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# Pucksat Payload Carrier

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**Abstract.** There is an ever-expanding need to provide economical space launch opportunities for relatively small science payloads. To address this need, a team at NASA's Goddard Space Flight Center has designed the Pucksat. The Pucksat is a highly versatile payload carrier structure compatible for launching on a Delta II two-stage vehicle as a system co-manifested with a primary payload. It is also compatible for launch on the Air Force Medium Class EELV. Pucksat's basic structural architecture consists of six honeycomb panels attached to six longerons in a hexagonal manner and closed off at the top and bottom with circular rings. Users may configure a co-manifested Pucksat in a number of ways. As examples, co-manifested configurations can be designed to accommodate dedicated missions, multiple experiments, multiple small deployable satellites, or a hybrid of the preceding examples. The Pucksat has fixed lateral dimensions and a downward scaleable height. The dimension across the panel hexagonal flats is 62 in. and the maximum height configuration dimension is 38.5 in. Pucksat has been designed to support a 5000 lbm primary payload, with the center of gravity located no greater than 60 in. from its separation plane, and to accommodate a total co-manifested payload mass of 1275 lbm.

## Introduction

There is an ever-expanding need to provide economical space launch opportunities for relatively small payloads. For example, the NASA administrator has issued a directive to "launch 12 small payloads per year with an increase within 3 years to 24 per year". Interestingly, there are a significant number of Delta II launches that are expected to have payload margins suitable for small satellites. A classical example of this situation is the Landsat 7 spacecraft which was launched with 1152 kg of payload margin. Therefore, one strategy for fulfilling this need for launch opportunities is to effectively utilize all appreciable excess launch vehicle performance. To provide a cost-effective way to implement this strategy, a team at Swales Aerospace has designed the Pucksat under a task order contract with NASA's Goddard Space Flight Center. The Pucksat is a highly versatile payload carrier structure compatible for launching on the Delta II two-stage vehicle and the Air Force Medium Class Evolved Expendable Launch Vehicle (EELV). Pucksat would be flown as a carrier system co-manifested with a primary payload. That is, it will be mounted between the primary payload and the launch vehicle upper stage standard interface plane (See Figure 1).

Initial Pucksat concept studies were performed during the 1996 – 1997 time period. A flight hardware design effort was performed during 1998. Fabrication drawings and report documentation, including a Users Guide and Structural Analysis Report, were completed December 1998. These drawings and documentation and further programmatic and technical information are available from the contact addresses given at the conclusion of the paper.

Pucksat's basic structural architecture is shown in Figure 2. There are six honeycomb panels attached to six longerons in a hexagonal manner and closed off at the top and bottom with circular interface rings that interface, respectively, with the primary payload attach fitting and the launch vehicle upper stage. Payload components can be mounted on the six panels both externally and internally. In addition, components can be mounted on a unique, user designed, horizontal bulkhead that can be located over a wide range of positions in the thrust axis direction.

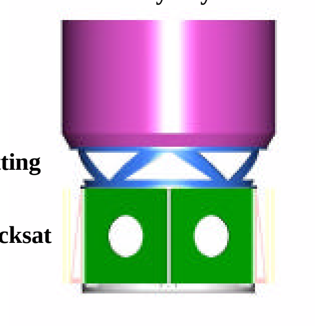



**Figure 1. Pucksat Mounting Configuration**

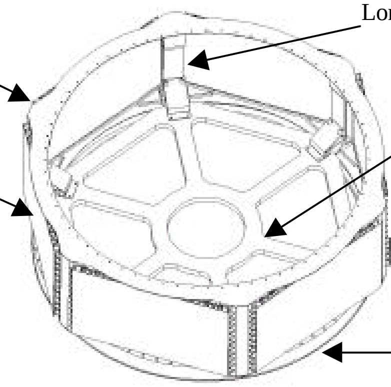



**Figure 2. Pucksat Basic Structural Architecture**

## Pucksat Design and Payload Configurations

Addressing the basic design in greater detail, Pucksat consists of a lower interface ring (LIR), six supporting longerons, six stiffening panels, and an upper interface ring (UIR). The LIR, machined from 7075-T7351 aluminum, serves as the interface path to the Delta II second stage. There are three designs for the LIR and they are specifically identified in a following section. The longerons, machined from 7075-T7351 aluminum, are bolted to the LIR and to the UIR to provide axial support for the primary payload. The UIR, also machined from 7075-T7351 aluminum, serves as the interface path to the primary payload. The Pucksat design makes use of six honeycomb panels, with aluminum facesheets and core, to provide lateral and torsional stiffness to the structure. These panels are bolted to the longerons and rings using close tolerance holes to provide maximum stiffness. As a user option, Pucksat allows for one or more horizontal bulkheads to be installed inside the structure as illustrated in Figure 2. Being a user option, the design and fabrication drawings for a horizontal bulkhead must be supplied by the user. Although not required to be utilized, a suggested design for semi-kinematic mounts, that can be used to attach a bulkhead to the longerons, is contained in the Pucksat documentation package. Otherwise, the user must also provide a mount design.

Figures 3 and 4 show additional details of the Pucksat design, some overall dimensions, and user defined optional features such as solar arrays, horizontal bulkhead, and panel holes. Figure 3 shows the maximum allowable diameter unreinforced hole in a vertical panel to be 15.0 in. Holes can be cut to user defined specifications in each panel. The exact shape of the cutouts may vary, but any panel with a cutout must be structurally analyzed on a case-by-case basis.

As shown in Figure 3, the baseline Pucksat design has a height of 38.5 in. Noted in this figure is the important feature that the height of Pucksat is scalable downward to a user established lower limit. A reasonable reduction in Pucksat height may easily be made by making simple modifications to the appropriate fabrication drawings via use of CAD software.

