Final Review Presentation

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Approval evidence is kept within the documentation management system.

EUROPEAN CHARGING STATION PRE-PHASE A

FINAL REVIEW

TABLE OF CONTENTS

FINAL REVIEW

/// Previous reviews

- **MTR :** DECEMBER 16^{TH}, 2022
- **DR :** APRIL 21^{ST} , 2023

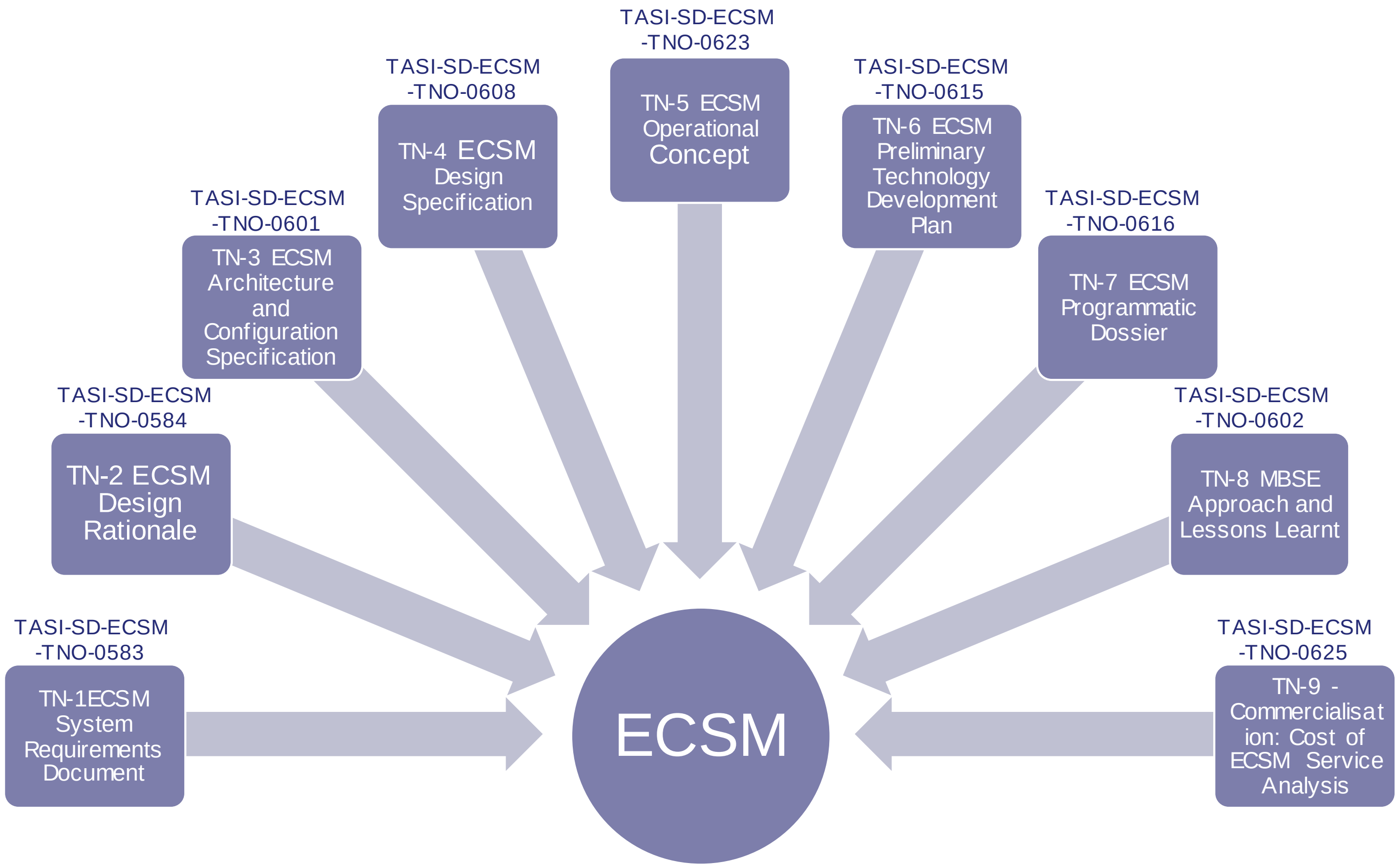
/// Review objective

- THE REVIEW IS HELD TO CRITICALLY ANALYSE THE OUTPUT OF ALL TASKS

/// Final review Data Package content

- **TECHNICAL DATA PACKAGE**
- **PHOTOGRAPHIC DOCUMENTATION** (NA)
- **OPEN CAD MODEL** (TASI-SD-ECSM-MDL-0056, TASI-SD-ECSM-MDL-0055)
- **FINAL PRESENTATION** (TASI-SD-ECSM-PRB-0285)
- **FINAL PRESENTATION RECORDING (NA)**
- **EXECUTIVE SUMMARY REPORT** (TASI-SD-ECSM-PRB-0284)
- **FINAL REPORT** (TASI-SD-ECSM-ORP-0287)

LAYOUT OF THE FINAL REVIEW TECHNICAL DATA PACKAGE



ACTION ITEM STATUS LIST

Reference Document	Action ID	Meeting Title	Meeting Date	Actionee Organisation	Action Description	Due Date	Status	Closure Date	Closure Reference
BID/NP/22/0287	TAS-I_#1	Negotiation Meeting for 1-11115 "NOVEL LUNAR SURFACE POWER PLANT - EUROPEAN CHARGING STATION PRE-PHASE A"	6/23/2022	TAS-I	TAS-I to provide list and roles of the non Key people involved in Pre-A phase (delivery of detailed CV is not mandatory)	6/27/22	Closed	7/1/2022	Signed BID/NP/22/0287
BID/NP/22/0287	TAS-I_#2	Negotiation Meeting for 1-11115 "NOVEL LUNAR SURFACE POWER PLANT - EUROPEAN CHARGING STATION PRE-PHASE A"	6/23/2022	TAS-I	TAS-I to provide apportion of budget (hours) allocated L.K Engineering.	6/27/22	Closed	7/1/2022	Signed BID/NP/22/0287
BID/NP/22/0287	TAS-I_#3	Negotiation Meeting for 1-11115 "NOVEL LUNAR SURFACE POWER PLANT - EUROPEAN CHARGING STATION PRE-PHASE A"	6/23/2022	TAS-I	TAS-I to provide master schedule updated by considering the agreed Kick-Off date and company closure due to summer period.	6/27/22	Closed	7/7/2022	TASI-SD-ECSM-0763 (Annex A)
TASI-SD-ECSM-MIN-0763	TAS-I_#4	Kick-Off Meeting for 1-11115 "NOVEL LUNAR SURFACE POWER PLANT - EUROPEAN CHARGING STATION PRE-PHASE A"	7/7/2022	TAS-I	Setup a meeting with Aidan Cowley to identify what could be exchanged between Industry and VR team. Some cross-potentialities between MBSE and VR could be prototyped in this frame	7/22/22	Closed	7/25/2022	Summary of the telecon distributed by email (CG on 25/7/22)
TASI-SD-ECSM-MIN-0763	TAS-I_#5	Kick-Off Meeting for 1-11115 "NOVEL LUNAR SURFACE POWER PLANT - EUROPEAN CHARGING STATION PRE-PHASE A"	7/7/2022	TAS-I	TAS-I to identify scenario to be used as reference for sizing power storage and generation taking into account shadowing effects during daylight.	7/22/22	Closed	7/25/2022	TASI-SD-ECSM-MIN-0765 (Annex A)
TASI-SD-ECSM-MIN-0763	ESA_#6	Kick-Off Meeting for 1-11115 "NOVEL LUNAR SURFACE POWER PLANT - EUROPEAN CHARGING STATION PRE-PHASE A"	7/7/2022	ESA	ESA to provide feedback/status about documentation and input expected to be delivered at the K-O.	7/22/22	Closed	7/25/2022	AD17, RD8 and RD9 provided (XB email)
TASI-SD-ECSM-MIN-0765	ESA_#7	EUROPEAN CHARGING STATION PRE-PHASE A" – PM#1	7/25/2022	ESA	ESA to assess possibility and eventually to distributed RFC TDA information	7/29/2022	Closed	8/9/2022	Telecon summary (PM email)
TASI-SD-ECSM-MIN-0765	ESA_#8	EUROPEAN CHARGING STATION PRE-PHASE A" – PM#1	7/25/2022	ESA	ESA to confirm that ECSM has to be considered thermally and electrically independent from LDE after landing only	7/29/2022	Closed	8/9/2022	Telecon summary (PM email)
TASI-SD-ECSM-MIN-0777	ESA_#9	EUROPEAN CHARGING STATION PRE-PHASE A" – PM#2	9/16/2022	ESA	ESA to provide/review the feedbacks on TAS-I comments (or raised issues) traced in both PM#1 and PM#2 MoM (and presentation)	9/21/2022	Closed	9/23/2022	File provided by email (XB on 23/9/2022)
TASI-SD-ECSM-MIN-0777	TAS-I#10	EUROPEAN CHARGING STATION PRE-PHASE A" – PM#2	9/16/2022	TAS-I	TAS-I to verify if plot about moon soil temperature can be shared by ESA.	9/21/2022	Closed	3/10/2022	TASI-SD-ECSM-0783
TASI-SD-ECSM-MIN-0783	ESA_#11	EUROPEAN CHARGING STATION PRE-PHASE A" – PM#3	10/3/2022	ESA	ESA to provide feedback on comments about LS-020 and SYS-060 as part of the evaluation of the TN-1.	10/17/2022	Closed	21/4/2023	TASI-SD-ECSM-0855 (superseded)
TASI-SD-ECSM-MIN-0783	ESA_#12	EUROPEAN CHARGING STATION PRE-PHASE A" – PM#3	10/3/2022	ESA	ESA to provide updated MSRD for uploading in DOORS (document in word format would be appreciated).	10/10/2022	Closed	11/15/2022	Draft revise [RD13] MSRD provided by email (XB on 15/11/22)
TASI-SD-ECSM-MIN-0783	TAS-I#13	EUROPEAN CHARGING STATION PRE-PHASE A" – PM#3	10/3/2022	TAS-I	TAS-I to include in the TN-2 description of the trade-off criteria.	10/10/2022	Closed	10/18/2022	TASI-SD-ECSM-TNO-0584
TASI-SD-ECSM-MIN-0790	ESA_#14	EUROPEAN CHARGING STATION PRE-PHASE A" – PM#4	11/4/2023	ESA	TAS-I to update the TN-2 as per clarification/recommendation traced in the section 3 of the TASI-SD-ECSM-MIN-0790.	12/2/2022	Closed	12/2/2022	TASI-SD-ECSM-TNO-0584 Issue_2

ACTION ITEM STATUS LIST

Reference Document	Action ID	Meeting Title	Meeting Date	Actionee Organisation	Action Description	Due Date	Status	Closure Date	Closure Reference
TASI-SD-ECSM-MIN-0805	TAS_#15	EUROPEAN CHARGING STATION PRE-PHASE A" – MTR	12/16/2022	TAS-I	TAS-I to reassess the Solar Array power conditioning technique as part of the Task-4, following notably an assessment of the current state of the technology for power units.	4/21/2023	Closed	31/1/2023	TASI-SD-ECSM-MIN-0816
TASI-SD-ECSM-MIN-0805	TAS_#16	EUROPEAN CHARGING STATION PRE-PHASE A" – MTR	12/16/2022	TAS-I	TAS-I to take benefit of the RFCS development activity currently on-going with TAS-IT on Lunar night survival for EL3 (contract # 4000138165) for both sizing and technology definition expected to be performed in Task-4.	4/21/2023	Closed	4/3/2023	TASI-SD-ECSM-MIN-0848
TASI-SD-ECSM-MIN-0805	TAS_#17	EUROPEAN CHARGING STATION PRE-PHASE A" – MTR	12/16/2022	TAS-I	TAS-I to provide reference of the NASA RFCS scheme presented in TN-3 page 23 (Figure 2.1-5).	1/31/2023	Closed	1/26/2023	PM email sent on 1/26/2023
TASI-SD-ECSM-MIN-0805	TAS_#18	EUROPEAN CHARGING STATION PRE-PHASE A" – MTR	12/16/2022	TAS-I	TAS-I to discuss the issue of RFCS mass calculation further with ESA during the execution of Task-4.	3/1/2023	Closed	4/3/2023	TASI-SD-ECSM-MIN-0848
TASI-SD-ECSM-MIN-0805	TAS_#19	EUROPEAN CHARGING STATION PRE-PHASE A" – MTR	12/16/2022	TAS-I	TAS-I to review the AD4 with the aim to identify potential conflict with the applicable ECSS standard for what concern the ECSM EPS design. The identification will be part of Task-4 on System Design.	4/21/2023	Closed	1/31/2023	TASI-SD-ECSM-MIN-0816 (and ESA confirmation - XB email on February 2nd)
TASI-SD-ECSM-MIN-0805	ESA_#20	EUROPEAN CHARGING STATION PRE-PHASE A" – MTR	12/16/2022	ESA	ESA to review the AD4 with the aim to identify potential conflict with the applicable ECSS standard for what concern the ECSM EPS design.	1/31/2023	Closed	3/1/2023	TASI-SD-ECSM-MIN-0826
TASI-SD-ECSM-MIN-0816	ESA_#21	EUROPEAN CHARGING STATION PRE-PHASE A" – PM#5	1/31/2023	ESA	ESA to provide feedback on the provided comments, assumption and interpretation together with confirmation that action AI TAS_#19 is properly closed	2/8/2023	Closed	3/1/2023	TASI-SD-ECSM-MIN-0826
TASI-SD-ECSM-MIN-0816	ESA_#22	EUROPEAN CHARGING STATION PRE-PHASE A" – PM#5	1/31/2023	ESA	ESA to provide feedback on the proposed TN-5 TOC and on the TAS-I proposal to not include the performance analysis of the operational concept as part of the same TN-5.	2/8/2023	Closed	4/3/2023	TASI-SD-ECSM-MIN-0848
TASI-SD-ECSM-MIN-0816	TAS_#23	EUROPEAN CHARGING STATION PRE-PHASE A" – PM#5	1/31/2023	TAS-I	To consider scenario where the load connection is performed in a robotic way through connectors.	4/21/2023	Closed	6/4/2023	TASI-SD-ECSM-TNO-0623 - TN-5 ECSM Operational Concept
TASI-SD-ECSM-MIN-0816	ESA_#24	EUROPEAN CHARGING STATION PRE-PHASE A" – PM#5	1/31/2023	ESA	ESA to provide feedback/comments on the TN-8 DRAFT presented as part of the documentation submitted to MTR.	2/8/2023	Closed	3/1/2023	TASI-SD-ECSM-MIN-0826

ACTION ITEM STATUS LIST

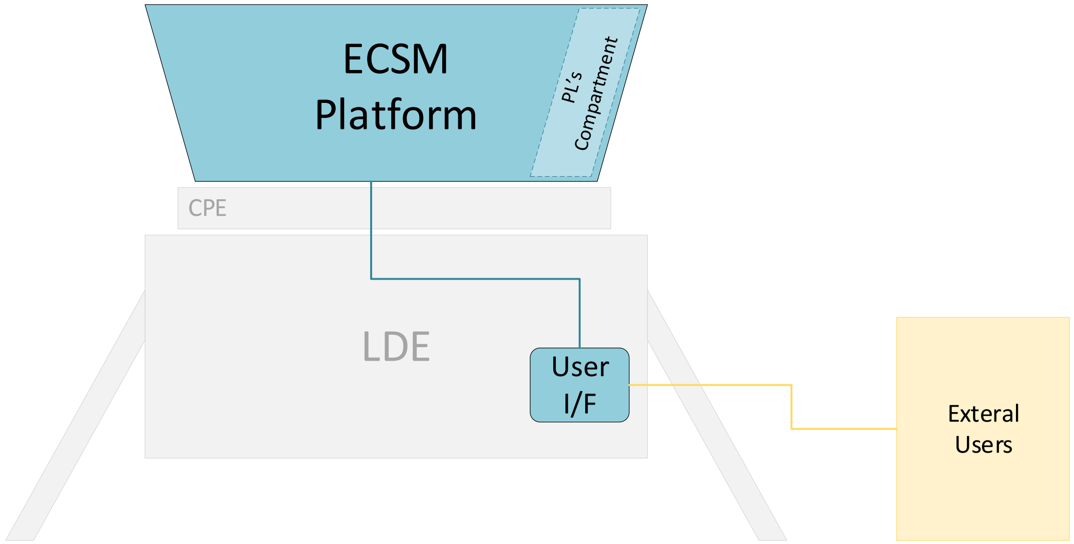
TASI-SD-ECSM-MIN-0855	TAS_#25	EUROPEAN CHARGING STATION PRE-PHASE A" – Design Review	4/21/2023	TAS-I	TAS-I to update EPS Design and then the TN-4 by including following agreed clarification. (Due date: Final review). The activation/deactivation of the RFC is autonomously managed by the PCDU in both the charge and discharge phases. Management of the RFCS is comparable to the battery ones i.e. controlled by the Main Error Amplifier signal generated inside the PCDU. RFCS is operated when the MEA signal is in within the voltage range corresponding to either RFCS Discharge or RFCS Recharge. List of domain follows: - External link Domain (Ext Link power source) - Tapering Domain (Solar Array power source, RFCS and Battery charged) - Recharge Domain (Solar Array power source, RFCS and Battery re-charged) - RFCS Discharge Domain (RFCS power source, RFCS discharged) - Battery Discharge Domain (Battery power source, Battery discharged)	6/21/2023	Closed	6/29/2023	TASI-SD-ECSM-TNO-0608 I2
TASI-SD-ECSM-MIN-0855	TAS_#26	EUROPEAN CHARGING STATION PRE-PHASE A" – Design Review	4/21/2023	TAS-I	TAS-I to update the TN-4 by correcting typos on 120V bus definition (unregulated instead of regulated)	6/21/2023	Closed	6/29/2023	TASI-SD-ECSM-TNO-0608 I2
TASI-SD-ECSM-MIN-0855	TAS_#27	EUROPEAN CHARGING STATION PRE-PHASE A" – Design Review	4/21/2023	TAS-I	TAS-I to update the TN-4 by including following agreed clarification. (Due date: Final review). The direct injection of the ECSM external power lines (the one from LDE/CPE) in the power bus means that the it will not be injected in parallel to other un-active power source (e.g. Solar Array) as it is done for instance in other EPS stack architectures where power chain is foreseen (e.g. BepiColombo). A dedicated converter(s) is foreseen in the PCDU to regulate power form either LDE/CPE or EGSE adapting also voltage levels (as visible in the EPS diagram). External link is autonomously managed by the PCDU (Main Error Amplifier) assigning to it the highest priority. Overall priority list for the power sources is the following: 1) External link 2) Solar Array 3) RFCS 4) Battery	6/21/2023	Closed	6/29/2023	TASI-SD-ECSM-TNO-0608 I2
TASI-SD-ECSM-MIN-0855	TAS_#28	EUROPEAN CHARGING STATION PRE-PHASE A" – Design Review	4/21/2023	TAS-I	TAS-I to update the TN-4 by harmonizing the nomenclature of the elements composing the PCDU (Figure 2.4-5 and Table 2.4-1)	6/21/2023	Closed	6/12/2023	TN-4 proposed updating accpeted (XB emial 6/12/2023)

ACTION ITEM STATUS LIST

Reference Document	Action ID	Meeting Title	Meeting Date	Actionee Organisation	Action Description	Due Date	Status	Closure Date	Closure Reference
TASI-SD-ECSM-MIN-0855	TAS_#29	EUROPEAN CHARGING STATION PRE-PHASE A" – Design Review	4/21/2023	TAS-I	TAS-I to update the TN-6 by re-assessing the PCDU TRL.	6/21/2023	Closed	6/12/2023	TN-4 proposed updating accpeted (XB emial 6/12/2023)
TASI-SD-ECSM-MIN-0855	TAS_#30	EUROPEAN CHARGING STATION PRE-PHASE A" – Design Review	4/21/2023	TAS-I	TAS-I to investigate proper parameter to be used as dust degradation factor (EL3 Argonaut project) and to propose it to ESA before redesign of the SA that will be reflected in the updated TN-4. (Due date: Final review)	6/21/2023	Closed	6/12/2023	TN-4 proposed updating accpeted (XB emial 6/12/2023)
TASI-SD-ECSM-MIN-0855	TAS_#31	EUROPEAN CHARGING STATION PRE-PHASE A" – Design Review	4/21/2023	TAS-I	TAS-I to update RFCS Design and then the TN-4 by considering 20% tank losses as per ESA recommendation.	6/21/2023	Closed	6/12/2023	TN-4 proposed updating accpeted (XB emial 6/12/2023)
TASI-SD-ECSM-MIN-0855	TAS_#32	EUROPEAN CHARGING STATION PRE-PHASE A" – Design Review	4/21/2023	TAS-I	TAS-I to update the TN-6 by addressing the TRL of each element belonging to "auxiliary equipment's".	6/21/2023	Closed	6/12/2023	TN-4 proposed updating accpeted (XB emial 6/12/2023)
TASI-SD-ECSM-MIN-0866	ESA_#33	EUROPEAN CHARGING STATION PRE-PHASE A" – PM#8	5/17/2023	ESA	ESA to provide feedback on the proposal for closure of action items: TAS#31, TAS#32, TAS#28, TAS#29, TAS#30.	9/6/2023	Closed	6/12/2023	TN-4 proposed updating accpeted (XB emial 6/12/2023)
TASI-SD-ECSM-MIN-0866	ESA_#34	EUROPEAN CHARGING STATION PRE-PHASE A" – PM#8	5/17/2023	ESA	ESA to provide feedback on the proposed content/format of the Final DP, in particular for: CAD, FPR, ESR.	9/6/2023	Closed	6/19/2023	TN-9 Clarification telecon

ECSM – ELEMENTS

- **ECSM Platform**
  - EPS & RFCS
  - TT&C
  - DHS
  - TCS
  - Structure
  - LDE/CPE I/F’s
  - PL’s compartment (Option)
- **User Interface**
  - Connectors
  - Lamps
  - Protection/Safety devices
  - Camera (Recommended)
- **External Users**
  - For power demand definition only



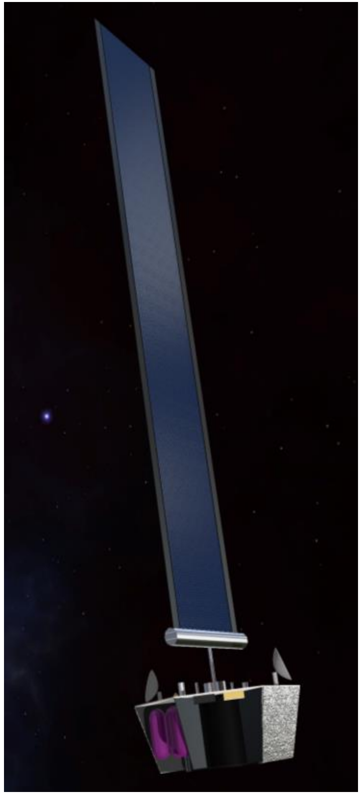
ECSM OVERVIEW

- The European Charging Station for the Moon (ECSM) has been designed to be integrated within the EL3 Architecture, which provides the function of transportation of ECSM to the lunar surface

- Following two main scenarios have been taken into consideration:
  - **ASTROSCI:** used as ECSM reference use case, aimed at making available a targeted continuous power (7.7kw) to the users during lunar day and at providing a reduced amount of power to the users during lunar night
  - **PEAKPWR:** aimed at maximizing the continuous power provision to the users during lunar day, providing a peak power boost for a short time period to the users (3 hours)

- In all analyzed scenario the power is generated by the on board Solar Array and stored in both RFCS and Li-Ion battery. Power is conditioned by the relevant sections in the PCDU unit and distributed by means of reliable power busses:
  - **120V UNREGULATED POWER BUS** (high power external loads, TCS, high voltage ECSM system equipment's)
  - **28V FULLY REGULATED POWER BUS** (low power external loads, low voltage ECSM system equipment's)

- Boundary constraints made applicable to ECSM study though the specification and applicable SOW:
  - **NO NUCLEAR THERMAL POWER GENERATION (E.G. RHU).**
  - **THE ECSM IS FULLY INDEPENDENT FROM THE LDE AFTER THE LANDING**



ECSM AVIONIC DRAWING

/// EPS

- PCDU
- LI-ION BATTERY (IES)
- RFCS
- SOLAR ARRAY ASSEMBLY

/// TT&C

- K AND S BANDS
- 3 LGA AND 2 HGA

/// DHS

- OBC+RTU
- MIL-BUS AND SPACEWIRE COMMUNICATION LINKS

/// TCS

/// LDE I/F

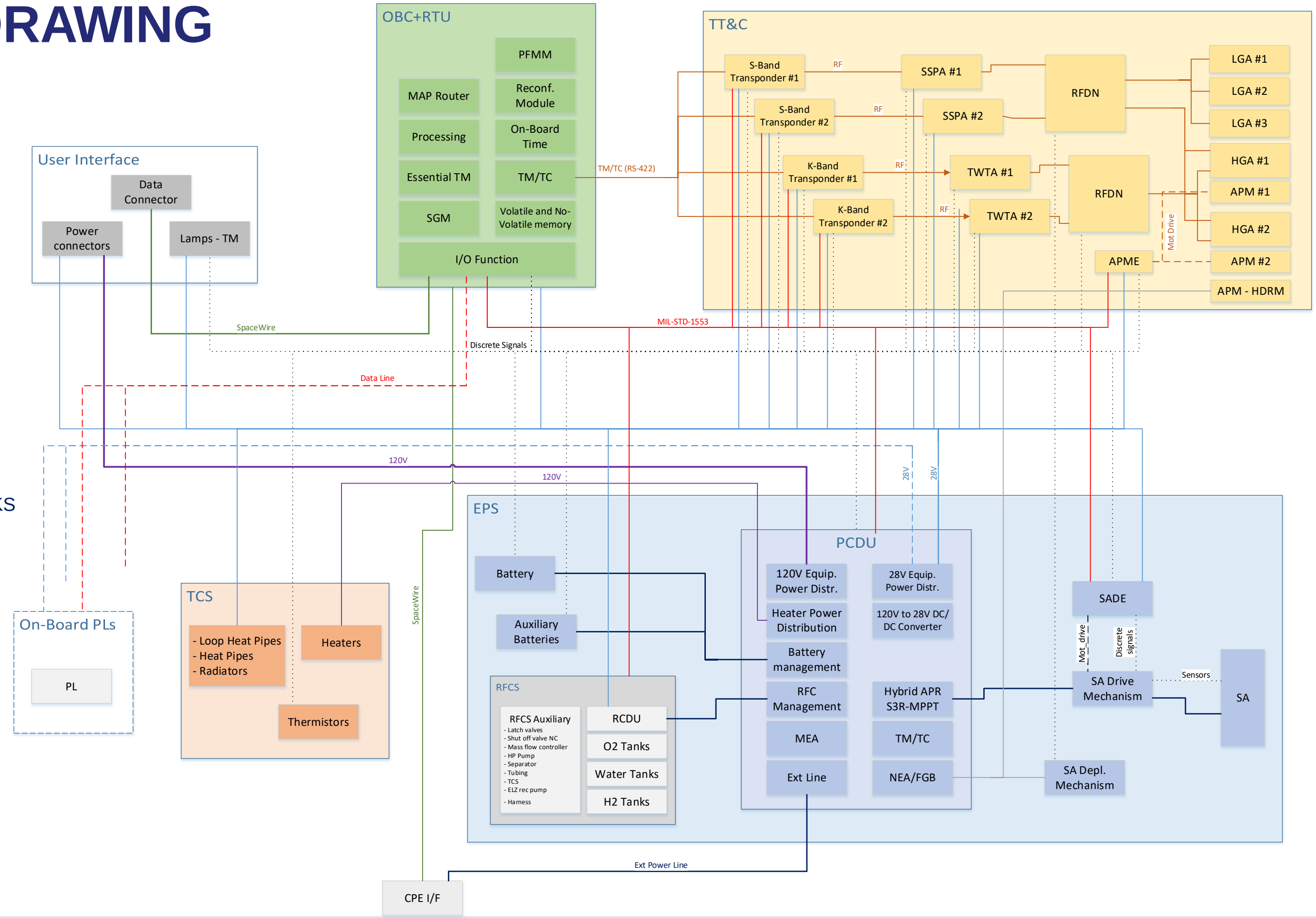
- POWER AND DATA

/// Users Interface

- LOCATED IN LDE COMPARTMENT

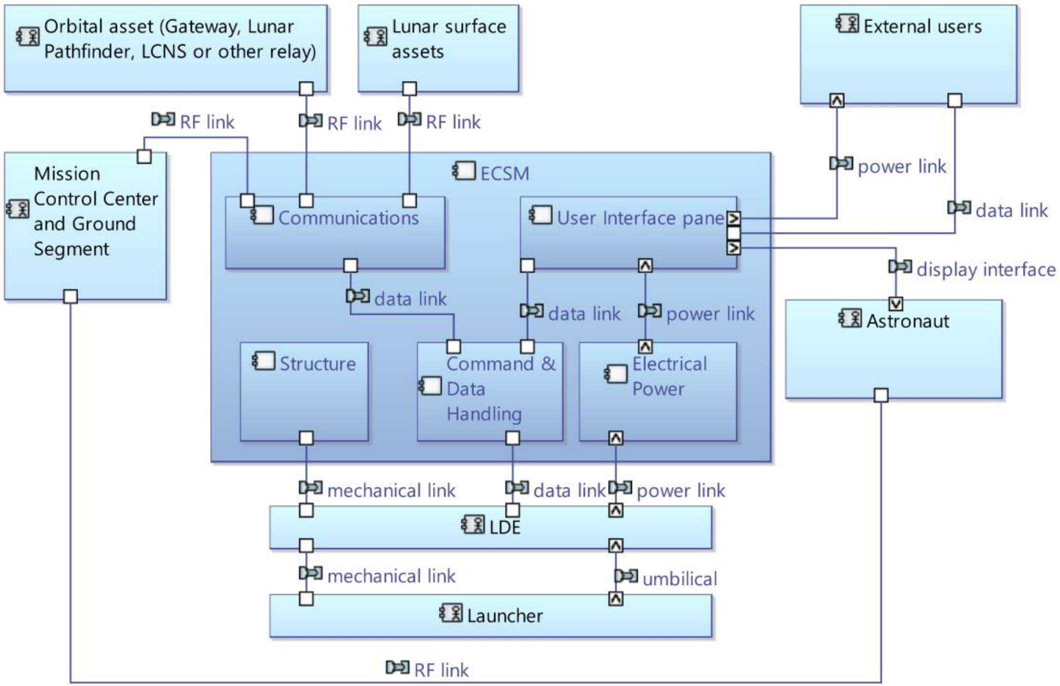
/// Option (modular approach)

