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Shuttle Performance Enhancements Using an OMS Payload Bay Kit

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SHUTTLE PERFORMANCE ENHANCEMENTS USING AN OMS PAYLOAD BAY KIT

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Abstract

With the use of orbital maneuvering system payload bay kits, the operational envelope of the Shuttle can be greatly increased. An OMS PBK is a means of carrying additional OMS propellant in a Space Transportation System Shuttle Orbiter. While a variety of configurations have been proposed for OMS PBK's, the essence of all of these concepts is to provide additional OMS propellant tank volume on a payload bay pallet. An attractive feature of OMS PBK's is that the penalties associated with the additional tankage provided by an OMS PBK would only be incurred on missions requiring greater orbital maneuvering capability than is available from the Orbiter OMS pod tanks.

The Systems Engineering Division of the National Aeronautics and Space Administration - Johnson Space Center has completed a study which assesses Shuttle performance enhancements using OMS PBK's. The study focused on the use of an OMS PBK designed to use OMS tanks identical to those currently used in the Orbiter OMS pods. The candidate OMS PBK design allows the OMS PBK to be outfitted with one to three pairs of OMS tanks which would provide approximately 500 feet per second of additional orbital velocity capability to the Orbiter per tank pair.

Study results include payload deployment capability and payload servicing/reboost capability augmentation presented in terms of payload mass, maximum deployment altitudes and initial retrieval and final deployment altitudes. The deployment, servicing and reboost requirements of two specific payloads, the Hubble Space Telescope and the Advanced X-ray and Astrophysics Facility, are singled out to show the benefits an OMS PBK can provide for these missions. OMS PBK's can provide the required capability enhancement necessary to support deployment of payloads which require operational altitudes greater than 325 nautical miles. For example, when used in conjunction with advanced solid rocket motors, an Orbiter and a 500 foot-per-second OMS PBK can deploy a 20,000 pound payload to 450 nautical miles or retrieve a 40,000 pound payload at 250 nautical miles and reboost it to 400 nautical miles. While more work is necessary to fully develop a usable OMS PBK, OMS PBK's should be given consideration for use in meeting the needs of current and future high altitude STS missions.

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Nomenclature

ASE	Airborne Support Equipment
ASRM	Advanced Solid Rocket Motor
ATP	Authority-To-Proceed
AXAF	Advanced X-ray and Astrophysics Facility
c.g.	Center-of-gravity
fsp	Feet per second
HST	Hubble Space Telescope
lbm	pounds-mass
NASA	National Aeronautics and Space Administration
n.mi.	Nautical miles
OMS	Orbital Maneuvering System
PMM	Planned maintenance mission
PBK	Payload Bay Kit
RCS	Reaction Control System
RSRM	Redesigned Solid Rocket Motor
STS	Space Transportation System

Introduction

OMS PBK's provide a cost effective solution to extending the STS Shuttle Orbiter payload deployment, servicing and retrieval capabilities up to 500 n.mi. orbit altitude. The OMS PBK's would provide payloads with: greater deployment altitudes;

greater reboost altitudes; increased payload servicing opportunities; and increased on-orbit flexibility.

An OMS PBK is a means of carrying additional OMS propellant in a STS Shuttle Orbiter. While a variety of configurations have been proposed for OMS PBK's, the essence of all of these concepts is to provide additional OMS propellant tank volume on a payload bay pallet. An attractive feature of OMS PBK's is that the penalties associated with the additional tankage provided by an OMS PBK would only be incurred on missions requiring greater orbital maneuvering capability than is available from the Orbiter OMS pod tanks.

OMS PBK Description

The OMS PBK originally proposed by the McDonnell Douglas Corporation was selected as the baseline OMS PBK. The McDonnell Douglas OMS PBK utilizes OMS tanks as designed for the Orbiter OMS pods. One fuel tank and one oxidizer tank along with a helium pressurization system comprises a tank set which is equal to adding an additional OMS pod to the Orbiter. Each tank set provides a velocity increment of approximately 500 fsp of additional performance to the Orbiter. The McDonnell Douglas design is a modular system allowing up to three tank sets to be inserted in the payload bay pallet structure (Figure 1).

