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A Small Satellite as an Attached Payload on ISS—The Merger of “Small” and “Very Large”

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Abstract

This paper describes the use of the Floating Potential Probe (FPP) as an “Attached Payload” on ISS. Background and motivation for building the FPP and well as detailed descriptions of its subsystems are described in another paper published in these proceedings (ref # SSC01-V-4b). With its solar arrays, primary/secondary power system, control/data processor unit, RF command/data link, thermal protection system, and two science instruments, the FPP displays most of the characteristics of a small spacecraft—with the exception of attitude control and propulsion subsystems. The FPP was attached to the top of the P6 truss during one of several Flight 4A EVAs. It uses an RF link to communicate with an antenna (deployed at the same time as the probe) which feeds through the module and into a transmitter/receiver and portable computer inside the habitable volume. Real time data on the ISS potential is displayed on the laptop and downlinked through the ISS server when requested. This paper will provide an overview of the major subsystems, discuss how such small satellites could be made to work within the ISS system, and the possibilities of using small satellites as attached payloads for short term science or technology experiments. We will provide insight into deployment and operational considerations, show examples of the use of such a low cost system, and discuss briefly the data and science impact of this small \$1M class probe.

Introduction

Motivation for designing the FPP as an autonomous small satellite came from the very short timeframe required for its deployment. During the summer of '00, when the concept and rationale for its development were being discussed within NASA, it was realized that there was no way that any external probe could manage the interface requirements needed to connect to the ISS power system or to the ISS data system and meet the aggressive schedule. Additionally, it was not known until almost October (the Launch was November 30) exactly where it could be positioned. There were many constraints on its position including those imposed by the experiment's functional

requirements as well as limitations imposed by the vehicle itself.

Two other significant factors influenced the FPP design, one was the method for getting the payload to orbit—where could it be fit into the shuttle manifest, and the second was the need to deploy by EVA.

The Shuttle manifest (already full) actually had to have other items removed to accommodate the FPP. It was initially decided that the FPP would go into a mid-deck locker. Although, in the end, it was carried in a “soft stowage” bag and stacked with equipment behind the mid-deck seats, the entire design cycle was carried out assuming that the locker fit was a requirement.

Secondly, the EVA requirements have a significant impact on design and fabrication of any system. The FPP could not fit in a mid-deck locker totally assembled. The size of the solar arrays, the need to have probes with at least an 18" extension, and the need to fly the system with its power system "dis-armed" all led to the requirements that the probe would have to be assembled on orbit. In addition to training the crew in the deployment activity, it was then necessary to build EVA friendly components that could be assembled either by hand or with standard, existing, tools.

The end result is a small satellite without attitude control that can be carried in a mid-deck locker, can support one or more simple experiments, has a model for crew training that exists at JSC, has been qualified for flight, and has a lifetime of one to two years on orbit. Figure 1 illustrates the FPP mounted on a GSE stand at KSC awaiting packaging for flight. Several of its key features are described in the figure caption.

The remainder of this paper will discuss the possibilities that exist for the use of small independent satellites on ISS and advantages and difficulties associated with their use.

Why a "Small-Sat" on ISS

The first appropriate question to ask is what possible advantage could there be in putting a small satellite on a (very) large one? It turns out there are several. They have to do with the resource and performance requirements on the design of the Small Satellite, the available flight opportunities, the instrument capability, and the flight duration. We examine each of these in turn.

Resources

What are the two subsystems that drive the cost, weight, and volume of even the most modest S/C bus? The answer is attitude control and propulsion. The FPP needs neither of these subsystems. The ISS provides the attitude control and propulsion (albeit not within your control) and therefore can dramatically reduce the cost and resource requirements needed by a small sat. The companion paper in these proceedings provides a number of details about the subsystems within the FPP chassis. It is important to note that the autonomous power and data systems had considerable NRE associated with their development, but with that out of the way, small probes like FPP could be produced

quite inexpensively and could provide a "carrier" for a certain class of simple science or technology experiments or in-situ observations.

Table 1 summarizes the characteristics of the FPP

Table 1 FPP Summary

Size (body)	16"
Length	54" tip to tip
Total Mass	40Kg
Insolation Power	15w (average)
Array size	14" x 14" (2)

For simplicity, the arrays were built as single panels that had to fit within the locker envelope. Carrying them in the soft stowage bag would have enabled them to be larger. This implies that the power limit of 15w average could easily be raised to something like 25w with little overall impact on the design.

Flight Opportunity

One of the most difficult problems to solve for small satellites is the issue of flight opportunities. Those who have been building these class of satellites know that the cost of a launch opportunity can often exceed the cost of the satellite itself. The shuttle program has had, for a number of years, numerous opportunities for small payloads, the Get Away Special or "GAS can" as it is often called is a typical example. It is cost effective for shuttle to fly with a *full payload*. The FPP was designed to fit in the mid-deck locker (or soft stowage). Mid-deck lockers must also be manifested, and often, there is a waiting line for the opportunity to fly, but, *the cost is not prohibitive and regular opportunities exist. This is more than we can say about most small-sat flight opportunities.*

Figure 2 illustrates the components of the FPP sliding into the mid-deck locker. Had it been flown there, the FPP components would have been packed in foam for launch protection.

