SMALL SATELLITE SOLAR ARRAY SUBSTRATE

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Abstract

The **SM**all **EX**plorer (SMEX) **F**ast **A**uroral **S**napsho**T** (FAST) Spacecraft (S/C) was developed to investigate plasma physics of auroral phenomena at high orbital altitude. The FAST Satellite is comprised of a variety of deployable booms with sensors on the ends, and instruments that protrude from the main body of the spacecraft to obtain the plasma and electromagnetic fields data. This required that the plasma disturbance around the satellite be kept to a minimum. Therefore a non deployable, body mounted Solar Array (SA) had to be implemented. This led to the design of a light weight SA substrate with a high degree of structural integrity. This SA substrate will be the topic of this paper.

1. INTRODUCTION

1.1 Satellite Description

The **SM**all **EX**plorer (SMEX) **F**ast **A**uroral **S**napsho**T** (FAST) Spacecraft (S/C) is the second in a series of small satellites, for scientific research, developed at the Goddard Space Flight Center (GSFC). The FAST mission required a S/C which is compact, lightweight, and extremely power efficient, in order to support and put into orbit a variety of instruments. These instruments have been developed at the University of California at Berkeley (UCB). They consist of Plasma field instruments, Electric field instruments, and Magnetic field measuring instruments. The on orbit configuration of the FAST Satellite is shown in Figure 1.

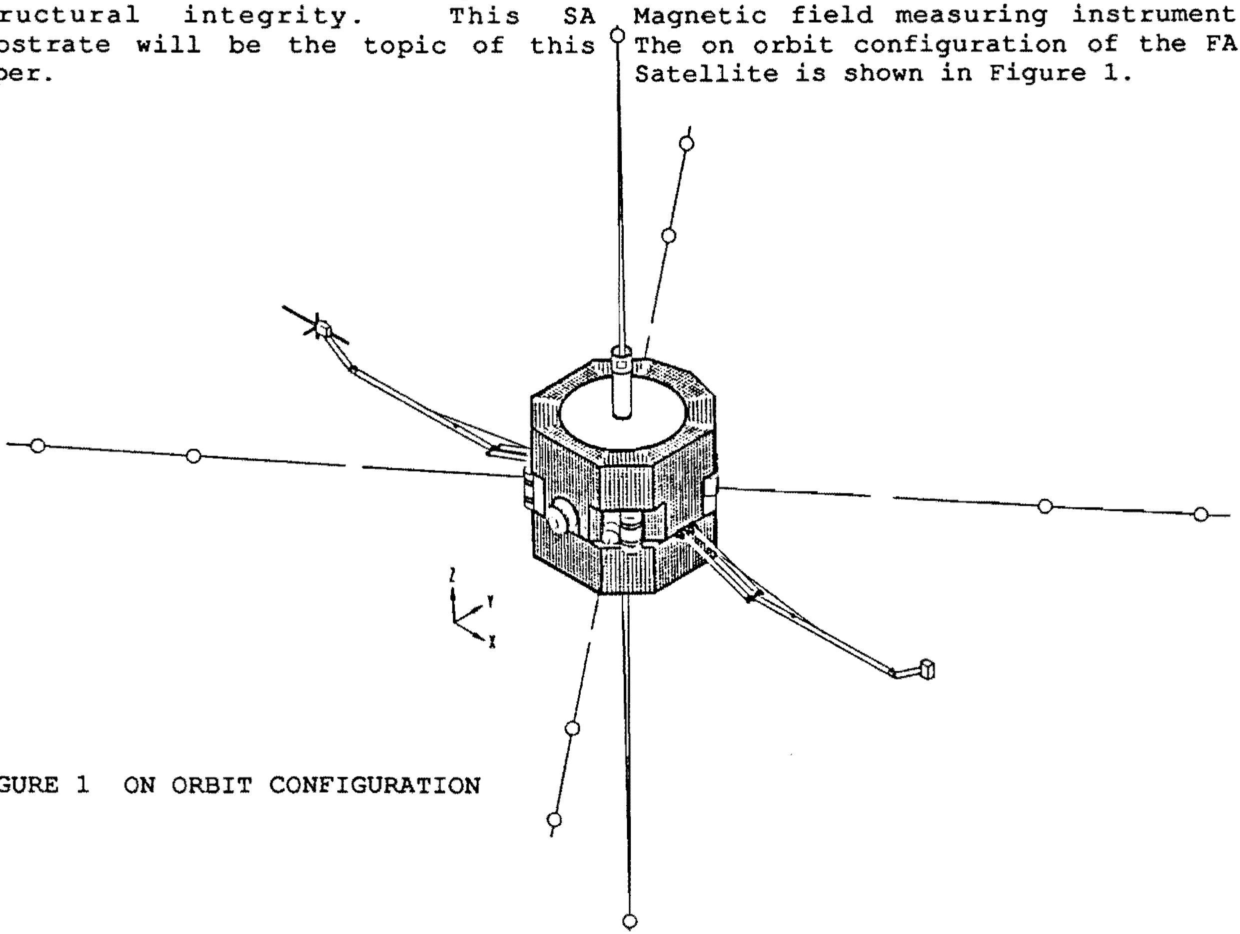

FIGURE 1 ON ORBIT CONFIGURATION

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The principle science measurements will be taken when the S/C passes through the earth's auroral zones at the high altitude portions of the orbit. The orbit for the FAST S/C is an elliptical, orbit measuring 350 km. X 4200 km at 83 degrees inclination. To attain this desired orbit, the FAST S/C will be launched atop the PEGASUS-XL Expendable Launch Vehicle (ELV). The FAST Satellite weight was limited to 412 pounds in order to stay within the PEGASUS capability for this particular orbit. The FAST mission commenced with the selection of the scientific investigator in 1989. The FAST Concept Review was held in 1990, and the Preliminary Design Review (PDR) in 1992. The SA substrate fabrication had to begin prior to the Critical Design Review (CDR) due to schedule constraints associated with the long lead time needed to install the flight solar cells, cover glass, and wiring. The FAST CDR was held in the fall of 1992. Fabrication and assembly of the remaining elements for the ETU began shortly after CDR. Environmental testing of the ETU was completed in the summer of 1993. During the fall of 1993 and spring of 1994 the flight S/C will be built and integrated. The FAST S/C will be launched from Vandenberg Air Force Base (VAFB) in August 1994. The stowed/launch configuration of the FAST satellite is shown in Figure 2, and an exploded view of FAST is shown in Figure 3.

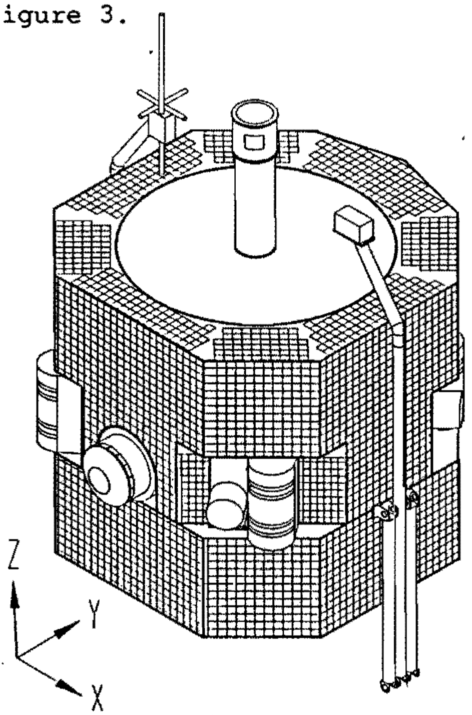


FIGURE 2 STOWED/LAUNCH CONFIGURATION

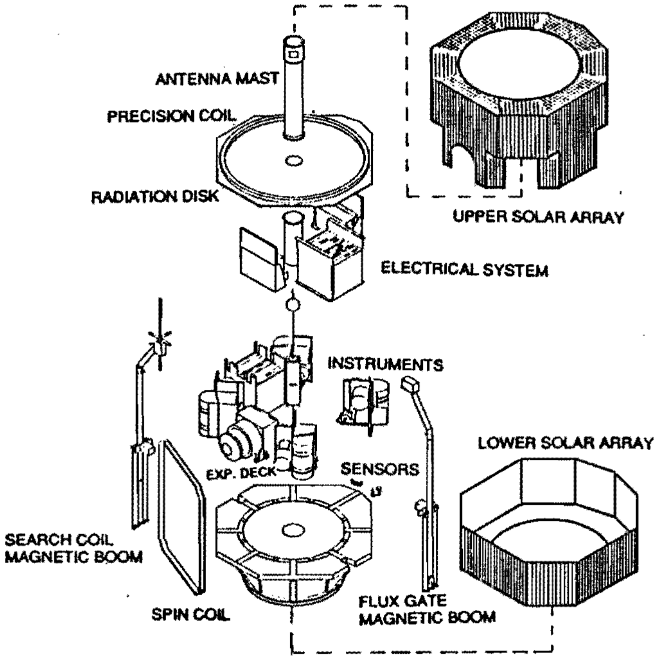


FIGURE 3 EXPLODED VIEW

1.1.1 Solar Array (SA)

The main body or volume of the S/C is comprised of a nine faceted roughly cylindrically shaped, body mounted SA. The SA substrate is the subject of this paper. FAST is a spin stabilized S/C with a final on orbit spin rate of 12 RPM, when all the boom appendages are deployed. As the satellite spins it gathers scientific data, some of which is plasma physics data. The body mounted SA minimizes the wake in the plasma field in which the plasma physics data must be gathered. The cylindrical SA has a diameter of approximately 45" and a height of 36.5". The SA utilizes 36 square feet of Gallium Arsenide (GaAs) solar cell area, which provide 120 Watts of power to the S/C, at Beginning Of Life (BOL). Fused Silica cover glass (60 mil thick) is used to protect the cells from the harsh radiation environment encountered at apogee of the elliptical earth orbit.

