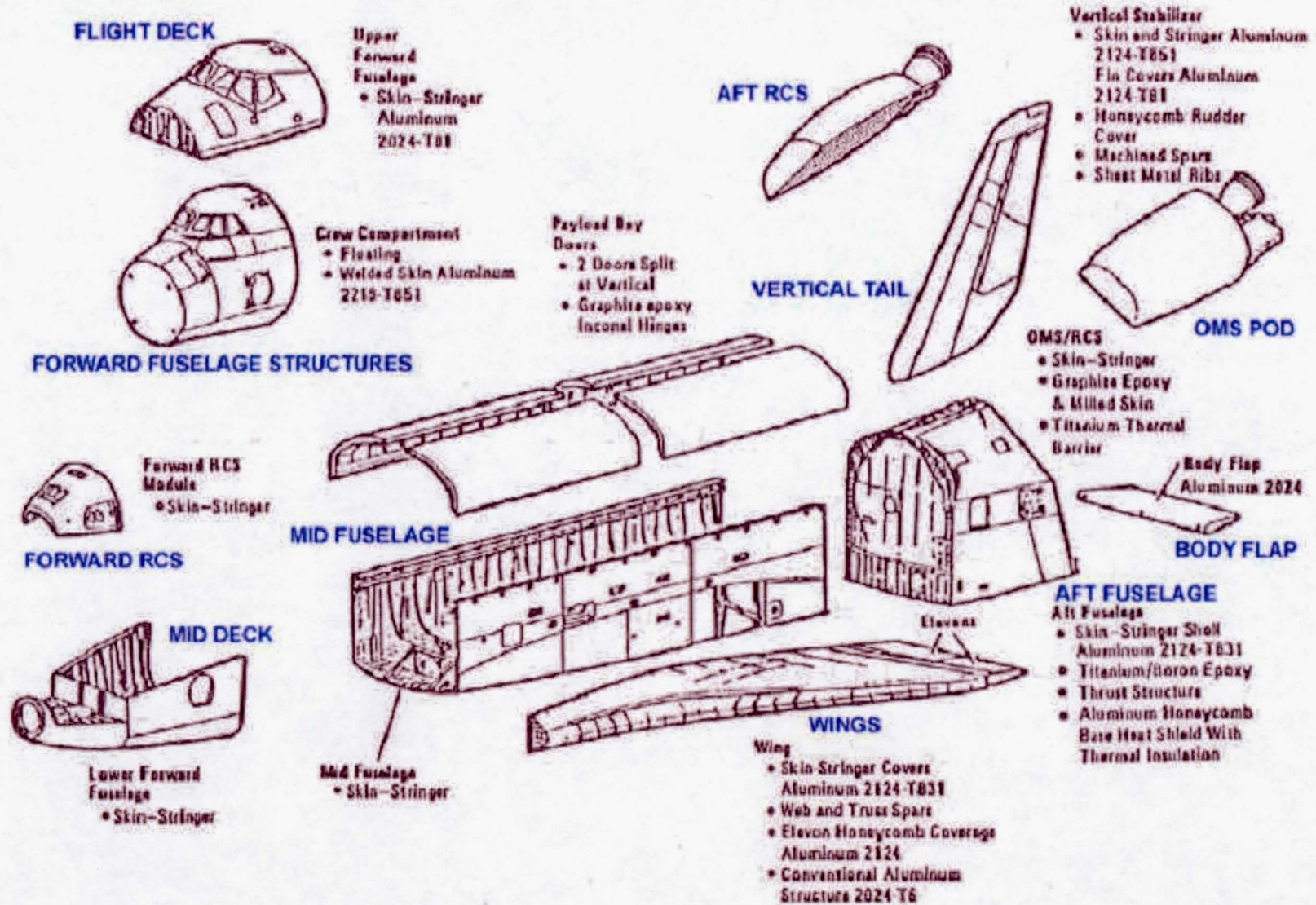


EMC Zones of the Orbiter





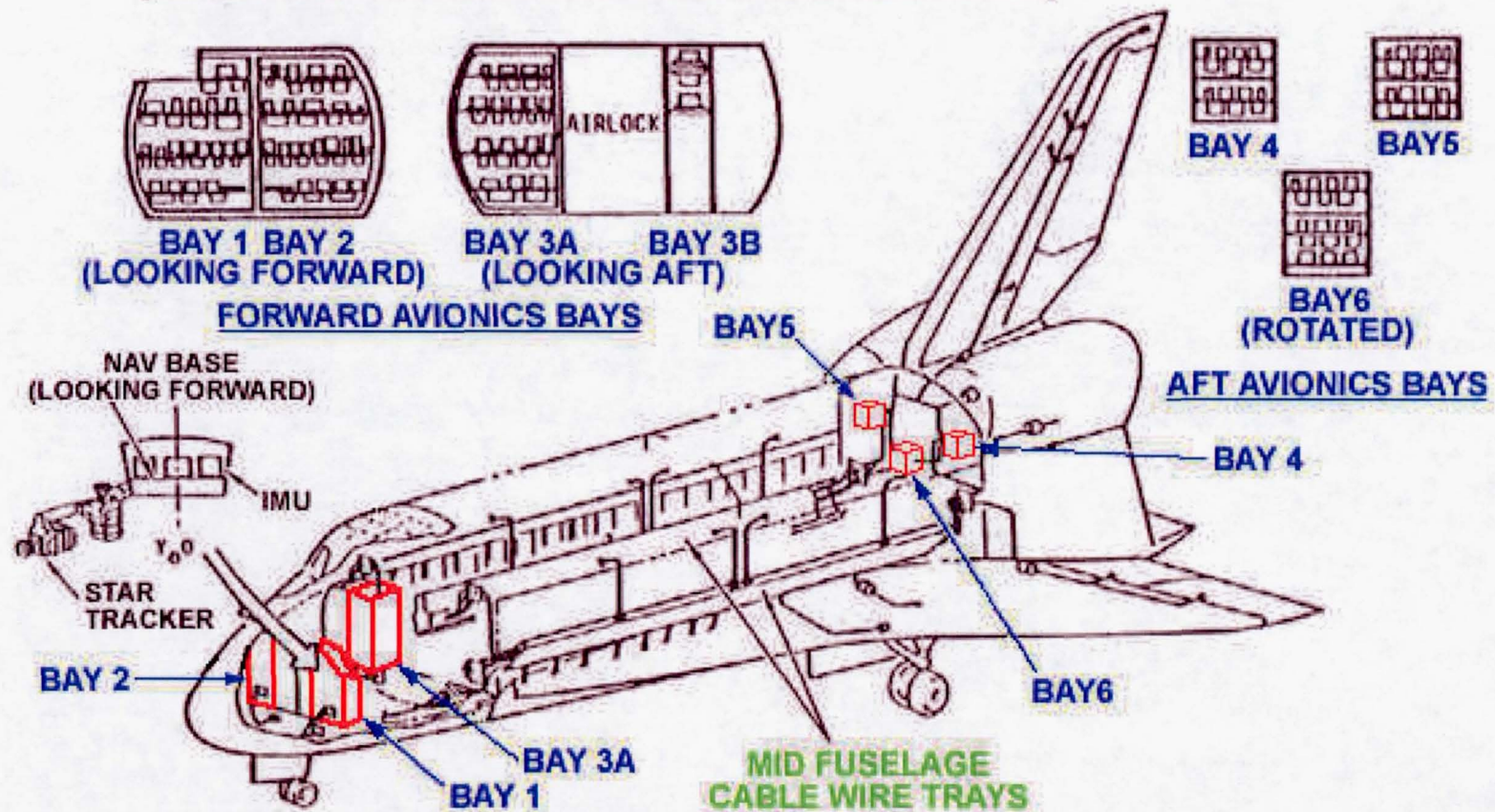
Orbiter Structures





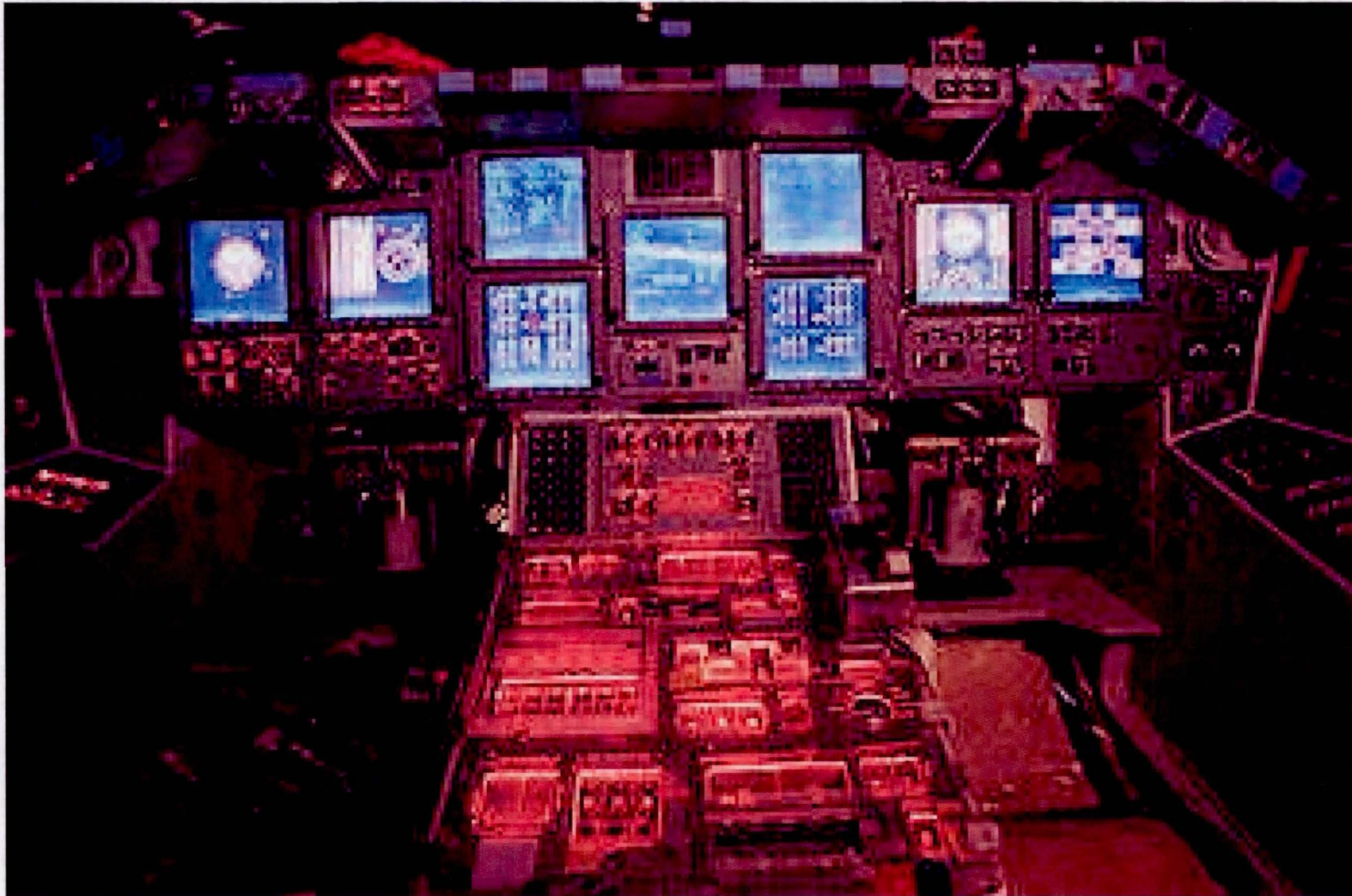
ORBITER AVIONICS SUBSYSTEMS

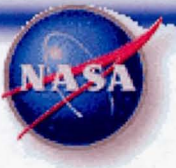
AVIONICS SUBSYSTEMS	
● GUIDANCE & CONTROL	● ELECTRIC POWER DISTRIBUTION
● COMM/TRACKING	● INSTRUMENTATION
● DISPLAYS & CONTROLS	● DATA PROCESSORS
● CAUTION & WARNING	● CLOSED CIRCUIT TELEVISION



