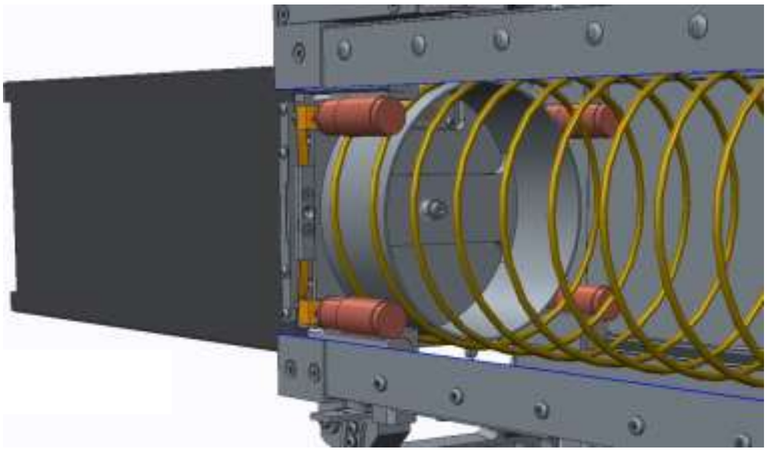
LV-POD Executive Summary Report

ISIS.LVPOD.TN.008



Issue 1.1

Release information

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List of Acronyms

AIM	Asteroid Impact Mission
CRS	CubeSat Release System
ISIPOD	ISIS POD
LV-POD	Low Velocity POD
POD	Pico-satellite Orbital Deployer

Change log

Date	Issue	Modified by	Section / Pages Affected	Reason for Change
2016-11-07	1.0	CBER	All	Initial version
2016-11-29	1.1	CBER	All	Update based on ESA's feedback. Added chapters 3.4, 3.5, 3.6 and 3.7. Footer removed.

1 Introduction

1.1 Background

Within the ESA's Asteroid Impact Mission (AIM) the CubeSat Opportunity Payload Inter-satellite Networking Sensors (COPINS) will make use of two Standard 3U CubeSats that will be deployed and operated as a network of sensors or as separate experiments relevant to the AIM scientific and asteroid mitigation objectives. Each of those CubeSats will be containerized in a standard deployment system.

This study deals with the definition of the concept for the AIM deployment system aka Low Velocity POD (LV-POD). The need for this activity is driven by the technical challenge of deploying a set of CubeSats within the Didymos asteroid system. For example, low ejection velocity needed to avoid both exceeding escape velocity for orbiting CubeSats and excessive surface impact (damage and rebound potential) for lander CubeSats.

Within the scope of the activity is an extension to the interplanetary, e.g., low separation velocity for deploying mother-daughter formations close to each other and with respect to mother spacecraft due to lack of significant propulsive capabilities. Low separation velocity error is a critical element for navigation.

1.2 Objectives

The output of the activity should show the necessary engineering changes to an existing CubeSat deployer to meet AIM mission and system requirements and prepare an appropriate interface definition for accommodation on the AIM spacecraft including among others:

- Identification of the requirements for a LV-POD in an interplanetary environment, first addressing the needs of AIM and extending to generic interplanetary missions.
- Review of technology to extend existing CubeSat deployment systems and identification of their limitations.
- Design the concept of the LV-POD and assess its feasibility.

2 LVPOD definition

CubeSats are generally designed and developed based on the CubeSat standard and later on launched using a deployers or POD. In essence the deployer is a box equipped with a door controlled by a HDRM system to accommodate and deploy in orbit the CubeSat after launch. The deployer is separately tested and qualified to survive the launch and operational loads.

2.1 General functionalities

The main missions of a deployer are among others are:

- To provide a standard interface between CubeSat and AIM mother spacecraft.
- To fully enclose the CubeSat.
- To protect the CubeSat from the elements around it (Launch Vehicle, AIM mother spacecraft and other payloads) and vice versa.
- To act as direct mechanical and electrical interface between the CubeSat and the AIM mother spacecraft.
- To deploy the CubeSats to the target orbit with a suitable velocity and spin rate. In the standard deployment approach the tubular geometry defines a predictable linear trajectory for the CubeSat.
- To reduces costs by having standard interfaces through the CubeSat and through the AIM mother spacecraft.
- To add flexibility to the development flow since CubeSat and AIM mother spacecraft can be decouple.

Figure 2-1 graphically shows the LV-POD system conceptual functionalities.