The SA is split into two major elements; a lower cylindrical section and an upper cylindrical section. The lower SA substrate section is comprised of aluminum honeycomb and bonded aluminum face sheets with light weight edge members for attachment and structural stiffness. The nine faces of the array are held together by a bottom end panel with a large 30" cut-out. The bottom end panel is also covered with solar cells to provide additional power during the precession of the orbit. The lower cylindrical section of the array stands approximately 13" in height and mounts to the edge of the instrument deck

The upper cylindrical section of the SA is similar to the lower cylindrical section, except that it is 23 inches high. The four intermediate facets of the upper array do not extend the entire height of the upper cylindrical section. They are recessed into the S/C to provide the required Field Of View (FOV) for the instruments that protrude from these Recess Panels. The Recess Panels have a height of approximately 13 inches from the end which attaches to the edge of the instrument deck. The upper array is also supported at the radiation disc for additional structural integrity. The upper cylindrical section of the SA is held together at the top by a Cover Panel with a 30 inch cut-out, similar to that of the lower array section. Figure 4 shows how the upper and lower substrate attaches to the instrument mounting deck.

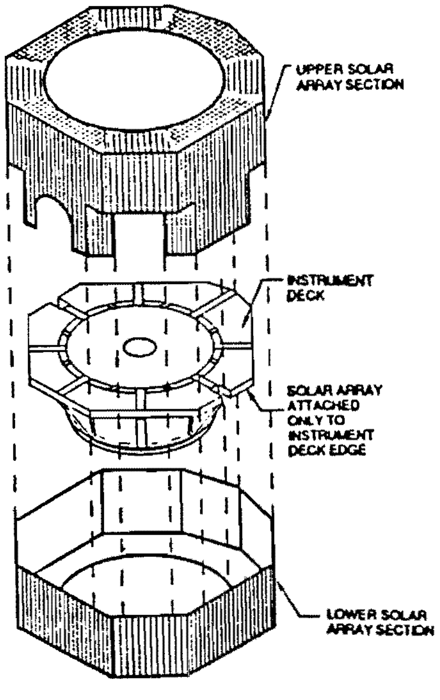


FIGURE 4 SUBSTRATE/INSTRUMENT DECK INTERFACE

1.1.2 Primary Structure

The main element of the FAST primary structure is the instrument mounting deck, which is a milled out isogrid aluminum alloy plate. The deck supports all of the instruments and electronics boxes. It also supports the SA which is mounted to the perimeter of the deck. The deck and instruments are located approximately at the center of the S/C. This allows the instruments and support electronics to be distributed in such a manner so as to maximize the spin mass Moment of Inertia (MOI) and minimize the lateral mass MOI. The required MOI ratio for the entire S/C is to be greater than 1.04. The loads from the instrument boxes on the deck are carried to the launch vehicle by way of a thrust tube and eight aluminum triangular gussets which are mounted to the lower side of the deck as shown in Figure 5. At the lower end of the thrust tube is the payload to vehicle interface ring which attaches to the launch vehicles marman clamp separation system.

1.1.3 Radiation Disc

Atop the instrument and electronic boxes is mounted an aluminum honeycomb radiation shielding disc. The radiation disc secures the tops of all the components together forming a very rigid closed box structure. This radiation disc, along with the instrument deck and heavy aluminum sheet metal material provided on the Wrap Panels, Recess Panels, and TEAMS Panel encapsulates the instruments and electronics, shielding them from the harsh orbital radiation environment.

1.1.4 Appendages (Booms)

Extending two feet above the top of the SA is the 4" diameter axial boom tube. This tube runs the entire length of the S/C and houses two diametrically opposed deployable "Stacer" booms. The axial (Stacer) booms have 3" diameter Langmuir probes on the ends and each deploys three meters from the S/C in order to collect electric field data along the spin axis of the satellite and normal to the orbit plane. The S/C antenna is mounted to the top of the axial boom tube. The antenna requires an unobstructed view angle of ± 45

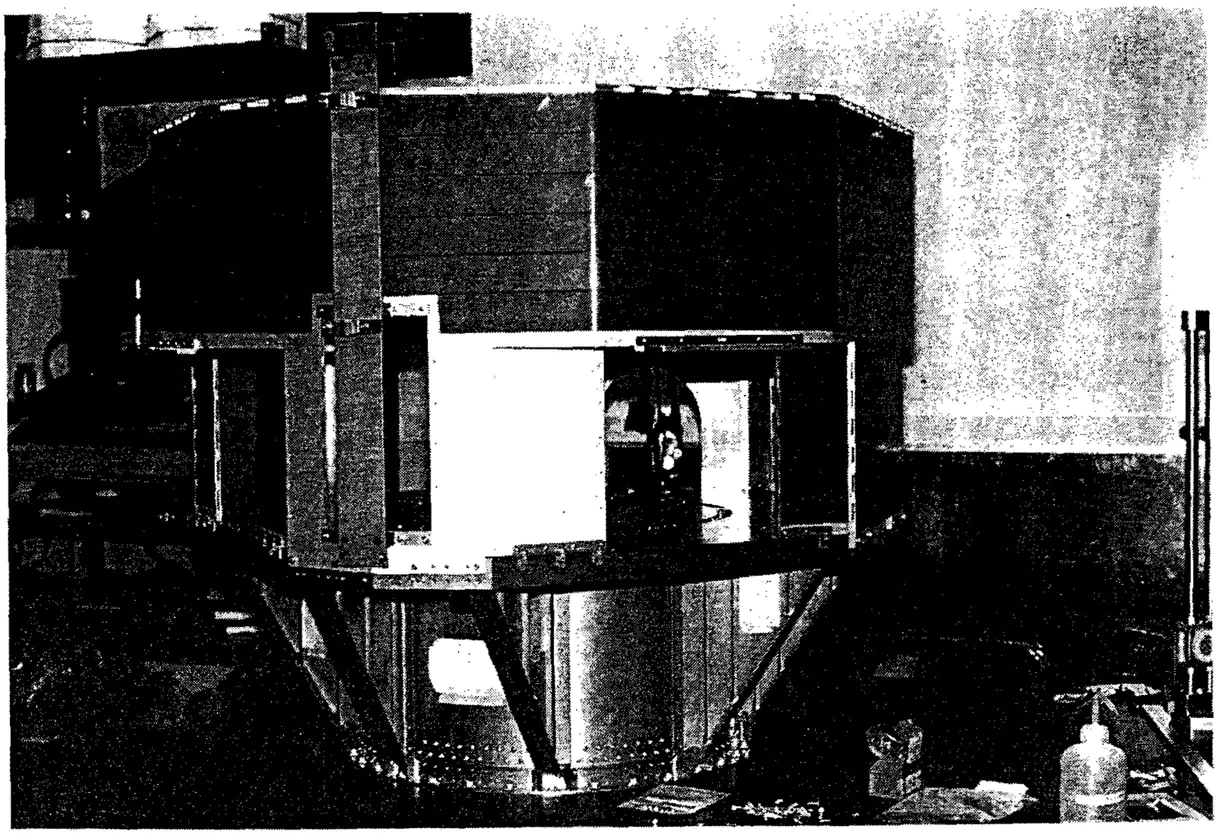


FIGURE 5A PRIMARY STRUCTURE

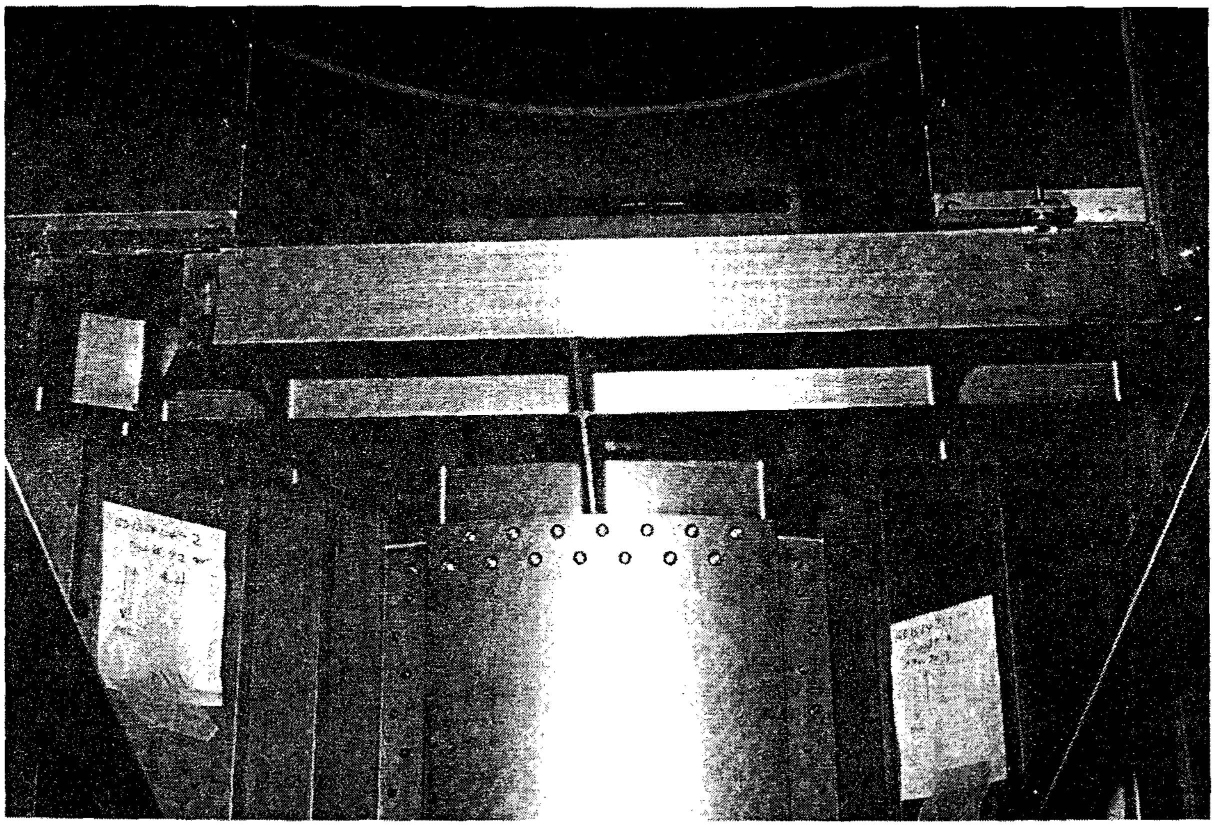


FIGURE 5B ISOGRID DECK

degrees, therefore, its mounting location must be located beyond the body mounted SA envelope.