Payload Capability

With a Volume capacity of approximately 1/2 cubic foot, a power capability of approximately 5 watts, a mass limit of 5kg., the ability to provide a "window" to the outside for access to remote sensing instrumentation, and the ability to telemeter an average of 8 kbits per second, the FPP Chassis provides a model (albeit, the first

generation model) of a small satellite that can provide the resources to carry out an experiment for relatively low cost on ISS. (Figure 5 gives a good feel for the volume available for an instrument in the current incarnation of the FPP).

The FPP can be refurbished and reused any number of times. The estimated refurbishment cost of less than 100k is dominated by battery replacement, instrument integration, software rework, and environmental requalification. Additionally, the FPP can be placed at numerous positions around the ISS because it is mounted on a WIF (Work-site InterFace) adaptor which placed all around the vehicle for use during assembly EVAs.

The FPP can be the prototype for a generation of “small-sat” attached payloads. If your purpose for building a “small-sat” is to provide, quick, inexpensive access to space for science and technology experiments, then constant development of new systems is not cost effective. The approach is to build a simple, “semi-standard” bus that could provide access to greater numbers of investigators. There is no such thing as a standard bus that can do everything for everyone, but some derivative of the FPP design can be quite useful for a large number of experiments.

Mission Time

The many generations of Shuttle experiments in GAS cans, lockers, and even those that have been deployed and recovered have enhanced the utility of the shuttle for doing science and doing it on modest budgets. One of the disadvantages of these inexpensive shuttle payloads is that their time on orbit is relatively brief. ISS provides a long term opportunity for missions that require measurements over seasonal changes, need access to long duration exposure to space, or want to test durability of prototype flight systems.

Doing “Real” Science

The FPP has two science instruments, a Langmuir Probe, which collects data on the plasma environment, and a Floating Probe, which collects data on the Space Station potential. Figure 3 illustrates some of the data taken by the FPP and model fits that provide a better understanding of the ionosphere.

Although the FPP is considered part of Vehicle Hardware, because of its criticality in monitoring

the charge balance of the Power Subsystem, Structure, and Plasma Contactor Unit (PCU), it could just as easily be an *autonomous attached payload* placed at some specified location of the external structure. That “small-sat” payload could be carrying an instrument that monitors the Earth’s environment, surveys the sky for gamma ray bursts, monitors solar weather, or tests the reliability of new electronics subsystems in the ISS radiation environment. The key point is that such a modest little satellite, when freed from the burden of providing attitude control and propulsion, can provide an *inexpensive route to do quality science and technology experiments* that otherwise would never fly because they are not “important enough” to get the larger sums of money required to fly on either a free flyer or e.g. shuttle Hitchhiker etc. Additionally, from the point of view of the ISS, the station becomes a place to do quick and simple science experiments with an easy, safe, and reliable interface.

Methodology

To take advantage of the opportunities discussed above, several simple steps are required. First of all, the instrumentation package must be integrated into an FPP-type carrier and that integrated system must undergo flight qualification tests. Secondly this integrated system must be manifested on a shuttle flight (in a locker or stowage bag) that is servicing the ISS. Last of all, the FPP with its instrument payload must be deployed at an available location on the ISS structure by EVA.

Accommodation and Integration in the FPP

Accommodation of a small instrument by an FPP style small-sat is fairly straightforward. The user simply has to fit the resource envelope and interface with the power and data system. The table below lists some of the constraints and capabilities of the current system. Since only one FPP exists at this point, the specification represents only a point design. We did NOT design the FPP with the idea that it could become a generic carrier for other experiments and thus many of the accommodations are currently unnecessarily restrictive. (NASA JSC is currently defining the specification for a follow-on unit which will have some additional capability and flexibility). These specifications should therefore be taken only as an example of the capability that could be available in such a system.

Table 2: Payload Interface Capability

Payload Parameter	Specification
Mass	5Kg
Power	5W
Voltage	+5, +19,+7.5, -5
Footprint (instrument)	6" x 8"
Height (instrument)	6"
Thermal Environment	+10 to +25C, 2C variation with orbit
Data rate	8Kbps
Data I/F	serial (up to 4), RS 485, or 1553B available
Discretes	32
Analog HK input	up to 32

The particular voltages selected as outputs of the power system were driven by a heritage payload (the Langmuir Probe). Several possibilities exist for the most efficient use of power. Nominally, ± 5 and ± 12 would be considered. The total amount of power available is a average value based on the size and insolation of the array configuration. Because FPP was needed at all orbit beta angles and vehicle attitudes, compromises were necessary on peak power to achieve an average that could support the instruments. As can be seen in Figure 4, the solar arrays can be mounted at a variety of locations and angles.

The volume and footprint constraints are largely due to the current design for the power and data system electronics, which was in turn driven by the footprint of an immediately available controller board. Future generations of the FPP will undoubtedly allow the control electronics to be more compact, providing more flexibility on science instrument accommodation. Figure 4 shows the layout of the inside of the hexagonal structure indicating the volume available for an instrument in the current configuration.