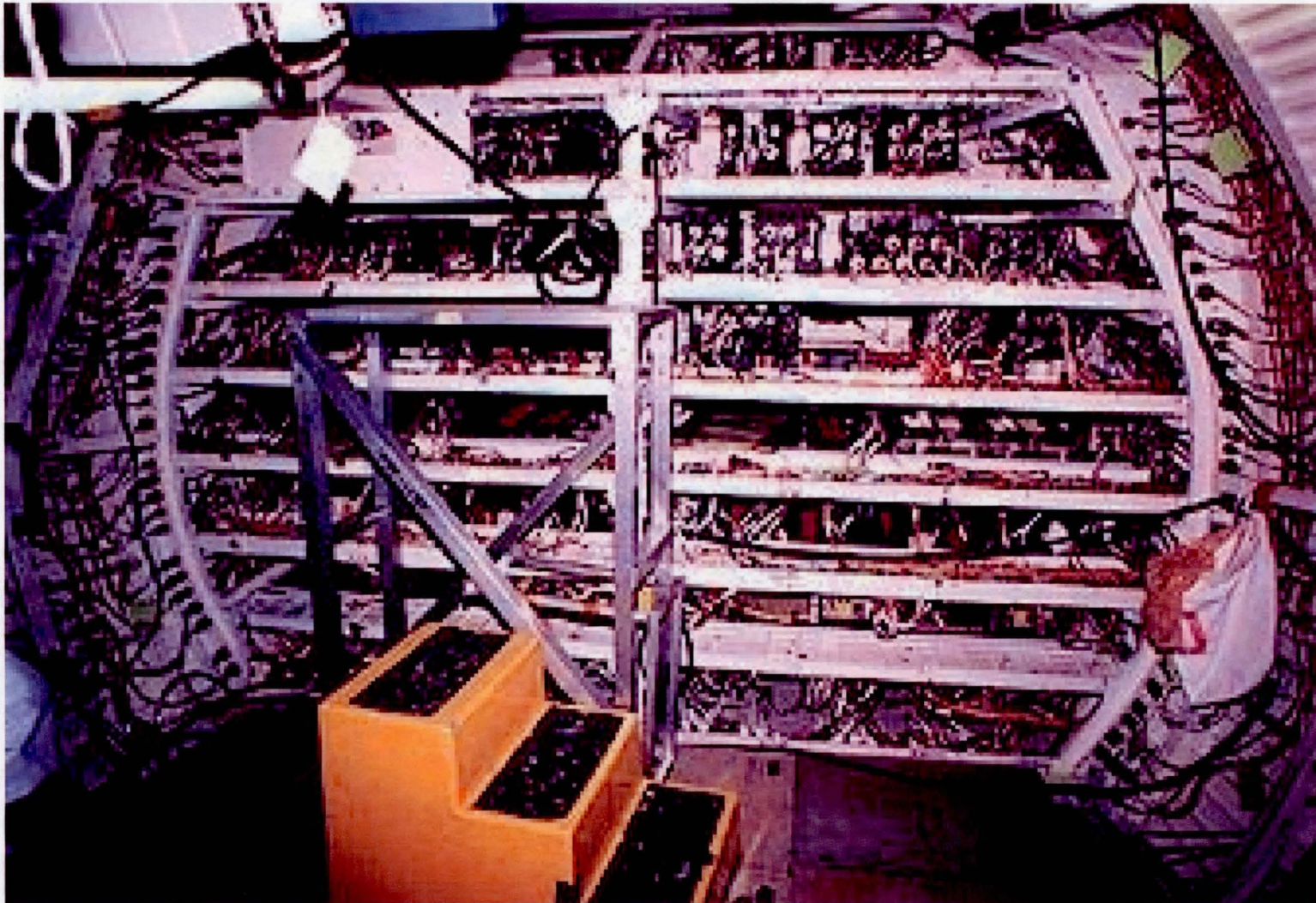


Glass Cockpit



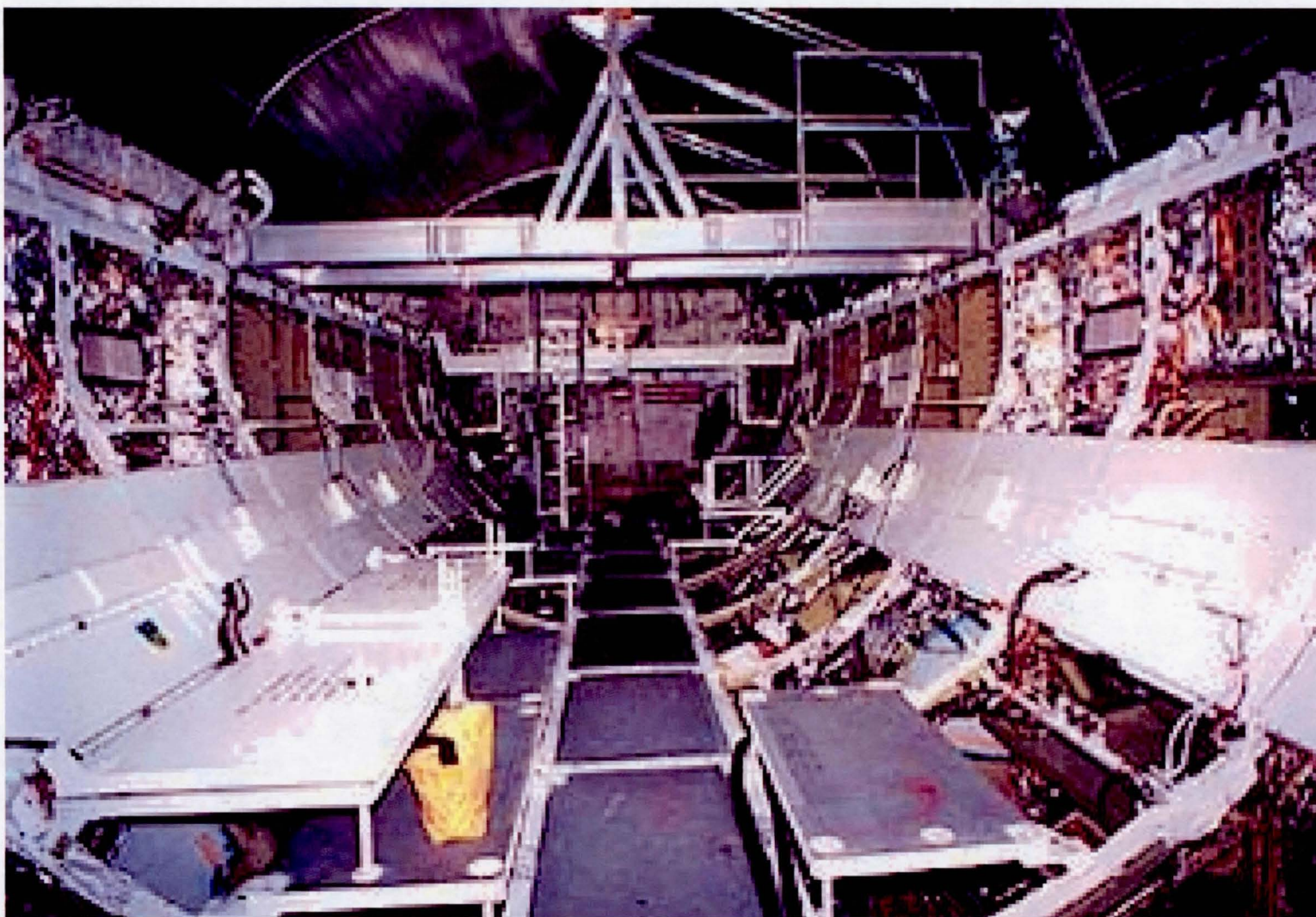


Forward Avionics Bays



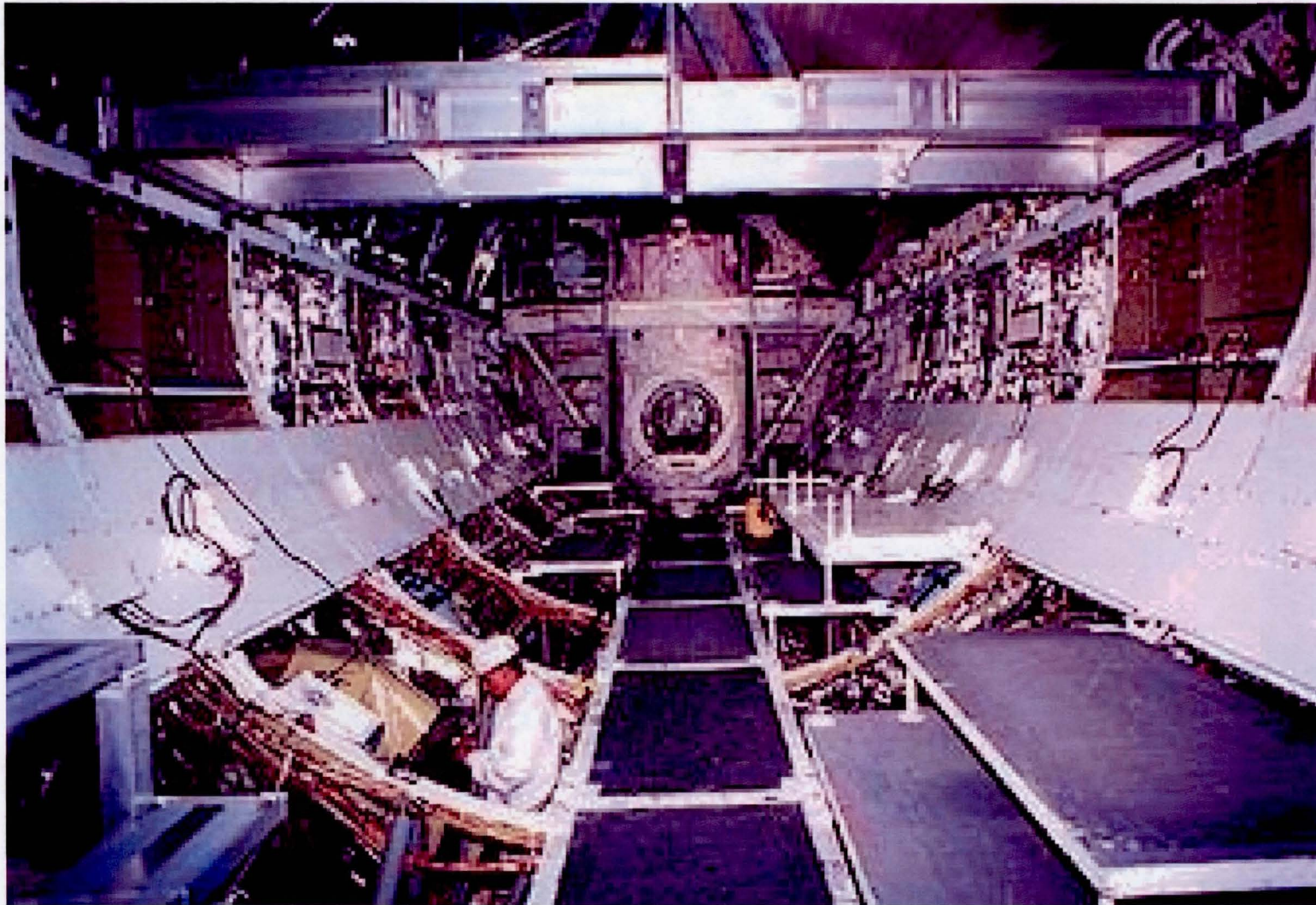


Payload Bay, Looking Aft



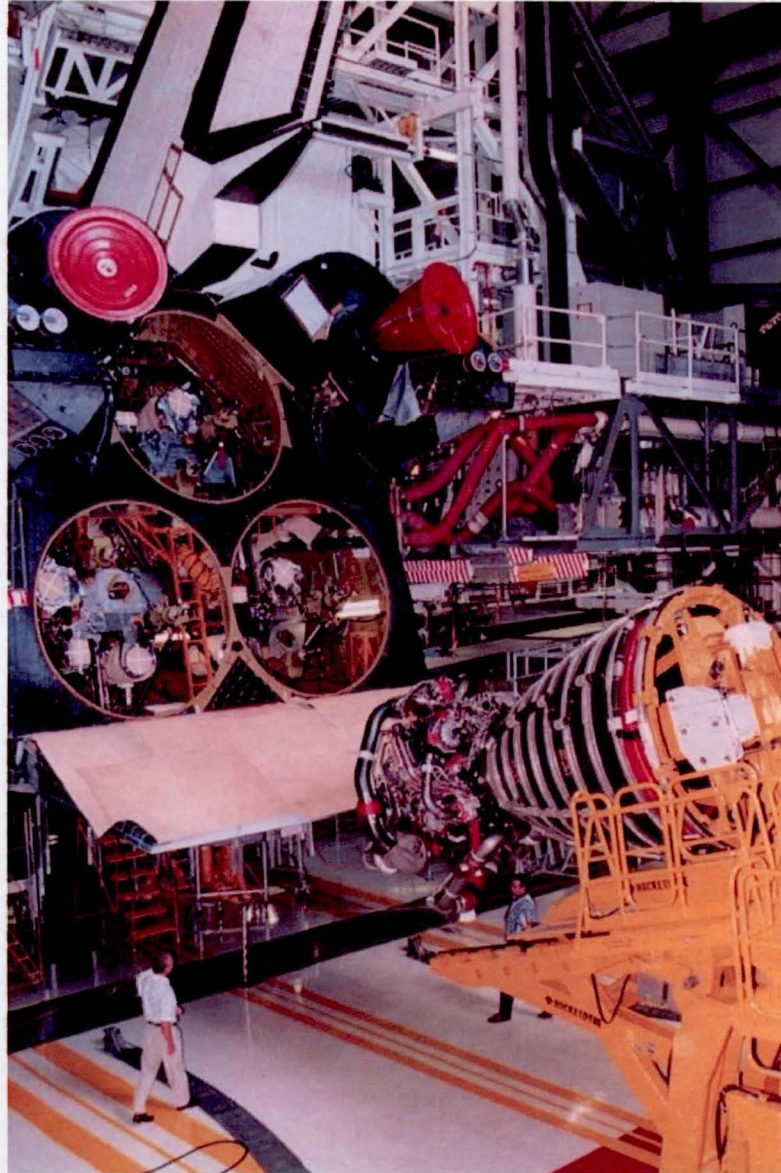


Payload Bay, Looking Fwd





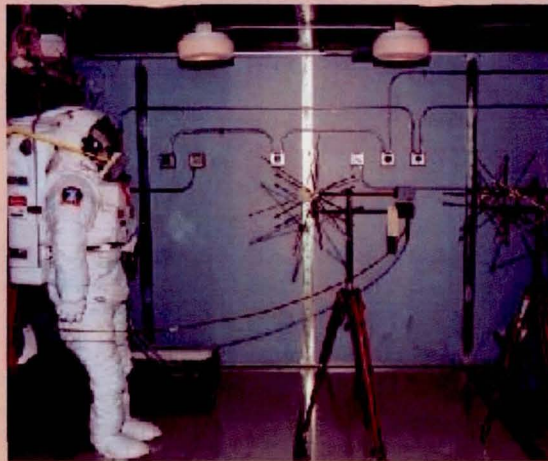
Main Engine Installation





Classic EMI

ELECTROMAGNETIC INTERFERENCE/ ELECTROMAGNETIC COMPATIBILITY (EMI/EMC) TEST FACILITY





Classic EMI

We provide electromagnetic compatibility and interference control engineering expertise

- Identification, definition and/or tailoring of EMI/EMC requirements**
- Assistance with mitigation of known or suspected failure(s) to meet EMI/EMC requirements**
- Areas of expertise include lightning protection, control of electrostatic discharge and corona, power supply filter design, signal routing and integrity, grounding, bonding, and shielding**



Classic EMI

We also offer advanced electromagnetic modeling capabilities, and can perform computation using approaches such as:

**Finite Difference Time Domain (EMA3D)
Method of Moments (NEC-BSC, GEMACS)
radar cross section calculation (X-Patch)**

Finally, we collaborate with EMI/EMC groups located at other NASA centers, such as Marshall Space Flight Center and Kennedy Space Center, to ensure we provide the best overall products and services possible.



Classic EMI

Space Shuttle Electromagnetic Interference limits and test methodologies were originally derived from Mil-Std-461A. Recently, the requirements were completely revised to reflect the current version, Mil-Std-461E. Although the Mil Spec was used as a basis, the limits were heavily tailored specifically for the Shuttle application.