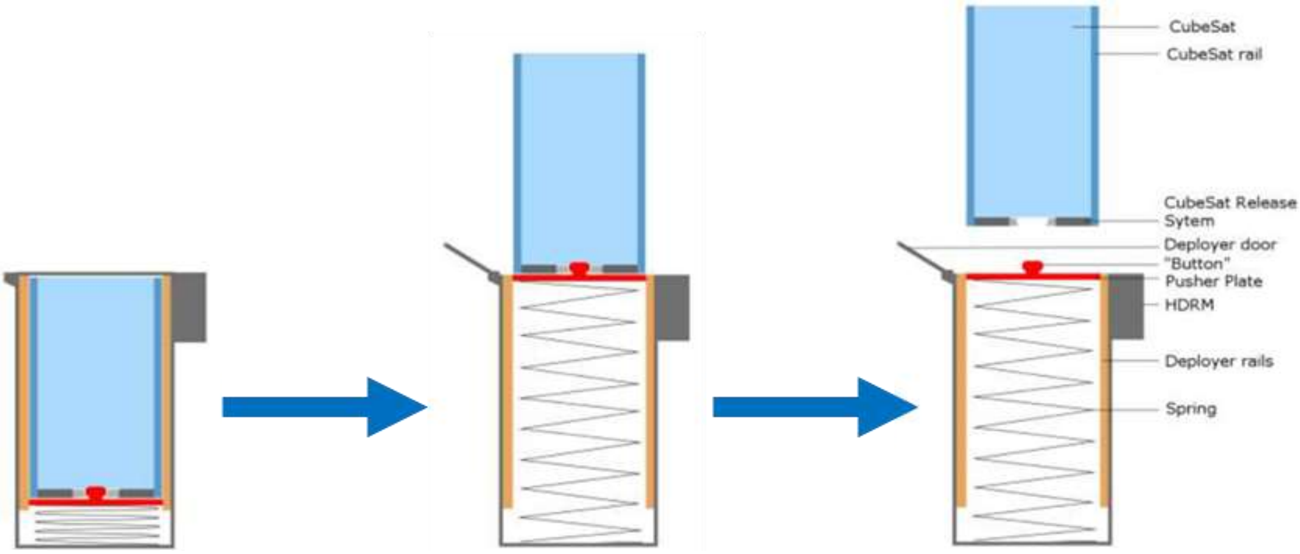


Figure 2-1 LV-POD conceptual functionalities

2.2 Specific functionalities

The specific functionalities to be considered in establishing the set of requirements for the LV-POD are the following:

- Umbilical connections with the AIM spacecraft resulting in nominal charge levels, at least partial on-board software update and telemetry status reporting of the CubeSats(s) before deployment.
- Monitoring CubeSat(s) health during cruise.
- Flexibility in the imparted Delta-V and accuracy on release. Including assessment of the tune-ability needed and the errors in deployment.
- The release velocity shall not exceed 5 ± 1 cm/s for the purposes of this study. The sphere of influence of the Didymos system shall be taken into account such that CubeSats would not escape, using the low velocity deployment module as a baseline.

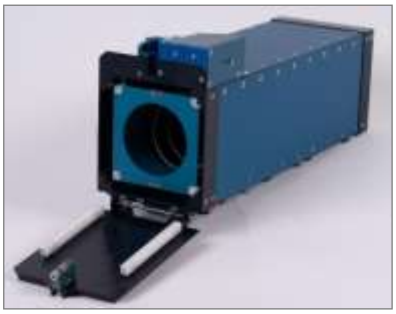
2.3 CubeSat Deployment Technology State-of-the-art

After the research on the state-of-the-art in terms of deployment systems technologies the available deployer that will be assessed and reviewed in the study are short listed. Table 2-1 gives a graphical overview of those deployment systems that are also gathered in the following list:

- ISIPOD
- ISIPOD with CRS
- QUADPACK
- P-POD
- XPOD
- PSL-TPL
- G-POD
- NRCSD
- J-SSOD
- Novanano
- CSD

Based on the result of the trade-off performed to compare the different deployers assessed in the document, the ISIPOD with CRS solution seems to be the most suitable deployer to be used as baseline for the LV-POD within AIM. The main characteristics that support this conclusion are the fact that the ISIPOD is a light weight, COTS, European deployer, already has the CRS devise that provides a tuneable and low release velocity as well as a data/power connectivity interface which are two of the more critical elements for the LV-POD. The main missing feature is the inflight deployment velocity tuning that will be study in the concept definition chapter.

