University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document (PDD)

Secondary Payload Adapter Concerned with Eliminating Mass and Optimizing Design (SPACEMOD)

Approvals

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Nomenclature

CAD	=	Computer Aided Design
CMM	=	Coordinate Measuring Machine
CU	=	University of Colorado at Boulder
DR	=	Design Requirement
$EELV$	=	Evolved Expendable Launch Vehicle
$ESPA$	=	EELV Secondary Payload Adapter
FBD	=	Functional Block Diagram
FOS	=	Factor of Safety
FOV	=	Field of View
FR	=	Functional Requirement
PDD	=	Project Definition Document
P/L	=	Payload
RSS	=	Root Sum Square
$SPACEMOD$	=	Secondary Payload Adapter Concerned with Eliminating Mass and Optimizing Design
TBD	=	To Be Determined
ULA	=	United Launch Alliance

Contents

1 Problem or Need

ESPA rings, as seen in Figure 1, were originally developed to allow for 6 secondary payloads to use the same launch vehicle as a primary 15,000 [lb] payload. For this reason, there was a strict requirement for the ESPA ring to be able to support a large mass primary payload. ULA approached the senior projects team with one overarching question: how much better can we make the design if we did not have the requirement of supporting a primary payload, effectively removing a 15,000 [lb] static load design requirement. To summarize: there is a need for a clean sheet design for a secondary payload adapter that allows Evolved Expendable Launch Vehicles (EELV) to carry six 400 [lb] payloads, optimized for minimizing mass while still surviving the loads, vibrations, and shocks associated with mission operations. The Secondary Payload Adapter Concerned with Eliminating Mass and Optimizing Design project, or SPACEMOD will consist of designing, building and testing a scaled version of the improved secondary payload adapter module.

Figure 1: ESPA Ring

2 Previous Work

Current ESPA rings have been in service since 2007 and have provided an interface for six 400 lb payloads, to be placed around a ring that would sit underneath a primary payload with an approximate mass of 15,000 lbs. The standard ESPA has a mass of 293 lbs, a height of 24 in, and a diameter of 62 in. There are 6 ports on this ring, each with a diameter of 15 in. The launch setup for an ESPA ring can be seen in Figure 2.

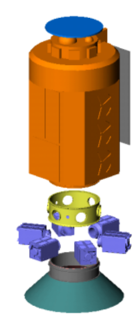

Figure 2: ESPA Ring (Yellow) with 6 Payloads (Purple) Attached and Primary Payload (Orange) on Top [2]

The secondary payload adapter was created in order to add additional satellites to larger missions when fairing spacing and orbit positioning allowed. This in-turn allowed for more cost efficient launches as secondary, or tertiary, missions could be fulfilled with minimal impact to the primary payload and mission. As market demand changes, it is necessary to understand how previous designs were influenced by previous markets and how emerging markets may change the requirements of specific launch structures. As the rise of small satellite design and implementation continues, a question arose about how the ESPA ring would change without the requirement of supporting a 15,000 lb primary payload on it. Specifically, this question is largely focused on how the weight of the ESPA ring could be reduced by removing the primary payload requirement while maintaining the ability to separate secondary payloads. That being said, other optimizations could be found within this redesign that were previously not considered.

3 Specific Objectives

To determine the specific objectives for SPACEMOD, requirements given by the United Launch Alliance as well as information collected from publicly available reference documents were utilized. The following table defines the success criteria for the 6 critical project elements of SPACEMOD as seen in the following table. The expected capability for each objective range from Level 1 to Level 3. Level 1 defines the absolute minimum to be accomplished for a project element and Level 3 defines up to the most that the project will plan to accomplish for the specified project element. The project will be considered an overall success if Level 1 objectives are achieved for all project elements.

Level 1 successes are defined as the baseline expectations for the outlined requirements and capabilities of SPACEMOD as given by the United Launch Alliance. Level 2 successes are defined as further development of Level 1 successes. Level 3 successes are defined as the goal or target expectations and capabilities of a specific objective. Level 3 is the maximum expectation that shall not be exceeded.

Meeting the success criterion shall be validated and verified via testing such as demonstration, analysis, and/or inspection. Demonstration testing includes verification of the intended performance of the specific objective either partially or completely, depending upon the status of the project overall. Analysis testing includes computation or simulation followed by the analyzing of numerical results. Finally, inspection testing will involve the qualitative analysis and validation of specific requirements upon the specific objective. All of the above tests will be demonstrated upon SPACEMOD as a cohesive component following the completion of all specific objectives.