In contrast, Space Station uses limits and test methodologies derived from Mil-Std-461C, whereas the Russian segment uses limits and test methodologies similar to both Programs.



Classic EMI

REQUIREMENT APPLICABILITY

	C	C	C	C	C	C	C	C	C	R	R	R	T
	E	E	S	S	S	S	S	S	S	E	E	S	T
	1	1	1	1	1	1	1	1	1	1	1	1	1
	0	0	0	0	0	0	0	1	1	0	0	0	0
Requirement/Test Method →	2	6	1	3	4	5	6	4	6	2	3	3	1
↓ Equipment type ↓ Note →		1		2	2	2		3	3, 6	4	1		5
Antenna-connected electronics, battery powered		X		X	X	X		X	X	X	X	X	
Antenna-connected electronics connected to Shuttle primary power source	X	X	X	X	X	X	X	X	X	X	X	X	X
Non-antenna connected electronics, battery powered								X	X	X		X	
Non-antenna connected electronics, connected to Shuttle primary power source	X		X					X	X	X		X	X
Electrical loads connected to Shuttle primary power without intermediate power conversion													X



Classic EMI

As an example of specific tailoring, Space Shuttle employs a Bulk Cable Emissions (BCE) test from 150 kHz to 200 MHz as a part of the more familiar RE102 radiated emissions requirement.

The BCE test utilizes a CISPR 16 absorbing clamp, calibrated as a current probe, to measure common mode radiated emissions associated with cable harness currents.

The intent of this measurement is to characterize possible crosstalk interference related to cable harness currents.



Classic EMI

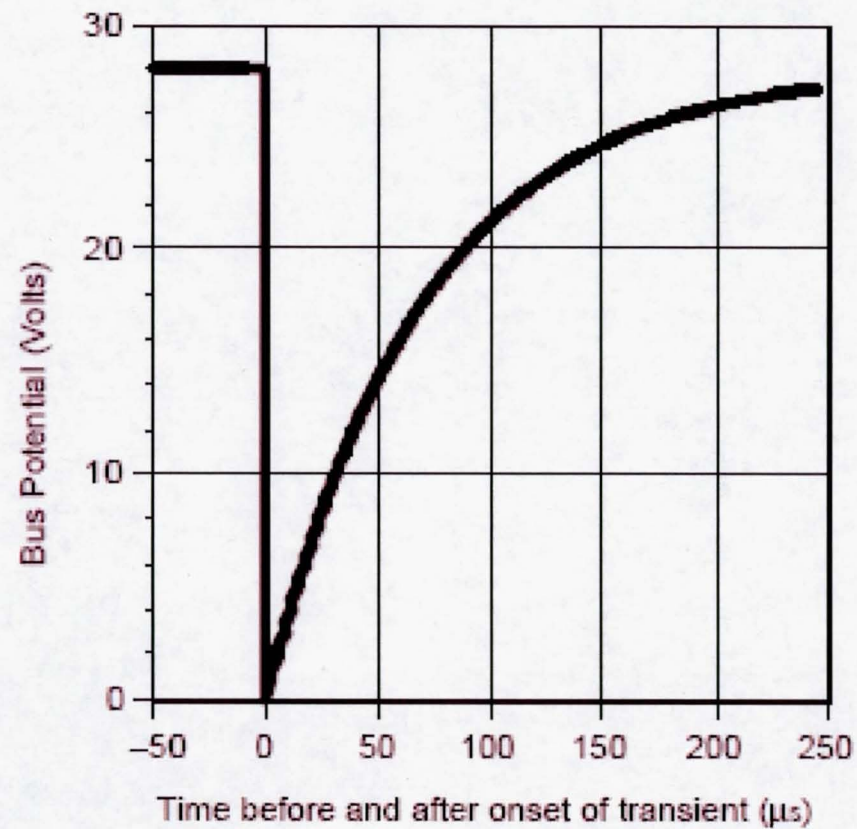
Another example of a unique test methodology created for Space Shuttle is the CS106 test, which replaces the obsolete CS06 limit and methodology in earlier versions of MIL-STD-461.

This test measures the EUT response to negative going transients on the power bus associated with equipment turn-on, and is an accurate simulation of load-induced power-line switching transients expected to occur on the Shuttle power bus.



Classic EMI

(CS106-1) TRANSIENTS ENVELOPE: 28 VDC BUS, 4//50 μ F LOAD

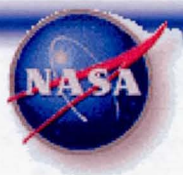




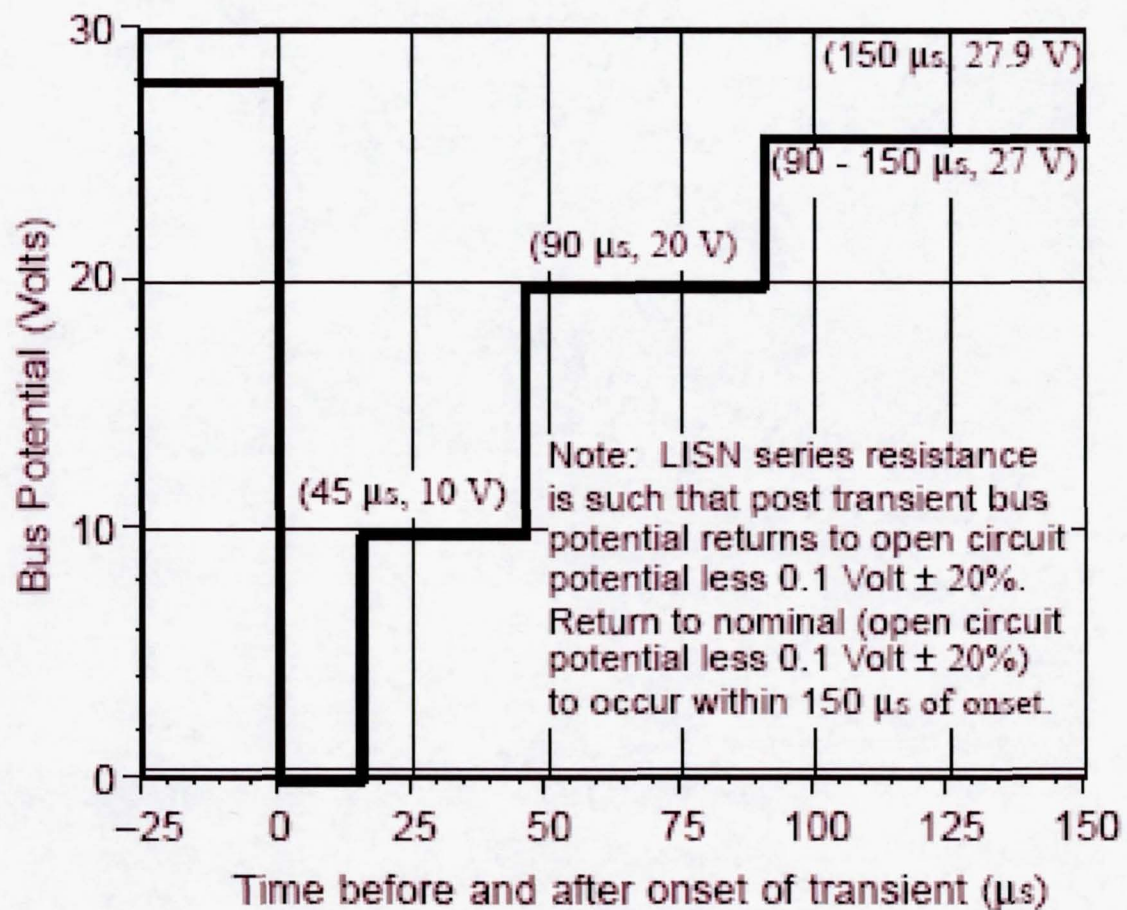
Classic EMI

An intentionally complimentary test methodology to CS106, modified from a previous unique Space Shuttle test, is the TT101 test, which also has no equivalent counterpart in MIL-STD-461.

This test measures the emitted negative going transient associated with equipment turn-on, and provides specific information regarding bus sag as a function of both time and magnitude, as well as insight into potential inrush current problems.