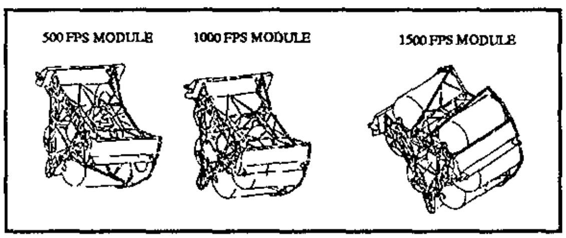

Figure 1. Payload Bay Kit General Arrangement

OMS PBK Mass Properties

Estimated OMS PBK weights used in this study are presented in Table 1. The inert weight of the 500 fps PBK is 3,778 lbm. This inert weight decreases the payload capability by an equal amount for Shuttle deployment missions. However, the remaining capability appears sufficient for current high altitude deployment missions. Weights for a 1,000 fps and a 1,500 fps OMS PBK are also presented.

OMS PBK Programmatics

Consultation with McDonnell Douglas Corporation in St. Louis, Missouri revealed that the manufacturing facilities for OMS PBK tanks are no longer in operation. The critical lead item for the OMS PBK is the OMS tank, requiring a 3 year lead time. Three tank shells are currently in storage and could be used for this type of OMS PBK. If it was determined that a 1,000 or a 1,500 fps OMS PBK were necessary, additional tanks would be required. It may be possible to "borrow" one or more tanks from the NASA spares inventory and replace them with new tanks once new tanks could be manufactured. It is estimated that the development of the OMS PBK would require 36 months. This estimate includes 6 months for restaffing critical personnel and assumes that tank shells are available at ATP.

Table 1. OMS PBK Masses

	500 FPS PBK	1000 FPS PBK	1500 FPS PBK
STRUCTURAL WEIGHT	2,978 lbms	3,955	5,257
ATTACHMENT FITTINGS	400	400	400
TRAPPED PROPELLANT	400	800	1,200
USABLE PROPELLANT	12,132	24,264	36,396
TOTAL PROPELLANT	12,532	25,064	37,596
TOTAL PBK WEIGHT (AT LAUNCH)	15,910	29,419	43,253

Payload Deployment/Servicing Capability Enhancements

OMS PBK deployment capability enhancements for the Shuttle using RSRM and ASRM were calculated for 500, 1,000 and 1,500 fps PBK's (Figure 2). Four current or near term payloads are depicted in the charts to show typical high altitude deployment requirements.

Table 2 shows candidate payloads with weights and desired deployment altitudes. The STS/RSRM is lift critical for the AXAF deployment. This is to say that the STS using RSRM's is not capable of reaching the desired deployment altitude with a payload having the mass of the AXAF. OMS PBK's wound not help to capture this mission. The STS/RSRM with a 500 fps OMS PBK will meet remaining projected deployment requirements. The STS/ASRM with a 500 fps OMS PBK satisfies

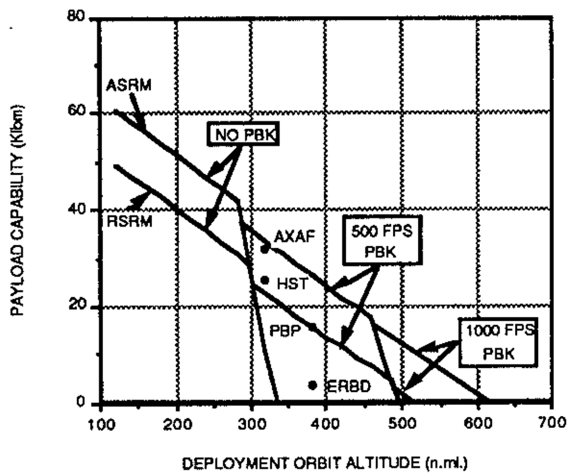

Figure 2. Shuttle Deployment Capability Enhancements Using OMS PBK's

projected payload deployment requirements. There is little benefit to be realized from a 1,000 fps OMS PBK for deployment missions. There are currently no payload in the weight and altitude deployment range that would require the use of the 1,000 fps OMS PBK. The 1,500 fps OMS PBK provides no capability extension for deployment missions.