Specific deliverables for SPACEMOD include the scaled, improved and optimized payload adapter itself as defined above in Section 2. It shall consist of a structural ring-like frame that will be constructed with 6 separate ring-like connectors on the surface of the structure. The adapter will be compatible with specific satellite deployment mechanisms and include the appropriate telemetry sensors necessary for the adapter to function independently.

Table 1: Specific Objectives for SPACEMOD

Project Elements	Level 1 (Threshold)	Level 2 (Objective)	Level 3 (Target)
Structural	- Support six P/L, each with a mass of TBD% of 400 lbs scaled by TBD scale factor	- Support six P/L, each with a mass of TBD% of 400 lbs scaled by TBD scale factor	- Support six P/L, each with a mass of 400 lbs scaled by TBD scale factor
Compatibility	- Maintain standard ESPA port compatibility scaled by TBD scale factor	- Maintain standard ESPA port compatibility scaled by TBD scale factor - Maintain TBD Field of View compatibility	
Quasi-Static Loads	-Perform simulation of 12g RSS quasi-static load (scaled by TBD scaled factor) test and achieve no simulated plastic strain	-Perform 12g RSS quasi-static load (scaled by TBD scale factor) test and gather data	- Perform 12g RSS quasi-static load (scaled by TBD scale factor) test and gather data - Withstand test with no plastic strain
Vibe/Acoustics	-Perform simulation of launch-like vibrations based on Atlas V User Guide** with no simulated plastic strain	- Perform test and gather data on vibration table that enacts launch-like vibrations as described in Atlas V User Guide**	- Perform test and gather data on vibration table that enacts launch-like vibrations as described in Atlas V User Guide** - Withstand test with no plastic strain

Table 2: Specific Objectives for SPACEMOD (continued)

Project Elements	**Level 1 (Threshold)**	**Level 2 (Objective)**	**Level 3 (Target)**
Separation	- Characterize shock propagation of separation-like shocks from TBD separation mechanism through simulation	- Characterize shock propagation of separation-like shocks from TBD separation mechanism through test and data gathering	- Characterize shock propagation of separation-like shocks from TBD separation mechanism through test and data gathering - Exhibit no plastic strain due to separation-like shocks from TBD separation mechanisms - Maintain attachments to all other attached P/Ls due to separation-like shocks from TBD separation mechanisms - Do not exceed TBD acceleration due to separation-like shocks from TBD separation mechanisms
Weight	Weight of ESPA is reduced by TBD% compared to Standard ESPA	Weight of ESPA is reduced by TBD% compared to Standard ESPA	Weight of ESPA is reduced by more than TBD% compared to Standard ESPA

** Atlas V User Guide Table 3.2.1-1 provides launch environment load limits. Table 3.2.2-1 provides maximum acoustics levels [4].

