CubISSat

Multipurpose Cubesat demonstrator at ISS

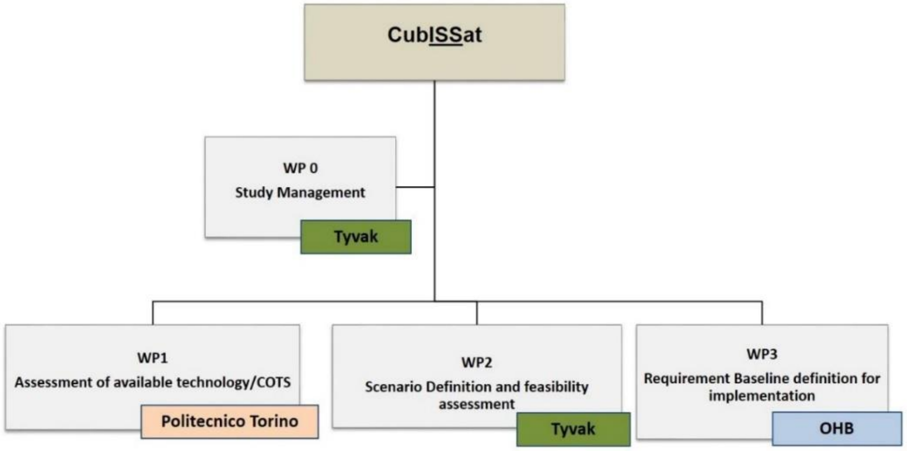
Final Presentation

Summary

Team Organisation

- **Tyvak is main technical and managerial responsibile of the study, and leader for WP0 and WP2.**

- **Politecnico di Torino and OHB System AG subcontractors and responsible for WP1 and WP3 respectively.**



Objectives of the activity

1. **To confirm technical feasibility of a multi-purpose platform based on CubeSat technologies that can be serviced in the ISS environment;**

2. **To define a conceptual design of the base platform, a reference inspection mission, and an additional reference mission to be selected by the Contractor;**

3. **To identify and trade-off concepts for the launch to ISS and deployment from ISS, logistics support concepts including maintenance and refuelling;**

4. **To identify the major constraints, including the safety aspects of a small free-flyer (10-12 kg), 3U-8U volume operating around the ISS.**

ESA main drivers

- **Short term goal:**
  - **Flying a demonstrator for human-tended operations at the International Space Station.**
- **Long-term goal:**
  - **Achieve a useful space asset for human exploration beyond ISS (e.g. support to cis-lunar habitat, moon exploration).**

- **As a result, the activity starts with the assessment of the State-of-the-Art and current development of the technologies/COTS suitable for a multipurpose CubeSat system targeted to realise the following set of missions:**
  - **MC1: Surveillance and inspection of the ISS**
  - **MC2: Scientific payload free-flyer**
  - **MC3: Retrieval of small target objects / CubeSats**
  - **MC4: Surveillance/servicing of a future cis-lunar habitat**

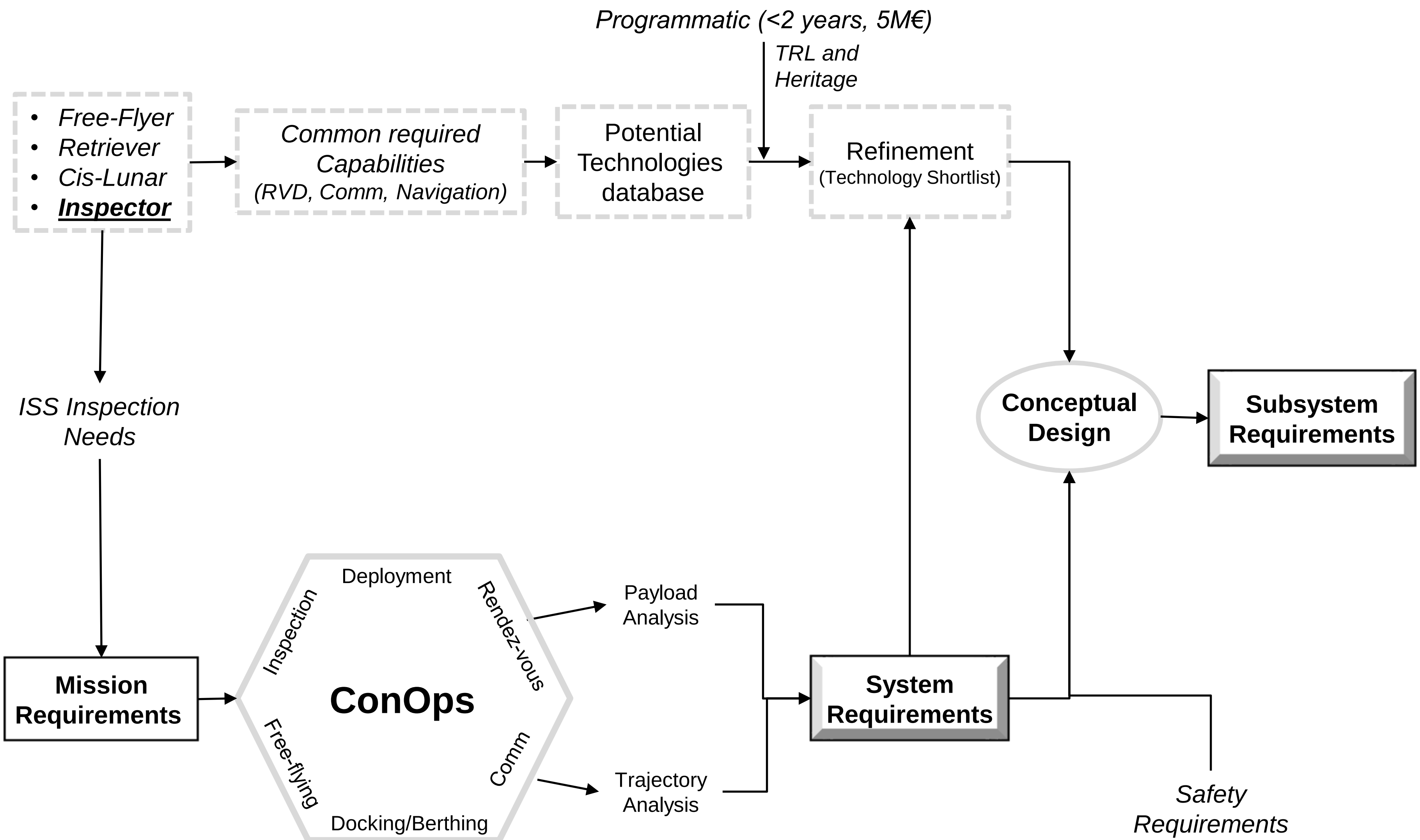
Mission trade-off and selection of the operational scenario

- **For each mission, the following characteristics are identified:**
  - **Root problem and stakeholder needs;**
  - **Key operational capabilities;**
  - **Goal & constraints;**
  - **High level mission objectives and requirements.**

- **Results and focus of the study:**
  - **Identify a demonstrator mission scenario pursuing most of the required capabilities in order to provide risk reduction and proof-of-concept for multiple applications.**

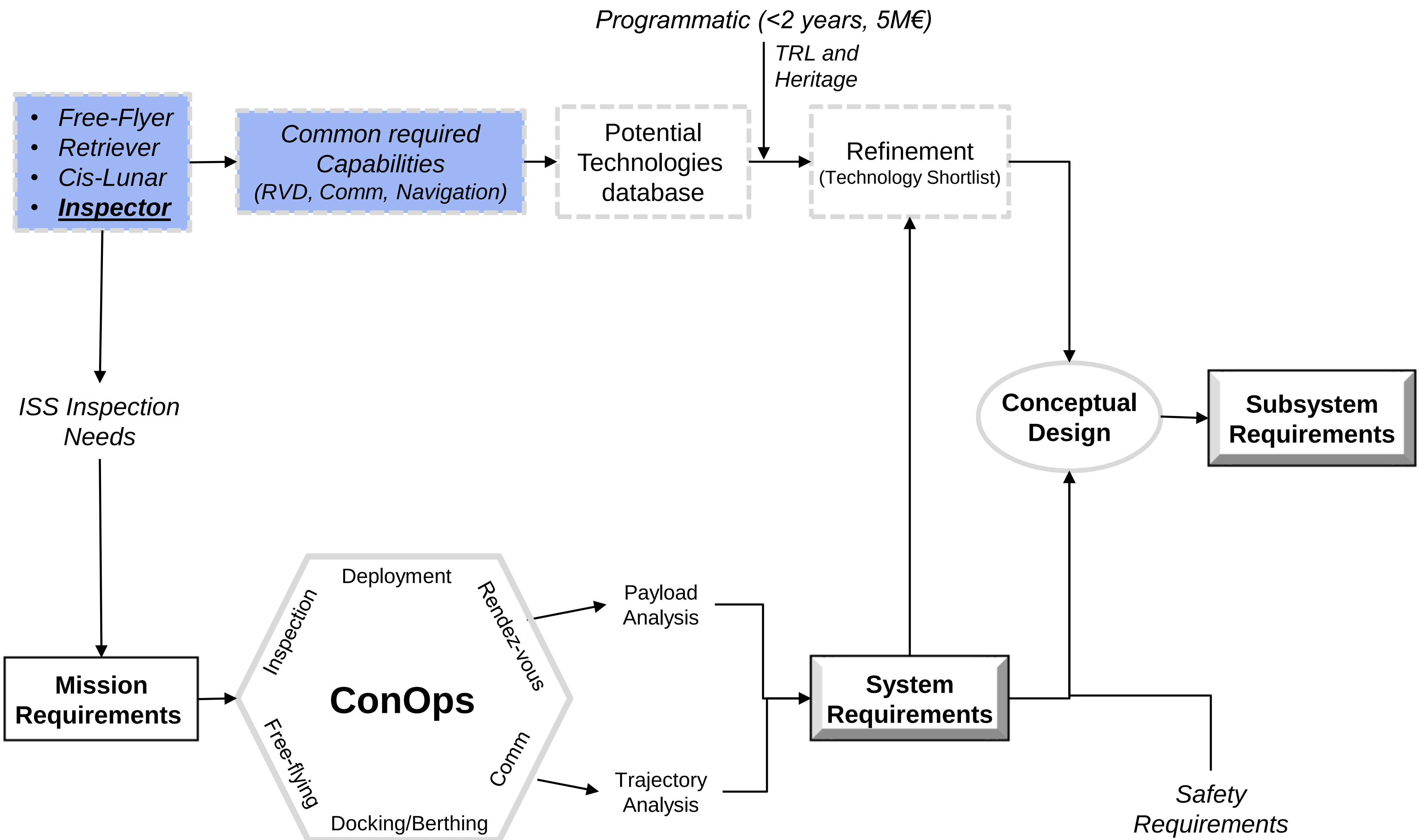
- **Demonstrator mission:**
  - **A reference mission scenario (*inspector*) is identified and fully analysed so as to confirm technical feasibility of a demonstrator platform based on CubeSat technologies that can be serviced in the ISS environment.**

CubISSat Work Logic Diagram



Mission Scenarios & Required Capabilities

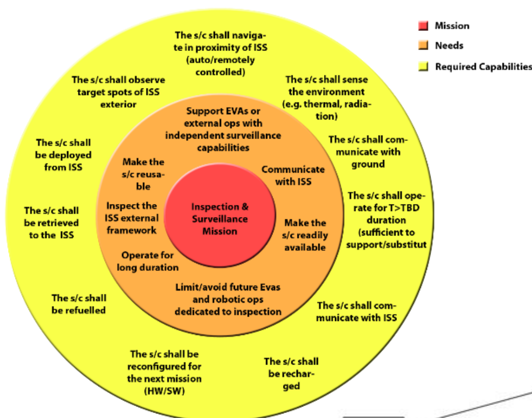
CubISSat Work Logic Diagram



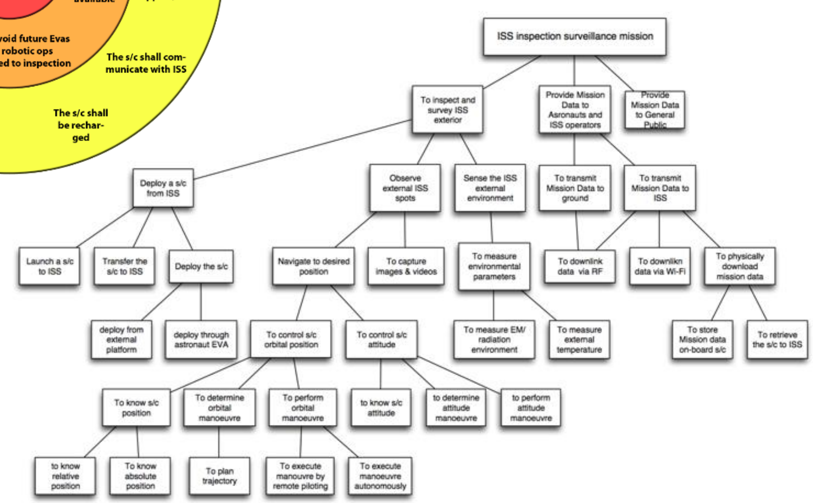
MC1: ISS inspection/surveillance

- **Mission Statement**
  - To provide **inspection and surveillance capabilities** of the external framework of the International Space Station, deploying and retrieving a multipurpose, (semi)autonomous vehicle based on CubeSat technologies. To support ISS crew and operators, complementing current surveillance capabilities, limiting or avoiding EVAs and robotic operations dedicated to inspection, in view of future long-duration human exploration missions. To engage the general public providing unprecedented imagery of the ISS for outreach purposes.

- **L0 – Mission Objectives:**
  - To inspect and survey the external environment of the ISS;
  - To provide mission data (images / video / environmental data) to ISS crew and operators;
  - To provide imagery/media to the general public;



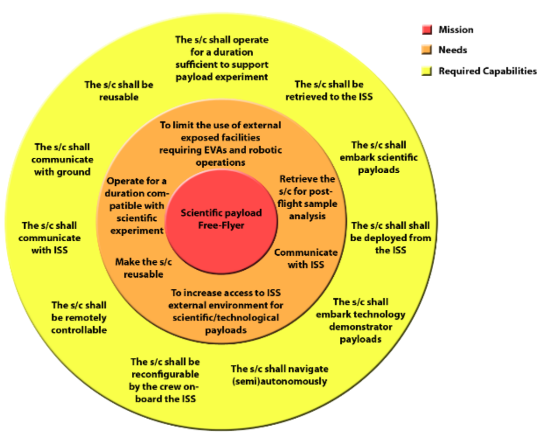
- **Lower-levels Functions**
  - L3 to determine s/c required capabilities;
  - L5 to derive basis function and needed equipment.

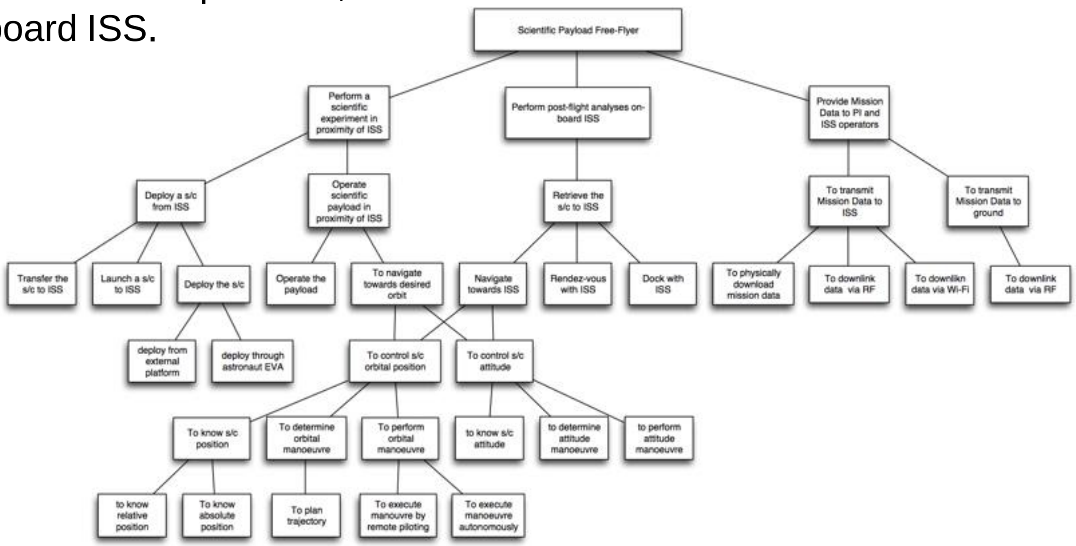


MC2: Scientific Payload Free-Flyer

- **Mission Statement**
  – Provide to science Principal Investigators, ISS crew, operators and science community with a **new approach for experiments in the ISS environment**, overcoming the traditional use of exposed facilities, robotic operations, EVAs or CubeSat missions as currently conceived. To **provide access to ISS external environment** for a variety of scientific/technological payloads, deploying a (semi)autonomous vehicle based on CubeSat technologies. To provide capability to retrieve the scientific experiment inside the ISS for post-flight analysis.

- **L0 – Mission Objectives:**
  - To perform a scientific experiment in proximity of the ISS;
  - To provide mission data to science PI and ISS operators;
  - To perform post-flight analyses on-board ISS.





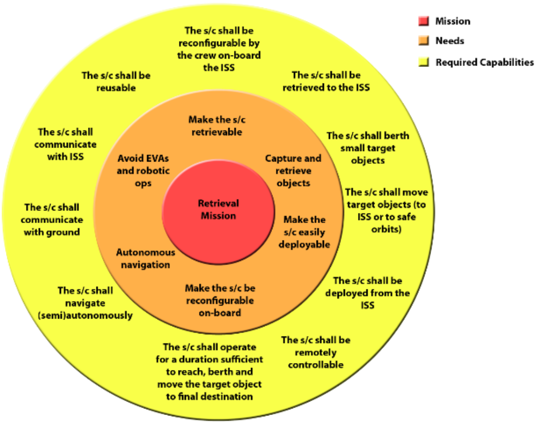
MC3: “Golden Retriever”

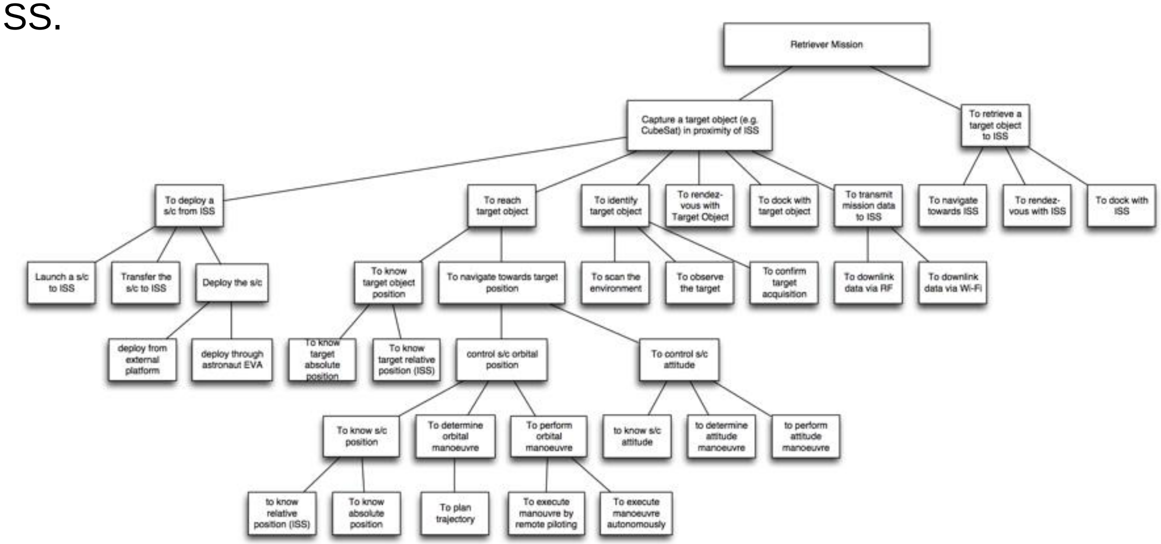
• Mission Statement

– To provide capability of target **object retrieval in the vicinity of the International Space Stati**on, for a variety of situations (post-test sample analysis, debris regulations, safety, etc.), deploying a reconfigurable, (semi)autonomous or remotely-controlled vehicle based on CubeSat technologies **and demonstrating unprecedented capabilities for rendez-vous and docking operations**. To provide ISS crew, operators, developers and scientific community with a new approach for CubeSat missions at ISS, overcoming the traditional positive separation and natural decay of the spacecraft orbit.

• L0 – Mission Objectives:

- To capture small “target” object(s) orbiting in proximity of the ISS (e.g CubeSats);
- To retrieve target object(s) to the ISS.

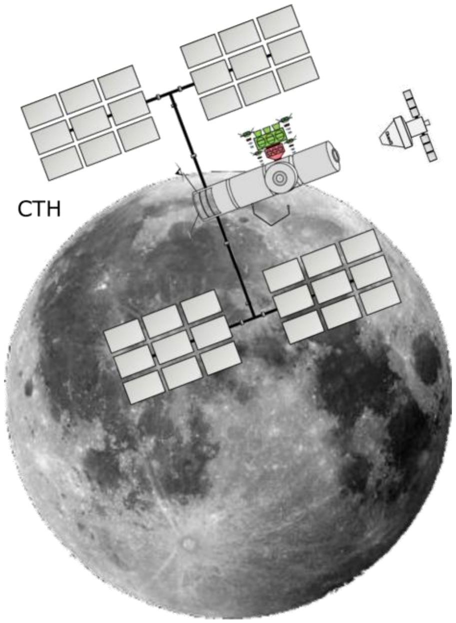




MC4: Cis-Lunar Habitat Mission

- **As the Cis-Lunar habitat concept is concerned, it has been decided together with ESA that the point of the study is to assess the effect of performing similar inspection/surveillance mission in proximity of a cis-lunar outpost.**

  - **A potential ConOps has been evaluated.**



N.	Cis-Lunar Habitat Scenario
1.	The Inspector Drone is delivered to CTH as cargo; two options are available: a. Inside pressurised and Crew performs outfitting & Checkout of the Inspector; b. Outside pressurised volume; Inspector is already prepared and need only checkout.
2.	The Inspector Drone is deployed; checked out and performs ***visible and thermal imaging*** (basic mission) + ***radiation monitoring*** (payload, e.g. Fast Neutron); control is done locally (at CTH) and remotely (from Earth); data are transmitted to Earth via CTH acting as relay.
3.	The Inspector performs ***approach, rendezvous and docking on the outside structure of the CTH***; it will remain there until next crew mission arrives a year later.
4.	***When needed, the Inspector is remotely activated***, deployed and used for specific imaging tasks; radiation is continuously monitored.
5.	Next crew mission arrives, carrying spares; e.g. propellant refill, batteries, new imaging sensors or dedicated payloads.
6.	The Inspector Drone is ret***rieved robotically and brought back inside the pressurised volume*** of the CTH through the airlock; it is serviced as necessary before being redeployed outside robotically, ready for its next mission.