- ON-BOARD PL'S



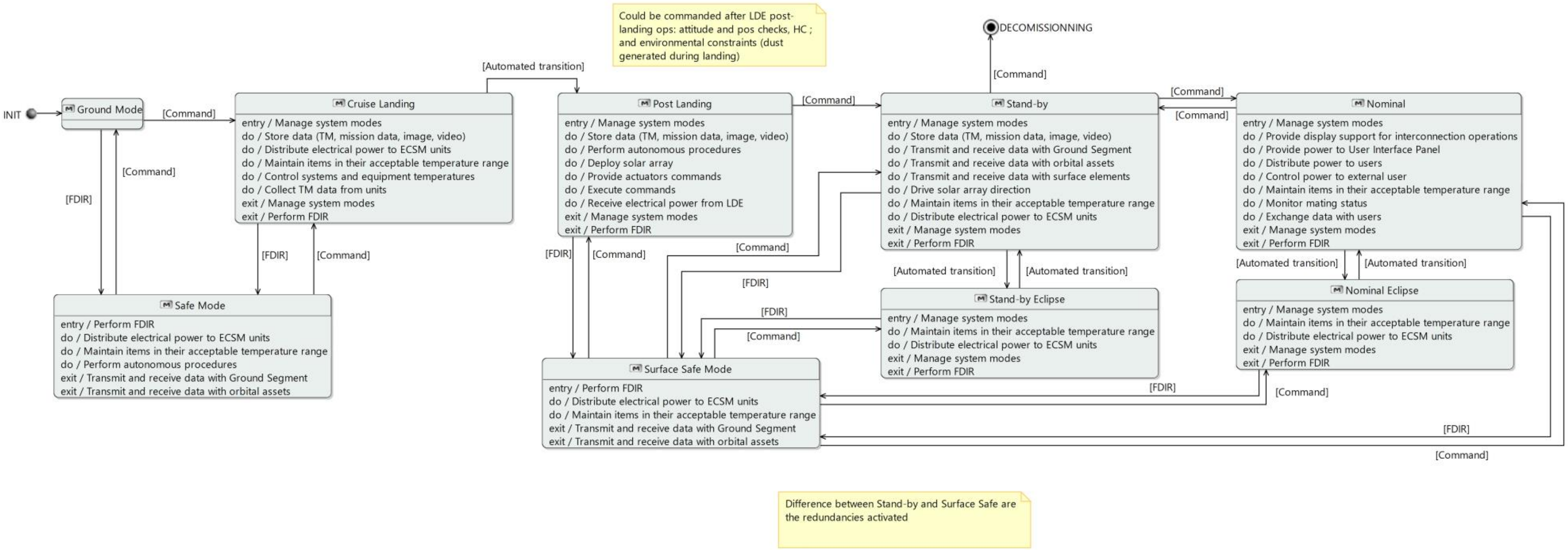
MBSE

/// Sub-system interfaces with external actors



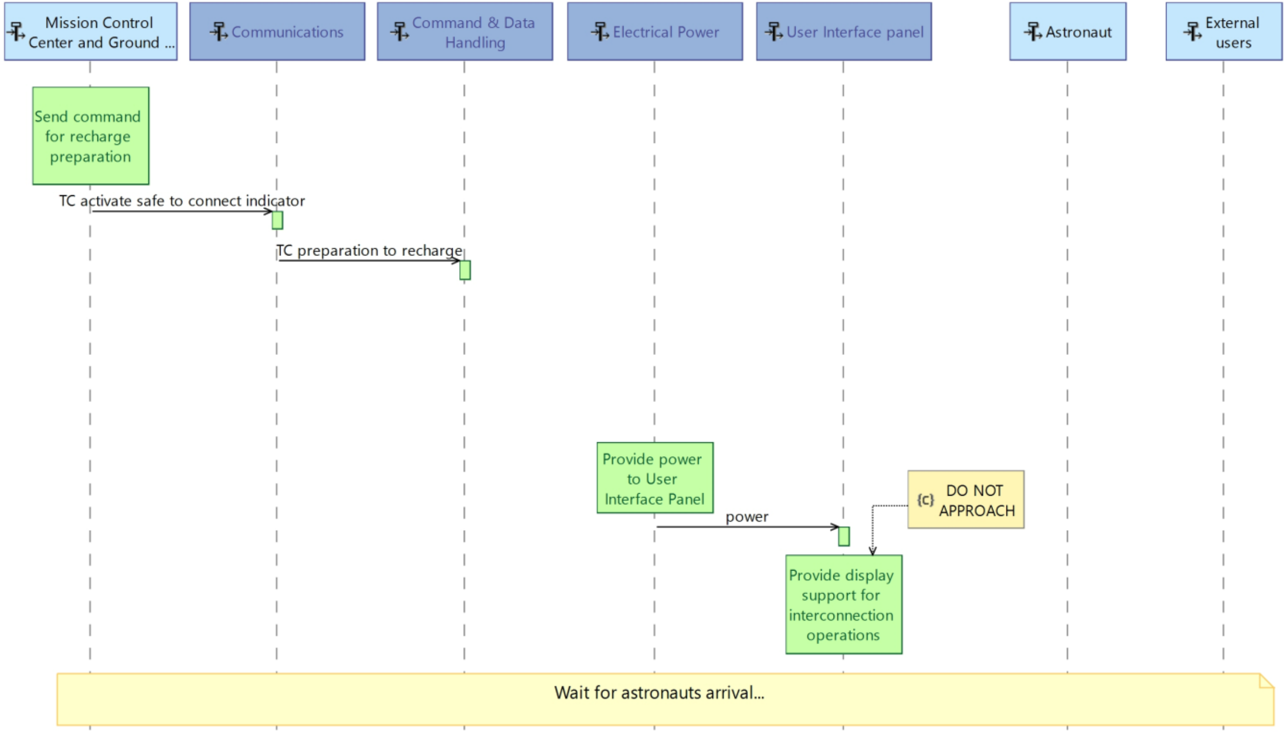
MBSE

/// System modes with allocated functions



MBSE

/// Operational concept of Astronaut-in-the-loop recharge scenario



MBSE

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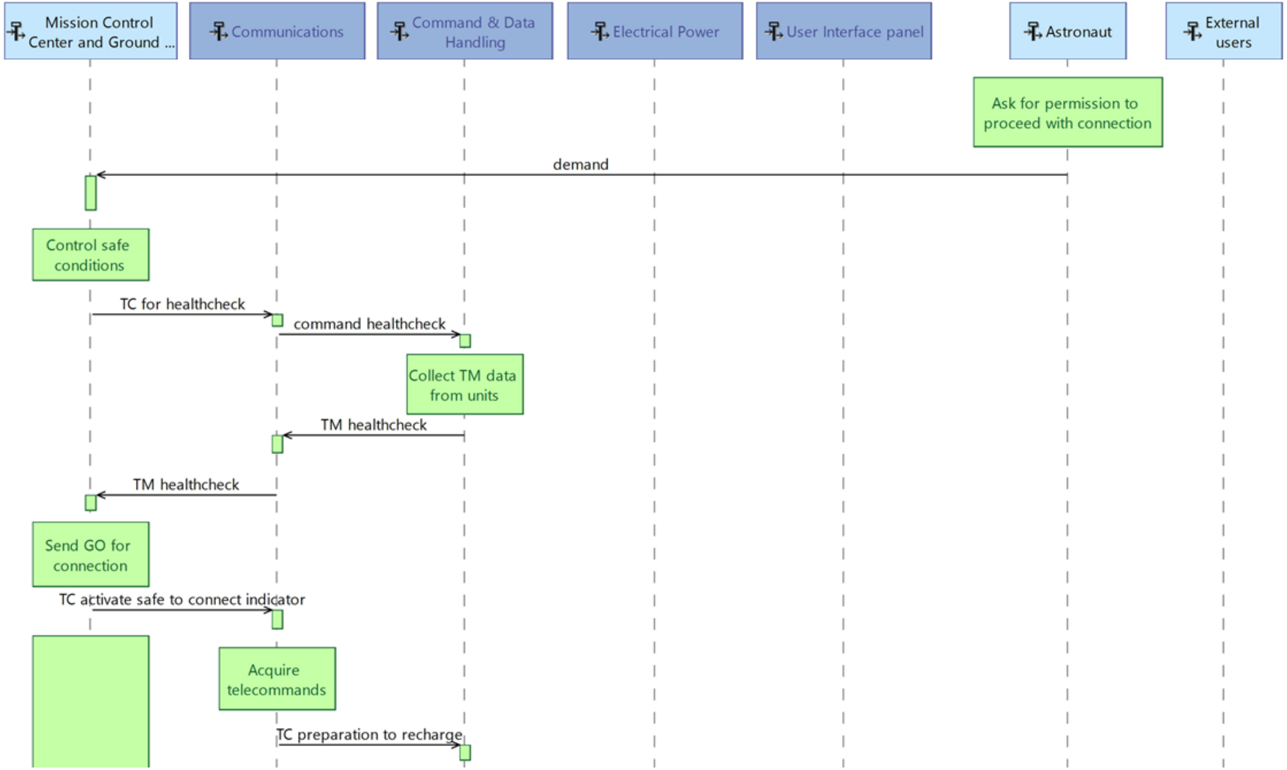

MBSE

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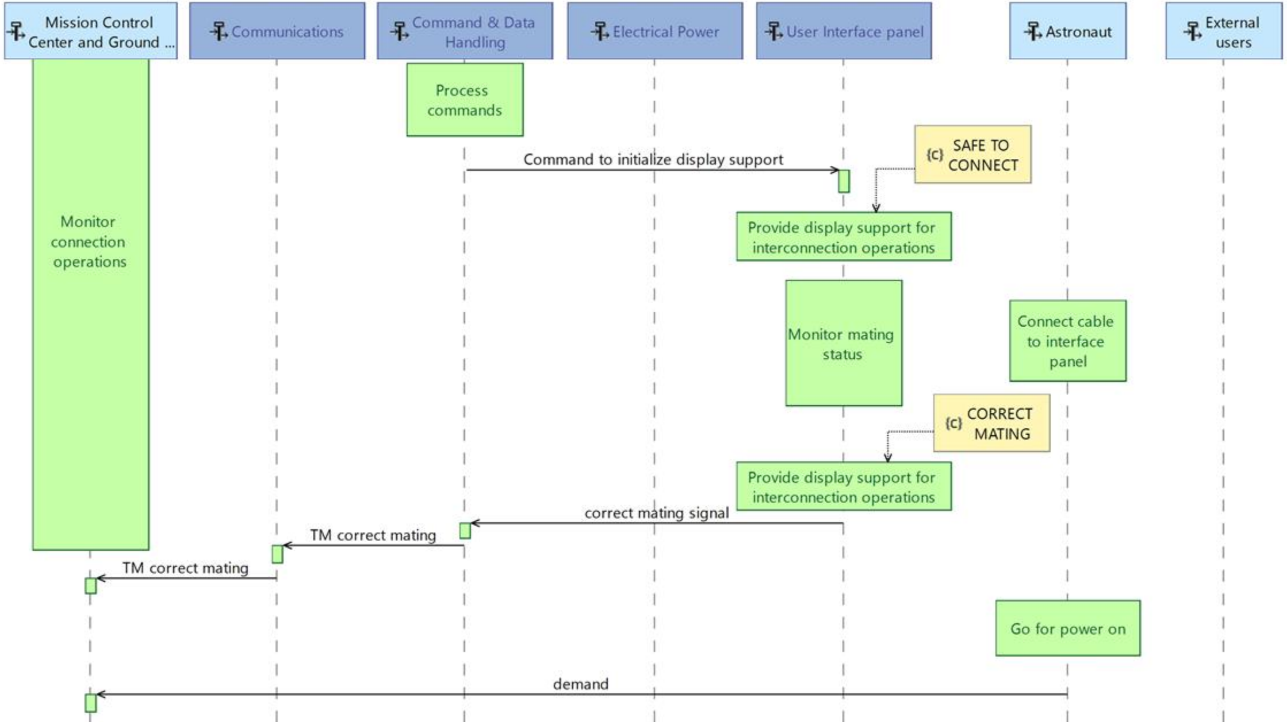

MBSE

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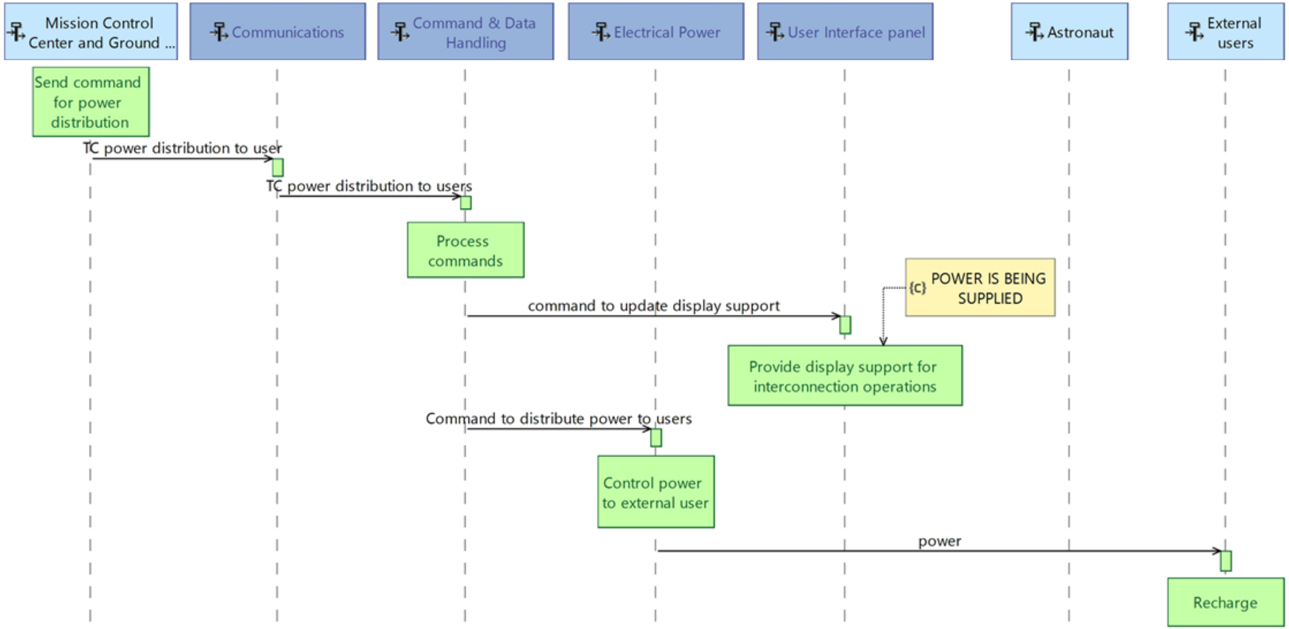

MBSE

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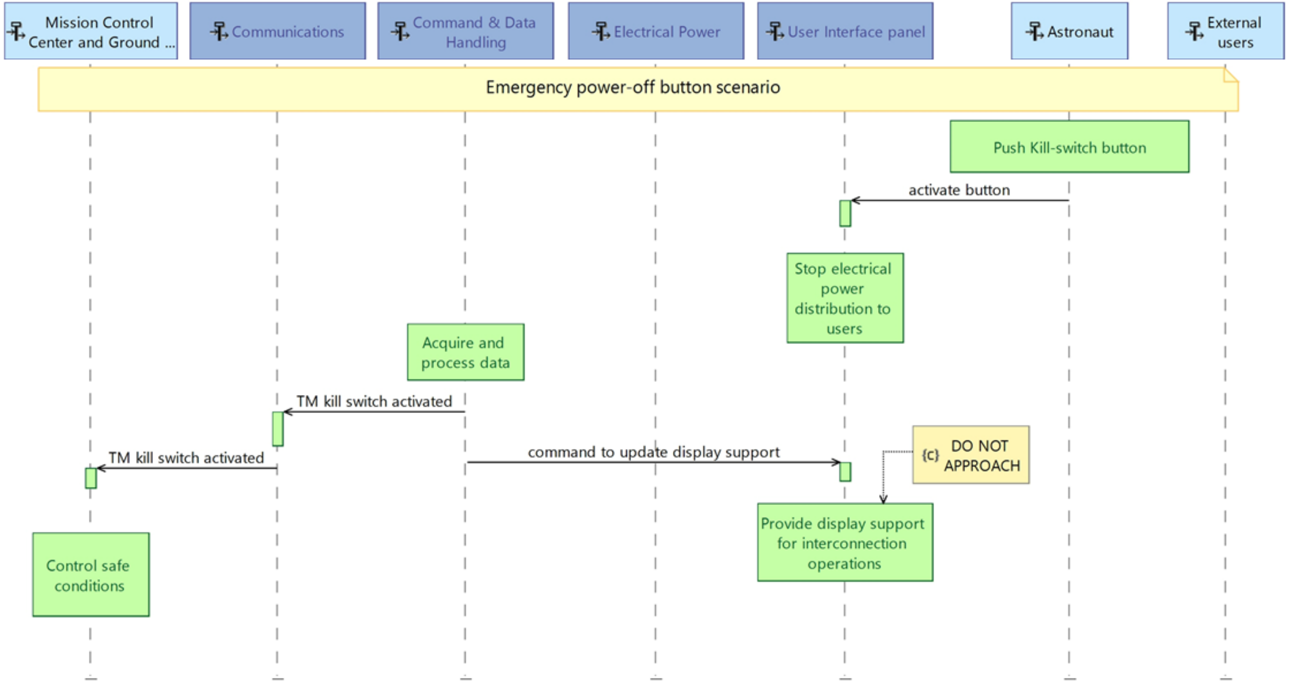
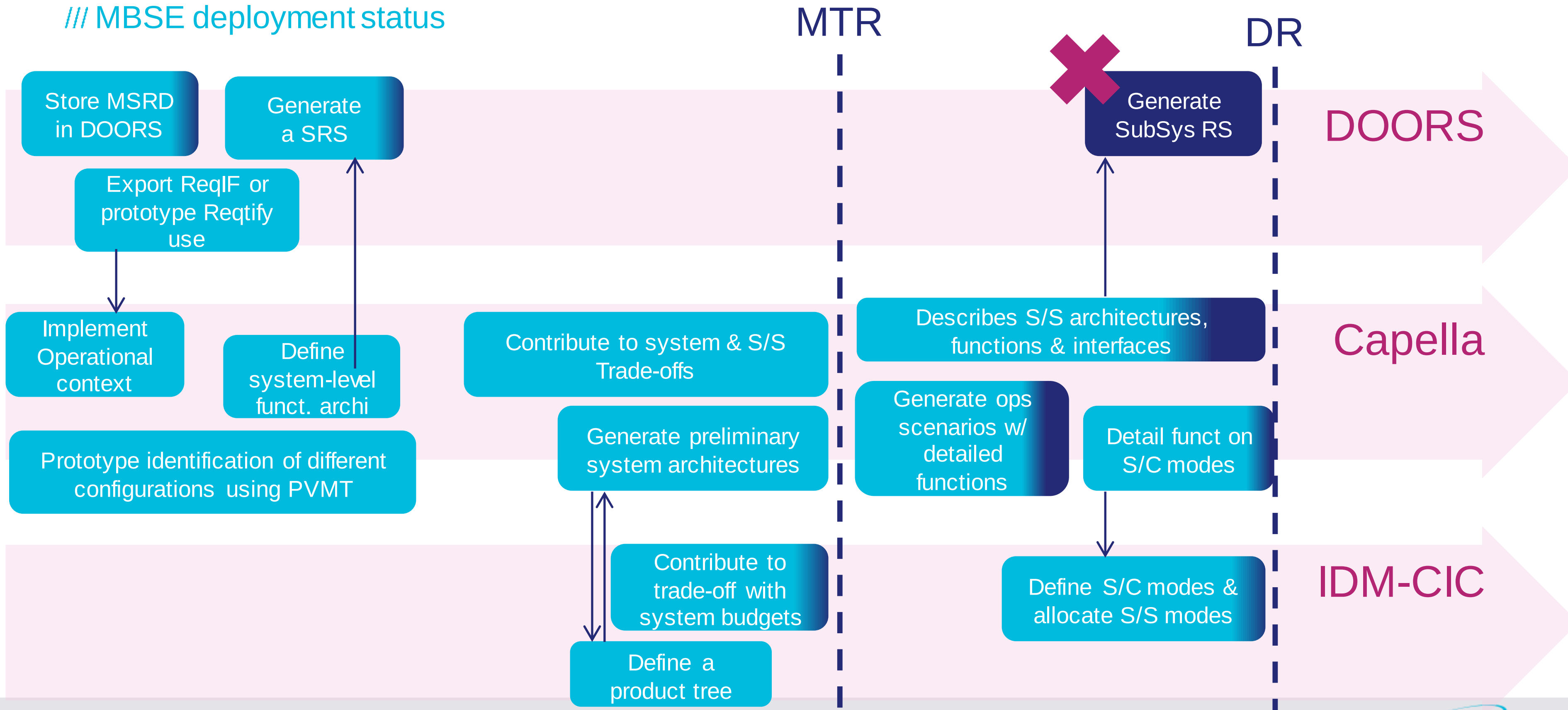


MBSE

/// MBSE deployment status



MBSE

/// Most interesting feedbacks on applying MBSE on ECSM (others are presented in TN-8)

MANAGE SYSTEM BUDGETS

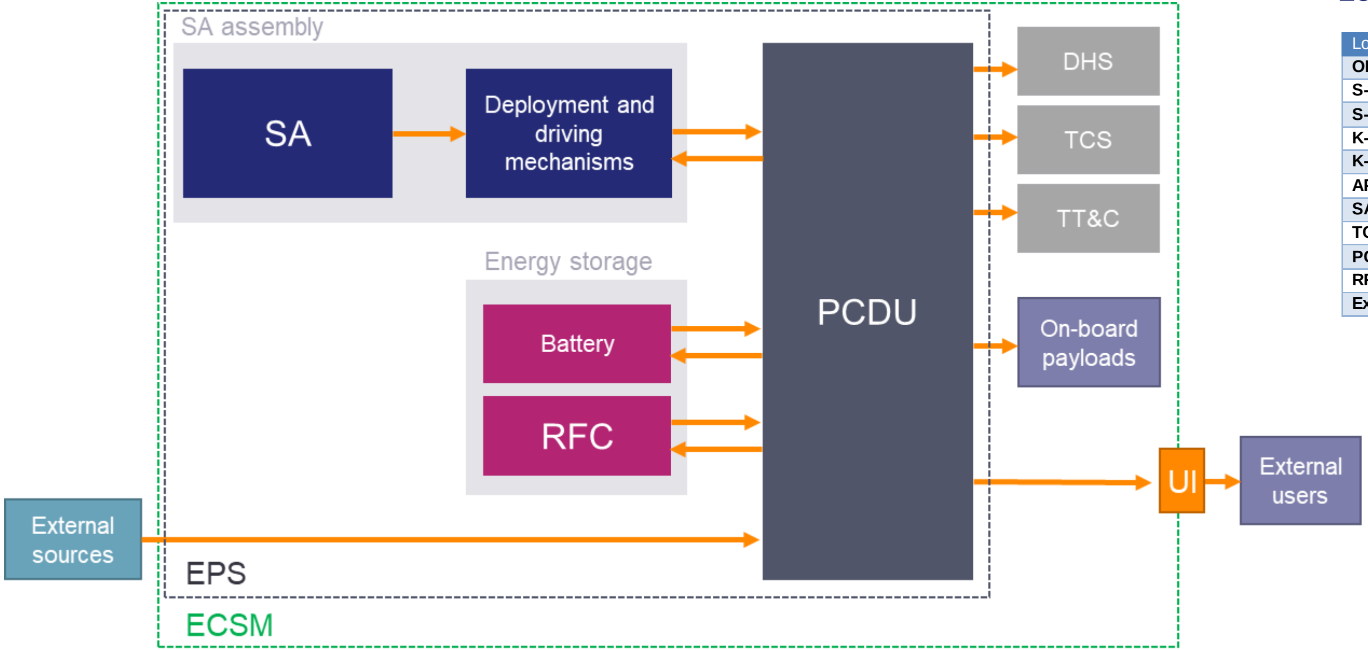
- The first iteration of the power budget has been made before the setup of the IDM-CIC environment
- EPS specialist complemented the IDM budget for the sizing of the EPS components (to take into account losses proportional to the EPS managed power)
- Since IDM does not provide this feature, the EPS sizing inputs and IDM power budget have been maintained aligned manually during the study
- **Take-away #1: It should be useful to increase some freedom for specialists to reuse the data of the IDM model, to increase the broad adoptability**
- **Take-away #2: The use of COMET would have enabled such capability of data re-use for specialist needs**

REQUIREMENTS FOR EARLY PHASE

- It is heavy to setup the DOORS project: IT process is long and it increase greatly the effort to handle requirements
- The reward of having requirements in DOORS is small when having only MRD and SRD.
- Therefore the requirements have been implemented on Excel at first, then implemented in Capella to be linked to Capella elements
- **Take-away #1: An easier way to handle requirements should be studied for early phases. Such alternative should be able to be transferred on DOORS easily as-well.**

EPS & RFCS

/// ECSM electrical power architecture overview



Loads operative voltage

Load	120 V	28 V
OBC	100%	
S-T		100%
S-TWTA		100%
K-T		100%
K-TWTA		100%
APMA		100%
SADA	100%	
TCS	100%	
PCDU	100%	
RFC		100%
External Payload	95%	5%

EPS & RFCS

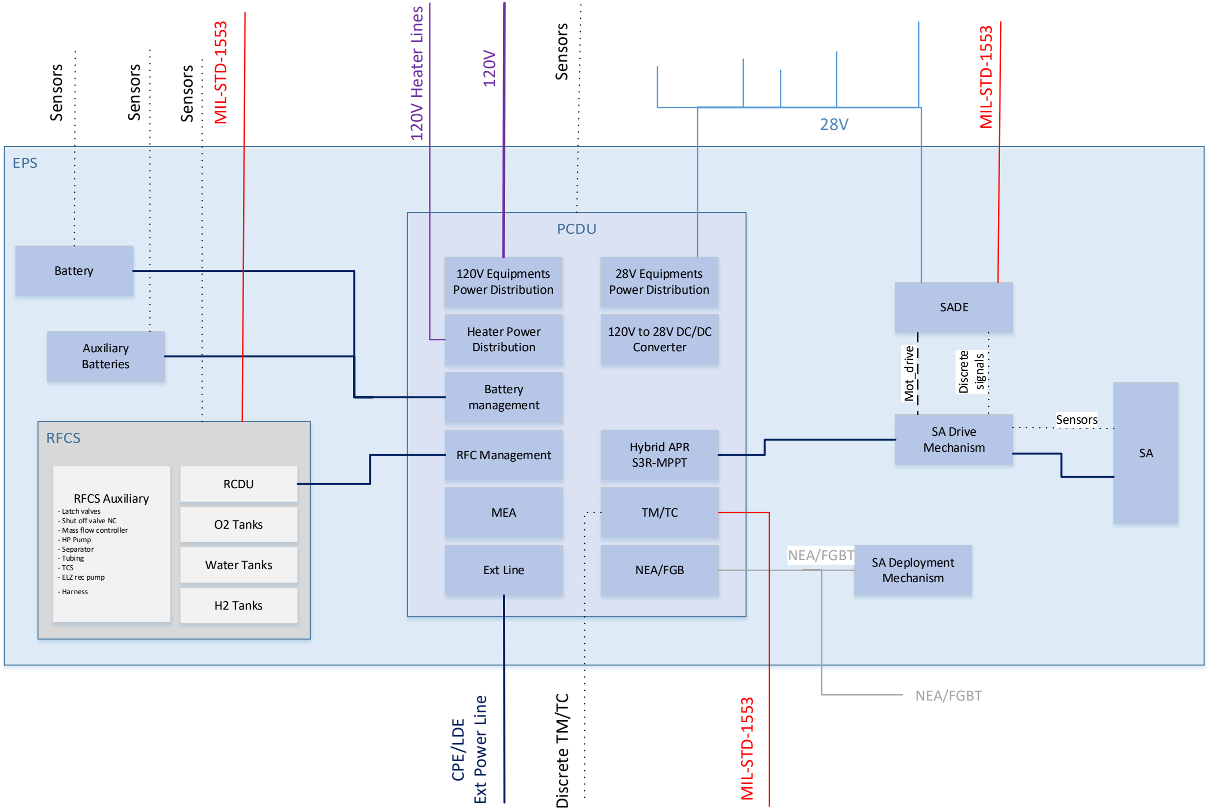
/// EPS avionic diagram

DUAL BUS
- 120 V unregulated
- 28 V regulated

SA POWER CONDITIONING
- S3R/MPPT hybrid

STORAGE SYSTEM
- RFCS units
- Li-ion battery packs

SOLAR ARRAY
- Rollable solution
- Vertical deployment
- Solar tracking on the vertical axis
- Each section connected to one dedicated converter

