THE PEACEKEEPER POST BOOST VEHICLE FOR CIVIL SPACE APPLICATIONS

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Abstract

Ownership of several Peacekeeper fourth stages has been transferred from the USAF to NASA for use in the civil space program. The production of Peacekeeper missiles was discontinued although several of the fourth stages known as Post Boost Vehicles or PBV's were in production and in various stages of completion. This paper examines the potential use of these PBV's for small civil space missions, especially Discovery class missions.

Several configurations of the PBV with small interplanetary missions are examined. The delivered configuration of the PBV is described along with modifications necessary to make them flight ready. This paper examines the use of the PBV as a booster stage and as a spacecraft bus. The booster configurations examined include use of the PBV alone and in combination with solid rocket motors. The Delta II and Shuttle launch systems are considered as launch vehicles for these combinations.

Discovery Mission performance requirements and compatibility with the PBV is reviewed. Four of the missions which appear to be compatible with the PBV include the MESUR Pathfinder, the Near Earth Asteroid Rendezvous, the Venus Atmosphere Composition Probe, and the Earth-Orbital UV Jovian Observer missions. The configurations and preliminary performance requirements of these missions are discussed.

This paper concludes that the Peacekeeper PBV provides adequate performance for these missions and is worthy of further consideration in the Discovery Program or other programs as a booster stage or a spacecraft bus. The PBV is found to be a versatile spacecraft requiring some technical work but costing far less than an equivalently capable three-axis stabilized vehicle.

Introduction

As the cold war ends, the possibilities of converting weapons related equipment to use in civil space program become more and more intriguing. This is especially true for the upper stage of the Peacekeeper missile. The Air Force will be discontinuing production of this weapons system and has in fact already canceled orders for any more of them. Some of the upper stages known as Post Boost Vehicles or PBV's are currently on the production line and in various stages of completion. Since they will not be needed for defense purposes, ownership of some of the PBV's has been transferred to NASA for use in the civil space program. The purpose of this paper is to examine the issues and some of the possibilities of using these PBV's for small civil space missions.

The number missions is limited in this study to a representative set of interplanetary missions. By examining this set of missions most of the topics surrounding use of the PBV will be covered. The Discovery Program of small scale, rapid turn-around, cost constrained interplanetary missions offers a number of opportunities for use with the PBV. The PBV is compatible with the Delta II launch vehicle which is a constraint of the Discovery Program. To illustrate more of the issues of integration, this study also focuses on the use of the Shuttle for launch purposes. At the time of this writing, it appears the Shuttle may be a available due to possible down-scaling of its commitment to Space Station Freedom missions. The study, then, of the PBV use in civil space programs will be limited, for this exercise, to the PBV with Discovery missions and will concentrate on the Shuttle as a launch vehicle.

The primary options for use of a PBV for Discovery missions include booster type missions and spacecraft bus missions. For some missions the best use of the PBV is as a three-axis-stabilized stage for injection of the primary spacecraft into its interplanetary trajectory. In some cases, the mission is such that the PBV can be used as an actual supporting spacecraft bus. This later option involves the use of the PBV as the primary spacecraft for the mission.

The Post Boost Vehicle

The PBV is an integrated, bipropellant stage designed to deliver multiple warheads onto highly accurate trajectories. Its design mission is about 30 minutes in duration and begins after an extended idle period in a missile silo. The entire missile system is designed to launch into and through a hostile environment. This mission is not the same as space booster or spacecraft bus missions so the PBV will require some adaptation.

The PBV is a capable spacecraft. Figure 1 is an illustration of the PBV itself. It uses a pressure-fed monomethyl-hydrazine and nitrogen-tetroxide propulsion system. The system includes a single, gimbaled, 11400 N (2563 lbf) thrust primary engine and eight 311 N (70 lbf) thrust attitude control engines for three-axis control. The structure is robust consisting of an aluminum isogrid skin with strong interior primary and secondary elements. It is 96 inches in diameter to match its launch vehicle and is approximately 43 inches in its axial direction. These dimensions leave a significant amount of interior space available. Well over 100 of these stages have been built and 18 have been successfully flight tested.