Functional Breakdown and Analysis

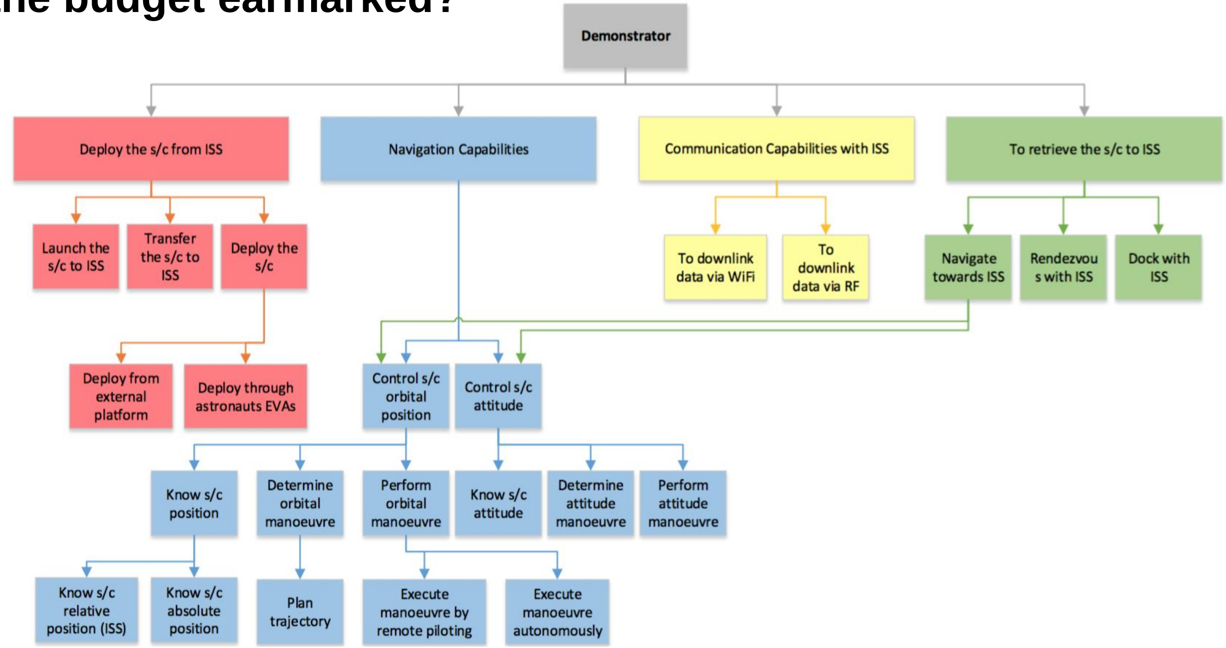
- **Root Problem**
- **Stakeholder Needs**
- **Goals & Constraints**
- **Mission Statement**
- **Mission Objectives**

- ***Functional analysis allowed to derive s/c required capabilities***
  - **Capabilities cross-related to technology assessment.**
  - **Basis to derive Demonstrator operational capabilities**

	M1: Surveillance & Inspection		M2: Scientific payload free-flyer		M3: Retriever
RP10	Current surveillance and inspection operations at ISS rely on EVAs, complex robotics TV ops, external TV technologies, imagery from internal crew. Crew time for imagery acquisition and inspection is limited. Future human exploration missions will be long and would need long surveillance/inspection operations. External view of the ISS is provided today by current assets installed on the station, and visiting vehicles.	RP20	CubeSats are routinely deployed from the ISS for classic stand-alone missions, relying on positive separation from the ISS and natural decay of the spacecraft orbit. Lifetime of these missions is dictated by the final orbit insertion and/or on-board propulsion availability. Capability to effectively relay mission data or ground is also a driver to mission success. Future CubeSat missions at ISS may require the capability to perform scientific experiments or technology in-orbital demonstration, without relying on the current exposed facility capabilities, complex robotic operations, IVAs or EVAs. Capability to free-fly in the vicinity of the station, navigate autonomously, and communicate at short-distance with ISS would be needed to maximise scientific return.	RP30	CubeSats are routinely deployed from the ISS for classic stand-alone missions, relying on positive separation from the ISS and natural decay of the spacecraft orbit. Next-generation CubeSat missions may have the capability to remain in close vicinity of the station, performing autonomous operations. In contingency situation, or at end-of-life, it may be necessary to retrieve them inside or move them far away. At the same time, small objects or material parts which orbit in close vicinity of the ISS as a consequence of different situations (e.g. MMOD strikes, ..), may require the same type of operations. Future missions at ISS may require the capability to capture and retrieve small target objects (including cubesats previously deployed) for a variety of situations, including re-usability, post-flight sample analysis, technology demo verification, space debris or collision avoidance, safety aspect related to ISS and visiting vehicles, etc. Capture and retrieval operations would have to be performed without relying on robotic operations or EVAs as currently conceived.
N110	inspect the ISS exterior	N210	host scientific payloads	N310	capture and retrieve objects
N120	avoid EVAs and robotics	N220	free-fly in the vicinity of ISS	N320	avoid EVAs and robotics
N130	s/c reusable	N230	avoid EVAs and robotics	N330	s/c to be reconfigurable on-board
N140	long duration ops	N240	long duration ops	N340	s/c easily deployable
N150	s/c to be reconfigurable on-board	N250	s/c to be reconfigurable on-board	N350	s/c retrievable
N160	s/c easily deployable	N260	s/c easily deployable	N360	autonomous navigation
N170	s/c retrievable	N270	s/c retrievable		
N180	autonomous navigation	N280	autonomous navigation		
EU110	astronauts	EU210	astronauts	EU310	astronauts
EU120	ISS operators	EU220	ISS operators	EU320	ISS operators
EU130	general public	EU230	Principal Investigators Science/IOD	EU330	Principal Investigators Science/IOD
		EU240	Scientific community	EU340	Scientific community
	having a set of small specialized drones capable to support the crew with independent inspection/&surveillance capabilities for long duration, complementing /avoiding EVAs and robotics operations. In order to facilitate the tasks of ISS crew and operators, the new assests should be multipurpose (adaptable for various missions or embarking different type of sensing instruments), reusable, reconfigurable by the crew, easily deployable and retrievable, remotely controllable or (semi)autonomous, capable to communicate with ISS or ground.		Having a set of small specialized drones able to embark different type of payloads, to be deployed from the ISS, navigate autonomously for a duration sufficient to perform experiment/IOD operations.		having a set of small specialized drones capable to be deployed from the ISS on demand, navigate autonomously towards the target, rendez-vous and capture the target object, retrieve the target object to the ISS, or moving it into a safe orbit.
G10	To provide surveillance/inspection capabilities of the external surfaces of the ISS.	G20	To provide scientific/technological payloads the possibility of deployment from ISS, free-flying in the ISS environment.	G30	to provide capability to capture objects (e.g. CubeSats) orbiting in the vicinity of the ISS, retrieval to ISS, or moving into safe orbit
AO10	To provide images/videos to engage the general public (outreach objective).	AO20	na	AO30	na
CN110	The Mission shall be implemented with a schedule < 2 years (up to Flight Readiness)	CN210	The Mission shall be implemented with a schedule < 2 years (up to Flight Readiness)	CN310	The Mission shall be implemented with a schedule < 2 years (up to Flight Readiness)
CN120	The mission shall be implemented with an overall budget < 5M€	CN220	The mission shall be implemented with an overall budget < 5M€	CN320	The mission shall be implemented with an overall budget < 5M€
CN130	The mission shall comply with ISS safety aspects	CN230	The mission shall comply with ISS safety aspects	CN330	The mission shall comply with ISS safety aspects
CN140	The spacecraft shall be based on cubesat technologies	CN240	The spacecraft shall be based on CubeSat technologies	CN340	The spacecraft shall be based on CubeSat technologies
CN150	The spacecraft volume shall be between 3 and 8 litres	CN250	The spacecraft volume shall be between 3 and 8 litres	CN350	The spacecraft volume shall be between 3 and 8 litres
MS1	To provide inspection and surveillance capabilities of the external framework of the International Space Station, deploying and retrieving a multipurpose, (semi)autonomous or remotely-controlled vehicle based on CubeSat technologies. To support ISS crew and operators, complementing or substituting current surveillance capabilities (EVAs, complex robotics TV operations, external TV technologies, crew imagery from internal module windows) in view of future long-duration human exploration missions. To engage the general public providing	MS2	To provide capability of free-flying in the vicinity of the International Space Station, for a variety of scientific/technological payloads, deploying a reconfigurable, (semi)autonomous or remotely-controlled vehicle based on CubeSat technologies. To provide scientific Principal Investigators, ISS crew, operators and scientific community with a new approach for experiments in the ISS environment ISS, overcoming the traditional use of exposed facilities, robotic operations, EVAs or IVAs.	MS3	To provide capability of target object retrieval in the vicinity of the International Space Station, for a variety of situations (post-test sample analysis, debris regulations, safety, etc.), deploying a reconfigurable, (semi)autonomous or remotely-controlled vehicle based on CubeSat technologies and demonstrating unprecedented capabilities for rendez-vous and docking operations. To provide ISS crew, operators, developers and scientific community with a new approach for CubeSat missions at ISS, overcoming the traditional positive separation and natural decay of the spacecraft orbit.
M110	To deploy a spacecraft based on CubeSat technologies from ISS		To host a scientific/IOD payload on-board a spacecraft based on CubeSat technology		To deploy a spacecraft based on CubeSat technologies from ISS
M120	To provide inspection and surveillance of the external framework of the International Space Station		To deploy the spacecraft from ISS		To capture small "target" object(s) orbiting in the vicinity of the ISS (e.g CubeSats)
M130	To provide mission data (images/video/other sensors data) to ISS crew and operators		To free-fly in the vicinity of the ISS for the duration necessary to the experiment		To retrieve target object(s) to the ISS
M140	To provide imagery/media to the general public		To communicate mission data to ISS		To move target object(s) to a safe orbit
M150	To retrieve the spacecraft to ISS		To retrieve the spacecraft to ISS		To retrieve the spacecraft to ISS
PSR11 0	The spacecraft shall embark observation instruments	PSR210	The spacecraft shall embark scientific payloads	PSR310	The spacecraft shall capture small target objects
PSR11 1	The spacecraft shall embark instruments for sensing ISS external environment (multipurpose)	PSR211	The spacecraft shall embark tecnology demonstrator payloads	PSR311	The spacecraft shall move target objects (to ISS or to safe orbits)
PSR11	The spacecraft shall be deployed from the ISS	PSR212	The spacecraft shall be deployed from the ISS	PSR312	The spacecraft shall be deployed from the ISS
PSR11	The spacecraft shall be retrieved to the ISS	PSR213	The spacecraft shall be retrieved to the ISS	PSR313	The spacecraft shall be retrieved to the ISS
PSR11	The spacecraft shall be reusable	PSR214	The spacecraft shall be reusable	PSR314	The spacecraft shall be reusable
PSR11	The spacecraft shall be reconfigurable by the crew on-board the ISS	PSR215	The spacecraft shall be reconfigurable by the crew on-board the ISS	PSR315	The spacecraft shall be reconfigurable by the crew on-board the ISS
PSR11	The spacecraft shall be remotely controllable	PSR216	The spacecraft shall be remotely controllable	PSR316	The spacecraft shall be remotely controllable
PSR11	The spacecraft shall navigate (semi)autonomously	PSR217	The spacecraft shall navigate (semi)autonomously	PSR317	The spacecraft shall navigate (semi)autonomously
PSR11	The spacecraft shall communicate with ISS	PSR218	The spacecraft shall communicate with ISS	PSR318	The spacecraft shall communicate with ISS
PSR11	The spacecraft shall communicate with ground (TBD)	PSR219	The spacecraft shall communicate with ground (TBD)	PSR319	The spacecraft shall communicate with ground (TBD)
PSR12 0	The spacecraft shall operate for a duration sufficient to support EVAs	PSR220	The spacecraft shall operate for a duration sufficient to support payload experiment	PSR320	The spacecraft shall operate for a duration sufficient to reach, capture and move the target objet to final destination
PSR12 1	The spacecraft shall operate for a duration sufficient to support robotic operations (e.g. surveillance of Visiting Vehicles rendez-vous and docking operations)				
PSR12	...				

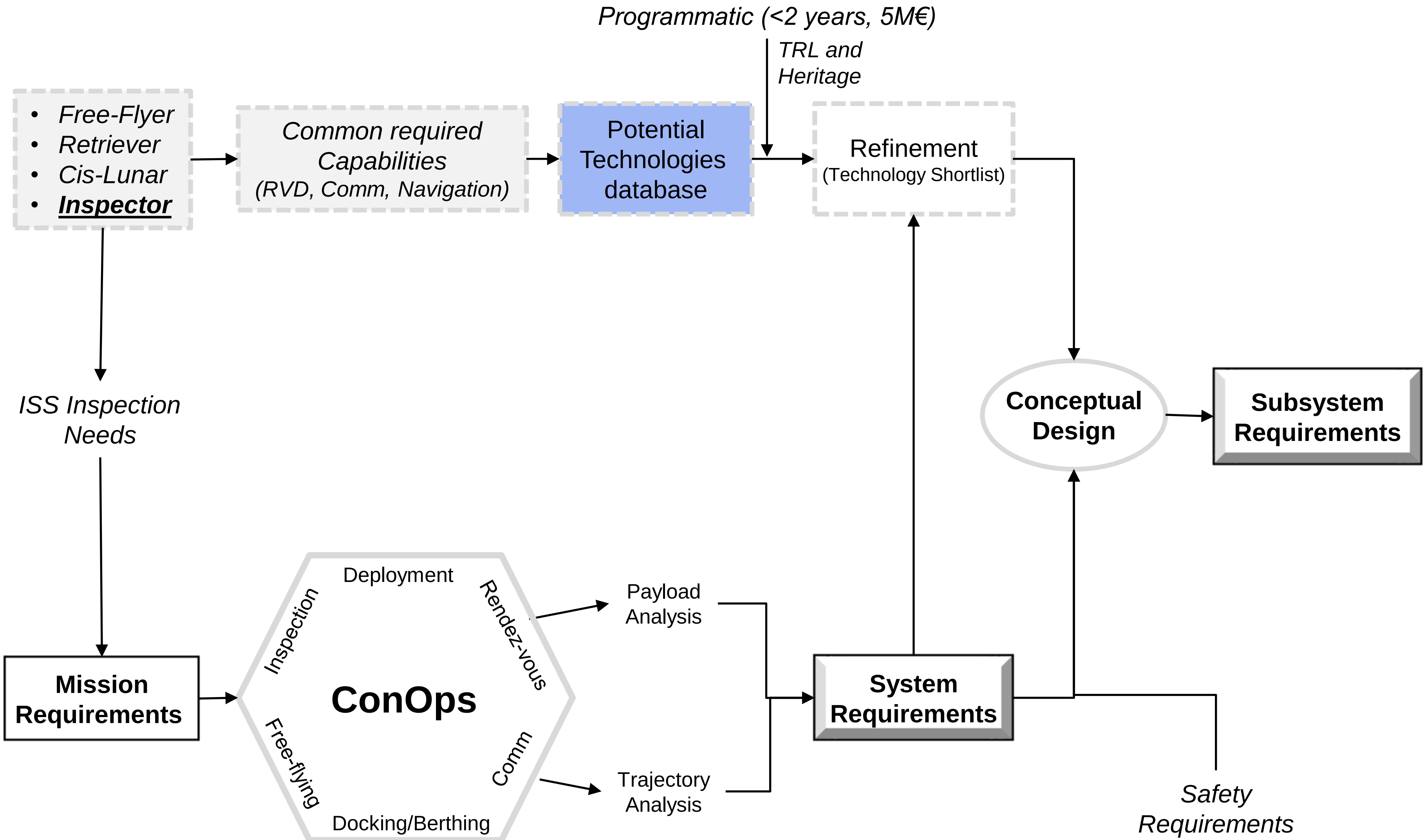
Required Capabilities Trade-Off

- **Based on preliminary analysis of s/c required capabilities**
  - **Feasibility (1st iteration): inputs from Technology Assessment**
    - **Is the full set of capabilities to be achieved by the ISS Demonstrator?**
    - **What is the technology required? Is the technology available?**
  - **Feasibility (2^{nd} iteration):**
    - **Inputs from WP3 (development plan)**
    - **Is it feasible within 2 years-implementation?**
    - **Is it feasible with the budget earmarked?**



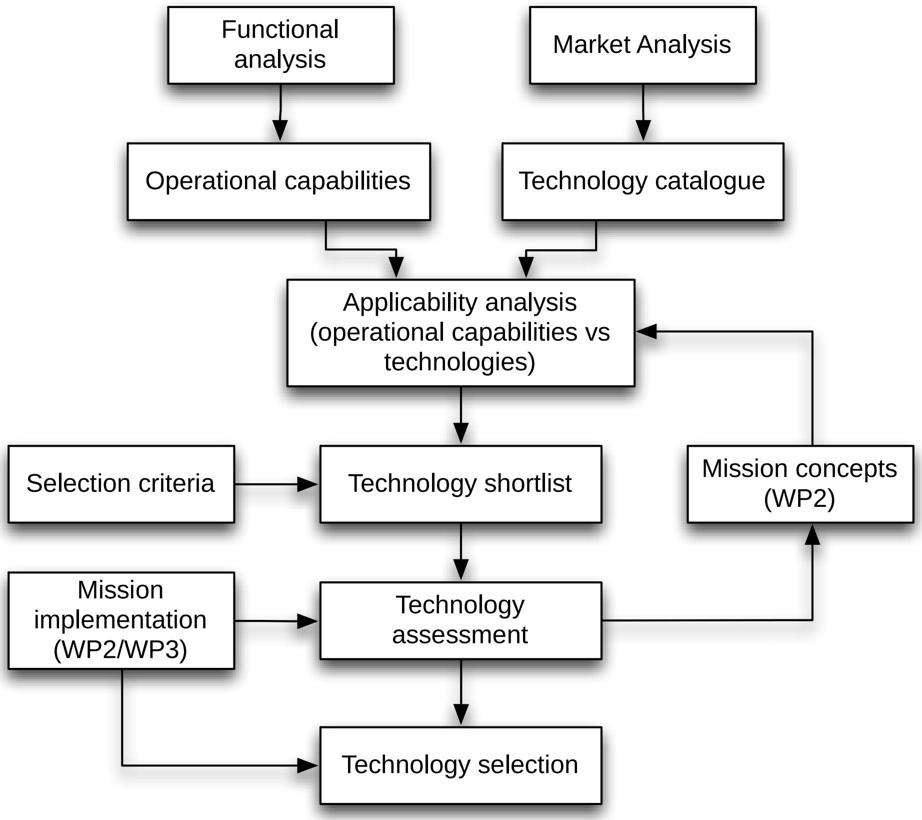
Potential Technology Database

CubISSat Work Logic Diagram



Potential Technbology Database

- **First step: identification of Operational Capabilities (OC)**
  - **High-level functional analysis for a multi-purpose CubeSat mission at ISS**
- **Second step: list of Technology Areas (TA)**
  - **For each TA, set of equipment/items (BBs) identified through market analysis**
  - **Outcome: catalogue of potential technologies**
- **Third Step: Applicability Analysis**
  - **Iterative process to match OC required by the demo mission with technology available**
  - **Selection Criteria identified**
  - **Outcome: Technology selection**



CubeSat Technologies Catalogue

- **9 Technology Areas (TAs)**

  Deployment systems
  Structures & Mechanisms
  OBDH
  Power
  ADCS
  Communication
  Propulsion
  Navigation
  Payloads

- **200+ technologies (BBs) identified**
- **Common properties**
  - **Developer**
  - **Physical (mass, size…)**
  - **Thermal**
  - **Design Life**
  - **Electrical/Power**
  - **Technology readiness (TRL and heritage)**
  - **Cost**
- **Specific properties identified for each category**

OBDH	
TRL VALUE	Conteggio di NAME
7	1
8	1
9	6
n/a	4
Totale complessivo	12

STRUCTURE	
TRL VALUE	Conteggio di Value
8	2
9	3
n/a	2
Totale complessivo	7

DEPLOYER	
TRL VALUE	Conteggio di Value
9	9
n/a	7
Totale complessivo	16

POWER_SOLAR_PCDU	
TRL VALUE	Conteggio di Value
7	1
9	3
Totale complessivo	4

POWER_SOLAR_CELLS	
TRL VALUE	Conteggio di Value
9	3
n/a	7
Totale complessivo	10

POWER_SOLAR_ARRAY	
TRL VALUE	Conteggio di Value
8	1
9	3
n/a	2
Totale complessivo	6

POWER_SOLAR_PB	
TRL VALUE	Conteggio di Value
9	5
n/a	1
Totale complessivo	6

ADCS_FULLKIT	
TRL VALUE	Conteggio di Value
8	1
9	3
n/a	1
Totale complessivo	5

ADCS_SENSOR	
TRL VALUE	Conteggio di Value
8	2
9	9
n/a	4
Totale complessivo	15

ADCS_ACTUATORS	
TRL VALUE	Conteggio di Value
9	9
n/a	14
Totale complessivo	23

ADCS_MOTHERBOARD	
TRL VALUE	Conteggio di Value
8	1
9	3
n/a	1
Totale complessivo	5

COMM_RADIO	
TRL VALUE	Conteggio di Value
5	2
6	1
8	3
9	8
n/a	2
Totale complessivo	16

COMM_ANTENNA	
TRL VALUE	Conteggio di Value
9	3
n/a	2
Totale complessivo	5

PROPULSION	
TRL VALUE	Conteggio di Value
3	1
5	2
6	2
7	4
8	5
9	4
n/a	5
Totale complessivo	23

NAVIGATION_RELATIVE	
TRL VALUE	Conteggio di Value
9	1
Totale complessivo	1

NAVIGATION_ABSOLUTE	
TRL VALUE	Conteggio di Value
9	4
Totale complessivo	4

PAYLOAD_LIDAR	
TRL VALUE	Conteggio di Value
8	1
Totale complessivo	1

PAYLOAD_CAMERA	
TRL VALUE	Conteggio di Value
9	7
n/a	8
n/a LOW TRL	3
Totale complessivo	18

Technology assessment criteria (1/2)

- **4 criteria have been proposed**

1. **TO: Technology Origin (EU / non-EU)**

   TO = 1 if EU

   TO = 0 if non-EU

2. **TR: Technology Readiness. Technologies are classified taking into account the Technology Readiness Level (TRL)* and the heritage from previous missions (heritage index HI)**

   TR = TRL*HI

   - **HI = 1,5 if the technology flown on >= 5 successful missions**
   - **HI = 1,2 if the technology flown on >= 2 successful missions**
   - **HI = 1 if the technology has no heritage, or for TRL >= 8****

***TRL defined according to ESA scale**

**** TRL >= 8 means the technology has flown at least one mission**

TRL	Description
1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical & experimental critical function and/or characteristic proof-of-concept
4	Component and/or breadboard validation in laboratory environment
5	Component and/or breadboard validation in relevant environment
6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
7	System prototype demonstration in a space environment
8	Actual system completed and "Flight qualified" through test and demonstration (ground or space)
9	Actual system "Flight proven" through successful mission operations

Technology assessment criteria (2/2)

3. **Compatibility with ISS (CISS): The technology has been already used in conjunction with ISS operations or not (the technology has already or has not a green light). This criterion also considers if it is possible to leverage any previous heritage or to achieve "fast" qualification.**
   - **CISS = 1 if technology is cleared for use on ISS;**
   - **CISS = 0,5 if technology has never been used but can be adapted for use on the ISS;**
   - **CISS = 0 if technology has never been used and has serious issues with use on ISS.**

4. **Safety (S): The technology can be critical with respect to safety aspects, i.e. a malfunction of the technology can impact the safety of the ISS**

Severity	Level	Dependability	Safety
Catastrophic	1	Failures propagation	Loss of life, life threatening or permanently disabling injury or occupational illness
			Loss of system
			Loss o fan interfacing manned flight system
			Loss of launch site facilities
			Severe detrimental environmental effects
Critical	2	Loss of mission	Temporarily disabling but not life-threatening injury, or temporary occupational illness
			Major damage to interfacing flight system
			Major damage to ground facilities
			Major damage to public or private property
			Major detrimental environmental effects
Major	3	Major mission degradation	none
Minor or negligible	4	Minor mission degradation or any other effect	none
When several categories can be applied to the system or system component, the highest severity class takes priority			

classification of malfunctions according to ECSS-Q-ST-30/40

Outcomes from technology assessment

- **Many developments are ongoing in the CubeSat technology area at European level:**
  - **For most part of the TAs, EU technologies are at the highest level of development;**