Table 2-1: Overview of deployment systems included in the LVPOD study

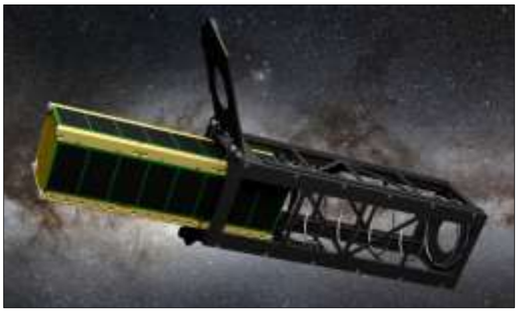


ISIPOD

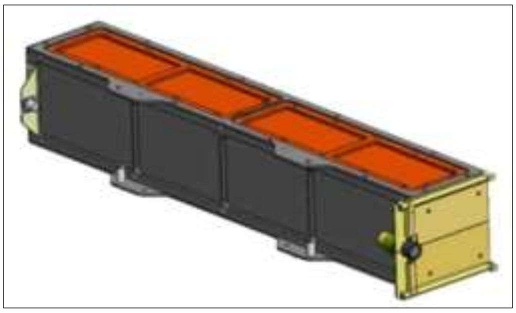
P-POD

Table 2-1: Overview of deployment systems included in the LVPOD study

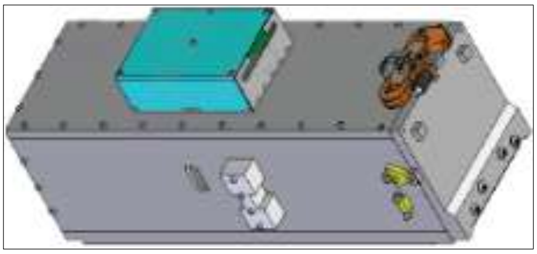
QuadPack



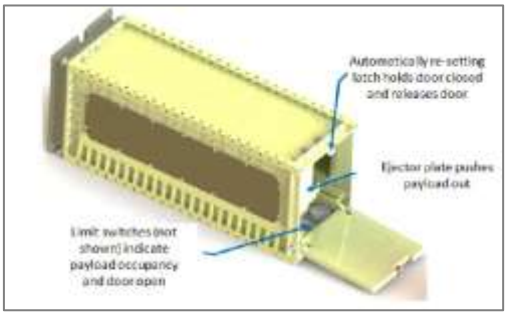
G-POD



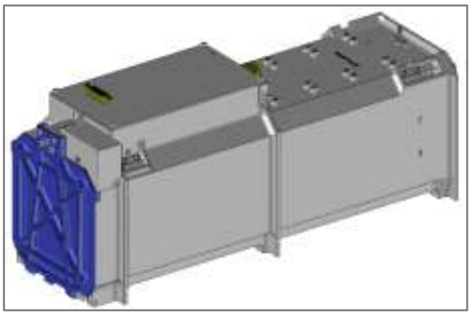
NRCSD



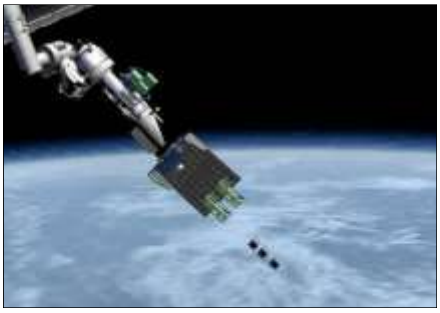
X-POD



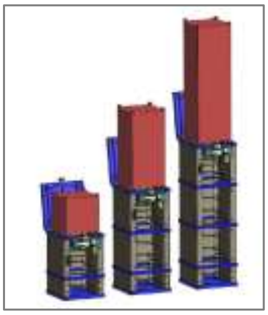
CSD



Novanano



J-SSOD



PSL

3 LVPOD system concept

As a result of the study a suitable concept has been found and proposed. Based on the information presented in this report, the proposed concept for the LV-POD system for AIM is a full solution composed by different elements: the LV-POD (modification of the baseline ISIPOD), the CRS (including the umbilical connection) and the velocity tuning subsystem. The LV-POD, the CRS and the umbilical connection have or will have flight heritage before flying with AIM.

The main new concept to be introduced is the velocity tuning subsystem which is critical for the success of the COPINS/AIM. Currently the tuning on ground is possible but the in-flight tuning has to be defined. Based on the trade-off and on the list of pros and cons of each of the assessed technologies the concept that has been found more suitable for the velocity tuning is the 'Spring with piezo stepper' concept.

3.1 LV-POD

The ISIPOD is a launch adapter for CubeSats that adhere to the CubeSat interface standard, it is developed within the scope of ISIS launch services as a (ITAR free) launch adapter.

