APPS
Autonomous Planetary Payload Support System

Executive Summary

ESA Contract 4000105102/11/NL/AF
CGS Ref. APPS-RP-CGS-002
Issue 1, 04/06/2014

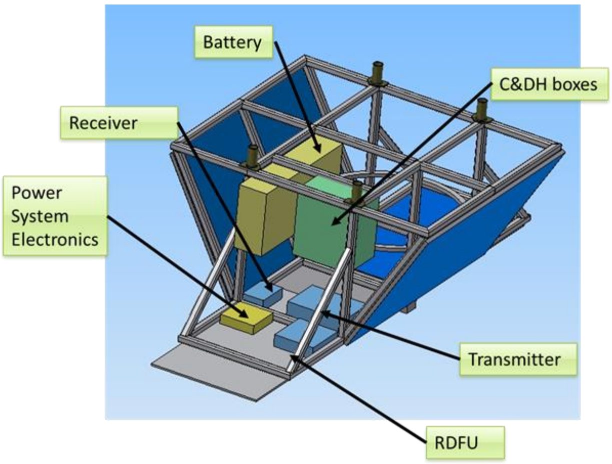
Table of Contents

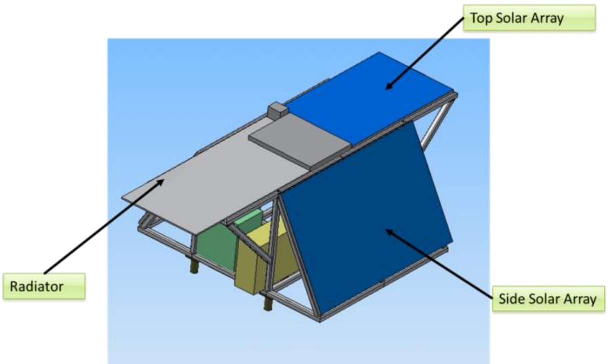
Scope

The objective of the APPS study has been to investigate the feasibility, architectural and system design, and potential performance of a non-nuclear system whose single goal is to provide survival and servicing support to a planetary payload element, in order to ensure its operations despite the absence of sunlight for extended periods. The principle aim is to advance concepts and overall approaches to meet this goal, and to provide a framework for the future development of key technologies. While an example payload element is specified in the frame of this activity, the results of this activity shall be applicable to various types of planetary payloads.

Design description

The APPS consist of a main structure made of CFRP on which are mounted the solar arrays and the radiator. On the bottom side of the radiator are connected several electronic boxes. The battery and the C&DH are fixed directly to the structure since they are too large and therefore cannot be mounted on the radiator. The Seismometer (SEIS) is connected to the structure trough an adapter ring. This ring shall be equipped with an Hold Down and Release Mechanism (HDRM) in order to allows the SEIS to be deployed on the moon surface.
All the boxes inside the APPS are covered with MLI, also the SEIS is covered with MLI. Furthermore the open sides of the APPS shall be covered with MLI. Two antennas will be mounted on the top of the APPS, between the radiator and the solar array. In order to dissipate the heat from the C&DH and from the SEIS, two heat pipes will be connected to the radiator and these elements.





Power Budget

The APPS supports as a minimum the following set of Operational Modes:

OP1 = Transportation Mode
OP2 = Commissioning Mode
OP3 = Deployment Mode
OP4 = Standby/Safe Mode
OP5 = Reconfiguration Mode
OP6 = Daytime – Nominal
OP7 = Daytime – Comms
OP8 = Night – Dormant
OP9 = Night – Download
OP10 = Night - TM/TC

In the following table the overall power budget is shown, for each Operational Modes in function of the different APPS subsystem and Payload Element (PE) or SEIS.

Subsystem	Operative Modes									
	OP1	OP2	OP3	OP4	OP5	OP6	OP7	OP8	OP9	OP10
Communications	2.6	5.3	5.3	5.3	5.3	5.3	35.9	0	2.6	2.6
Command & Data Handling	1.9	6	6	6	6	6	6	1.6	3.1	3.1
Total	4.5	11.3	11.3	11.3	11.3	11.3	41.9	1.6	5.8	5.8
Margin	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
Total with Margin	5.5	13.5	13.5	13.5	13.5	13.5	50.3	1.9	6.9	6.9
SEIS Assembly	0	0.6	3.7	0.6	0.6	0.6	0.6	0.3	0.3	0.3
SEIS EBX	0	1.8	1.5	1.8	1.8	1.8	1.8	1.7	1.7	1.7
Total with SEIS	5.5	15.9	18.7	15.9	15.9	15.9	52.7	3.9	8.9	8.9

Mass Breakdown

In the following table the overall mass budget is shown, for each different APPS subsystem and PE (SEIS) with relative margin.