- **Many developments still need to be proven in an operational environment:**
  - **Especially true considering the level of reliability and safety required for a mission in the vicinity of the ISS (to be confirmed by safety assessment).**
  - **Some technologies are still missing at the proper level of development.**
  - **In particular, a lack of dedicated/integrated/ready COTS solutions for *relative navigation* has been identified. Many items able to perform the required functions for relative navigation exist, but need to be flight proven as a single BB.**

Selection of the demonstrator operational scenario

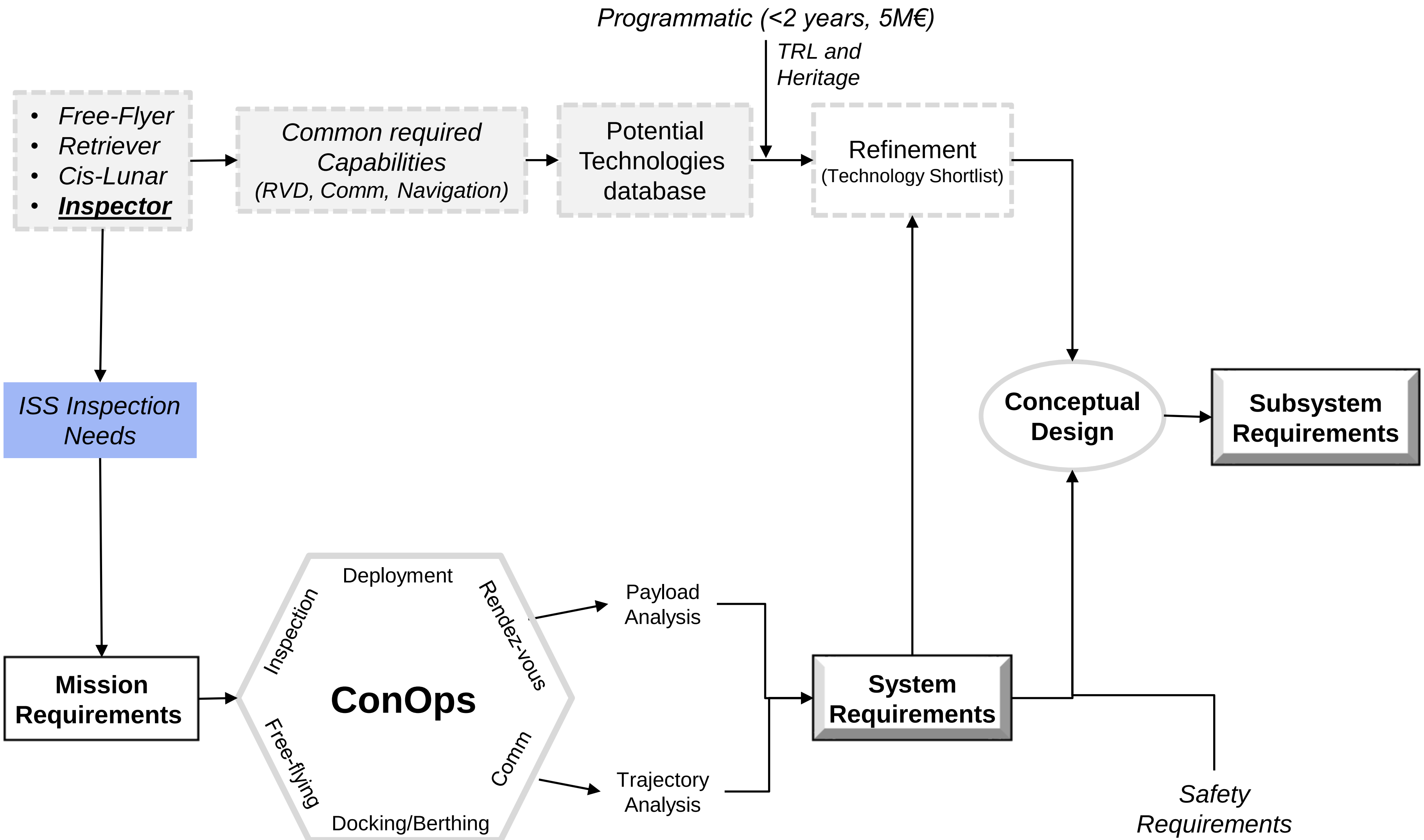
- **Mission scenario selection:**
  - **Among the given four mission scenarios and related s/c required capabilities, the inspection mission at ISS has been selected as reference mission;**

- **Focus of the study:**
  - **The study will focus on an ISS inspector demonstrator based on CubeSat technologies capable to operate safely in proximity of the ISS, providing imagery of the ISS exterior, data about the ISS environment and engaging the general public with unprecedented imagery of the ISS;**

- **Demonstrator capabilities:**
  - **The inspector shall be able to provide demonstration of (semi)-autonomous navigation, rendez-vous, berthing and docking, communication operations, refurbishment capabilities, and payload re-configurability capabilities.**

ISS Inspection Needs

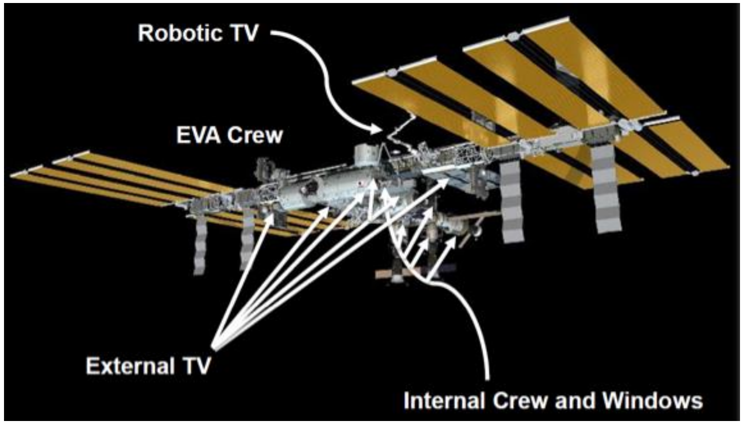
CubISSat Work Logic Diagram



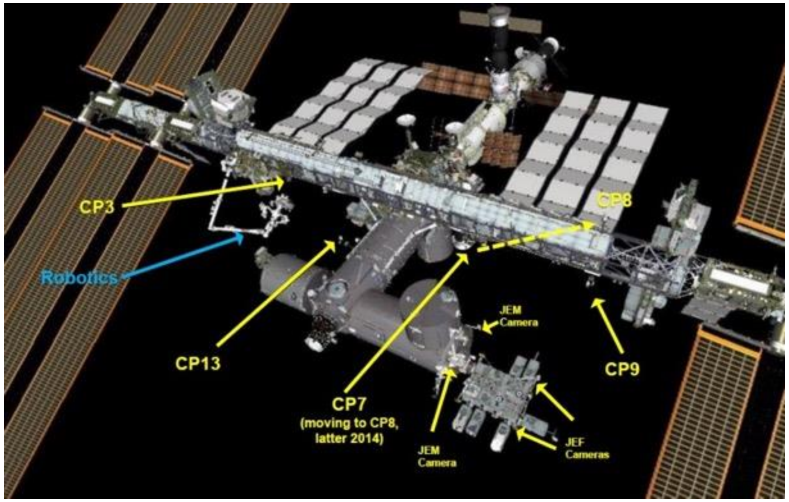
Inspection Mission: current assets available at ISS

JSC-CN-31488 - ISS inspection capabilities and challenges

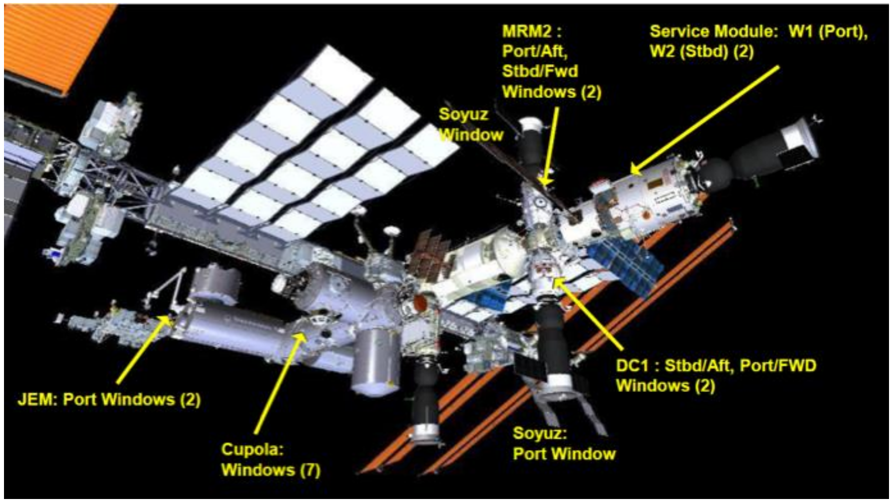
- **Robotic TVs:**
  - SS-RMS, JEM-RMS;
- **External mounted TVs**
- **Windows for visual inspection:**
  - Cupola, Soyuz port windows, JEM port windows, etc;
- **Crew equipment for EVAs**



ISS visual inspection assets



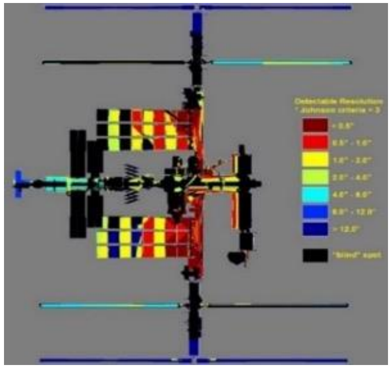
External ISS TV cameras



Windows for external surface inspection

Inspection Mission: challenges

- **Operational challenges associated with inspection operation:**
  - **Crew has very limited time available for inspection operations;**
  - **Complex robotic operations inhibit general purpose inspection surveys.**

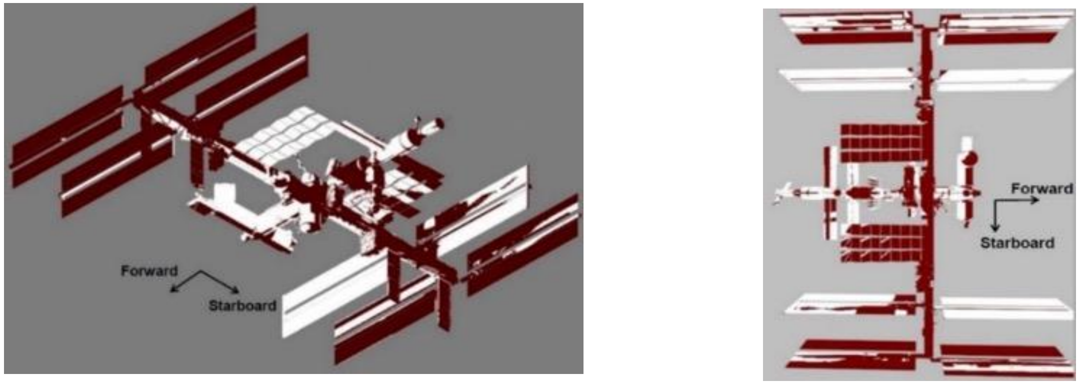


External TVs detectable resolution

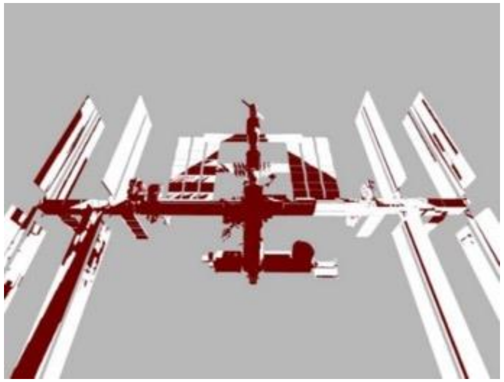
- **Technical challenges associated with inspection operation:**
  - **Few documented specific inspection requirements available;**
  - **Current detectable resolution (External TVs at max zoom):**

    0.25 inch (6.35 mm) at 25 feet (7.6 m);

    0.5 inch (12.7 mm) at 50 feet (15 m).
  - **External TVs mounting locations, windows view and robotic devices result in several blind spots (brown in pictures).**



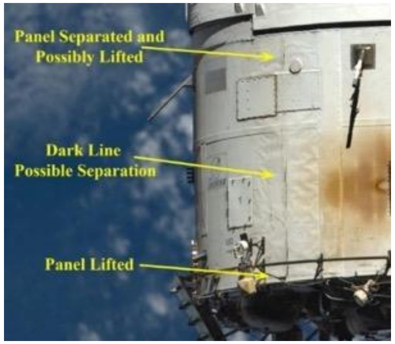
ETVCG and JEM cameras blind spots



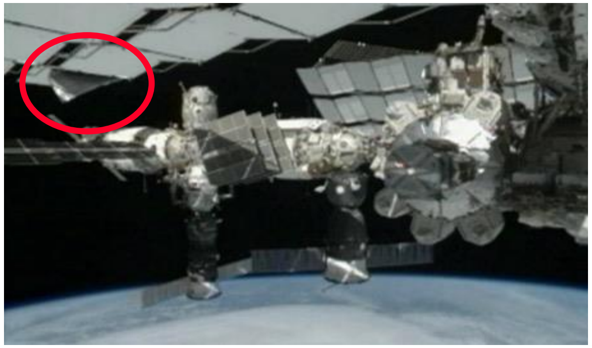
ISS window blind spots (line-of-sight view)

Inspection Mission: applications - 1/2

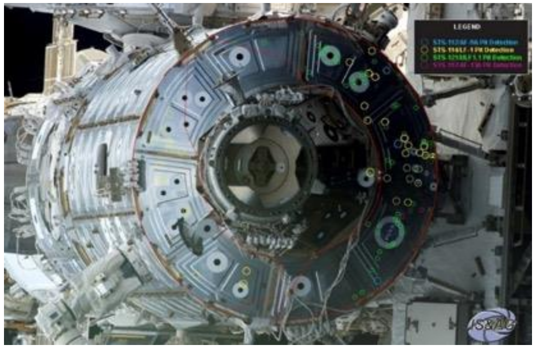
- **Monitoring ISS external conditions:**
  – Material degradation, damaged surfaces, MMOD strikes;



Areas of decoloration



Damaged radiator surface



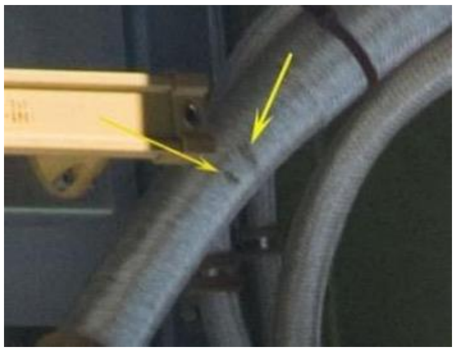
MMOD strikes

- **Verification of ISS configuration:**
  – Installation faults, solar array not fully retracted;

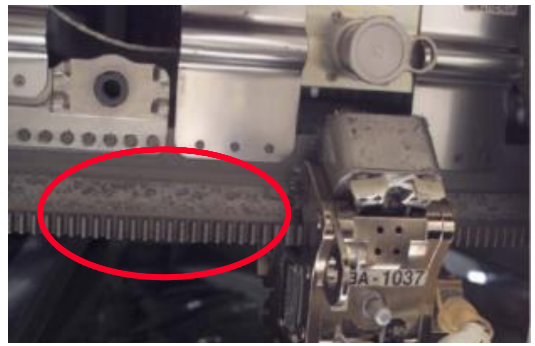
Separated Solar Array Leader Panel

Inspection Mission: applications - 2/2

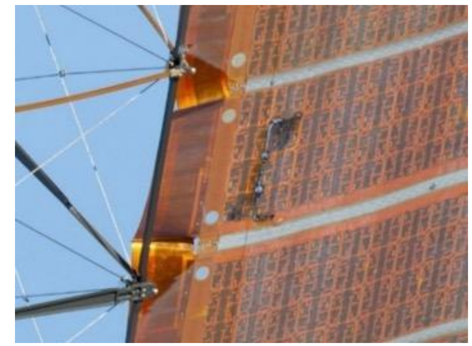
- **Anomaly assessment:**
  - Survey of external systems after anomaly detection, leakages;



Electrical anomaly on wire harness

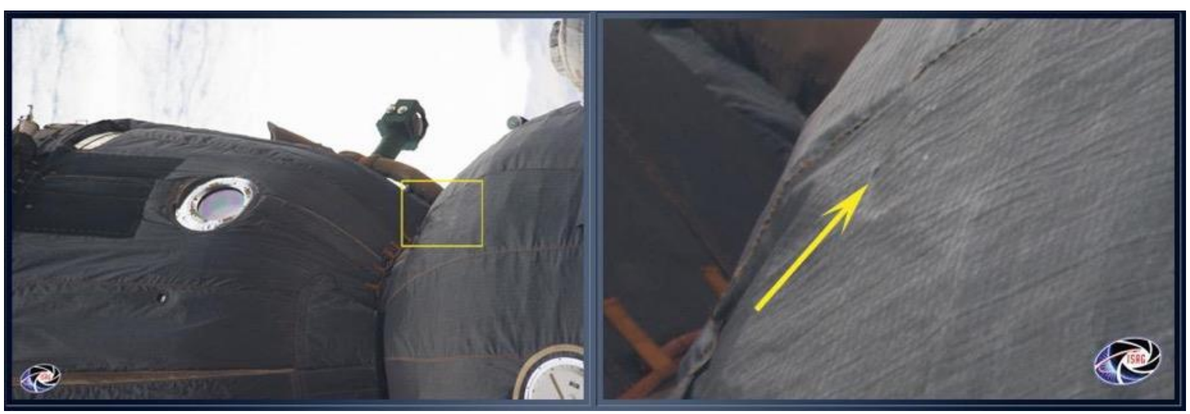


Surface damage



Electrical anomaly on solar array

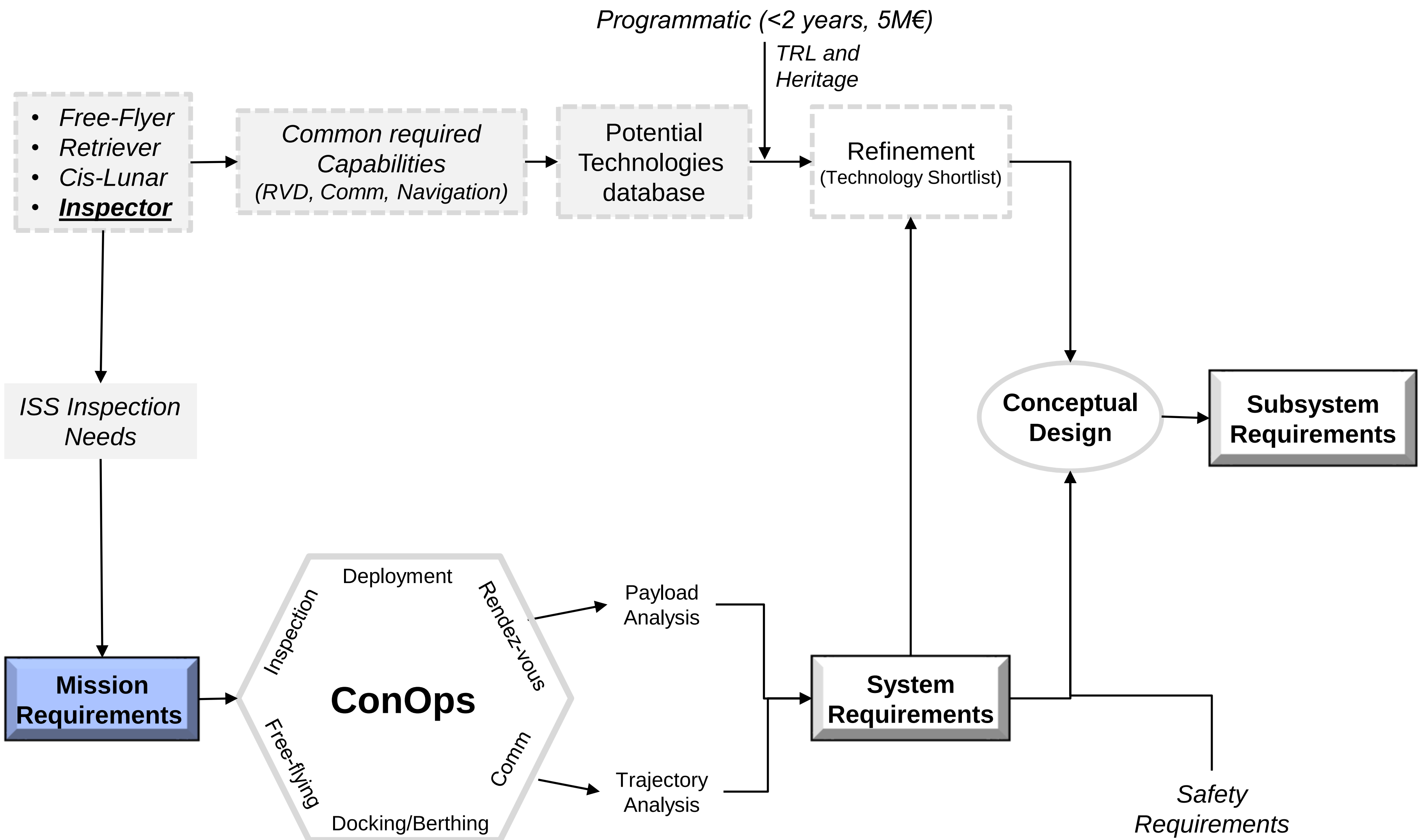
- **Visiting vehicles inspection and assessment;**



Anomaly on thermal cover

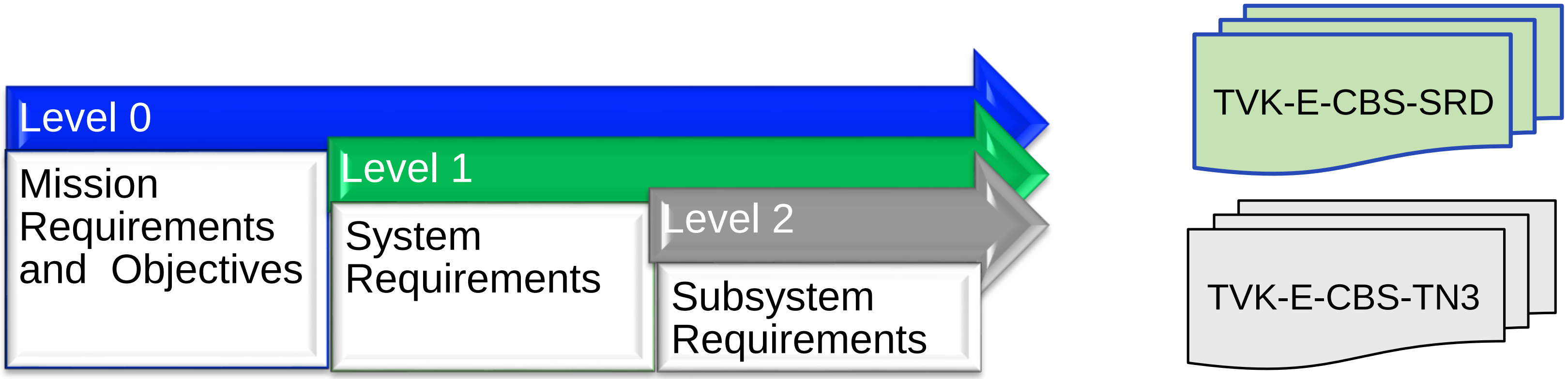
Mission Requirements

CubISSat Work Logic Diagram



Requirements Definition for the DEMO Mission

- **Preliminary system requirements, associated to the overall mission scenario and spacecraft design for the Demonstration Mission, have been identified.**