The FPP science instruments (housed in one single package) did not have microprocessors and used the discrete drivers and differential analog data channels of the microcontroller. Most science instruments would probably want to take advantage of the 422 or multidrop 485 interfaces for communication with the data system.

The current FPP uses two long external probes for measuring the plasma characteristics and floating potential. These probes were assembled on-orbit via EVA. The assembly is illustrated in Figure 6. Using the standard mount which is

now EVA qualified, an external sensor could be mounted on any of eight surfaces of the FPP structure and oriented in any of six orientations at the mounting point (See Figure 4 for detail). The mounting adaptor includes a 9 pin D-sub connector for power and data. Currently, one set of wires on each of the connectors is used to complete a circuit and light an indicator to allow the astronauts to know when they have engaged the system successfully.

In addition to being able to mount an external sensor, each of the side panels is manufactured with two access holes to allow remote sensors a field of view to the outside world. These could be modified or enlarged without affecting the structural integrity of the system.

The data rate support is currently limited by the "off the shelf" design of the Wireless Instrumentation System which was used for the telemetry module. Higher data rates and a different commanding configurations are easily possible.

Flight Manifesting

The FPP is currently qualified for a locker or mid-deck payload. The Payload Accommodation Handbook specifies the environment the hardware must be tested to and compared to many launches, it is a benign environment. It is desirable to perform a protoflight qualification prior to integration into the FPP at which point only a workmanship vibration of the entire probe is required. Manifesting of mid-deck locker experiments can be handled through any NASA sponsor with the focus of activity (for ISS servicing missions) at JSC.

Along with manifesting for a given shuttle service flight, the EVA for installation must be added to the EVA schedule for that flight (or for the ISS crew once they begin EVA activity) and the location for installation must be arranged through the ISS payload office at JSC. Since FPP was the first of its type to achieve this manifest (and it was done at very high levels), no organized process yet exists for manifesting other payloads in a similar manner. This process must be developed, first by creating an advocacy for a "small sat" program within the ISS and shuttle offices and also through a sponsoring agency. Design_Net, GRC, and some JSC personnel are currently beginning work on that process. The fact that the ISS has a very busy build sequence will make it difficult to get

another payload through this gate for a while (unless it has some level of urgency with the agency), but the point of this discussion is that FPP serves as a pathfinder for other similar missions and points the way both technically and programmatically for such a possibility.

Installation and Operation

The installation of a payload on any of numerous technically “available” locations depends strongly not only on the need for the instruments to have particular view factors, attitudes, etc, but also on the planned usage of that mounting point by the ISS EVA activity and the assembly sequence. It has already been necessary to move the FPP to a nearby location on one occasion so that an EVA service could be performed on some solar array drive electronics.

Figure 6 illustrates the actual mounting method for the Probe on ISS. Three key pieces of hardware are involved. The first is at the mounting location (in this case, it is a passive WIF or Worksite Inter-Face), the second is a specially made mounting assembly called a Stanchion (variable length) that has a load limiter mechanism which prevents the probe from “breaking off” if the astronauts should inadvertently kick against it. On the ISS side of the interface, the Stanchion fits into the passive WIF mechanism on the ISS and on the FPP side of the interface, it fits into third critical piece of hardware called the ECOM (EVA Change-Out Mechanism) which is mounted to the FPP. The ECOM and its mating piece are designed so that the EVA crew simply needs to slip the FPP containing the “passive” side of the ECOM over the Stanchion containing the “active” side of the ECOM (the “active” side has the latch mechanism incorporated) and twist an adapter ring to lock it in place. All of this hardware is available though the ISS office and with exception of the long length of the Stanchion was considered standard hardware for EVA. It should be noted that the WIF adapters are numerous on ISS and are placed for EVA and assembly use.

Figure 6 is a cartoon illustrating the mounting hardware as it would appear when completely assembled.

It is instructive to go over the EVA activity in detail. The total EVA time required for the installation is approximately one hour. Starting inside the Orbiter, the crew removes the FPP from its stowage bag or locker. The Solar

Arrays are carried to orbit in a beta cloth pouch (referred to by NASA EVA personnel as the “pizza box” because of the way it folds open). The pouch is unfolded and the arrays inspected for damage prior to leaving for EVA activity. Figure 7 shows a close-up of this carrying pouch which is also shown in its installed configuration on ISS in Figure 8. It should be noted that the “Christmas Tree” stitched on the outside was an addition to mark the “topping off” of space station on this particular installation and is not a standard feature of the carrying pouch. In this particular case, the two probes were also mounted inside the beta cloth bag in two separate pouches. Once the crew has verified that all is in order the entire FPP can be carried out of the airlock and out to the EVA site. On the “top” of the FPP one notices what appears to be a “suitcase handle” (see Figure 1 and Figure 4) which is actually a standard EVA bar made to fit into the BRT (Body Restraint Tether) which is hardware carried by the astronaut that fastens to this bar and can be rigidized. The Astronaut does not actually carry the FPP by this handle when on EVA, instead the FPP is fastened to the BRT for translation, freeing the astronaut's hands for other tasks.