Subsystem	Mass [kg]	Average Margin [%]	Mass with margin [kg]
Power	4.9	6	5.3
Communications	1.4	6	2.3
Command & Data Handling	1.3	8	2.3
Structure & Mechanisms	4.9	10	6
Thermal Control	2	9	2.1
Total APPS Mass with system margin		20	21.6
SEIS Assembly	4.9	17	5.7
SEIS EBX	1.2	20	1.5
Total APPS + SEIS			28.8

External Interfaces

During its entire life, APPS has to interact with a large set of building blocks and actors (the different experienced environments). In the following, the different interfaces with these building blocks and actors are described. In identifying them, a conservative approach has been applied, taking into account that APPS will be able to autonomously work and will not beneficiate of Lunar Lander resources once its operational phase is started.

The resulting interfaces are the following:

- Ground Segment (GS). The interaction with the Ground Segment will happen in two different ways, depending on the phase of the mission:
  - during launch preparation, APPS will be connected to the ground support equipment receiving from it electrical power and commands and providing telemetry back;
  - from launch to delivery on lunar surface, APPS will transmit telemetry and receive telecommands with GS via the Lunar Lander communication system;
  - once separated from Lunar Lander, the interaction will be via an own communication link, receiving commands and providing telemetry and science data collected by the PE(s) (this latter only once deployed at its operational site).
- Lunar Lander (LL). From launch up to separation after delivery on lunar surface, APPS will provide mechanical, electrical and data interfaces to the Lunar Lander. In particular, APPS will behave as a “dead payload” and will receive from the LL electrical power and commands. Mechanical interfaces will be necessary to withstand the launch environment as well as the landing manoeuvre and the delivery on surface (via LL deployment mechanism).
- Payload Elements (PE). The APPS mission objective is to support one or more small payloads operating on lunar surface in order to sustain scientific investigations. In such a frame, three are the main payloads that can be supported: a Seismometer, a Magnetometer, and an Instrumented Mole. In the following, a high level description of the required interfaces with them is provided:
  - Seismometer (Reference PE) → SEIS represents the “reference” payload to be supported by APPS during its whole lifetime. In particular, APPS is aimed at providing a set of interfaces to the SEIS, among which:
    - Mechanical interfaces, to withstand loads in all the experienced environments (i.e. launch, transfer, landing). Such an interface must be disconnectable to enable separation once delivered on the surface and then guarantee mechanical decoupling;
    - Electrical power interfaces, i.e. umbilicals, for power supply in order to sustain SEIS operations and survival;
    - Data management interfaces (at Hardware and Software level), to collect SEIS acquired scientific data and telemetry, and send to it the telecommands received from Ground.
  - Magnetometer (Delta-PE) → the Magnetometer represents one of the Delta-PEs that could be supported by APPS during its lifetime. In this case, the interfaces are made by a telescopic boom, allowing deploying the sensor at a distance of about 1.5m in order to minimise the disturbances. At the same time, the associated electronic boards can be instead accommodated/ integrated within APPS structure. Taking this into account, the following interfaces are envisaged:
    - Mechanical interfaces, to withstand loads in all the experienced environments (i.e. launch, transfer, landing). Such an

interface must be fix as no mechanical decoupling is required;

- Electrical power interfaces, i.e. umbilicals, for power supply in order to sustain Magnetometer operations and survival;
- Data management interfaces, to collect Magnetometer acquired scientific data and telemetry, and send to it the telecommands received from Ground.