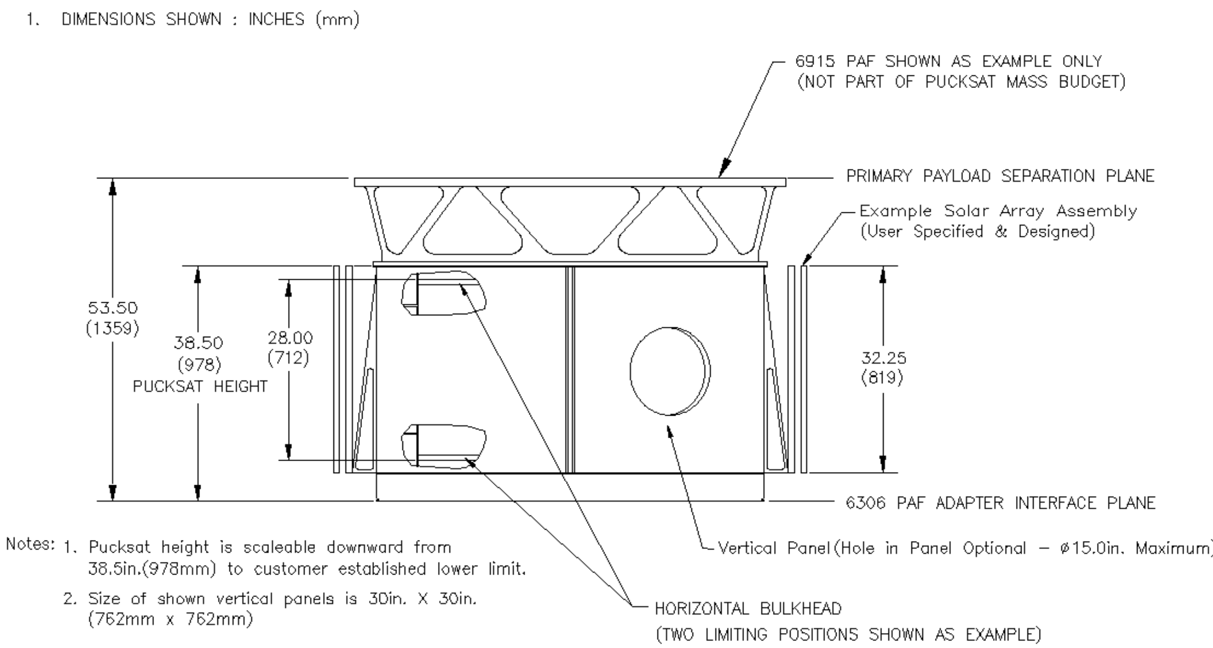



**Figure 3. Pucksat Side View**

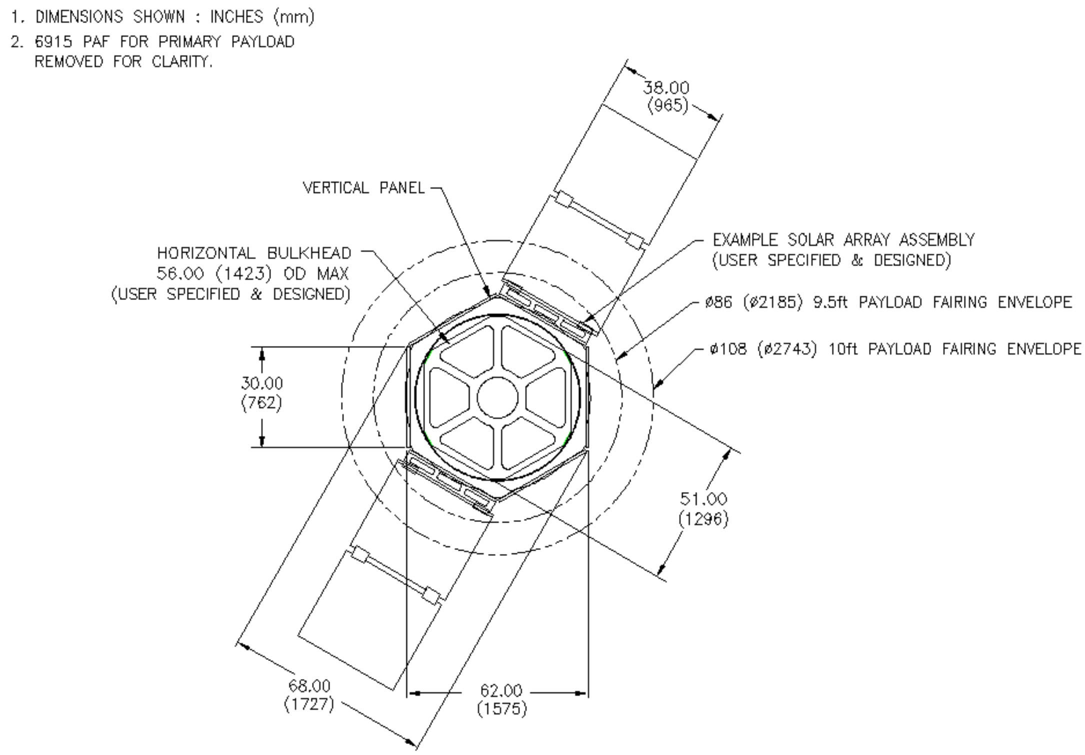



**Figure 4. Pucksat Plan View**

Users have the flexibility to configure co-manifested Pucksat spacecraft for a large variety of missions. The first three illustrations in Figure 5 give examples for a range of mission configurations. These configurations are further identified as follows:

- Pucksat Dedicated Mission Configuration
  - Entire spacecraft dedicated to a single experimenter.
- Pucksat Instrument Carrier Configuration
  - Spacecraft used by two or more experimenters.
- Pucksat Multiple Satellite Carrier Configuration
  - Spacecraft used to dispense multiple small satellites.
- A hybrid of the above configurations

The upper interface ring (UIR) baseline design is configured to accommodate standard payload attach fittings (PAF's) for the mounting of two-stage Delta II class primary payloads. Other class primary payloads can be readily accommodated via use of unique adapters. For example, Pucksat can accommodate a payload designed for a smaller class launch vehicle through the use of an adapter cone as illustrated in the third example in Figure 5.

In addition to the three illustrated co-manifested configurations, Figure 5 shows a Pucksat-only "stacked" configuration that could be suitable for constellation type missions. This configuration uses a Delta II 6306 PAF attached to the LIR of each Pucksat to permit both the connections and separations to be made. By performing a frequency analysis of "stacked' Pucksats, it was determined that it should be possible to stack a maximum of four Pucksats and still remain within the Delta II two-stage frequency constraints of 12 Hz lateral and 35 Hz axial. But a final decision must also consider the payload allowable static/dynamic envelope dimensions for the selected payload fairing.