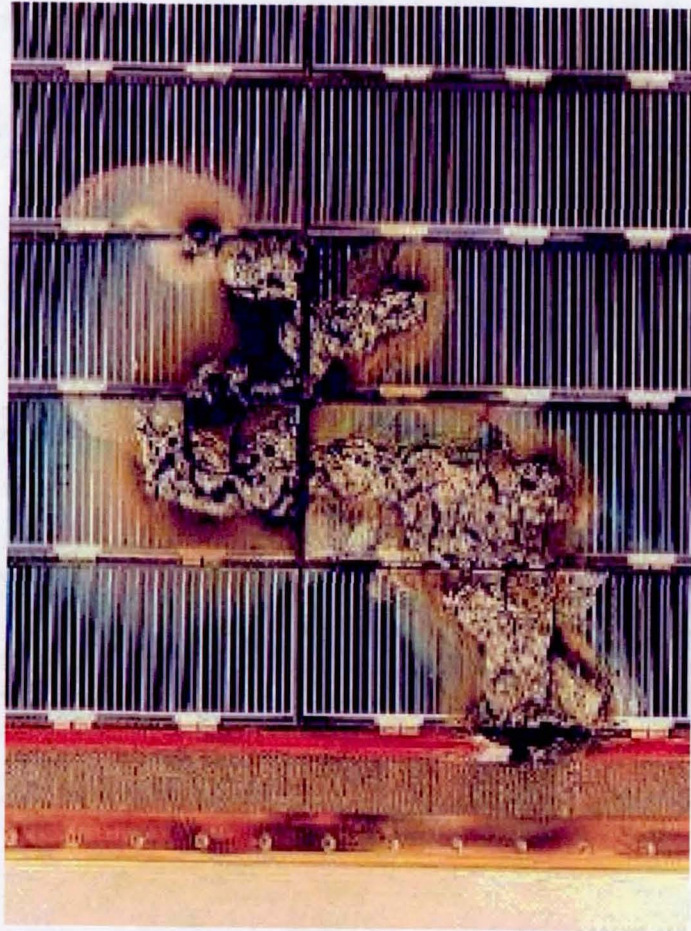


Classic EMI



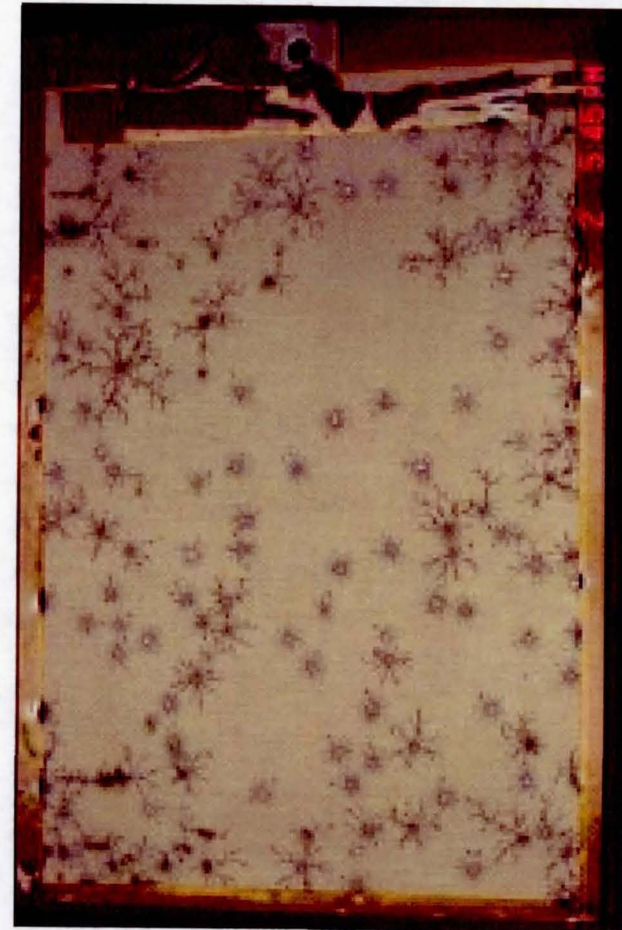


Electrostatic Charging



*Sample of Flight Array from
ESA EURECA Mission*

*Anodized Al Plate After
Repeated Arcing*





Electrostatic Charging

Electrostatic discharge is a constant threat to the Space Shuttle and its various components and equipments, whether on the ground during preparation for flight, or in Low Earth Orbit approaching the International Space Station.

For many years, Shuttle relied on Mil-Std-1686 and Mil-HDBK-263 for guidance and requirements for protection of equipment. These documents have now been superseded within NASA by ESD Association Standard ANSI/ESD S20.20-1999. As additional reference, the ESD Association Technical Report TR20.20-Handbook is also available.



Electrostatic Charging

Electrostatic charging can generally be reduced to three primary mechanisms:

- triboelectric charging
- exogenous charging
- ionic charging

Of these, triboelectric charging is probably the most familiar, and presents the most ubiquitous threat to Shuttle equipment.



Electrostatic Charging

Triboelectric charging results from the separation of material surfaces. The amount of charge transfer is dependent on the surface roughness, and the difference in their respective work functions. A work function describes the amount of energy necessary to liberate an electron from its orbit about the nucleus of an atom. Clearly, different materials will exhibit different work functions.

Surface separation can occur from frictional contact between one's feet and the floor surface, or the flow of a gas contaminated with slight amounts of particulate matter.



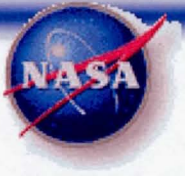
Electrostatic Charging

In Low Earth Orbit, the Orbiter is in contact with the plasma environment, and is potentially subject to current collection. Negative surfaces collect ions; positive surfaces collect electrons.

The charge process is governed by the Poisson Equation

$$\nabla^2 \phi = -4\pi\rho$$

Experiment has shown the Orbiter main engine bells collect sufficient ion current to achieve balance with the surrounding plasma at a low potential difference, as long as the main engine bells are not in the Orbiter wake.



Electrostatic Charging

Exogenous charging results from near proximity to a strong concentration of electric charge, and is thought to play a role in triggered lightning events. This type of electrostatic charging is not generally a threat to Shuttle.

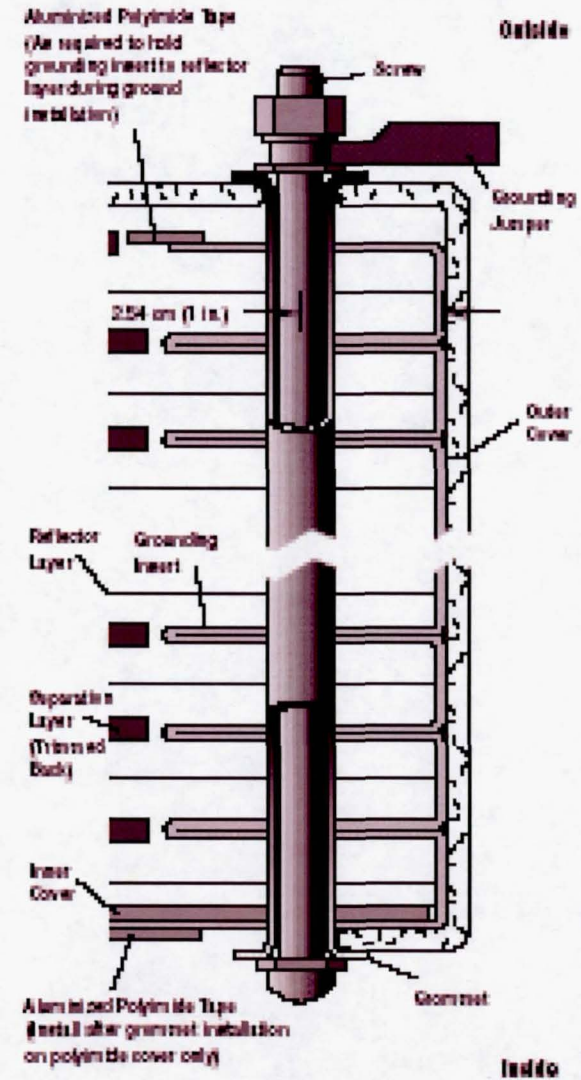
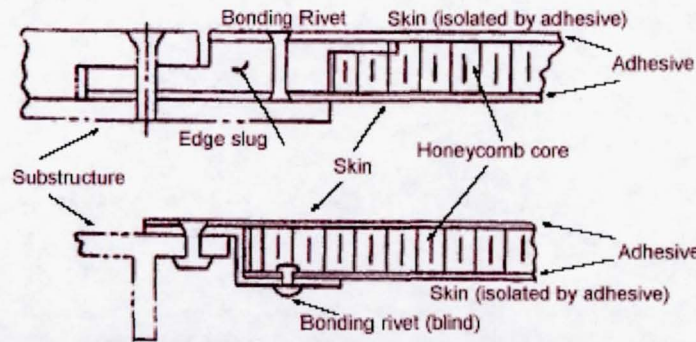
So, how do we control all this transfer of electric charge?

In the case of ionic vehicle charging, we try to keep the main engine bells out of the Orbiter's wake so we can balance Poisson's Equation. Space Station uses a device known as a Plasma Contactor, which uses Xenon gas as an ion source.



Electrical Bonding

TYPICAL ELECTRICAL BONDING OF DETAILS WHICH ARE ELECTRICALLY BONDED BY ADHESIVES





Electrical Bonding

Space Shuttle currently uses Mil-B-5087B as the source for its bonding criteria. Several classes of electrical bonding are described in Mil-B-5087B, among them Class A, C, H, L, R and S.

Recently released NASA-Std-4003, titled Electrical Bonding for Launch Vehicles, Spacecraft, Payloads and Flight Equipment, combines requirements contained in Mil-B-5087B and SAE ARP 1870, and the experience of NASA EMC engineers from several NASA centers. This new standard includes bonding classes C, H, L, R and S (A is included in R), provides general and specific requirements, and a section containing design guidance.