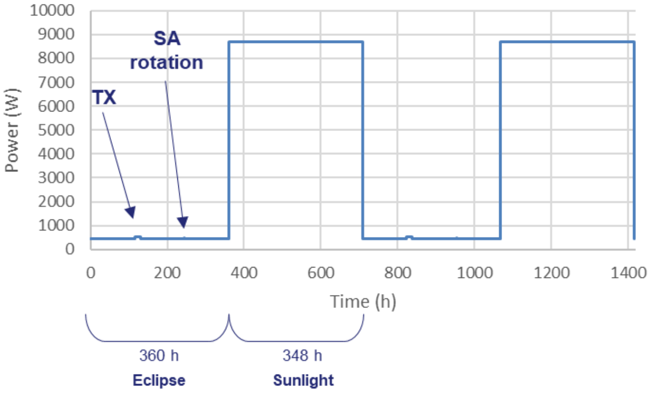


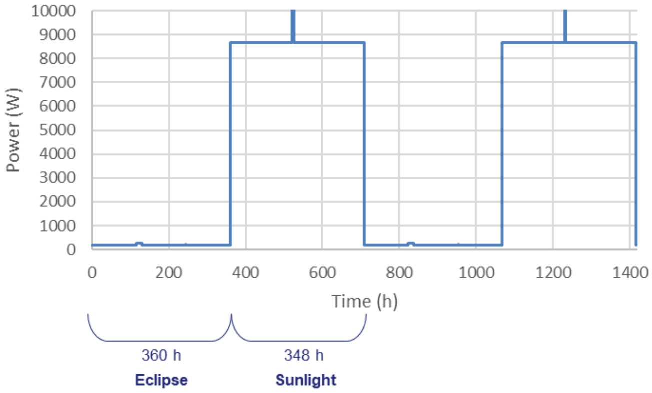
EPS & RFCS

/// Sizing cases

POWER BUDGET PROFILES

Peak power up to ~ 17 kW





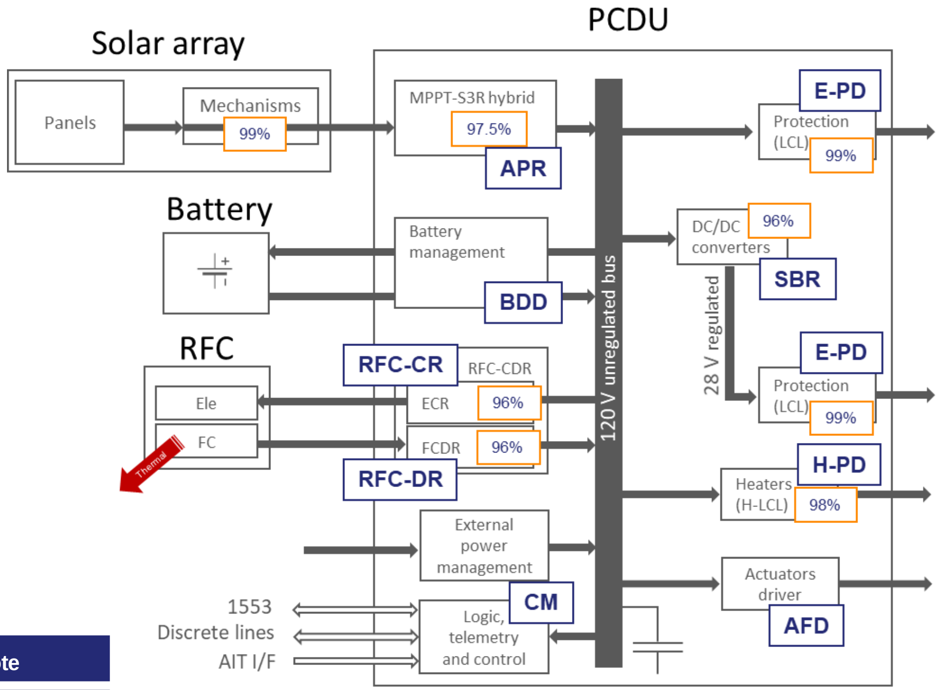
ECLIPSE REQUEST
- AstroSci: ~ 400 W (+ peak power request for TX and SA rotation)
- PeakPwr: ~ 150 W (+ peak power request for TX and SA rotation)

SUNLIGHT REQUEST
- AstroSci: ~ 8.7 kW
- PeakPwr: ~ 8.7 kW (+ peak power request from external loads)

EPS & RFCS

/// PCDU

- **SAME DESIGN FOR ASTROSCI AND PEAKPWR**
- **MPPT-S3R HYBRID SOLUTION**
  - High efficiency (low thermal dissipation)
  - Loss of a solar array section as failure case
- **TWO STORAGE SYSTEM MANAGEMENT**
  - Battery clamped on the primary bus
  - RFCS interface through power converters with the primary bus
- **SECONDARY BUS**
  - By mean of dedicated converters
- **POWER PROTECTION AND DISTRIBUTION**
  - By LCL, R-LCL and H-LCL
- **OUTPUT POWER CAPABILITY**



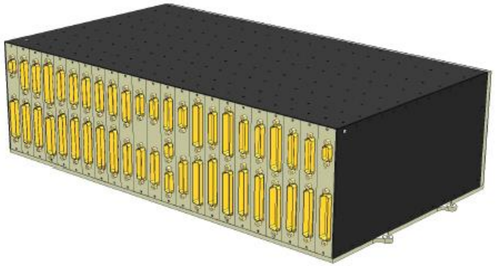
	Unit	Nominal	Single failure	Note
Maximum input from SA	kW	11.3	10.9	1 converter in failure
Maximum power output to the loads at 28 V	W	1050	700	1 converter in failure
Maximum output power to the electrolyzer	W	1800	1575	1 converter in failure
Maximum input power from the FC	W	2000	1500	1 converter in failure

EPS & RFCS

/// PCDU

- REFERENCE MANUFACTURER TERMA
- PCDU NUMBER OF BOARDS AND MASS ESTIMATION

Boards	Number of boards	Mass (kg)
APR	8	8.1
BDD	1	1.0
RFC-CR	2	2.0
RFC-DR	1	1.0
SBR	3	3.1
E-PD	2	1.8
H-PD	2	1.7
AFD	2	1.5
CM	1	1.5
Back Plane	/	3.3
Case	/	4.4
Total	22	29.4
Total with 10% maturity margin	**22**	**32.3**



Modular PCDU concept (heritage design by Terma)

- APR, RFC-CR AND AFD BOARDS SWITCHED OFF IN ECLIPSE

EPS & RFCS

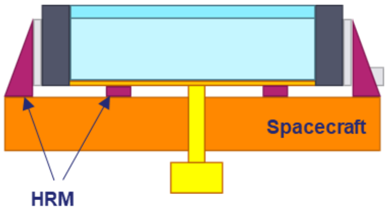
/// Solar Array assembly

- **ROLLABLE SA WITH VERTICAL SUN TRACKING**
- **MAIN SUBASSEMBLIES**
  - PVA – Photovoltaic assembly
  - SA mechanisms

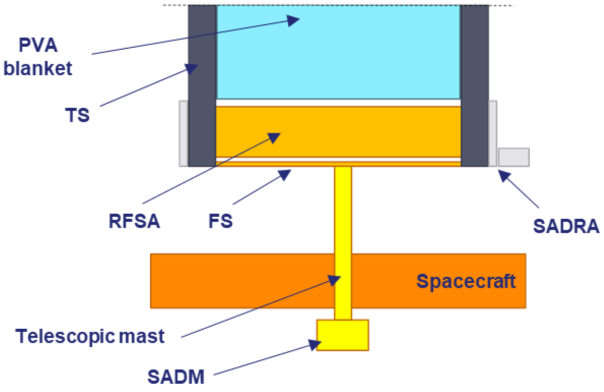
SA assembly mass breakdown	Mass (kg)
Solar cells, diode, cover glass	30
Harness	6
Blankets	25
RFSA HRM structure	6
FS HRM structure	3
HDRM actuators	1
Rolled Flexible Solar Array (RFSA)	36
Tape Springs (TS)	19
Solar Array Deployment Retracting Actuator (SADRA)	3
Preload Device	5
Fixed Structure (FS)	6
Telescopic mast	30
Dust covers	3
Solar Array Drive Mechanism (SADM)	7
Solar Array Drive Electronics (SADE)	4
Total mass without system margin	**184**
Total mass with system margin	**220**

PVA

SA mechanisms



Stowed



Deployed

EPS & RFCS

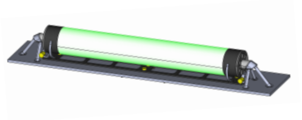
/// PVA – Photovoltaic assembly

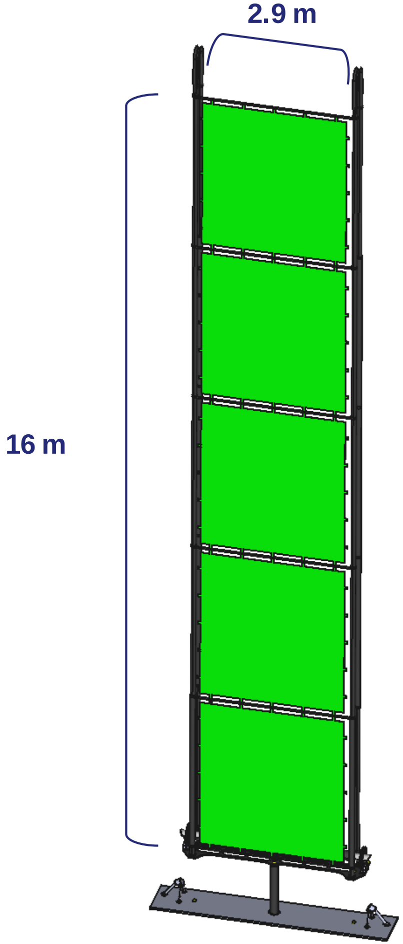
- **SOLAR ARRAY POWER GENERATION AT SA INTERFACE WITH PCDU:**
  - Power at MPP at BoL 11.1 kW (239 W/m2)
  - Power at MPP at EoL 10.0 kW (213 W/m2)
  - Power at MPP at EoL with 1 section in failure 9.5 kW (204 W/m2)

UNDER THE FOLLOWING CONDITIONS:
  - Solar flux 1321 W/m2
  - SAA 15°
  - Temperature 100°C

- **PVA DISTANCE FROM THE MOON SOIL:**
  - Bottom side about 5 m
  - Upper side about 21 m

Stowed





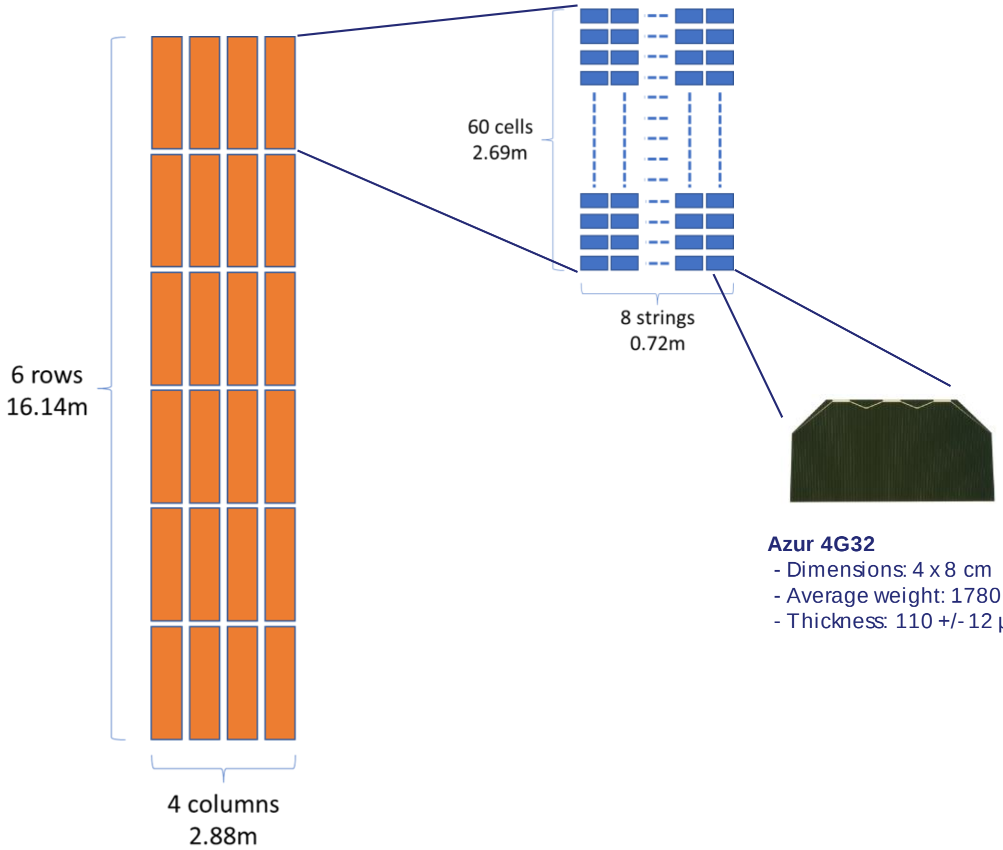
EPS & RFCS

/// PVA – Photovoltaic assembly

SOLAR CELLS CONFIGURATION
- Cells series: 60
- Number of strings per section: 8
- Number of sections: 24
- Total number of cells: 11’520
- Fill Factor: 0.75
- SA area: 46.5 m2

DEGRADATION AND LOSS FACTORS
- Degradation factors:
  - Proton/Neutron
  - Dust regolith → recalculated after DR (from 0.2% to 1%)
  - Debris
  - UV and ESD degradation
  - Thermal cycling
- Loss factors:
  - Tracking point error
  - String current mismatch
  - By-pass diode
  - Single string failure

Solar cells configuration



Azur 4G32
- Dimensions: 4 x 8 cm
- Average weight: 1780 mg
- Thickness: 110 +/- 12 µm

EPS & RFCS

/// Focus on dust degradation

- REFERENCE: ARGONAUT MISSIONS ENVIRONMENTAL SPECIFICATION, ESA-TECEPS-SP-020864 ISSUE 4.2

Lunar Dust Deposition Rates

ENV-DUST-0020 Dust deposition rates on landed systems reported in Table 24 shall be assumed.

Note 1: *The numbers provided in* Table 24 are consistent with the figures reported in [35].

Note 2: *Natural dust mobilization due electrostatic effects has a large variability depending on latitude, local topology and illumination conditions. The number reported in* Table 24 *is an upper limit as derived from Apollo observation (smaller amounts were reported in the case of Change'3). Local effects on specific surfaces can be estimated using dedicated models and simulations.*

Transport source	Measurements	Reference
Meteoroid impacts	$10\frac{\mu g}{cm^2}$ per year	(Katzan and Edwards, 1991)
Electrostatic	$100\frac{\mu g}{cm^2}$ *per year*	(Hollick & O'Brien, 2013)
Human / Rover displacements	$<400\frac{\mu g}{cm^2}$	NASA-STD-1008
Landing [Informative]	*up to 10 µm* thick or 1mg/cm² at 155m from Apollo LM landing site*	Based on Surveyor III data (Satkiewicz and Marmo, 1972) *this excludes self-induced plume contamination

Table 24: **Lunar Dust Deposition rates**

220 µg/cm² for 2 years of mission

Relative Transmittance of light through a dust layer of particles

ENV-DUST-0070 The ESA model 10µm from **Figure 4-11** describing the total solar flux reduction factor (dust factor) through a deposited dust layer on top of sensitive surfaces (e.g. solar cells) as a function of dust accumulation shall be assumed as baseline.

Note 1: *this choice is considered as reasonably conservative for a general use and is motivated by the large variability in coverage scenarios, which depend on lander configuration (e.g. height of solar arrays above the lunar surface and orientation with respect to the various sources of contamination) as well as on environmental factors (wide size distribution of lunar dust, large variability in particles sizes possibly landing on spacecraft surfaces which are process and source dependent, illumination and plasma environment conditions).*

Note 2: *the applicability of such dust factor shall be considered for solar arrays located typically from 1.5m over the lunar surface and above- for different configurations, specific assessment might be necessary depending on the specific sub-systems configurations at risk (e.g. a variation in height with respect to the surface and orientation might strongly affect the dust deposition properties) and shall be discussed upfront with ESA.*

Note 3: the model outputs (see [43] for a short model description) have been derived for a 45°N latitude location and Solar Equinox conditions for a horizontal panel at 12h LLST, assuming no influence of topological effects.

1%/year degradation

220 µg/cm²

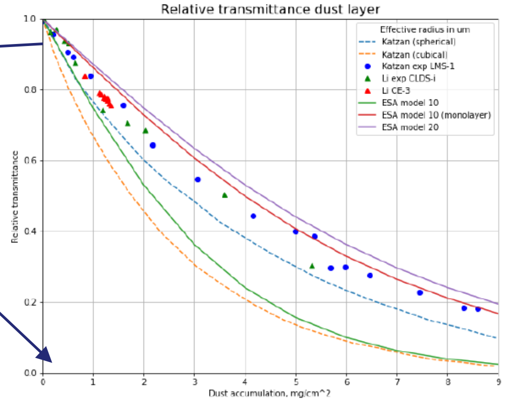
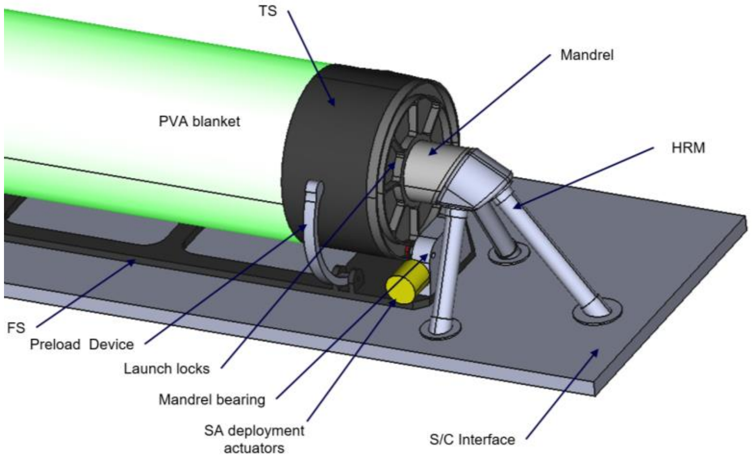


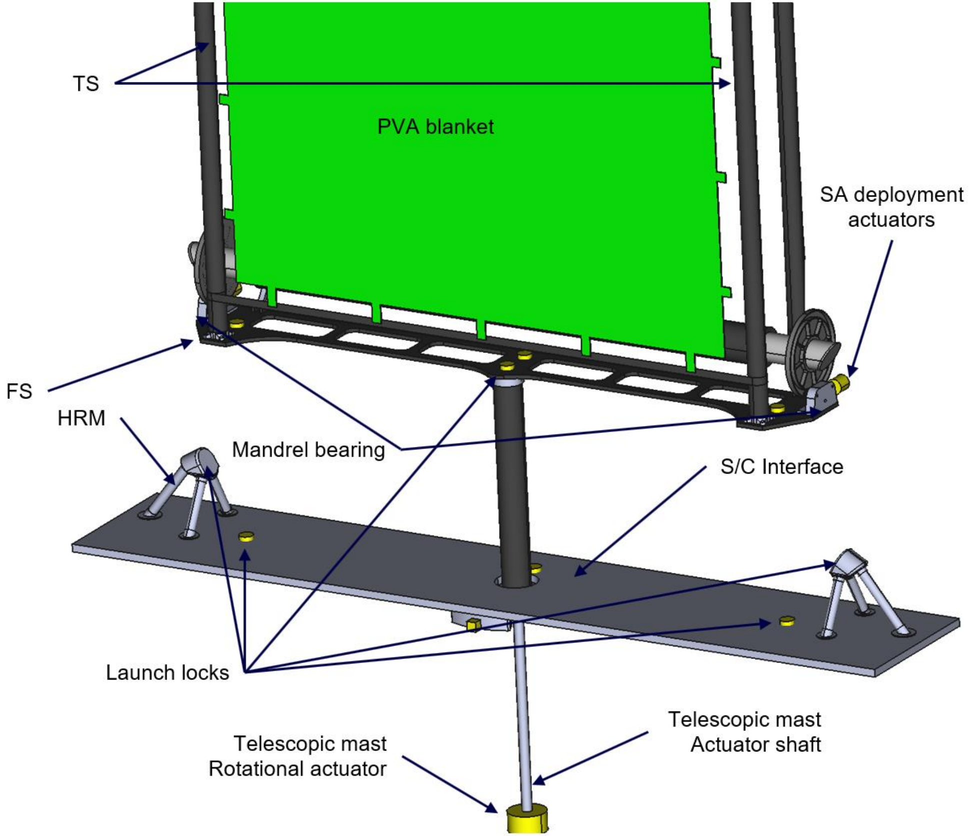
Figure 4-11: Relative transmittance of light through a dust layer of particles (comparison between different data sources and models)

EPS & RFCS

/// Solar Array mechanisms

- **BLANKET MECHANISM**
  - Two motor actuators for blankets deployment
- **DRIVE MECHANISM**
  - One motor actuator for lift-up deployment and sun tracking

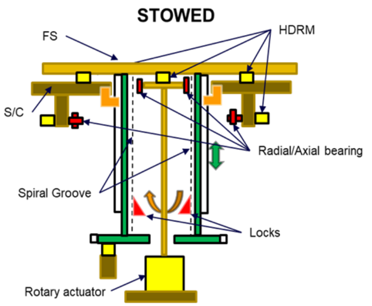


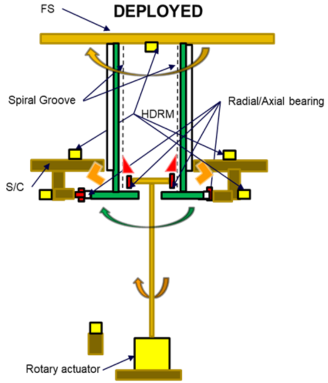


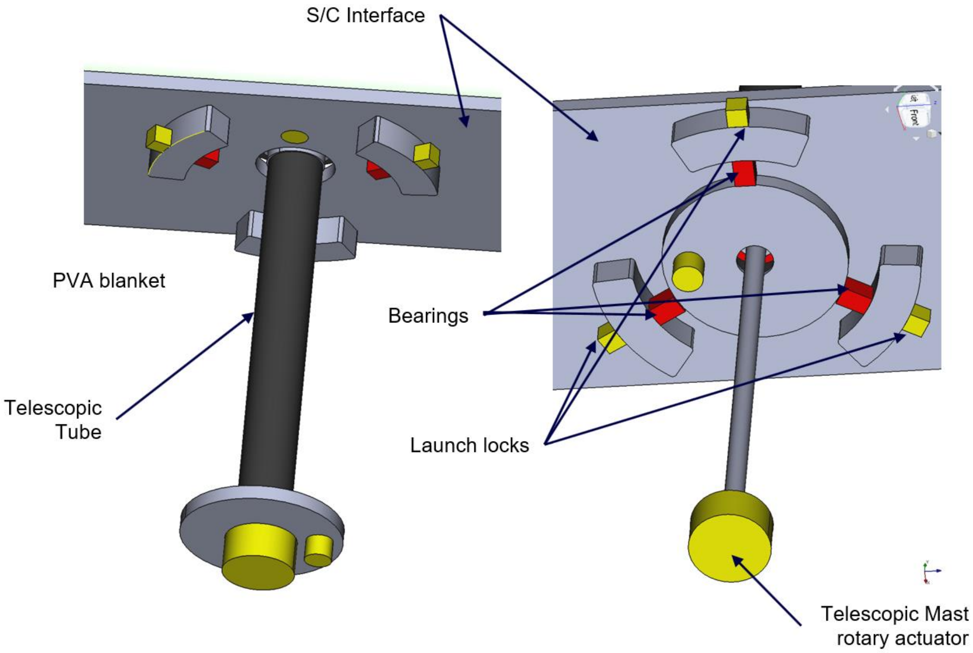
EPS & RFCS

/// Solar Array mechanisms

- **DRIVE MECHANISM**
- **DEPLOYMENT SEQUENCE:**
  - HDRM actuation
  - Lift up the SA rollable structure
  - Deploy the SA blankets





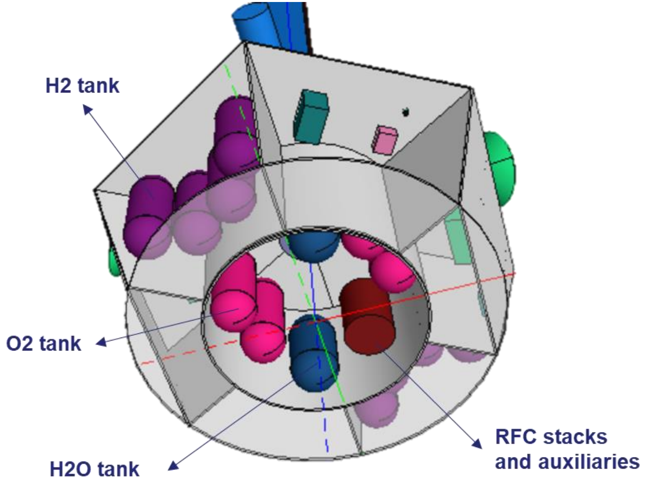


EPS & RFCS

/// RFCS

MASS, VOLUME AND MECHANICAL CONFIGURATION

		AstroSci		PeakPwr	
RFC mass breakdown	Maturity Margin	Qty (#)	Mass (kg)	Qty (#)	Mass (kg)
Water/Reactants	10%	1	93	1	34
H2 tank	20%	8	117	3	44
O2 tank	20%	4	59	2	29
H2O tank	10%	2	50	1	25
FC stack	20%	1	4	1	4
ELY stack	20%	1	5	1	5
Auxiliaries	20%	1	58	1	58
Total without Maturity Margin			386		199
Total with Maturity Margin			449		233

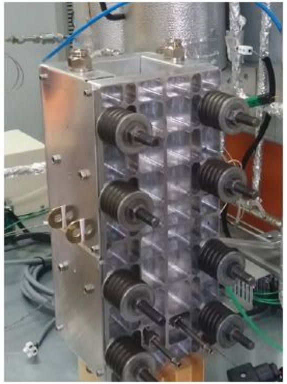


Note:
Reactants and tanks mass recalculated after DR in order to take into account a 20% of reactants margins for H2O migration and gas leakage.

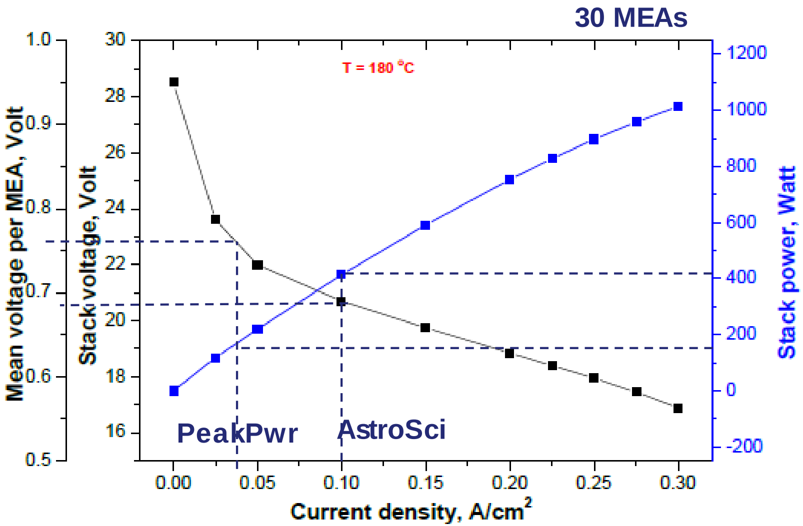
EPS & RFCS

/// RFCS

FC STACK



High Temperature PEM FC developed by FORTH



Conditions of the curves in the graph:

- 1 bar
- Reactants: H2 and air

Design conditions for ECSM:

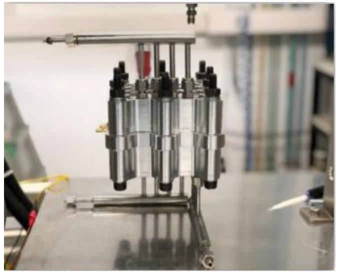
- 2 bar
- Reactants: H2 and O2

Electrical efficiency > 60%

EPS & RFCS

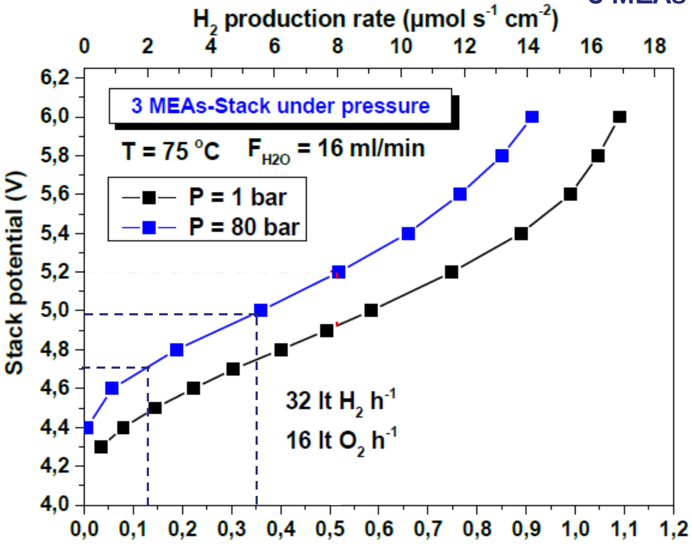
/// RFCS

ELECTROLYZER STACK



High Pressure PEM electrolyzer developed by FORTH

3 MEAs



PeakPwr

AstroSci

Conditions of the curves in the graph:

- 80 bar

Design conditions for ECSM:

- 10 bar

Electrical efficiency > 90%

EPS & RFCS

/// RFCS

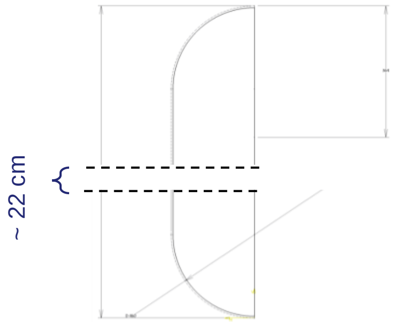
GAS TANKS DIMENSIONS

- Gas tanks dimensions modified with respect to the tanks under development for EL3 in order to optimize the number of tanks → about 22 cm added in height (total height 1.22 m)