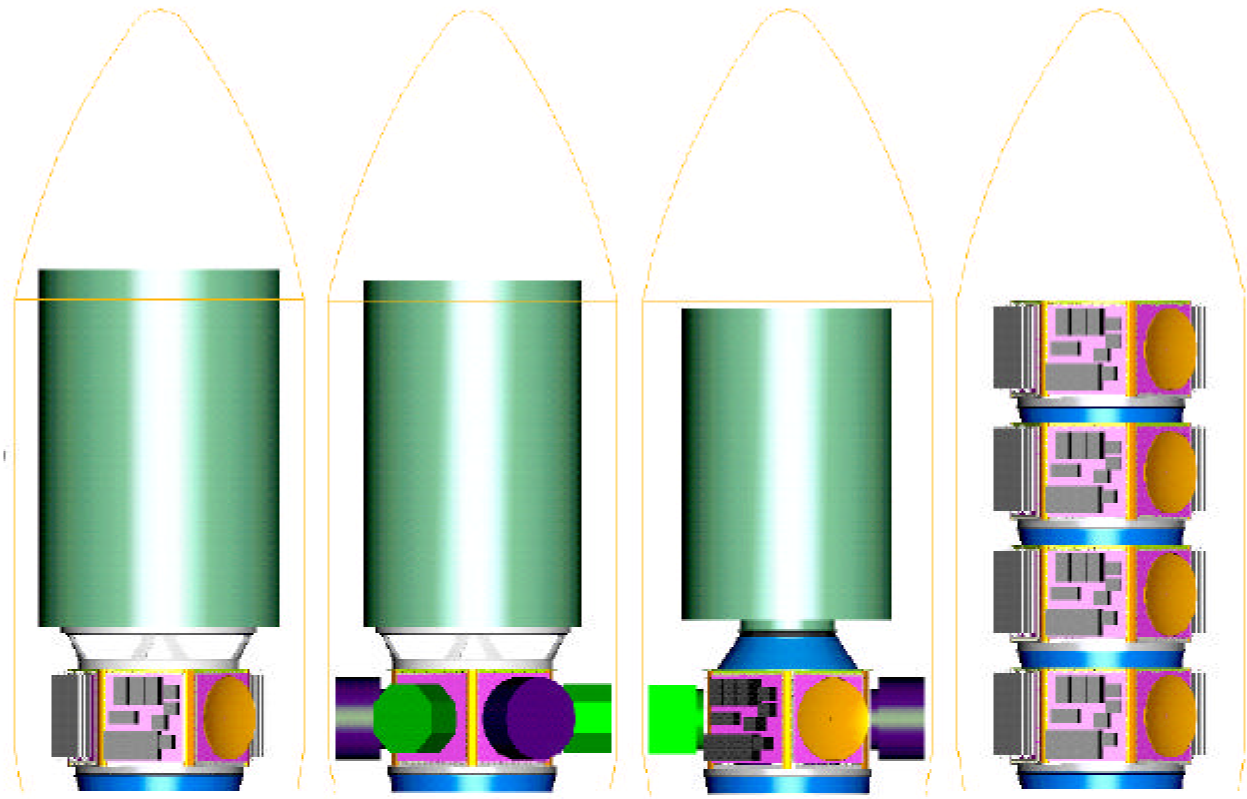



**Figure 5. Example Pucksat Payload Configurations**

Figures 6 and 7 present more detailed conceptual views of how a Pucksat can be integrated with hardware components to produce entirely different spacecraft configurations. The idea to be gained from Figures 5-7 is that opportunities have been created to satisfy a very large variety of spacecraft missions. These opportunities are largely due to the combined possible usage of both the outside and inside surfaces of the vertical panels, the option to put holes in the panels, and the option to use one or more horizontal bulkheads for mounting components and/or instruments.

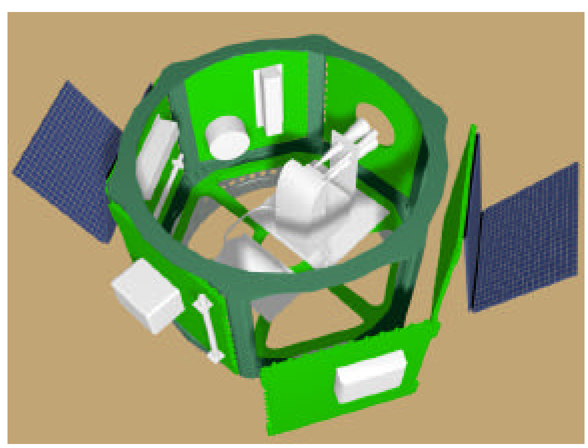


**Figure 6. Pucksat as Instrument Carrier Configuration**

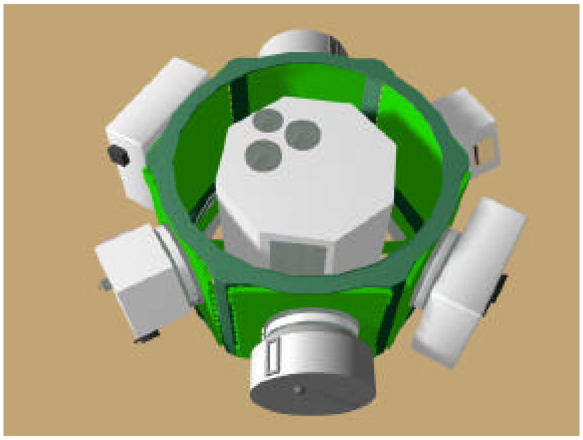


**Figure 7. Pucksat as Small Satellite Carrier Configuration**

## Major Structural Interfaces

The Pucksat UIR, designed to accommodate the mounting of the primary payload PAF, has the same bolt attachment as the Delta II second stage forward ring 56.83 in. diameter bolt circle (64 bolts). If a standard Delta II PAF is not suitable, unique attach fittings or adapters can be provided to allow a variety of different primary payload interface attachment configurations to be created.

An important feature to be noted is that the primary payload PAF will remain attached to Pucksat. Therefore, its presence must be accounted for if a Pucksat payload has a viewing requirement sector that intersects with the body of the PAF. A positive benefit is that a Pucksat payload could possibly be allowed to extend beyond the Pucksat nominal height into the PAF interior volume.

As stated earlier, there are three designs for the LIR. The baseline design for Pucksat is that it be deployable and utilizes a LIR-Deployable. A second possible variation, especially if it is used as a multiple payload carrier, is for it to be non-deployable. This configuration is made possible by use of a non-deployable LIR-Fixed rather than the baseline LIR-Deployable. The baseline LIR-Deployable is designed to mate with the Delta II 6306 PAF, whereas the baseline LIR-Fixed is designed to bolt directly to the Delta II second stage forward ring. A third possible variation is a modified baseline LIR-Fixed that has been redesigned to satisfy the Air Force Medium Class EELV Standard Interface Specification which requires a 62.01 in. diameter bolt circle (121 bolts). This element is known as a LIR-Fixed (EELV). Drawings of all the above described major interface structures are given in Figures 8-11.