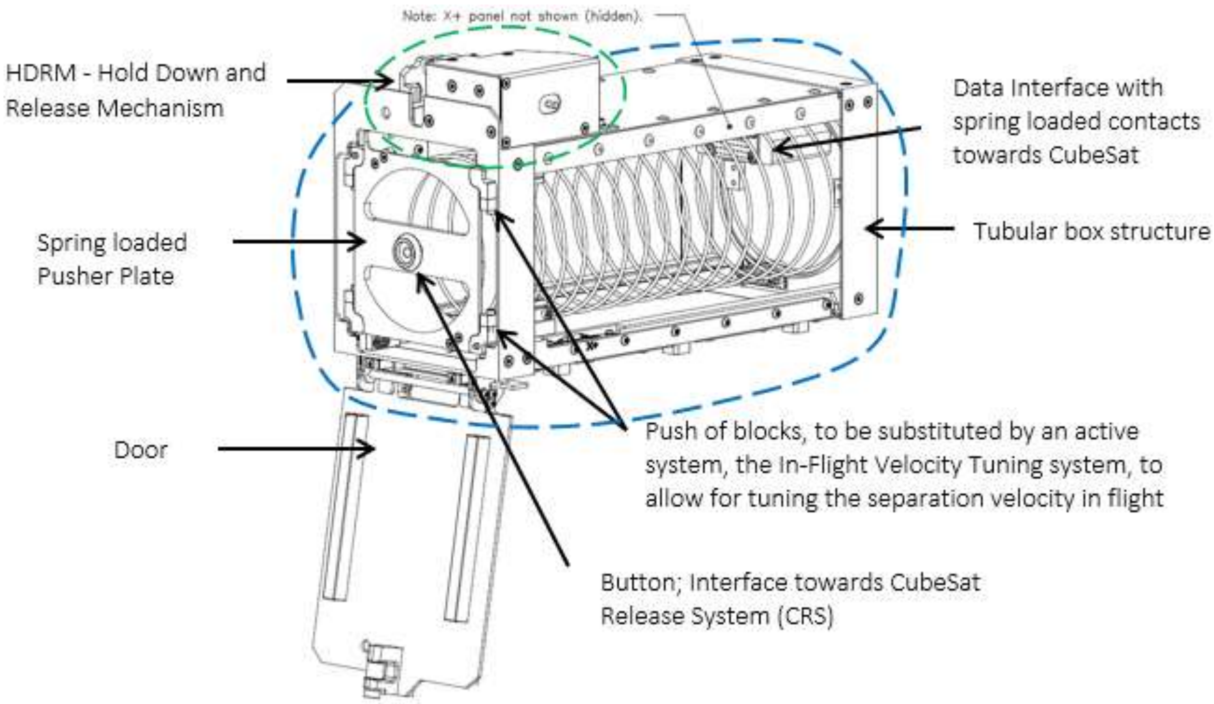


Figure 3-1 LVPOD overview

3.2 CubeSat Release System

The CubeSat Release System (CRS) is developed by ISIS for the Remove DEBRIS mission and can be used for the LV-POD of the AIM mission. The mentioned functionalities umbilical system, Clamping and release with velocity were already combined in this build and tested CRS.

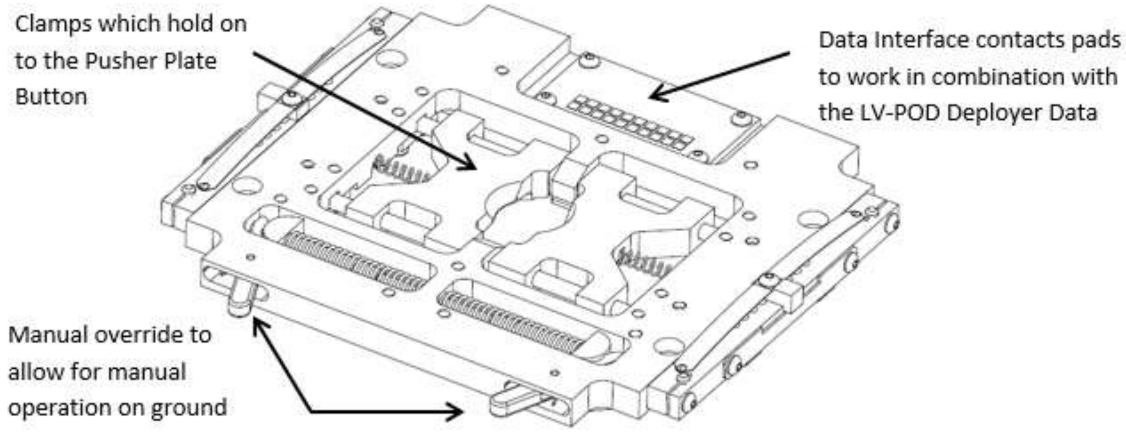


Figure 3-2 CRS overview

The CubeSat Release System is depicted below in Figure 3-3. It is a system with a similar envelope as the common ISIS antenna systems and uses the same mounting pattern. The system is based upon an aluminium frame which contains all the different components and forms the interface towards the CubeSat.

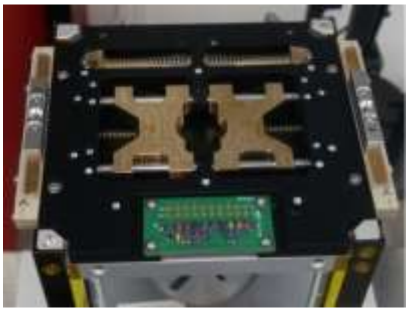


Figure 3-3 CRS on CubeSat Frame

3.3 Velocity tuning system (spring with piezo stepper)

A piezo stepper tunes the deflection of the push off springs. The force is measured via a strain gauge. The stepper consists of a guiding rod, axial driven by a piezo element. A table is clamped onto the rod. When a saw tooth shaped voltage (with a typical repetition rate of 200Hz) is applied to the piezo, the table moves along the rod using the stick-slip principle.

