Multiple Payload Ejector for Education, Science and Technology Payloads

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ABSTRACT: The education and small research payloads community no longer has a means of being regularly manifested onto Hitchhiker and Gas carriers on Space Shuttle flights. Therefore, many small payloads do not have a launch opportunity, or await flights as secondary payloads on ELV missions, as the ELV primary payload manifest, secondary payload volume and mass allows. This has resulted in a backlog of small payloads, and an inability for the small payloads community to achieve routine access to orbit. This paper overviews the NASA-Goddard Wallops Flight Facility effort, funded by SOMD's KSC Launch Services Program, to leverage its competencies in small payloads, sounding rockets and range services to develop a low cost, multiple payload ejector (MPE) carrier for small orbital experiments and other users. The goal of the MPE is to provide a low-cost carrier intended primarily for educational flight research experiments. MPE can also be used by academia and industry for Science, Exploration and technology payloads.

The MPE carrier will take advantage of a DARPA/ NASA SOMD agreement allowing NASA to fly MPE on a DARPA Falcon demo launch vehicle from Wallops Island, Virginia. The Falcon launch vehicle and MPE payload carrier are complimentary in their goals of providing low cost, responsive access to space. Therefore, MPE is planning on using Falcon to provide the small payloads community with a ride to orbit. MPE is being developed and readied for flight within 18 months by a design team of Swales and NASA engineers. Currently, MPE is preparing for Critical Design Review in Fall 2005, payloads are being manifested by NASA on the first mission, and the carrier will be ready for flight on the first Falcon demo vehicle of opportunity, as early as Summer 2006. It is the long term goal of the design team to develop an MPE that will succeed in paving the way for a sustained NASA program to support education, technology and Exploration payloads with regular flight opportunities.

PURPOSE

The purpose of the Multiple Payload Ejector (MPE) is to provide a low-cost, lightweight carrier to be used for educational, scientific and Exploration Program technology experiments. The MPE carrier will be designed to accommodate multiple lightweight primary, secondary and tertiary payload configurations. Similarly, one purpose of the Falcon program is to provide a launch system that responsively provides affordable flight opportunities for small payloads. The MPE is being developed for \$2M on an 18 month schedule, and the project has a goal of designing an MPE carrier that meets a \$1M/unit recurring cost target. The development effort includes design, fabrication, and testing of the first MPE flight article, and placing it in a configuration that is ready to begin payload integration.

SYSTEM DESCRIPTION

The MPE is being designed by a team of NASA and Swales (Engineering Services Contract) engineers at the Wallops Flight Facility. The MPE is a modular structure that supports small individual payloads and produces the required number of individual separation signals and ejections not provided by the launch vehicle (LV). The MPE is configurable, with as many as three segments, each with two secondary spacecraft, and a primary spacecraft mounted on top. MPE can take advantage of larger envelopes and orbital insertion mass by being configured into a stack of three segments, or by flying fewer segments with a larger primary payload. MPE can also accommodate a smaller envelope or orbital insertion mass by being as small as a single segment, and flying smaller spacecraft. Many of the MPE configurations fit in an envelope and orbital insertion mass that are consistent with the DARPA Falcon demonstration launch objectives of 40-inch diameter and 60-inch height. Figure 1 shows three sample configurations of the MPE.

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Figure 1. Several Representative MPE Configurations

The MPE will perform the function of generating separation signals to each of the separation systems for attached payloads, using a pre-programmed timer. Flight analysis will be performed to verify timing and ejection speeds to minimize probability of any MPE or payload recontact. This event is initiated by the LV after orbital insertion has been attained. Prior to ascent, some services are provided by the LV, pad and MPE. After ascent, the only services provided by MPE will be confirmation of separation of primary and secondary payloads. MPE will utilize a WFF-developed low cost TDRSS transmitter (LCT2) and instrumentation to verify successful separation of payloads. Instrumentation may include payload separation breakwire confirmation, bus voltages and currents, and magnetometer data.