- Instrumented Mole (Delta PE) → the Instrumented Mole is the second Delta-PE. Such a payload requires to be placed over the surface with a certain level of initial force in order to be able to start its penetration operations on lunar terrain. Also in this case, the associated electronic boards can be accommodated/integrated within APPS structure. Taking this into account, the following interfaces are envisaged:
  - Mechanical interfaces, to withstand loads in all the experienced environments (i.e. launch, transfer, landing). Such an interface must be disconnectable to enable separation once delivered on the surface and then allow mole operations (autonomous surface drilling);
  - Electrical power interfaces, i.e. umbilicals, for power supply in order to sustain Instrumented Mole operations and survival;
  - Data management interfaces, to collect Instrumented Mole acquired scientific data and telemetry, and send to it the telecommands received from Ground.

For all these payloads, APPS will represent the interface through which to communicate with Earth, transmitting to this latter science data and telemetry, and receiving telecommands back.

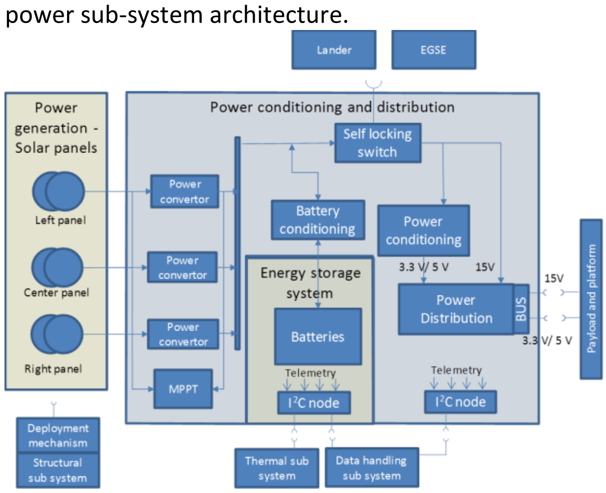
Finally, APPS will need to be able to withstand each environment faced during its life (launch environment, LEO environment, LTO environment and Moon Environment).

Power Subsystem

The APPS Power Subsystem consists of:

- ➢ Solar panels (Power generation function)
- ➢ Batteries (Energy storage function)
- ➢ Power Conditioning and Distribution Unit (PCDU)
  - Power regulation and Power-point tracking
  - Self-locking switch (between APPS and Lunar lander)
  - Power conditioning (3.3V, 5V)
  - Power distribution

The following figure depicts block diagram of APPS power sub-system architecture.



The APPS Power Distribution exploits the electrical power provided by:

- ➢ Solar panels during daylight
- ➢ Batteries during night
- ➢ Solar panels and batteries during daylight to supply electrical power peaks (occurring during Comms Mode)

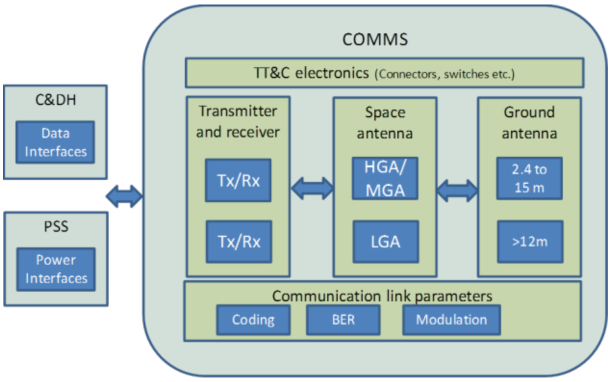
The main challenges that are imposed on APPS equipment are low mass and high TRL (8-9 by 2018).

Communication Subsystem

The Communications S/S is aimed at supporting the exchange of data between the APPS operating on lunar surface and one (or more) Ground Station(s) located on the Earth, in particular:

- ➢ Science data collected by the SEIS are processed and sent to The Earth together with telemetry data via APPS;
- ➢ Telecommands are sent from The Earth and received on lunar surface by APPS.