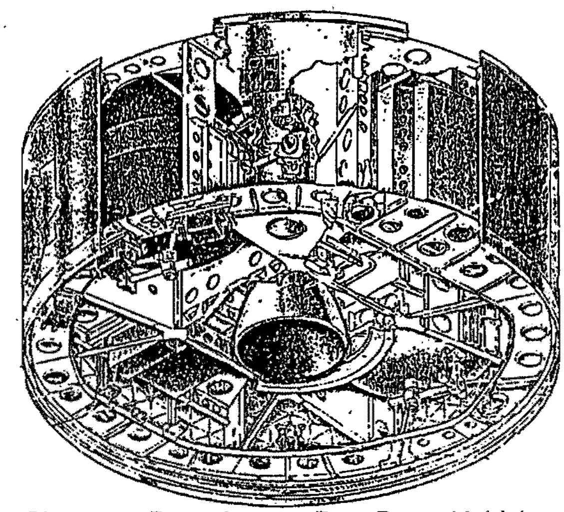

Figure 1 - Peacekeeper Post Boost Vehicle

The basic PBV is delivered without its Guidance, Navigation and Control system and power system, and does not include a thermal control or a communication system. The power or avionics subsystem hardware would be clearly inappropriate for most civil space applications and may not have been declassified. The PBV never had communications or thermal control systems because its mission did not require them. The PBV is structurally robust but does not have launch vehicle or payload mating accommodations. The modifications necessary for adaptation of the PBV to civil space missions include design development and integration of avionics, power and thermal system as required along with structural adaptation to launch vehicles and payloads.

The NASA Johnson Space Center owns 12 PBV's in various stages of completion. Rocketdyne, the manufacturer, has 4 stages with all components available and requiring only final assembly. There 6 units for which the components are nearly complete and piece-parts and raw materials are available on the remaining 2. Cost estimates for bringing the PBV's to flight ready status including the NASA added subsystems such as avionics are in the neighborhood of $ 5 million for each PBV. The availability and estimated cost of the PBV make it a good candidate for a number of applications.

PBV Use in Civil Launch Systems

A PBV is currently planned for the low-earth-orbit, Liquid Plume Generator (LPG) mission, an SDIO mission launched from the Shuttle. Consequently, avionics, power, and thermal control subsystems for a non-Peacekeeper application have been designed. In addition, the structural adaptations and safety reviews have been completed for PBV integration into the Shuttle. No required safety modifications have been identified. The choice of launch vehicle will make little difference in the work required to make the PBV flight ready. So, while the PBV will require some adaptation for civil space missions, much of the work has already been accomplished.

PBV Performance

Figure 2 shows the performance capabilities of the PBV in various configurations. Shuttle configurations include the PBV by itself and a lightened version of the PBV with extra propellant. This lightened version is assumed to have structure removed and tanks added such that the dry mass remains constant and the mass of propellant is doubled. Performance figures for the PBV alone and with extra propellant are shown in solid lines. As will be shown later, these capabilities are inadequate for any of the Discovery missions.

The PBV capacity as a booster can be enhanced by the addition of a solid rocket motor. In these cases the combination of solid rocket and PBV is a two-stage upper stage with primary control by the PBV. The performance of the PBV launched in Shuttle with a Morton Thiokol Star 48b and a Star 63f are also shown with solid lines and, relative to the single stage PBV configurations, have correspondingly increased capability.

The shaded lines in Figure 2 illustrate the performance of the PBV with the Delta II launch system. The first line indicates PBV performance without the standard Star 48b Delta third stage and is strikingly close to that of the Shuttle Star 48b line. The second line, which is to the right represents PBV performance with the Delta II and its third stage. This line indicates that a PBV with a Star 48 can provide better performance on a Delta than when launched from Shuttle. This difference is due to the fact that the Delta can place the PBV directly on its injection trajectory without the need to circularize as with Shuttle.