In the on orbit deployed configuration, two sets of diametrically opposed wire booms extend 60 meters (tip to tip) from the S/C. Each wire boom originates from a mechanism that protrudes through the cut-outs in the Recess Panels of the SA. Each 30 meter wire boom has two Langmuir probes on the end, which are used to measure electric fields in the spin plane of the orbit.

In the stowed configuration, two deployable magnetometer booms are mounted to the side of the SA. Each boom has a magnetometer mounted to its tip: one is a Flux Gate magnetometer and the other a Search Coil magnetometer. The main hinges of the magnetometer booms mount to the side of the instrument deck. The booms are also supported at saddle points located at the top and bottom edges of the SA. When the magnetometer booms are deployed, they each extend to a length of 2.5 meters from the S/C.

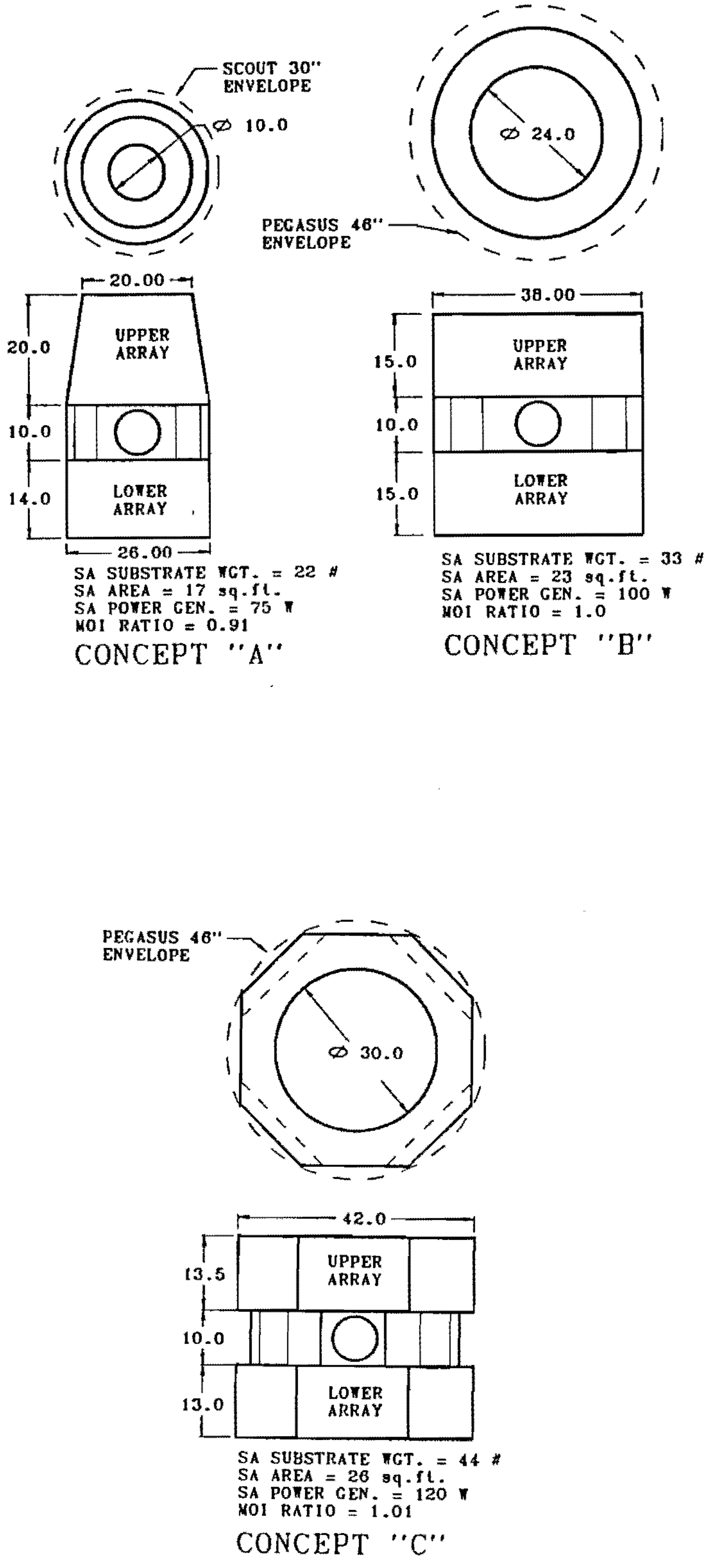
1.1.5 Instruments

Four electrostatic Analyzers (ESA's) protrude through the four apertures in the Recess Panels. Finally, the last instrument, "TEAMS", protrudes through an opening in the large facet or TEAMS Panel of the upper SA. These five instruments gather plasma field data and have distinct FOV requirements, which dictated the unique shape of the FAST SA.

2. SOLAR ARRAY CONFIGURATION

2.1 Trade-Off Studies

The FAST SA has endured many design iterations. Only four major SA design concepts are discussed in this section including the final as built design. Figure 6 shows the three major design iterations ("A", "B", and "C") of the SA and Figure 7 shows the ETU configuration of the final SA design.



SA SUBSTRATE WGT. = 22 #
SA AREA = 17 sq.ft.
SA POWER GEN. = 75 W
MOI RATIO = 0.91

CONCEPT "A"

SA SUBSTRATE WGT. = 33 #
SA AREA = 23 sq.ft.
SA POWER GEN. = 100 W
MOI RATIO = 1.0

CONCEPT "B"

SA SUBSTRATE WGT. = 44 #
SA AREA = 26 sq.ft.
SA POWER GEN. = 120 W
MOI RATIO = 1.01

CONCEPT "C"

FIGURE 6 SA STUDIES

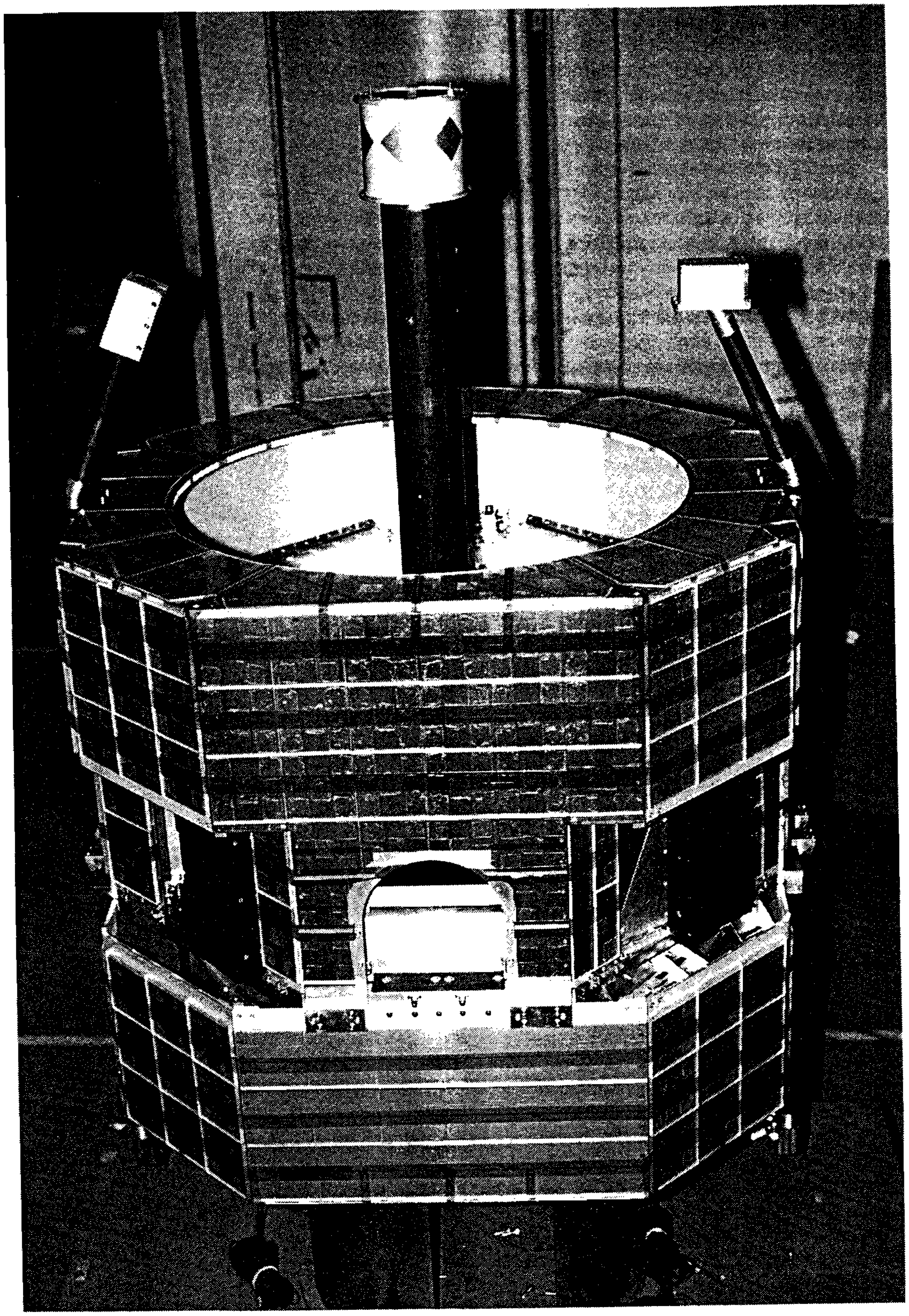


FIGURE 7 SA FINAL CONFIGURATION

2.1.1 Solar Array Concept "A"

In the early stages of design, FAST was slated to launch aboard an LTV-SCOUT launch vehicle. The SCOUT launch vehicle had a 30 inch diameter payload envelope in the lower section and a conical upper section that necked down to a diameter of 24". These envelope restrictions resulted in SA design concept "A". Concept "A" had a lower section which was a straight cylinder 26" in diameter and 24" in height. The upper section was a frustum of a cone with a lower diameter of 26" and an upper diameter of 20" having a height of 20". The disadvantages to this concept were that it did not have a favorable MOI ratio because the instrument FOV requirements prevented use of the entire ELV payload envelope. This limited the available S/A area reducing the power generating ability of the array. Another disadvantage to this concept was that both sections would be quite difficult to build. Two sets of tooling fixtures would have to be designed and fabricated, driving costs up. However, this concept was discarded when GSFC selected the much larger OSC-PEGASUS as their ELV.