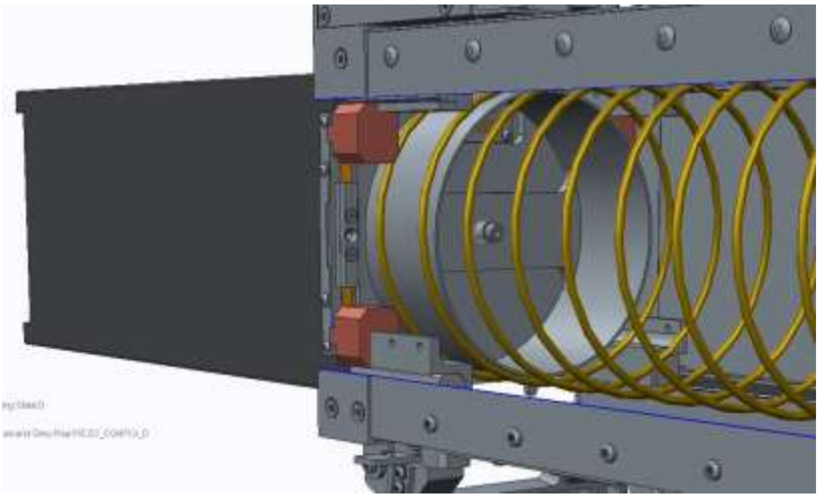


Figure 3-4 Piezo Stepper Configuration

3.4 Budgets

Table 3-1, Table 3-2 and Table 3-3 show mass and volume, estimated operation and storage temperature range and power budget per operational mode respectively for the LVPOD concept.

Table 3-1 LVPOD Mass and Volume Budgets

Property	Units	Value
Mass	[kg]	2.466
Volume	[m^3]	$6.57 \cdot 10^{-4}$
Operation Temperature Range	[˚C]	-30 / +40
Storage Temperature Range	[˚C]	-40 / +50

Table 3-2 LVPOD Thermal Budget

Property	Units	Value
Operation Minimum Temperature	[˚C]	-30
Operation Maximum Temperature	[˚C]	+40
Storage Minimum Temperature Range	[˚C]	-40
Storage Maximum Temperature Range	[˚C]	+50

Table 3-3 LVPOD Power Budget

<table>
<tr><th colspan="2" rowspan="2">Component</th><th colspan="6">Mode</th></tr>
<tr><th>Containing the CubeSat</th><th>Door opening, Driving out the CubeSat</th><th>Clamping the CubeSat</th><th>Inflight Tuning</th><th>Releasing the CubeSat</th><th>Deployed</th></tr>
<tr><td rowspan="2">LV-POD</td><td>Current</td><td rowspan="2">0</td><td>1.75 [A]</td><td rowspan="2">0</td><td rowspan="2">0</td><td rowspan="2">0</td><td rowspan="2">0</td></tr>
<tr><td>Power</td><td>49 [W] *</td></tr>
<tr><td rowspan="2">CRS</td><td>Current</td><td rowspan="2">0</td><td rowspan="2">0</td><td rowspan="2">0</td><td rowspan="2">0</td><td>1.28 [A]</td><td rowspan="2">0</td></tr>
<tr><td>Power</td><td>6.4 [W]</td></tr>
<tr><td rowspan="2">Velocity Tuning</td><td>Current Average/Peak</td><td rowspan="2">0</td><td rowspan="2">0</td><td rowspan="2">0</td><td>27 [mA] / 7 [A]**</td><td rowspan="2">0</td><td rowspan="2">0</td></tr>
<tr><td>Power Average/Peak</td><td>1.1 [W] / 278 [W]*</td></tr>
</table>

*250 millisecond duration

** 10 microsecond duration, 200Hz repetition rate

3.5 Interfaces

3.5.1 Mechanical Interface

The mechanical interface between the LVPOD and the mother-craft is based on 8 M6 bolts in a 100x106mm pattern. This is shown in Figure 3-5.