Once on site, assembly begins with installation of the stanchion and then the body of the FPP. Last of all the two solar arrays and probes are removed from their carrying pouch and installed. Close-ups of the latch hardware for this assembly are illustrated in Figure 5. Each Solar Array powers a separate side of the primary power system (see companion paper for details on the power system), when it has been engaged properly, it activates the power system and connects the battery for the first time. The result is that a green light comes on and blinks with approximately 1Hz frequency. The light serves as a signal to the EVA crew that the Solar Array has been properly engaged. The blinking implies the microprocessor is also active and healthy. A separate light is provided for each of the arrays and one for the probes. Once the lights are activated, installation is complete and the crew proceeds with other EVA activity.

On this particular mission a separate EVA was needed to install a small antenna on the outside of the habitation module. This antenna is used to communicate with the FPP. It is important to note that line of sight communication is required for this antenna so if other locations not within its line of sight are to be used on future missions, either new antennas must be installed or the

current one will have to be moved. In general, one could have several antennas installed that will cover most of the view factors required for future payloads.

One advantage of using the FPP design for future missions is that a model has been built and is available in the Neutral Buoyancy Facility at JSC for training of future crew in both installation and retrieval of the probes. Likewise, the EVA hardware has been designed to enable the Crew to operate it easily, without tools. Considerable work was necessary to achieve a design that was acceptable to the crew and the safety office and it would be desirable to avoid having to deal with additional NRE for redesign and retest of a new system.

The deployment worked very well and feedback from the crew indicated that everything went as planned and was easier than expected.

Operation of the FPP is described in more detail in the companion paper but it is appropriate to discuss some of the lessons learned from that process which will be incorporated in any future use.

The FPP communicates through a transceiver located inside its frame and another located inside the vehicle. The receiver/transmitter inside the vehicle is referred to as the NCU and interfaces to a laptop computer. It was discovered, once on orbit, that the RS232 interface between the laptop and the NCU or Network Control Unit, does not provide isolated grounds and allows current to flow in chassis. This causes a ground fault in the power system and creates operational problems because the two units needed to be connected to separate power outlets. After overcoming this difficulty, it was discovered that there were some other incompatibilities between the operating system and the software. Eventually everything became a routine operation, but not without some headaches and it is evident that a new methodology must be developed to ensure smoother operation in the future. Additional problems arose when new equipment brought to orbit degraded the RF path to the antenna.

It is important to note, however, that this very simple and inexpensive system *did work* and a

large volume of data has been collected by the FPP system. Design_Net and GRC together with the JSC operations team have developed a set of requirements for a follow-on mission which will smooth out many of the operational difficulties and which will also provide for more data and commanding than is currently available.

Conclusion

FPP can be a pathfinder for “small-sat attached payloads.” It proves that a low cost, small satellite can achieve important and worthy objectives when given the opportunity to “ride along” on a larger vehicle.

By eliminating the most costly subsystems on the small sat, providing it an inexpensive ride into space, and giving it a platform that enables long term observations, we can provide an important service to a wide range of deserving science and technology experiments. Integration costs with ISS are minimized because there is only a simple mechanical interface on existing ISS structures. There are literally hundreds of possible mounting locations even now with an unfinished ISS and there will be many more within a few years.

The simple short distance 900MHz radio link allows interaction by either the crew or the ground with operation and data collection on the payload. The system is designed to be able to service many payloads with one laptop and one transceiver unit.

This methodology takes advantage of the inexpensive and reliable method of transport (mid-deck stowage bag or locker) on the shuttle, provides an “easy ride” for the instrumentation, and is easy and quick to assemble by the EVA crew.

All that remains is to develop an advocacy and a process for routine manifesting, deployment, and retrieval of such payloads and Design_Net together with our NASA sponsors are beginning work on this process. New generation “FPPs” will have more robust power, volume, and data handling capability and can be built inexpensively and quickly.