Demo Mission Overview

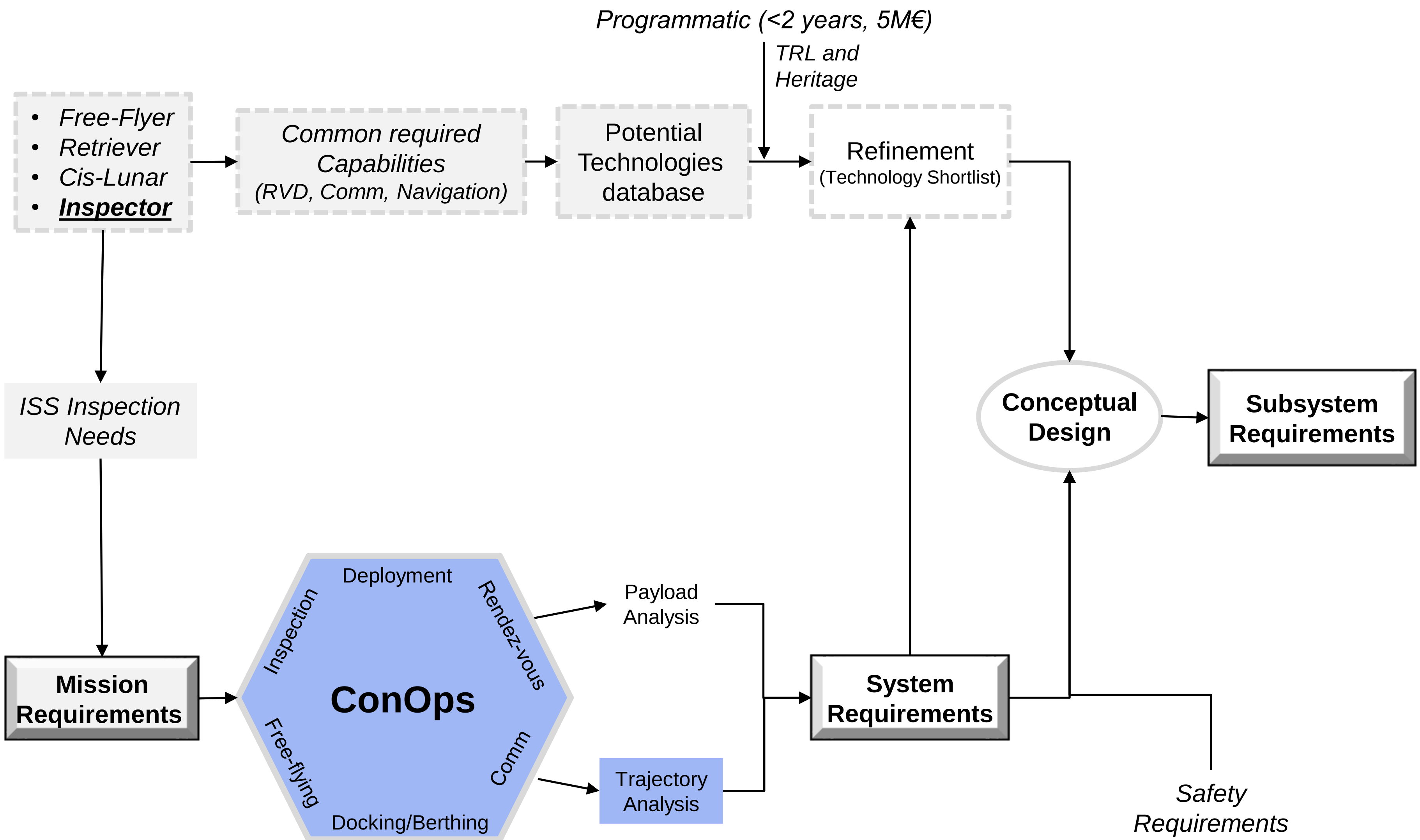
Multi-purpose CubISSat Demonstration Mission Overview		
Mission Objectives (MO)	**Mission Needs (MN)**	**Mission Implementation Constraints (MI)**
Demonstrate the **feasibility** and reliability of the whole life cycle and the critical mission phases: *free-flying, rendezvous* and *retrieval.* Deliver a **proof of the communication approach** of the CubISSat. Verify on the on-board **procedures for refilling and recharging.** Demonstrate the payload **re-configurability,** swapping or addition of dedicated payload(s).	Complement current capabilities at ISS, providing imagery (frames and videos) of **blind-spots and areas of low resolution.** Avoid / limit crew operations for inspection purposes. Provide a **fly-around imagery** set (to replace previous Shuttle operation capabilities). Provide **high-resolution** imagery of small external features and complement current **IR imaging** systems.	The mission shall be implemented with a schedule <2 years (up to flight readiness) → System / sub-system must have a high TRL to be "**ready to fly**" on **2018** **Maximise the use of existing ISS infrastructures** (e.g. External Platform, C2V2 etc.). The mission shall be implemented with an overall budget **<5M€**. The overall mission shall comply with **ISS safety** policies The spacecraft volume shall be between 3 and 8 litres.
Mission Requirements – Level 0		

Mission Requirements – Level 0

ID	Requirement
DM-MR-01	The CubISSat demonstrator mission shall not compromise the ISS safety.
DM-MR-02	The CubISSat demonstrator mission shall be designed with the aim to improve/increase the ISS safety through inspection operations.
DM-MR-03	The CubISSat demonstrator shall operate in LEO environment (ref. ISS orbit 330 to 410 km altitude, 51.6 deg inclination).
DM-MR-04	The CubISSat demonstrator shall be deployed from a VV outside the KOS.
DM-MR-05	The CubISSat demonstrator shall communicate with ISS and MCC.
DM-MR-06	The CubISSat demonstrator shall navigate semi-autonomously outside and inside the KOS.
DM-MR-07	The CubISSat demonstrator shall provide imagery of the current ISS framework: • Visible optical imaging with 0.25 inches spatial resolution from 200m distance; • IR imaging with 10 cm resolution from 200m distance.
DM-MR-08	The CubISSat demonstrator shall rendezvous with ISS.
DM-MR-09	The CubISSat demonstrator shall mate with the ISS through berthing and docking operations.
DM-MR-10	The CubISSat demonstrator shall undock from ISS.
DM-MR-11	The CubISSat demonstrator shall be retrieved inside the ISS.
DM-MR-12	The CubISSat demonstrator shall be refurbished inside the ISS (battery charging and propellant refilling).
DM-MR-13	The CubISSat demonstrator shall be "payload re-configurable".
DM-MR-14	The CubISSat demonstrator shall perform additional missions after stowing.
DM-MR-15	The CubISSat demonstration shall be compatible with VV unpressurized P/L requirements
DM-MR-16	The Docking Platform (DS01) shall be compatible with ISS environment and constrains.
DM-MR-17	The Docking Platform (DS01) shall be compatible with Japanese Experiment Module Airlock (JEM A/L).
DM-MR-18	In all operational orbit regimes, the CubISSat shall be designed not to release debris during normal operations.
DM-MR-19	The CubISSat system shall minimize the potential for On-Orbit Break-ups. It shall be designed and operated so as to prevent accidental explosions and ruptures at end-of- mission.

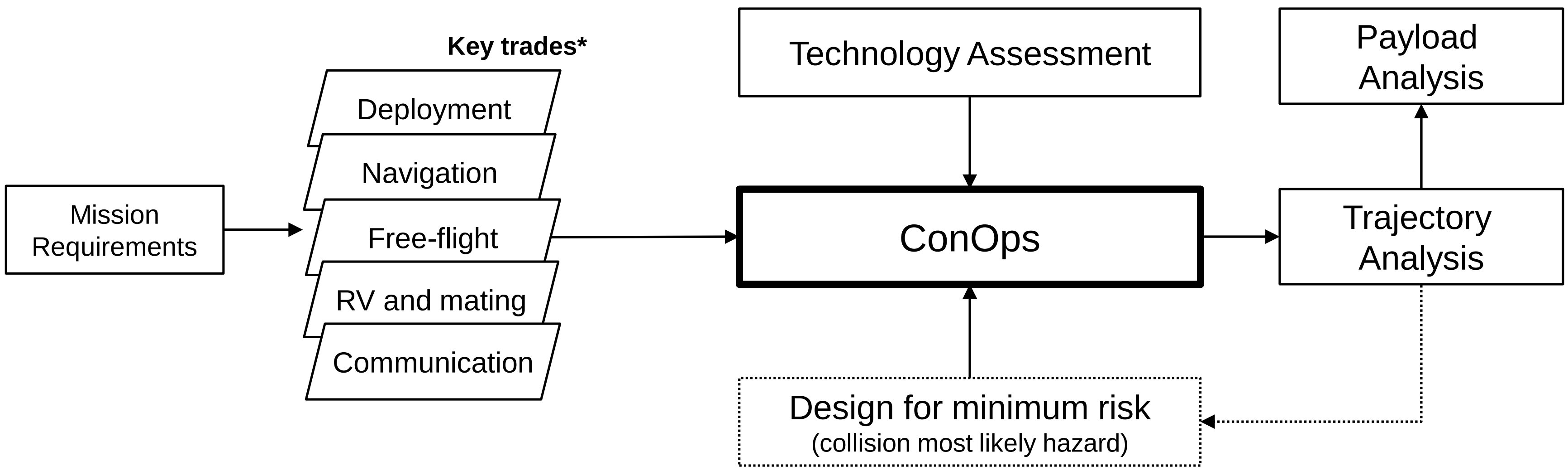
Mission ConOps
&
Trajectory Analysis

CubISSat Work Logic Diagram



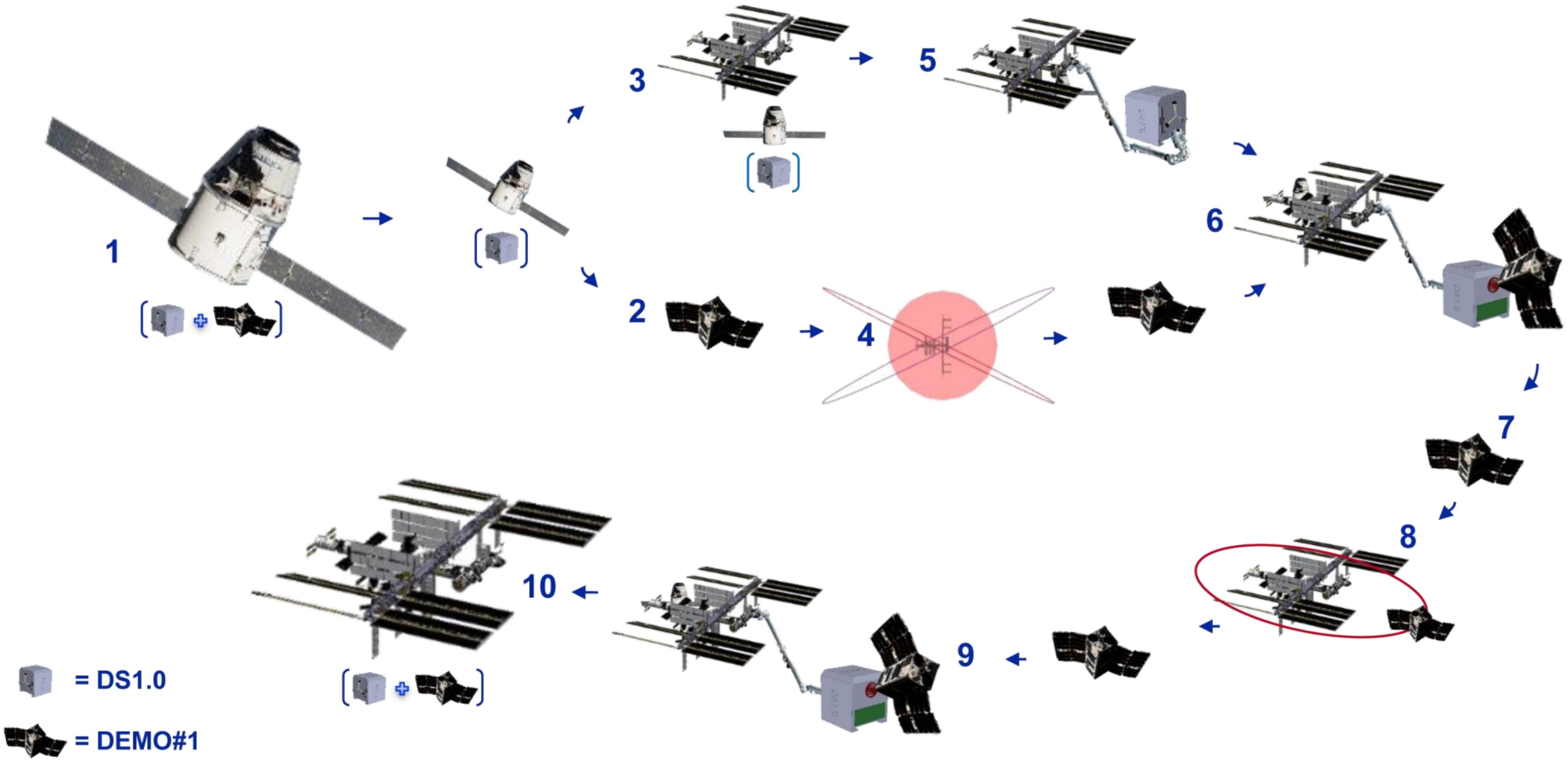
ConOps development

- **Iterative optimization process**
  - **Inputs from Technology assessment and key trades**
  - **Output to trajectory and payload analysis**



***key trades described in detail in TN2**

Demonstration Mission ConOps

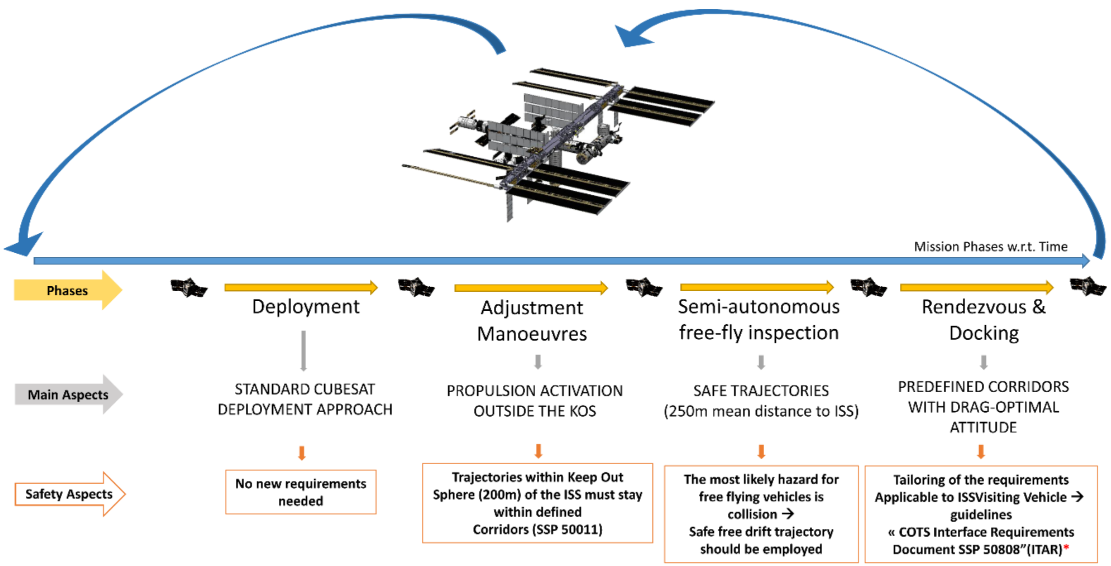


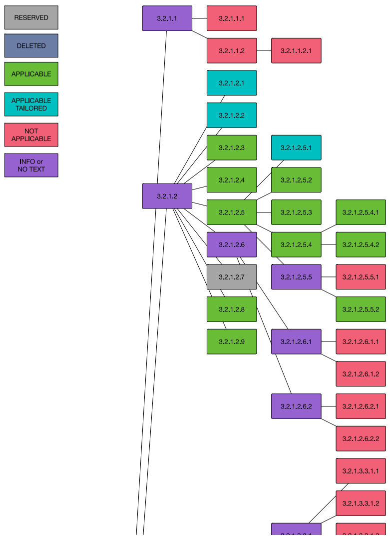
1 - DS1.0 and DEMO#1 are stowed as cargo on board the VV respectively in the press. and unpress. bays.	2 - DEMO#1 is released from its dedicated deployer while the DS1.0 stays on VV; the demonstrator is checked out.	3 - VV is berthed to ISS.	4 - DEMO#1 performs inspection mission#1 scan 1 & 2 outside the KOS.	5 - DS1.0 is moved to be mounted onto the sliding table of the Airlock module.	6 - DEMO#1 is berthed to DS1.0.
7 - DEMO#1 undocks the DS1.0.	8 - DEMO#1 performs inspection mission #2, 30m far from ISS.	9 - DEMO#1 is berthed to DS1.0.	10 - DEMO#1 and DS1.0 are retrieved inside ISS. Crew performs post-mission detailed inspection of the CubISSat and DS1-0; close up imagery and test the on board operation for battery charging and propellant refilling. CubISSat and DS1.0 are stowed until next mission.		

Considerations on Safety Aspects (1/3)

Multipurpose CubeSat at ISS – Final Presentation

- **The general approach would be to try to avoid the spacecraft to be considered as a pure "Visiting Vehicle", at least for the standard deployment procedures and manoeuvres outside the KOS, leaving room for discussion on the applicability of SSP 50808 (or applicable tailoring) for the Rendez-Vous and Docking approach.**





ID	TITLE	Text	A/A-T/NA	Rationale for N/A (if any)	Tailoring (if any)	Impacts on
3.2.1.6.1.2	BONDING		A			System Design
3.2.1.6.2	THERMAL	No text				
3.2.1.6.2.1	THERMAL INTERFACE FOR DOCKING	No text				
3.2.1.6.2.1.1	INTERNATIONAL DOCKING ADAPTER		NA	No pressurized section		
3.2.1.6.2.1.2	INTERNATIONAL DOCKING ADAPTER UNPRESSURIZED BEFORE CAPTURE		A - T		To be tailored (no IDA, but docking station)	System Design
3.2.1.6.2.1.3	INTERNATIONAL DOCKING ADAPTER UNPRESSURIZED AND HARD MATED		A - T		To be tailored (no IDA, but docking station)	System Design

Considerations on Safety Aspects (2/3)

- **ISS Safety Requirements Document (SSP 50021) was not designed for free-flight phase so additional requirements may also apply*.**

- **The most likely hazard for free flying vehicles is collision. To mitigate this hazard the vehicle designers could:**
  - **Meet the Fault tolerance requirement for all systems (or design to minimum risk where appropriate);**
  - **Pair being less than two fault tolerant with the ability to safely abort the operation and leave the vicinity of the ISS;**
  - **Show that collision does not create a catastrophic failure on the ISS.**
- **There are still other Safety related requirements that have been imposed on vehicles flying near the ISS:**
  - **Fail Safe: The system must be automatically (for uncrewed vehicles) fail safe or initiate a collision avoidance maneuver while in free flight;**
  - **Safe Trajectory: Targeting and Trajectories must be designed such that the safety of the ISS is preserved.**

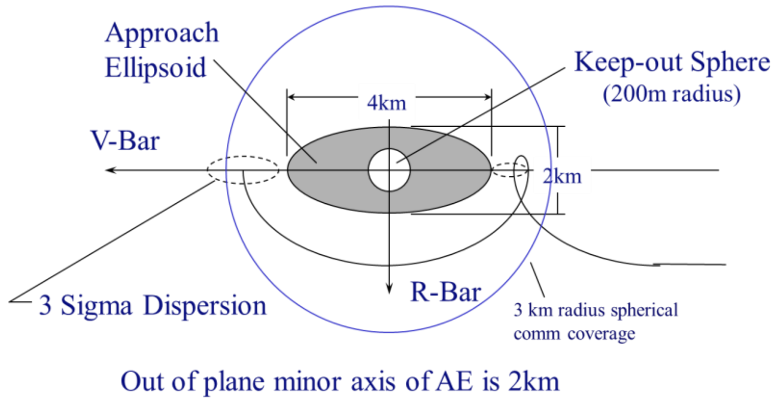
**Main source: ISS Rendezvous, Proximity Operations, Docking & Berthing Considerations“* -Presented and edited by Al DuPont

NASA/JSC/Aeroscience & Flight Mechanics Division

Considerations on Safety Aspects (3/3)

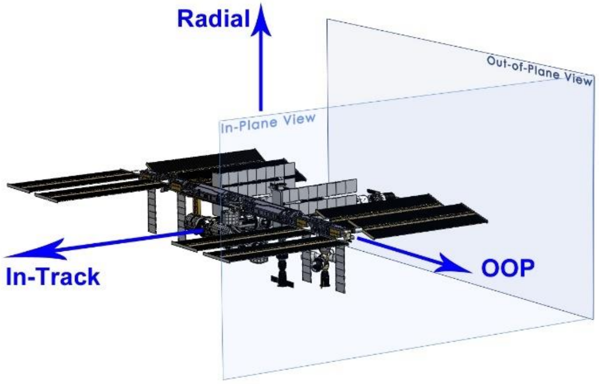
- **Safe trajectories must be defined for each region near the ISS*:**
  - **Baselined regions defined in concept documents:**
    - Approach Ellipsoid (AE): 4x2x2 km (SSP 50011);
    - Keep out Sphere (KOS): 200 m radius (SSP 50011);
    - Omni directional communications disk: 3x1½ km (SSP 50235);
  - **Safe free drift trajectories should be employed when ever possible:**
    - Maximize safe free drift trajectory when practical inside KOS;
    - Trajectories within Keep Out Sphere (200m) of the ISS must stay within defined corridors (a survey flight may have exceptions);
    - The vehicle shall not get closer than 6 ft to any ISS structure - *specific requirements for capture mechanisms and attachment points may have exceptions.*

- **In order to revise the scenario approach on the applicability of safety requirements (or need of tailoring), an interation with ESA/NASA safety panel is planned by January/February 2017.**



Trajectory Simulation: assumptions

- Trajectories have been evaluated according to safety requirements and considerations previously reported;
- The entire trajectory, with the exception of the first part of the deployment phase, has an **out-of-plane component** of the velocity in order to reduce the chance of collision with the ISS in case of either subsystem failures or loss of contact with the demonstrator;
- The effects of the drag on the trajectories were not included at this stage. Despite this, a **constant contribute of 0.1m/s/hr for orbital maintenance has been considered for both the total Delta-V and the amount of propellant needed to complete the mission**;
- For the simulations, the following parameters have been used:
  - **mass of the satellite: 12kg;**
  - **Satellite with Drag-optimal attitude.**