2.1.2 Solar Array Concept "B"

The PEGASUS ELV permitted the payload dynamic envelope to increase to 46" in diameter, and had additional height, with only a slight taper at the top of the envelope. The SA could now be made entirely cylindrical, without taper. The diameter for the SA could now be increased to 38", providing desperately needed solar cell area, and increased MOI ratio. It would also be easier and less expensive to build. Since both sections were the same diameter, only one tooling fixture would be required, reducing costs.

Even though Concept "B" was a much more favorable design than Concept "A", it did not quite meet all the requirements of the S/C. Again the FOV of the instruments did not allow the SA to take full advantage of the entire ELV payload envelope. In order to attain the desired SA area needed for the power requirements of the S/C, the array would have to grow in height. This growth in height adversely affected the MOI ratio. If the array got taller, it would have to shrink in diameter to meet the instrument FOV requirements. This, once again reduced the SA area, resulting in a "CATCH-22" situation.

2.1.3 Solar Array Concept "C"

The cylindrical approach to the SA design was dropped in favor of a multifaceted flat panel construction. The flat panel concept took full advantage of the available volume in the ELV, with the apexes of the panels touching the 46" diameter dynamic payload envelope. (See Figure 6.)

The outside perimeter of the array was roughly cylindrical in shape, and since the overall cylindrical diameter of the array was increased, there was enough SA area to meet the power requirements for the S/C. With additional side array area available, we were able to decrease the overall SA height and also the total area on the top and bottom Cover Panels. This essentially made the end panels thin rings of array at the outer perimeter of the cylinder and helped the MOI ratio. The Recess Panels provided ample FOV for the ESA's and the large TEAMS Panel provided ample FOV for the TEAMS instrument. Originally a fully symmetrical octagonal configuration was designed but it did not meet the 1.04 MOI ratio. Therefore, the S/C Battery which is located opposite the TEAMS instrument on the instrument deck was moved outward in order to increase the spin MOI. To accommodate this, an additional facet had to be added to the SA. This semi-symmetrical, nine sided, roughly cylindrical array provided a solution for meeting all of the FAST S/C requirements. (See Figure 8).

Each facet of the array would be made of a flat bonded aluminum honeycomb sandwich with 6 mil aluminum face sheets. The individual facets would have continuous light weight edge members for ease of assembly and structural integrity. The facets would be mechanically fastened to each other through aluminum backing clips located on the inside corners of each set of flat panels. The upper section of the array would have 13 flat honeycomb panels, including the Recess Panels, and one flat honeycomb ring shaped panel for the top end. The lower array would have nine flat honeycomb panels and one flat ring shaped panel for the bottom end. All the panels would be

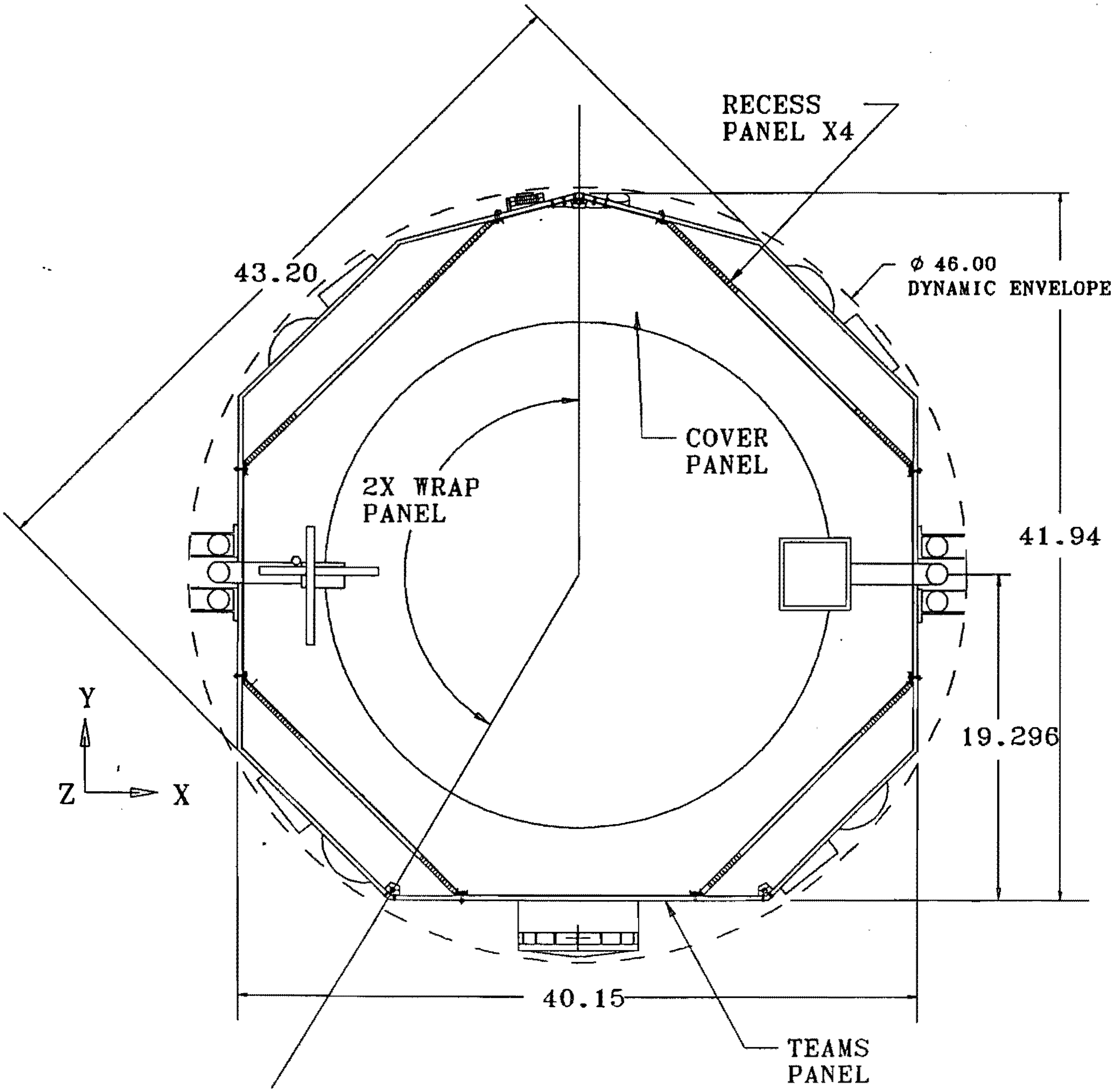
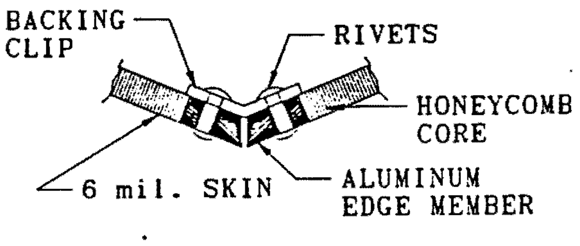


FIGURE 8 SA SUBSTRATE - PLAN FORM

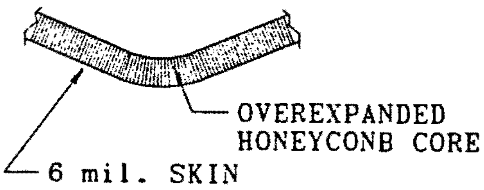
fastened together using aluminum rivets and backing clips. The increase in SA area coupled with the numerous splices between the panels resulted in a substantial unacceptable increase in weight. NASA/GSFC reviewed this problem with Fairchild Space and Defense Company and a solution was proposed to use a method of fabrication previously used in a Fairchild IR&D program for a small satellite generic bus structure. This led to the final design of the FAST SA substrate.

2.1.4 Solar Array Substrate Final Design

The final SA substrate design is very similar in geometry to Concept "C", however, the design to net fabrication and assembly were quite different. Most of the intermediate joints between facets were eliminated. Figure 9 shows a cross section of the facet apexes before and after the redesign. Eliminating six of the nine longitudinal splices in the substrate reduced the overall substrate weight by 7.25 pounds, resulting in a final weight of 38 pounds.



ORIGINAL JOINT DESIGN



JOINT RE-DESIGN

FIGURE 9 FACET APEX CONFIGURATION

The joints were eliminated by having the honeycomb panel be continuous around the corners or apexes between the flat panels. The inner aluminum skin would be continuous around the corner as well as the aluminum honeycomb core and the outer skin. The fabrication of the Wrap Panels was more labor and cost intensive than fabricating individual panels but the overall delta cost may have been negligible due to the reduced cost of assembly and assembly tooling. The weight saving using this approach was substantial. It has since been confirmed that every pound of S/C weight saved yields an additional 18 nm of orbit altitude. Since the scientific instruments gather high altitude auroral data (the higher the better), the principle investigators at UCB welcomed the reduction in weight and resulting 130 nm increase in orbit apogee.

3. STRUCTURAL & MECHANICAL DESIGN CRITERIA

3.1 Launch Environment

The FAST S/C will be launched on the PEGASUS-XL ELV. The environmental loads which FAST will be subjected to are, static loads, transient loads, shock, random vibration and acoustics. Since the PEGASUS-XL vehicle is still under development an uncertainty factor of 1.25 has been applied to the environmental loads.

3.1.1 Static Loads

Static loads are based upon initial PEGASUS flight data and analytical projections of the PEGASUS-XL stretch vehicle. The expected static loads derived for FAST are:

X AXIS = 13.5 g (THRUST AXIS)
Y AXIS = 2.0 g (LATERAL AXIS)
Z AXIS = 7.5 g (LATERAL DROP AXIS)
SAFETY FACTOR YIELD = 1.25
SAFETY FACTOR ULTIMATE = 1.5

3.1.2 Transient Loads

Transient loads are developed when the PEGASUS is dropped from the belly of a LOCKHEED L-1011 aircraft. The minimum natural frequency of the FAST payload must be higher than 20 Hz. in order to fully decouple the payload from the vehicle driving frequency. The maximum acceleration at the FAST center of gravity in the lateral drop axis is 7.5 g at the center of gravity. It also has a rotational acceleration associated with it, due to the flexure mode of the PEGASUS.