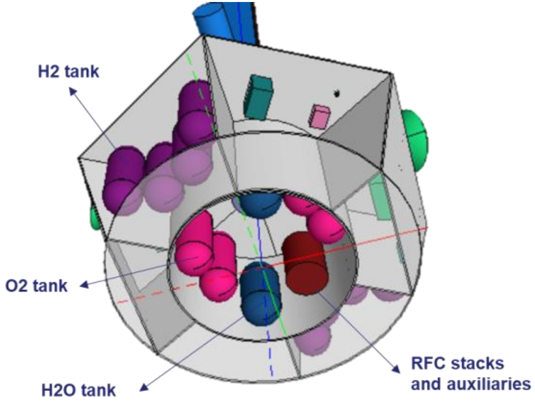
WATER TANKS

- Water tank dimensions in line with MPCV heritage → high TRL

Gas tank dimensions



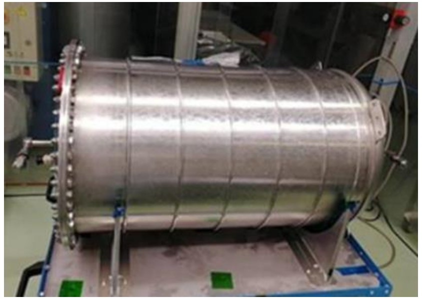
Tanks disposition in AstroSci



Number of tanks

Tanks	AstroSci	PeakPwr
H2 tank	8	3
O2 tank	4	2
H2O tank	2	1

Water tank developed for MPCV



EPS & RFCS

/// RFCS

FC SIZING

- Discharge time 360 h
- Average power:
  - AstroSci 430 W
  - PeakPwr 150 W

FC energy	Unit	AstroSci	PeakPwr
Energy request	kWh	154	53
Energy available at beginning of mission	kWh	203	70
Energy available after leakage and H_2O molecules migration	kWh	185	64

ELY SIZING

- Charge time 348 h
- Average power:
  - AstroSci 800 W
  - PeakPwr 280 W

RFC performance	Units	AstroSci	PeakPwr	Illumination conditions
FC electrical power	W	430	150	Eclipse
FC dissipated power	W	260	90	Eclipse
Electrolyzer electrical power	W	800	280	Sunlight

Thermal power for TCS

ELECTRICAL ENERGY DENSITY

- AstroSci 342 Wh/kg
- PeakPwr 227 Wh/kg

EPS & RFCS

/// Battery

BATTERY SIZING CASE DEPENDS ON THE USE CASE

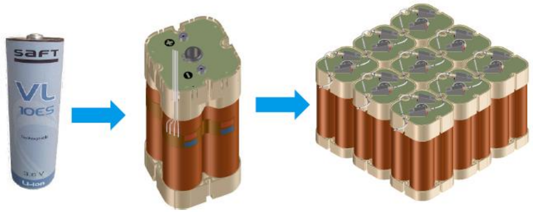
- AstroSci → 1.3 kWh (for TX operations and the SA rotation during eclipse period)
- PeakPwr → 25 kWh (for external payload of about 8 kW for 3 h during sunlight period)

REFERENCE CELL SAFT VL10ES

- Energy density 220 Wh/kg
- Nominal voltage range [4.2 – 2.7] V
- Operative temperature range [10°C ; 30°C]

BATTERY CONFIGURATION

- AstroSci → 32S3P (single pack)
- PeakPwr → 32S24P (3 battery packs)



Battery cells and module arrangement

BATTERY MASS

Battery mass breakdown	Unit	AstroSci	PeakPwr
Cells mass	kg	20	164
Equipment mass	kg	4	33
Total mass	kg	25	196
Total mass with 10% maturity margin	kg	**27**	**216**

EPS & RFCS

/// Battery

DESIGN PARAMETERS

- Low Number of cycles (1000 from requirement)
- Max DoD 80%
- EoL degradation 5%
- 1 string in failure

BATTERY PERFORMANCE

	Unit	AstroSci	PeakPwr
Voltage range	V	134.4 - 102	134.4 - 102
Energy capacity at BoL	kWh	4.5	36.0
Energy capacity at EoL	kWh	4.3	34.2
Energy capacity at EoL with 1 SF	kWh	2.8	32.8

EPS & RFCS

/// TRL status

PCDU AND BATTERY

Component/ Subsystem solution	TRL	Remarks	Critical
Battery	5	Baseline cells are under qualification campaign which is expected to be complete by the end of 2023. Considering the high modular design no criticality is expected for ECSM needs	N
Power Conditioning and Distribution Unit	4	Baseline PCDU includes electronic boards with high TRL at 100 V. The power levels to be managed are also in line with heritage missions. Three main points are expected to affect the design for ECSM: - The requested 120 V primary bus could lead to the redesign of electronic parts - The management of two different energy storage systems is a quite new features for power electronic units for the space sector but it is highly frequent in terrestrial applications - The electronic boards with converter for RFCS are assumed to be in line with the heritage available for batteries but some uncertainties are present Therefore, activities of boards development and redesign are needed in order to match all ECSM requests	Y

EPS & RFCS

/// TRL status

SOLAR ARRAY

Component/ Subsystem solution	TRL	Remarks	Critical
PVA	5	Solar cells qualified according to ECSS. Strong heritage on the manufacturing of PVA. Qualification campaign according to ECSM mission environmental conditions is needed.	N
Tape Spring	3	Tape spring has been developed for similar Space projects. However lunar gravity impact has to be assessed.	Y
RFSA	3	As for TS, RFSA mechanism has been developed in the frame of similar Space missions but in a different environment.	Y
SADRA	5	The baseline SARA24 is currently under qualification for Solar Array Drive Mechanism. The actual TRL is at least 6 but some modifications are expected in order to work with the mission required power.	N
Preload Device	3	Preload mechanism concept is already designed for similar projects. However modifications due to specific mission needs and environment are expected.	Y
HDRM	9	Products with load capability in line with mission needs have been already used in flight models.	N
Telescopic tube	2	Telescopic tube mechanism is a new mechanism which has to be developed for ECSM.	Y
SADM	3	SADM has good heritage in Space missions. However, design modifications are expected in order to switch from the telescopic mast deployment phase to the sun tracking operation. The lunar environment has impacts on the design.	Y
SADE	5	Standard electronic boards for motor actuator are part of the design.	N
Dust covers	2	Dust covers have to be manufactured specifically for ECSM mission needs.	Y
Bearings	2	Bearing have to be manufactured specifically for ECSM mission needs.	Y

EPS & RFCS

/// TRL status

RFCS

Component/ Subsystem solution	TRL	Remarks	Critical
FC stack	4	FC stack performance already proven in laboratory environment. However, performance at end of life in the RFC integrated system have to be better studied in particular to check the whole system reliability.	Y
Electrolyzer stack	4	ELY stack performance already proven in laboratory environment. However, performance at end of life in the RFC integrated system have to be better studied in particular to check the whole system reliability.	Y
Gas tanks	4	This items take advantage from the strong heritage on H2 and O2 management for space missions. However, ECSM mission requests and operative needs are under study in order to optimize the design.	Y
Water tank	6	Item already qualified under MPCV programme. The qualification campaign due to the different environment is not considered critical.	N
Auxiliaries		See next table	Y

EPS & RFCS

/// TRL status

RFCS

Component/ Subsystem solution	TRL	Remarks	Critical
Auxiliaries	4		Y
A – Latch valves	6	The item is already qualified for spaceflight but some delta qualification activities are expected for performance demonstration in the operational environment.	N
A – Shut off valve NC	6	The item is already qualified for spaceflight but some delta qualification activities are expected for performance demonstration in the operational environment.	N
A – Mass flow controller	6	The item is already qualified for spaceflight but some delta qualification activities are expected for performance demonstration in the operational environment.	N
A – High pressure pump	4	TASI team is developing a TRL5 breadboard that will be used in the RFCS breadboard.	Y
A – Separator	4	The item is already available for terrestrial applications but qualification campaign is expected for ECSM mission needs.	Y
A – Tubing	6	The item is already qualified for spaceflight but some delta qualification activities are expected for performance demonstration in the operational environment.	N
A – TCS	4	TCS is based on classical active and passive TCS techniques but it has to be properly designed for ECSM mission needs	Y
A – RCDU	6	Classical monitoring and control functions requested to this units can be performed by already qualified hardware.	N
A – Harness	6	The item is already qualified for spaceflight but some delta qualification activities are expected for performance demonstration in the operational environment.	N
A – ELY recirculating pump	4	The item is already available for terrestrial applications but qualification campaign is expected for ECSM mission needs.	Y

EPS & RFCS

/// Technology development schedule

Items to be developed	Current TRL	TRL at SRR (Q3/2025)	TRL at PDR (Q2/2027)	Remarks	Critical (Y/N)
SA - PVA	5	5	6	PVA qualification campaign expected in line with heritage space missions	N
SA - Tape Spring	3	5	6	The qualification campaign now on place for microgravity has to be performed in order to sustain also the lunar environment.	Y
SA - RFSA	3	5	6	The qualification campaign now on place for microgravity has to be performed in order to sustain also the lunar environment.	Y
SA - SADRA	5	5	6	Design modification to sustain power level request and lunar environment	N
SA - Preload Device	3	5	6	Design to be adapted to the SA assembly for ECSM.	Y
SA - HDRM	9	9	9		N
SA - Telescopic mast	2	5	6	Design activities and qualification campaigns are needed in order to develop and manufacture this critical item	Y
SA - SADM	3	5	6	Design modifications with respect to standard SADM in order to drive both the Telescopic mast deployment and sun tracking. Design activities are also expected to face the lunar environment	Y
SA - SADE	5	5	6	Design modification to control the motor actuators included in SA assembly	N
SA - Dust covers	2	5	6	Design and qualification activities to sustain lunar environment and in particular lunar dust	Y
SA - Bearings	2	5	6	Design and qualification activities to sustain lunar environment and in particular lunar dust	Y
RFC					
FC stack	4	5	6	Stack design and performance are expected to be studied for ECSM mission request. Technical effort and qualification campaigns needed in order to set the final design	Y
Electrolyzer stack	4	5	6	Stack design and performance are expected to be studied for ECSM mission request. Technical effort and qualification campaigns needed in order to set the final design	Y
Gas tanks	4	5	6	Gas tanks final design and management has to sustain test and qualification campaign to rise the TRL.	Y
Water tank	6	6	6	The item takes advantage from the MPCV heritage. Qualification campaign needed in order to comply with ECSM operational environment.	N
Auxiliaries	4	5	6	Auxiliaries design optimization is needed for ECSM mission. High reliability of the system is to be assessed and final RFCS configuration is to be set in order to rise the TRL.	Y
PCDU	4	5	6	PCDU boards redesign in order to be able to work with the ECSM voltage range and implementation of the management for the double storage system	Y

TCS – OVERALL DESIGN DESCRIPTION

- /// Purpose of the ECSM thermal control is to provide a thermal design able to:

  guarantees the requested temperature ranges for all the equipment throughout all the mission phases and in the different operational modes, based on the environmental conditions and ECSM unit's power dissipation

- /// To meet the moon harsh thermal environment the first main thermal solution is to have a system passively insulated with the maximum extent:

  ECSM global main body insulation covered by MLI thermal blankets. The insulation has to maintain free areas where the radiators are located, to permit the internal heat rejection to space

TCS – OVERALL DESIGN DESCRIPTION (cont.'d)

In addition 3 points:

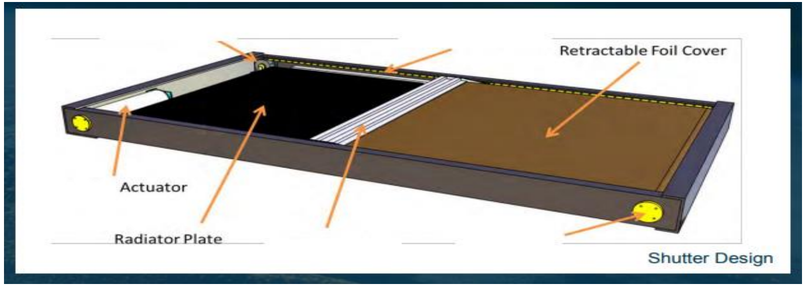
/// ECSM thermal design is requiring the introduction of an Heat Rejection System able to perform:

- from ON condition when is requested the rejection of a power dissipation to space through a radiator
- to OFF condition when the radiator is maintained decoupled from the main system for certain reason.

For ECSM mission is required a full capability to reject during the sunlight on the moon and a decoupling from external environment during the darkness on the moon when the limited generated power dissipation has to be saved internally to help the equipment survival.

/// The trade-off louvers-shutters indicated that the shutter concept seems more indicated for Moon and Mars application on the soil. The concept "rollable shutter" seems more indicated to be applied on a moon lander: it's supported by an actuator able to deploy and/or store the shutter area, opening and/or closing the radiator area.

/// To be considered the fact that the dust is anyway depositing on the radiator: directly when open to space but also during the shutter movements. So the combination with a dedicated dust-removal is necessary: the adoption of Electrodynamic Screens (EDS) is proposed for the ECSM radiators



TCS – DESIGN DESCRIPTION

Preliminary proposed TCS solution for Heat Rejection System considered today for ECSM scope are:

- **Passive radiator:** it's a radiator area trimmed inside the MLI area and dedicated to a direct reject of a unit mounted on the back side of the panel radiator identified area. This solution is dedicated to unit presenting power dissipation around 50 Watts and with a large contact area with the panel (thermal filler inter-position is suggested to guarantee the full contact in all the area zones).

  ECSM is presenting OBC unit conforming this rejection solution

- **Heat pipe (HP):** this solution is normally adopted for some units located on a panel area presenting different power dissipations from 10 to 80-100 Watts. the HPs are located in parallel to create a linear grid under the units and/or inside the honeycomb panel. the positioning of these HPs is to have the head in correspondence of the power dissipation injection in the panel and the tail located in the radiator area to reject to space. this solution is adopted also when the units are located in proximity of the radiator panel but not mounted on its back side.

  ECSM is presenting the TT&C subsystem located on a panel not presenting capability for a direct rejection to space and an HPs branch is selected to connect this panel with the outside radiator area. The HPs branch has been selected also to connect the RFCS stack hot surface with OBC and TT&C areas to help these units during the darkness period with the RFCS heat produced during that period of time and rejected from the RFCS

TCS – DESIGN DESCRIPTION (cont'd)

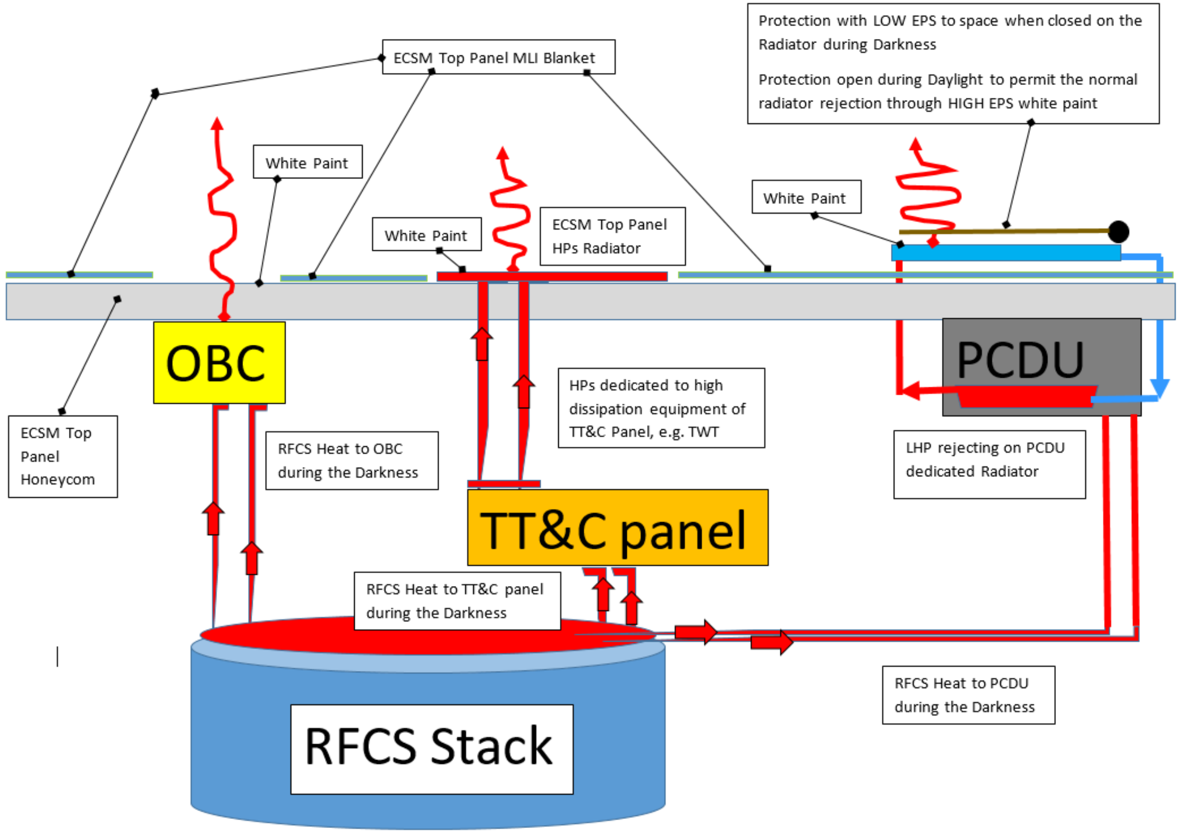
Preliminary proposed TCS solution for Heat Rejection System considered today for ECSM scope are (cont'.d):

- **Loop Heat Pipe (LHP):** The LHP is normally selected for a unit presenting an high power dissipation and located not in proximity of the radiator rejection area. the LHP has an high efficacy to transfer the heat drained from the unit to its radiator located outside and it's able to work in every condition also under moon gravity because the capillary forces are greater than the moon gravity effect.

    ECSM selected this solution dedicated to an high dissipation unit EPS-PCDU (more than 500 watts). The LHP has flexible fluid and vapour lines able to follow the configuration constraints, it has an higher pumping capability wrt the HP. It can manage higher power dissipation through co-current liquid and vapor flow, in contrast to the counter-current flow in the HP. This permit to transport the heat for greater distance between evaporator and condensator and different elevations between evaporator and condensator are permitted

TCS – DESIGN DESCRIPTION (cont’d)

/// The preliminary design of ECSM TCS concept is represented in the sketch



TCS - DESIGN PERFORMANCES

- ECSM has been thermally assessed considering two configurations: Astro-Sci and Peak-Pwr.
- Astro-Sci is presenting a power dissipation of 880 W in daylight and 145 W in Darkness.
    - During daylight the power dissipation rejection is through a global radiator area of 4.35 [m2].
    - During darkness the reduced level of internal power dissipation requires the help of heat from RFCS for 115 W, saving 93 W available for other user.
- Peak-Pwr is presenting a similar power dissipation: 839 W in daylight and 129 W in Darkness.
    - For the daylight case and radiator sizing, the results already performed for Astro-Sci have been considered. So also here a radiator with a global area of 4.35 [m2] is applicable.
    - During darkness the reduced level of internal power dissipation requires the help of heat for 130 W. The RFCS has availability of only 72. W and so the Peak-Pwr configuration needs 58. W of thermal heaters to survive.
- With the previous thermal design, it's demonstrated that the equipment are able to meet their relevant temperature requirements.

TCS – CLARIFICATIONS ON THE PERFORMED ASSESSMENTS

1) Lunar regolith infrared emissivity range is variable between 0.92 to 0.98. Considering the ECSM radiators position on the top panel and considering the greater emissivity value, there is no impact on the temperature results and radiator sizing, because the radiator present a low view factor with the moon soil

2) The thermal assessments have been made considering representative thermal node and view factors manually defined and calculated without the support of a thermal geometrical model. Anyway this job has considered the real positioning and identity of the hardware

3) For ECSM P/L the transit case is less severe wrt the evaluation on moon soil daylight and darkness, where we have the additional presence of the penalizing moon surface. Knowing the needs to survive on moon soil during daylight and darkness, we are expecting a less severe transit case (today not evaluated because are necessary dissipations level applicable during transit case for all the main equipment)

TCS – CLARIFICATIONS ON THE PERFORMED ASSESSMENTS (cont.'d)

4) TT&C proposed Heat Rejection System is through Heat Pipes. Loop Heat Pipe is proposed at level of PCDU due to its high power dissipation to be rejected and equipped with a large radiator

5) Absorptivity change (aging effect) of the radiator is impacting the heating power demand:
   a) Today we have no information on the saving of radiator absorptivity, if we are using a closure (as a shutter) for the half of time on the moon. So the performed evaluation is conservative, because considered the full absorptivity degradation without any help
   b) The sun heat load is arriving laterally on the Lander and with an angle very limited (below 45 degrees) at moon south polar region. The radiators on the top panel are not so impacted by sun, but greatly impacted by darkness

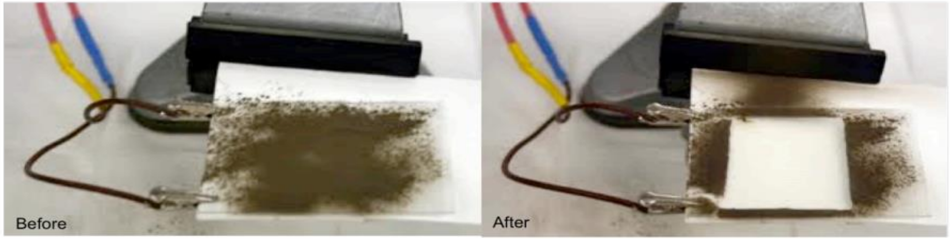
TCS – CLARIFICATIONS ON THE PERFORMED ASSESSMENTS (cont.'d)

6) The shutter is closing the radiator during the darkness to permit acceptable temperature at level of equipment PCDU. The propylene itself has no problem to arrive at low temperature without radiator cover at all. The issue is the limit temperature of PCDU: the reason to cover the radiator in darkness is due to this fact. As hardware solution, the shutter equipped with MLI blanket is able to maintain a low external layer emissivity and also to insulate the radiator area from the cold sink. This because the LHP fluid is not stopped during the darkness: the PCDU is switched ON in a reduced power dissipation mode

TCS – CLARIFICATIONS ON THE PERFORMED ASSESSMENTS (cont.'d)

6) For EDS shield for dust removal, we contacted via teleconference USA people preparing similar hardware for space American project for the moon in the frame of Artemis program. They indicated us application on very sensitive areas to be maintained clean as delivered: window, camera, helmet visor, etc. This shield is «transparent», i.e. the thermo-optical properties of base material are not changed

7) The shutter on the radiator reference is considering the status of development of the European project / TDE activity "Lunar dust resilient louvered radiator", as presented in the Workshop "RFIs for Moon and Mars – Technology Workshop by D.Schmitt (HRE-S), G.Magistrati (HRE-E) 17/12/2021"



TCS – DESIGN DESCRIPTION

ECSM TCS ASSESSMENT for EXTENDED LIFE

- The following Table is showing in green (positive result) and in red (not acceptable result) the results for an extended life of 6 months and up to 5 years, saving the radiators area previously defined in all the columns of the extended life.

Wait paint thermo-optical parameters

	BOL	2 years	5 years	
Epsilon	0.92	0.93	0.95	White paint
Alpha	0.15	0.27	0.5	

Ageing effects on TCS design

ASTRO-SCI				DAYLIGHT		
	T limit with 15 C margin	2 years	2.5 years	3 years	4 years	5 years
DHS Temperature [C]	50	42.7	44.7	46.7	50.4	54
TT&C Temperature [C]	60	55	57.2	59.3	63.4	67.3
PCDU Temperature [C]	45	44	46.5	48.9	53.5	57.9
PEAK-PWR				DAYLIGHT		
	T limit with 15 C margin	2 years	2.5 years	3 years	4 years	5 years
DHS Temperature [C]	50	42.7	44.7	46.7	50.4	54
TT&C Temperature [C]	60	55	57.2	59.3	63.4	67.3
PCDU Temperature [C]	45	41.7	44.3	46.8	51.5	56

- The previous Table is not impacting the Darkness assessment, maintaining the above requested RFCS heating and thermal heaters need, as applicable in the two configuration.

TCS – DESIGN DESCRIPTION

- The revision of radiator areas, contained in the following rows, solves the Daylight issue but requires more heat from RFCS and/or thermal heaters due to larger radiator areas now introduced.
- It could be noted that the PCDU is the critical item and need more radiator area with an extended life.
- The exercise has been made for AstroSci because enveloping the PeakPwr.

Impact on Daylight AstroSci (applicable also to PeakPwr)					
Equipment	Radiator Area sqm Nominal (2y)	Radiator Area sqm Extended (2.5y)	Radiator Area sqm Extended (3y)	Radiator Area sqm Extended (4y)	Notes
DHS	0.25	0.25	0.25	0.25	
TT&C	0.5	0.5	0.5	0.55	
PCDU	3.6	3.8	4.1	4.9	

Impact on Darkness AstroSci (Request of HEAT from RFCS)					
Equipment	Nominal (2y)	Extended (2.5y)	Extended (3y)	Extended (4y)	Notes
DHS	50 W	50 W	50 W	50 W	
TT&C	65 W	65 W	65 W	> 65 W	
PCDU	0 W	10 W	15 W	> 15 W	
TOTAL	115 W	125 W	130 W	> 130 W	

Impact on Darkness PeakPwr (Request of HEAT from RFCS or HEATERS)					
Equipment	Nominal (2y)	Extended (2.5y)	Extended (3y)	Extended (4y)	Notes
DHS	50 W	50 W	50 W	50 W	
TT&C	65 W	65 W	65 W	> 65 W	
PCDU	15 W	25 W	30 W	> 30 W	
TOTAL	130 W	140 W	145 W	> 145 W	

- In conclusion, values after 3 years are too severe because requiring more heaters for PeakPwr and the radiators dimension for both the configurations AstroSci and PeakPwr are larger and could be an issue, if compared with the available space on the ECSM top panel, locating also other main equipment.

TCS – TRL STATUS

Component/ Subsystem solution	TRL	Remarks	Critical
Heat Pipe / Loop Heat Pipe with associated Radiator (without TCV)	8	Both the rejection systems present an high TRL, not deemed critical.	N
Loop Heat Pipe (with TCV)	4	Today the issue is at level of TCV: activities are in progress (current TRL 4). Estimated TRL for Moon by 2028 is 8. Not applicable to ECSM TCS design solution	Y
Rolled Shutter	1/2	This technology is recently started and the present model is a small BreadBoard to be upgraded, verified and tested	Y
Electro Dynamic Screens (EDS)	4	The Electro Dynamic Screens (EDS) is proposed for the ECSM radiators to remove continuously the lunar dust. In year 2005 the first ESD patent was published: electrodes inside a dielectric transparent film, non-conductive with high electrical resistivity for EDS operation and protecting the electrodes from environment.	Y
Thermal straps	8	High TRL, not deemed critical	N
Multi-Layer Insulation (MLI)	8	Strong TAS-I heritage from ISS modules and Exomars. Manufactured according to TAS-I qualified process.	N
Thermistors	8	Strong TAS-I heritage from BEPI-COLOMBO/METIS/Solar Orbiter/CSG/Exomars 2016 TGO/ HERSHEL-PLANK and Exomars	N
Heaters	8	Strong TAS-I heritage from Cygnus/ ATV/ Nodes 2&3/ Columbus/ MPCV-ESM and Exomars	N

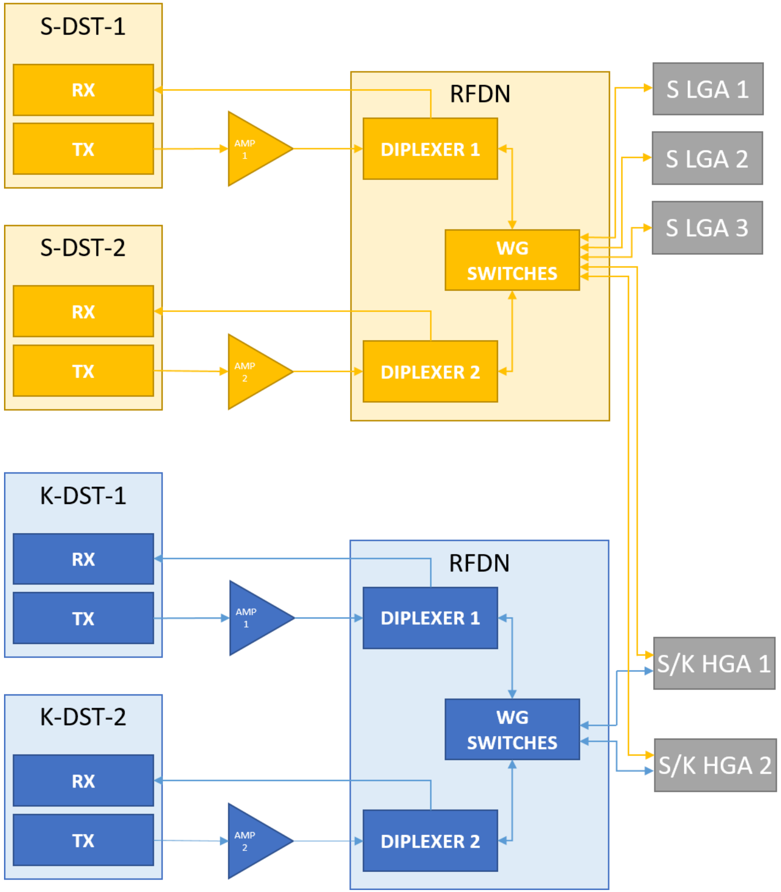
TT&C – ARCHITECTURE

/// Main features:

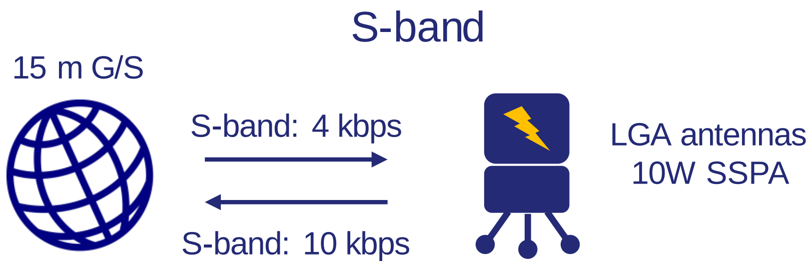
- Fully **redundant**
- **Omnidirectional** coverage
- Support for **different data rates**
- Support for both **DTE** and **Relay satellites**

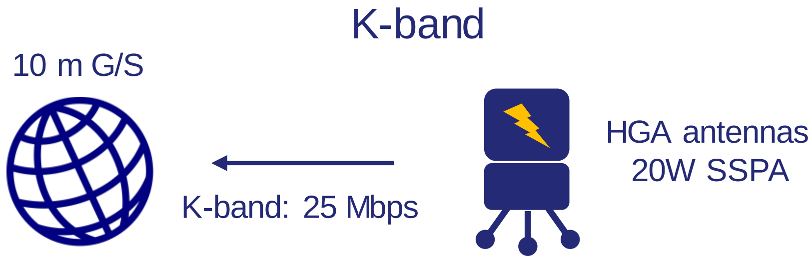
/// Architecture units:

- 2 x S-Band Deep Space Transponders
- 2 x K-Band Deep Space Transponders
- 2 x S-Band 10 W SSPA
- 2 x K-Band 20 W SSPA
- 2 x RFDN
- 3 x S-Band LGA: minimum gain of 0 dB at an off-boresight angle of 60°
- 2 x S/K-Band steerable HGA
- 2 x APM



TT&C – DTE PERFORMANCES



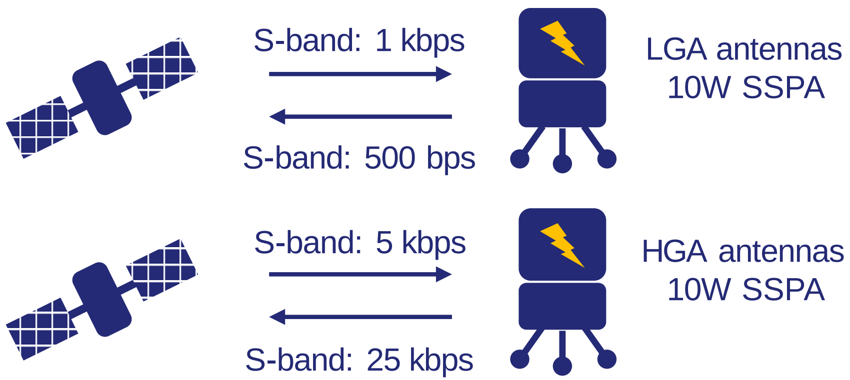


Link	Band	Antenna	Data rate [kbps]	RF Power [W]	Link Margin [dB]
DTE Downlink	S-Band	LGA	10	10	9,74
DTE Uplink	S-Band	LGA	4	-	19,63
DTE Downlink	K-Band	HGA	25000	20	10,54

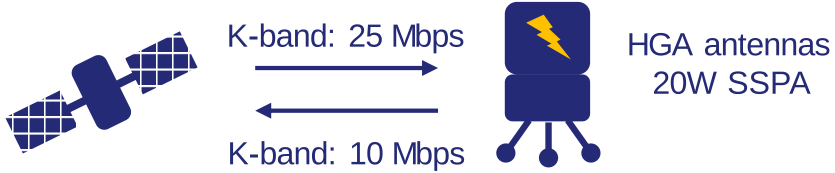
- ✓ Data rates are **compliant** with the requirements
- \+ **Optional DTE** high data rate link in **K-Band**

TT&C – PROXIMITY PERFORMANCES

S-band



K-band



Link	Band	Antenna	Data rate [kbps]	RF Power [W]	Link Margin [dB]
Proximity forward	S-Band	LGA	1	-	3,45
Proximity return	S-Band	LGA	0,500	10	3,10
Proximity forward	S-Band	HGA	5	-	17,46
Proximity return	S-Band	HGA	25	10	7,11
Proximity forward	K-Band	HGA	10000	-	5,65
Proximity return	K-Band	HGA	25000	20	6,09

- ✓ Data rates are **compliant** with the requirements
- ✓ Data rates are **compatible** with the Gateway IRD

TT&C – TRL STATUS

Unit	TRL	Remarks	Critical
SBT	7	S-band terminal will use a recurrent unit from the Gateway HLCS, which is procuring this transceiver.	N
iDST	6	HW is already space qualified. The delta-design is just a SW development.	N

ANTENNAS

Unit	TRL	Remarks	Critical
S-band LGA	7	Based on Beyond Gravity TT&C SBA models.	N
S/K-band dish antenna	8	Customization of RUAG K antennas does not require re-qualification.	N

APM

Unit	TRL	Remarks	Critical
APM for HGA	8	A recurrent unit from the Gateway HLCS will be employed, which is procuring this mechanism.	N

RFDN

Unit	TRL	Remarks	Critical
RFDN	8	RFDN has always to be customized to the selected platform. However composing units are recurrent from several telecom and scientific missions.	N

Delta-qualifications might be needed for the **lunar environment**, especially concerning **lunar dust**.