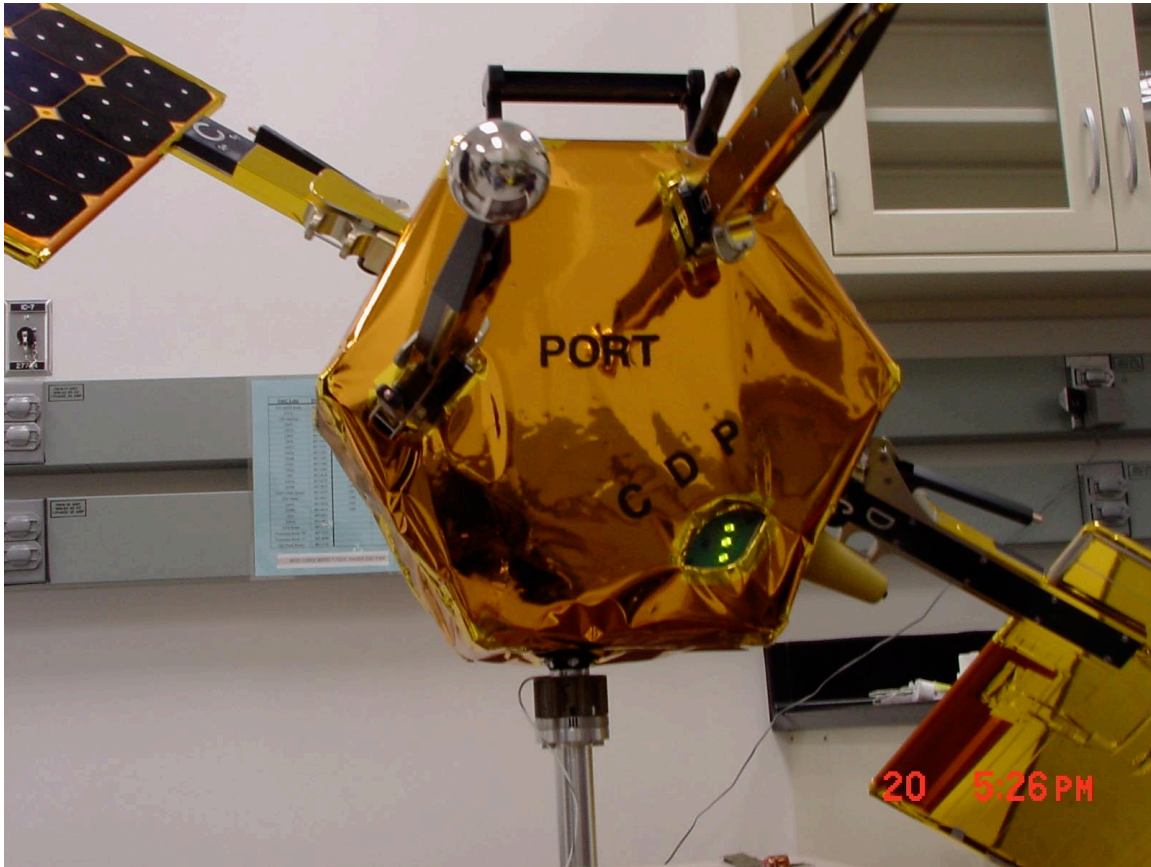


Figure 1: A photograph of the completed FPP prior to integration in the Shuttle Orbiter at KSC illustrates the two solar arrays, oriented at different angles to maximize insolation over ± 75 degrees of Beta angle. Also shown (coming out of the page) are the two 15" probes for sensing the plasma and the potential, the RF link antenna (lower right just under the solar array arm), the 3 lights used during EVA installation, and the ECOM bracket at the bottom of the probe, the mount point to ISS. The "suitcase" handle at the top is a special "dogbone" profile made to fit the BRT used by the Crew during EVA translation.

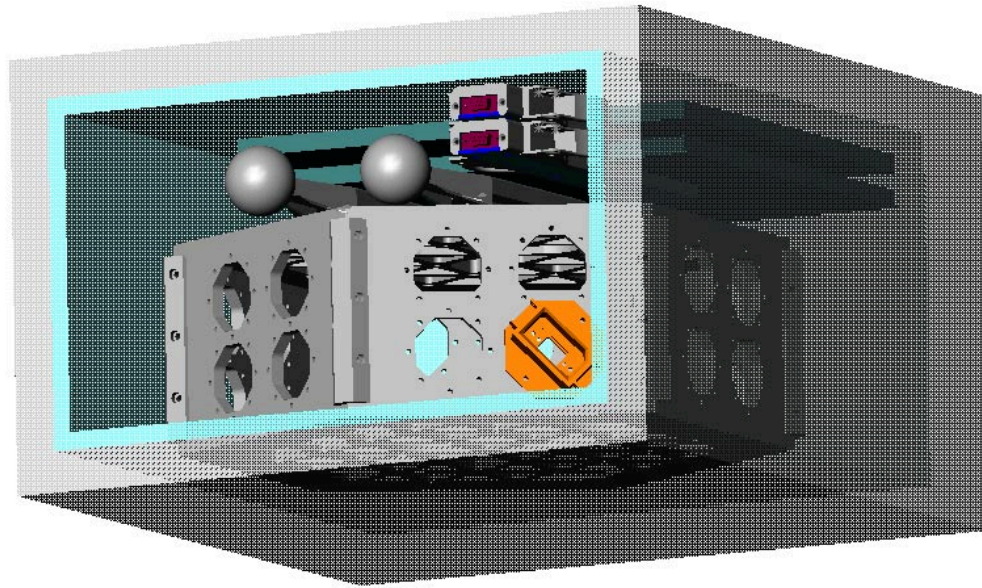
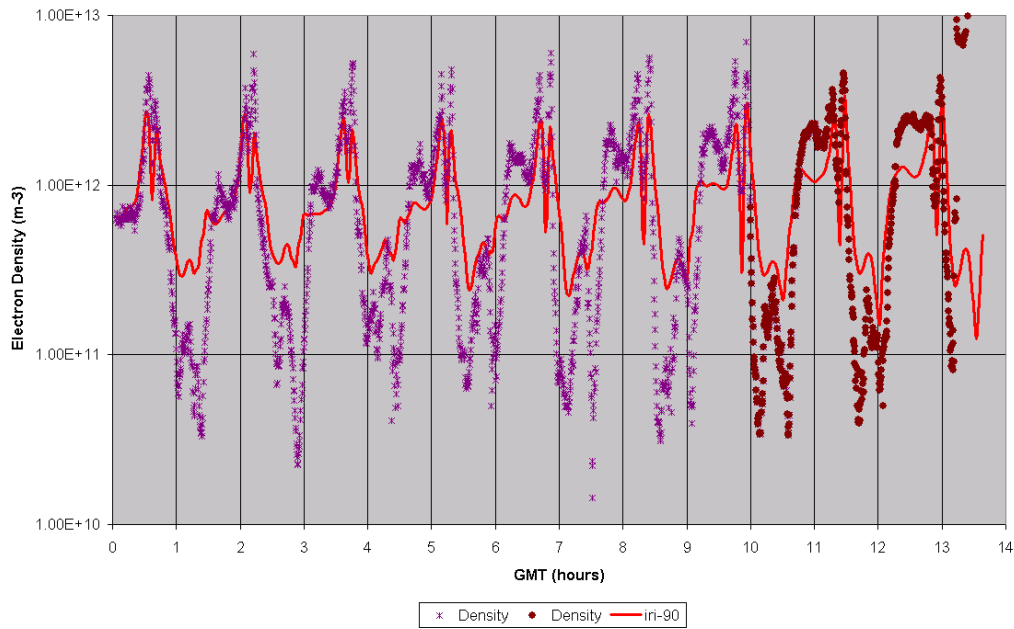