Table 2. Candidate Payloads for STS/OMS PBK

PAYLOAD	WEIGHT (lbs.)	DESIRED ALTITUDE (n.mi.)
ADVANCED X-RAY ASTROPHYSICS FACILITY (AXAF)	32,800	320
HUBBLE SPACE TELESCOPE (HST)	25,022	320
PRODUCTION BIO-PROCESSION PRODUCTION (PBP)	16,535	380
EXO- AND RADIATION BIOLOGY DEVELOPMENT (ERBD)	2,865	380

Payload Reboost Capability Enhancements

OMS PBK servicing and reboost capability enhancements were studied next. A broad range of payload weights were used to see the effect of payload mass on total reboost capability. There boost scenario envisioned for payloads in this study called for the Orbiter to rendezvous with the payload at some initial altitude and then reboost the payload to the highest possible altitude from which return to Earth was still possible for the Orbiter without the payload attached. Figures 3 and 4 show STS/RSRM reboost capability for a 10,000 lbm and a 40,000 lbm payload. It should be noted that on the 1,000 fps and the 1,500 fps OMS PBK curves, the slope of the curves change to or are always a shallower slope than the NO PBK or 500 fps PBK curves. This is due to the fact that the 1,000 fps and the 1,500 fps OMS PBK's are at some point being flown in an off-loaded condition. Due to lift limitations of the STS/RSRM combination, OMS propellant was off-loaded from the OMS PBK in order for the Orbiter to reach the rendezvous altitude. The break point on the curves is the point at which the PBK goes from a full propellant state to an off-loaded state.