PAYLOAD STATIC ENVELOPE FOR MINIMUM DARPA REQUIREMENTS

The segments have been sized to maximize use of the DARPA Falcon static payload volume, being used as a minimum payload volume by Falcon contractors. Many configurations of the MPE structure and all attached spacecraft can fit within this DARPA minimum requirement of 40-inch diameter by 60-inch tall envelope. If larger volumes are made available by the Falcon launch vehicles, MPE can take advantage of this with its modular, stackable features, including external mounting of tertiary payloads on the 2nd segment. The flight manifest can either maximize volume for the Primary Payload, or not, as shown in Figure 2.



Figure 2. Primary Payload Dimensions for Minimum DARPA Envelope

The full 40-inch diameter of the DARPA minimum required static envelope is available to the primary payload. However, manifest options make only either 34 inches of height or 12 inches of height available between the top of the envelope and the top mating surface of the 15" Motorized Lightband separation interface. Additional volume below the top-mating

surface of the 15" Motorized Lightband may be available and can be negotiated. The spacecraft mating plane to the Lightband is considered to be the interface plane between the spacecraft and the MPE. The DARPA envelope also drove the sizing of each segment and secondary payload volume, shown in Figure 3.



Figure 3. Secondary Payload Dimensions for Minimum DARPA Envelope

POTENTIAL MPE MANIFEST OPTIONS

MPE can accommodate between three and 30 small payloads, depending on launch vehicle performance and static envelope. Assuming the performance and volume is typical of a Space-X Falcon 1 commercial launcher or Minotaur I class vehicle, any of the manifest options shown in Table 1 would be possible. Options constrained by minimum DARPA requirements are indicated.

	Number of Segments						
	1	1	2	2	2	3	3
Fits Minimum DARPA							
Envelope?	Y	Y	Y	Y	N	N	N
Use a secondary slot							
for 12 Cubesats*?	N	Y	N	Y	N	N	Y
Primary	1	1	1	1	1	1	1
Secondary	2	1	4	3	4	6	5
Tertiary (Cubesat*)	0	12	0	12	12	12	24
Total Spacecraft	3	14	5	16	17	19	30

 Table 1. Payload Manifest Options for MPE

* 3 Cubesats packaged into one P-Pod

DESIRED ORBIT AND PERFORMANCE

MPE desires orbital altitudes in excess of the DARPAindicated minimum of 100 nautical miles. Maximum feasible altitudes are being requested from the LV provider to achieve useful orbit life for the ejected payloads. As a baseline, the MPE team is requesting a minimum acceptable altitude of 190 nautical miles, which flight analysis has shown to provide 300 days on-orbit during solar minimum cycles, and 60 days onorbit during solar maximum cycles. The requested orbital inclination for the demo mission is 53 deg, plotted in Figure 4. Flight analysis has shown that this optimizes launch head and downrange range safety, accommodates vehicle tracking, and maximizes ground station overflight opportunities for the Starshine 4/5 candidate payload.



Figure 4. 53 degree Orbit Accommodates Payloads, Launch Vehicle and Range Safety Requirements

Launch vehicle performance capability required to carry at least a 2-segment MPE stack is requested from Falcon, in order to demonstrate the multiple segment features and provide a suitable number of demo launch payload opportunities to customers. MPE has mass estimates which map to three of the configurations. Configuration 1 is the stack of one MPE segment with a total launch mass of ~450 lbs. Configuration 2 is the stack of two MPE segments with a total launch mass of ~700 lbs. Configuration 3 consists of 3 MPE segments with a total launch mass of ~1100 lbs.

DESCRIPTION OF PAYLOAD CLASSES

MPE can accommodate multiple payload classes, ranging from over 400 pounds (ESPA class) to under 10 pounds.