DHS

/// DHS is based on SAVOIR functional architecture

- TC reception, decoding, validation and distribution
- TC acquisition, formatting and coding
- Processing capability
- Execution Platform and Application software
- Data Storage
- Interfacing with all S/C subsystems
- Interfacing w/ External Payload units
- Autonomy supervision and management of the system

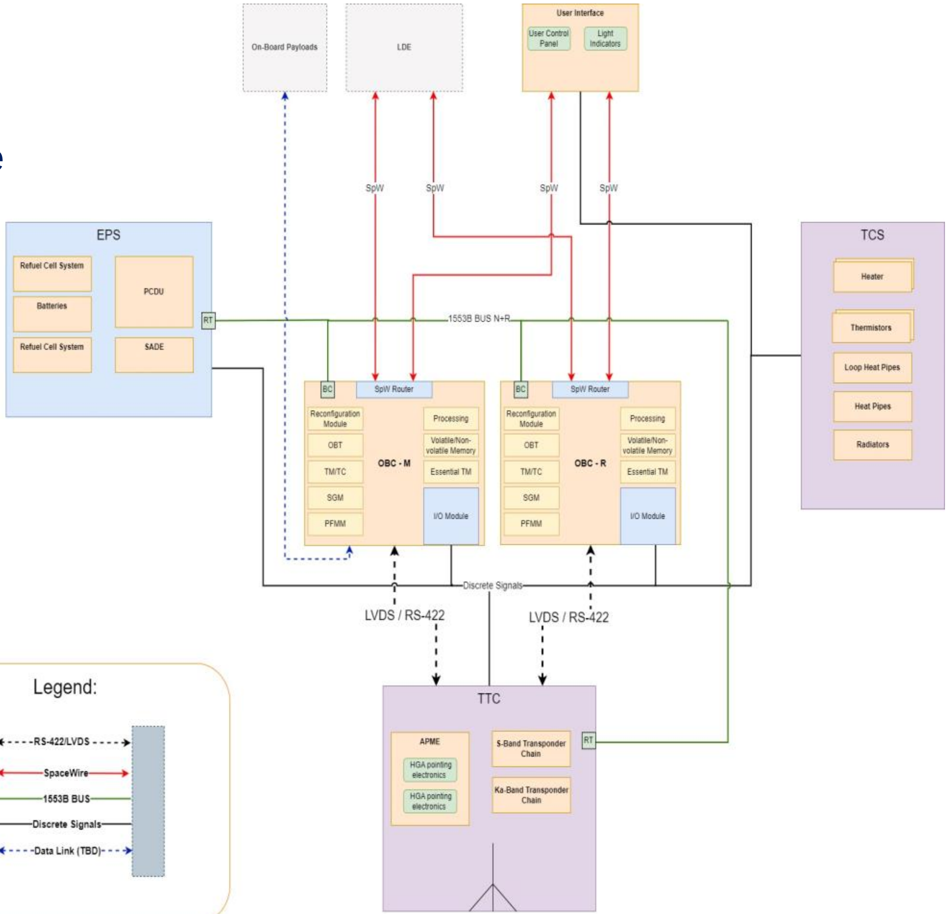
/// DHS is composed by:

- **On-Board Computer (Core module):**

Central computer, hosts the ASW

- **I/O Module**

Analog/Digital signal acquistion



Data Interfaces

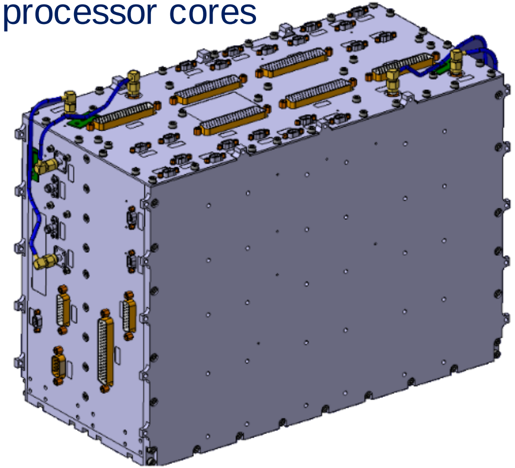
- **MIL-STD-1553B:** command/control exchanges between OBC and other equipment units.
  - Reliable but limited to some hundreds of kbits per second.
- **SpaceWire** is a high-speed data communication protocol.
  - It connects ECSM Data Handling with EL3 (LDE), improving overall performance.
  - SpaceWire also provides a high-speed data link to the User Interface.

DHS

///OBC:

/// The TAS-I IPAC (Core Module) HiRel is proposed for ECSM mission

- Fully redundant On-Board Computer
- Integrated Remote Terminal (I/O Module)
- Quad high performance LEON4FT (Sparc V8) processor cores
- 1700 DMIPS
- Platform Data Storage of 256 Gbit (N+R)
- TRL 6
- MASS < 7,5 Kg
- Average power dissipation: < 40W
- Security Function

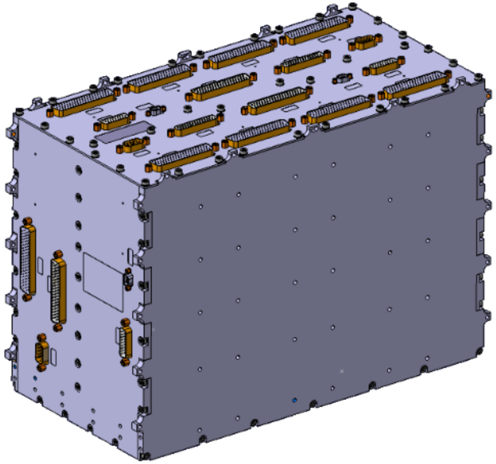


DHS

///I/O Module:

/// The TAS-I IPAC Integrated I/O Module is proposed for ECSM mission

- Nominal and redundant HK boards
- S/C HK Data Collection
- I/O and IPAC Internal HK Data
- Mass < 7,6 Kg
- Power dissipation < 10W



STRUCTURE

I/O Budget

IPAC Core Module			
I/O	**Nominal**	**Redundant**	**Note**
MIL-1553	1	1	
S/X Band TM/TC	1	1	
Spacewire	9	2	TBC
HPC	160	160	TBC
Sync	1	1	TBC
Ext Alarms	1	1	TBC

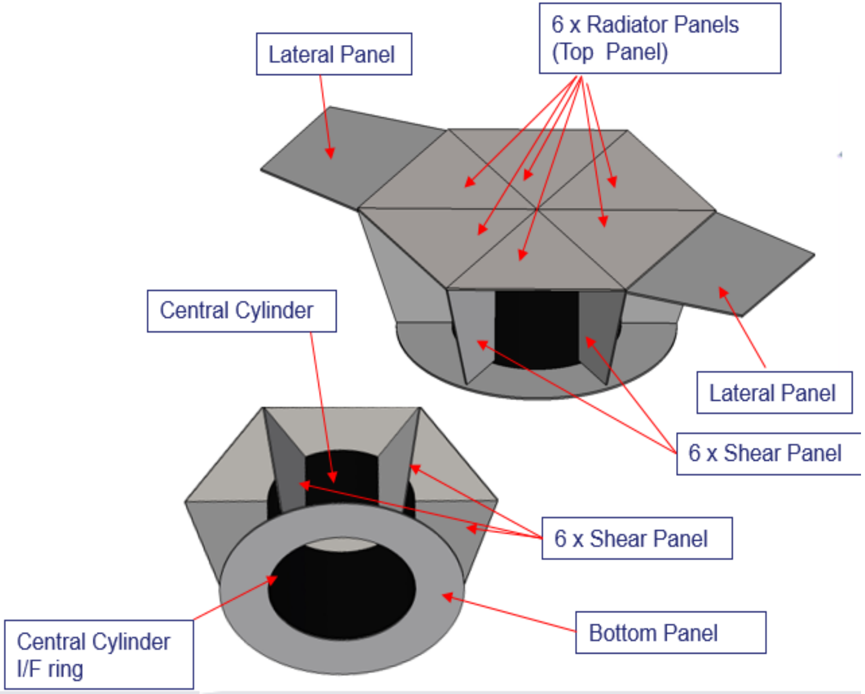
IPAC I/O Module			
I/O	**Nominal**	**Redundant**	**Note**
ASM	24	24	
TSM	92	92	
Thermocoupler	4	4	
DRM (CC)	16	16	Contact Closure
BSM	16	16	Digital BiLevel
M/L RS422	4	4	Memory Load
DS16 RS422	4	4	Digital Serial

STRUCTURE CONFIGURATION

/// The mechanical configuration is composed by the following elements :

- Central Tube With Two Circular Rings: CFRP Cylinder With I/F Diameter ~2120 Mm And 1500 Mm Of Height. It Plays An Essential Role In Providing Sufficient Stiffness, Limiting The Thermal Distortion, Sustaining The Launch Load And Support The Spacecraft In The Launch Stack Configuration. The Load Distribution And Cylinder Structural Integrity Is Also Aided By The Top And Bottom Aluminum Rings.
- 6 Shear Panel With Trapezoidal Shape Creating Six Compartment Inside The S/C
- A Top Platform Panel With Hexagonal Shape, Acting As Radiator Panel, Divided In Six Triangular Panels. EPS Electronic. DHS, Lgas, HGA, SADM, HDRM And SA (Auxiliary Batteries For Peak Power Configuration) Are Mounted On The Top Panel. The Triangular Panels Constituting The Top Platform Have Al Skins, As The Top Platform Is Used As Radiator Panel.
- A Bottom Platform, With Circular Shape To Reduce The Complexity Of The Mechanical Interface With The Central Tube.
- 2 Lateral Panels, Which Close The Structure And Accommodate The Tt&c Equipment An Apm.
- 3 Cfrp Rods With 40 Mm Diameter , 2 Mm Of Thickness With 1700 Mm Of Height-> Titanium Terminal Are Foreseen For The Cfrp Rods. The Three Rods Have An Angular Separation Of 120°, And Connect The SADM To The Stiff Points Of The S/C Where The Central Cylinder, Reinforced By An Al Ring, Interfaces Three Shear Panels
- Brackets And Tertiary Structures As Needed (To Support RFCS Unit And Several Tanks, Pending On The Configuration Adopted).

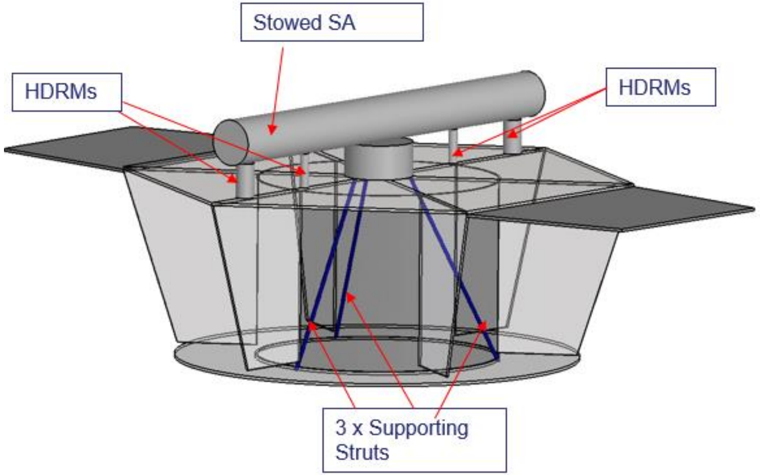
/// The proposed structure is mainly made of sandwich panels with Al honeycomb and CFRP skins



STRUCTURE CONFIGURATION

Structure Subsystem Panels Composition	Facesheet Material	Facesheet Thickness [mm]	Core Thickness [mm]	Panel Thickness [mm]
Central Tube	CFRP	2	16	20.00
Top Panel (Radiator Panels)	AL	1.20	27.60	30.00
Bottom Panel	CFRP	0.60	28.80	30.00
Shear Panel	CFRP	0.60	18.8	20
Lateral Panel	CFRP	0.6	18.8	20

Preliminary Design of structural panels



Solar Arrays Supporting Struts-
120° of angular separation, connecting the SADM to S/C stiff points. In the launch configuration the 200 kg of SA and SADM are supported by the auxiliary struts and by HDRMs positioned in correspondence of the I/F between the shear panels and radiator panels.

STRUCTURE MASS BUDGET

	AstroSci Configuration				
Element	Quantity	Mass (kg)	Maturity Margin %	Mass with Margin (kg)	Total Mass (kg)
Radiator Panel	1	47,8	20	9,6	57,4
Shear Panels	6	3,5	20	0,7	25,5
Base	1	20,8	20	4,2	24,9
Lateral Panel	2	8,9	20	1,8	21,4
Central Cylinder	1	72,8	20	14,6	87,4
Tanks and RFCS support	1	16,6	20	3,3	19,9
Central Cylinder Rings	2	10,0	20	2,0	24,0
Tertiary Structure	1	25,6	20	5,1	30,7
SA Supporting struts	3	5,0	20	1,0	18,0
total Mass					309,2

	Peak Power Configuration				
Element	Quantity	Mass (kg)	Maturity Margin %	Mass with Margin (kg)	Total Mass (kg)
Radiator Panel	1	47,8	20	9,6	57,4
Shear Panels	6	3,5	20	0,7	25,5
Base	1	20,8	20	4,2	24,9
Lateral Panel	2	8,9	20	1,8	21,4
Central Cylinder	1	72,8	20	14,6	87,4
Tanks and RFCS support	1	10,8	20	2,2	13,0
Central Cylinder Rings	2	10,0	20	2,0	24,0
Tertiary Structure	1	24,7	20	4,9	29,6
SA Supporting struts	3	5,0	20	1,0	18,0
total Mass					301,2

/// The main difference between the two configuration in terms of structural mass is related to the “Tanks and RFCS support mass”. This mass is related to the number of Tanks of the configuration; indeed , in the PeakPwr configuration the H2,O2, and Water tanks are halved, and there’s a consequent reduction of 6 kg of the structural support mass as showed by the following figure.

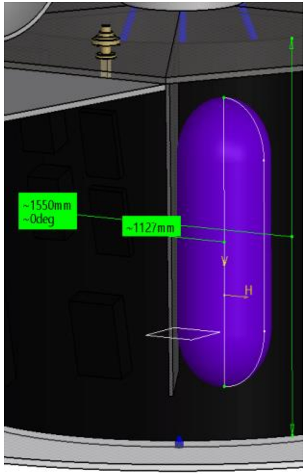
	AstroSci		Peak Power	
	N. of Items	Support Mass (kg)	N. of Items	Support Mass (kg)
H2	8	6,4	4	3,2
O2	4	3,2	2	1,6
water	2	2	1	1
RFCS	1	5	1	5
tot		16,6		10,8

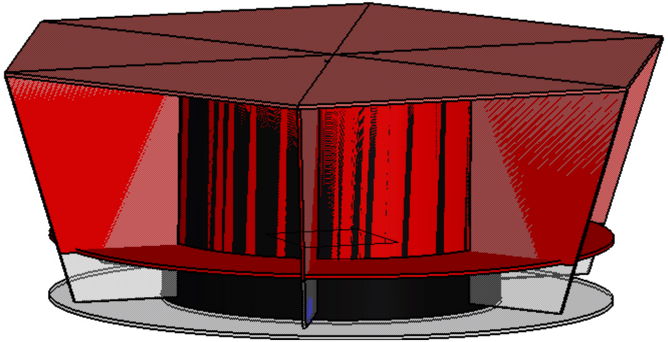
The structural to wet mass ratio of the ECSM spacecraft is larger (about 20%) wrt the usual range for this class of spacecraft 9-13%.

STRUCTURE OPTIMIZATION

/// Optimization the S/C height:

- Limiting Factor Is The H2 Tanks Height-> 1.1 Mt.
- Current Structure Height -> 1.5 Mt
- Possible Reduction Of The Central Cylinder Height, The Shear Panels Height, Also The Three Rods That Connect The SADM With The Primary Structure.
- A Reduction Of 30 Cm Is Possible From The Accommodation Point And Will Positively Affect The Mechanical Performance Of The S/C, Increasing The Stiffness , Making The S/C More Robust And Compact, Also Optimizing The Mechanical Connections Between The Tanks And The Central Cylinder, The Bottom And Top Panels.
- With A Rough Calculation Is Possible To Observe The Reduction Of 25 Kg Of Structure Mass, Without Considering The Application Of The System Margin On Top Of These Values.





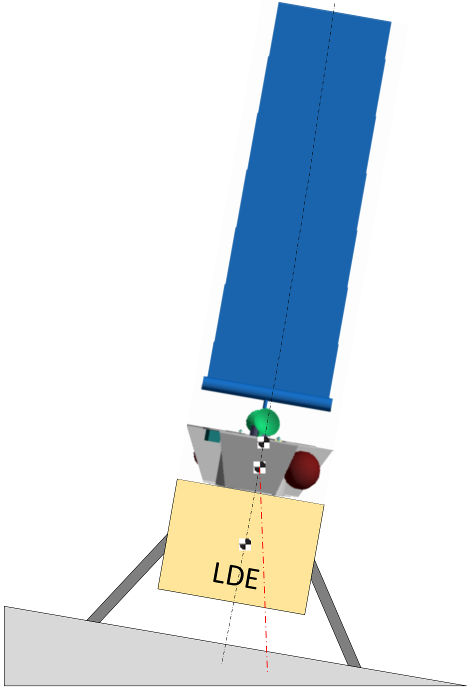
Reduced Structure vs Non-Optimized Structure

	AstroSci Configuration Optimized structure				
Element	Quantity	Mass (kg)	Maturity Margin %	Mass with Margin (kg)	Total Mass (kg)
Radiator Panel	1	47,8	20	9,6	57,4
Shear Panels	6	3,2	20	0,6	22,7
Base	1	20,8	20	4,2	24,9
Lateral Panel	2	8,9	20	1,8	21,3
Central Cylinder	1	58,7	20	11,7	70,5
Tanks and RFCS support	1	16,6	20	3,3	19,9
Central Cylinder Rings	2	10,0	20	2,0	24,0
Tertiary Structure	1	23,4	20	4,7	28,1
SA Supporting struts	3	5,0	20	1,0	18,0
total Mass					286,8

286.8 kg vs 309 kg of the non optimized configuration

TIPPING OVER ANALYSIS

/// AstroSci

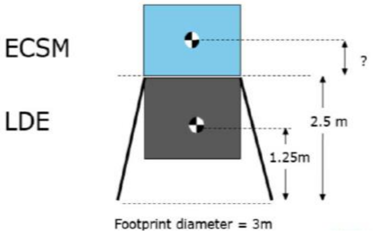


►	ECSM_Platform	COG			COG including mass margins		
		x [mm]	y [mm]	z [mm]	x [mm]	y [mm]	z [mm]
Total		44.7	96.5	1696.9	43.9	92.3	1710.7
Total with system margins		44.7	96.5	1696.9	43.9	92.3	1710.7

IF Height	2.5 mt
ECSM CoG from I/F	1.71 mt
Base diameter	3 mt

	LDE	ECSM	RLS
mass (kg)	1750	1558	3308
CoG (mt)	1.25	4.21	2.64

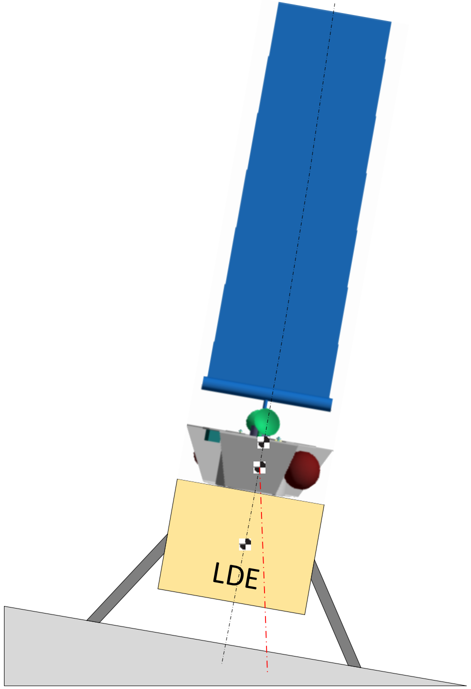
- m_{ECSM} = 1700 kg



/// Using the assumptions mentioned above, the maximum angle of **29.56 deg** is calculated as the maximum angle of the RLS before tipping over start

TIPPING OVER ANALYSIS

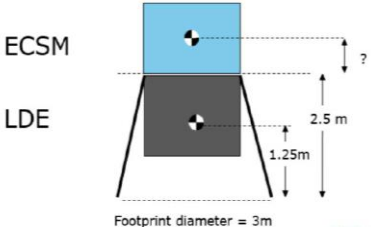
/// PeakPWR



▶ ECSM_Platform	COG			COG including mass margins		
	x [mm]	y [mm]	z [mm]	x [mm]	y [mm]	z [mm]
Total	**-12.7**	**-39.8**	**1802.1**	**-5.5**	**-32.6**	**1817.1**
Total with system margins	**-12.7**	**-39.8**	**1802.1**	**-5.5**	**-32.6**	**1817.1**

IF Height	2.5 mt
ECSM CoG from I/F	1.817 mt
Base diameter	3 mt

- m_{ECSM} = 1700 kg

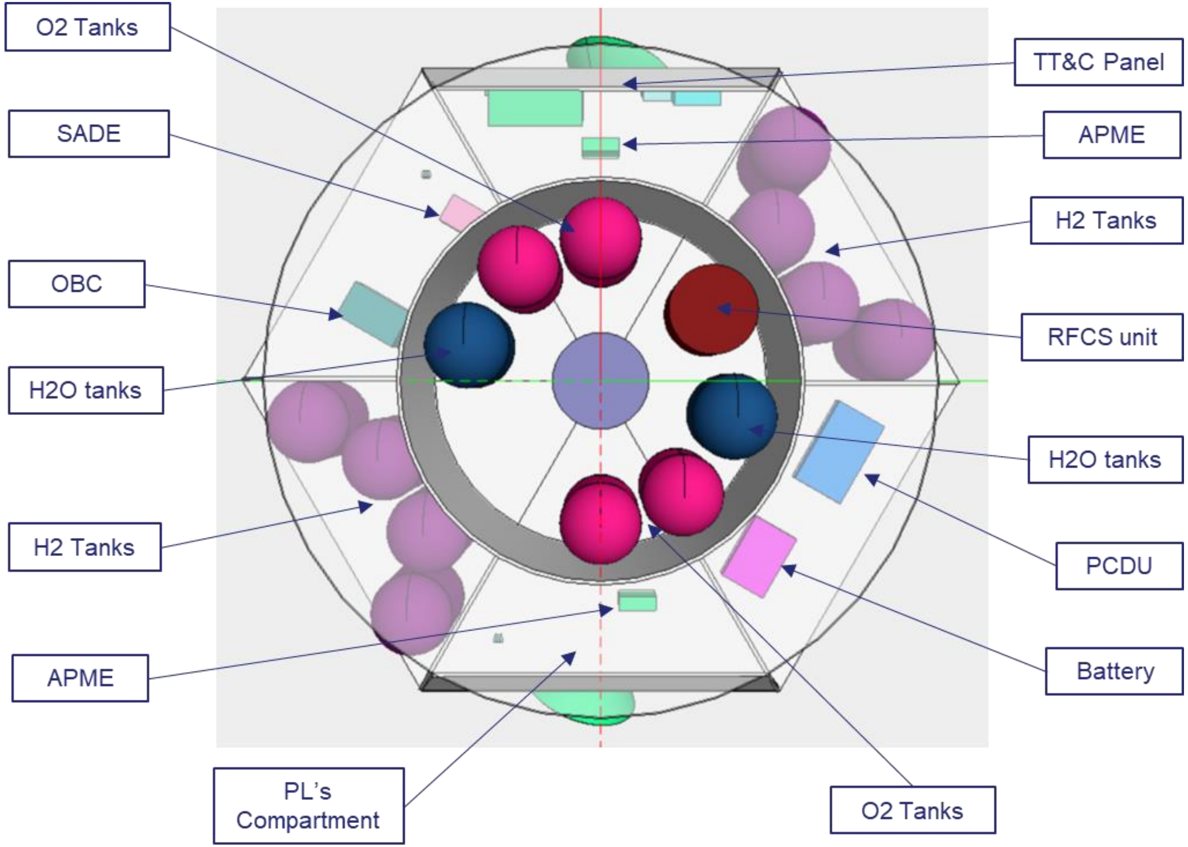


	LDE	ECSM	RLS
mass (kg)	1750	1529	3279
CoG	1.25	4.32	2.68

/// Using the assumptions mentioned above, the maximum angle of **29.23 deg** is calculated as the maximum angle of the RLS before tipping over start