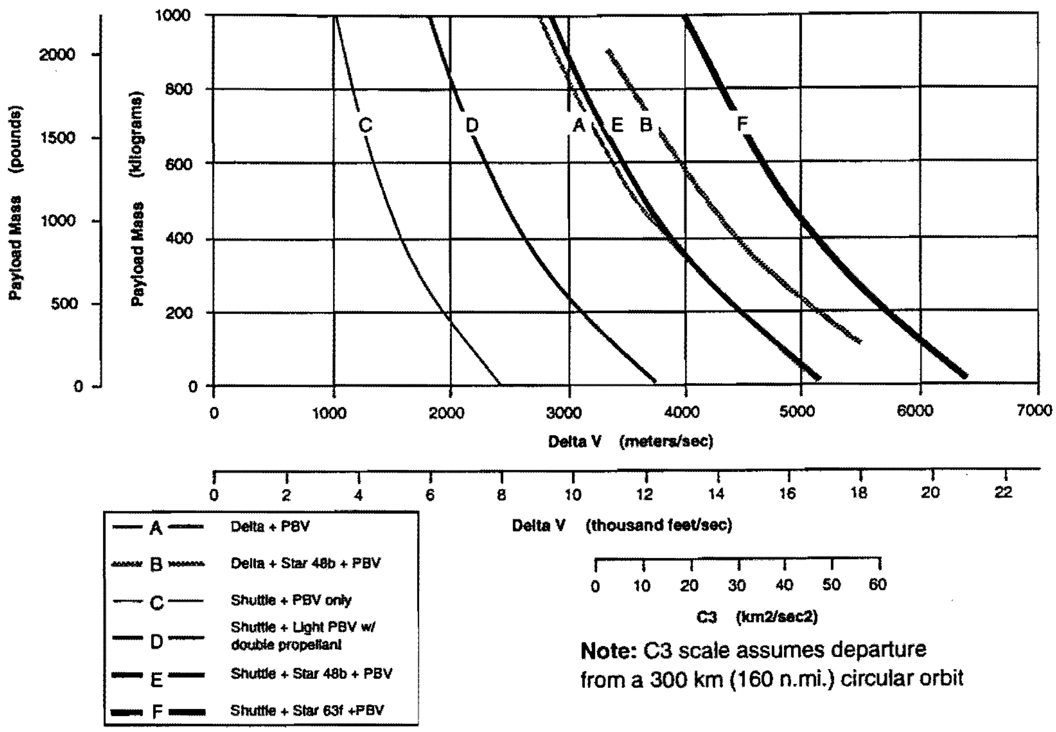

Figure 2 - PBV Performance Capabilities

<u>PBV/Star 48b Booster Missions</u>

The Star 48b is the most likely and easiest solid for use as a PBV booster. This system is typically spin-stabilized using the Star 48b as a kick motor during the injection burn. The PBV spacecraft and motor are placed in the appropriate inertial attitude for the injection burn, spun-up, and released from the launch vehicle, whether it is the Shuttle or the Delta. The configuration on a Delta is the standard Delta 7925 configuration while on the Shuttle a carrier will be needed.

The most likely candidate for a Shuttle carrier is the PAM-D. Typical spacecraft using this carrier in the past were geosynchronous satellites. Integration of with Shuttle has been accomplished numerous times so mission planning, integration, and operations should not present any extraordinary issues. The PBV has already been qualified for Shuttle use. However, the PAM-D carrier represents a payload for which humans are not particularly required. These types of payloads have been groundruled out of the Shuttle manifest since the 1986 stand down. This ground rule must be lifted before the further consideration can be given to Shuttle flights. Assuming the ground rule can be lifted, the experience base for the PAM-D carrier must be resurrected which may present some issues. Further, the remaining carriers have apparently been destroyed which will require rebuilding them from existing plans.