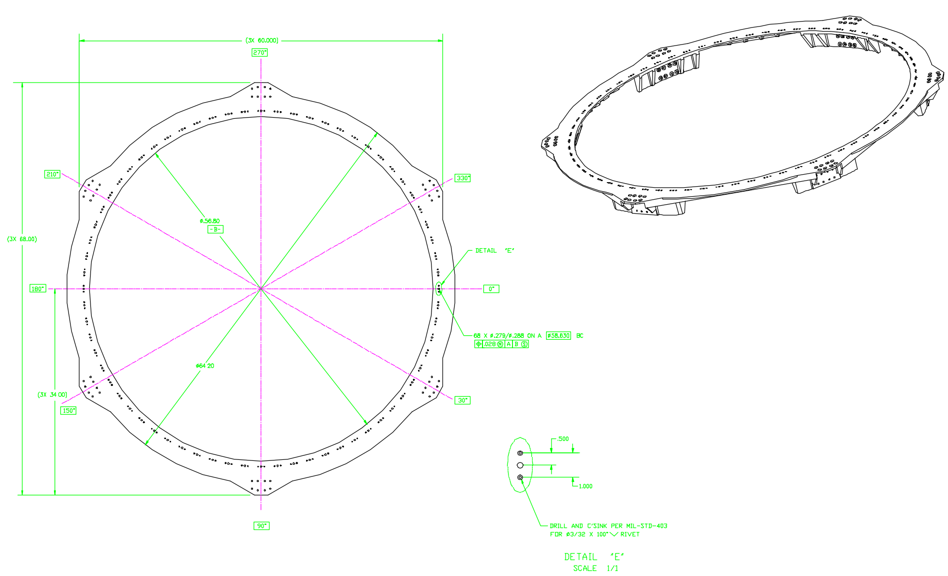



**Figure 8. Pucksat Upper I/F Ring**

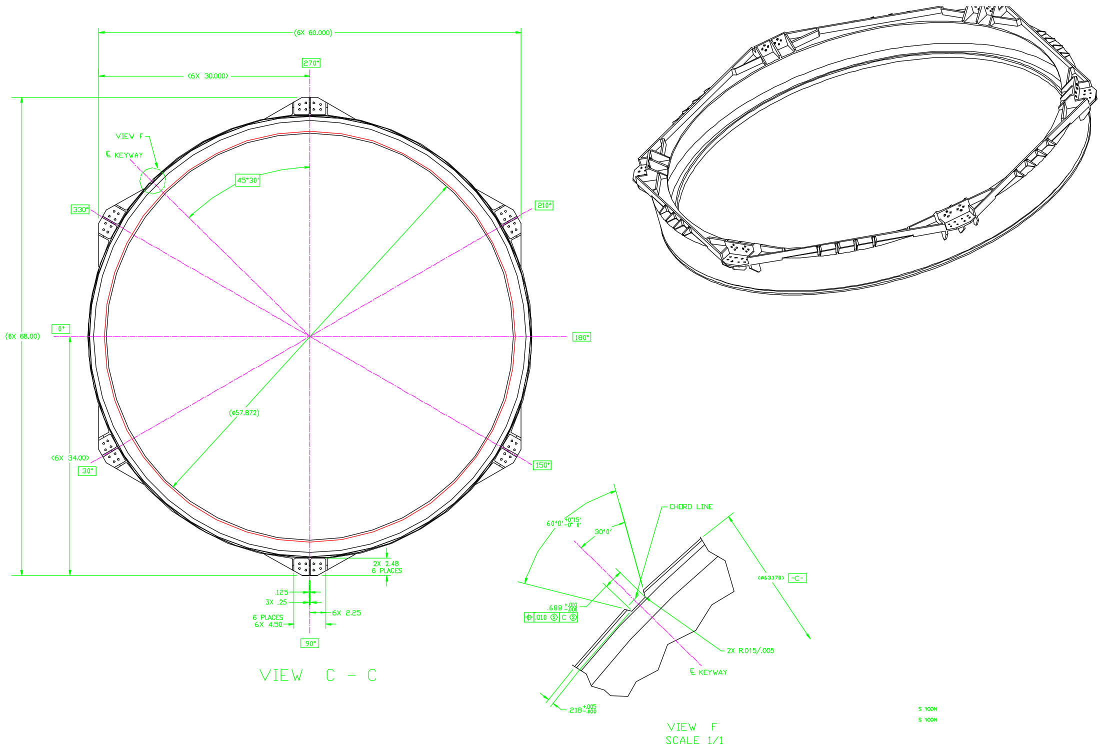



**Figure 9. Pucksat Lower I/F Ring – Deployable**

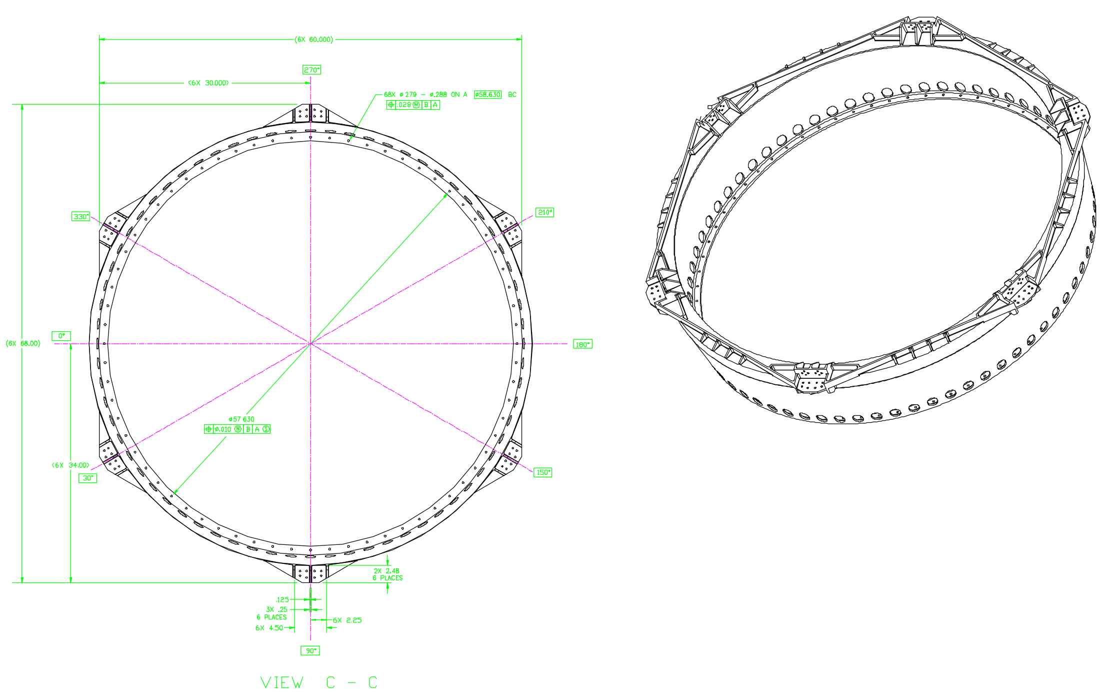



**Figure 10. Pucksat Lower I/F Ring – Fixed**

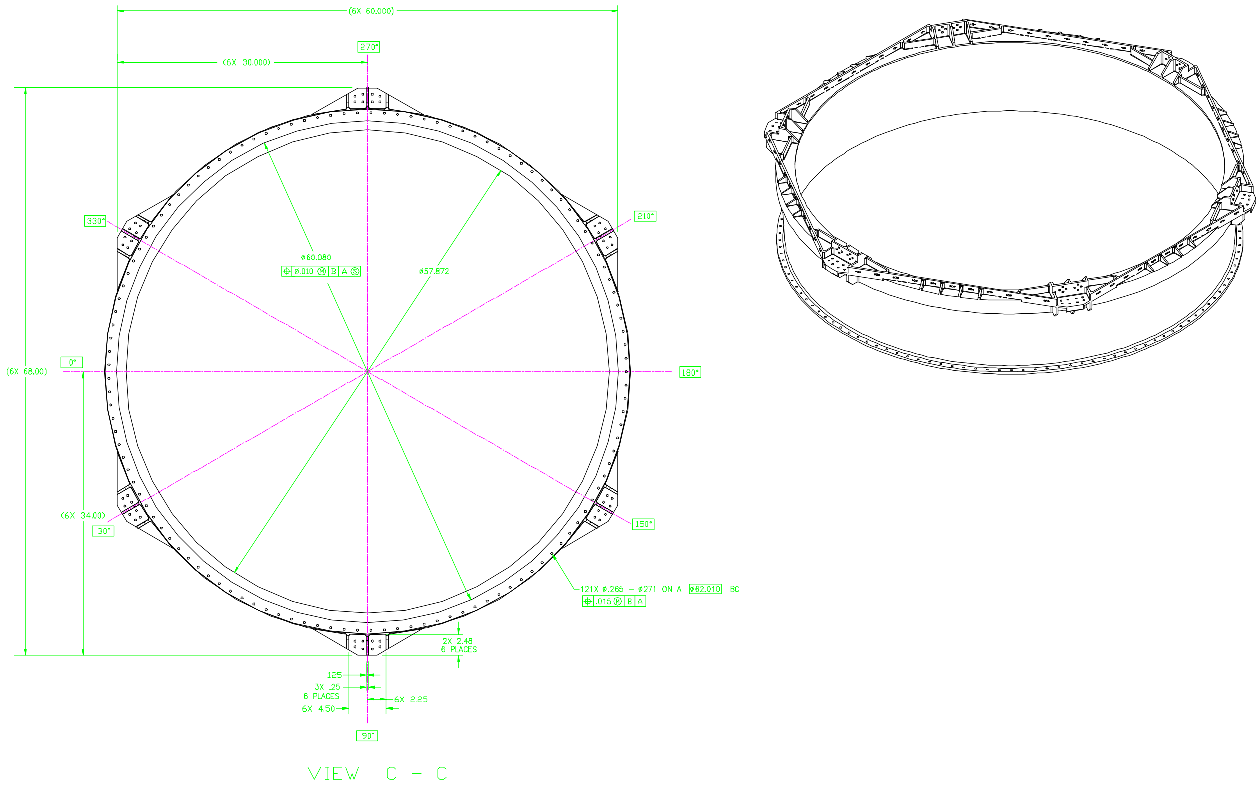



**Figure 11. Pucksat Lower I/F Ring – Fixed (EELV)**

## User Accommodations

### Payload Mass and Size Form Factors

A summary of the Pucksat payload mass and size form factors capacities is given in Table 1. As given, Pucksat has a grand total maximum payload capacity of 1275 lbm (578 kg). In simplified approximate terms, the maximum size volume for externally panel mounted payload components is a 20 in. x 30 in. x 30in. prism for an individual panel. For internally mounted payload components, the maximum size volume is a 31 in. x 28 in. x 30 in. prism for an individual panel or a 62 in. diameter x 30 in. height cylindrical prism for the horizontal bulkhead. The given capacities are based on a Pucksat with a baseline height of 38.5 in.