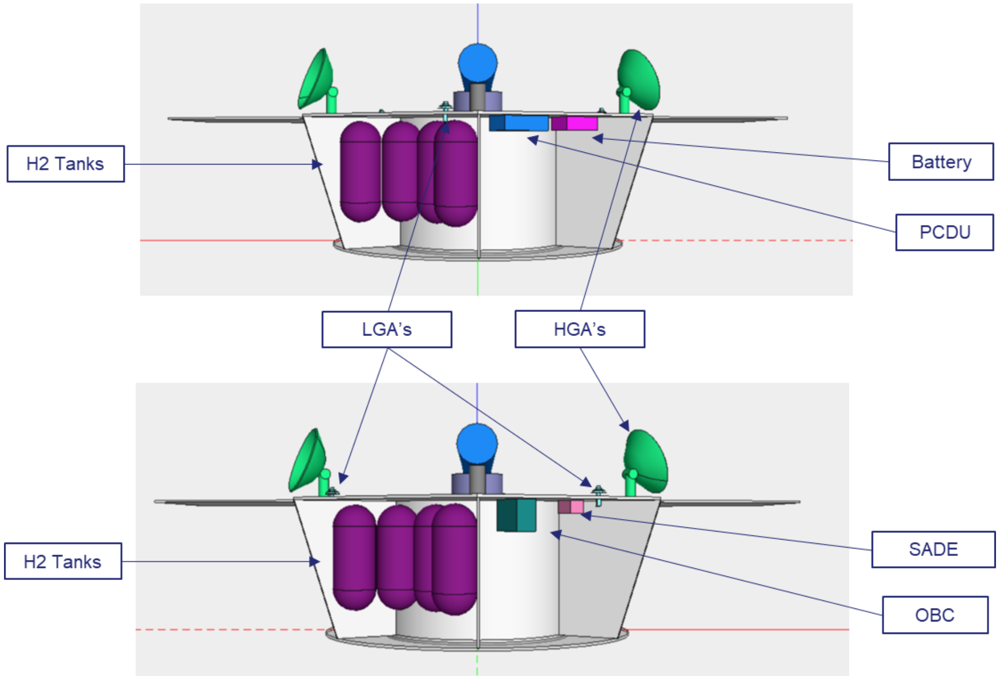
CONFIGURATION

/// AstroSci –Z Axes

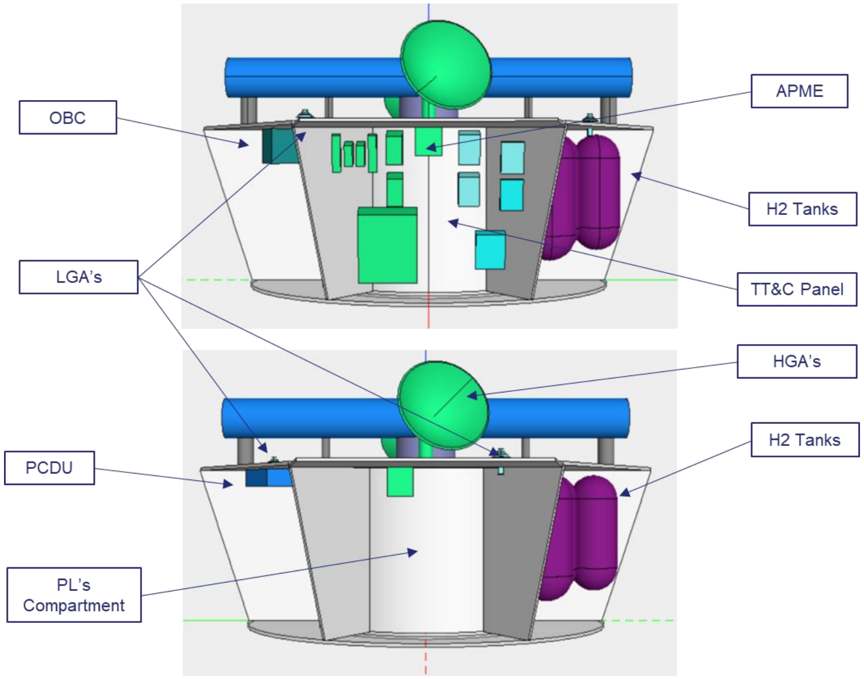


CONFIGURATION

/// AstroSci +Y/-Y Axes

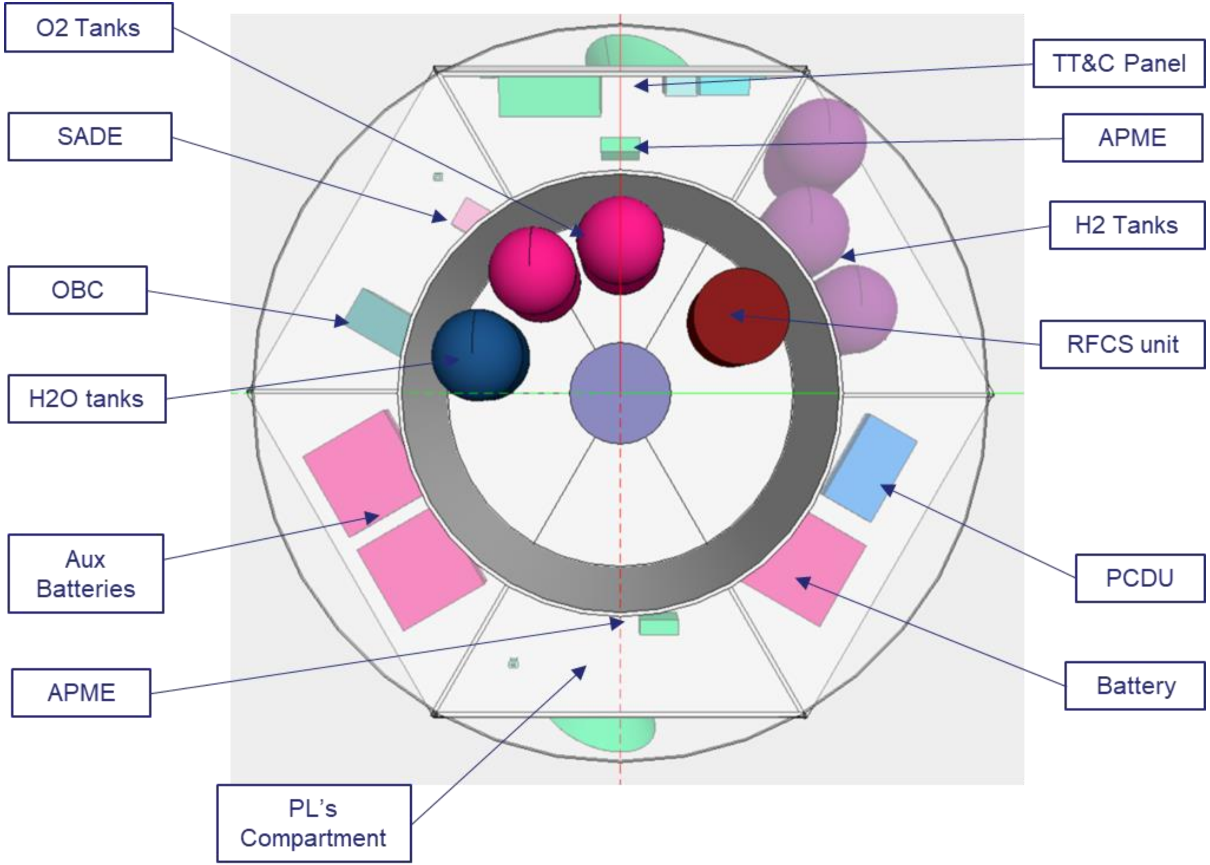


/// AstroSci +X/-X Axes



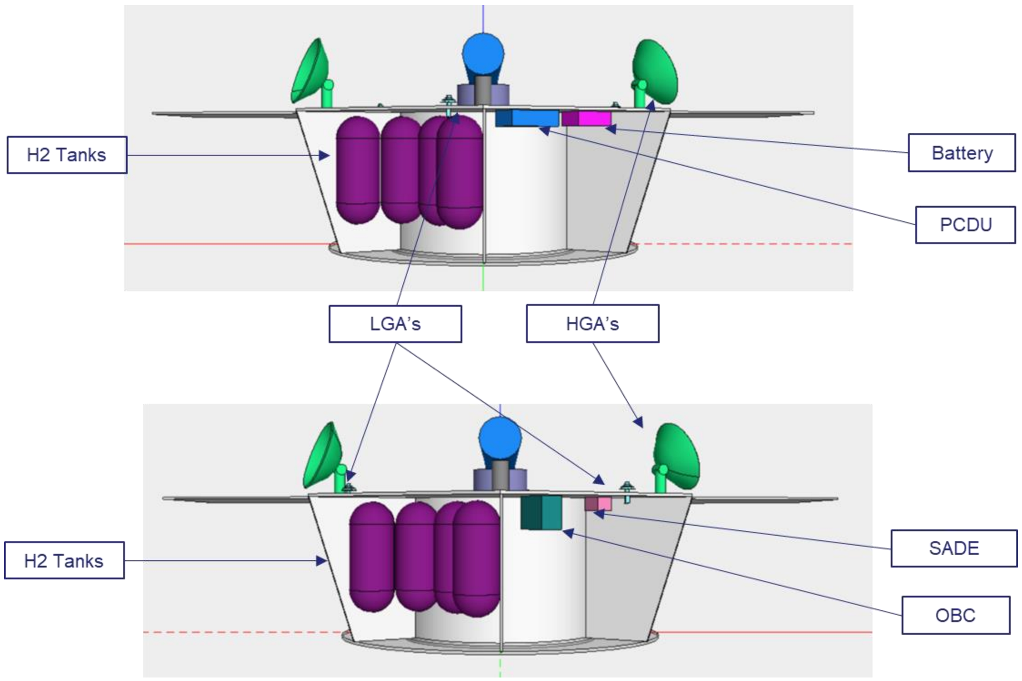
CONFIGURATION

/// PeakPWR –Z Axes

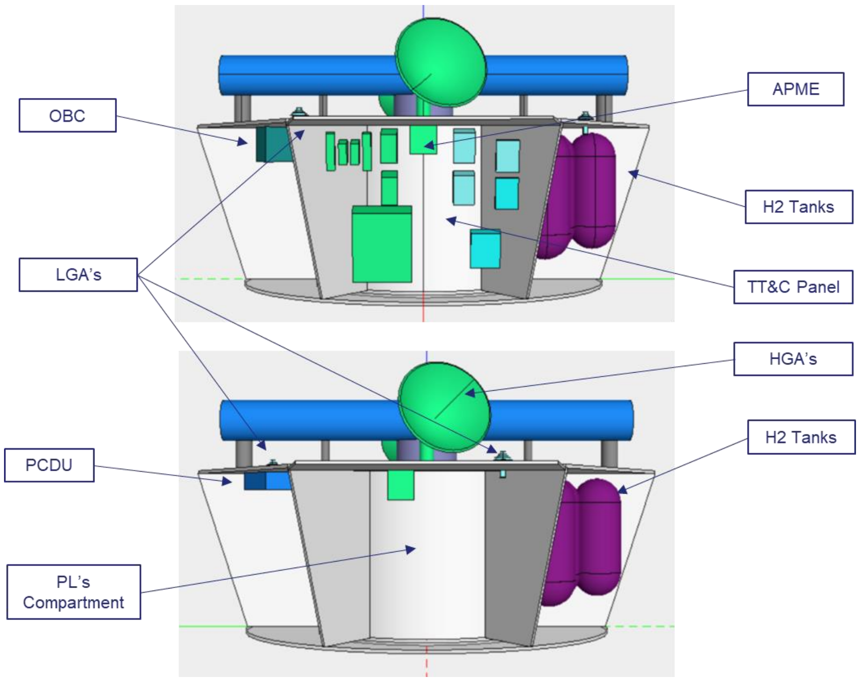


CONFIGURATION

/// PeakPWR +Y/-Y Axes

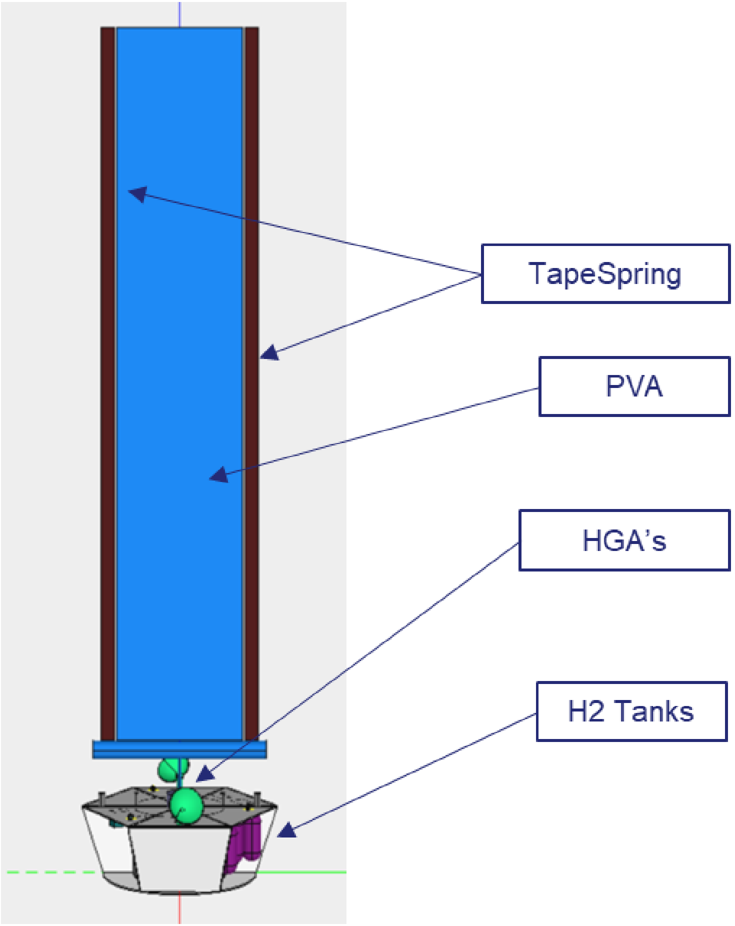


/// PeakPWR +X/-X Axes



CONFIGURATION

/// AstroSci & PeakPWR +X



ECSM BUDGET - MASS

Mass

The total mass budget of ECSM is:

- AstroSci configuration - **1594 kg** including
  - 18% maturity margin (resulting from margin policy applied to each individual items)
  - 20% system margin

- PeakPwr - **1551 kg** including
  - 17% maturity margin (resulting from margin policy applied to each individual items)
  - 20% system margin

- *ECSM-SYS-REQ-0290 - ECSM Dry mass shall not exceed 1.5 ton TBC*

ECSM - AstroSci - Mass Budget			
Platform	Without margin [Kg]	Margin [%]	Including margin [Kg]
Electrical Power SubSystem	294	18%	346
Data Handling System	12	20%	14
TTC	94	12%	105
Thermal Control System	78	20%	94
RFCS	387	16%	450
Structure	258	20%	309
Subsystem USER-IF-SS	8	20%	9
Total mass without system margins	1130	18%	1328
Total mass including all margins			1594

ECSM - PeakPWR - Mass Budget			
Platform	Without margin [Kg]	Margin [%]	Including margin [Kg]
Electrical Power SubSystem	464	15%	533
Data Handling System	12	20%	14
TTC	94	12%	105
Thermal Control System	78	20%	94
RFCS	200	17%	234
Structure	258	20%	309
Subsystem USER-IF-SS	8	20%	9
Total mass without system margins	1107	17%	1292
Total mass including all margins			1551

ECSM BUDGET - POWER

Power

The Power subsystem provides about **9 kW** continuous power in both scenarios (in sunlight conditions) considering the 20% system margin.

Specifically for PeakPwr the EPS provides more than **17 kW** for a duration not exceeding the specified **3 hours** (in sunlight conditions). Both Solar Array and Battery are used simultaneously as ECSM power sources during peak power mode

ECSM - AstroSci - Power Budget										
		CRUISE-LANDING	DEPLOYMENT	COMM.	ECLIPSE-SURV	ECLIPSE-TX	ECLIPSE-SAROT	DAYLIGHT-STANDBY	DAYLIGHT	DAYLIGHT-TX
Power Source		LDE	Battery	Solar Array	RFCS	RFCS	RFCS	Solar Array	Solar Array	Solar Array
Platform including margin	W	109	482	985	243	320	285	864	864	1027
User I/F including margin	W	0	0	0	6	6	6	0	185	185
EXT User	W	0	0	0	260	260	260	0	7700	7700
TOT Power inclufding margi	W	109	482	985	509	586	551	864	8749	8911

ECSM - PeakPwr - Power Budget											
		CRUISE-LANDING	DEPLOYMENT	COMM.	ECLIPSE-SURV	ECLIPSE-TX	ECLIPSE-SAROT	DAYLIGHT-STANDBY	DAYLIGHT	DAYLIGHT-TX	PEAK-POWER
Power Source		LDE	Battery	Solar Array	RFCS	RFCS	RFCS	Solar Array	Solar Array	Solar Array	Solar Array / Battery
Platform including margin	W	109	463	943	224	301	266	823	823	985	823
User I/F including margin	W	0	0	0	0	0	0	0	185	185	384
EXT User	W	0	0	0	0	0	0	0	7700	7700	16000
TOT Power inclufding margi	W	109	463	943	224	301	266	823	8708	8870	17207

ECSM BUDGET - DISSIPATION

Dissipation

The ECSM dissipation depends on power distributed to both internal end external loads.

PCDU is the critical item in terms of power dissipation, the RFCS power dissipation during lunar night is not reported in the following tables but taken into account as het source for the TCS design.

The ECSM power dissipation is within the **100W to 1.2kW** for both AstroSci and PeakPWR configurations.

ECSM - AstroSci - Dissipation Budget

Power Source		CRUISE-LANDING LDE	DEPLOYMENT Battery	COMM. Solar Array	ECLIPSE-SURV RFCS	ECLIPSE-TX RFCS	ECLIPSE-SAROT RFCS	DAYLIGHT-STANDBY Solar Array	DAYLIGHT Solar Array	DAYLIGHT-TX Solar Array
Platform including margin	W	109	440	944	243	299	285	864	864	985
User I/F including margin	W	0	0	0	6	6	6	0	185	185
EXT User	W	0	0	0	0	0	0	0	0	0
TOT Power inclufding margi	W	109	440	944	249	305	291	864	1049	1169

ECSM - PeakPwr - Dissipation Budget

Power Source		CRUISE-LANDING LDE	DEPLOYMENT Battery	COMM. Solar Array	ECLIPSE-SURV RFCS	ECLIPSE-TX RFCS	ECLIPSE-SAROT RFCS	DAYLIGHT-STANDBY Solar Array	DAYLIGHT Solar Array	DAYLIGHT-TX Solar Array	PEAK-POWER Solar Array / Battery
Platform including margin	W	109	421	901	224	280	266	823	823	943	823
User I/F including margin	W	0	0	0	0	0	0	0	185	185	384
EXT User	W	0	0	0	0	0	0	0	0		
TOT Power inclufding margi	W	109	421	901	224	280	266	823	1008	1128	1207

OPERATIONS – TN5 ECSM OPERATIONAL CONCEPT

/// TN-5 document (TASI-SD-ECSM-TNO-0623) presents the ECSM operational concept, addressing the following aspects:

- Mission Scenario:
  - general mission,
  - ground segment and communication,
  - mission phases,
  - systems modes and mode transitions
- User Cases high level timelines
- Critical phases timelines for Post Landing and User Connection phases
- Findings and recommendations

OPERATIONS - GENERAL OVERVIEW

- /// The ECSM will be launched on-board an EL3 mission, with Ariane 6 launcher from Kourou Spaceport.
- /// After launch and LEOP phase, the transfer phase to the Moon could last from a few days in case of a direct injection into Lunar Transfer Orbit (LTO), up to 4-6 months in case of a Weak-Stability Boundary (WSB) transfer strategy.
- /// From LEOP to post-landing the LDE supplies power to the ECSM, and ECSM HK data are transferred to ground via LDE by means of the LDE communications system. All manoeuvres during transfer, descent and landing are performed by LDE.
- /// After landing, ECSM Solar Array will be deployed and the LDE resources will be disconnected. A commissioning phase will be run for about 1 day to check ECSM subsystems. After Commissioning the nominal operational phase providing power to the Users can start.
- /// The mission EOL and the ECSM passivation is planned 2 years after the launch date.

OPERATIONS - POWER USERS

/// AstroSci Mission Scenario

- AstroSci requires continuous power supply during lunar day to 2-3 ISS-like racks, and reduced power during eclipse:
  - 7700 W to external users during lunar day
  - 260 W during the eclipse/lunar night
- For AstroSci, the battery is requested to supply power in the deployment phase and during the peak loads, while the RFC is in charge to satisfy the internal and external loads in the eclipse period.

/// PeakPwr Mission Scenario

- PeakPwr requires continuous power supply during lunar day to 2-3 ISS-like racks, with peak power for a limited time period, and no power during eclipse:
  - - 7700 W to external users during lunar day
  - - 8300 W peak power for 3 hours during lunar day, (provided on top of the 7700W nominal)
- In the PeakPwr, the battery is sized for the 3 hours peak power request from external users in sunlight period, while the RFC is in charge to satisfy only the internal ECSM loads during the eclipse period, with no external power request. After the 3 hours of peak power provision, the battery shall be recharged for 21 hours to restore peak power provisioning capability (while still providing nominal power to an user).
- From CFD analysis RD01, a maximum of two peak power periods of three Lunar days each are considered.

OPERATIONS - GROUND SEGMENT AND COMMUNICATION SCENARIO

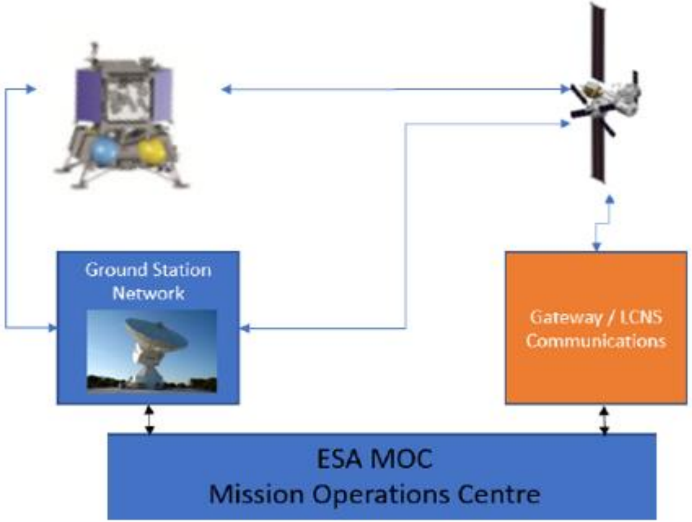
/// The ECSM operation ground segment will be based on the maximum sharing of the general ESA/ESOC infrastructure and reuse of manpower, facilities and tools of the EL3 infrastructure.

/// ESA MOC will be responsible for ECSM Command and Control from LEOP up to the end of the mission.

/// It is assumed that the operations are primarily automatically conducted, based on an event and/or scheduler driven system. Real-time operations will be needed during mission critical operations, e.g. solar panel deployment, users interfacing operations, and decommissioning activities. ECSM users perform manual connections operations during illuminated periods, and when Direct to Earth (DTE) is available.

/// ECSM will produce Housekeeping Telemetry, and store it in non-volatile memory. The Control & Data Handling System will provide ECSM management, using standard PUS Services (TC, HKTM), either autonomously, or controlled from Ground Centre. ECSM will report, and annunciate faults for alerts, caution, warning, and emergency events to the Ground Centre.

/// ECSM has different communication needs during the different phases of the mission. In addition to using a network of ground stations, it will use the Gateway NASA communications capabilities (option LCNS) when DTE communication is not available



OPERATIONS - OPERATIONAL PHASES

PHASES	Start event	End Event	Duration	Main Events
LAUNCH AND LEOP	Launch Countdown	Correction Maneuver	Few days	Launch, Ascent, Separation from launch vehicle, Launch Correction Maneuvers, LDE commissioning. ECSM OBC in Stand-by, HK telemetry downloaded on a regular bases
CRUISE TRANSFER	Correction Maneuver	Lunar orbit injection	TLO: 5 to 10 days WSB: 4 to 6 months	TCMs, Lunar Insertion ECSM OBC in Stand-by, HK telemetry downloaded on a regular bases
DESCENT AND LANDING	Lunar orbit injection	Touch-down	1 month	LO insertion maneuvers, touch down ECSM OBC in Stand-by
POST LANDING	Touch-down	End of SA deployment	2,5 hours	Health Checks, attitude determination ECSM solar Arrays deployment,
COMMISSIONING	End of SA deployment	End of Health and performance checks	24 hours	ECSM on internal resources, system and subsystems commissioning
SURFACE	End of Commissioning	End of Life	2 years	User Power provision
DECOMMISSIONING	End of Life	ECSM passivation and switch-off	24 hours	ECSM passivation and switch-off

OPERATIONS - OPERATIONAL PHASES

/// LAUNCH and Early Operations (LEOP) PHASE

- The LDE will be launched with Ariane 6, from the European Spaceport located in Kourou (French Guyana).
- The Launch Period will be: 2030-2032 (TBC).
- This phase starts from Launch Countdown, main events are Ascent to orbit, Separation from the launch vehicle, De-tumbling, Sun acquisition, Early Operations, including commissioning of critical sub-systems such as power and communications, and performing Launch Correction Maneuvers. The LEOP will last a few days.
- During this phase ECSM needed resources (power, TM/TC routing, thermal) are provided by LDE.
- The Ground Centre will perform LDE commissioning. Periodic ECSM health checks will be run in this period, it is expected that a reduced team from ECSM industry engineering will provide real time support for selected timeframes to the Ground Centre.

OPERATIONS - OPERATIONAL PHASES

/// CRUISE TRANSFER PHASE

- The expected duration of this phase can vary according to the selected transfer typology:
- from 5 to 10 days in case of direct LTO
- from 4 to 6 months via weak stability boundary (WSB)
- No impacts on ECSM since in this phase all the resources are provided by LDE.
- It is assumed that during Cruise the ECSM HK telemetry will be downloaded regularly by Ground Centre and sent to the ECSM industry engineering support team for off-line evaluation and trend analysis. ECSM Periodic ECSM health checks will be run during, it is expected that a reduced team from ECSM engineering will provide real time support for selected timeframes to the Ground Centre.

/// DESCENT AND LANDING PHASE

- LDE will perform all maneuvers and phasing with target landing site. The expected phase duration is up to 1 month (TBC).
- During this phase ECSM needed resources (power, TM/TC routing, thermal) are provided by LDE.

OPERATIONS - OPERATIONAL PHASES

/// POST LANDING PHASE

- After LDE-ECSM touch-down, health checks will be performed by the Ground Centre to verify that all LDE S/Ss' and ECSM are in the correct configuration, and the LDE GNC data are retrieved to calculate the accurate position and attitude. Data from on-board LDE cameras will be retrieved to have accurate landscape images.
- After health and position checks, Ground Centre can activate the ECSM Solar Array deployment sequence, including HGA Antennas hold-down release mechanism activation, to allow HGAs Antenna deployment in the operational position and pointing.
- Starting with deployment, the ECSM will rely on its own power, thermal and communication systems. A period of up to 2 hours is foreseen until solar panels are deployed and operational. During this period of time the ECSM is powered by a battery.

OPERATIONS - OPERATIONAL PHASES

/// COMMISSIONING PHASE

- The total time assumed for ECSM deployment and commissioning is up to 24 hours. It is assumed to have real-time communication coverage during this period.
- After commissioning ECSM is ready to start power provision as soon as a user connects to the station.

OPERATIONS - OPERATIONAL PHASES

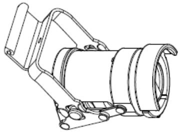
/// SURFACE PHASE (1 of 2)

- Lunar Day corresponds to 29,5 Earth days. For ECSM Storage systems sizing, it is assumed a fixed profile of 14,5 earth days sunlight and 15 days eclipse for each Lunar day within the 2-years mission. Detailed sunlight/eclipse variation periods analysis are not in the scope of this study, and related data have been derived from study reference documents for design sizing purposes.
- In this phase the ECSM will switch autonomously from day user supply (NOMINAL) to night user supply (SURVIVAL, as applicable, night power provided for AstroSci mission only) for the duration of the mission. It is assumed that the operations are primarily automatically conducted based on an event and/or scheduler driven system.
- During surface operations, if no user is connected, during Lunar daylight the ECSM is oscillating between charging and tapering to ensure batteries are always fully charged.
- During eclipse periods, ECSM is set to eclipse survival mode, with limited system power consumption and reduced User Power supply, as applicable.
- HKTM data retrieval and commanding opportunity is assumed at least once every 24 hours.
- Real-time operations will be needed for ECSM User interfacing operations, that are allowed only when Direct to Earth (DTE) is available. The User Interface operations are detailed in the following paragraph.

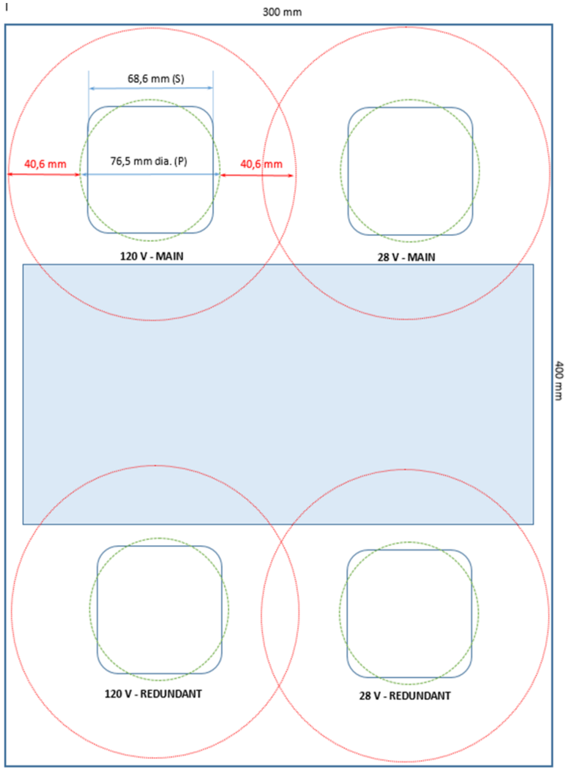
OPERATIONS - OPERATIONAL PHASES

/// SURFACE PHASE - USER INTERFACE OPS (2 of 2)

- The User interface panel layout has been evaluated taking into account the following aspects:
  - Available front area dimensions
  - POWER CONNECTORS: the selected connectors are used in EVA application for ISS. The type is NZGL (NASA Zero-Gravity Lever (NZGL), selected size 25.
  - stay-out area of 40.6mm all around the selected connector as per SSP 50005 11.10.3.6 connector arrangement design requirements)



- The available area on the interface panel can accommodate a maximum number of 6 connectors.
- The area on the interface panel is compatible with the accommodation of two 120V connectors, Main and Redundant, and two 28V connectors, Main and Redundant, in line with the needs identified for ECSM.
- The remaining free area is to be used for the accommodation of lights to support safe crew operations, one emergency Kill Switch, dummy connectors for protective caps.



OPERATIONS - OPERATIONAL PHASES

/// DECOMMISSIONING

Depending on the launch date, ECSM End of Life can occur between 2031-2037 timeframe.