There appears to be adequate clearance inside the PAM-D carrier sunshield after the envelope for the PBV is accommodated. This is one of the issues that must be addressed for each spacecraft. Figure 3 illustrates this envelope within the large PAM carrier. It consists of a cylinder approximately 109 inches diameter by 30 inches high plus an additional 20 inches maximum height in the curved portion of the shield. The Delta configuration also shown in Figure 3 has somewhat less clearance than Shuttle in diameter and considerably more in the vertical. In general though the two are comparable for PBV payload space.

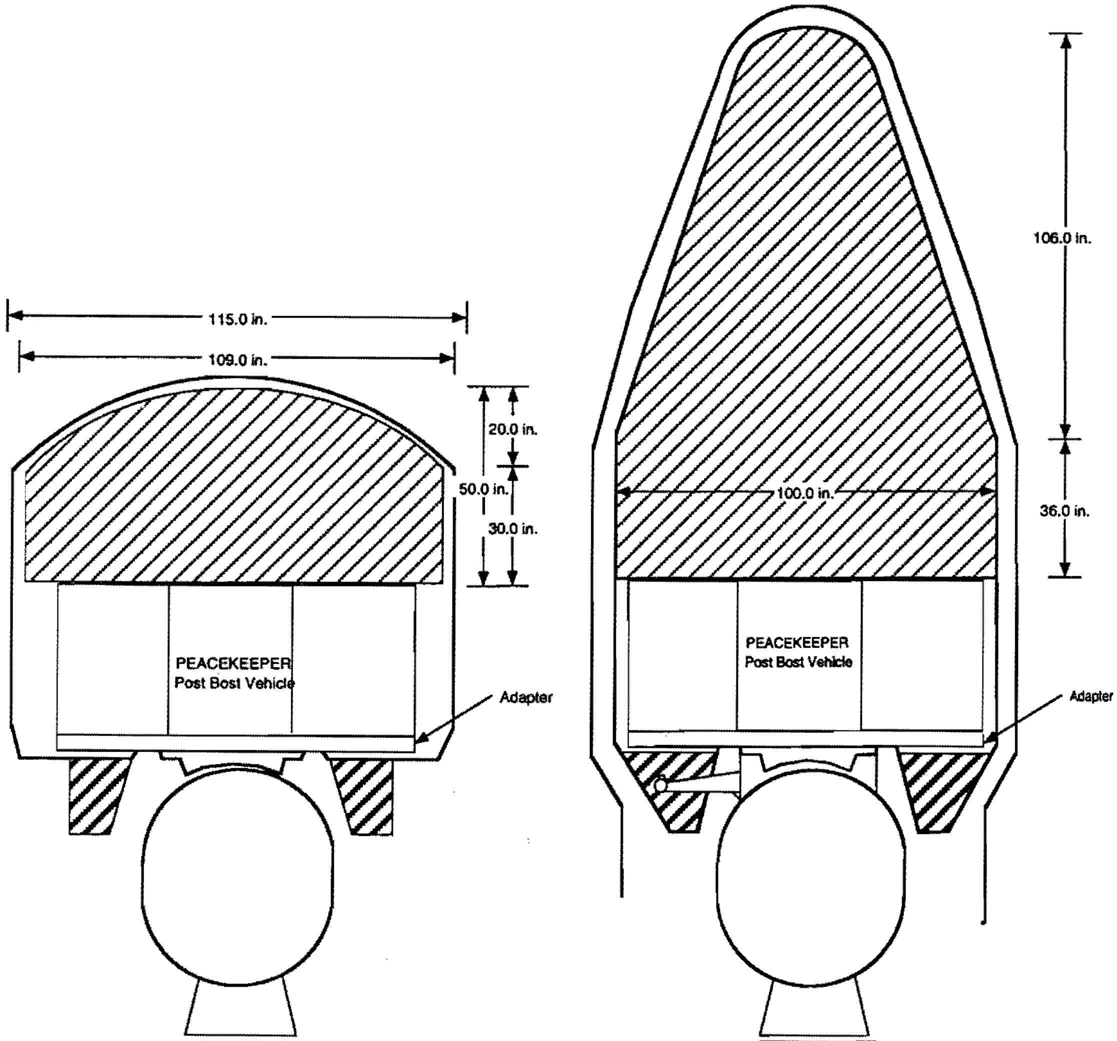

Figure 3 - PBV Spacecraft Envelope on Shuttle PAM-D and Delta

PBV modifications should be minimal. Structural design and component work consists of design of the PBV/Star 48 interface and the PBV/spacecraft interface. Structural analysis will be required for this work and for verification of the Spacecraft/PBV/Star 48/Shuttle configuration. The PBV should perform its maneuvers shortly after Star 48b burnout and the mission therefore is not of long duration. Because the mission is short and the PAM-D carrier contains a sunshield, thermal controls should not be needed and the heaters on the LPG rated PBV may not be needed. Thermal characteristics should be modeled to verify this point. The GN&C system developed for the LPG mission should be appropriate for this application. Understanding of the software and software configuration will require some analysis. Also, if the PBV burn initiation occurs significantly after Star 48 burnout a star tracker along with IMU update software may be needed. Since the PBV application here is of the "fire and forget" character, a communication subsystem should not be needed. The primary battery power system qualified for the LPG mission should also be adequate for this application. A mission by mission verification of this should be done. At this time, there do not appear to be any propulsion system issues.

PBV/Star 63f/Shuttle Booster Missions

In the some cases, the Star 48 does not provide sufficient energy for an interplanetary mission. The Morton Thiokol Star 63f has been identified as a potential solid rocket motor to be coupled with the PBV. No specific carrier for use in the Shuttle has been identified for this combination. A search for a known carrier and Shuttle integration experience is on-going at the time of this writing. Expendable launch vehicle capability with the Star 63f has not been investigated so Shuttle has been assumed as the launch vehicle in these cases.

Since no Shuttle carrier is known to have been flown with the Star 63, some significant mission planning, Shuttle integration, and operations work may therefore be necessary. If a carrier with flight experience is identified the need for planning and integration work may be mitigated somewhat. However, the considerable flight experience of the PAM-D is certainly not available for the Star 63 and integration efforts can be expected to be more involved than for the PAM.