Electrical Bonding

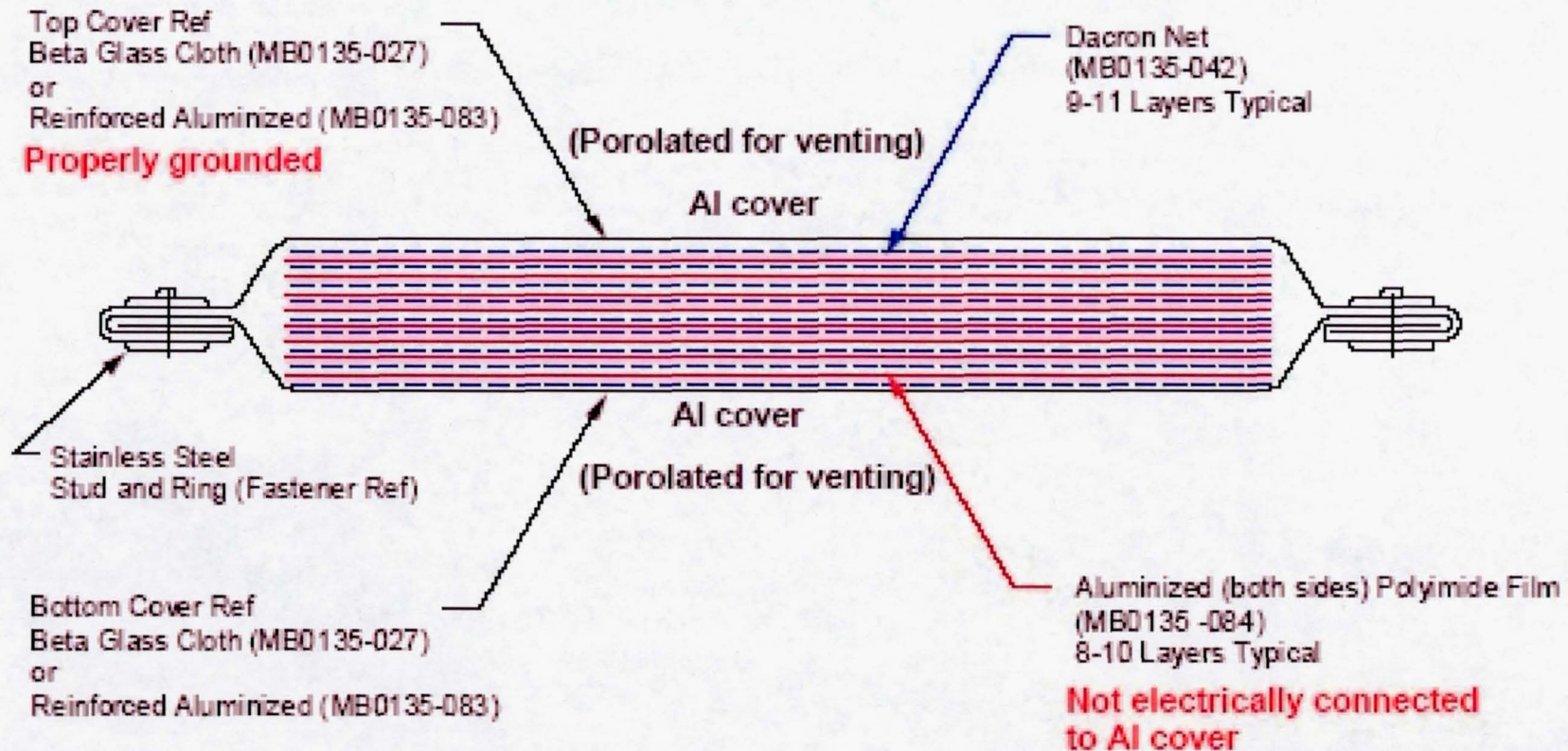
Electrical bonding is the *process* we use to electrically and mechanically join two or more materials together to minimize electrical potential differences.

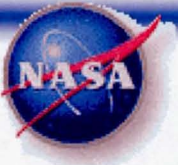
In the electrostatic case, we want to control the accumulation and distribution of electrical charge. That's true, whether the charge is on your body, or covering the surface of a Space Station solar array upon which an astronaut is about to perform routine maintenance.



Electrical Bonding

One of the largest bonding challenges for Shuttle is to control electrostatic charging on multilayer insulated blankets and related materials.





Lightning Protection





Lightning Protection

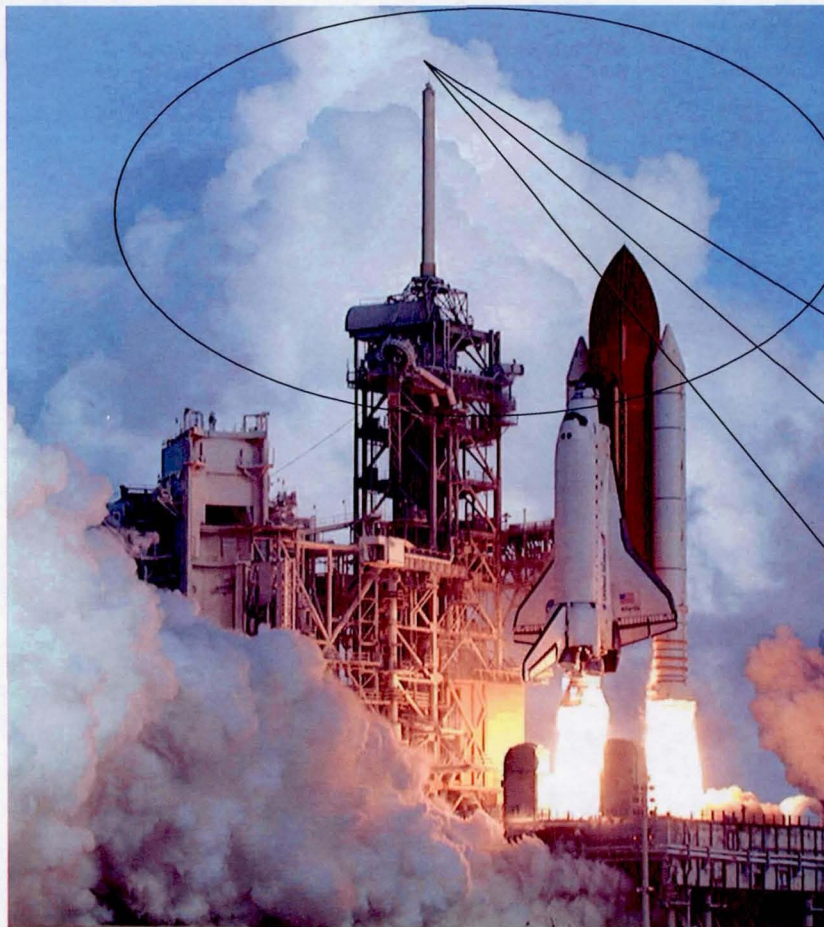
The primary protection for Space Shuttle from the effects of lightning is avoidance.

Stringent weather avoidance criteria are in place to ensure the Shuttle vehicle is not exposed to lightning events.

During launch, the Shuttle is exposed for about 80 seconds as it ascends into orbit; during landing, the exposure time is a bit longer, only about 5 minutes as it passes through the lower atmosphere where lightning might be expected to occur.



Lightning Protection



On the pad, Shuttle is protected by the Catenary Wire Lightning Instrumentation System





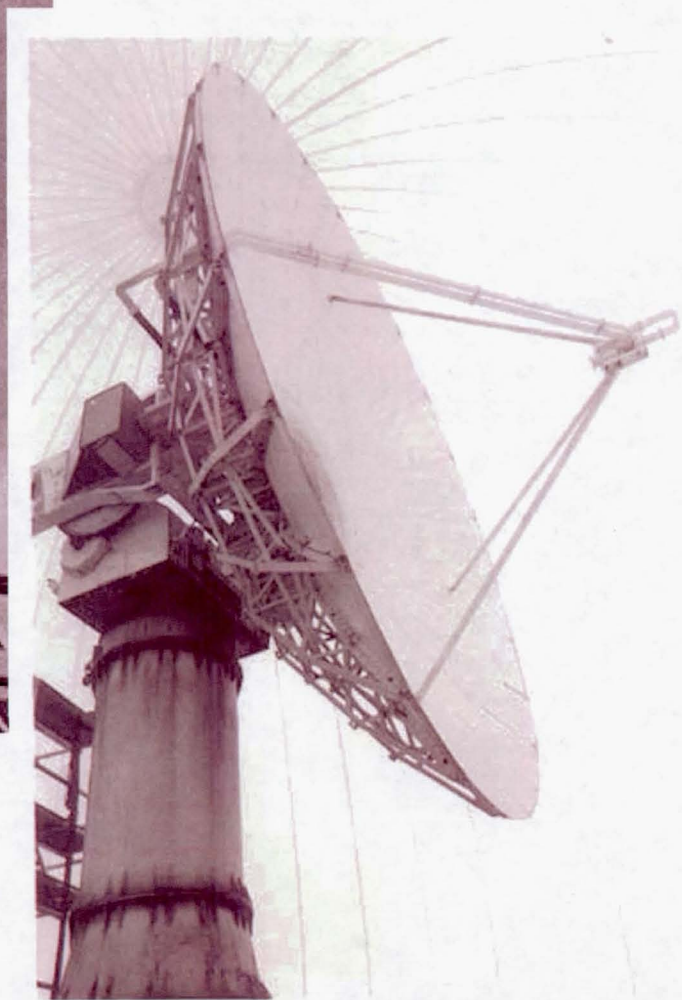
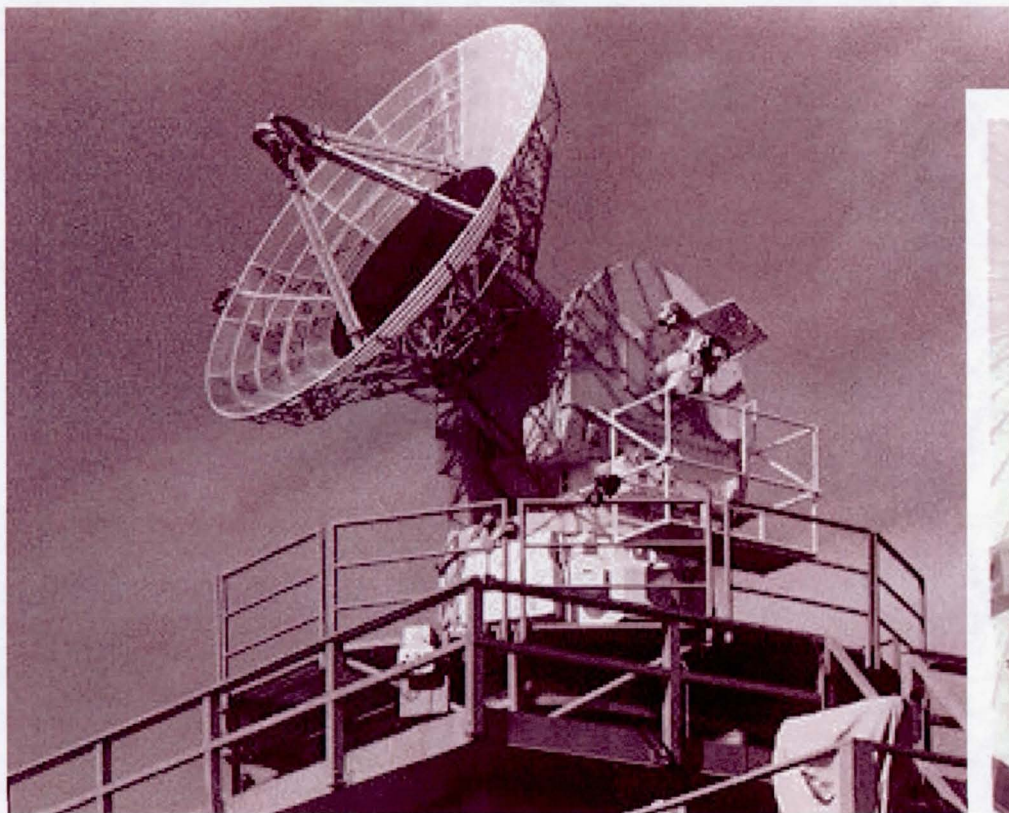
Lightning Protection