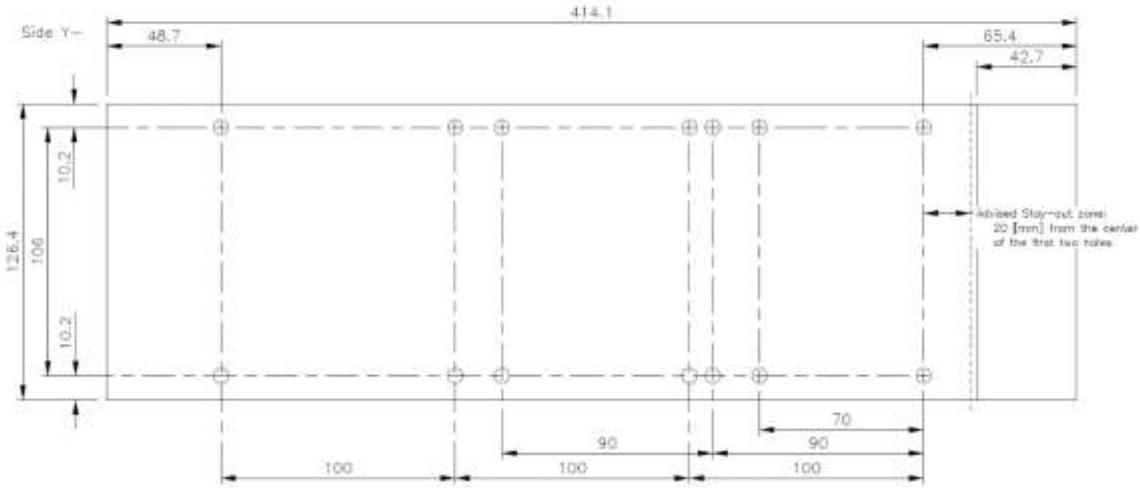


Figure 3-5 LVPOD external interface

The mechanical interface between the LVPOD and the CubeSats complies with the CubeSat standard. Some of the specific features are shown in Figure 3-6.

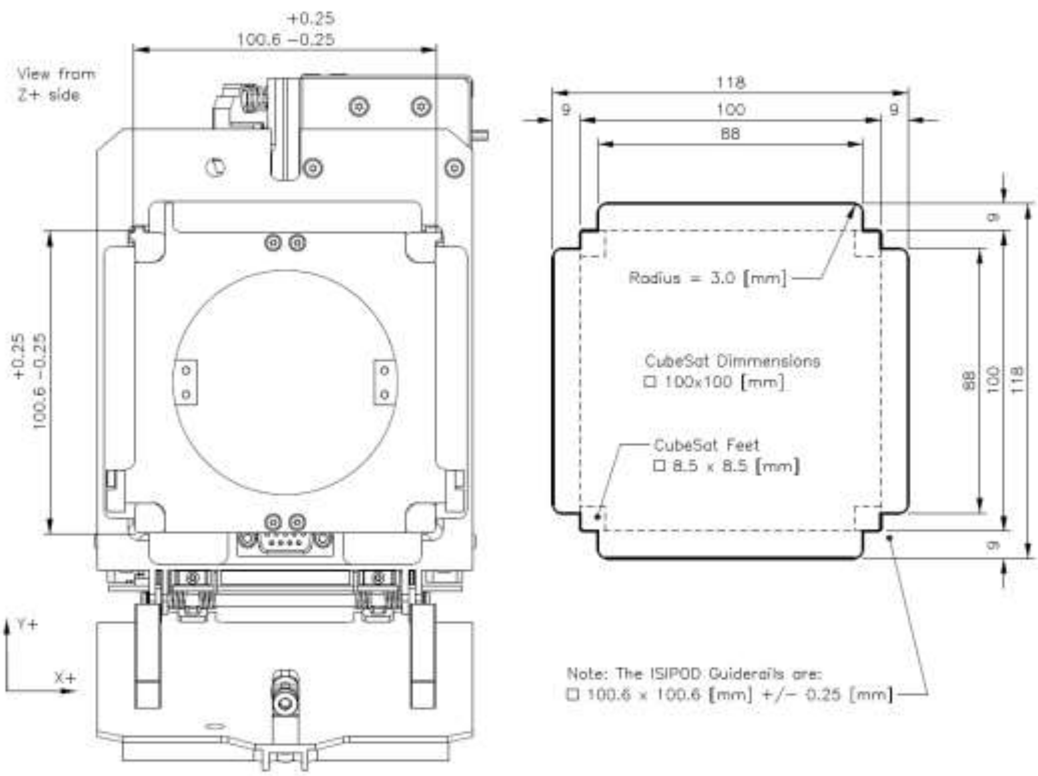


Figure 3-6 LVPOD internal dimensions

3.5.1 Electrical Interface

The LVPOD has separated electrical interfaces for the deployment command and the telemetry. This means that there are two different electrical connections for the mother-craft and each has its own dedicated interface connector. For ccommanding the HDRM a Male DSUB9 connector is accommodated whereas for telemetry a Female DSUB9 connector is used.

Table 3-4 and Table 3-5 summarize the parameters for the command signal as well as the ones correspondent to the telemetry switches.