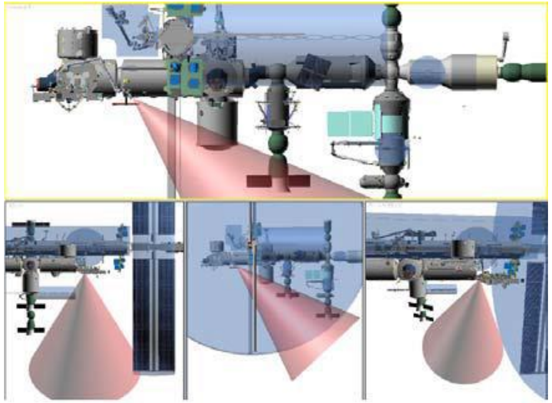
Reference system used for simulations

Departure corridor

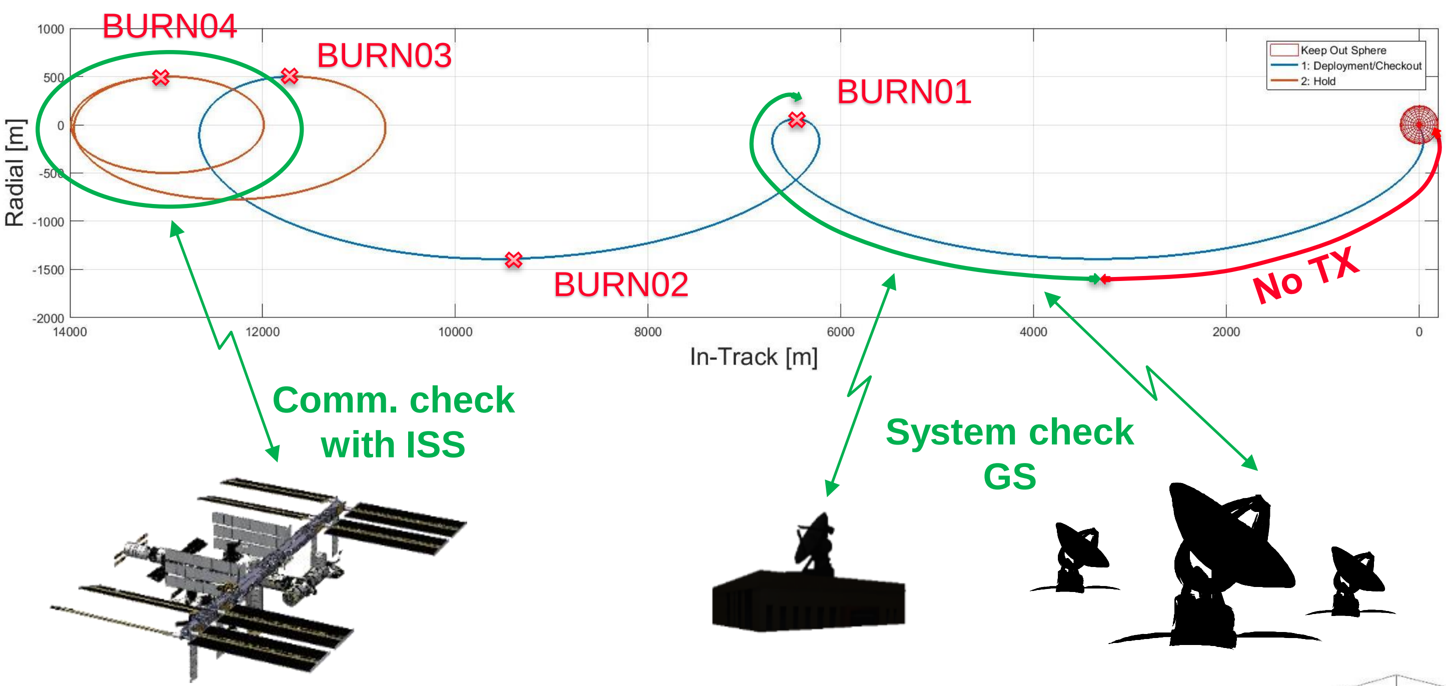
- **Considering a mission profile where the satellite is released from a VV, no departure corridors shall be defined within the KOS. The satellite would get deployed along a given direction which allows it to phase away safely without the need of any own propulsion system, ensuring it will not be a threat to the ISS.**

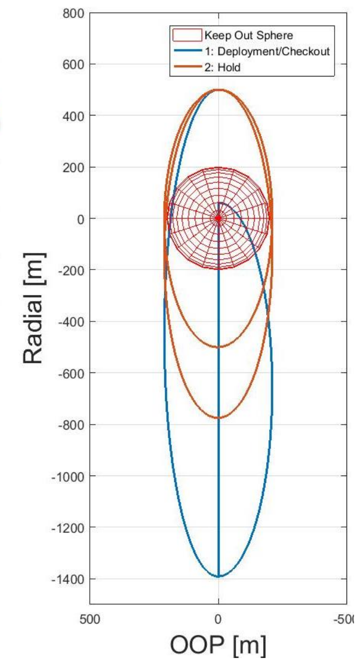
- **For the purpose of demonstrating applicability to different operational scenarios, the departure corridor is chosen so as to resemble the orbital path obtained by an ISS standard deployment.**

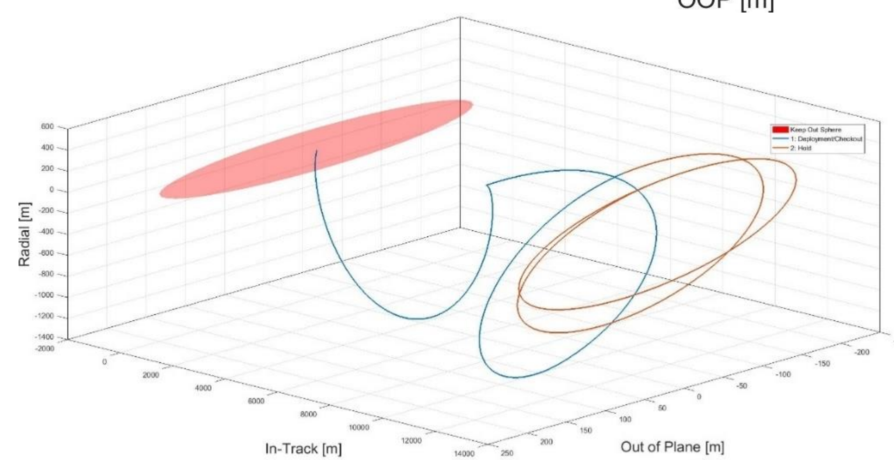
- Ejection velocity: 0.9 ± 1.0 m/s;
- Ejection orientation: Nadir-aft 45° from the ISS Nadir side;
- Deployment accuracy: less than ± 5°;
- Orbit Inclination: 51.6°;
- Orbital releasing altitude: $400 \leq h_e \leq 406$ km.



Deployment and holding phases







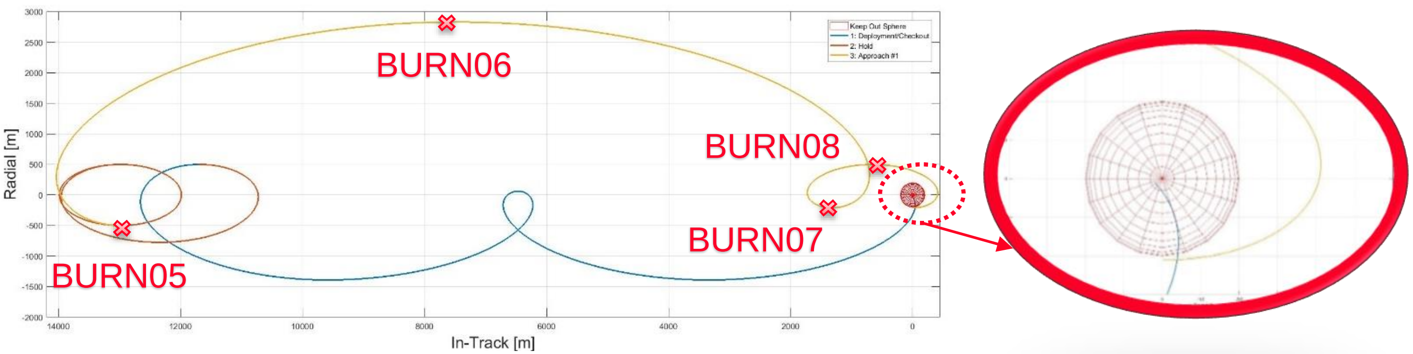
Deployment

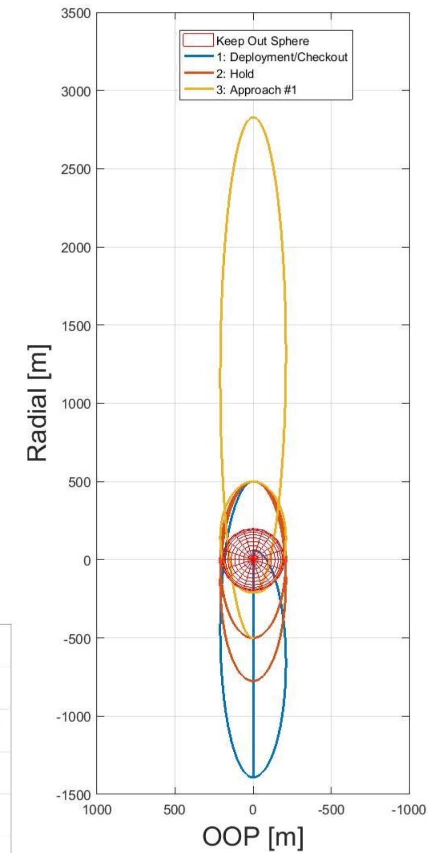
Phase Duration - 2.98 hr
Mission Duration - 2.98 hr
Propellant cons. - 27,37 g
Total propellant cons. - 27.37 g
Delta-V - 0.83 m/s
Total Delta-V - 0.83 m/s

Holding

Phase Duration - 5.39 hr
Mission Duration - 8.37 hr
Propellant cons. - 20.29 g
Total propellant cons. - 47.66 g
Delta-V - 0.62 m/s
Total Delta-V - 1.45 m/s

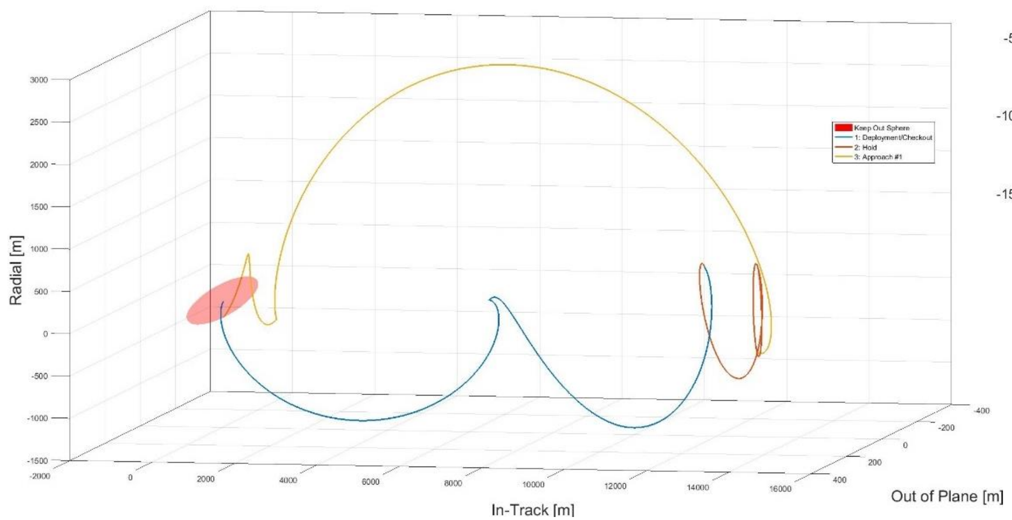
Approach #1





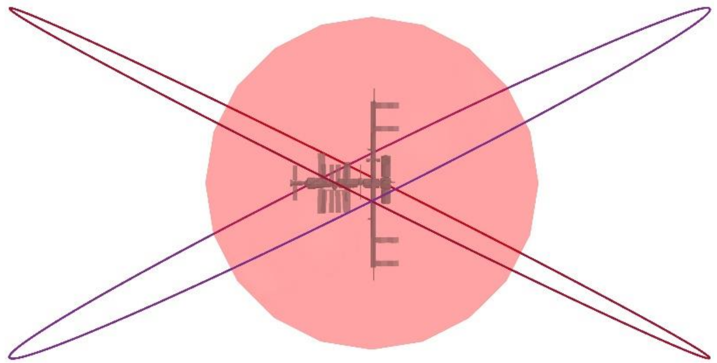
Phase Duration - 3.09 hr
Mission Duration - 11.46 hr
Propellant cons. - 59.24 g
Total propellant cons. - 106.90 g
Delta-V - 1.81 m/s
Total Delta-V - 3.26 m/s

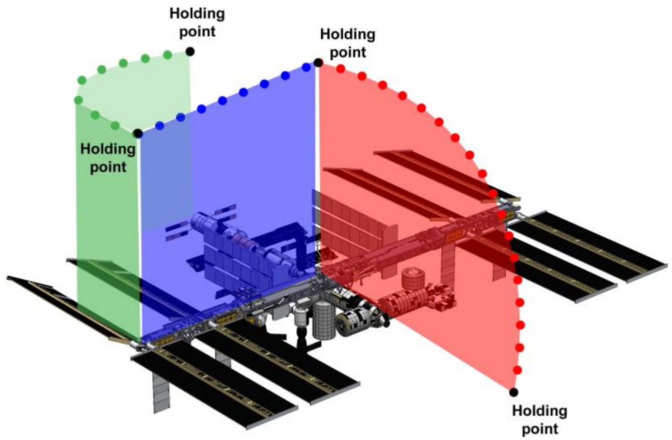
The Approach#1 puts the satellite in position for a retrograde scanning pass



Navigation for inspection purposes

- **A semi-autonomous strategy with operator control and override will be adopted as baseline for two different inspection approaches:**

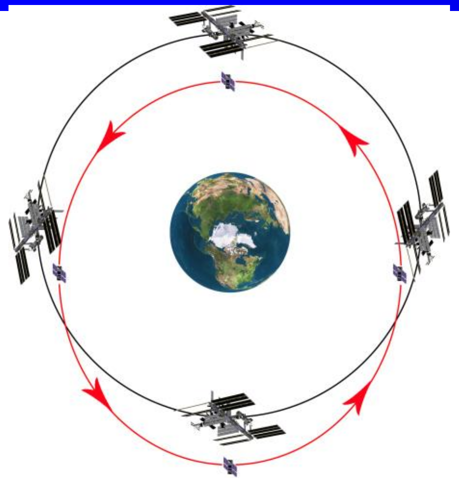


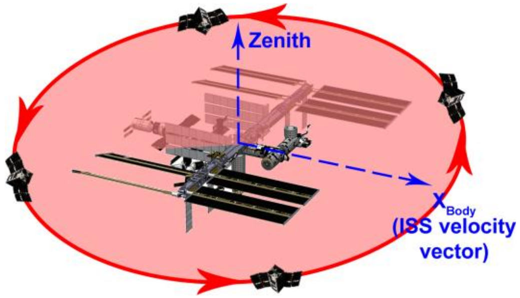


The far-range inspection mission is based on a «fly-around» approach, resulting in regular relative ellipsis wrt the ISS.

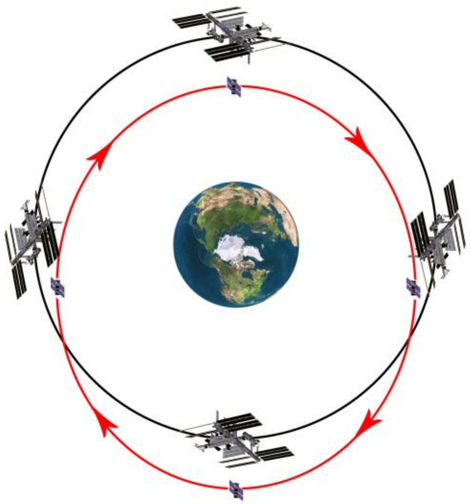
The close-range inspection mission is based on a «hovering» approach, since the ISS geometry has to be taken into account to maintain a 30m distance. This results in a pre-determined not elleptic inspection paths.

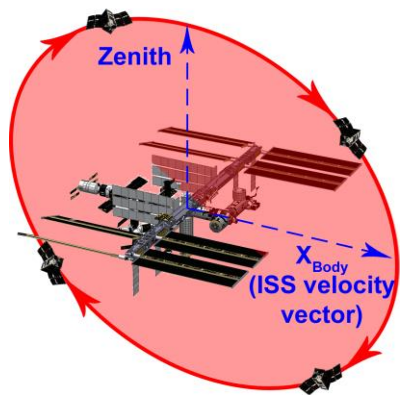
Far-range inspection orbits





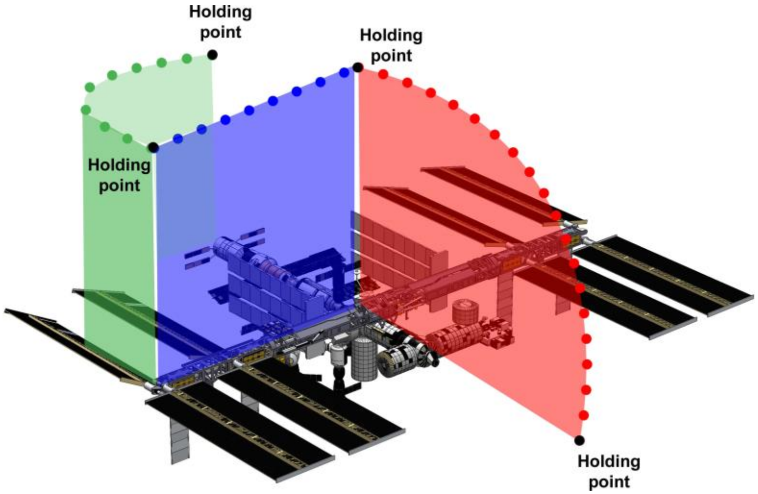
- **Retrograde orbit:**
  - Non-zero eccentricity;
  - Orbital plane rotated up to +45° wrt XZ_{body} plane of ISS;
  - Five orbits executed;
  - Orbital period ≃ 92 minutes.





- **Prograde orbit:**
  - Non-zero eccentricity;
  - Orbital plane rotated up to -45° wrt XZ_{body} plane of ISS;
  - Five orbits executed;
  - Orbital period ≃ 92 minutes.

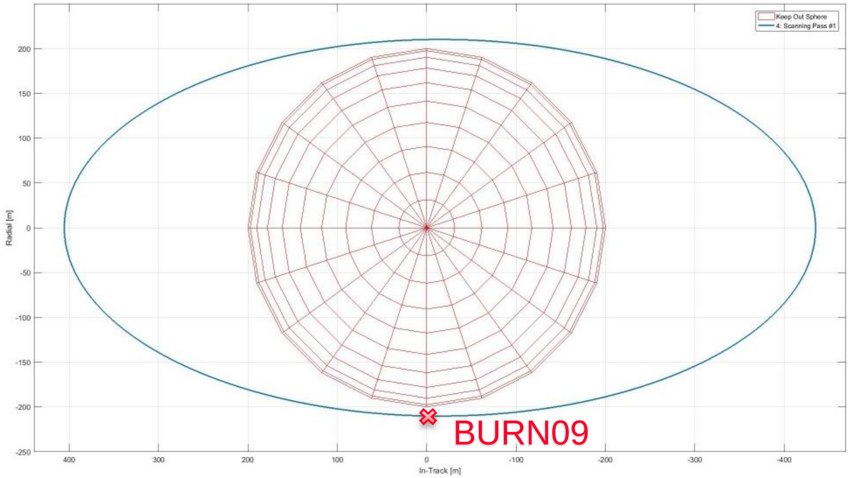
Close-range inspection mission

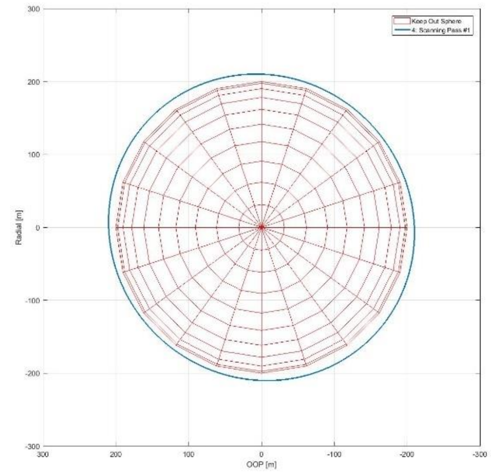


- The inspection approach is designed to hold the spacecraft at a pre-determined point for a given time inside the KOS, 30m far from the target, with the possibility to translate to other points and inspect different visual spots.

- This leads to:
  - The target spot to observe doesn't change if the attitude of ISS changes;
  - The s/c can manoeuver straight to a new target, without necessarily complete a full orbit (far-range approach);
  - All of the visually exposed modules, vehicles, systems and areas might be inspected;
  - The s/c can carry out a complete inspection mission even in case of visual prohibitive conditions due to the Earth shadowing, just keeping its relative position with respect to the ISS and waiting for better conditions;

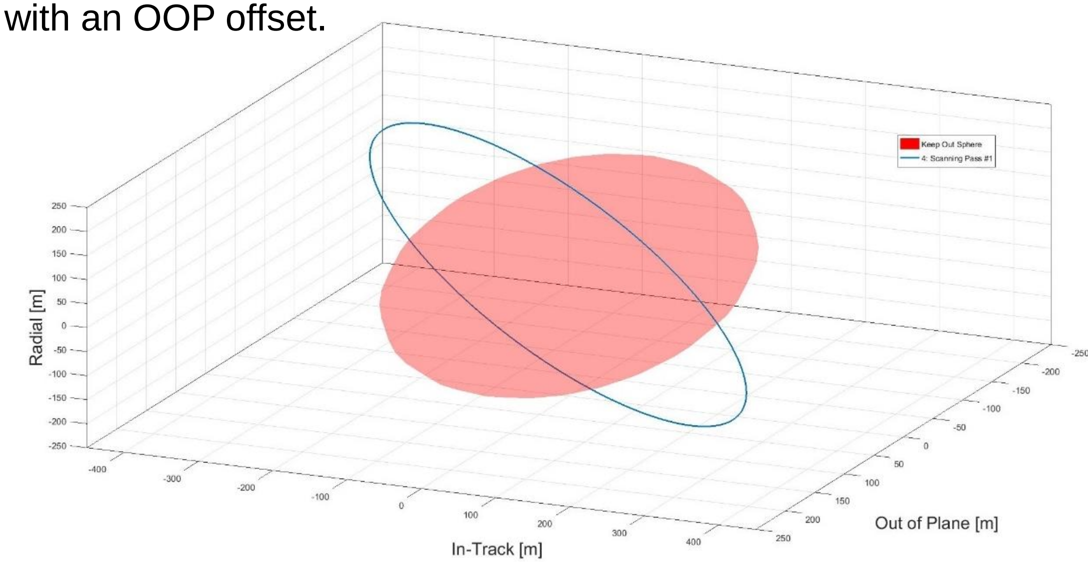
Scanning phase #1



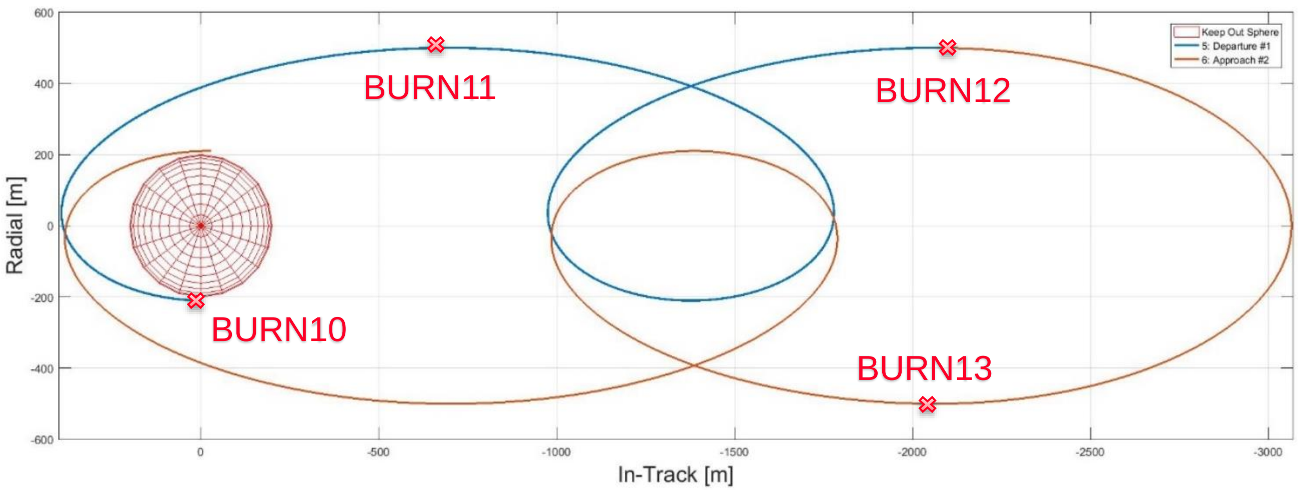


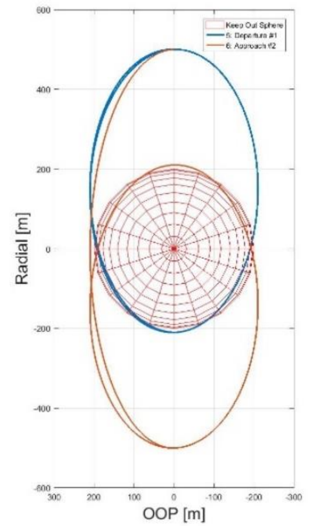
It is a V-Bar hold pass around the ISS with an OOP offset.