Since lightning is ultimately unpredictable even with strict weather controls in place, NASA still uses design criteria, analysis, and protective measures to provide protection from both direct and indirect effects of lightning.

A good example of such protective measures is the incorporation of aluminum mesh in the outer mold line of the composite payload bay doors. This technique has been proven in many aircraft designs using composite materials, such as the Bell-Boeing V-22 Osprey, and the Beech Starship.



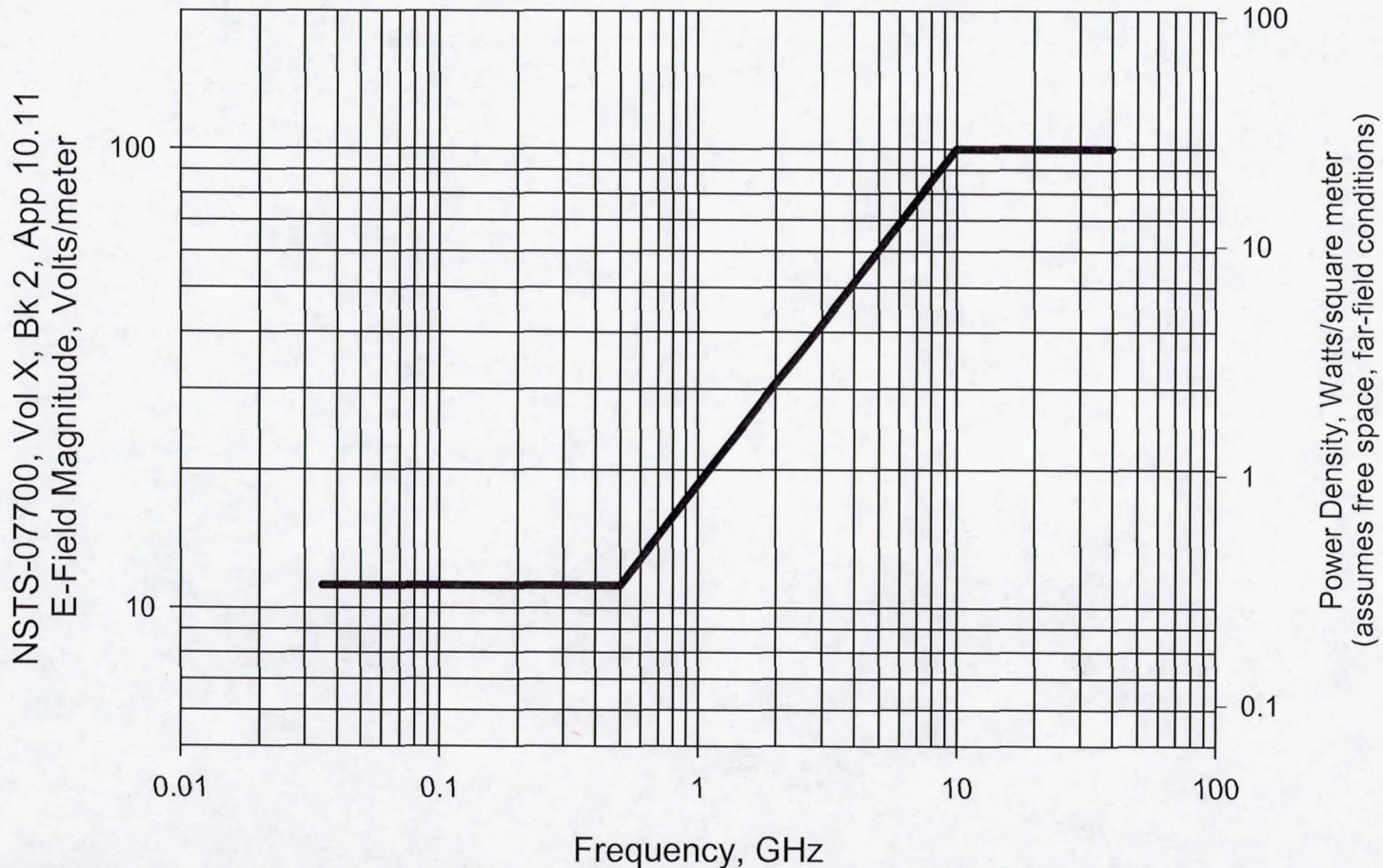
Radar Monitoring





Radar Monitoring

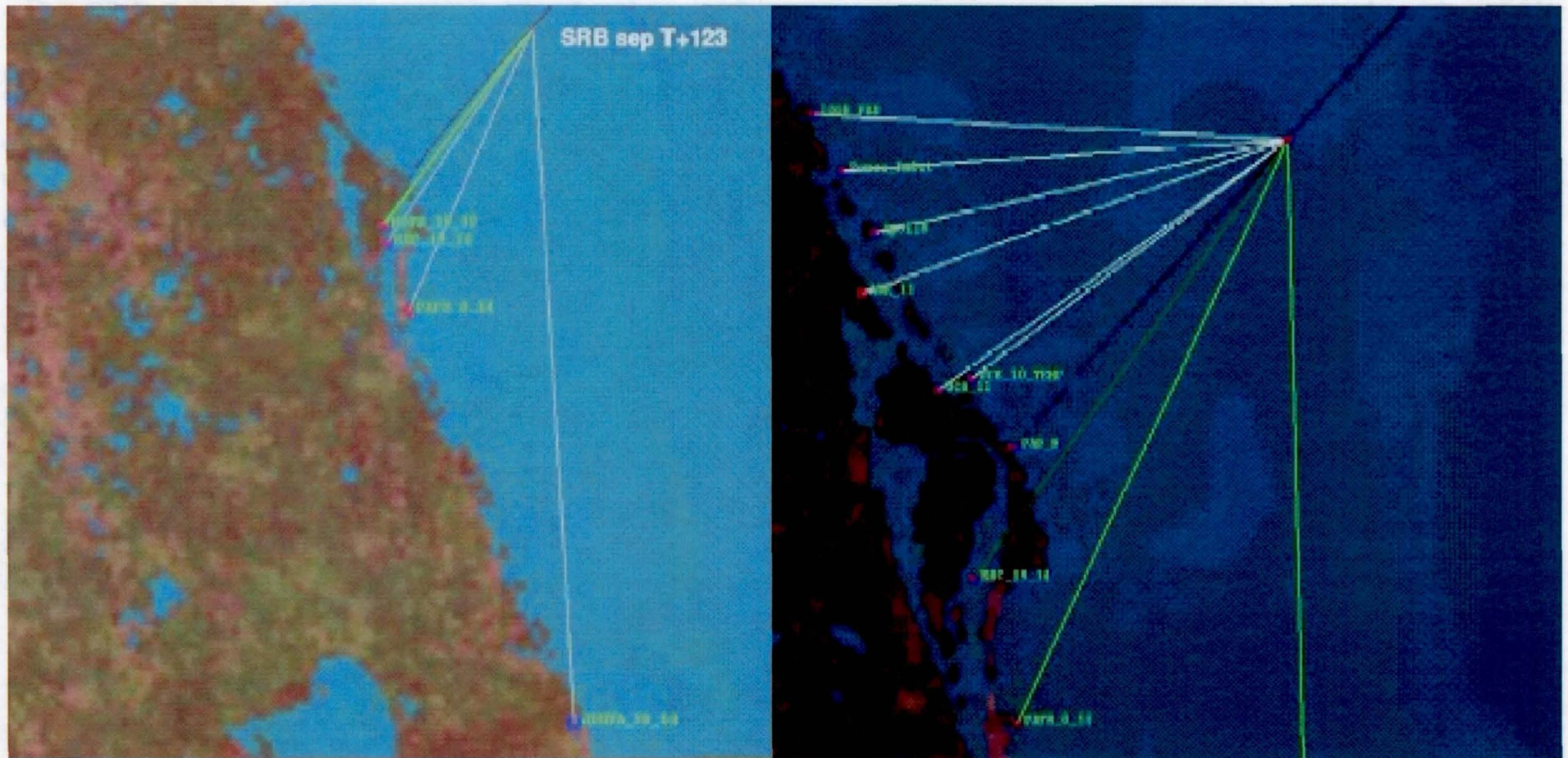
Maximum Launch, Descent and Landing External RF Environment Level