3.1.3 Shock Loads

The shock loads are developed during pyro initiation of the payload to vehicle separation system.

3.1.4 Random Vibration Loads

The random vibration loads are developed at the payload to vehicle interface during the launch sequence.

3.1.5 Acoustic Loads

The acoustic loads are developed during the launch sequence.
Acoustic loads are probably one of the worst case loading scenarios for the SA, due to the large area of each facet.

3.2 Structural Analysis Results

The stress analysis performed on the FAST S/C was very conservative in nature. The assumptions that were imposed always tended to be the worst case scenario. Even with all the conservatism and the additional 1.25 uncertainty factor imposed on the structure and the SA substrate, there were no negative stress margins in the entire structural model. Figure 10 shows the FAST NASTRAN Finite Element Math Model. As can be seen in the margin of safety Table 1, the SA substrate is one of the strongest and stiffest components of the entire FAST S/C structure. The continuous structure between facets had very high margins of safety for all load cases.

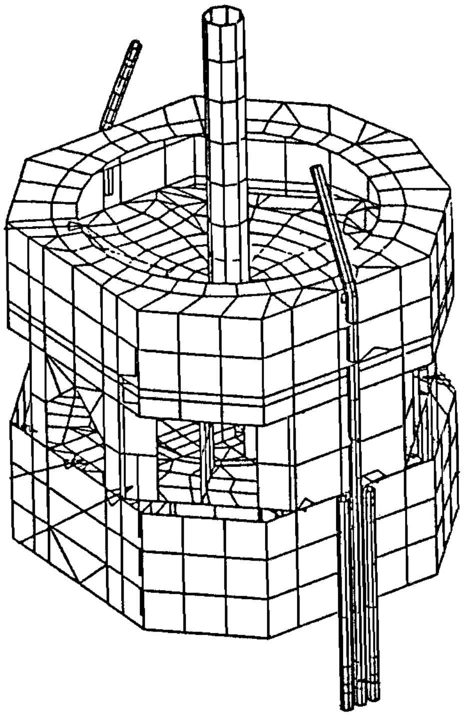


FIGURE 10 NASTRAN FINITE ELEMENT MODEL

The first fundamental frequency of the S/C is shown in Figure 11. This shows the primary cantilever bending mode of the entire structure. It can be seen in Figure 11 that the SA is deflecting along with the instrument deck/primary structure. There are no local panel modes of the SA below 120 Hz. This indicates that the SA is a very rigid structure. The design and method of fabrication of the SA substrate had surpassed our expectations.

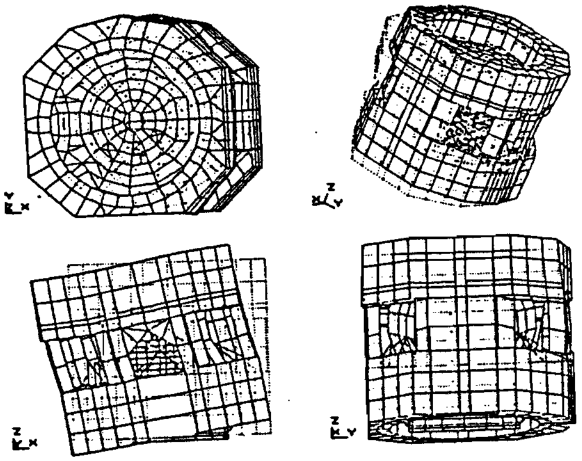


FIGURE 11 FIRST FUNDAMENTAL FREQUENCY (62.2 Hz)

4. SUBSTRATE GEOMETRY

The basic substrate consists of a nine sided (nonagon) cylinder with end covers and Recess Panels. The cylindrical halves, upper and lower substrates, are mechanically joined at the Instrument Deck and the cylindrical axis coincides with the "Z" axis of the spacecraft as shown in Figure 2. The nonagon is symmetrical about the spacecraft "Y" axis. The substrate's overall height is 36.50 inches and it satisfies the 46 inch diameter of the Pegasus ELV dynamic envelope.

4.1 Upper (+Z) Substrate and Lower (-Z) Substrate

4.1.1 Major Subassemblies

The upper substrate is made up of two symmetrical Wrap Panels consisting

COMPONENT	MATERIAL	CRITICAL FAILURE MODE	CRITICAL LOAD CASE	MARGIN OF SAFETY
PRIMARY STRUCTURE	7075-T73	BUCKLING	31	0.44
INSTRUMENT DECK	7075-T73	BUCKLING	32	0.69
BATTERY MOUNT	7075-T73	BUCKLING	33	0.39
TRANSPONDER MOUNT	7075-T73	BUCKLING	33	6.52
UPPER SOLAR ARRAY SUBSTRATE	7075-T73	TRANSVERSE SHEAR	33	2.01
LOWER SOLAR ARRAY SUBSTRATE	7075-T73	ULTIMATE	27	0.83
RADIATION DISK	7075-T73	TRANSVERSE SHEAR	34	0.84

TABLE 1 STRENGTH SUMMARY

of four sides each, together with a TEAMS Instrument Panel, four Recess Panels, and an Upper Cover. (See Figure 12A and 12B.) All the panels are made from aluminum alloy honeycomb sandwich structures. The upper substrate, in addition to supporting the SA, doubled as a radiation shield for the instruments and electronics.

The lower substrate is comprised of two symmetrical Wrap Panels, together with a TEAMS Panel Extension and a Lower Cover. (See Figure 13A and 13B.)

4.1.1.1 TEAMS Panel

The TEAMS Panel formed the ninth side of the Nonagon substrate. It was comprised of .006 inch thick chemically milled 7075-T73 Aluminum Alloy sheet skins in a sandwich structure. The core of the sandwich was made up of edge members and honeycomb core. The machined edge members were cut from .250 inch thick 7075-T7351 plate or bar stock. The honeycomb core was made from 5056 H39 aluminum alloy x 1/4 inch hexagonal cell, .234 inches thick. The core was perforated and had a density of 2.3 PCF (pounds per cubic foot). The TEAMS Panel was bonded together using FM 410-1 foaming adhesive, FM 300 M film adhesive, and BR127A primer, all made by the American Cyanamid Company. Radiation shielding in the form of a .060 inch thick 7075-T73 aluminum alloy sheet was also bonded to the inner skin of the upper TEAMS Panel. The overall thickness of the TEAMS Panel was .25 inches not including the radiation shielding.

4.1.1.2 Recess Panels

The four Recess Panels of the upper substrate were set back from the main facets of the nonagon and were comprised of virtually the same materials as the upper TEAMS Panel except that the inside skin of the sandwich was a single face sheet, .060 inch thick, in place of the laminated .060 to .006 inch thick face sheets. The basic thickness of the Recess Panels are .25 inches and .17 inches at the mounting flanges.

4.1.1.3 Wrap Panels

The mirror image Wrap Panels (one left, one right) were made up of the same materials as the Teams Panel except that a CR III aluminum alloy, OVEREXPANDED core supplied by Hexcel Corporation was substituted for the standard expanded 1/4" hexagonal core material. This core has the unique to accept single plane curvature.

4.1.1.4 Cover Panels

The upper and lower Cover Panels were comprised of the same .006 inch thick chemically milled skins for the face sheets and differed from the other panels in profile and thickness as can be seen in Figure 7. The inner circular edge of the cover panels had an edge member fabricated from a high density 22 PCF 5052 aluminum alloy core called Dura-Core also made by the American Cyanamid Company. The increase in the end Cover Panels thickness and the inner ring core density was to provide additional stiffness. The overall thickness of the upper and lower Cover Panels was .38 inches.

5. FABRICATION

5.1 General

Manufacturing of the SMEX/FAST SA substrate was typically comprised of three major phases:

- Fabrication of details
- Manufacturing of the bonded subassemblies
- Mechanical assembly of all the component parts.

The weight was the principal driver for using the design to "Net Shape" fabrication concept. The approach for reducing the substrate weight was to eliminate as many splices as possible and to utilize principles permitting light weight honeycomb sandwich construction. As previously noted, numerous iterations led to the final design, but the key contributor for reducing the weight was the use and modification of a manufacturing technique previously used by Fairchild to produce a highly efficient primary structure for a small spacecraft. This technique included the use of a "Dog House" type of bonding fixture to produce the continuous Wrap Panels as shown in Figure 14. The design to "Net Shape" and fabrication approaches for the Wrap Panels is highlighted in this section.

5.2 Tooling

5.2.1 Bonding

Standard type tools were used throughout the fabrication process; however, in the interest of schedule and cost, most of the tools were designed for multiple use. Layup and cure of either Upper and Lower Panels as well as "Shown" and "Opposite" structures were accommodated on the same tool. The bonding tools were typically comprised of platens, perimeter dams, locators and caul plates. Routing templates for the Upper and Lower Cover Panel skins also served to fabricate the honeycomb core patterns. The "Dog House" fixture used for the second stage bonding of the Wrap Panels is shown in Figure 15. It also met the primary objectives of producing all four of the Wrap Panel bonded assemblies using one tool. The Wrap Panels required multiple bonding stages. The first stage tool was designed to bond the inner skin, edge members, and the OVEREXPANDED honeycomb core and core splices in a flat pattern. The layout pattern for this tool is shown in Figure 16. The third stage bonding tool used to integrate the bonded heavy sheet metal shielding material was the actual individual Wrap Panels themselves.

5.2.2 Assembly

A single primary integration tool called the "Payload Deck Simulator" was used to assemble the Wrap Panels, TEAMS Panels, and the Recess Panel Assemblies as applicable for both the Upper and Lower Substrate Canisters as shown in Figure 12A and Figure 13A. In order to ensure interchangeability of both the ETU and FU, a mating tool was configured and designed to drill the matching provisions in the Payload Instrument Deck. Small drill fixtures and backing bars were used throughout to prevent spalling of the thin skins when the drill bits broke thru.

5.3 Detail and Subassembly Manufacturing Considerations

5.3.1 Mechanical Edge Members

Pocket locations for all the Edge Members were critical for ensuring subsequent mechanical fastener provisioning. Another major concern for the Edge Members was the departure from flatness that could be permitted after machining, without affecting the overall flatness requirements of .010 inches per foot for the substrate. An analysis which was supported by a small development test panel, provided the basis for establishing permissible departures for flatness for the machined edge members.