After User disconnection, the ECSM will be passivated. The passivation activities will include:

- Solar array rotation and locking into a fixed position toward the shade, to avoid storage systems recharging
- Battery and RFC gradual depletion, leading to the ECSM units switch-off

OPERATIONS - OPERATIONAL MODES (1/2)

PHASES	CRUISE LANDING	POST-LANDING	ECLIPSE-SURV	DAYLIGHT-STANDBY	NOMINAL
LAUNCH AND LEOP	X				
CRUISE TRANSFER	X				
DESCENT AND LANDING	X				
POST LANDING		X			
COMMISSIONING				X	
SURFACE			X	X	X
DECOMMISSIONING				X	

/// GROUND MODE: used in ground processing and testing phases. No SW predefined ECSM configuration, equipment are activated manually by the operators via dedicated procedures.

/// CRUISE LANDING: used during launch, cruise and landing phases. Power Supply and TM/TC routing via LDE.

/// POST LANDING: It is commanded after post-landing conditions checks. This mode is used for:

- Deployment: SA deployment and HGA antenna pointing mechanism activation
- Commissioning: the ECSM final configuration will allow a full ECSM commissioning. After commissioning the STAND-BY will be commanded

OPERATIONS - OPERATIONAL MODES (2/2)

/// DAYLIGHT STAND-BY: used during Sunlight periods, all subsystems active, no power to Users. Periodic Data Transmission activated by timeline.

/// DAYLIGHT NOMINAL: used during Sunlight periods, all subsystems active, power supply available to Users. Periodic Data Transmission activated by timeline. For power budget three main power modes are identified:

- DAYLIGHT
- TX
- PEAK POWER (only for PeakPWR Scenario)

/// ECLIPSE SURVIVAL: used during ECLIPSE periods, with power to User for AstroSci scenario, no power to Users for PeakPwr Scenario. ECSM configuration is tailored for a minimum power consumption. For power budget two main power modes are identified:

- TX: one hour every 24 hours is assumed
- SAR ROTATION: this rotation is foreseen in order to achieve already the correct position to start charging at the first moment of the next daylight

OPERATIONS - TIMELINES

/// The following timelines are included in TN5:

- High-level timeline of ECSM operations for the AstroSci mission
- High-level timeline of ECSM operations for the PeakPwr mission
- Low-level timelines for critical ECSM operations: POST LANDING and User Interface Connection

/// Main assumptions:

- The energy storage system (either battery of RFCS) is considered fully charged at the time of the switch off of the LDE power line suppling ESCM during module transfer and moon landing.
- The Commissioning duration is assumed 24h, with continuous coverage in DTE or Proximity Link
- For each lunar day, 29,5 earth days, fixed periods of 15 days for eclipse and 14,5 days of sunlight are considered
- Peak Power timeline: as per CDF analysis RD01, 2 periods of Peak Power are assumed, first one on LD6-7-8, second one on LD18-19-20.
- User connection/disconnection: for AstroSci only one connection and one disconnection are tracked at the beginning of the mission and at the end of the 2 years, for Peak Power, one additional connections / disconnection cycle is considered for each of the two Peak Power periods.
- Peak Power cycles have been defined of 24 hours, power provided for 3 hours plus 21 hours for battery charge.

OPERATIONS – TIMELINES - ASTROSCI

EARTH DAY [start]	LUNAR DAY (29,5 earth day)	Sun/Eclipse	MAIN STEP	Steps Breakdown	Relative time	Duration (h)	Total Duration (h)	Elapsed Time (h)	Comment	System Mode	Power to Ext User [W]	Storage System - RFC	Storage System - Battery
1	LD1	Sun	Touchdown				0,5	-0,50	Additional time needed to perform LDE post-landing checks and for dust deposition to be defined	CRUSE LANDING	0	Full Charge	Full Charge
▪ 1	LD1	Sun	LDE-ECSM power disconnection				0	0,00	T0 The energy storage system (either battery of RFCS) is considered fully charged at the time of the switch off of the LDE power line suppling ESCM during module transfer and moon landing.	POST LANDING	0	Full Charge	Full Charge
1	LD1	Sun	Solar array deployment				2	2,00		POST LANDING	0	Full Charge	Discharging
1	LD1	Sun	Commissioning (external users not attached)				24	26,00	The Commissioning duration is assumed 24h as conservative assumption (range from 24h to 48h is mentioned by ESA during the meeting)	POST LANDING	0	Charging	Charging
2	LD1	Sun	External User Connection				0,50	26,50	See detailed timeline	DAYLIGHT STAND-BY	0	Charging	Charging
2	LD1	Sun	Sunlight				124	150,50	Total sunlight time from T0 to first eclipse (150 hours) External User Load of 7,7 kW is considered in this phase	NOMINAL	7700	Charging	Charging
6	LD1	Eclipse	First eclipse				360	510,50		ECLIPSE SURVIVAL	260	Discharging	Discharging
	LD1			Survival		115			SURVIVAL: OBC in SB, both K-antennas in RX, ext. PL				
	LD1			TX		15			TX activation in eclipse is assumed as 1 hour per day; for this timeline it is shown as concentrated in a single slot				
	LD1			Survival		115							
	LD1			AS eclipse SA rotation (RFC)		0,1			SA rotation in eclipse are assumed for this timeline concentrated in a single slot				
	LD1			Survival		115							
21	LD2	Sun	Sunlight				348	858,50	EPS sizing case is an alternation of continuous 360 hours of eclipse and 348 hours of sunlight with full sun disk visibility SA rotation and TX activation in sunlight are not identified in this timeline	NOMINAL	7700	Charging	Charging
36		Eclipse	Eclipse				360	1218,50		ECLIPSE SURVIVAL	260	Discharging	Discharging
				Survival		115							
				TX		15			TX activation in eclipse is assumed as 1 hour per day; for this timeline it is shown as concentrated in a single slot				
				Survival		115							
				AS eclipse SA rotation (RFC)		0,1			SA rotation in eclipse are assumed for this timeline concentrated in a single slot				
				Survival		115							
51	LD3	Sun	Sunlight				348	1566,50	User Connection/disconnection activities within the mission are not included in this timeline, only one connection and one disconnection are tracked at the beginning of the mission and at the end of the 2 years.	NOMINAL	7700	Charging	Charging
65		Eclipse	Eclipse				360	1926,50		ECLIPSE SURVIVAL	260	Discharging	Discharging
80	LD4	Sun	Sunlight				348	2274,50		NOMINAL	7700	Charging	Charging
95		Eclipse	Eclipse				360	2634,50		ECLIPSE SURVIVAL	260	Discharging	Discharging
700	LD25	Sun	Sunlight				348	17142,50		NOMINAL	7700	Charging	Charging
714		Eclipse	Eclipse				360	17502,50		ECLIPSE SURVIVAL	260	Discharging	Discharging
729	LD26	Sun	Sunlight				24	17526,50		NOMINAL	7700	Charging	Charging
730	LD26	Sun	External User Disconnection				0,50	17527,00	Assumption: same duration as per connection activities.	DAYLIGHT STAND-BY	0	Charging	Charging
730	LD26	Sun	Decommissiong and Power OFF				24	17551,00		DAYLIGHT STAND-BY	0	Discharging	Discharging

OPERATIONS – TIMELINES - PEAKPWR

▪

EARTH DAY [start]	LUNAR DAY (29,5 earth day)	Sun/Eclipse	MAIN STEP	Steps Breakdown	Relative time	Duration (h)	Total Duration (h)	Elapsed Time (h)	Comment	System Mode	Power to Ext User [W]	Storage System - RFC	Storage System - Battery
1	LD1	Sun	Touchdown				0,5	-0,50	Additional time needed to perform LDE post-landing checks and for dust deposition to be defined	CRUSE LANDING	0	Full Charge	Full Charge
21	LD2	Sun	Sunlight				348	858,50	EPS sizing case is an alternation of continuous 360 hours of eclipse and 348 hours of sunlight with full sun disk visibility SA rotation and TX activation in sunlight are not identified in this timeline	NOMINAL	7700	Charging	Charging
36		Eclipse	Eclipse				360	1218,50		ECLIPSE SURVIVAL	0	Discharging	Discharging
				Survival		115,00							
				TX		15,00			TX activation in eclipse is assumed as 1 hour per day; for this timeline it is shown as concentrated in a single slot				
				Survival		115,00							
				AS eclipse SA rotation (RFC)		0,10			SA rotation in eclipse are assumed for this timeline concentrated in a single slot				
				Survival		115,00							
51	LD3	Sun	Sunlight				348	1566,50	Nominal User Connection/disconnection activities within the mission are not included in this timeline, only one connection and one discomession are tracked at the beginning of the mission and at the end of the 2 years. Peak Power Connections are considered for a maximum of 6 Lunar days during the mission.	NOMINAL	7700	Charging	Charging
65		Eclipse	Eclipse				360	1926,50		ECLIPSE SURVIVAL		Discharging	Discharging
139	LD6	Sun	Sunlight				348	3690,50		NOMINAL	7700	Charging	Charging
				Peak Power User Connection		0,50			Connection possible only if Communication with MCC is avalable. As per CDF analysis RD01, two periods of Peak Power are assumed, first one on LD6-7-8, second one on LD18-19-20				
			Peak Power Cycle 1	Peak Power		3,00			Peak Power can be provided for 3 hours, followed by 21 hours for battery charge.		8300	Charging	Discharging
				Recharge after Peak		21,00					7700	Charging	Charging
			Peak Power Cycle 14	Peak Power		3,00					8300	Charging	Discharging
				Recharge after Peak		21,00						Charging	Charging
154		Eclipse	Eclipse				360	4050,50		ECLIPSE SURVIVAL		Discharging	Discharging
169	LD7	Sun	Sunlight				348	4398,50		NOMINAL	7700	Charging	Charging
			Peak Power Cycles 1 to 14	PeaK Pwr		3							
				Recharge after Peak		21							
183		Eclipse	Eclipse				360	4758,50		ECLIPSE SURVIVAL	260	Discharging	Discharging
198	LD8	Sun	Sunlight				348	5106,50		NOMINAL	7700	Charging	Charging
			Peak Power Cycles 1 to 14	Peak Power		3,00					8300		
				Recharge after Peak		21,00					7700		
				Peak Power Disconnection		0,50			Disconnection activities possible only if Communication with MCC is avalable		7700		
213		Eclipse	Eclipse				360	5466,50		ECLIPSE SURVIVAL		Discharging	Discharging
228	LD9	Sun	Sunlight				348	5814,50		NOMINAL	7700	Charging	Charging
242		Eclipse	Eclipse				360	6174,50		ECLIPSE SURVIVAL	0	Discharging	Discharging
700	LD25	Sun	Sunlight				348	17142,50		NOMINAL	7700	Charging	Charging
714		Eclipse	Eclipse				360	17502,50		ECLIPSE SURVIVAL	260	Discharging	Discharging
729	LD26	Sun	Sunlight				24	17526,50		NOMINAL	7700	Charging	Charging
730	LD26	Sun	External User Disconnection				0,50	17527,00	Assumption: same duration as per connection activities.	DAYLIGHT STAND-BY	0	Charging	Charging
730	LD26	Sun	Decommissiong and Power OFF				24	17551,00		DAYLIGHT STAND-BY	0	Discharging	Discharging

OPERATIONS – TIMELINES – POST LANDING

EARTH DAY [start]	LUNAR DAY [29,5 earth days]	Sun/Eclipse	MAIN STEP	Steps Breakdown	Duration (s)	Duration (h)	Total Duration (h)	Elapsed Time (h)	Comment	System Mode	SA	Ext User	Storage System - RFC	Storage System - Battery
Launch-3 days	N/A	n/a	Battery Charging						It is assumed that the ECSM battery is fully charged on the ramp , 3 days before the launch. The RFC storage system tanks are full.	GROUND	Stowed	n/a	Full Charge	Full Charge
Launch/ Cruise and Landing	N/A	n/a	Periodic health checks						Power and data via LDE	CRUSE LANDING	Stowed	n/a	Full Charge	Full Charge
DAY1	LD1	Sun	Touchdown				0,5	-0,50	Additional time needed to perform LDE post-landing checks and for dust deposition to be defined	CRUSE LANDING	Stowed	NO	Full Charge	Full Charge
				MCC: ECSM Health Check										
DAY1	LD1	Sun	LDE-ECSM power disconnection				0	0,00	T0 The energy storage system (either battery of RFCS) is considered fully charged at The time of The switch off of The LDE power line suppling ESCM during module transfer and moon landing.	POST LANDING	Stowed	NO	Full Charge	Full Charge
DAY1	LD1	Sun	Solar array deployment				2	2,00		POST LANDING	Stowed	NO	Full Charge	Discharging
				MCC - TC for SA Deployment sequence start	3									
	LD1			telescopic mast vertical lift up		0,33								
	LD1			SA blanket deployment		0,67								
				HGA antennas Hold down mechanism release		TBD								
				Move HGA antennas in operational positions - tracking		TBD								
	LD1			margin		1,00								
DAY1	LD1	Sun	Commissioning (external users not attached)				24	26,00	The Commissioning duration is assumed 24h as conservative assumption (range from 24h to 48h is mentioned by ESA during the meeting). Continous coverage for commissioning via DTE or Proximity link is assumend	POST LANDING	Deployed	NO	Charging	Charging
DAY2	LD1	Sun	External User Connection				0,50	26,50	At the end of manual User connection the system is sent to NOMINAL, with automatic switch to SURVIVAL during ECLIPSE	DAYLIGHT STAND-BY	Deployed	YES	Charging	Charging

OPERATIONS – TIMELINES USER INTERFACE CONNECTION

.

MAIN STEP	Performed by	Steps Breakdown	Duration (s)	Elapsed Time (s)	Elapsed Time (min)	Comment	Constraint
Connection Preparation		T0		0,00	0,00		Sunlight MCC real time support
	MCC	Send TC for recharge preparation	3	3,00	0,05	Time for signal propagation moon-earth is about 2,54 s. Condidering processing time for TT&C e DHS, 3 seconds are assumed.	
	ESCM	Power to User Interface Panel (UIP)	1	4,00	0,07	User I/F Panel display set to DO NOT APPROACH	
	CREW	Ask for GO for manual connection	25	29,00	0,48	Direct communication Crew-MCC Crew stops at about 1 meter from UIP	
	MCC	Check ECSM data	120	149,00	2,48		
	MCC	Give GO for manual connection /TC	25	174,00	2,90	User I/F Panel display set to SAFE TO CONNECT	
Manual Connection	CREW	Approch User I/F panel	30	204,00	3,40		
		Temporary store the User power cable	60	264,00	4,40		
		Identify Connector position on UIP	10	274,00	4,57	Read Label on UIP	
		Remove protective cap from the UIP	150	424,00	7,07	Protective cap can be fixed to dummy connector on UIP, if enought space is available. Two-steps operation.	
		Connect the protective cap to the dummy connector	150	574,00	9,57	Protective cap can be fixed to dummy connector on UIP, if enought space is available. Two-steps operation: put in contact the two parts, and push the lever to close	
		Remove protective cap from User cable and store	150	724,00	12,07	It is assumed that the protective cap operations are similar to the ones for UIP connector cap	
		Mate the connector	150	874,00	14,57	Two step operation: put in contact the two parts, and push the lever to close	
	ESCM	Display CORRECT MATING	1	875,00	14,58	User I/F Panel display set to CORRECT MATING	
	CREW	GO to MCC for Power on	25	900,00	15,00		
		Margin 100%	900,00	1800,00	30,00		
Power Provision to User	MCC	Send TC for Power distribution	3	1803,00	30,05		
	ESCM	Power to User	1	1804,00	30,07	User I/F Panel display set to POWER SUPPLIED	

OPERATIONS - FINDINGS AND RECOMMENDATIONS FROM OPERATIONAL ANALYSIS

/// User Interface Panel (UIP)

The volume available for the Lower Payload Compartment and cables routing has to be defined with LDE geometrical models.
The User Interface panel dimensions provided (300mm x 400mm) can be suitable for this study, since the four baseline power connectors can be accommodated, but dedicated layout study shall be run taking into account Crew displays dimensions, dummy connectors for caps temporary accommodation, lights and the possibility to add two cameras to allow Ground Centre follow-up of crew operations.

Panel layout could be optimized taking into account the new EVA suits/gloves that are under development, that may have impacts on the current requirement of the stay-out area of 40.6mm all around the EVA connector
For User Interface panel utilization from a robotic user, dedicated layout and different connectors shall be identified, since the NZGL connectors are optimized for manual operations.

The need of UIP protective thermal covers during launch/cruise or in Surface when the UIP is not used shall be assessed in future stages. The cover shall be compatible with EVA standard for crew removal/installation operations.

/// Cable Transportation and handling

The aspects related to the power connection of a User that can be far from LDE/ECSM shall be evaluated.
The cable diameter and length can require a dedicated support equipment to allow the crew handling and transportation on lunar surface up to the ECSM User interface panel.
Moreover a study could be activated to evaluate the possibility to have the power cables as part of ECSM, exploiting available free volumes in the structure.

SYSTEM GROWING CAPABILITY (MODULAR APPROACH)

/// A Modular approach is applied for the evaluation of:

- **INCREASING POWER DEMAND FROM EXTERNAL USER**
- **POTENTIAL ACCOMMODATION OF PAYLOADS INSIDE THE ECMS MODULE (NOT PART OF THE STUDY)**

/// Assessment of impacts for each individual subsystem follow:

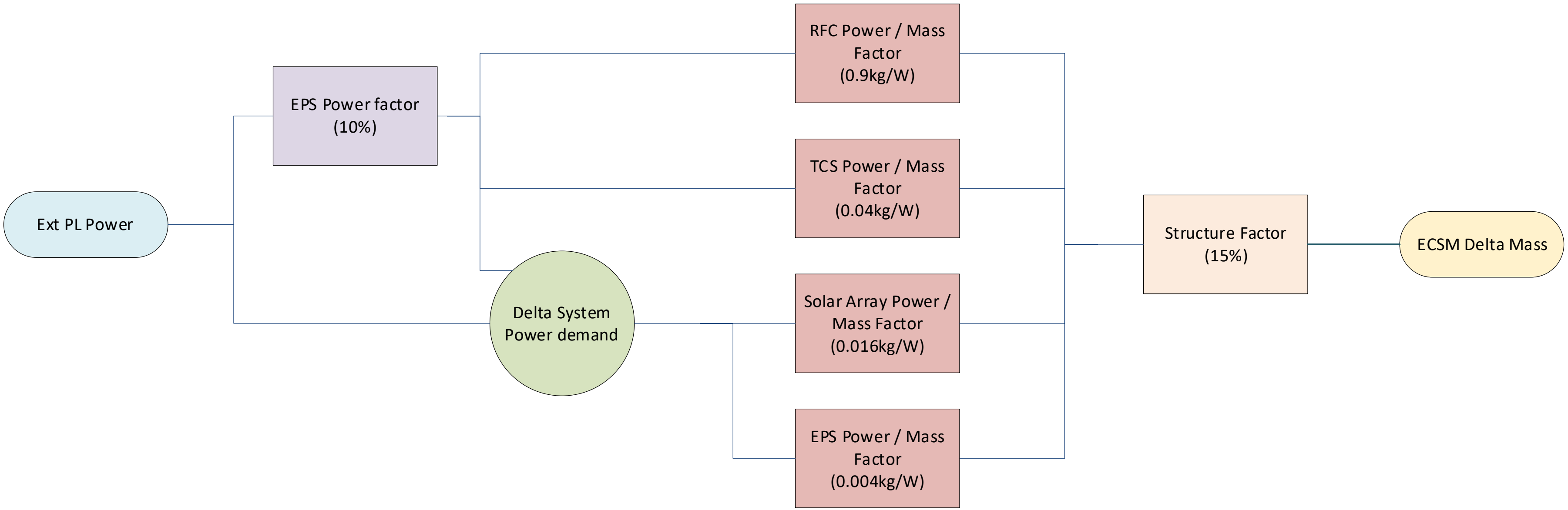
- **EPS**
  - Assuming payloads operated during lunar day only an increase of power demand from either On-Board Payloads or external users implies an increase of power demand from the Solar Array **6 m2 per KW 16 kg per kW**.
  - Even though not operated during night the embarked Payloads would require power during lunar night to guarantee TRP within the non-operative voltage range. Additional extra power would be provided by the RFCS as electrical power and thermal power (**1.3 kg per W**)
  - PCDU requires a redesign of the distribution section (**4 kg per kW**) the increased PCDU power dissipation would be in the order of **100W per kW**.
- **TCS**
  - Dissipation of thermal power generated by the Payloads during lunar day implies increase area allocated to the radiator. The current configuration of the top deck panels allow increasing the radiator of additional 4m2 which is an area comparable with the one allocated to PCDU, therefore, dissipation of power figure in line with the one dissipated by the PCDU (about 500W) can be assumed as capability offered by the ECSM design.
  - To change the thermo-optical properties respectively during lunar day and night a louvered radiator is deemed necessary with estimated impacts in mass of about **5kg per m^2**.

SYSTEM GROWING CAPABILITY (MODULAR APPROACH)

- **DHS**
  - Management of Science data might require additional mass memory that would result in the need of a dedicated MMU (mass memory unit). The estimated impacts due to additional **2Tbit Mass Memory modules is 4kg and 15W** (power consumption). Additional data interfaces wrt the one currently available in the baseline OBC would impacts the OBC configuration (additional boards, mass, volume and power consumption/dissipation) with unavoidable effects on thermal and power design in particular during lunar night.
- **TT&C**
  - Limited impacts are envisaged on TT&C directly connected to the presence of internal Payloads only. Additional units generating Telemetry might require additional communication time frame and therefore additional power dissipated by the units composing the subsystem.
- **STRUCTURE/MASS**
  - A dedicated Payloads compartment has been allocated to the accommodation of on-board PL's. The compartment allows installation of units directly on the radiator side (for thermal critical items) or on a lateral panel.
  - The additional mass due to increased ECSM sub-systems has increase in the mass of the structure estimated (**about 15% of the increased mass figure**).

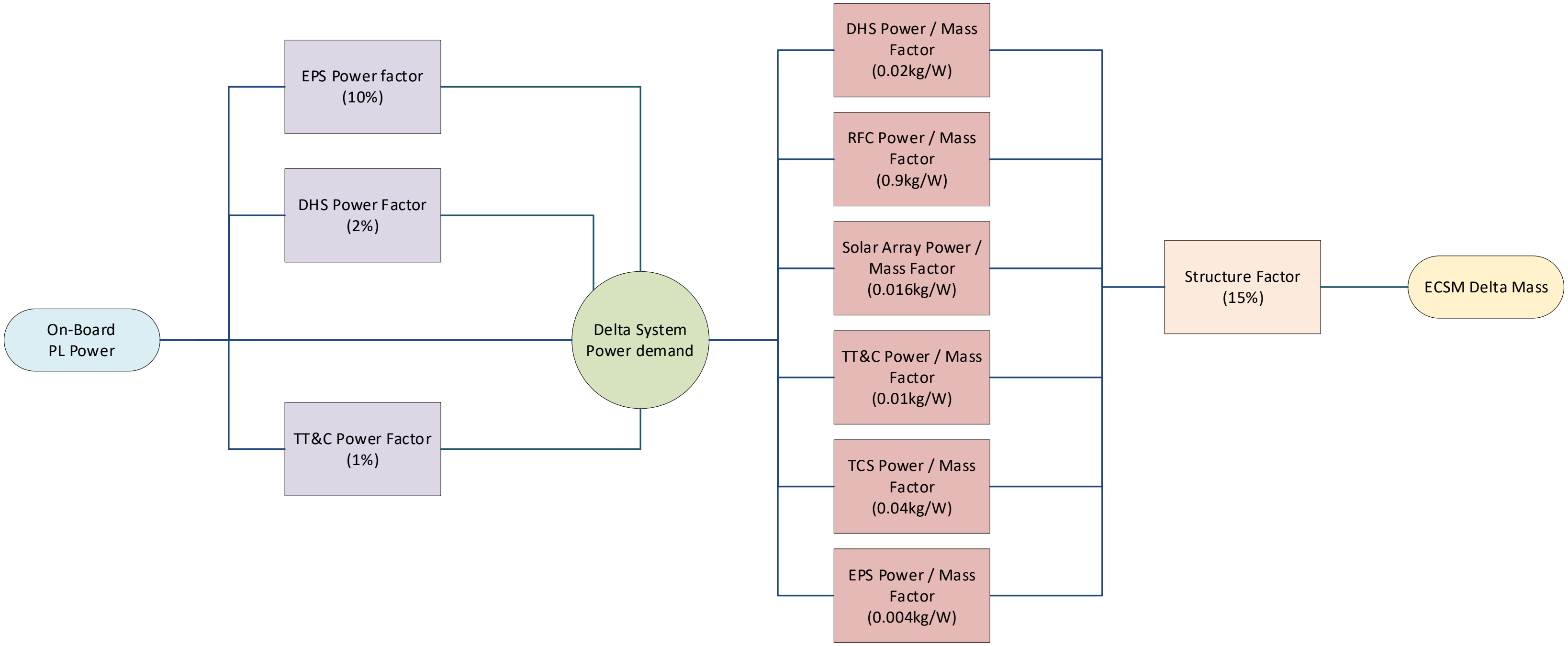
SYSTEM GROWING CAPABILITY (MODULAR APPROACH)

/// Delta mass algorithm - delta power to External Loads



SYSTEM GROWING CAPABILITY (MODULAR APPROACH)

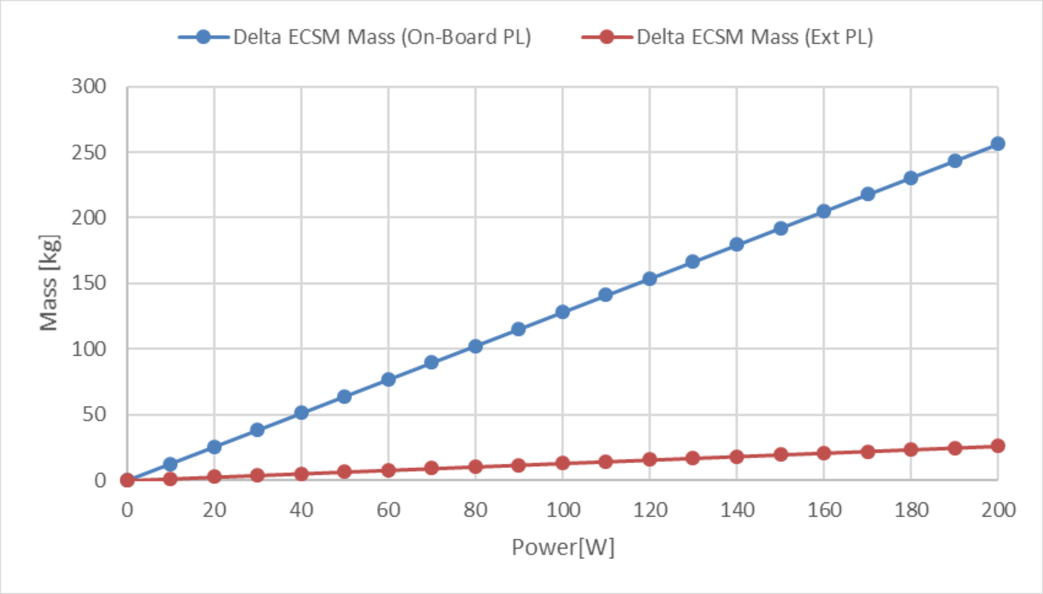
/// Delta mass algorithm - delta power to On-Board Payloads



SYSTEM GROWING CAPABILITY (MODULAR APPROACH)

/// Delta-Mass estimation plots

- FOR POWER PROVIDED TO ON-BOARD REALISTIC UPPER LIMIT IS IN THE RANGE 100W TO 150W WHICH RESULT IN A MASS INCREASE OF ABOUT 130KG TO 190KG. HIGHER POWER VALUES MIGHT IMPLY SEVERE IMPACTS ON THE OVERALL DESIGN.
- FOR POWER PROVIDED TO EXTERNAL LOADS THE EFFECTS IN TERMS OF MASS INCREASE IS LOWER. TO PROVIDE ADDITIONAL 200W WOULD IMPLY AN ESTIMATED MASS INCREASE OF ABOUT 26KG.



COMMERCIALIZATION

Business Plan

The establishment of permanent human activities on the Moon is envisaged as a stepping stone for future space exploration and for the expansion of mankind in the solar system.

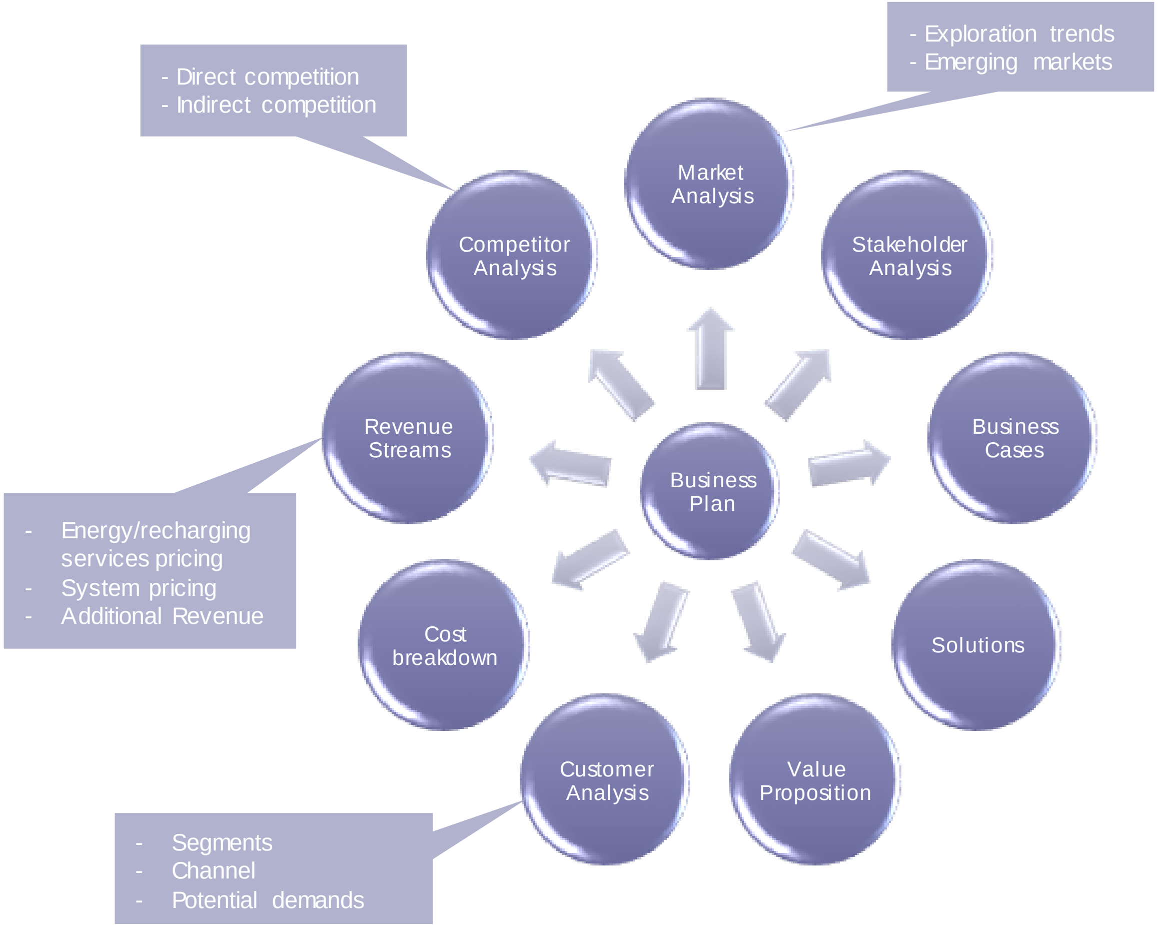
Besides the technical opportunity there is also an important business opportunity considering the different business models built around the following main features:

A. EV recharging services supply: build, own, operate, and maintain the system and sell EV recharging services to customers (private players, national and international agencies)

B. Sale of system plus O&M: build and sell the system, possibly along with O&M services, to the final customers

C. System as-a-service: build and sell the system to a financial intermediary, which leases it to the final customer, and provision of O&M services

All business models could be applied to ventures that involve, or do not involve, third party investors in their relative financial structures.