Retrograde orbit
Phase Duration - 7.71 hr
Mission Duration - 19.17 hr
Propellant cons. - 28 g
Total propellant cons. - 134.9 g
Delta-V - 0.85 m/s
Total Delta-V - 4.11 m/s



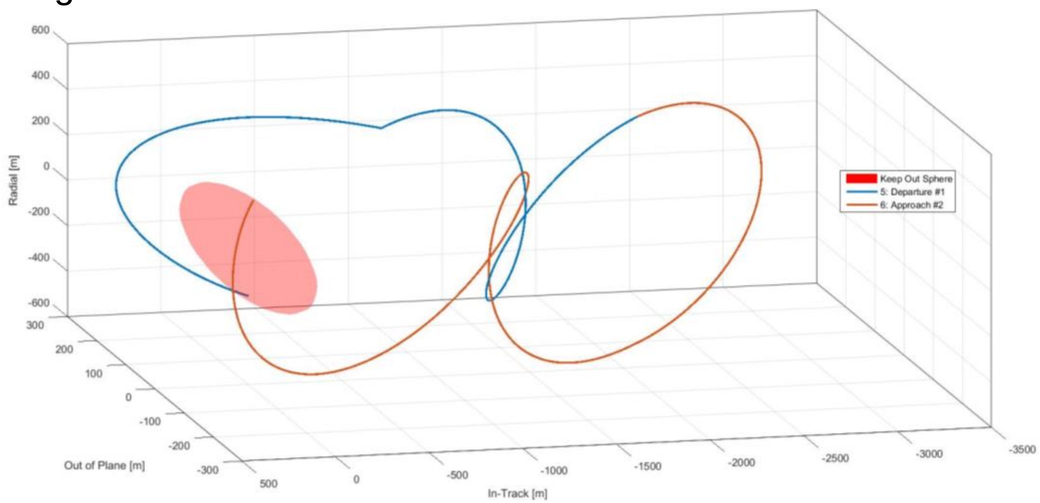
Departure and Approach #2





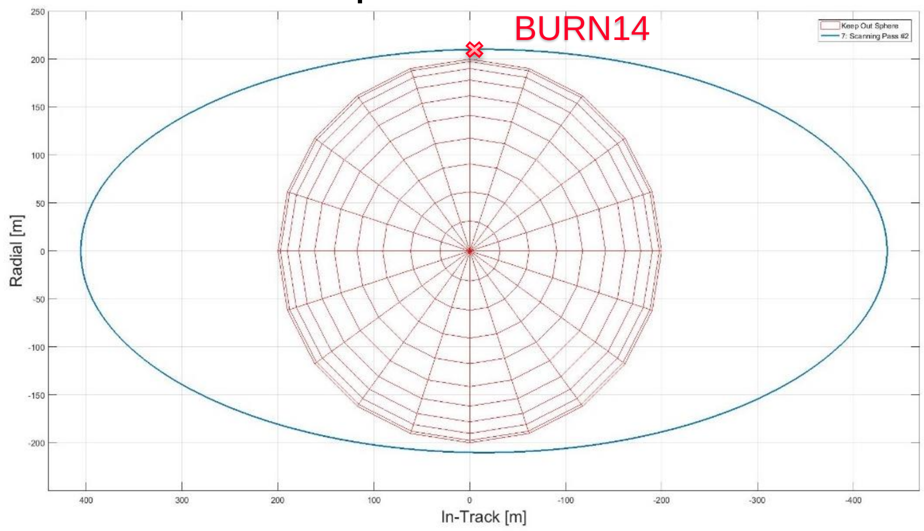
A new scanning orbit is obtained
by switching the OOP offset direction.

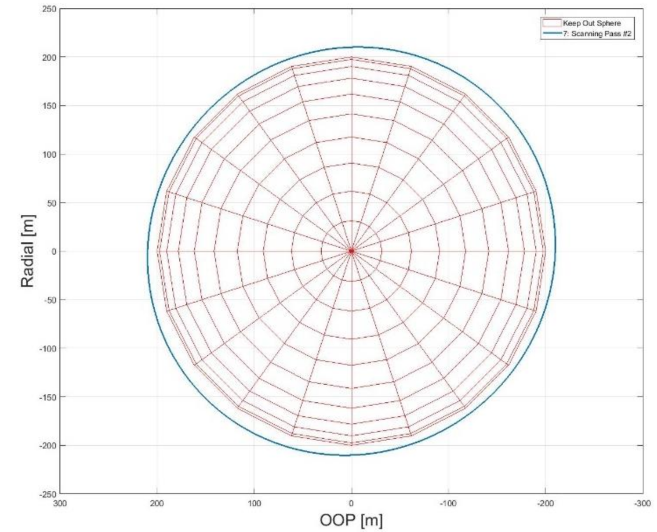
Phase Duration - 5.4 hr
Mission Duration - 24.57 hr
Propellant cons. – 38.7 g
Total propellant cons. – 173.60 g
Delta-V - 1.18 m/s
Total Delta-V - 5.29 m/s



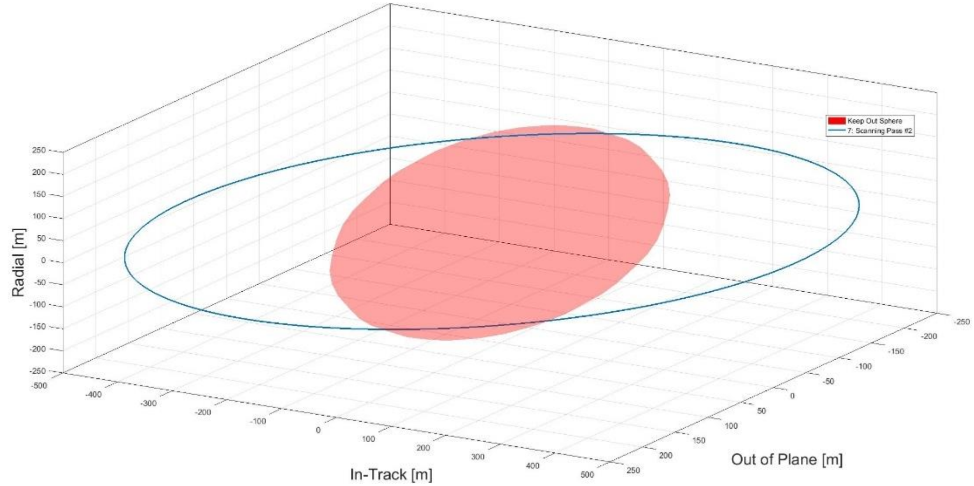
Scanning phase #2 – Orbital and mission properties

It is a V-Bar hold pass around the ISS with the opposite OOP offset as Scanning #1

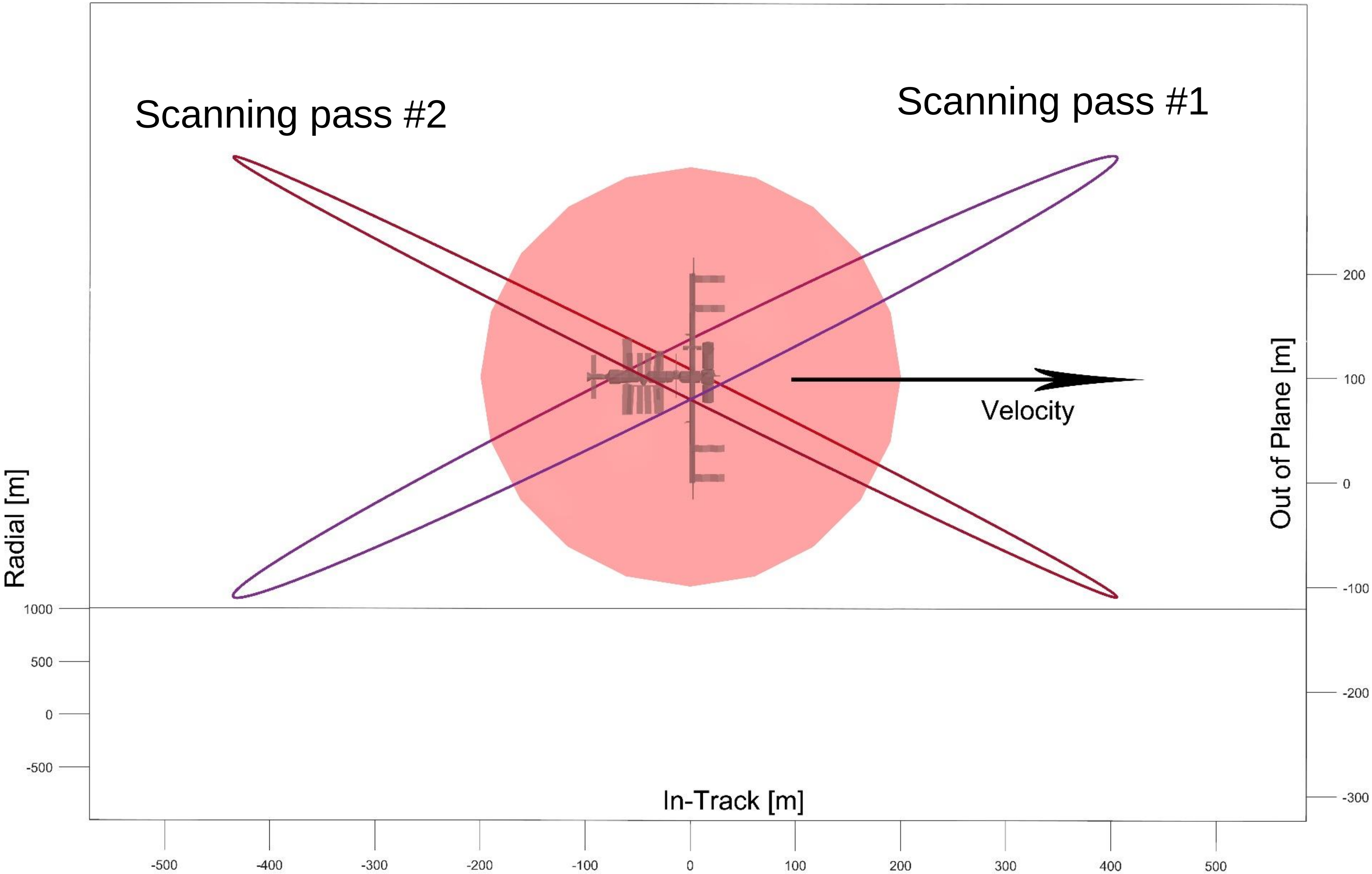




Posigrade orbit
Phase Duration - 6.94 hr
Mission Duration - 31.51 hr
Propellant cons. – 25.50 g
Total propellant cons. - 199.10 g
Delta-V - 0.81 m/s
Total Delta-V - 6.10 m/s

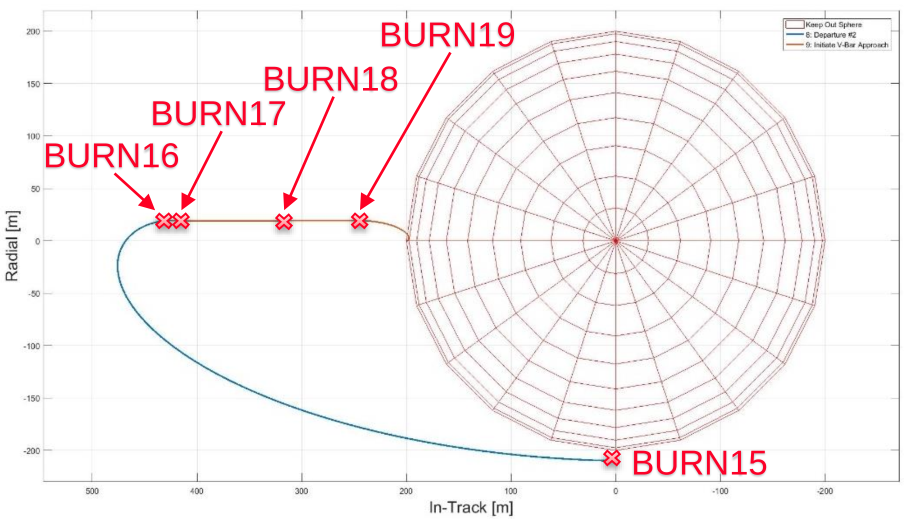


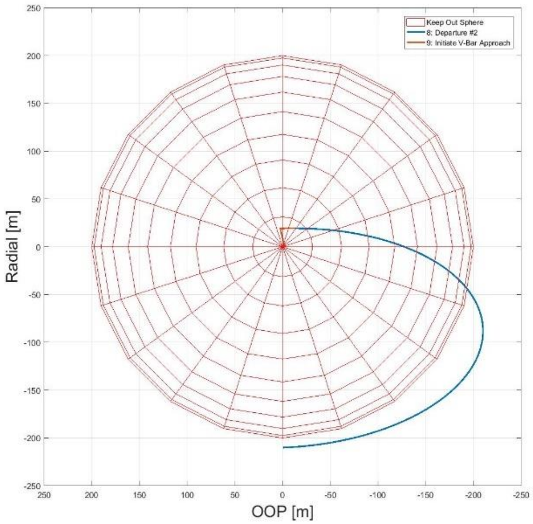
Scanning passes comparison



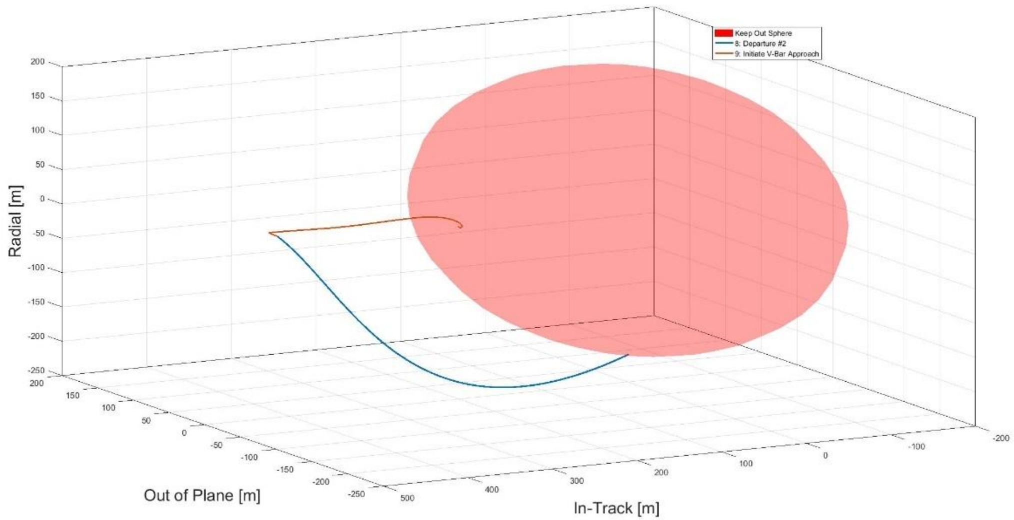
Departure and Approach for RV

A V-Bar Approach for RV ops is obtained. The OOP component is null.



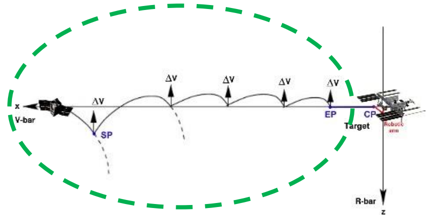


Phase Duration - 3.84 hr
Mission Duration - 35.35 hr
Propellant cons. - 24.70 g
Total propellant cons. - 223.80 g
Delta-V - 0.72 m/s
Total Delta-V - 6.82 m/s

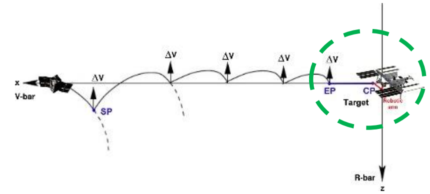


Rendez-vous

- The rendez-vous phase is likely to follow a step-by-step approach, which sequence can be summarised in:
  - Far-Range RV: transfer from operations trajectory to a first aim point in proximity of the target;



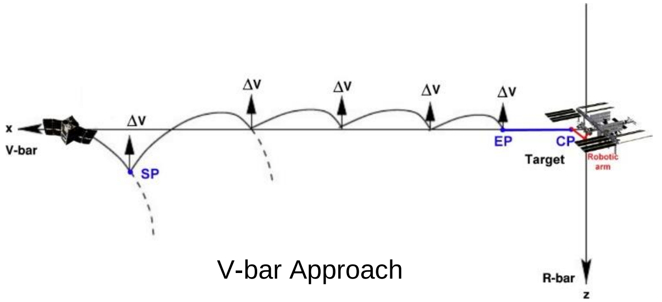
  - Close-Range RV: manoeuver along the approach corridor leading to the capture point.



- Strategies evaluated:
  - +R-bar;
  - +V-bar;
- Major safety characteristics:
  - The incapacity to execute a thrust manoeuvre, whether fully or partially, does not leave the vehicle on a trajectory that eventually leads to a collision. In case of dangerous trajectory situations, however, the spacecraft shall be able to initiate a collision avoidance manoeuvre (CAM).

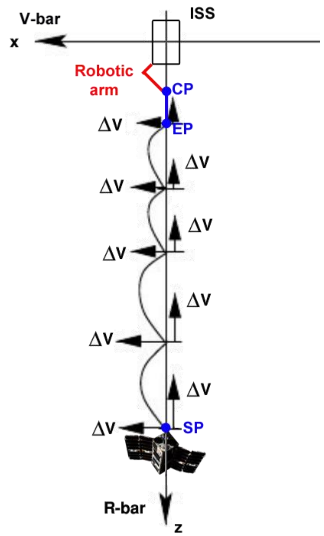
Rendez-vous strategies Trade-Off

- **V-bar approach characteristics:**
  - **Acceptable orbital manoeuvers in terms of navigation and propellant consumption;**
  - **Reduced amount of burns in both number and direction;**
  - **Acceptable illumination conditions during approach.**



V-bar Approach

- **R-bar approach characteristics:**
  - **Demanding navigation operations;**
  - **High number of burns needed during the approach;**
  - **Extremely high propellant usage;**
  - **No-safe free drift trajectories.**

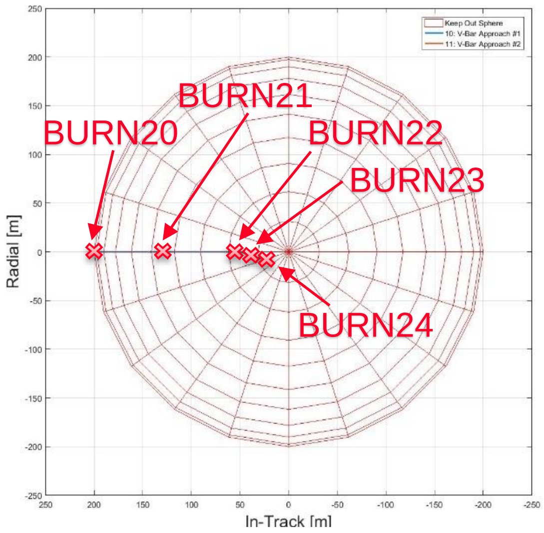


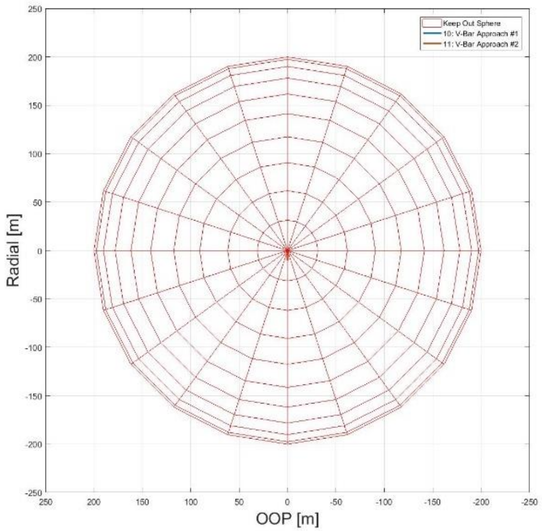
R-bar Approach

- **Conclusion:**
  - **The V-bar approach has been selected as the favourite strategy for the short them mission.**

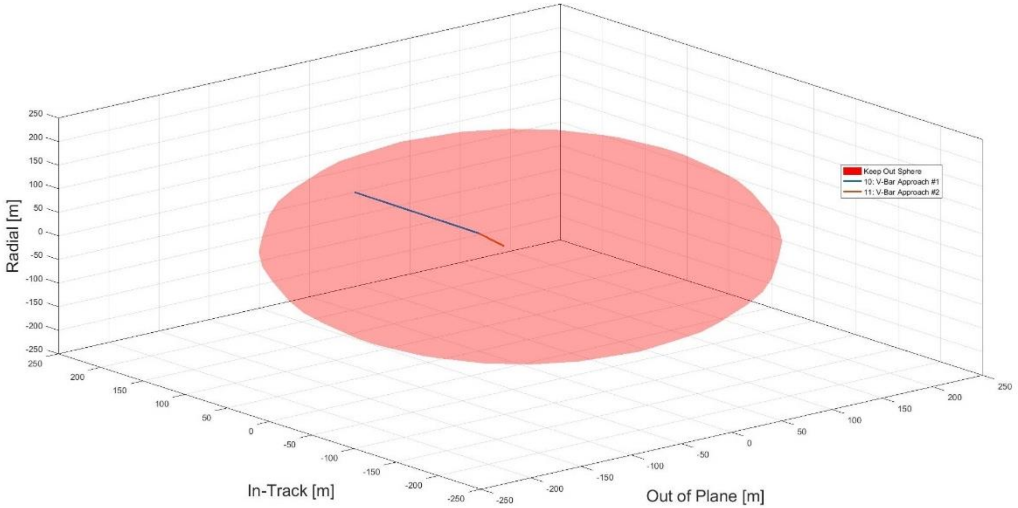
Rendezvous phase

A V-Bar Approach for RV ops is obtained. The OOP component is null.