The Spacecraft/PBV/Star 63f configuration will need to be flown in a longitudinal orientation in the Shuttle Payload Bay and will thus be expected to take up a significant fraction of the available length. This will make the available spacecraft envelope more roomy than the PAM-D layout but may also present manifesting limitations. At this writing, Rocketdyne is investigating its use with the Teal-Ruby cradle which is flying with the PBV, in a different orientation, for the LPG mission. The use of this cradle will significantly reduce the qualification requirements below those of a new design.

PBV modification can be expected to be very similar to the modifications for the Star 48 configuration. Structural design work may be more involved if an existing cradle does not prove adequate.

PBV as Spacecraft Bus

The PBV has also been identified as a potential spacecraft bus for mission specific instruments. The mission of the PBV will then be significantly different and the efforts needed to ready it for use will be more involved. The most obvious difference between the original PBV mission and the spacecraft bus mission is the duration. The issues must be addressed on a mission by mission basis but all have a common thread. The LPG configuration should provide a good starting point of departure.

Structural modifications will be similar to the booster configuration which includes interface development and launch environment analysis. If weight considerations require modifications or if instrument integration into the PBV is anticipated, additional design work will be needed. The thermal control system from the LPG will have to be verified for the specific mission but should be adequate. Thermal characteristics should be modeled and power requirements will have to be accommodated.

The GN&C system developed for the LPG mission should be a good point of departure for this application. Hardware reliability for the longer duration mission must be verified. Also, the spacecraft will almost certainly require IMU updates so the addition of a star tracker should be expected. Navigation updates, telemetry, data, and spacecraft commands will require a communications system for the spacecraft bus configuration. This will be a new design as the LPG has no communication system. Also, methods of data collection, storage, and processing which will most certainly be needed for the spacecraft. These needs are beginnings of requirements for a data management system for the spacecraft. Thus, the data needs for housekeeping of the spacecraft and for scientific data collection of the instruments must be examined very closely. It is possible that an integrated avionics package is appropriate for the spacecraft bus application. The avionics for this application should be developed as a system.