The designation of primary payload is given by the manifesting organization and notionally indicates greater priority, privileges, or services over the other payloads manifested. The top payload position of the MPE is designated as a primary payload "slot". However, the primary payload slot can be given to a secondary for other purposes, such as simply greater volume, without also passing along the priority, privileges and services that would accompany the designation of primary payload. The additional designation as primary payload entitles that payload organization to have greater input toward final orbit, ejection options, cleanliness requirements, and limiting accelerations during system-level vibration (suitable analysis or previous vibration tests would be required). The primary payload envelope and mass can be significantly larger than the secondary payloads.

A secondary payload may be manifested in the primary payload "slot" without being given the additional designation. A secondary payload receives specific services, such as battery charge, but perhaps lacks significant input towards the final orbit, ejection options, cleanliness, and system-level vibration levels.

A tertiary payload lacks an electrical interface, verification of separation, and has potentially no input toward final orbit, ejection options, cleanliness requirements, and integration activities. Additionally, the volume and mass of a tertiary payload is significantly smaller than secondaries and the primary.

Designation as primary or secondary is assigned by the manifesting organization, which is currently NASA Headquarters. For the purposes of NASA Headquarters, no distinction will likely be made between secondary and tertiary payloads.

For the initial demo mission, Citizen Explorer has been identified as a primary payload candidate, Starshine 4/5 as a secondary payload candidate, and Cubesats, flown in Cal Poly P-Pods, as tertiaries. These payloads are shown in Figure 5.



Citizen Explorer

Starshine 4/5

P-Pod

Figure 5. Candidate Payloads for MPE Demo Flight

DESCRIPTION OF MPE SERVICES

The following are services that MPE plans to provide to the payloads.

Payload Battery Charging

MPE will provide battery charging to primary and secondary payloads, while payloads are integrated to

the MPE, as well as on-pad battery charging. Battery charging is limited to battery trickle and top-off activities and will be current-limited. This battery charging service will be provided within the confines of LV activities, and will therefore be terminated per LV request at any time. Battery charge will cease prior to LV fueling, currently planned for L-8 hours. Battery charge hardware is designed as a GSE service and is supplied by the MPE.

Separation System Accommodation

MPE accommodates a 15" motorized Lightband separation system, shown in Figure 6, for separation of primary and secondary payloads.



Figure 6. 15 in. Lightband Separation Interface for Primary and Secondary Payloads

The top plate of the MPE structure accommodates a 15" Motorized Lightband from Planetary Systems. The ejection of the primary payload from the MPE is in the MPE +X direction (presumed launch vehicle thrust axis with positive towards nose). A Lightband separation interface for a typical segment with secondary payloads was depicted previously in Figure 3.

If the payload requires a different separation system, then accommodation may or may not be possible to the MPE, depending on impacts to the design. Additional costs might be incurred for different separation devices. MPE takes the responsibility to re-route the single LV to MPE separation signal and multiplex it to multiple separation systems. The 15" Lightband has a 15 pin connector that will be used for payload launch inhibit, a path for MPE-Payload breakwire confirmation, and a path for GSE battery trickle charge.

Tertiary Accommodations

CubeSats residing in Cal Poly P-Pods (Figure 5) will be accommodated where possible. Three CubeSats fit in each P-Pod ejector. The P-Pods can be fit on the exterior of the 2nd segment, if the LV has payload diameters exceeding 40 in., or they can be fit in a cluster of four within the volume of a secondary payload slot. External mount is preferred, for secondary payload customer manifest reasons.

Payload Separation Events

Separation according to a pre-determined schedule of duration up to one orbit after initial LV-MPE separation signal receipt. Note that the LV may choose for orbital insertion reasons that the sending of the initial LV-MPE separation signal may occur some time after reaching the orbital environment. The entire mission of the MPE is scoped at less than one orbit in duration after reaching orbital altitudes, which should accommodate safe separation timing of all payloads. An MPEprovided telemetry system will confirm payload separation of the MPE breakwire through monitoring of breakwires. Voltages, currents, and magnetometer readings will also be monitored and telemetered to ground via TDRSS, using the LCT2 transmitter.