4 High Level Functional Requirements

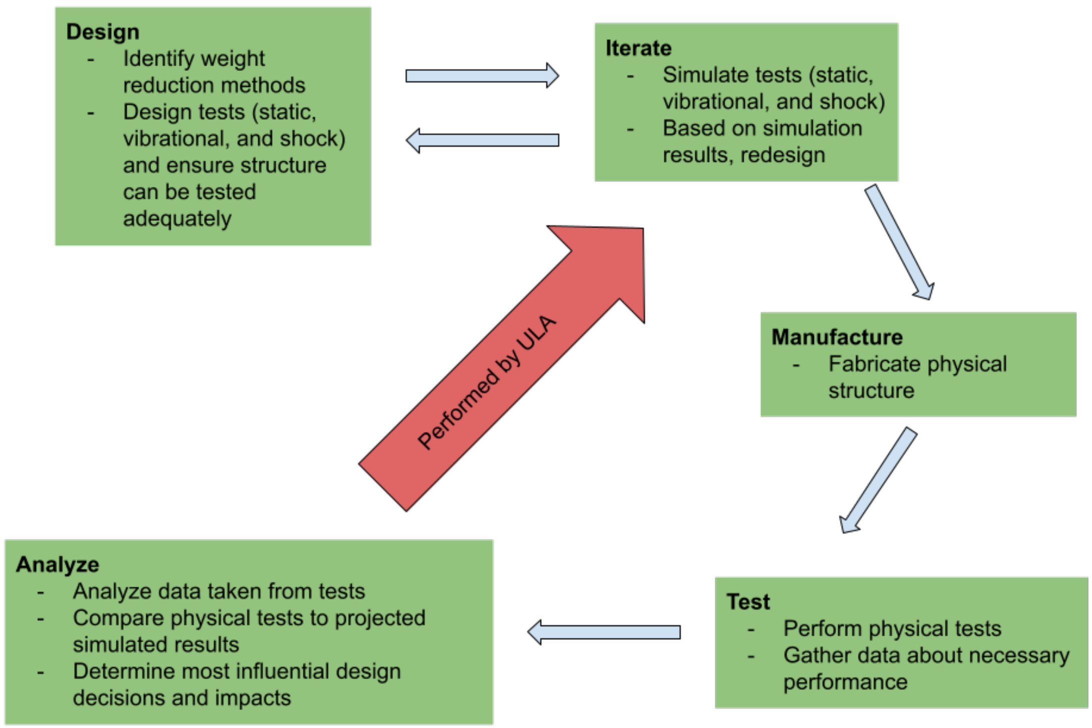

Figure 3: SPACEMOD FBD

1. FR 1 - The SPACEMOD scaled launch ring shall maintain structural integrity and payload attachments when exposed to launch-like loads.
   (a) DR 1.1 - The SPACEMOD shall not see any plastic deformation up to 12g RSS loads with a FOS of 1.4.
      i. Testing: Characterization – High fidelity geometric inspection prior to and after testing in a CMM, strain gauges in areas of concern during testing.
   (b) DR 1.2 - The SPACEMOD shall maintain the attachments to all six attached payloads during exposure to launch-like loads, provided the payloads are scaled models, scaled by a scale factor of TBD, of ESPA-class payloads, as defined in requirement 2.1.
      i. Testing Method: Demonstration – The payloads shall be visually inspected after the launch-like loads have been applied in order to confirm that they maintain their attachment to the SPACEMOD.

(c) DR 1.3 The SPACEMOD shall not undergo plastic strain when exposed to a range of TBD vibration conditions.

  i. Testing Method: Characterization – Plastic deformation shall be measured using TBD methods.

2. FR 2 - The SPACEMOD shall maintain standard ESPA Interface compatibility, scaled by a TBD scale factor, as defined in Section 4 of the MOOG "ESPA's User Guide" [2].

   (a) DR 2.1 - Design: The SPACEMOD shall have the ability to successfully attach up to 6 scaled ESPA-class payloads, scaled by a TBD scale factor, in evenly spaced locations about the ring. ESPA-class payloads are defined as 400 pound payloads with a center of gravity located 20 [in] from the interface plane that can fit entirely within a volume that is 24 [in] in height, 28 [in] in width, and 38 [in] in depth.

      i. Testing Method: Inspection – Through inspections of the physical device, it shall be concluded that the SPACEMOD maintains the ability to attach ESPA payloads.

   (b) DR 2.2 - The SPACEMOD shall have 6 circular ESPA interfaces at evenly spaced locations around the ring, with a diameter of 15 [in], scaled by a scale factor of TBD.

      i. Testing Method: Inspection – Through inspections of the physical device, it shall be concluded that the SPACEMOD has these required circular ports.

3. FR 3 - The SPACEMOD shall maintain structural integrity and additional payload attachment when exposed to scaled, simulated payload separation shocks, which will be characterized.

   (a) DR 3.1 - When exposed to simulated payload separation shocks as modeled by TBD common use separation methods for ESPA-class separation and scaled by a scale factor of TBD, the SPACEMOD shall not see any plastic strain.

      i. Testing Method: Characterization – High fidelity geometric inspection prior to and after testing in a CMM, strain gauges in areas of concern during testing.

   (b) DR 3.2 - When exposed to simulated payload separation shocks as modeled by TBD common use separation methods for ESPA-class separation and scaled by a scale factor of TBD, the SPACEMOD shall undergo a maximum magnitude of acceleration less than TBD [$\frac{ft}{s^2}$].

      i. Testing Method: Characterization – The maximum acceleration of the SPACEMOD shall be measured using accelerometers.

   (c) DR 3.3 - All payloads attached to the SPACEMOD that are not intended to be released during the test shall maintain their attachment to the SPACEMOD.

      i. Testing Method: Demonstration – The payloads shall be visually inspected after the separation-like loads have been applied in order to confirm that they maintain their attachment to the SPACEMOD.

   (d) DR 3.4 - The shock propagation through the SPACEMOD due to simulated versions of the common ESPA-class separation methods shall be characterized through simulation and testing.

      i. Testing Method: Inspection – Data from the separation shock test described above will be analyzed and presented to characterize the separation shock propagation.