**Table 1. Summary of User Accommodations**

1. Maximum Primary Payload
   5000 lbm with 60 in. CG axial offset from separation plane or other equivalent combinations.

2. Maximum Mass Loading

   (a) Vertical Panels
   250 lbm per panel
   Not to exceed 775 lbm for all six panels combined

   (b) Horizontal Bulkhead
   500 lbm

   (c) Grand Total
   1275 lbm

3. Maximum Available Volume and Geometric Form Factors

   (a) Internal (Panel and/or Bulkhead mounted)

   Volume
   87,000 cu-in. (Total)

   Geometric Form Factors - Cylindrical Prism
   Diameter = 62 in.
   Height = 30 in.

   (b) External (Panel mounted)

   Volume
   11,900 cu-in. per panel (9.5 ft PLF)
   29,000 cu-in. per panel (10 ft PLF)

   Geometric Form Factors – Annular Prism (per panel)

   Radial Depth = 11.0 in. (9.5 ft PLF)
   = 22.0 in. (10 ft PLF)

   Axial Height = 30.0 in.

   Inner Sector Arc Length = 32.5 in.
   Outer Sector Arc Length = 45.0 in. (9.5 ft PLF)
   = 56.5 in. (10 ft PLF)

Figure 11 below shows further details of available payload volume.