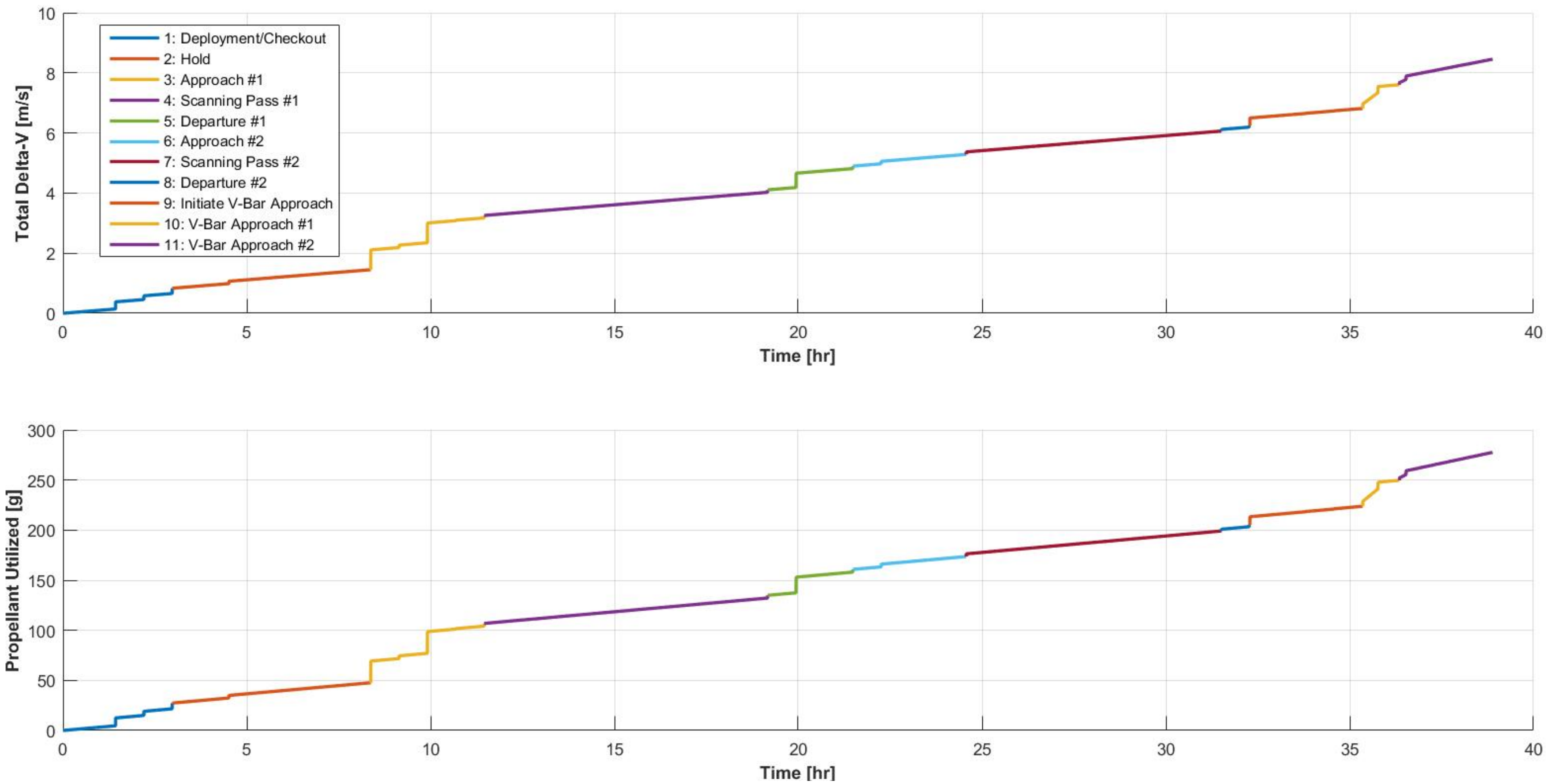




Phase Duration - 3.55 hr
Mission Duration - 38.90 hr
Propellant cons. - 53.9 g
Total propellant cons. – 277.7 g
Delta-V - 1.64 m/s
Total Delta-V - 8.46 m/s



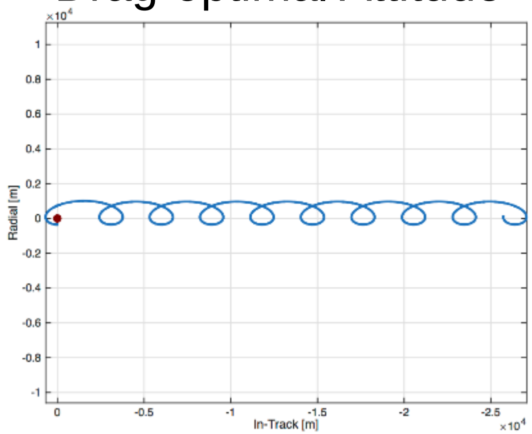
Total Delta-V and propellant budget

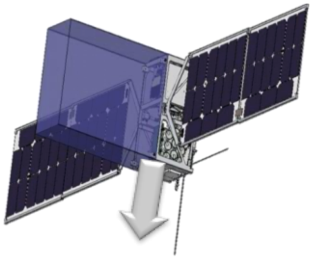


Trajectory Analysis results

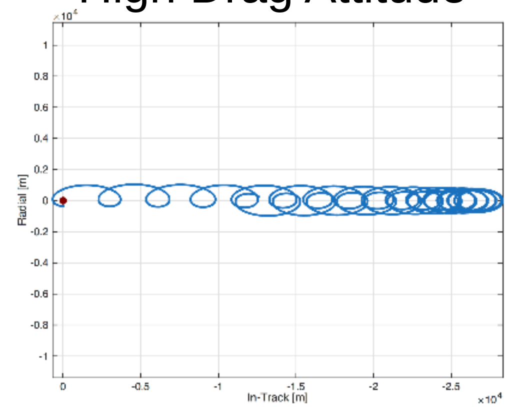
- **Feasibility of the proposed ConOps can be confirmed from the point of view of the trajectory analysis**
  - **Drag is the most important disturbance acting on the S/C**
  - **S/C Configuration and attitude can impact on final delta-v requirements**

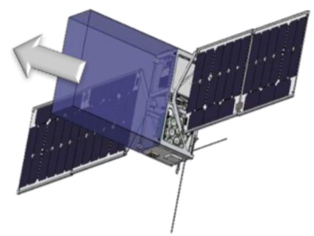
Drag-optimal Attitude





High Drag Attitude





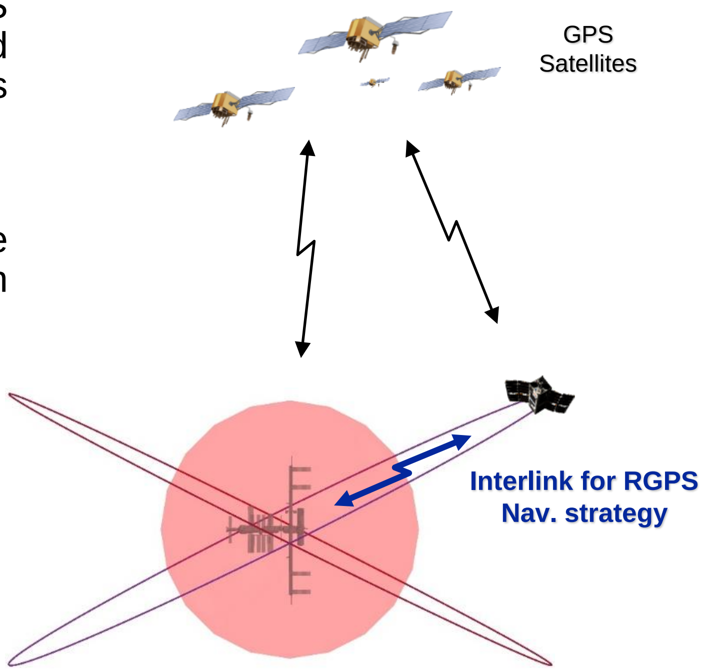
Navigation Strategy for Far-range RV (outside KOS)

Inspection strategy

For inspection missions outside the KOS, the satellite shall maintain a passively safe trajectory around the ISS. The ISS geometry does not affect the orbital path of the satellite and predetermined orbits can be designed. As a result, all trajectories would not intercept the KOS.

Navigation Strategy: RGPS mode

Raw data of both receivers (CubISSat and ISS) and reference time will be processed in the RGPS navigation filter for Δ-position and Δ-change of range between CubISSat and the ISS.



Fly-around navigation approach

Major disturbances:

- Shadowing;
- Multipath effects;

Accuracy

- ± 10m @ > 200m from ISS;

Future iterations:

- Accessibility to the ISS GPS antennas and technical requirements (GPS data frequency availability);
- Inspection orbits shall minimize both shadowing and multi-path effects.

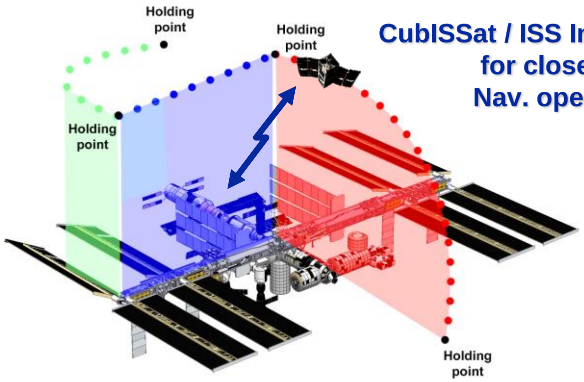
Navigation Strategy for Close-range RV (within KOS)

Inspection strategy

The satellite is supposed to hold pre-determined positions with respect to the ISS attitude, with the possibility to translate to other points and inspect different visual spots. For such inspection operations, ISS geometry has to be taken into account to maintain a safe distance from its external surface.

Navigation Strategy: LIDAR + lighting & retro-reflectors aids

LIDAR/LADAR technology could be baselined for such navigation strategy in combination with lighting and retroreflectors aids placed in various points of the ISS and DS. Moreover, for very close-range operations, VIS and IR cameras with enhanced image recognition algorithms can also be used in case of favourable lighting conditions.



CubISSat / ISS Interlink for close-range Nav. operations

Main limitations:

- High power consumption;
- Complex scan patterns for acquisition and tracking;
- Multiple LIDAR sensors and aids interfaces might be needed;

Accuracy

- ± 1m @ 30m from ISS (LIDAR capabilities)
- few cm @ berthing/capture point (LIDAR + VIS and IR recognition algorithms)

Future iterations:

- Identify retro-reflector and lighting aids visibility and availability on board of ISS (possible customized framework);
- 3D model of the docking frame would be needed whether the VIS and IRInspection orbits shall minimize both shadowing and multi-path effects.

Navigation Strategy for Close-range RV (within KOS)

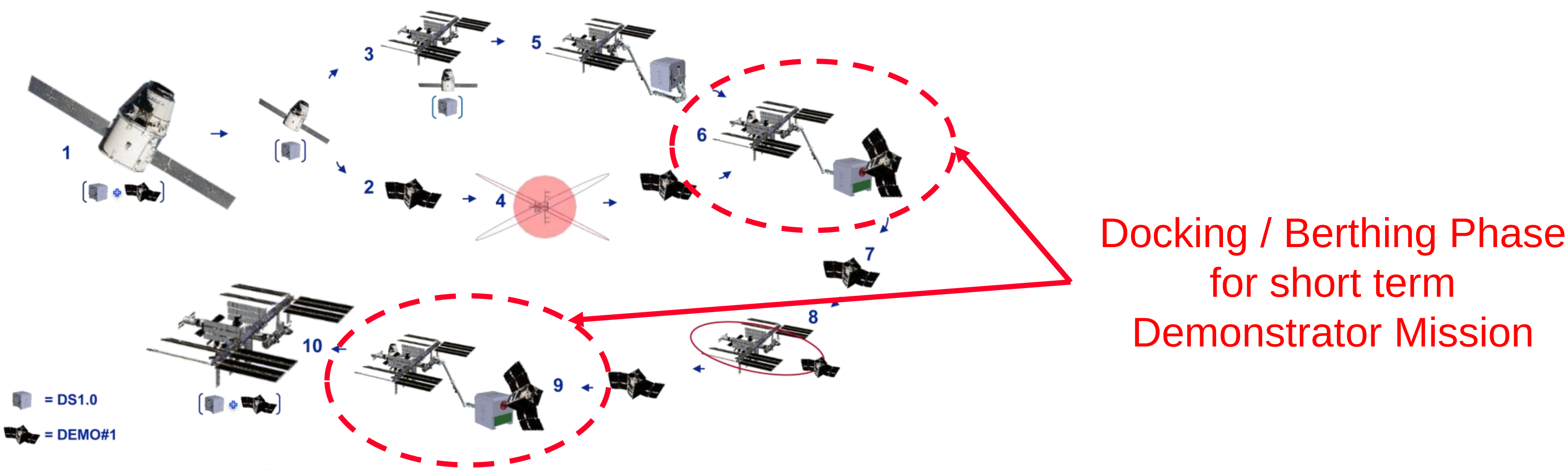
- **For both navigation strategies, fault tolerance requirements and navigation rules should be also addressed for each phase of the s/c mission (far-range/close-range inspection, proximity operations, berthing/docking, etc) according to the safety of the ISS.**

- **The implementation of a dedicated communication system on board of the DS might be used also for navigation purposes when the s/c is in LOS with it. This happens during the final path of the rendez-vous phase, for which a +V-bar approach has been selected as baseline for berthing operations.**

- **As a result of this trade-off, the level of effort declared in the development plan for the rendezvous, proximity operations software and sensors shall be increased and addressed accordingly.**

Docking Phase

- **In view of short term demonstration mission and long term mission, two Docking Stations (DS) will be involved in the study:**
  - **DS1.0 is designed to be part of the demonstrator mission, so it is compatible with robotic arms (both with SS-RMS and JEMRMS) through the installation of a Power and Data Grapple Fixture (PDGF), and KIBO sliding table, via brackets.**
  - **DS2.0 is developed for long term mission scenarios, so as to provide the satellite with refurbishment capabilities (propellant and batteries). It is also provided with a CubeSat deployer system already on-board DS1.0 (and the optional communication system).**

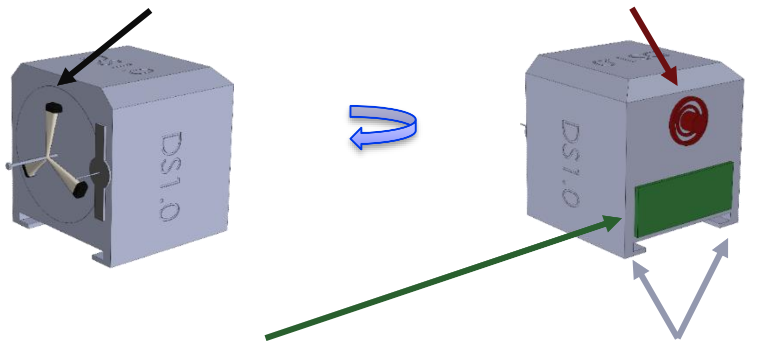


Docking Stations: DS1.0 vs DS2.0

DS1.0

Flight Releasable Grapple Fixture

Docking/Undocking System



CubeSat Deployer

Brackets for KIBO Sliding Plate

Compatible with:

SS-RMS

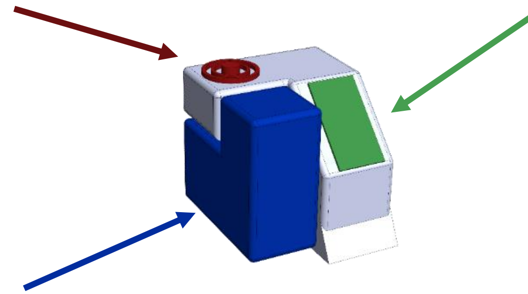
JEM-RMS

KIBO Sliding Table

DS2.0

Docking/Undocking System

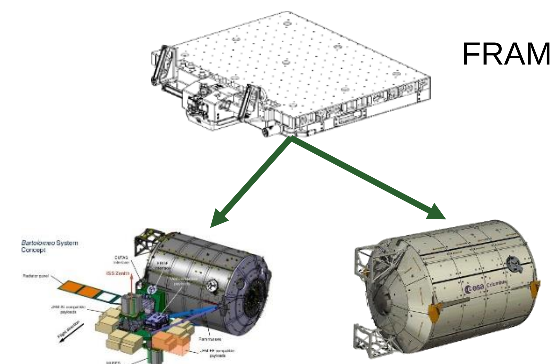
CubeSat Deployer



Replaceable Propellant Tank (by SPDM robotic ops)

Compatible with:

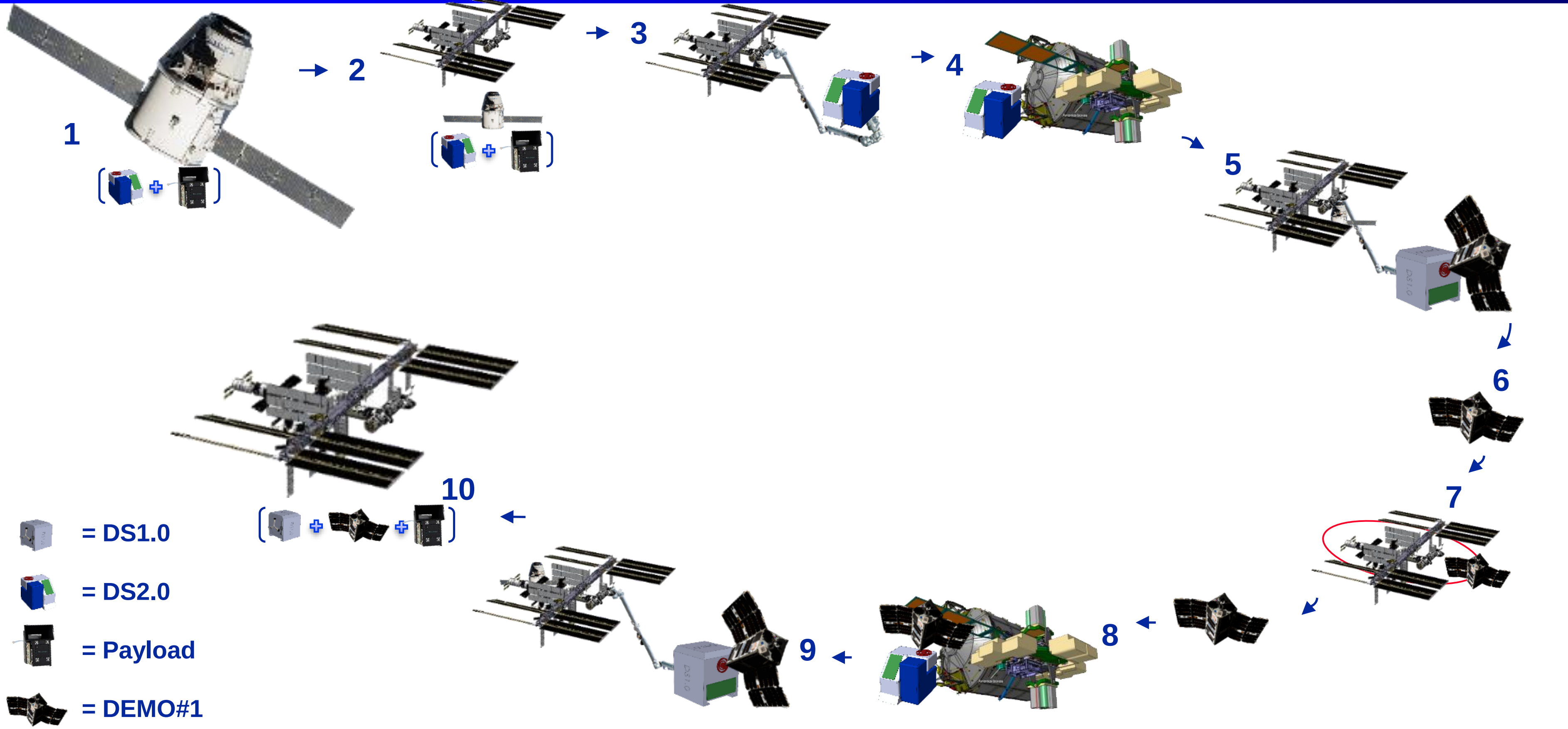
SPDM



Bartolomeo

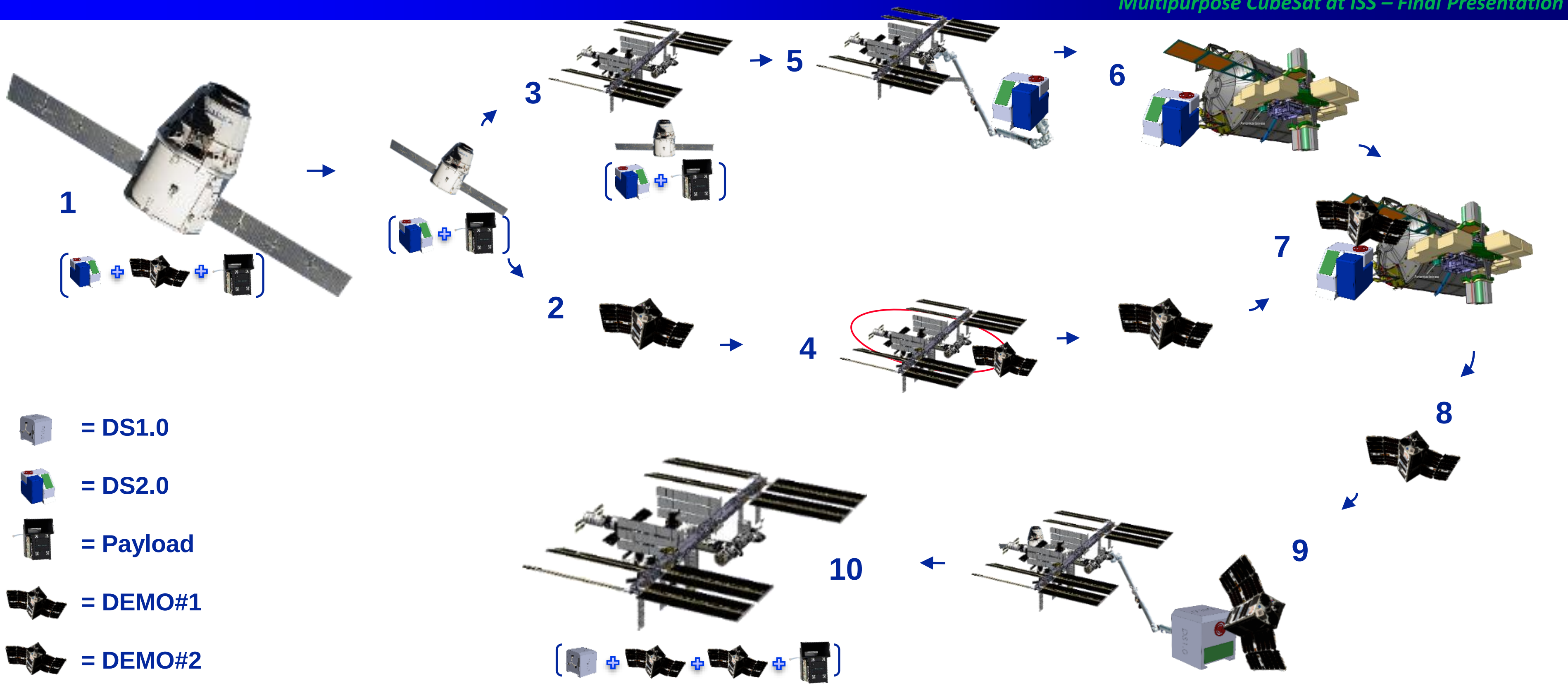
Columbus External Platforms

Future Operational Mission : reusing DEMO#1



1 – DS2.0 and a payload are delivered as cargo to ISS on board a VV.	2 - VV is berthed to ISS.	3 - DS2.0 is grappled by the SS-RMS.	4 – DS2.0 is robotically mounted onto Columbus or Bartolomeo external platforms; payload is moved inside the KIBO where it is swap with an existing payload of the DEMO#1	5 – JEMRMS grapples the DS1.0 with DEMO#1 docked and moves them into release position.
6 – DEMO#1 performs undocking.	7 - DEMO#1 starts its inspection mission #3 towards a specific point (centimeters distance).	8 - DEMO#1 docks with the DS2.0.	9 - As necessary and / or at end of life time, DEMO#1 is returned inside ISS by docking with DS1.0.	10 - DEMO#1, DS1.0 and payload are stowed inside the KIBO module where Crew performs post-mission detailed inspection.