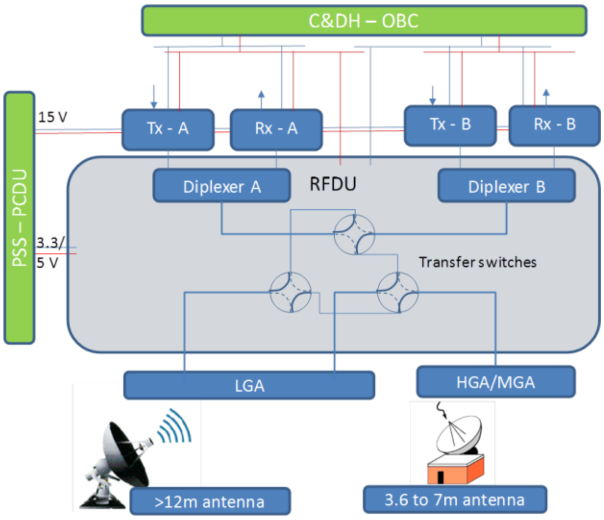
The following figure depicts functional breakdown of COMMS and its interfaces with C&DH sub system (Command and Data Handling) and PSS (power sub-system).



The general approach that has been followed for performing the design of the Communications Subsystem is to focus on low mass, small volume, low power consuming equipment, in order to limit as much as possible the impacts on the overall APPS.
In the following, special care has been given to redundancy aspects that are driving for the feasibility of the mission. In particular, the most critical issue is represented by the power consumption for supporting night survival/operations, which has a direct impact on the energy storage sizing. For this reason, the applied approach has been, first of all, to do not consider transmissions during night, providing only the capability to receive telecommands, secondarily, to investigate the receivers' redundancy strategy, in order to understand how the APPS resources depend on how many receivers are active and for how much time.
The APPS communication subsystem consists of the following on-board equipment:

- Transmitter (Tx); (Transmitter + amplifier)
- Receiver (Rx);
- Transmitter antenna;
- Receiver antenna;
- Radio Frequency Distribution Unit (RFDU);
  - Diplexers
  - switches

The following figure depicts COMMS architecture of APPS and its interfaces with C&DH sub-system and PSS

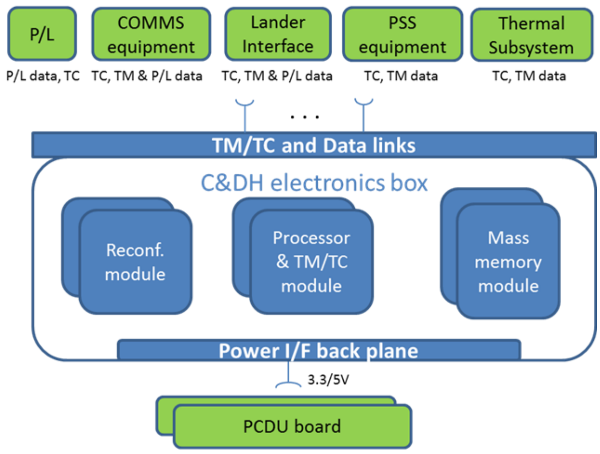


C&DH Subsystem

The main functions of the APPS C&DH Subsystem can be summarised as here in the following:

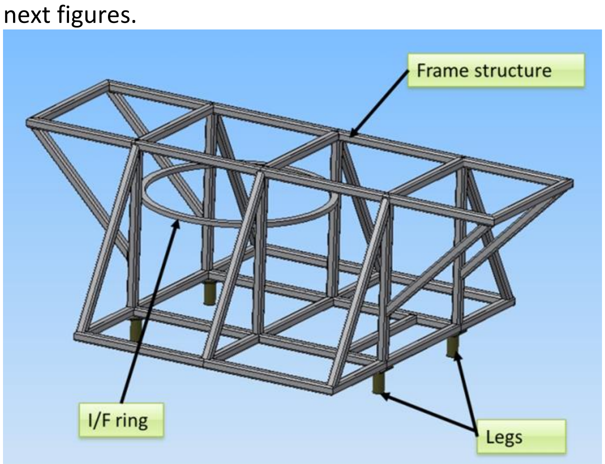
- computation capabilities for running both the APPS platform software and the reference payload application software (PE-ASW);
- interfaces with the Lunar Lander;
- interfaces with the Communications Subsystem;
- interfaces with the Power Subsystem;
- interfaces with the reference payload, i.e. the SEIS;
- interfaces with the Delta-Payloads, i.e.
  - the Magnetometer;
  - the Instrumented Mole;
- end of life mass memory capable to accommodate 2 lunations of payload and housekeeping data, with an upper limit of 30 Gbits;
- single failure tolerant;

The following figure depicts the functional diagram of the APPS C&DH sub-system and its interfaces with other sub-systems and external entities, such as PSS, COMMS, Thermal sub-system, payload and lander.