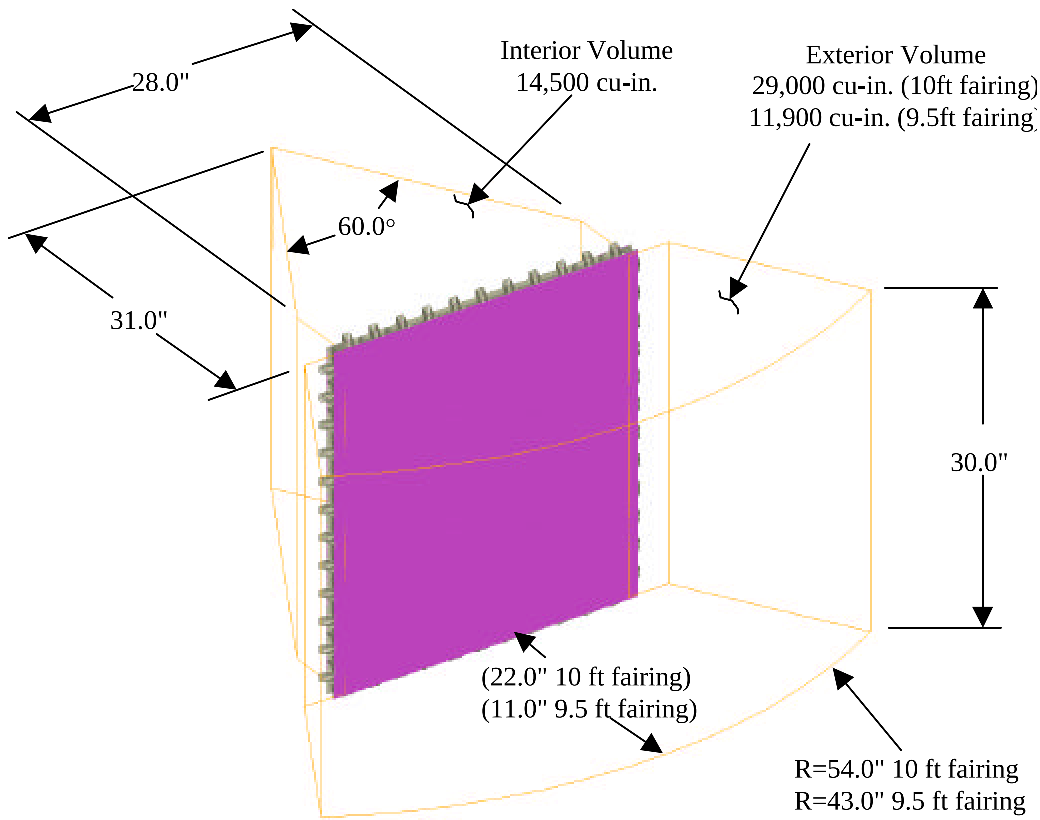



**Figure 12. Payload Allowable Volumes Per Panel**

## Effect on Primary Payload Structural Launch Loads

When a Pucksat is inserted beneath a primary payload, it is logical to ask what effect there will be on primary payload launch loads since its CG has been raised by at least 44.5 in. While it is impossible to predict this effect for all specific combined configurations, a parametric study was performed for a wide range of simplified models of primary payload mass configurations and fixed base frequencies with and without a co-manifested Pucksat payload. This study consisted of performing a series of preliminary Delta II 7920-10 launch events coupled loads analyses. The final results provided the ratio of launch-induced maximum bending moments at the base of the primary payload PAF for with and without a Pucksat being used versus primary payload mass and fixed-base fundamental lateral frequencies. As shown in Figure 13 below, inserting a Pucksat, in general, did not cause a significant increase in the primary payload base bending moment. Details of this study are contained in Swales Aerospace Technical Memorandum SAI-TM-1153.

Notwithstanding the above results for the hypothetical test cases, it is critical that a potential user have a coupled loads analysis performed as soon as possible. This will assess the effect of Pucksat on primary payload launch loads and the combined system fundamental frequencies.

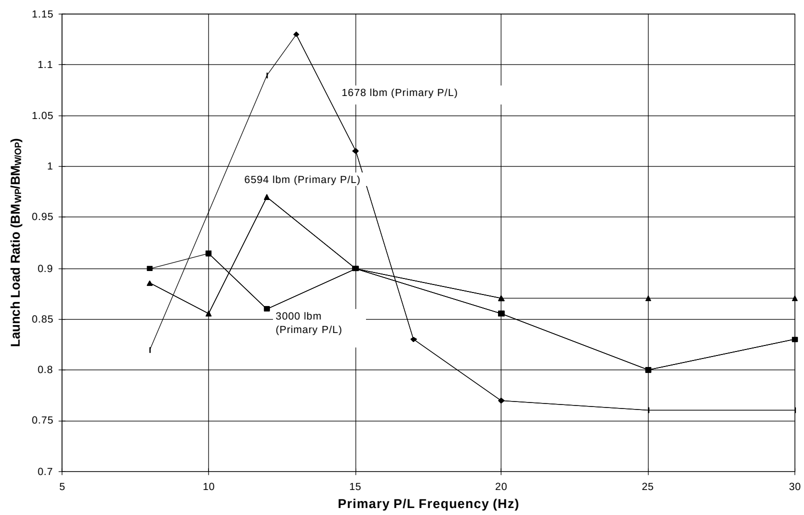



**Figure 13. Pucksat Effect on Primary Payload Delta II Launch Loads**

## Thermal Control

Thermal control feasibility analyses have been performed for two worst case hot orbits of 500 km circular sun-synchronous at i=94.7° and 700 km circular at i=28.5°. In general, the Pucksat honeycomb vertical panels provide ample available radiator area to accommodate a wide range of thermal input conditions and satellite configurations. Figure 14 shows the maximum radiator area necessary to reject the internal power dissipation from a component mounted to a vertical panel. More specifically, it is typical to expect that a radiator design temperature should be between 0°C and 40°C. With the outside dimensions of the panels being 30 in. x 30 in., the 800 in.$^2$ area condition represents the maximum practical size radiator. Knowing also that the maximum peak power dissipated by any one component is most likely not to exceed 50W, Figure 14 shows that the maximum size radiator should be between 200 in.$^2$ and 400 in.$^2$.

Based on the above discussion, it is expected that a typical electronics box can maintain reasonable temperatures by simply hard mounting to a vertical panel. Components with relatively high power dissipations or small mounting footprints may need to employ doubler plates or similar heat spreading hardware to help transfer its heat to the radiator.

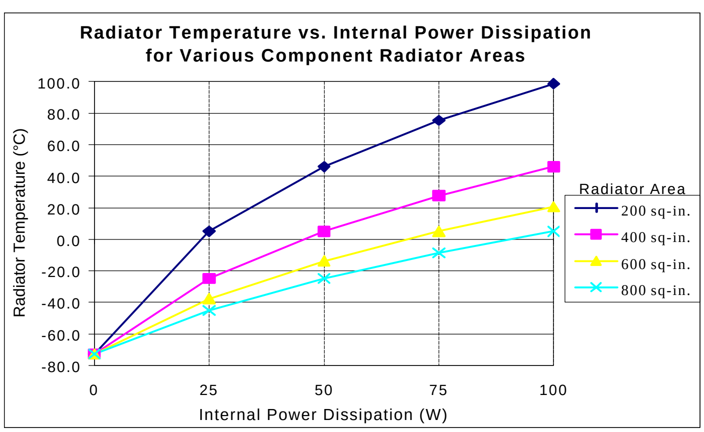



**Figure 14. Radiator Temperature vs. Internal Power Dissipation**

**Electrical Harness Requirements**

Electrical connections between Pucksat, the Delta II, and the primary payload require detailed attention. The interfaces are so dependent on mission specific considerations that a complete description of all possible configurations is impossible. However, Figure 15 below shows how the electrical harnessing schematic may appear for a deployable Pucksat configuration that corresponds to the first configuration example in Figure 5. The harnessing can be considered to be composed of three types of parts as noted in the harness figure. For other than the noted standard parts, the Pucksat mission will be responsible for the cost of the remaining items. The following discussion gives further explanation of Figure 15, generalizes on its content, and gives guidelines on how the harnessing can be constructed for other Pucksat configurations.