Thermal Environment through First Orbit Completion

Thermal environments on the carrier will be controlled passively through planning of mission sequences and timelines, and surface optical treatments of MPE components. The MPE will manage payload thermal environments to space industry acceptable levels. These environments will be presented in the MPE Payload ICD.

Provision of Cleanroom I&T Facilities at WFF

MPE will have available for Payload teams 100K class facilities for integration and test (I&T) to MPE. These facilities are expressly for payload-to-MPE integration activities.

Safety Documentation Interface

MPE will act as interface for Payload teams to the ground and flight safety organizations.

Control of MPE surfaces and components to meet < 1% TML and < 0.1% CVCM

MPE design and integration will meet cleanliness requirements of most payloads.

MPE OPERATIONS CONCEPT

MPE Pre-Integration Flow

This flow diagram shows the MPE nominal preintegration sequences, and MPE assumptions of data delivery to and from LV provider. The duration of events depicted in Figure 7 encompasses approximately three months, can occur prior to arrival of LV and LV staff, and is intended to be independent of the LV schedule. One feature of the MPE is that the payloads can be integrated with each of the three segments and checked out in parallel. This maximizes payload schedule and MPE manifest flexibility, and allows for swap-out of payloads relatively late in the flow.



Figure7. MPE Integration and Test

Integration and Test FLOW through Launch

The following flow diagram in Figure 8 summarizes current understanding of the steps required to successfully integrate the MPE to LV, and launch. This includes encapsulating the integrated MPE, transporting to the LV, mating to the LV, transporting to the pad, MPE primary and secondary payload trickle charge, countdown, launch, ascent and LEO orbit insertion.



Figure 8. Launch Vehicle Integration & Test and Launch

On-orbit Operations

The Figure 9 flow diagram depicts the on-orbit concept of operations for MPE. Once the LV completes orbit insertion and other critical maneuvers, it generates a separation signal to MPE, which initiates power-up of the timer circuit. The MPE timer then sends pre-timed separation commands - first to the primary payload, then pairs of secondaries, and finally the tertiary payloads. Timing events and separation velocities are designed pre-mission by flight analysis, to provide safe separations and acceptable body rates.



Figure 9. On-Orbit MPE Operations Flow

The alternate path depicted above is not the MPE Project's desired mode of operations, but is shown for completeness if the LV cannot support attached MPE operations. MPE would prefer to make use of the ACS and / or the larger moment of inertia afforded by the attached LV upper stage to stabilize separation operations. Early flight analysis has shown that high rotation rates would be induced on a non-attached MPE, due to payload separations.

There is no mechanism for in-flight modification of the pre-programmed sequence. After mission completion, the batteries are drained to prevent the possibility of explosive debris generation. The MPE will disintegrate upon deorbit within a year, at 190 nmi. altitude, thus preventing orbit debris concerns.

Typical Mission Timeline

A typical operational timeline is shown in Figure 10 for MPE preparation and launch on a Falcon vehicle. This timeline assumes a direct orbit insertion, which may not be offered by all Falcon contractors, therefore the MPE systems are designed to cover at least one full orbit duration, in the event of a LV Hohman transfer. It is the goal to perform all preprogrammed payload separations as quickly as possible, subject to telemetry system, separation/recontact safety, launch vehicle and payload customer constraints.



Figure 10. MPE Mission Timeline

SUMMARY STATUS

The MPE design team completed System Requirements and Mission Definition Reviews in March, Preliminary Design Review in June, and is preparing for Critical Design Review in September. Environmental testing of the protoflight MPE unit is still scheduled to be complete by April 2006. At this point, the MPE will await arrival of manifested payloads for integration, testing and flight on the first launch vehicle of opportunity.

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