Structure Subsystem

The structure of the APPS shall be able to withstand launch loads and shall be able to sustain the SEIS on the Moon. The structure is a frame made of CFRP tubes (square cross section 20 mm x 20 mm x 2.76 mm). Four titanium legs are attached to the bottom of the frame structure, and the large solar arrays are fastened to the lateral beams. The radiator is also fastened to the beams on the top of the frame structure and an interface ring for the SEIS shall be connected to the frame structure as can be seen in the next figures.



During the launch four HDRM are foreseen to lock the APPS on the lander. At present stage, these items are not modelled nor the type of HDRM has been selected however, their constraint are taken into account for the following analysis.

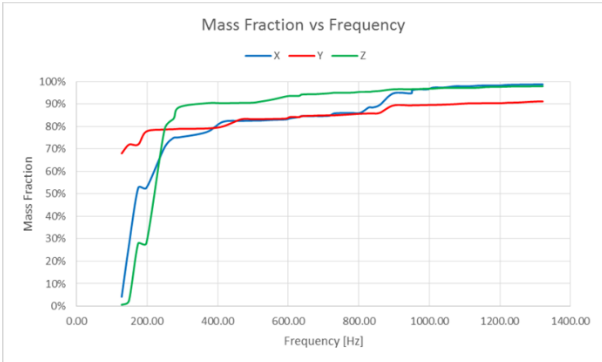
The preliminary FE model has been built as follows:

- Frame structure and legs are modelled as beams
- I/F Ring is modelled as a beam (10 mm x 40 mm)
- Radiator is modelled as a plate
- Solar arrays are modelled as laminated plates
- All the electronic boxes and SEIS are modelled as point masses connected with RBE2 elements to the structure.
- The structure is constrained on four points

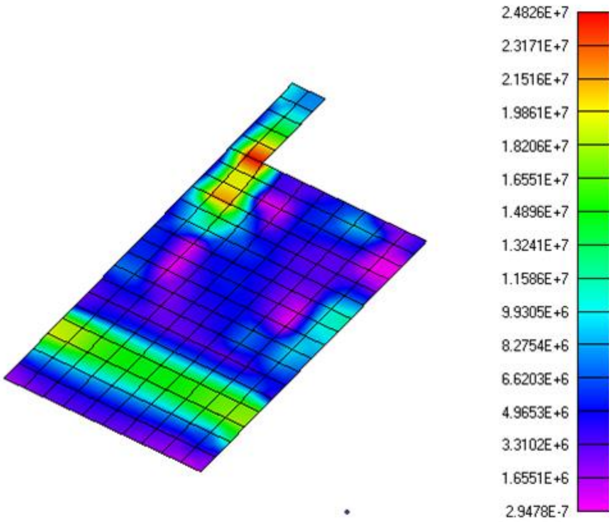
The modal analysis results are reported in the following table.

	f [Hz]	X [kg]	Y [kg]	Z [kg]
1	128	0.89	14.48	0.14
2	148	4.86	0.83	0.37
3	175	5.45	0.02	5.45
4	198	0.00	1.23	0.00
5	250	3.86	0.18	10.82
6	275	0.89	0.03	0.97
7	291	0.05	0.03	1.10
8	369	0.50	0.03	0.38
9	414	0.97	0.19	0.00
10	467	0.09	0.68	0.03

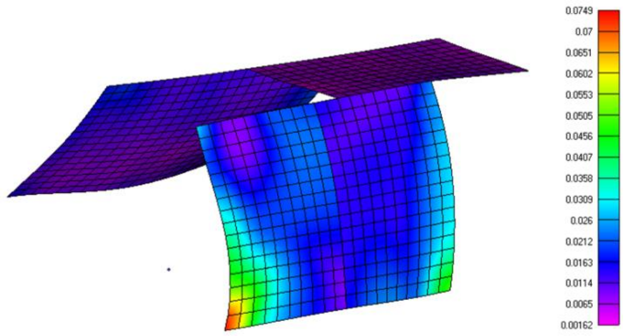
The next image shows the mass fractions.