Table 3-4 LVPOD deployment command parameters

Property	Unit	Minimum	Typical	Maximum
Actuation Voltage	[V]	24	28	32
Current	[A]	1.5	1.75	2.0
Duration	[ms]	100	250	1000

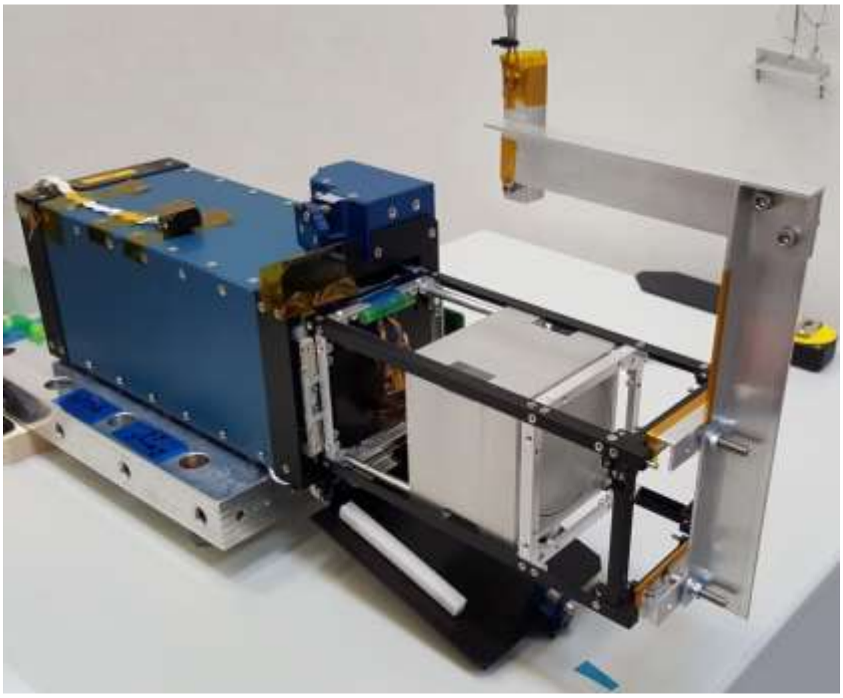
Table 3-5 LVPOD telemetry parameters

Parameter	Unit	Minimum	Typical	Maximum
Switch current	[mA]	2	50	100
Switch voltage	[V]	n/a	n/a	30
Reed Switch resistance	[mΩ]	n/a	n/a	100
Micro Switch resistance	[mΩ]	n/a	n/a	200

3.6 Interplanetary Extension

The current ISIPOD which forms the basis for the LV-POD has been initially developed for use in Low Earth Orbit (LEO) hence some of the requirements in particular related to space environment and life time are different from the AIM LVPOD specific ones.

The scope of this document is to investigate the engineering modifications that are required to upgrade the ISIPOD to make suitable as LV-POD deployment system for the AIM project as well as for other Interplanetary Missions. The Interplanetary Missions range of scenarios includes missions to the Moon, Mars and visit to an asteroid.



The following list gathers the different elements and technologies that have been reviewed in order to identify the potential engineering changes and modifications for the interplanetary extension of the LVPOD:

- Operational Lifetime
    - Stowage behavior of springs
    - Outgassing of engineering plastic materials
    - Lubrication of bearings in the release mechanism
    - Creep sensitive HDRM materials (Dyneema wire)
- Thermal Control
- Radiation tolerance
- Radiation level inside the LV-POD

3.6.1 Stowage behaviour of springs

No changes with respect to the current implemented spring materials or processes are required to satisfy the AIM mission and interplanetary extension requirements and needs.

3.6.2 Out-gassing of engineering plastic materials

For the scope of the AIM mission and interplanetary extension it is recommended to substitute all the components which are manufactured from the POM engineering plastic material in the LV-POD system into PEEK. This PEEK material with its higher mechanical stability also has better outgassing properties making it the more preferred engineering plastic material. This substitution has previously also been employed for the QuadPack design which has successfully flown in LEO multiple times and is seen as a logic and safe substitution, justifying the substitution from POM to PEEK.

3.6.3 Creep sensitive HDRM materials (Dyneema wire)

It is recommended to substitute the current employed braided SK75 Dyneema wire for the new ISIS custom made braided DM20 Dyneema wire in thin diameters with negligible creep compared to SK75. Thereby reducing the influence of creep on the design of the LV-POD CRS and improving the ability to meet the required 3 years in interplanetary space for the AIM mission. The current and ongoing tests at ISIS show promising results justifying the move to DM20 Dyneema. In the next phase of the AIM mission dedicated test with the braided DM20 Dyneema wire on the LV-POD CRS will be performed under representative spaceflight conditions.

3.6.4 Thermal Control

The LV-POD in the current implementation is thermally a passive system and covers a wide range. The thermal range will in all likelihood be dictated by the CubeSat payloads. However if required for both the LV-POD CRS as the LV-POD HDRM alternative solutions are offered that would have minimum impact to the overall end product while allowing for lower minimum operational temperatures.

For the LV-POD CRS the Actuators, the resistors could be substituted by ceramic heaters. For the LV-POD HDRM thermal couple could be added to the Actuator, the Solenoid together with a heater tape wrapped around it, such that prior to operation the temperature could be verified and raised to acceptable levels.

3.6.5 Radiation Tolerance of the electronic components

Perform Radiation tests on the different electrical component and substitute for radiation hardened equivalents where applicable, unless the component is known to fail in which it is recommended to substitute these components directly. These activities are to be performed in the next phase of the AIM project.