Power components qualified for the LPG mission are probably not adequate for this application although mission by mission verification of power requirements should be done. Primary batteries if not appropriate would probably be replaced by secondary batteries and a solar panel recharging system. A mission by mission analysis of the spacecraft power needs, pointing requirements, etc. will indicate whether body mounted arrays are appropriate or deployable arrays are needed. The power system for the spacecraft bus application will almost certainly be very different from the LPG configuration power system.

There are some issues with the propulsion system of the PBV for long duration spacecraft bus application. First, butyl rubber has been identified in the propellant valves and will be incompatible for long duration exposure to propellants. These valves will have to be replaced involving some design, fabrication and qualification testing. Also, the attitude control system presents some issues. First, the attitude control system uses 70 lbf thrusters with a minimum impulse bit of 0.4 lbf-sec. The mission specific pointing requirements may not tolerate such a thruster and some sort of momentum exchange system may need to be added. Also, the control thrusters are apparently canted forward since the PBV's mission required it to deliver then back away from the warheads. Compatibility with the instrument suite must be verified and ensured through design. Finally, the control authority of the thrusters must be established relative to the mission requirements.

The Discovery Program

The Discovery Program is an outgrowth of an effort begun about 2 years ago to develop a program of small planetary missions that would complement larger missions and keep the scientific community involved with a steady stream of new planetary data. While this planning was under way, the Senate Appropriations Committee in April 1992 directed NASA to prepare "a plan to stimulate and develop small planetary or other space science projects, emphasizing those which could be accomplished by the academic or research communities." In addition, more constrained budgets have lead to a call for "faster, better, cheaper" missions.

The Discovery Program is responsive to this environment. The time frame of small Discovery missions is consistent with academic degree programs, which makes these missions an excellent training ground for graduate students and post-doctoral researchers. Because small missions can be conducted relatively quickly and inexpensively, they provide frequent opportunity for access to space. In addition, small missions help sustain a vital scientific community by increasing the available opportunities for direct investigator involvement from just a few projects in a career to many.

A number of missions which are under study for the Discovery in fiscal year 1993. Table 1 shows four of the missions examined in some detail in this study; the MESUR Pathfinder, the Venus Composition Probe, the Earth-Orbital UV Jovian Observer, and the Near Earth Asteroid Rendezvous missions are representative and illustrative of the use of the PBV. Table 2 shows the PBV configuration for some of the other

Table 1 - FY 1993 Discovery Missions Under Study

Mission Title	Description	C3 Range (km^2/sec^2)	S/C Mass (kg)	Dry Mass (kg)	PBV Configuration
Venus Composition Probe	Uses a single probe to measure the venusian atmospheric composition.	6.4 - 14.3	340	N/A	Booster Mission Shuttle/48/PBV Delta/PBV
Near Earth Asteroid Rendezvous	This mission would rendezvous with and study near-Earth asteroids.	11 - 39	837	437	Booster Mission Shuttle/63/PBV
Earth-Orbital UV Jovian Observer	Orbits the L1 Lagrangian point and performs observations of the Jovian system.	ΔV: 3800 m/s	191	N/A	Bus Mission Shuttle/48/PBV Delta/PBV
Mars Environmental Survey (MESUR) Pathfinder	This Mars environmental technology demonstration mission is a precursor to a network of martian environmental stations.	8.7 - 17.5	330	N/A	Booster Mission Shuttle/48/PBV Delta/PBV

Discovery missions under consideration. The information in these tables is understandably very preliminary and some of the mission energy and mass figures have been estimated by the authors. These data are used to develop the PBV configurations needed to perform the mission.