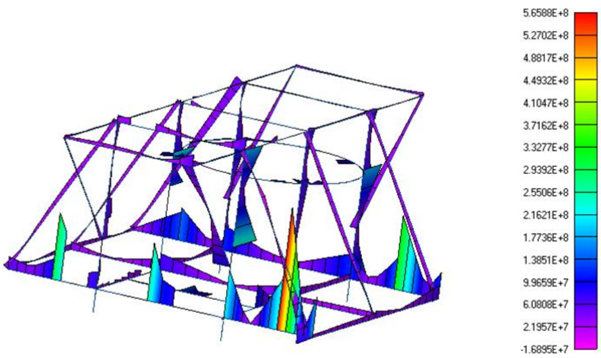
The maximum Von Mises Stress on the radiator among all the load cases is 25 MPa, therefore assuming a safety factor of 2 the resulting margin of safety is 4.8.



The maximum failure index on the Solar Array composite panel is 0.075 (well below the unit) therefore these components are able to survive to launch loads.



For what concerns the frame structure, it is pointed out that the margin of safety cannot be directly evaluated since a beam model was used with an "equivalent material" to represent a composite laminate. It turns out that the maximum stress in the frame is 566 MPa that is near to the ultimate strength of the Aluminium 7075 (~572 MPa) therefore further investigation should be done in order to assess the strength of the frame.



Thermal Control Subsystem

A simplified thermal network has been built and a worst hot and cold case were identified.
It is assumed that each electronic box is covered with MLI and connected to the frame structure by means of insulating washers, the open side of the APPS are also covered with MLI. The radiator is connected to the frame structure with mica thermal insulating washers and the top surface is covered with solar optical reflectors (SOR). The four electronic boxes attached to the radiator are connected using a conductive thermal filler, meanwhile the battery and the other two electronic boxes are connected to the radiator using heat pipes. Titanium legs provide a first insulation from the Moon ground.
Two load cases are taken into account:

- Worst Hot Case: Moon surface at 400 K, sun directly above the APPS for a site at 45° of latitude.
- Worst Cold Case: APPS on the lander with the deep sky in view.

During the Hot case it turns out that the radiator is enough to keep the electronic boxes at a temperature lower than 50 °C however, if the SEIS shall operate at a controlled temperature, a small dedicated radiator (0.01 m2, i.e. 20 cm x 10 cm) shall be used.
During the Cold case it is necessary to provide about 100 W to the heaters in order to keep the electronic boxes within a reasonable temperature range. All the equipment connected to the radiator by heat pipes will be disconnected using heat switches (SEIS, Battery, C&DH).

Development Plan

The APPS development plan shall be defined taking into account all the results coming from the previous phases. In particular, this shall exploit the results obtained by the critical technologies development phase in order to perform the APPS mission within the considered timeframe (2015-2018).

Therefore, for what concerns the APPS development plan, this foresees the following:

- a reference schedule compatible with a mission to be flown in the 2018 timeframe. This is structured into the following main phases:
  - Phase A, lasting 6 months
  - Phase B, lasting 12 months
  - Phase C/D, lasting 30 months
- During phase A study all the possible critical technology shall be investigated and assessed
- during the phase B, predevelopment study will be performed on possible critical technology identified during phase A
- during the phase C/D, AIT activities are foreseen starting from SS level;

Here below (see Table 3 1), it is then reported the proposed APPS Model Philosophy.

APPS	Hardware Matrix			
	STM	Development Model BB	EM	PFM
Structure	1			1
Thermal Control	1			1
C&DM	dummy		1	1
Power Generation	dummy	1	1	1
Energy Storage	dummy		1	1
Power Mgm&Dist	dummy		1	1
Communication	dummy		1	1

Cost Assesment

Considering the estimated costs provided for each different program phase, achieved via a bottom-up method, it is here provided the estimation of the program total cost as the pure algebraic sum of the min. and max. cost estimations from each different phase. It has to be remarked that this sum is performed without making any statistical analysis.

Project Phases	Total Bottom Up Costs (k€) – Min	Total Bottom Up Costs (k€) - Max
Phase A	374,4	583,2
Phase B	986,4	1536,48
Phase C/D	7936	11861,6
APPS Total Cost	**9296,8**	**13981,28**