5 CONOPS

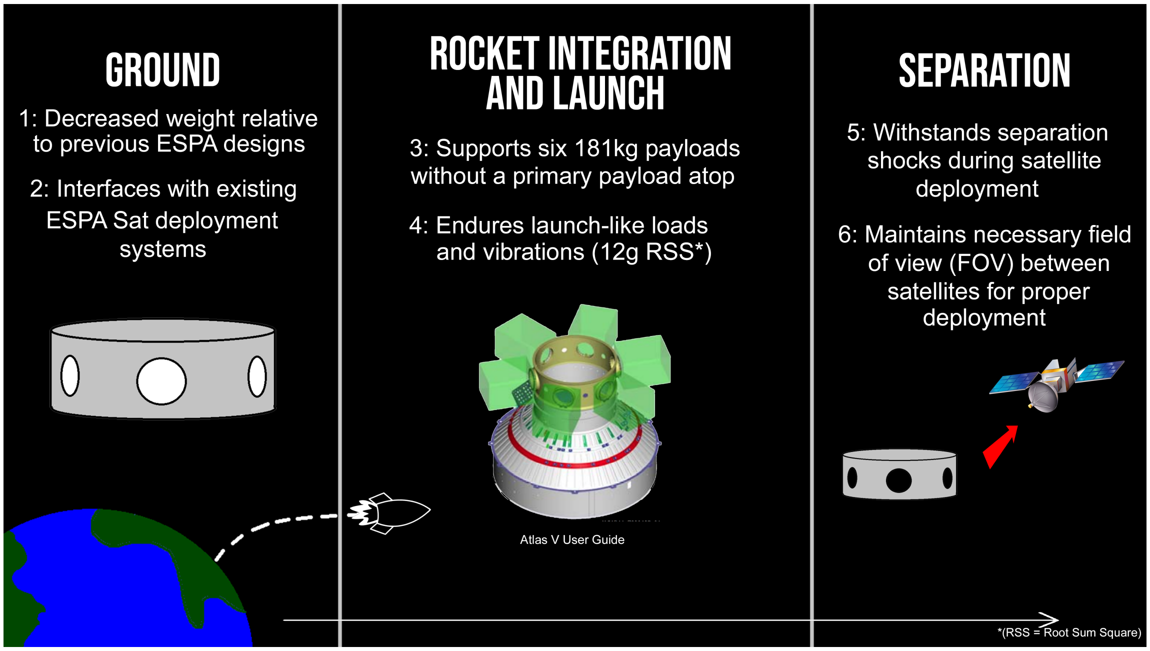

Figure 4: SPACEMOD Concept of Operations

6 Critical Project Elements

6.1 Technical

6.1.1 Manufacturing

Finding proper manufacturing services that will allow us to create a scaled ESPA model that we can use to test our designs. Without proper manufacturing services we will be unable to test a physical model of the ESPA ring and will be limited to testing with a digital model. A physical model is needed to test the effects of vibrations and launch loads of up to 12g on our design when 6 24"x28"x38" payloads are scaled down and attached to the ring's scaled standard ports.

6.1.2 Simulation and Validation

In order to validate that the new design can withstand separation shock before manufacturing and testing, a simulation will be designed to ensure our design is able to withstand the shocks associated with separation and to characterize the propagation of shocks throughout the part. This simulation would ensure the viability of our design and increase confidence that testing would be successful. Additional simulations in programs such as ANSYS, would confirm that the new design could withstand launch loads and that it can move on to the manufacturing and testing phases.

Further, vibrations and modal analysis simulations may be needed to fully explore the impacts and consequences of potential design choices.

6.1.3 Testing and Data Analysis

Physical vibration and load testing is necessary to verify the requirements set forth by ULA and the team. Static load testing, along with vibration modal analysis, will likely serve as the majority of the analysis. Vibration and g-load requirements will be adjusted to reflect the scaled-down size of the adapter.

6.1.4 SPACEMOD Mechanical Design

A crucial component of this project is the design of the SPACEMOD. This task will consist of multiple iterations of first order models and increasingly optimized CAD designs. This task has dependencies with the simulation and validation task.

6.1.5 Electronics: Testing Apparatus Implementation

While many of the details are TBD, it is likely that this project will need some sort of testing apparatus consisting of multiple strain gages and accelerometers. These may interface with a microcontroller, computer, or LabView interface. This is the central electronic component of this project.

6.2 Logistical

6.2.1 Testing Limitations

The University sponsored facilities are not capable of physically accommodating the full-sized payload adapter, once again underscoring the need for the small version. Despite this, it may be possible to use the facilities provided by University affiliates.