MESUR Pathfinder

The next scientific mission to Mars may be a global network of about 16 small surface landers (the MESUR Network mission). The Network mission vehicles will have a very different, and quite possibly more stressful, landing procedure than the one used by Viking. Therefore, it is important to demonstrate the cruise, entry, descent, and landing functions before the first flight of the MESUR Network landers. This demonstration mission, designated Pathfinder, will send a single aerocraft to Mars in 1996. The objective of Pathfinder is to demonstrate the flight and landing systems required for the MESUR Network mission, while acquiring limited, but important, scientific and exploration data on the Martian surface.

The MESUR Pathfinder can use the Peacekeeper Post Boost Vehicle (PBV) as a trans-Mars injection stage. The energy requirements of this mission require that, for Shuttle launch, the PBV be coupled with a Star 48 solid rocket motor to place it on the required trajectory. If launched on the Delta the Star 48 is not required. This configuration is relatively simple to fly in the PAM-D carrier or in the Delta, and should have plenty of envelope for the MESUR trans-Mars configured spacecraft. Few modifications to the PBV from its Shuttle-qualified Liquid Plume Generator (LPG) configuration are needed.

NEAR

Another Discovery project under study is a Near Earth Asteroid Rendezvous mission. The NEAR project development will begin in Fiscal Year 1996. Development time will be 27 months with a launch in January 1998. The current mission scenario calls for the spacecraft to rendezvous with the asteroid 4660 Nereus and remain in orbit for at least eight months. A backup launch opportunity to the asteroid 3361 Orpheus occurring two months after the nominal launch date provides the mission with additional schedule resilience.

Table 2 - Example Discovery Missions

Mission Title	Description	PBV Configuration
Mercury Polar Flyby	Studies Mercury's polar caps and photographs the planet.	Booster Shuttle/63/PBV Delta/48/PBV
Mercury Orbiter	Remote sensing of Mercury.	Booster Shuttle/63/PBV
Venus Multiprobe Mission	Uses 14 probes to study the venusian atmosphere.	Booster Shuttle/63/PBV
Near Earth Asteroid Returned Sample (NEARS)	Returns samples from a near-Earth asteroid.	Booster Shuttle/63/PBV
Mars Upper Atmosphere Dynamics, Energetics and Evolution (MAUDEE)	This mission studies the martian atmosphere as its name implies.	Booster Shuttle/63/PBV
Small Missions to Asteroids and Comets (SMACS)	Sends small scientific spacecraft to several asteroids and comets.	Booster Shuttle/63/PBV Delta/48b/PBV
Comet Nucleus Tour (CONTOUR)	Rendezvous with, and orbits a comet nucleus.	Booster Shuttle/63/PBV
Cometary Coma Chemical Composition (C4) Mission	Rendezvous with a comet nucleus and performs chemical analysis.	Booster Shuttle/63/PBV

Carrying between three and five instruments, NEAR will assess the asteroid's mass, size, density, and spin rate, map its surface topography and composition, determine it internal properties, and study its interaction with the interplanetary environment.

The NEAR mission can use the PBV as a booster stage. It has a high energy requirement and, to be launched from the Shuttle, appears to require a Star 63f solid rocket motor along with the PBV. The Delta with a Star 48 appears to be inadequate for this mission. The Shuttle or some expendable launch vehicle larger than the Delta will be required. The PBV itself should require relatively few changes from its Shuttle-qualified Liquid Plume Generator configuration.

Venus Composition Probe

This mission builds on the knowledge gained from the Pioneer Venus mission flown by the U.S. in 1978 and the Venera and Vega missions flown by the Soviet Union during the '70s and '80s. The entry probe design for this mission is similar to the Large Probe used for the Pioneer Venus mission. The mission scenario for this proposed mission calls for the probe to be launched on a direct trajectory to Venus and enter the atmosphere on the daylight side of the planet. Measurements by one of the four instruments will begin during hypersonic flight at an altitude of 75 kilometers. The entry shield will be released and a parachute deployed at an altitude of 65 kilometers. At an altitude of 42 kilometers, the parachute and two instruments used to investigate the upper atmosphere will be jettisoned and the pressure vessel will freefall to the surface. Due to the very high atmospheric density, the impact speed of the pressure vessel is expected to be slow enough for this component to survive and the instruments to take additional measurements.