Delta II provides the following equipment with its standard launch package: a 6306 PAF, pyros and harnesses for the PAF (Part 1), two pull-off brackets to the primary payload (Part 2), one fairing pull-off bracket (Part 3), and one Delta harness to fairing bracket (Part 4) as noted in Figure 15. Additional pyros, harnesses, and pull-off brackets and connectors will be needed for each new separation system. Delta II has the standard capability to send seven payload separation signals for a 10 ft PLF or five signals for a 9.5 ft PLF. All pyro harnesses must remain attached to the Delta II harness until after payload separation. This means the harnesses for these units cannot be attached to the fairing and must be mated with pull-off connectors where they cross spacecraft separation planes. Pucksat will provide extension and pull-off brackets for pyro harnesses at the 6306 PAF interface (Parts 8 & 13) and for the fairing harnesses as necessary (Part 12). Extension harnesses may be required to connect various payloads to Delta II harness interfaces at Pucksat pull-off brackets (Parts 6, 9, & 14). Multiple Delta harnesses to pyros and fairing pull-off brackets are required as shown (Parts 7 & 11) as well as an additional fairing pull-off bracket (10). The primary payload PAF, shown as an example 6915 PAF, requires pyros (Part 5) and harnesses (Part 6). All pull-off connections can be accomplished by using MS3470 or MS3424 flange-mount receptacles.

Pucksat customers must provide room for the primary wiring harnesses where it passes across the Pucksat structure. Because this provision depends on mission specific requirements, Pucksat does not have a specific stay-out zone. This issue will need to be addressed as part of the Delta II integration definition process for each mission.

For the case where Pucksat serves as a carrier for small deployable satellites (i.e., configuration examples two and three in Figure 14), pyro harnesses for the small satellites can emanate from Part 7 harnesses at the Part 8 extension brackets. Power/command harnesses can also branch off the same way as for the pyros or they can branch off from Part 4 and/or Part 11 harnesses at fairing brackets Part 3 and/or Part 10. Pull-off connectors at brackets Parts 8/13, 10/12, and 3/12 can be used. Whichever route the small satellite power/command harnesses follow, additional pull-off brackets and connectors will need to be installed at the Pucksat to small satellite interfaces.

For the case where Pucksats are stacked (i.e., configuration example four in Figure 4), successive pyro harnesses can be routed from one Pucksat to the next via use of multiple brackets Parts 8/13. Power/command harnesses can be routed the same way as for the pyros or multiple fairing to Pucksat pull-off brackets (e.g., Parts 10/12) and connectors can be used.

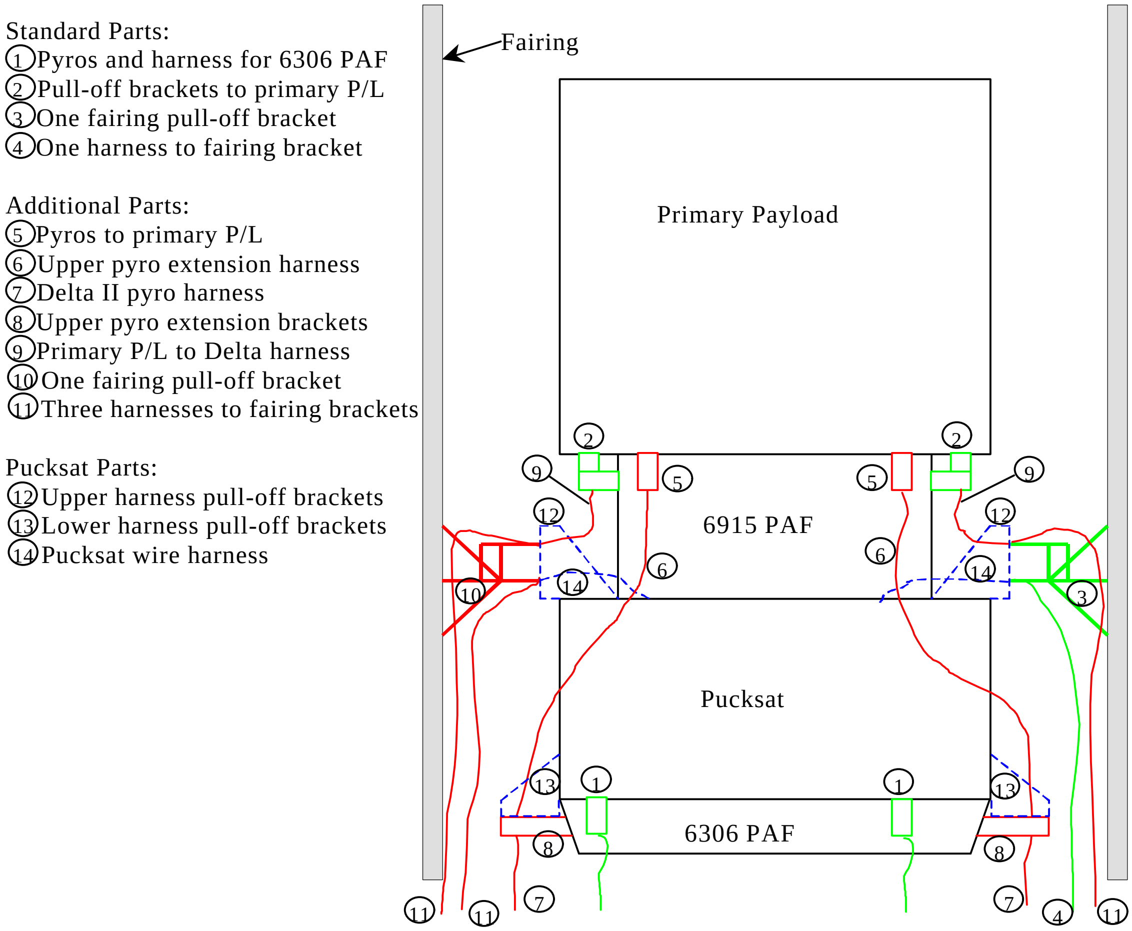



**Figure 15. Pucksat Harness Requirements Example, Deployable Pucksat**

## Cost and Schedule

### Estimated Cost

Table 2 contains two basic cost estimates. The first cost estimates are the costs to fabricate and test the first and recurring structural units. The second estimates are the costs to fly the first and recurring hypothetical missions. These costs are based on the following assumptions:

- Full cost accounting for civil service manpower
- ROM cost for small satellite attach fittings (PAF) quoted by Saab Ericsson
- Qualification testing consists of mass properties, modal survey, and strength tests.
- Delta II integration cost is GSFC ROM estimate.
- Launch site support cost shared with primary payload.
- Hypothetical mission has full complement of seven co-manifested payloads.
- Grand total cost equally divided between seven payloads to obtain per payload cost.
- 1999 dollars

As can be seen, the grand total "to fly" cost is driven by the $3.0M Delta II integration cost. Therefore, if a significant reduction in payload mission cost is to be achieved, a cooperative effort is needed to try to reduce the launch vehicle integration cost.