The 500 fps OMS PBK yields a 100 n.mi. increase in

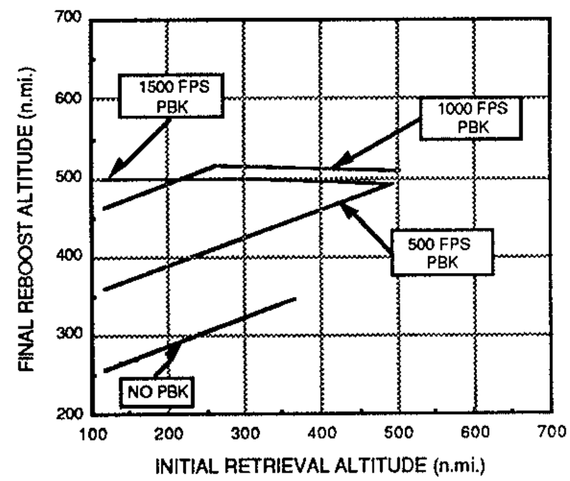

Figure 3. STS/RSRM Reboost Capability For A 10,000 lbm Payload

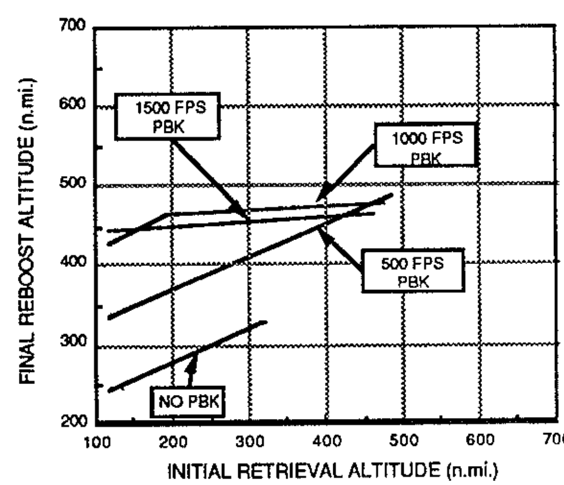

Figure 4. STS/RSRM Reboost Capability For A 40,000 lbm Payload

reboost altitude when compared to the NO PBK case. The 1,000 fps OMS PBK yields a 200 n.mi. reboost altitude increase initially but diminishes to match the 500 fps PBK as more OMS propellant is off-loaded. The 1,500 fps OMS PBK is of little value for reboosting payloads with the STS/RSRM vehicle because it must always be flown in an off-loaded state regardless of the rendezvous altitude.

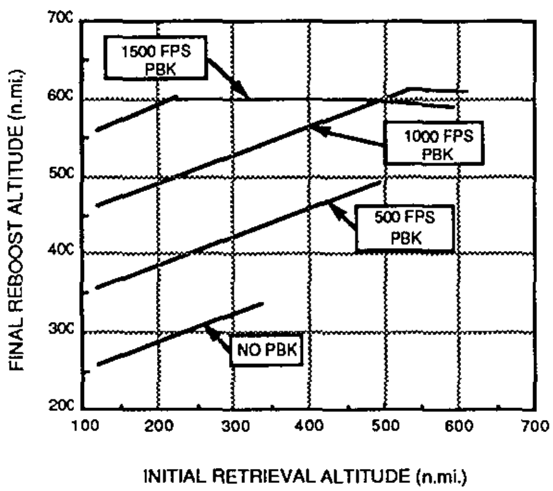

Figure 5. STS/ASRM Reboost Capability For A 10,000 lbm Payload.

Figures 5 and 6 show the enhancement capabilities if the ASRM's are used along with OMS PBK's. The STS with ASRM's maximizes the benefit of the 500 fps and 1,000 fps OMS PBK's. A 1,000 fps OMS PBK yields a maximum of 200 n.mi. of additional reboost altitude capability. The 1,500 fps OMS PBK

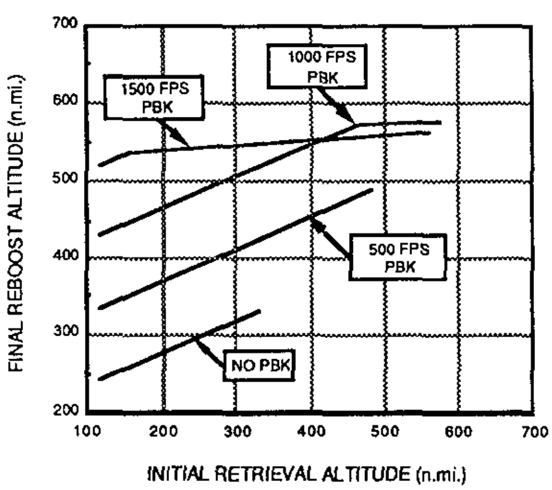

Figure 6. STS/ASRM Reboost Capability For A 40,000 lbm Payload

shows some benefit at the lower rendezvous altitudes but the need for such a capability has yet to be matched with any requirements.

Servicing & Reboost Capability For The Hubble Space Telescope

The Hubble Space Telescope has been deployed and will need regular maintenance. Figures 7 and 8 show the STS/RSRM reboost and servicing capability using OMS PBK's and the orbital maneuvering engines and the reaction control system for servicing and reboosting the HST. The orbital maneuvering engines provide a higher impulse and higher thrust than the reaction control engines and therefore can reboost the HST to slightly higher final altitudes. However, due to acceleration limits on the HST while attached to the Orbiter in the payload bay, the reaction control system will be used for reboosting the HST after servicing is complete. The planned maintenance