COMMERCIALIZATION

General considerations

EV recharging services supply

After the first moon colonization step, the system can be used to enlarge the surface area that is available during the exploration considering the maximum distance that vehicles can support.

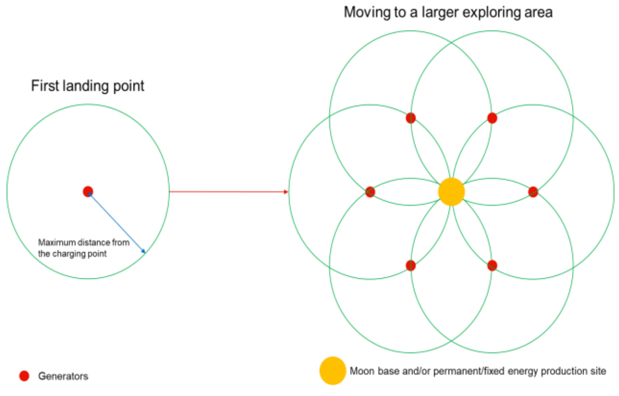
This scenario can be considered as one of the possible business cases to support the moon exploration and activities on large scale (construction, mining etc). considering the intermediate period required to build a permanent infrastructure able to cover all the areas of interest we can estimate the possibility to use for decades the system as a fundamental building block for the colonization of the moon.

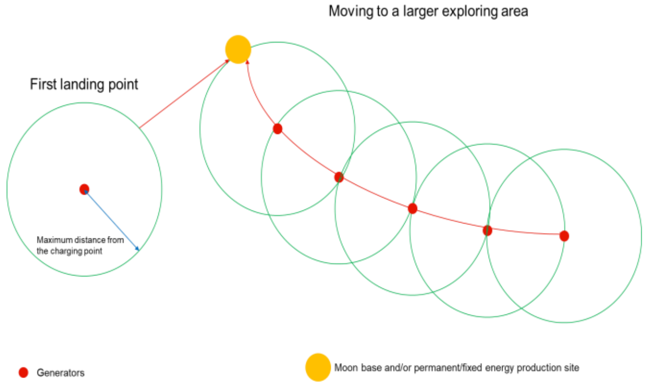
ISRU Supply plant

The establishment of permanent human activities on the Moon is envisaged as a stepping stone for future space exploration and for the expansion of mankind in the solar system.

Lunar in situ resource utilization (ISRU) will not only play a crucial role in extending human presence in space but also has the potential to strongly benefit life on Earth and to boost new interplanetary economy.

Power generation is key element in the LOX production, for these reason, the ECSM can be considered keystone in the achievement of the ISRU objectives.





COMMERCIALIZATION (ENERGY COST ESTIMATION) (ENEL)

///Levelized cost of electricity (LCOE) model input

- **THE COST OF THE COMPLETE SYSTEM –** It takes into account all the construction costs including all the efforts related to the specific know-how development and testing and for all the required certifications
- **THE SYSTEM LIFETIME –** In line with the applicable specification
- **THE DECOMMISSIONING COST –** Costs related to passivation or, if deemed necessary, transfer back of the module to hearth surface
- **COST FOR MAINTENANCE –** ECSM is designed to work without any maintenance for the specified 2 years nevertheless a prolonged lifetime might require maintenance activities to be performed on Lunar surface (e.g. gases/water refuelling for RFCS)
- **INSTALLED CAPACITY AND PRODUCTION RATES –** Energy distributed to external and (on-boad) users
- **THE WACC (WEIGHTED AVERAGE COST OF CAPITAL) -** financial parameter representing a firm's average after-tax cost of capital from all sources, including common stock, preferred stock, bonds, and other forms of debt. WACC is the average rate that a company expects to pay to finance its assets

COMMERCIALIZATION (ENERGY COST ESTIMATION) (ENEL)

$$LCOE = \frac{\sum_{t=-t_c}^{0} I_t\,(1+r)^{-t} + \sum_{t=0}^{t_l} (M_t + D_t)\,(1+r)^{-t}}{\sum_{t=0}^{t_l} E_t\,(1+r)^{-t}}$$

- /// **LCOE**= Average lifetime levelized cost of electricity
- /// **I_t** = Investment expenditures in the year t
- /// **M_t** = Operations and maintenance expenditures in the year t
- /// **D_t** = Decommissioning expenditures in the year t
- /// **E_t** = Electricity generation in the year t
- /// **r** = Discount rate
- /// **t_c** = Construction time
- /// **t_l** = Life time

MODEL PHYLOSOPY AND VERIFICATION APPROACH

SW Validation Facility (SVF)

The SVF will provide a testbed to validate the OBSW without the real HW in the loop.

it will be composed of a Functional Model of the On-Board computer plus simulators of all the users coming from the platform and the payload.

Avionics Test Bench (ATB)

The ATB will provide a testbed to validate by test the electrical design of the Spacecraft, its operational and functional interfaces, the system functions including on-board software, system database, and the constellation interconnection links.

The ATB will be representative of the flight units in terms of electrical and functional interface, and it will support the flight On Board SW.

The units integrated on ATB will be typically EM (Engineering Model) or FUMO (Functional Model)

Structural Thermal Model (STM)

The STM will subject to a full mechanical and thermal qualification campaign to validate the mechanical analysis and to correlate the thermal model of the Spacecraft.

The STM will be "Flight-like" in terms of mechanical capabilities, and it will include STM of all platform and payload elements: structures, harness, and units

Proto Flight Model (PFM)

In this proposed scenario, the structural model will be refurbished after the mechanical qualification and reconverted to become the proto-flight model (PFM).

This solution was implemented for several satellite (e.g. GOCE), optimizing cost and schedule

MODEL PHYLOSOPY AND VERIFICATION APPROACH

- The objective is to perform a maximum of verification and validation works before the acceptance of the sub-contracted components and their delivery for the system integration.
- Activities of product development and system AIVV are very interdependent. In one hand, the selected scenario for system AIVV is restrained by the pre-development strategy for critical items identified in described in ECSM Preliminary Technology Development Plan; in particular, for the availability of the supplied components.
- The equipment, sub-systems, module, and system are put through a progressive testing until the system FAR. This progress is necessary to trust the design maturity at a given level before the beginning of the upper level verification and validation.
- The primary objectives accomplished by the AIVV strategy include:
  - **SUPPORT THE DESIGN DEVELOPMENT**
  - **PROVIDE DEMONSTRATION THAT ALL SPECIFIED DESIGN REQUIREMENTS ARE MET AND, THEREFORE, QUALIFY THE PROJECT**
  - **PROVIDE DEMONSTRATION THAT ALL MISSION ELEMENTS ARE VERIFIED, PREFERABLY BY OPERATING THEM IN A CONFIGURATION FULLY REPRESENTATIVE FOR THE INTENDED FUNCTIONS**
  - **VERIFY THAT THE AS-BUILT HARDWARE IS IN COMPLIANCE WITH THE AS-DESIGNED HARDWARE**

MODEL PHYLOSOPY AND VERIFICATION APPROACH

- Critical performances or identified design issues shall be consolidated as early as possible, at the lowest possible level, by specific development program. The ECSM development and verification program will be defined according to the main drivers, both programmatic and technical.

- To guarantee high level of design reliability, the verification model philosophy has been developed. It is based on ECSS-E-ST-10-02C Verification and ECSS-E-ST-10-03C Testing, and taking into account the peculiarity of the mission with the need to:

- **AVOID OVERSTRESS ON THE FLIGHT HARDWARE;**
- **MINIMIZE THE RISK TO HAVE DIFFERENT BEHAVIOUR IN FLIGHT**
- **TO ENSURE THE LAUNCH NO EARLIER THAN 2030 TBC AND NO LATER THAN 2033 AS PER ECSM-SYS-REQ-0110;**

MODEL PHYLOSOPY AND VERIFICATION APPROACH

/// Tests performed at ECSM – PFM level are focused on:

- PHYSICAL PROPERTIES MEASUREMENTS, ALIGNMENT AND MECHANISM RELEASE (WITHOUT ACTUATION TROUGH NEA OR PYRO) IN REPRODUCED REPRESENTATIVE GRAVITY CONTEXT.
- FUNCTIONAL AND PERFORMANCE TEST (AS PER ABOVE TABLE)
- POWER QUALITY AND EMC CONDUCTED EMISSION
- RF TEST
- LEAK AND PRESSURED TEST DONE ON RFCS SYSTEM BY USING REPRESENTATIVE GAS IN PLACE OF HYDROGEN AND OXYGEN

/// Last column related to test campaign at RLS are addressed as recommended but not part of the ESCM development flow

	STM	SVF	ATB	ECSM - PFM	RLS - PFM
Mechanical					
Physical properties	X (MCI)			(MCI)	
Sine	X (Q)				X (Q/A)
Random or Acoustic	X (Q)				X (Q/A)
Release Mechanisms				X	X
Alignment	X			X	X
Shock test					X
Thermal					
Thermal Balance	X				X (Q/A)
Thermal cycling	X				X (Q/A)
Functional & Performance					
Performances			X	X	X
Functional References tests			X	X	X
Interface Test			X	X	X
SW Validation		X	X		
Illumination test					X
EMC					
Bonding, Grounding, Isolation, Cont.			X	X	X
Power quality				X	X
Conducted emission				X	X
Conducted susceptibility					X
Radiated emission					X
Radiated susceptibility					X
Auto compatibility					X
RF					
RF compatibility					X
RF Test				X	X
RCFS					
Leak test	X			X	X
Pressure test	X			X	X

MASTER SCHEDULE

- The Scheduling exercise presented in this document has been performed taking into account the launch time slot defined in the applicable specification i.e.: ***not earlier than 2030 (TBC) and not later than 2033***

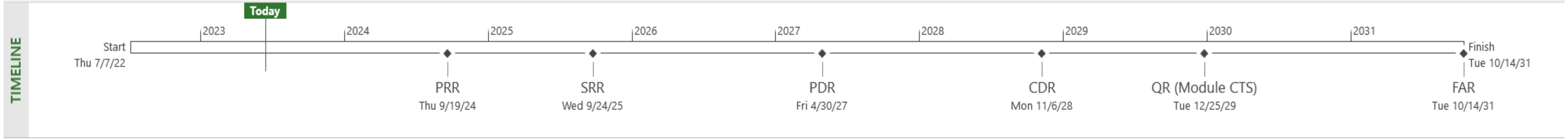
- ***CMIN25*** date has been taken into account. It is expected that the CMIN25 will be the moment in the planning when the decision to proceed with the implementation phases will be taken

- The presented schedule led to a FAR date (RLS) in third quart of the 2031 giving enough margin to comply with the specified launch slot

- The phase A/B1 are supposed to be carried out from **Sept 2023 to Sept 2025** i.e. for and duration of 24 months

- The phases B2/C/D will last from **Jan 2026 to Oct 2031** in total 64 months

- Plan includes:
  - 6 months margin
  - ECSM and CPE integration
  - RLS integration (after ECSM QR – Module CTS)

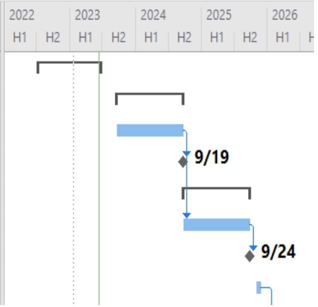


MASTER SCHEDULE

The project phases occurring before the Industrial Implementation as supposed on the bases of other projects managed by TAS-I:

- Start of Definition Phase (A/B1) in Sept 2023 (after formal Kick-off)
- Start of Implementation Phase (B2, C/D) in January 2026 (after CMIN25 and approval)

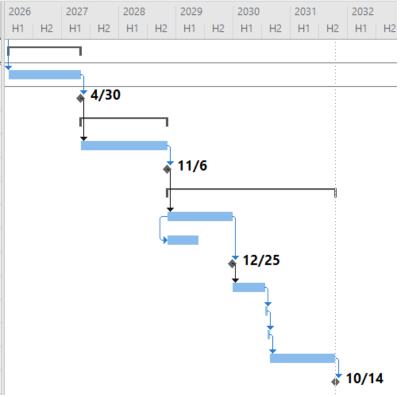
Task Mode	Task Name	Duration	Start	Finish
	Phase 0	**252 days**	**Thu 7/7/22**	**Fri 6/23/23**
	Phase A	**264 days**	**Mon 9/18/23**	**Thu 9/19/24**
	Phase A	264 days	Mon 9/18/23	Thu 9/19/24
	PRR	0 days	Thu 9/19/24	Thu 9/19/24
	Phase B1	**264 days**	**Fri 9/20/24**	**Wed 9/24/25**
	Phase B1	264 days	Fri 9/20/24	Wed 9/24/25
	SRR	0 days	Wed 9/24/25	Wed 9/24/25
	CMIN25	20 days	Mon 11/3/25	Fri 11/28/25



The ECSM project is assumed to proceed through the following phases and reviews:

- Phase B2 16 months from B2 KO to PDR
- Phase C 18 months from C/D KO to CDR
- Phase D 36 months including support to Qualification test campaign at RLS level
  - D1 one from CDR to ECSM Delivery (14 months)
  - D2 from QR to ECMS-FAR (16 months)
- Contingency 6 months
- Phase E Not requested

Task Mode	Task Name	Duration	Start	Finish
	Phase B2	**330 days**	**Mon 1/26/26**	**Fri 4/30/27**
	Phase B2	330 days	Mon 1/26/26	Fri 4/30/27
	PDR	0 days	Fri 4/30/27	Fri 4/30/27
	Phase C	**396 days**	**Mon 5/3/27**	**Mon 11/6/28**
	Phase C	396 days	Mon 5/3/27	Mon 11/6/28
	CDR	0 days	Mon 11/6/28	Mon 11/6/28
	Phase D	**766 days**	**Tue 11/7/28**	**Tue 10/14/31**
	Phase D task-1	296 days	Tue 11/7/28	Tue 12/25/29
	STM Ref.	142 days	Tue 11/7/28	Wed 5/23/29
	QR (Module CTS)	0 days	Tue 12/25/29	Tue 12/25/29
	Contingency	150 days	Wed 12/26/2!	Tue 7/23/30
	ECSM shipment	10 days	Wed 7/24/30	Tue 8/6/30
	RLS integration	10 days	Wed 8/7/30	Tue 8/20/30
	Phase D task-2	300 days	Wed 8/21/30	Tue 10/14/31
	FAR	0 days	Tue 10/14/31	Tue 10/14/31



RISK ASSESSMENT

/// The Risks have been classified according to:

- **TECHNICAL DEVELOPMENT RISK ASSOCIATED TO DESIGN MATURITY AND CURRENT UNCERTAINTY OF EFFORT ESTIMATION**
  - Design Maturity/Technical
  - Uncertainty of effort estimation (manpower quotation uncertainty)
- **PROGRAMMATIC**
  - Managing schedule delays
  - Management of class B changes
  - Project schedule risk, such as an overall project schedule shift due to (e.g.) unavailability of one of the equipment at the appointed date of delivery
- **PROCUREMENT**
  - GEO return selection exceeding allocation
  - Risk of additional procurement
  - Risk of EEE non recurrent vendor cost increase
  - HW matrix uncertainty and uncertainty of HW prices

/// The outcomes of the preliminary Risk Register can be used for:

- **Relevant development, inclusive of the mitigation actions**
- **Define the risks that need to be limited or excluded for reason of excessive cost, schedule incompatibility or induced by third parties**
- **Starting point for building the Management Reserve coherently**

/// Key points can impacts the ECSM design are the:

- **consolidation of the external loads**
- **consolidation of the applicable environmental conditions**
- **presence of on-board payloads**
- **LDE/CPE design evolution**

RISK ASSESSMENT - PRELIMINARY MANAGEMENT RISKS

High Risk

- Team partially changed between A/B1 and B2/C/D (3A)

Medium Risk

- Selection of equipment imposed by georeturn (3C)
- Uncertainty on purchasing due to a quotation based on heritages (not RFI) (3C)
- Uncertainties on market conditions (3D)
- Equipment delta qualification (3C)
- Project schedule risk due equipment proc. delay (2C)
- Delays in the procurement of raw materials, tools, mechanical parts or subsystem / equipment (3C)
- Rework on the industrial consortium according to ESA proposition during B2/C/D negotiation. (2C)
- Manpower quotation uncertainty (3B)
- Deficit and dispersion of resources, due to transfer to other projects, retirement or resignation (2B)
- Underestimation of external dependencies influences (e.g 3rd parties products & manufacturing) (3C)

Likelihood						
	A			1		
	B		1	1		
	C		2	5		
	D			1		
	E					
		1	2	3	4	5
		Severity				

RISK ASSESSMENT - TECHNICAL RISKS

High Risk

- Non-consolidated requirements baseline (3A)

Medium Risk

- Risks related to the critical requirements (Ext. PL's) (3B)
- Risks related to the critical requirements (OnBoard PL's) (3B)
- Technical risk related the development of Solar Array mechanisms (3B)
- Risk related to difficulties in the development of RFCS (3B)
- Risk related to the development of the flexible roller solar array for lunar environment (e.g. gravity) (2A)
- Risk related to the development of peculiar Thermal radiators (3B)
- Technical risk related to difficulties in the development of adequate dust protection systems (3B)
- OBSW development more complex than expected (2B)
- The PFM model philosophy for the structure development may rise unexpected deviations at dynamic qualification tests (2B)
- Need for architectural design or requirements change (3C)

Likelihood						
	A		1	1		
	B		2	6		
	C			1		
	D					
	E					
		1	2	3	4	5
		Severity				

COST ESTIMATION - ASSUMPTIONS

- The estimated price is a preliminary Rough Order of Magnitude (ROM) estimate on the basis of an assumed Fixed-Price-plus-Variation type of contract at mid-2023 economic conditions.
- The quotation is done assuming only a Prime level (no subcontractors are considered in this exercise and all the quotations of the FTE are internal to TAS)
- The procurement of the HW has been treated as procurement only (no agreement/commitments yet with potential supplier)
- It is to be intended that the procurement includes:
  - ALL THE EQUIPMENT INCLUDED IN THE HW MATRIX
  - TESTING AND FACILITIES
  - GROUND SUPPORT EQUIPMENT
- The Risk Contingency includes an allowance for risk coverage evaluated on the basis of a preliminary, high-level, risk analysis.
- The categories for which an allowance is made include:
  - TECHNICAL RISK ASSOCIATED TO MATURITY OF REQUIREMENTS
  - TECHNOLOGY RISK, E.G., RISK ASSOCIATED TO COMPLETION OF QUALIFICATION FOR THE ITEMS CANDIDATE FOR TDAS
  - PROCUREMENT RISK, E.G., HARDWARE MATRIX UNCERTAINTY AND UNCERTAINTY OF HARDWARE PRICES;
- In addition, a reserve is included covering:
  - CONTRACT TERMS AND CONDITIONS UNCERTAINTY

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COST ESTIMATION - EXCLUSIONS

/// The following items and activities are excluded from this Cost estimate:

- Duties and taxes, custom duties, excise tax and other charges
- All the CFI (e.g. Payload items provided as CFE)
- The technology Development Activity (TDA) program undertaken by ESA was assumed to have successfully taken place before the Implementation Phase bid
- Mission operations
- The integration on the LDE/CPE platform (the estimate stops at the delivery to the Mission responsible and the Customer) and anyhow the mating of the CPE with LDE is a cost which is already accounted for in the RLS costs, and is of course not repeated here
- ESA internal Costs
- Launcher, launch campaign, launch services
- Mission analysis (provided by ESA)
- Participation in the launch campaign and support to the commissioning
- Ground Segment
- Transportation cost of the ECSM module for integration with both CPE and LDE
- RFCS Hardware
- Geo-return constraints were not considered (too early for this cost estimate)

COST ESTIMATION - INCLUSIONS

/// The following items are included in this ROM cost estimate:

- All activities and items needed to develop, implement, integrate, verify, and deliver the ECSM ready for the integration on the carrier (LDE/CPE)
- Travel & subsistence, transportation for testing and insurance costs (allocation)
- Reserve covering development/implementation risks and uncertainties in the cost estimates.

WORK BREAKDOWN STRUCTURE

Compact Team focused to Prime activities

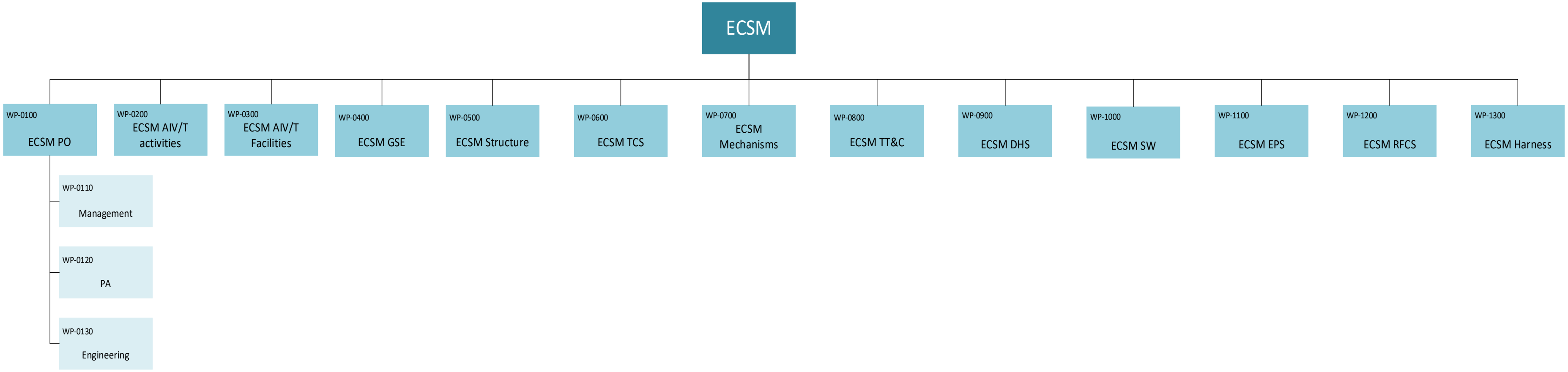
- Lean organization limiting the number of layers

6 Main Subsystems

- Electrical Power System
- RFCS
- Thermal Control System
- TT&C
- Structure
- Data Handling System

The WBS is structured according to the Product Tree.

- This gives full visibility on the activities covered by Core.



COST ESTIMATION – HARDWARE MATRIX

ECSM HW/SW	Unit Mass (kg)	TRL today	Identified pre-developments	STM	EM (ATB)	PFM	Spare
RFCS							
RFC Auxiliary (Assy)	58.0	4	YES	1 (DM)			
- Latch valve	1.5	6	NO		4	4	k
- Shut off valve NC	1.0	6	NO		4	4	k
- Mass Flow controller	1.0	6	NO		2	2	k
- High pressure pump	3.0	4	YES		2	2	k
- Separator	2.0	4	YES		4	4	k
- Tubing	10.0	6	NO		1	1	k
- TCS	4.0	4	YES		1	1	k
- RCDU	9.0	6	NO		1	1	k
- Harness	5.0	6	NO		1	1	k
- ELY recirculation pump	4.0	4	YES		1	1	k
RFC Tank H2	14.7	4	YES	8-AS 3-PP		8-AS 3-PP	2-AS 1-PP
RFC Tank O2	14.7	4	NO	4		4	1
RFC Water Tank	25.0	6	NO	2-AS 1-PP		2-AS 1-PP	1
FC stack	4.0	4	YES	1 (DM)	1	1	k
ELY stack	5.0	4	YES	1 (DM)	1	1	k
Data Handling							
OBC	12.0	6	NO	1 (DM)	1	1	k
On-board Software	0.0		NO		1	1	
Communications							
S-Band Transponder	3.2	7	NO	2 (DM)	1	2	k
S-Band SSPA	2.2	8	NO	2 (DM)		2	k
S-Band RFDN	1.9	8	NO	1 (DM)	1	1	k
S-Band LGA	0.3	7	NO	3 (DM)		3	1
K-Band Transponder	3.5	6	NO	2 (DM)	2	2	k
K-Band TWTA	2.2	8	NO	2 (DM)	2	2	k
K-Band RFDN	10.0	8	NO	1 (DM)	1	1	k
K/S Dual Band HGA	12.0	8	NO	2 (DM)		2	k
APM	13.0	8	NO	2 (DM)	2	2	k
APM-E	4.0	8	NO	2 (DM)	2	2	1
Ant-HDRM	0.2	9	NO	4 (DM)		4	4
Electrical Power							
PCDU	29.4	4	YES	1 (DM)	1	1	k
Solar Array Assembly	184.0	2	YES	1		1	k
- PVA	30.0	5	NO				
- Harness	6.0	6	NO				
- Blankets	25.0	5	NO				
- Tape spring	19.0	3	YES				
- RFSA	36.0	3	YES				
- RFSAStructure	6.0	6	NO				
- FS	6.0	6	NO				
- FS HRM structure	3.0	6	NO				
- SADRA	3.0	5	NO				
- Preload Device	5.0	3	YES				
- HDRM	1.0	9	NO				
- Telescopic tube(inc. Bearings)	30.0	2	YES				
- SADM	7.0	3	YES				
- SADE	4.0	5	NO				
- Dust Cover	3.0	2	YES				
Battery (AstroSci)	25.0	5	NO	1 (DM)	1	1	1
Aux Battery (PeakPwr)	65.0	5	NO	3 (DM)	1	3	1

	Unit Mass (kg)	TRL today	Identified pre-developments	STM	EM (ATB)	PFM	Spare
Harness	45.0	8	NO	1	1	1	k
Structure							
Central Cylinder	72.8	9	NO	1		1	k
Primary Structure	89.8	9	NO	1		1	k
3rd Strucure	24.7	9	NO	1		1	k
Central Cylinder rings	20.0	9	NO	1		1	k
Tanks Supports (AstroSci)	10.8	9	NO	1		1	k
Tanks Supports (PeakPwr)	7.0	9	NO	1		1	k
SA Support	15.0	9	NO	1		1	k
Lateral Panels	17.8	9	NO	1		1	k
Thermal Control							
Heaters	1.5	8	NO	245		350	k
Filler (m2)	1.2	8	NO	2.6		2.60	k
Loop Heat Pipe	7.5	4	NO	2		2	k
Rolled shutter	22.0	2	YES	1		1	k
Multi Layer Insulators	8.0	8	NO			72	k
Temp Sensors	0.2	8	NO	880 (TC)		600 TC 280 Therm	k
Thermal Paint (Z-93C55 and Chemglaze	2.8	8	NO	52.89		52.89	k
Heat Pipe	35.0	8	NO	10		10	k
USER I/F							
Harness	3.0	8	NO		1	1	k
Connectors	0.3	8	NO		1	4	k
Lamps	0.3	8	NO		1	4	k
Housing and Labels	2.0	8	NO		1	2	k
Kill Switch	0.2	8	NO		1	2	k

COST ESTIMATION – MAJOR COST DRIVER

/// The harsh lunar environment imposes sever constrains on the ECSM design in particular the long lunar night and temperature conditions.

/// The major cost drivers are strictly related to the architectural and technological solutions identified to comply with environmental context as well as to comply with functional and performance requirements.

/ Development and procurement of the **Rollable Solar Array**. The technology is already consolidated in space application nevertheless it needs to be contextualized in lunar environment taking into account gravity , temperature and lunar dust detrimental effects

/ Development and procurement of the **RFC System** (not part of this quotation). RFCS has been identified as viable alternative to the nuclear power and thermal generation (not allowed in ECSM mission). Such power source is recognized by the community as the suitable one for providing power in an efficient way during the lunar night and, due to that, dedicated technological development studies are on-going.

/ Development and procurement of **Rollable shutter** able to change the thermo-optical properties of the radiator, allowing to increase the power dissipation during lunar day and reducing thermal dispersion during lunar night. Need of dedicated device able to remove dust deposition on the rollable shutter is element contributing the cost increase, such device is deemed necessary in order to guarantee the performance of the radiator.

/// The required capability to communicate regardless the landing orientation impose duplication of a relevant part of the TT&C (HGA, APM, APME and LGA) leading to increase cost estimated for overall TT&C system.

AOB AND CONCLUSION

Thank you for your attention

LOG OF CHANGES AND APPROVAL

Révisions	Log of change - Description	Date
001	First Issue	27 June 2023
002	General Updating after Final Review	19 July 2023

Actors	Approval - Name and role	Date
Written by	P. Morsaniga	19 July 2023
Verified by	G. Gervasio	19 July 2023
Approved by	P. Morsaniga	19 July 2023