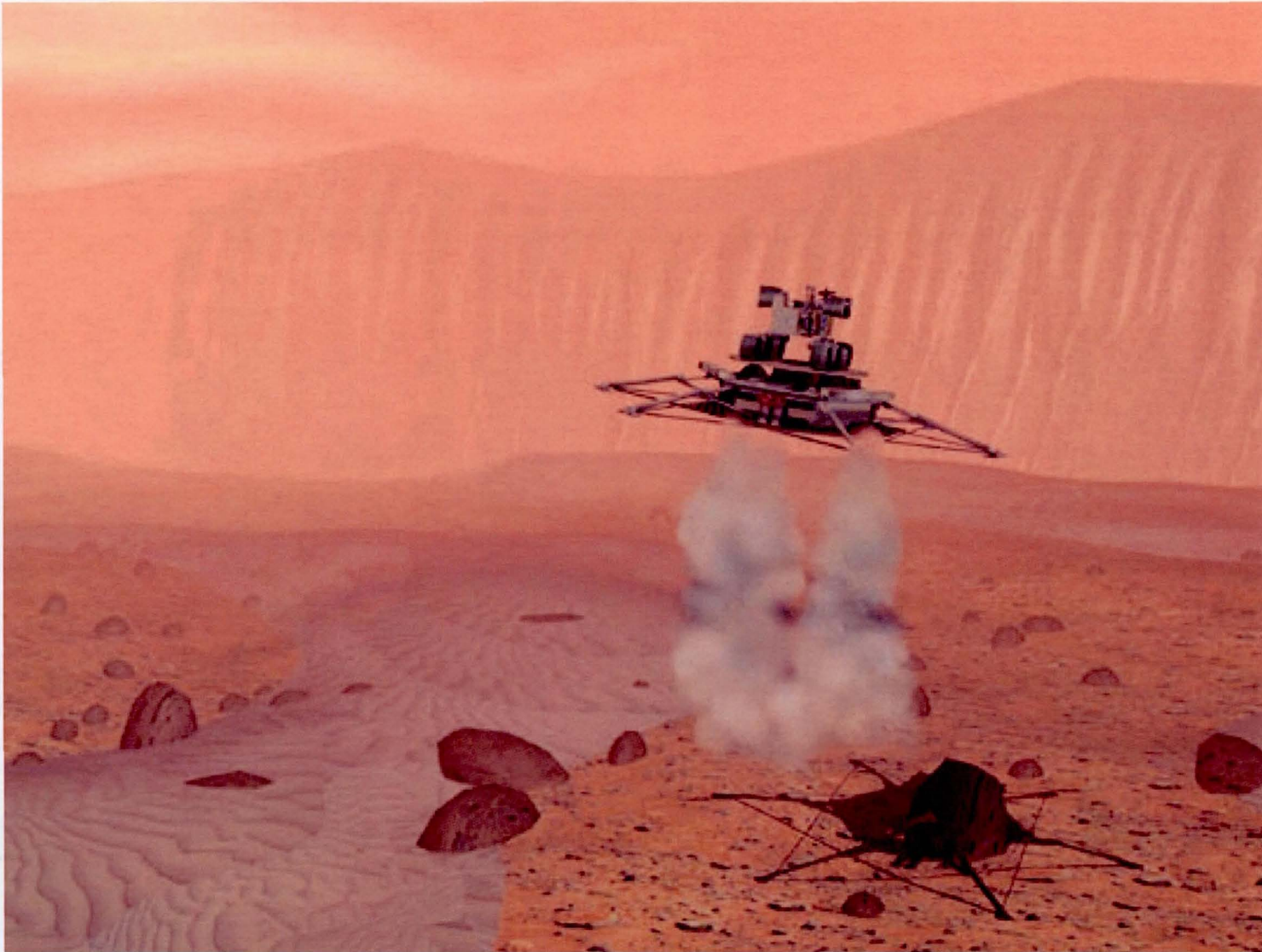
Radar Monitoring

Current versus Potential New Monitoring Radar Sites





Future Work





Future Work

Measurement of the RF attenuation of aircraft has been a problematic issue for several years

Older methods utilized a very time consuming, direct illumination process that required many antenna positions to be used

- Often the results were questionable, thus leading to high cost for low return on the investment

NIST has been working to develop a direct illumination method in the time domain, and has recently been successful with this approach



Future Work

Other new methodologies have been developed in the recent past that utilize reverberation chamber theory

- The statistical basis of these methodologies has been carefully explored and verified by multiple tests on large aircraft**
- These new methodologies require fewer antenna positions, and generate a lot of accurate and reliable data in a (relatively) short time**

Both Patuxent River NAWC and Dahlgren NSWC have successfully utilized this approach



Future Work

Two major Orbiter vehicle tests are currently in planning:

- RTF (quick look) test to validate aft compartment shielding**
- Full Orbiter EMI characterization**

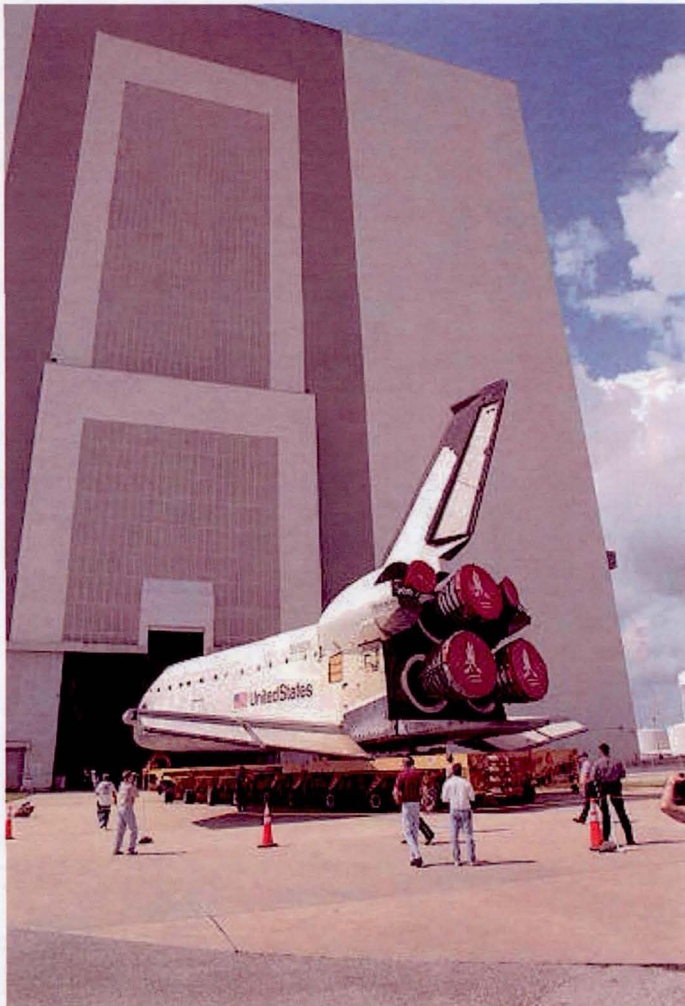
The RTF test is planned to utilize the AFRL Mobile Diagnostics Lab (MDL) and drag on instrumentation in the Orbiter aft compartment. Testing will occur during transfer of the Orbiter from the OPF to the VAB prior to flight.



Future Work

Small transmitting antennas will be placed in near proximity to the aft avionics bays and the three SSMEs. These antennas will be adjusted such that they do not radiate more than a 1 V/m electric field strength on any avionics equipment located in the aft compartment.

The measurements will be made in a 180 degree semicircle around the aft end of the vehicle. The receiving antennas on the AFRL MDL can be adjusted to various heights, so that we can take data on a quasi-cylindrical surface as we move around the vehicle.



The AFRL MDL will be used to collect the radiated data from transmitters located inside the aft compartment of the Orbiter.

The instrumentation will be “drag on”, and can be placed well before the actual test start time.

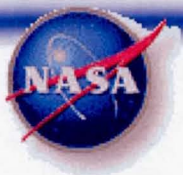


Future Work

A test stand will need to be constructed such that the transmitting antennas described above can be placed in the same geometric position as if they were mounted in the aft compartment.

This will enable us to collect data for these transmitters with and without the Orbiter structure in between the transmitting antennas and the AFRL MDL receive antennas.

That measured delta represents the attenuation of the vehicle.



Future Work

The Full Orbiter test will be conducted inside an electromagnetically reflective enclosure and will characterize the vehicle RF attenuation as a function of internal location for the entire Orbiter vehicle.

Our current plan is to modify an existing purge tent structure by replacing the tent's exterior covering with conductive cloth, and extending the structure so that it covers the forward section of the vehicle.



Future Work

The full scale test will be made inside the VAB, utilizing a modified purge tent structure.





Future Work

Personnel from the National Institute of Standards and Technology, Denver, Colorado will be collecting data from below 6 GHz, using a direct pulse technique. These measurements are similar in nature to those proposed for the aft compartment of the vehicle.

US Navy personnel from the E3 Division, Naval Air Warfare Center Aircraft Division, Patuxent River, Maryland will be collecting data from 6 GHz to 18 GHz, using reverberation chamber methods.



Summary

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Radar Monitoring

Lightning Protection

Future Work

Summary & Closing



Summary & Closing

**Questions, comments,
kudos, aspersions...???**



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