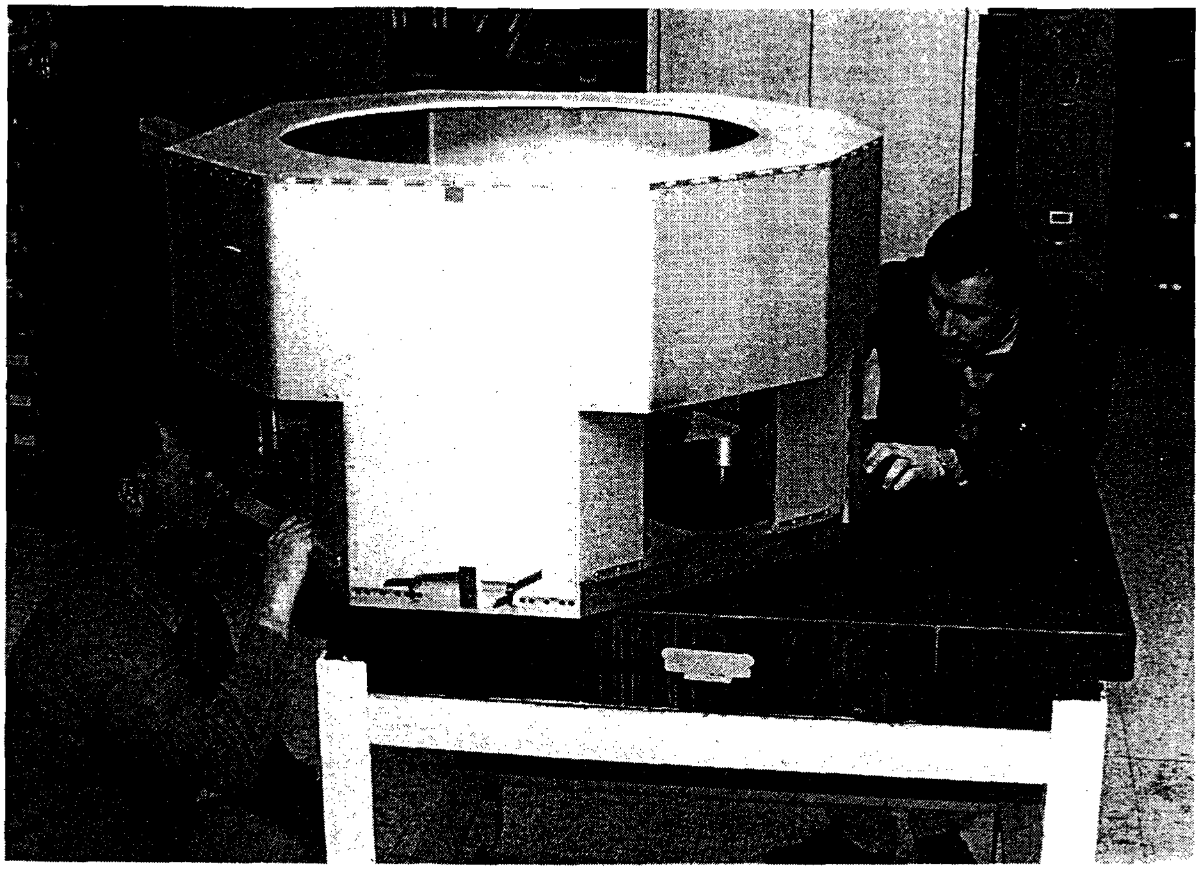


FIGURE 12A UPPER SUBSTRATE

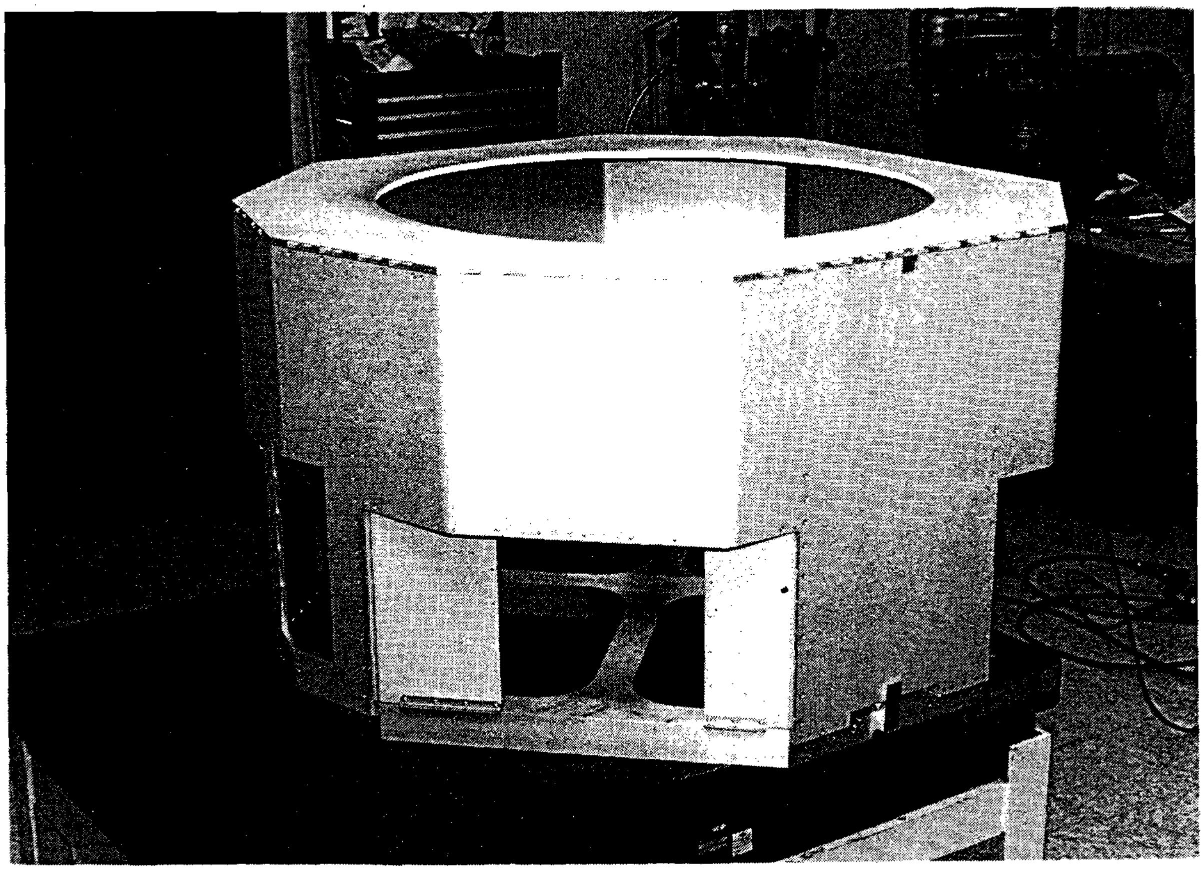


FIGURE 12B UPPER SUBSTRATE

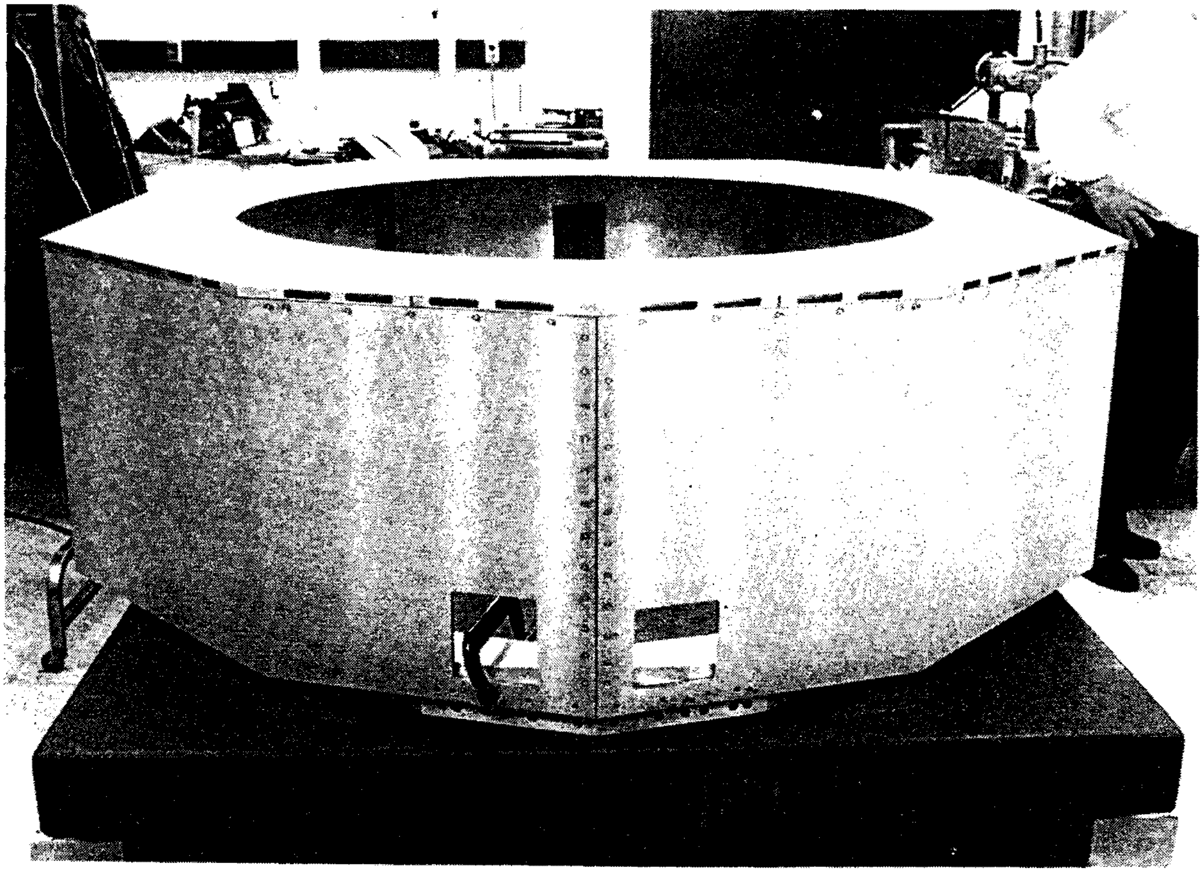


FIGURE 13A LOWER SUBSTRATE

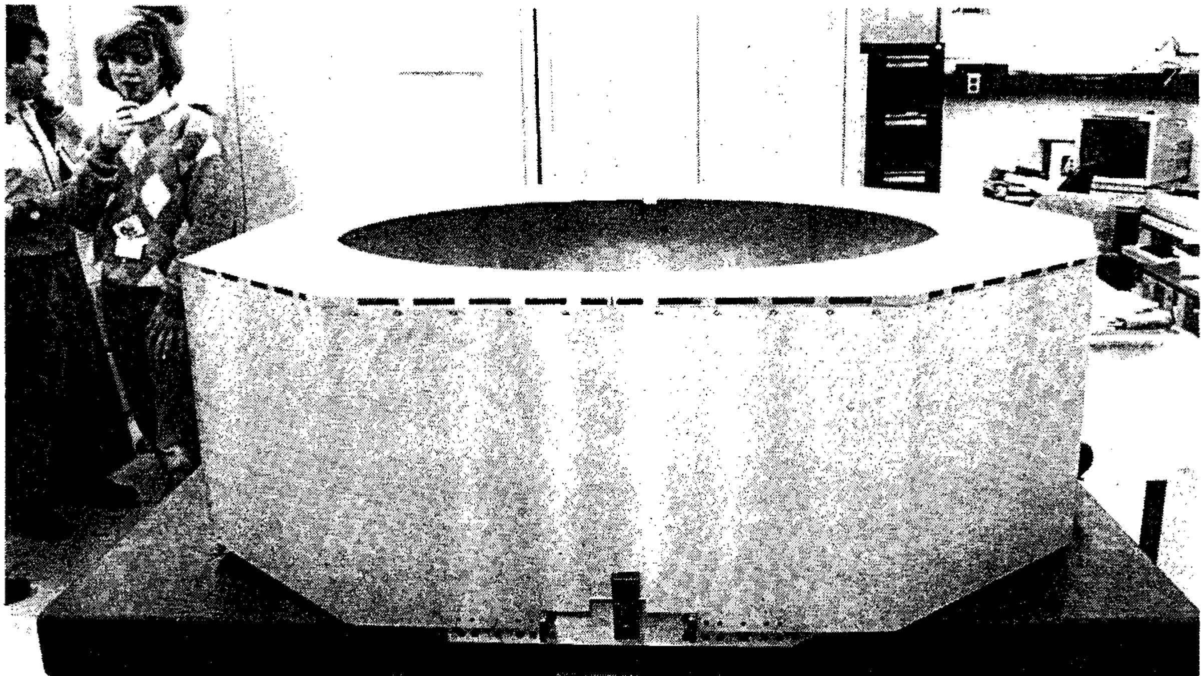


FIGURE 13B LOWER SUBSTRATE

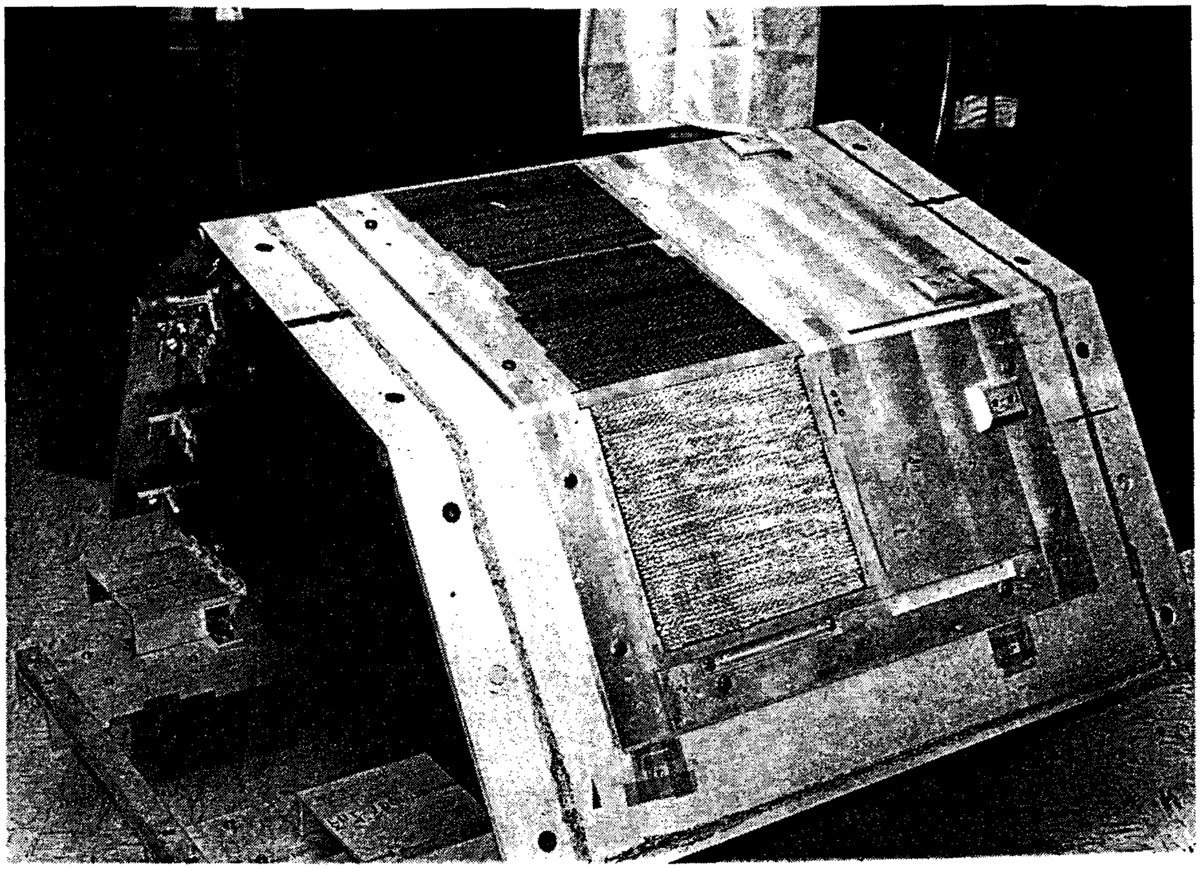


FIGURE 14 "DOG HOUSE" BONDING TOOL

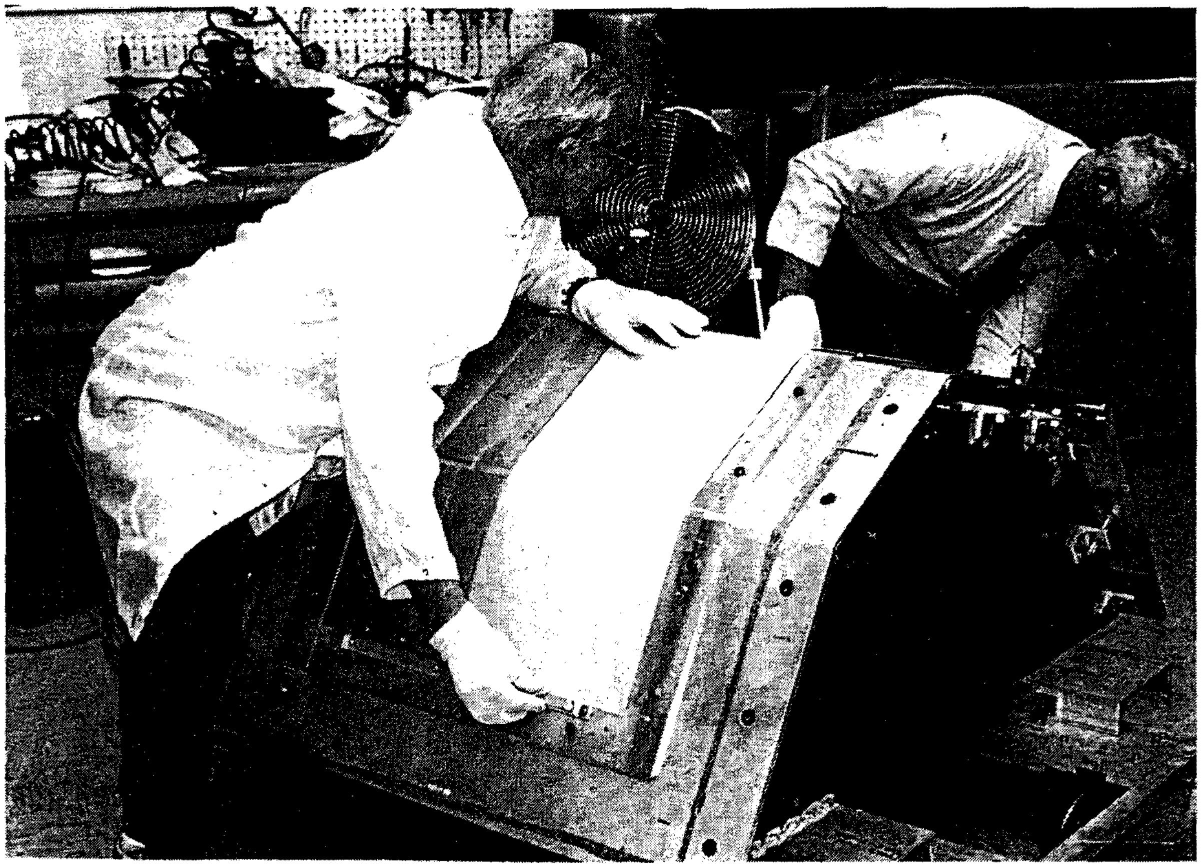


FIGURE 15 WRAP PANEL LAYUP

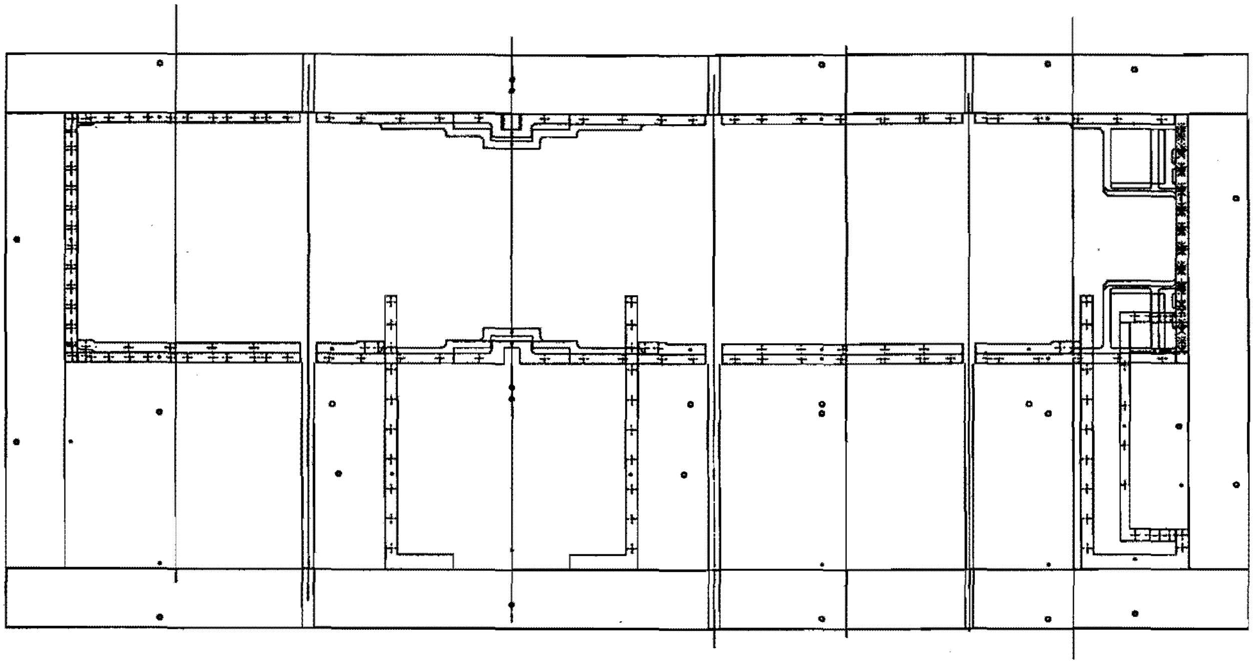


FIGURE 16 FLAT PATTERN TOOL - WRAP PANELS

5.3.2 Chemically Milled Skins

The 7075-T73, .006 inch thick aluminum alloy skins were machined chemically from a .040 inch thick rolled sheet fabricated with Minimum Residual Stresses (MRS). To ensure satisfying minimum thicknesses, a 4" X 4" inspection grid was specified for each chemically milled sheet.

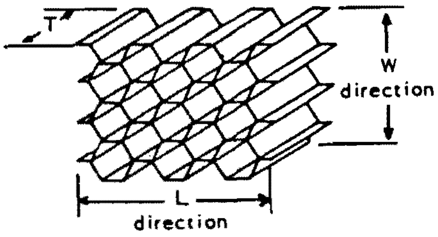
5.3.3 Bonded Subassemblies

All bonding materials and processes were controlled by Fairchild Process and Material Specifications and approved by NASA's Goddard Space Flight Center's (GSFC) SMEX Flight Assurance Office. Typical bonding procedures included prefit of the details, application of release agents to the tools, and cleaning, etching, and priming of all the details. The use of FM 300 M film adhesive, cured at a temperature of 360°F was selected over other film adhesives due to its extremely low outgassing characteristics, as well as its ability to retain physical strength properties at the elevated service temperatures. A reduced density casting material, established during a Fairchild Post Bonded Insert IR&D program was used to fill open honeycomb core edges. This material was comprised of a Shell EPON 828 Epoxy, Versamid 140 fixing agent, and hollow glass micro balloons in controlled mix ratios and curing cycles.

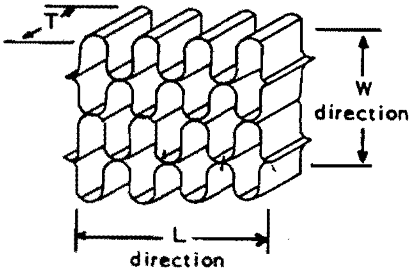
5.3.3.1 Wrap Panels

As previously discussed the Wrap Panels required special consideration to ensure success. After establishing a concept, two eight inch high development units were fabricated. Some flaws were noted on the first unit which resulted in a tooling change that provided us with the necessary assurance for the deliverable hardware. In all previous references to the Wrap Panel Honeycomb Core Material, the word "OVEREXPANDED" was capitalized. Overexpanded core is different from typical hexcore, in that it has been pulled beyond the typical "hex" core configuration until the cells take on a rectangular shape as shown in Figure 17. The unique properties that result from this type of core are:

- Its ability to be formed into a single plane of curvature without cell wall collapse.
- The transverse and longitudinal shear and shear modulus properties are almost equal.
- The density and compressive strengths are slightly higher.



Hexagonal Core



OX-CORE

FIGURE 17 OVEREXPANDED VS HEXAGONAL CORE

The first stage bond was accomplished in the flat on a universal flat pattern tool as shown in Figure 16 and was comprised of the .006 inch thick inner skin, the overexpanded core, the Edge Members, and the necessary adhesives. The second stage consisted of draping this flat pattern on to the "Dog House" tool and applying skin membrane loading devices to position the first stage bond while ensuring its intimate contact with the tool. Film adhesive was applied to the cleaned, etched, and primed outer skin, and it was draped over the first stage bondment already positioned on the "Dog House" tool. A second set of outer skin membrane loading devices was used to ensure intimate contact between the outer skin and the core and edge members of the first stage bond. This assembly was also cured under a vacuum bag at a temperature of 360°F. The .060 inch thick Aluminum Alloy doublers required to shield the Instrument Enclosure were added in a third bonding stage using the cured Wrap Panel as the tool and applying envelope vacuum bagging techniques. The TEAMS Instrument Panel was similarly treated to provide shielding requirements. We considered revising the tools to eliminate the envelope bagging technique but it would have increased both the number and complexity of the tools.

6. ENVIRONMENTAL TESTING

6.1 Objectives

The objectives of the environmental tests were to qualify the FAST mechanical/Structural system for launch aboard the PEGASUS-XL ELV. This objective includes the following:

- Verify and correlate the FAST Finite Element math model in terms of frequencies and mode shapes.
- Verify that the FAST S/C can survive and sustain random qualification levels
- Derive random vibration levels for selected instruments located on the instrument deck. This includes the base input vibration specification for the SA.
- Strength qualify the FAST S/C by performing qualification level sine burst quasi-static structural tests.