**Table 2. Pucksat Estimated Cost**

| Pucksat Fabrication & Qualification Test Cost | | |
|---|---|---|
| Category | First Unit | Recurring |
| Fabrication & Assembly | $470K | $270K |
| Qualification Test | $130K | $130K |
| 24 in. PAF Procurement | $78K | $78K Each * |
| 17 in. PAF Procurement | $102K | $52K Each * |
| Subtotal | $768K | $518K |
| GSFC Manpower | $62K | $31K |
| Total | $842K | $561K |

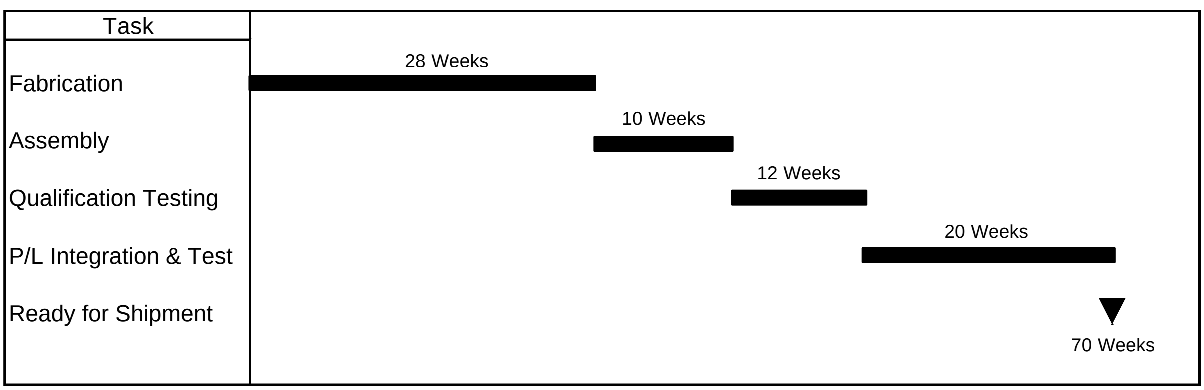
* 30% Discount For Purchase of 3 or More
** GSFC Estimate

| Pucksat Spacecraft Flight Cost | | |
|---|---|---|
| Category | First Mission | Recurring Mission |
| Delta II Integration | $3.0M ** | $3.0M ** |
| Launch Site Support<br>Launch Site Integration Facility | $300K (Shared) | $300K (Shared) |
| Payload Attach Fittings<br>(Assume 5 Added 17 in. PAF's) | $200K | $200K |
| Pucksat Structure | $842K | $561 |
| GSFC Manpower | $134K | $134 |
| Travel | $54K | $54 |
| Grand Total (No Travel) | $4.5M (7 P/L's)<br>$637K Each P/L | $4.2M (7 P/L's)<br>$600K Each P/L |

## Schedule

Table 3 presents a Pucksat authority to proceed (ATP) to shipment readiness schedule. As shown, it is projected that Pucksat can be fabricated, assembled, and ready for qualification testing after 38 weeks and ready for payload integration after 50 weeks. A hypothetical payload integration and test schedule span of 20 weeks is shown in the table. But it must be emphasized that, in reality, this portion of the schedule will be dictated by users. Therefore, what is shown here for payload integration and test is somewhat speculative. Nevertheless, it is believed that, with no unusual programmatic and technical delays, a Pucksat spacecraft can feasibly be ready for shipment to the launch site in a minimum of 70 weeks after ATP.

**Table 3. Pucksat Schedule – ATP to Shipment Readiness**




## Lessons Learned

Over the period spent developing Pucksat, there have been a number of lessons learned that are believed to be generic in nature and worth sharing with other developers of similar spaceflight hardware. These lessons learned are as follows:

- Demonstrate what impact the adapter may have on primary payload primary structure design loads and flight environment levels.
- Avoid transmitting overly concentrated loads into the launch vehicle interface structure.

- Make early accommodations for electrical wiring and ordnance coming from the launch vehicle for adapter payloads and for wiring that passes through the adapter to the primary payload.
- By appropriate design engineering and fabrication process, make detachable panels to be fully interchangeable.
- Design the primary structure to be scaleable in height.
- Design the adapter to withstand the loads, from a primary payload with a maximum mass and axial cg offset combination, that match the launch vehicle interface maximum structural load limits.
- Make maximum use of both inside and outside usable volumes of the adapter.
- Provide both deployable and non-deployable adapter configurations.
- Create an integrated product team (IPT) to understand user communities needs as thoroughly as possible.
- Start as early as possible to develop users for the adapter and to mitigate their concerns.
- Give users a number of options that can be readily incorporated.
- Give users a large degree of flexibility in how the adapter payload(s) can be configured.
- Build flight qualified mass simulators for adapter payloads to install, if needed, to eliminate impact on primary payload dictated launch schedule.
- Work directly with launch vehicle contractors to minimize the launch integration cost.

## Conclusions

The following conclusions summarize the status and potential usage of Pucksat.

- Pucksat is a low cost, mass efficient way to avoid performance waste on the two stage Delta II and Medium Class EELV launchers.
- Pucksat is a highly versatile payload carrier adapter because it can be either deployable or non-deployable; it can be launched on either the two-stage Delta II or the medium class EELV; it is capable of having components and/or instruments mounted on the vertical side panels both internally and externally; viewing holes can be put into the side panels; a user has the option to utilize one or more horizontal bulkheads; and small independent deployable satellites can be mounted on the side panels and horizontal bulkhead.
- Pucksat fabrication drawings and Users Guide are completed and the adapter is ready for first unit production.
- Standard or custom payload attach fittings can be used to accommodate a variety of interfaces for attaching primary payloads.
- It is projected that the first unit Pucksat can be fabricated, tested, and be ready for payload integration 50 weeks after ATP.
- Pucksat recurring cost to fly is approximately $4.2M or $600K per each payload for a full complement of seven payloads.
- Pucksat is currently looking for flight opportunities.

## Points of Contact

- Programmatic Information and Documentation Requests

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