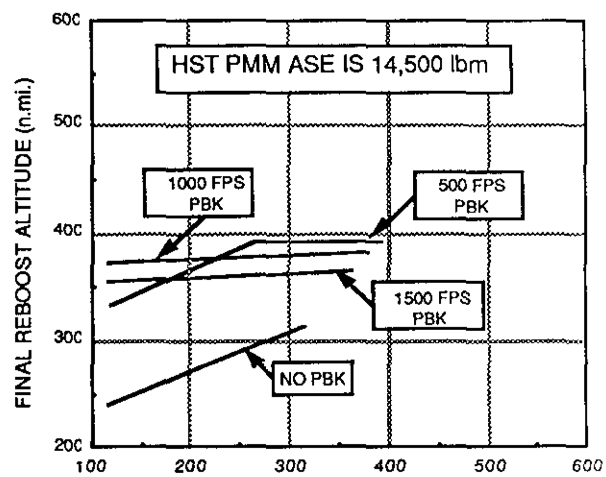

Figure 7. STS/RSRM HST Servicing And Reboost Capability Using OMS Engines

mission ASE accounts for 14,500 lbm. of the payload capability of the STS on every HST maintenance mission.

The current plan for HST maintenance is to use the STS/RSRM vehicle. This is depicted in the graphs on Figure 7 as the NO PBK curve. As can be seen, in order to have the capability to reboost the HST to it's initial deployment altitude of 320 n.mi., the Shuttle must rendezvous with the HST before the HST falls below approximately 300 n.mi. altitude. This scenario leaves little room for contingencies. Reboosting the HST to lower altitudes than the

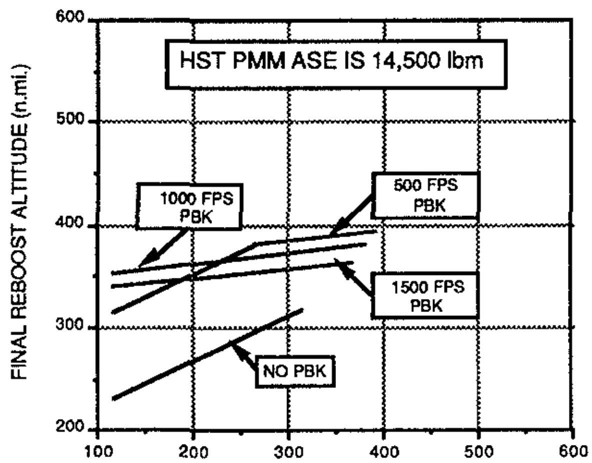

Figure 8. STS/RSRM HST Servicing And Reboost Capability Using RCS Engines

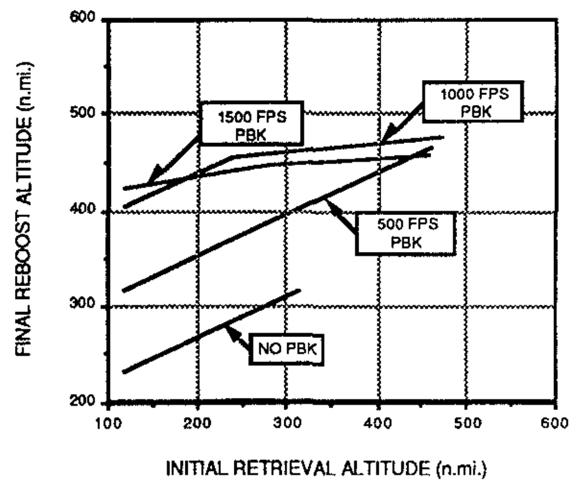

Figure 10. STS/ASRM HST Servicing And Reboost Capability Using RCS Engines

initial deployment altitude opens the possibility of requiring more and frequent missions simply to reboost the HST to keep it at optimal operating altitudes. As can be seen on Figure 7, augmenting the STS/RSRM vehicle with a 500 fps OMS PBK would enable the Orbiter to service and reboost the HST to 320 n.mi. and beyond if desired.