6.2 Test And Evaluation

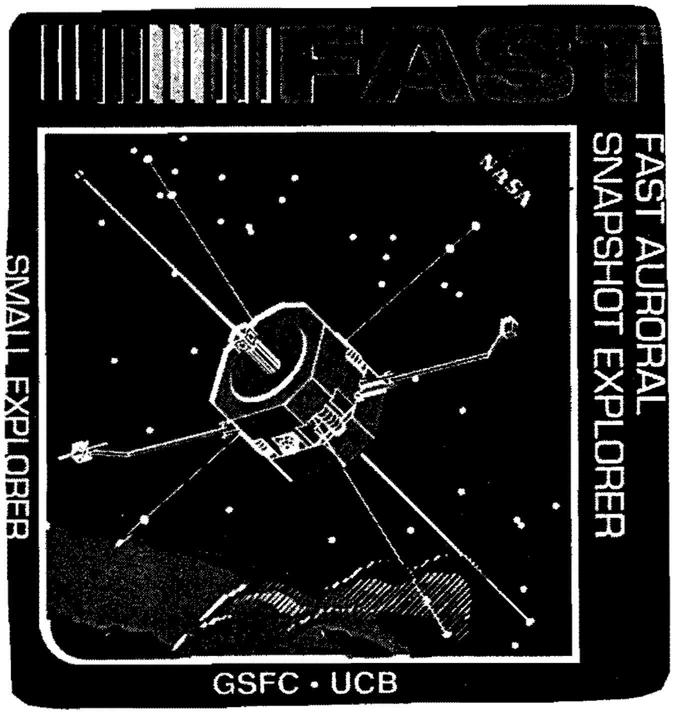
The FAST Engineering Test Unit (ETU) successfully completed environmental testing in July 1993. There were no problems or anomalies encountered during testing. The FAST mechanical/structural subsystem, including the SA substrate, has been fully qualified for launch. A test factor of 1.25 was applied to the design limit loads in order to obtain the qualification loads.

6.2.1 Test Sequence

The following sequence of tests were performed on the FAST ETU in order to qualify the mechanical/structural system. Tests were performed in all three axes of the S/C:

- Low Level Sine Sweep
  - 0.25 G, 2 Octaves per minute, from 5 to 250 Hz.
- High Level Sine Sweep
  - 1.0 G, 2 Octaves per minute, from 5 to 250 Hz.

- Low Level Random Vibration
  - Low Level Random Flat Spec. 0.004 g^2/Hz 5 to 250 Hz. (1.0 GRMS).
- Qualification Level Random Vibration
  - Qualification Level Random, PEGASUS base input spec. 2 minute duration. (5.6 GRMS).
- Sine Burst Quasi-Static Qualification Levels
  - X & Y axis Resultant load 9.60 g's at 22.5 degrees off of the Y axis, frequency of Sine Burst was 15 Hz, minimum 5 cycles at full level.
  - Z axis 17.0 g's, frequency of Sine Burst was 25 Hz, minimum five cycles at full level.
- Low Level Sine Sweep
  - Repeated 0.25 g sine sweep after each axis Sine Burst test to determine if structural degradation occurred after strength qualification testing.



6.2.2 Environmental Test Results

Strain gauges were placed in critical high stress areas of the structure. These strain gauges demonstrated no material yielding or over stress during the structural qualification tests.

The fundamental frequencies of the FAST S/C matched very well to predicted math model natural frequencies. Measured fundamental frequency during vibration test was 61.4 Hz. Expected math model predictions were 62.2 Hz., a very close match. The FAST ETU S/C correlated very well with the math model inclusive of the SA substrate which successfully passed all the structural tests.

7. CONCLUSIONS

The SMEX/FAST SA substrate has met or exceeded all the S/C requirements. It has proven to be an extremely efficient, lightweight structure. The design to "Net Fabrication Techniques" resulted in a substantial weight reduction when compared to traditional concepts. It has successfully completed qualification testing in preparation for launch.