The Venus Composition Probe mission can use the Peacekeeper Post Boost Vehicle as a trans-Venus injection stage. The energy requirements of this mission are such that, for Shuttle launch, the PBV be coupled with a Star 48b solid rocket motor to place it on the required trajectory. If launched on the Delta the Star 48 is not required. This configuration is relatively simple to fly in the PAM-D carrier or in the Delta shroud and should have plenty of envelope for the trans-Venus configured spacecraft. Few modifications to the PBV from its Shuttle-qualified Liquid Plume Generator (LPG) configuration are needed.

This mission may also use the PBV in more than a booster role. It may keep the PBV attached to the spacecraft to provide final pointing to the probe. This configuration will involve significant departures from the LPG configuration. The heaters will be kept but the avionics and power systems will probably need revision. The avionics may need to be completely changed since the spacecraft will be subject to IMU drift, may need navigation updates, and will probably require data handling capabilities. Some propulsion system changes may also be needed to accommodate the missions duration.

Earth-Orbital UV Jovian Observer

The primary science objective of this mission is to study both Jupiter and the Io plasma torus that surrounds Jupiter in the ultraviolet and extreme ultraviolet portions of the spectrum. The data to make these studies will be collected by a 60 centimeter diameter telescope to which are attached a UV spectrometer and an EUV imaging device. The mission scenario places the spacecraft carrying this telescope at the Lagrangian point between the Earth and moon. From this point, the spacecraft will be able to view Jupiter on a continuous basis for eight months of the year. Should the spacecraft survive past the nominal one year mission duration, many other solar system targets could be observed (e.g., comets). The two instruments, the telescope optics and the spacecraft systems are all based on designs used on previous NASA and DoD spacecraft.

This mission can use the PBV as a spacecraft bus as well as a booster. The PBV would require a Star 48b to provide the appropriate initial energy from the Shuttle Payload Bay. This Star 48 configuration is relatively simple to fly in the PAM-D carrier and should have plenty of envelope for the spacecraft. From the Delta II expendable launch vehicle, the PBV alone is sufficient.

The spacecraft bus configuration involves significant departures from the existing Liquid Plume Generator (LPG) configuration. The propellant heaters will be kept but the avionics and power systems will probably need to be changed. The avionics may need to be completely changed since the spacecraft will be subject to IMU drift and may need navigation updates. The spacecraft will also require data handling and communications capabilities which it does not currently have. Some main propulsion system changes may also be needed to accommodate the missions duration and some attitude control modifications may need to be made to provide adequate pointing and Lagrangian Point orbiting.

Conclusions and Recommendations

The PBV is a versatile spacecraft requiring some technical work to bring it to flight status in a new mission but costing far less than an equivalently capable new design for a three-axis stabilized vehicle. In the course of developing concepts and designs, a number of considerations enter into the choice of launch vehicles, injection stages, and spacecraft bus systems. Many of these consideration are peculiar to a specific mission and cannot be examined in a study of this scope. However, based on this brief assessment of the PBV, it appears to be worthy of further consideration in the Discovery Program as a booster stage or a spacecraft bus. Indeed, this stage is worthy of consideration for any number of small civil space missions. Use of the PBV should be considered as an option for a booster or a spacecraft bus for small interplanetary or near-Earth missions.

More information on specific missions is needed to further assess the use of the PBV with missions of the Discovery class. The needs of the mission for propulsive energy, guidance, power, communications, etc. all play a role in determining what will have to be done to bring the PBV to flight status. Mission duration will define whether thermal control is needed or whether any material reliability problems exist. These types of information are developed as the progress is made in definition of the mission. As more development takes place on the Discovery Program, further examination of the use of the PBV should be pursued.