6.2.2 Data Recording and Presentation

To ensure that our research and findings can be presented our customer, it will be important to keep track of each step of our design, manufacturing, and testing processes. Keeping track of the methodology will allow us to present our findings in a professional and detailed manner. This will ensure the customer can follow and understand our methodology throughout the processes.

6.3 Budgetary

6.3.1 Financial Limitations

This project must stay in the budget of $5,000. Manufacturing costs force us to carefully track our spending. Inventory will be taken that will monitor planned spending, and each purchase that is made as we go.

7 Team Skills and Interests

Table 3: Team Skills and Interests

Team Member	Skills	Interests	CPEs
Ryan Collins	Programming (C++, Matlab, Python, Git, Java Script, SQL, SAP HANA, Data Management, HTML), 3D Printing, Modeling (Solidworks, AutoCAD, FEM), Project Management, Quality Assurance Inspection and Tolerancing	Testing and Modeling, CAD Modeling, Systems Engineering, Electronics, Software, Finances	6.1.2, 6.1.3, 6.1.4, 6.1.5, 6.2.2, 6.3.1
Ryan Block	Programming (MATLAB, Python, C/C++, Git), LabView, Microcontrollers, 3D Printing, Rapid Prototyping, Agile	Machining and Manufacturing, Testing and Model Validation, Mechanical Design and CAD, Simulation and Modeling, Test Setup Design and Analysis	6.1.1, 6.1.2, 6.1.3, 6.1.4, 6.1.5
Ankrit Uprety	Programming (MATLAB, Python, C++, Git), Electronics, Management	Software, Electronics, Structural Analysis, Testing	6.1.2, 6.1.3, 6.1.5, 6.2.2
Holland Morris	Programming (MATLAB, Python, Git), Technical Writing, Project Management, Agile, Structural Analysis	Hardware, Test Operations, Structural Design, CAD, Systems Engineering, Management	6.1.1, 6.1.2, 6.1.4, 6.2.2
Kenlyn Darrah	Programming (MATLAB), CAD Modeling (Solidworks/Creo), Management, Technical Writing.	Hardware Manufacturing/Machining, Structural Design, Management	6.1.1, 6.1.2, 6.1.4, 6.2.2
Michael Bauer	Programming (MATLAB), Hardware, Electronics, Management and Presentation.	Hardware, Programming, Concept Creation, Presentation, and Testing.	6.1.2, 6.1.3, 6.2.2, 6.3.1

Scott Mansfield	Programming (MATLAB, C++, Javascript, Git), Data Analysis	Software, Structural Analysis, Data Analysis, CAD, Electronics	6.1.2, 6.1.3, 6.2.2
Donavan Harshfield	MATLAB Programming, Structural Design and Analysis, Communication, Technical Writing, Management.	Testing, Orbital Mechs, Electronics, Design, Hardware Manuf.	6.1.1, 6.1.3, 6.1.4, 6.1.5
Cole MacPherson	Programming (MATLAB, Python, C++, Git, html), CAD (Solidworks), Management, Finance.	Testing, Design, CAD, Programming, Management	6.1.2, 6.1.1, 6.1.3, 6.2.2, 6.3.1
Zach Lesan	MATLAB, Large Structure/Mechanism Design and Analysis, FEM, Agile, CAD (NX, Solidworks), Machining, Welding, DFM, GD&T, Management	Scaling of Models for Accurate Modal Analysis, CNC Mill Operation, Scaled Structures Testing Practices	6.1.1, 6.1.2, 6.1.3, 6.1.4, 6.2.1, 6.3.1

8 Resources

Table 4: Resources

Critical Project Elements	**Resource/Source**
Manufacturing	Matt Rhode, AERO Machine Shop to manufacture scaled prototype
Simulation and Validation	Microsoft Excel for hand calculations and FEM documentation, FEMAP and ANSYS for structural analysis, Solidworks for CAD, MATLAB to process data
Testing	Katie Rae Williamson Is the Vibration table specialist.
Data recording and presentation	Microsoft Office to organize and present findings

References

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[2] Moog Space and Defence Group, "ESPA USER'S GUIDE", Moog, Inc., 2018. https://www.moog.com/content/dam/moog/literature/Space_Defense/spaceliterature/structures/moog-espa-users-guide-datasheet.pdf

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[4] United Launch Alliance, "Atlas V Launch Services User's Guide", United Launch Alliance, LLC., March 2010. https://www.ulalaunch.com/docs/default-source/rockets/atlasvusersguide2010.pdf

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