Figure 2: This drawing illustrates the main body of the FPP, the two solar arrays and the two probes and how they were originally going to be packaged to fit in mid-deck locker space. This view is an isometric from the front opening of the locker. Eventually a decision was made to pack the FPP in a “soft stowage” bag and load it behind the mid-deck Crew compartment. Had the FPP flown in the locker these components would have been packaged in foam for protection during launch. The blue border around the FPP components represents a clearance envelope required for packing. The locker set the original size of the probe body and limited the size of the solar panels.



FPP data electron temperature 04/11/01

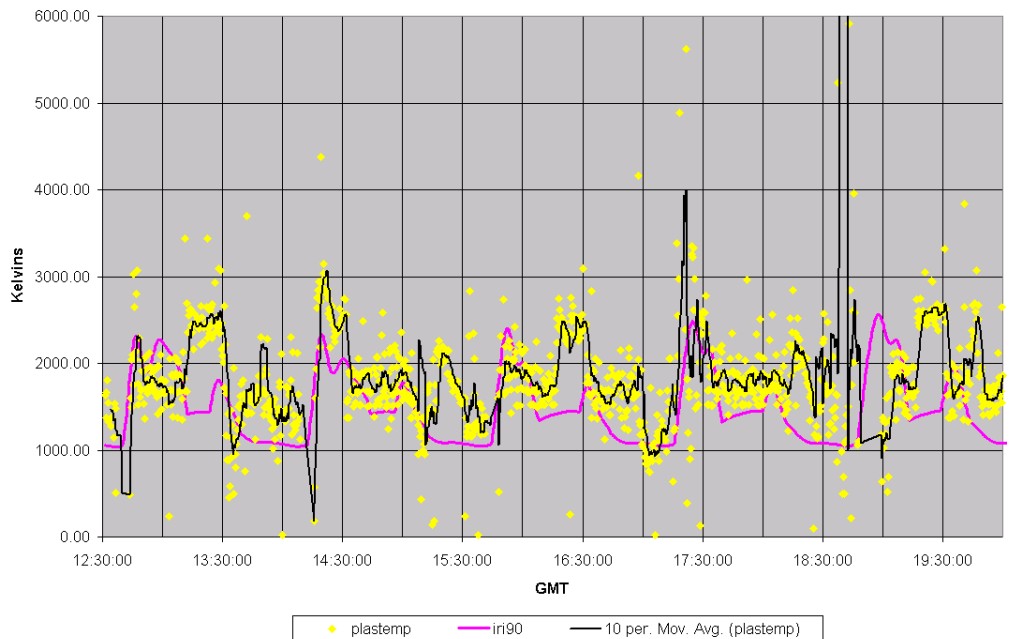


Figure 3a,b: These data represent ionospheric plasma density and temperature overlaid with the IRI model ionosphere. Clearly, although the density fit is reasonable, the temperature model is not very accurate. In addition to supplying data for understanding the floating potential of the ISS itself, the Langmuir Probe instrument on FPP provides data which will allow update of the IRI. No new data has been available for the lower ionosphere for many years. This is an excellent illustration of the quality science that can be done at low cost with the “small-sat attached payload.”