Figures 9 and 10 show HST PMM using the STS/ASRM and OMS PBK's. Here, as in the case with RSRM's and NO PBK's, the Orbiter is limited in it ability to reboost the HST after servicing unless it is augmented with a 500 fps OMS PBK.

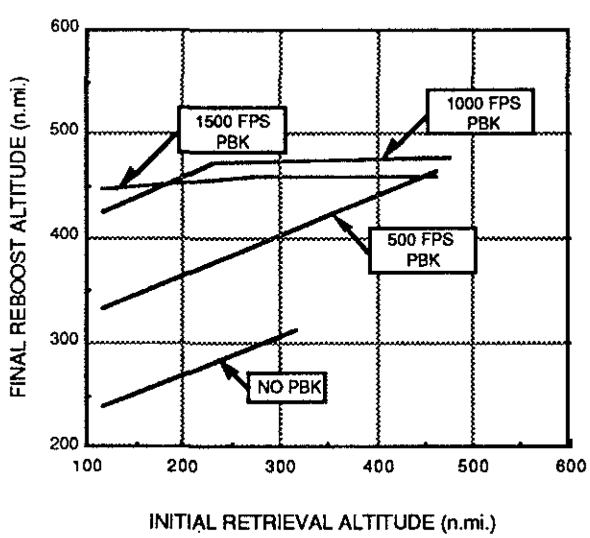

Figure 9. STS/ASRM HST Servicing and Reboost Capability Using OMS Engines

Issues & Concerns

Several issues are still open concerning the use of OMS PBK's:

Identification of the Orbiter c.g. location for nominal end of mission and aborts has been identified and all are within the current c.g. envelope or within the contingency abort c.g. envelope. However, the OMS PBK structure is not designed to land with the tanks full as might be required in an abort. Resizing the structure and adding the additional weight to the OMS PBK must be done before an understanding of this issue is complete.

ASRM lift capability augmentation was estimated to be 12,000 lbm. This is the current goal of the ASRM program but some estimates of the true capability to be realized from the program have the been as low as 8,000 lbm. While a reduction of 4,000 lbm will affect the final deployment and reboost altitudes, the trends evident in the ASRM charts and the conclusions drawn from these trends will still hold true. Additional lift capability will help OMS PBK's provide more on-orbit performance to the Orbiter by enabling the Orbiter to carry more payload thus providing a PBK the opportunity to carry more propellant.

Operational implementation of OMS PBK's and OMS pod burn scheduling was not taken into account when calculating final altitudes. It is the feeling of the Johnson Space Center and McDonnell Douglas propulsion systems communities that switch-on-the-fly capability can be made available for the OMS-PBK-to-OMS-pod plumbing setup. Software and gaging for this type of system will need refinement and will cost additional development and testing dollars.

The OMS PBK's depicted in this study requires approximately 10 feet of length in the aft payload bay. Smaller options exist but will require new tank designs and additional development costs.

Conclusions

Hubble Space Telescope servicing and reboost missions can be accomplished with today's current STS but mission performance is marginal. A maximum reboost altitude of 320 n.mi. is achievable assuming that the Orbiter rendezvous with the HST at an altitude no lower than 300 n.mi. Additional STS flights may be required to maintain an operational altitude should the HST be allowed to pass below the 300 n.mi. altitude. The Advanced X-ray and Astrophysics Facility deploy, reboost and servicing missions can be accomplished with ASRM augmentation but mission performance is marginal.

Orbital maneuvering system payload bay kits can provide significant performance improvements for the STS. To insure that the HST and AXAF missions can be serviced and reach there desired deployment altitudes, OMS PBK's are necessary. OMS PBK's are required to support deployment, reboost and servicing of payloads which require altitudes greater than 325 n.mi.

A 500 or 1,000 fps OMS PBK can provide added STS performance when needed while not penalizing the missions which can be met with the current STS. While more work is necessary to fully develop a usable OMS PBK, OMS PBK's should be given serious attention for use in meeting the needs of current and future high altitude STS missions.

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