3.6.6 Radiation level inside the LV-POD

ISIS at this stage is not in the possession of analyzing software to calculate the reduction in radiation level that is present inside the LV-POD and requires ESA guidance in this aspect.

The total reduction will however be small due to the existing design of the LV-POD which is made from thin aluminum panels of 0.8 [mm] thickness. This thickness can’t be increased without a direct mass penalty.

3.7 Test Approach

Various tests should be performed in order to verify that the LV-POD system, subsystems and key technologies are compliant with the mission and LV-POD requirements.

3.7.1 Qualification

In order to qualify the LV-POD system several tests have to be performed on the system. The LV-POD has to be submitted to Environmental test according to the standard qualification levels derived from the mission and launch requirements and environment or against representative loads in terms of vibration, shock, thermal and vacuum conditions.

Performance tests have to be performed in order to characterize the performances of the LV-POD system including the velocity of deployment, direction of deployment and tumbling of the CubeSats.

Functional tests have to be performed to probe the correct functioning of the LV-POD system in the different conditions and functionalities such as door opening, deployment, release, connectivity, etc.

For certain elements such as wires and springs endurance tests have to be performed to confirm in particular the life time of the HDRM wires as well a spring properties along mission duration. Storage in load configuration during representative time has to be performed too.

3.7.2 In-orbit validation/demonstration

Some of the baseline elements of the LV-POD solution will be flown before they are implemented and used in the AIM mission. This is the case of the baseline ISISPOD that already has flight heritage since 2013. Other elements currently have no flight heritage but are foreseen to be flown before AIM mission makes use of them. This is the case of the CRS baseline subsystem as well as the umbilical connection solution.

Nevertheless it has been identified the convenience of a dedicated IOD/IOV activities for the LV-POD system solution. The advantage of this IOD/IOV activity would be to expose the full LV-POD system to a representative space environment, for this purpose a LEO environment would be suitable. By this mean the end-to-end functionalities and performances of the LV-POD can be evaluated and measured in orbit for later comparison with the expected design values. This would allow to a second iteration and optimization of the system based on the in-orbit results. It is known that there are already initiatives from ESA to study and potentially perform this IOV/IOD activity together with representative COPINS CubeSats. This combination of LV-POD and AIM CubeSats would be the perfect scenario for the validation of the combined systems.

A Zero-g flight could be a complement to the IOD/IOV activity, it can be seen as an intermediate step in the validation of the LV-POD system. Although it is not a fully representative space environment, it is a more representative environment at least in terms of microgravity conditions than the conditions that can be found on ground.

3.7.3 Acceptance

Once the LV-POD system has been qualified and eventually gone through IOD/IOV activities, the flight model has to be submitted to similar environmental tests but with the adequate loads. In addition similar characterization and functional tests have to be performed.

4 Conclusions and Main results

As result of the LVPOD study the following conclusions and results have been achieved:

- The set of requirements applicable to the LV-POD system has been identified and categorized.
- A state-of-the-art of available deployment systems has been addressed and among them a trade-off has been performed to compare the different options
- The ISIPOD with CRS solution has been identified as the most suitable deployer to be used as baseline for the LV-POD within AIM. This warrantees the reuse of the state-of-the-art and available technology and developments.
- Some of the characteristics that support the ISIPOD and CRS selection are: a light weight, COTS, European origin, provides a tuneable and low release velocity and has data/power connectivity interface.
- The missing feature in the ISIPOD and CRS is the inflight deployment velocity tuning. In order to solve it a trade-off is performed and as a result a concept definition is proposed and the correspondent CAD model is provided.
- The engineering modifications that are required to upgrade the ISIPOD and CRS to make suitable as LV-POD deployment system are assessed and addressed.
- Similarly for other Interplanetary Missions those potential modifications are identified. The Interplanetary Missions range of scenarios includes missions to the Moon, Mars and visit to an asteroid.
- The concept complies with the deployment velocity requirement which is one of the key features of the concept. Although the required dispersion for the velocity of deployment is 20%, the measured one in the engineering model is below 5%.
- Definition of the standard mechanical and electrical interfaces between the LVPOD and the CubeSats as well as between the LVPOD and the mother spacecraft.

5 Future works and recommendations

As result of the LVPOD study the following recommendations and future works are identified:

- Next step would be to continue with the detailed design in particular of the inflight velocity tuning system, prototyping and validation together with the LVPOD (ISIPOD and CRS).
- Extended test campaign has to be performed to qualify of the LVPOD system for the AIM mission environment.

- Intermediate steps for validating and characterizing the performances in representative environments would be recommendable. Zero-g flight or even IOV/IOD missions to LEO would be a de-risk activity for LEVPOD system.

- Due to the results and measurements of the engineering models in terms of accuracy and dispersion of the deployment velocity, the CRS concept could be reused for similar application within AIM but also in other missions where separation with low velocity and low dispersion is required