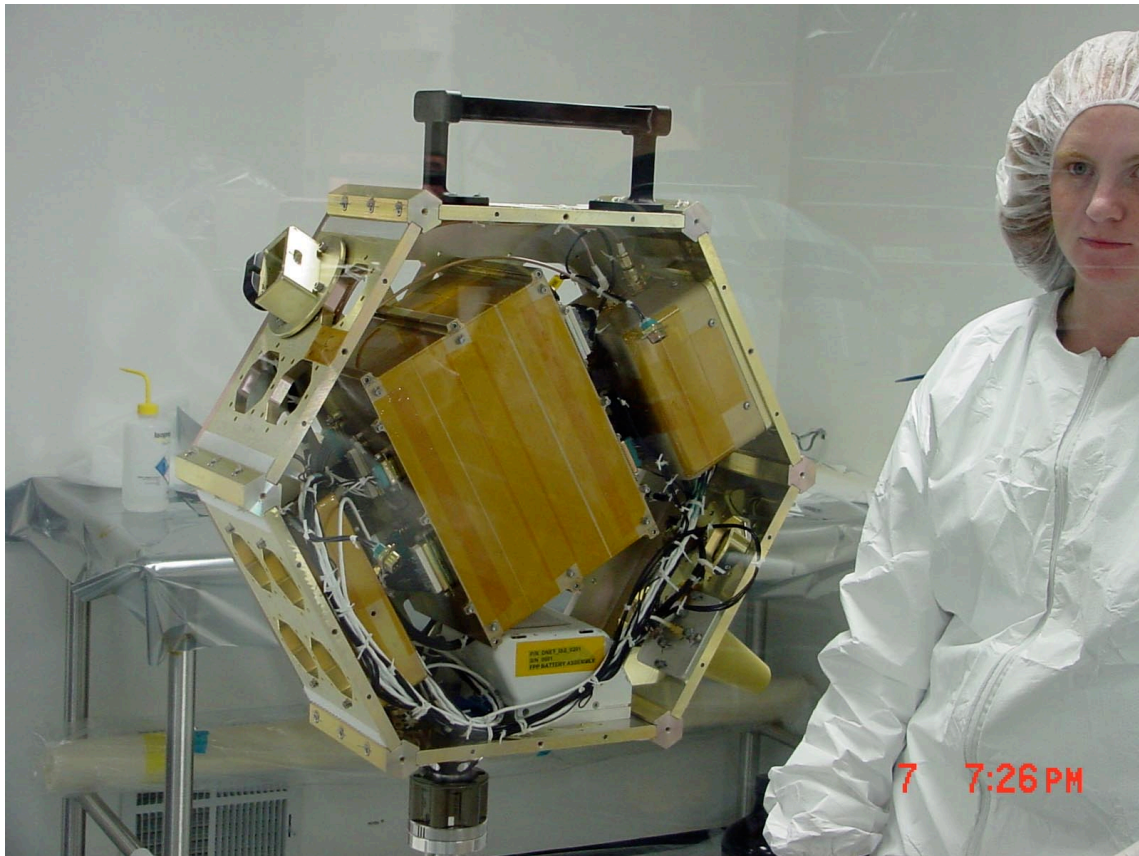


Figure 4: This view of the open structure of the FPP frame illustrates how on *each face of the hexagon* a probe or solar array mounting bracket (shown in upper left quadrant) can be mounted in one of four places at one of 6 rotation angles. This allows a lot of flexibility in assuring that the fixed mount arrays are oriented such that maximum insolation is possible. The probes, which mount on the large hexagonal face (removed) can mount in numerous positions as well. Either arrays or probes can be mounted on any face of the FPP.

This figure also illustrates the main electronics box (center), the plasma instrument (upper right), the battery pack (bottom) and the communication electronics (left). Additionally, this layout illustrates the space currently available for an instrument in the FPP Chassis (that occupied by the plasma instrument). The next generation of the unit will likely have a smaller main electronics box which incorporates the telemetry system allowing almost double the usable volume for instrumentation.

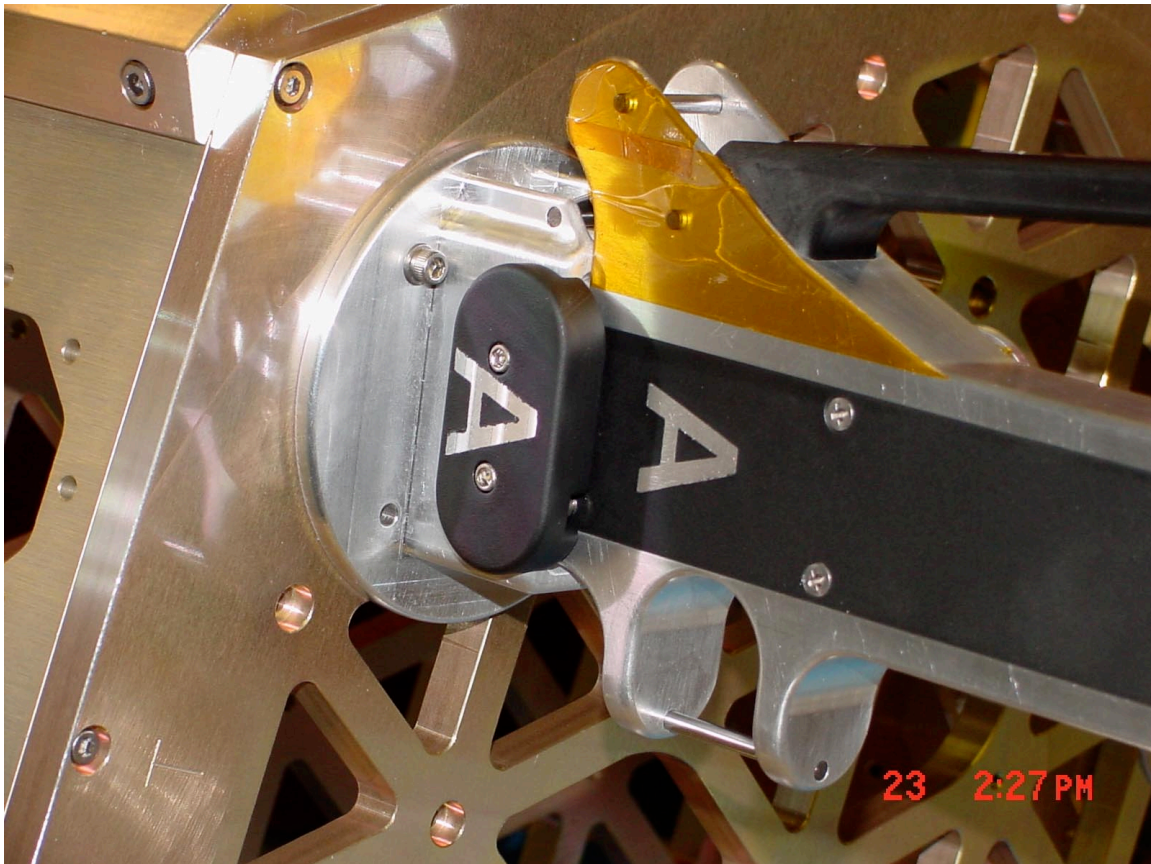
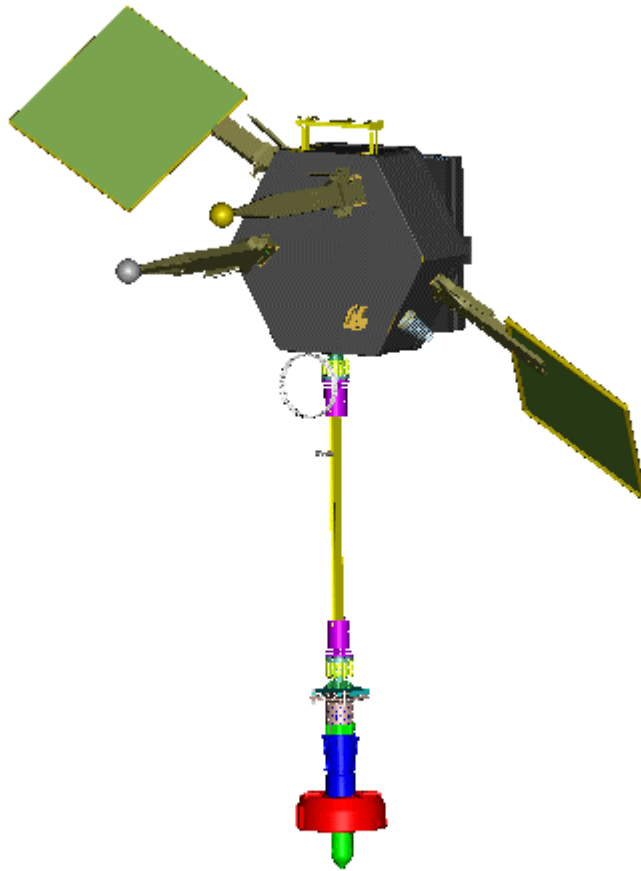


Figure 5: Probe Mount Detail. This illustrates the mounting of one of the two probes on the face of the FPP. Several features are notable, first the lettering which indicates to the crew which socket to install the probe, second, the latch handle which provides positive lock for the mechanism, third, the EVA tether attachment point and last of all, one can see that the mounting bracket is attached at one of many three-point mounting positions available on the surface of the face plate.



**18100650 P6 ELEMENT ASSEMBLY
(On Orbit Configuration)**

Figure 6: This drawing illustrates the principal components necessary to mount a small-sat on the ISS. The mount point on the ISS is the passive WIF (Worksite InterFace) which mates to the green colored mechanism at the bottom of the picture. The Stanchion Assembly, which goes between the FPP mounting plate (a passive ECOM or EVA Change-Out Mechanism) and the ISS WIF, consists of the Active side of the WIF (red/blue), a load limiter and adapter plate (just above), followed by an Active ECOM, extension tube (made of EVA dogbone material and shown in yellow) and lastly another active ECOM to interface with the FPP's passive ECOM. All of these components are either designed or provided by the program office. The FPP simply provided six mounting holes for the passive ECOM provided by JSC.



Figure 7: The “pizza box” is shown unfolded with the arrays inserted. Note the transparent “window” for inspection prior to removal from the package. The long pouch unfolded at the bottom of the picture (one of two) was used for storing the probes. This entire assembly was fastened to the outside frame of the FPP and provided a convenient single package for the Crew to transport on EVA.



Figure 8: This is a photo taken of the FPP after installation on the ISS showing the back side of the “pizza box” assembly used for carrying the solar arrays and probes to the work site. The “Christmas tree” is not a standard feature. The back side of one solar array and the dogbone handle for the BRT interface are also clearly visible. The large cylinder in the background is the solar array canister.