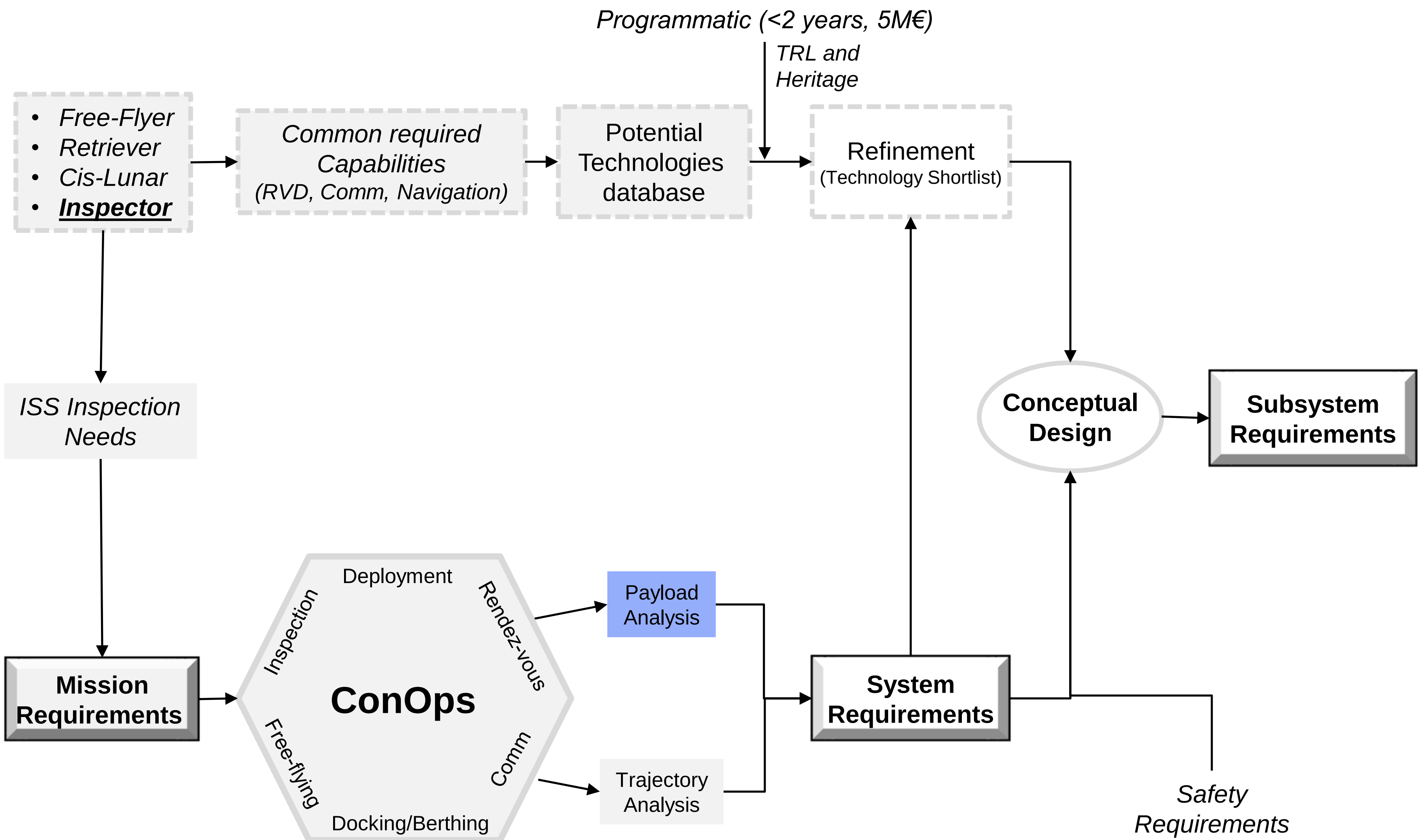
Future Operational Mission : DEMO#2



1 – DS2.0 and DEMO#2 are delivered as cargo to ISS on board a VV.	2 - DEMO#2 is released from DS2.0 while the DS2.0 stays on VV.	3 - VV is berthed to ISS.	4 – With a new payload on board, DEMO#2 performs inspection mission#3 towards a specific point (centimeters distance).	5 – DS2.0 is grappled by the SS-RMS.
6 - DS2.0 is robotically mounted onto Columbus or Bartolomeo external platforms; payload is moved inside the KIBO where it is swap with an existing payload of the DEMO#1 ready to fly.	7 - DEMO#2 docks with the DS2.0.	8 – As necessary and / or at end of payload life time, DEMO#2 leaves the DS2.0 to return inside the ISS.	9 – DEMO#2 docks with DS1.0.	10 - DEMO#1, DEMO#2, DS1.0 and payloads are stowed inside the KIBO module where Crew performs post-mission detailed inspection.

Inspection Payload Analysis

CubISSat Work Logic Diagram



CubISSat demo imaging payload

- **Demonstrator imaging capabilities**
  - Driven by mission requirements (inspection needs at ISS)
    - Fly-around imaging and video of external frame of the station to cover blind-spots (Zvezda, Columbus, Kibo, Integrated Truss)
    - Precise inspection for damage assessment (cracks, MMOD impacts, etc)
  - Current capabilities at ISS
    - 12.7 mm optical resolution from 15 m
    - IR cameras used by crew to assess anomalies (FLIR ThermaCAM S60)
  - Analysis is also influenced by trajectory analysis results
    - capability to perform scanning passes @ 200m with free-drift safe ellipses
  - Target features: size > 1 cm (optical resolution < 2 cm) from 200m
  - IR target resolution < 10 cm from 200m, would complement current assets in the evaluation of structure ageing/change of physical configuration

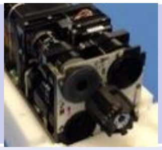
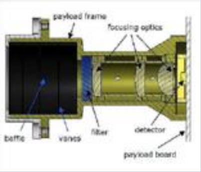
CubISSat demo spacecraft - Payload

Preliminary Payload Requirements

ID	Demonstrator Payload Requirements	Traceability
DM-PL-010	CubISSat demo P/L shall enable inspection of the overall external configuration of the ISS, in particular of : • Zvezda Service module, Columbus Laboratory, Kibo, Integrated Truss Structure	• Inspection needs • MR-020 • Trajectory analysis
DM-PL-020	CubISSat demo P/L shall provide optical visible (VIS) images of external features (e.g. MMOD strikes, sharp edges) with a target spatial resolution 0.6 cm @ 200m.	• Inspection needs • MR-030
DM-PL-025	CubISSat demo P/L shall provide infrared (IR) imagery (Optional) with target resolution <= 10 cm @ 200m.	• Inspection needs • MR-030
DM-PL-030	CubISSat demo P/L shall provide still frames and video imagery	• Inspection needs

CubISSat demo spacecraft - Payload

Payload Technology solutions – Camera Systems

NAME	COMPANY NAME	ORIGIN	TRL	# Mission	HI	TR	PHOTO
RPOD VIS and IR camera Module	Tyvak	EU/USA	7	<2	1	7	
NanoCam C1U	GOMspace	EU	9	<2	1	9	
Telescope: Swiss cube payload	Ecole Polytechnique Fédérale de Lausanne	EU	9	<2	1	9	
C3188A	General Electric Company	USA	9	>=2	1.2	10.8	
OV2655	OmniVision	USA	9	<2	1	9	

Payload technologies – Preliminary comparison

Visible imagers resolution computation

Pixel Sampling Distance

$PSD = \frac{R*s}{FL}$, R= 200m, s=px size, FL= focal length

Optical Resolved Distance

$$ORD = \frac{R * 1.22 * w}{D}$$

$D = \frac{FL}{f/\#}$ (aperture)

Options	f/#	Pixel size (um)	Sensor width (pixels)	Wavelength (um)	PSD (cm)	ORD (cm)
Tyvak VIS imager (70mm)	11	3.75	1280	0.55	1.07	2.1
Tyvak modified VIS imager (150mm)	2.8	1.4	2048	0.55	0.18	0.25
NanoCam C1U (70mm)	2.2	3.75	2048	0.7	1.07	0.53
C3188A (9.6mm)	1.6	7.6	664	0.7	15.9	2.9
OV2655 (15 mm)	1.9	1.75	1600	0.7	2.3	2.2

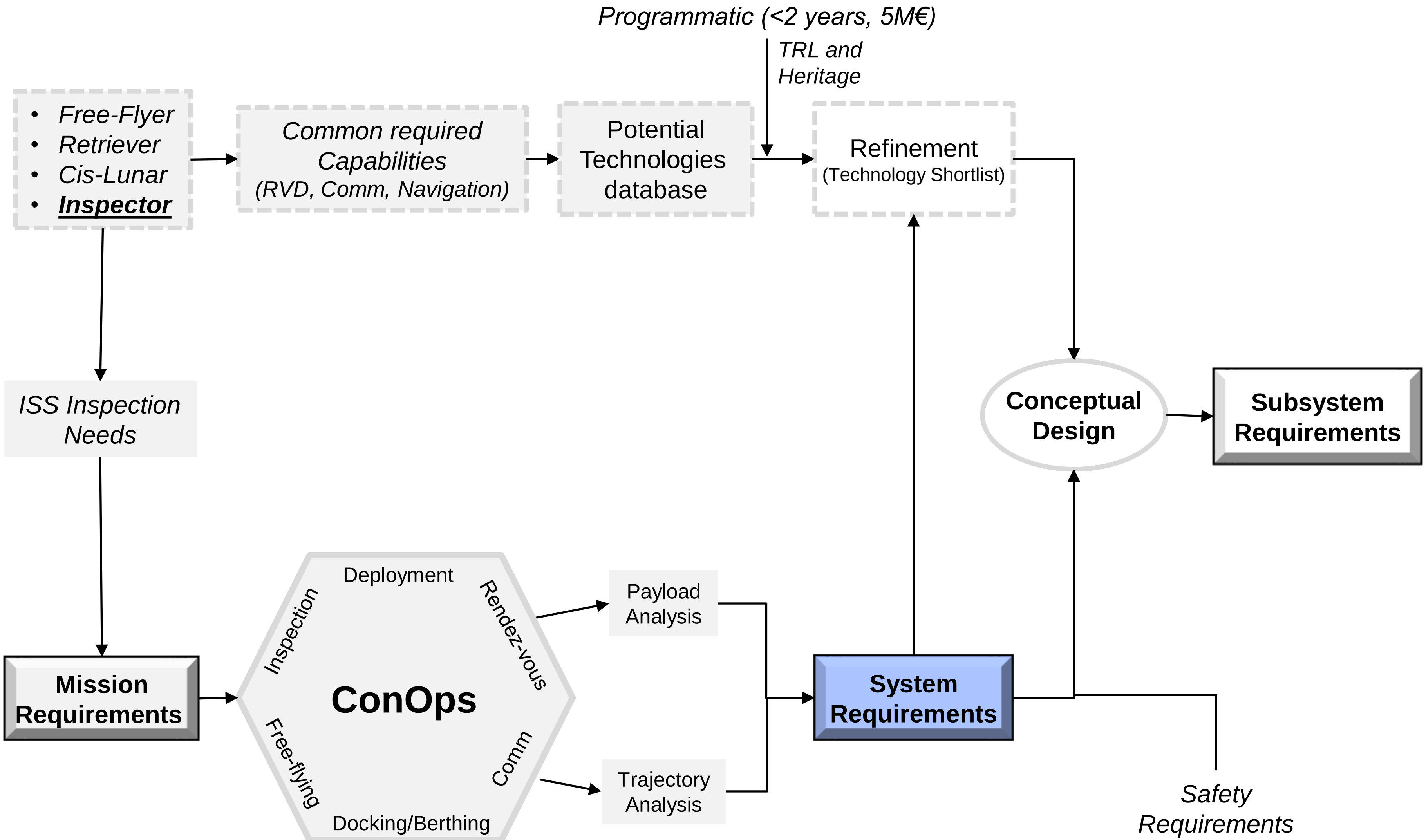
Example of Tyvak integrated solution

- **Tyvak RPOD assembly: 70 mm VIS, 50 mm / 35 mm IR**
  - **Current capability can meet requirements**
  - **Modified solution can achieve sub-cm resolution**

	Tyvak RPOD imagers		Tyvak modified RPOD	
Camera	**VIS**	**IR**	**VIS**	**IR**
Sensor	Aptina MT9M021	FLIR Tau2 640	Aptina MT9T112	FLIR Tau2 640
Lens (FL)	Schneider 70 mm	FLIR 50 mm	Schneider 150 mm	FLIR 100 mm
Pixel Size (s)	3.75 um	17 um	1.4 um	17 um
Sensor Width	1280	640	2048	640
f/#	11	1.2	2.8	1.2
Capture Rate	3 fps	7fps	15-30 fps	15-30 fps
PSD	**1.07 cm**	**8.5 cm**	**0.18 cm**	**3.4 cm**
ORD	**2.1 cm**		**0.25 cm**	

System Definition and Requirements

CubISSat Work Logic Diagram



System Definition

- Preliminary system definition is obtained consolidating the following key elements:
  - Platform form-factor;
  - Deployment strategy and interfaces;
  - Communication approach and systems to be implemented;
  - Mating (docking/berthing) solution;
  - Preliminary Identification of safety-critical functions:
    - Iteration with safety review panel needed;
    - Requirements for redundancy at system/subsystem level;
- Preliminary System Requirements derived:
  - From Mission Requirements, ConOps, trajectory and payload analysis;
  - +Key trades consolidated;
- First technology shortlist:
  - Filtered on the basis of the above elements.

Preliminary System Requirements (Level 1)

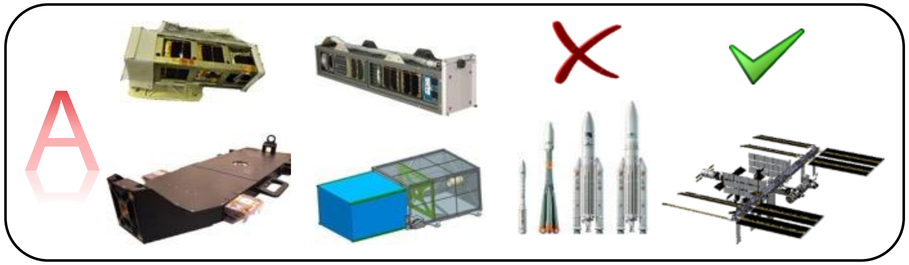
ID	Preliminary Demonstrator System Requirements
DM-SYS-010	The volume of the spacecraft shall be in the range 3-8 litres. 6U form factor is baseline
DM-SYS-020	The s/c mass total shall be compatible with s/c form factor and deployment system. A reference target total mass is 12 kg
DM-SYS-030	The Deployment system shall be compatible with the s/c form factor. Use of available technologies is preferable for the demonstrator mission
DM-SYS-040	A docking station should be integrated together with the deployment system so as to form a single device called DS1.0
DM-SYS-050	The docking mechanism shall provide both berthing/docking and undocking operations
DM-SYS-060	The docking mechanism of DS1.0 system shall be compatible with the s/c docking interface
DM-SYS-070	The DS1.0 volume shall be compatible with dimension of the Airlock module access port
DM-SYS-080	The DS1.0 system shall be mounted onto the sliding table of KIBO module and grappled by the JEM-RMS
DM-SYS-090	The DS1.0 system shall be compatible with the mechanical and electrical characteristics of both the sliding table and JEM-RMS grapple fixture
DM-SYS-100	The s/c + DS1.0 system assembly shall be grappled by the JEM-RMS and installed onto the sliding table of KIBO module and vice versa
DM-SYS-110	The s/c + DS1.0 system assembly volume shall be compatible with dimension of the Airlock module access port
DM-SYS-120	The spacecraft shall provide mechanical support and interfaces to the payload and subsystems
DM-SYS-130	The spacecraft shall provide electrical interfaces to payload and subsystems
DM-SYS-140	The s/c shall protect subsystems and payload from temperature environment
DM-SYS-150	The s/c shall protect subsystems and payload from radiation environment
DM-SYS-160	The s/c shall generate, store and distribute electrical power for continuous operations
DM-SYS-170	The s/c shall provide 3-axis attitude determination and control. Attitude knowledge and pointing accuracy TBD
DM-SYS-180	The s/c shall determine absolute orbit position with < 10m (TBC) accuracy
DM-SYS-190	The s/c shall determine and control relative orbit position wrt ISS (ISS state vector shall be known)
DM-SYS-200	The s/c shall determine and execute collision avoidance manoeuvres
DM-SYS-210	The s/c shall receive, execute and process commands on-board
DM-SYS-220	The s/c shall manage (gather, store, process and transfer) housekeeping and payload (mission) data
DM-SYS-230	The s/c shall provide bi-directional communication with ground for telemetry and commands
DM-SYS-240	The s/c shall provide bi-directional communication with ISS for telemetry and commands
DM-SYS-250	The s/c shall provide communication to TDRSS/EDR constellation (optional/ real-time ops)
DM-SYS-260	The s/c design lifetime shall be > 12 months (TBD) in LEO/ISS orbit (considering possible multiple deployment and retrievals)

Preliminary System Requirements

- **A specific configuration form-factor is not required and many possibilities have been addressed. However, it would be preferable to consider a traditional CubeSat form-factor definition (e.g. 3U, 6U, 12U) in order to evaluate the best configuration with respect to the following aspects:**
  - **Traditional CubeSat form factors can be leveraged in terms of availability of orbital deployers (both qualified and operational at ISS and qualified for LEO). In view of a demonstration mission with budget and schedule constraints, the choice of a standard from-factor (e.g. 3U or 6U) is favourable with respect to a custom configuration (e.g. 8U);**
  - **ISS safety is primary driver of the mission. This aspect will impact on to the s/c design in terms of redundancy of on-board equipment and avionics, among other aspects. This shall be taken into account in volume allocation to different subsystems;**
  - **Sufficient volume for the accommodation of payload(s) and propulsion elements is crucial. The constraint on 3-8 litres volume drive the choice to a 3U or 6U form factor. With the abovementioned assumptions, the choice of a 6U platform as baseline seems favourable, and it will be kept as reference for requirement definition and future design iterations.**

Deployment Strategy

- **Survey of the available deployment technologies for CubeSats**



Name	Heritage	Flexibility	Dev. Time and budget
NRCSD	Deployed 61 CubeSats Suffered anomalies in Sept. 2014, repaired on Feb. 2015	3U max volume per deployer	No qualification required
J-SSOD 3U	> 10 nanosats deployed	6U max volume per deployer (3U+3U linear)	No qualification required
J-SSOD 50cm	1 small satellite was deployed (DIWATA-1)	Customized form factor (55x55x35cm)	No qualification required
SSIKLOPS (Cyclops)	SpinSat satellite	No CubeSat form factor. Dedicated mechanical interface needed	No qualification required
Use of existing deployer onboard VVs	Several Orbital Deployer qualified for Space, with LEO heritage	Several options available (3U, 6U, 12U)	No qualification required
Qualification of existing deployer at ISS	Several Orbital Deployer qualified for Space, with LEO heritage	Several options available (3U, 6U, 12U)	Need qualification for use at ISS
New dedicated deployer at ISS	No heritage	Possibility to tailor the deployer on customized satellite form factor	Adds complexity and cost. Need a precursor mission to reduce risk.

Deployment Strategy – Trade-off

Deployment from ISS	
Advantages	**Drawbacks**
No propulsion is needed to exit the KOS and phase away from ISS.	Dedicated ISS crew operations to prepare the s/c for releasing.
The approach is reliable and was performed several time. So far, it is the only strategy adopted to release small satellites.	Robotic operations and Airlock cycles have to be scheduled in advance.
Depending on the Airlock cycle availability, the deployment of the s/c may be scheduled on demand.	Two Airlock cycles are needed to release and retrieve the s/c.

Deployment from VVs	
Advantages	**Drawbacks**
The s/c doesn't need to be handled for its releasing, resulting in crew time saving and no use of ISS systems (robotic arms, airlock cycles, etc).	The deployer plays no active roles after the s/c releasing, resulting in an additional unusable mass for the rest of the VV mission.
The satellite is stowed inside the deployer which protects the VV in case of s/c main issues occurring after take-off.	This specific approach has never been tried so far.
The s/c is released when the VV is still outside the KOS. This makes the deployment phase safer, resulting in more free-drift trajectory opportunities.	The deployment of the s/c depends on the VV mission schedule.
No propulsion is needed to phase away from ISS.	
More available deployers for various CubeSat form-factors (3U, 6U, 12U). No development time and budget needed for a custom space deployer.	

Communication

- **Why Communication is required:**
  - VVs and ISS navigation data interlink;
  - Commands from ISS to the VVs;
  - Data interlink for the ISS to the VVs for un-crewed VVs.
- **What kind of data the demonstrator should send/receive:**
  - Command and Telemetry (CMD/TLM);
  - Data (imagery data).
- **Communication system available at ISS:**
  - US space-to-space for data and video;
  - Russian space-to-space for data, voice and video (Russian AR&C);
  - Japanese space-to-space for data (HTV AR&C);
  - European space-to-space for data (ATV AR&C).
- **Future implementation:**
  - Common Communications for Visiting Vehicles (C2V2);
  - Express Logistic Carrier (ELC) Wireless system (already available onboard but ready for upgrading);
  - A fully dedicated communication system installed on DS is taken into account. It could represent a solution in case the current available systems do not guarantee sufficient link availability and data rate.

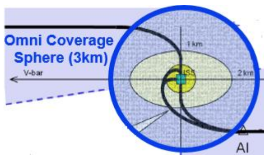
Communication Strategy

- **According to the available systems onboard, and the amount of imagery data to transfer (i.e. a single frame captured with Tyvak modified RPOD, without compression, is approximately 6MB as detailed in TN3), a detailed communications strategy for Far-range and for Proximity operations phases has been developed as follows:**
  - **Far-range phase: for what concerns the CMD/TLM, primary communication link is with ground control network used as data relay for the Ground Control Centre. The band used is UHF. There is a backup solution with ISS, based on UHF / C2V2 (TBC) system. As already said before, link via TDRS is kept as optional, due to the complexity and cost. Imagery data are downlinked via S-Band / X-Band to ground control network, while the backup solution is represented by DS-dedicated system or C2V2.**
  - **Proximity operations phase: it is based on two communication links (i.e. with ground control network using UHF / S-band / X-band, and with ISS using UHF / C2V2 / DS-dedicated / WIFI (TBC)) active at the same time.**

- **Additional assumptions:**
  - **At the moment, Wireless communication link is not discarded, but further documentation is needed to assess feasibility of its adoption.**

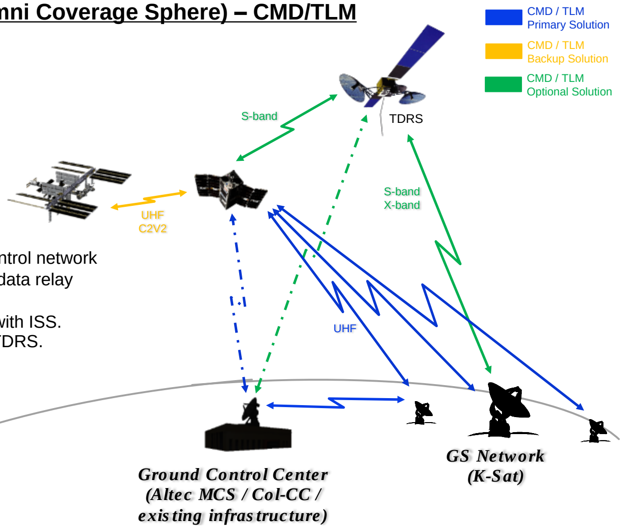
Communication Strategy

Far-range ops (out of Omni Coverage Sphere) – CMD/TLM

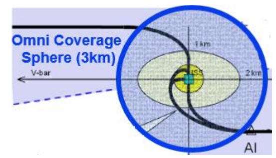


Commands & Telemetry

Primary: UHF link to ground control network (e.g. K-SAT) used as data relay network for the GCC.
Backup: UHF / C2V2 interlink with ISS.
Optional: S-band interlink with TDRS.

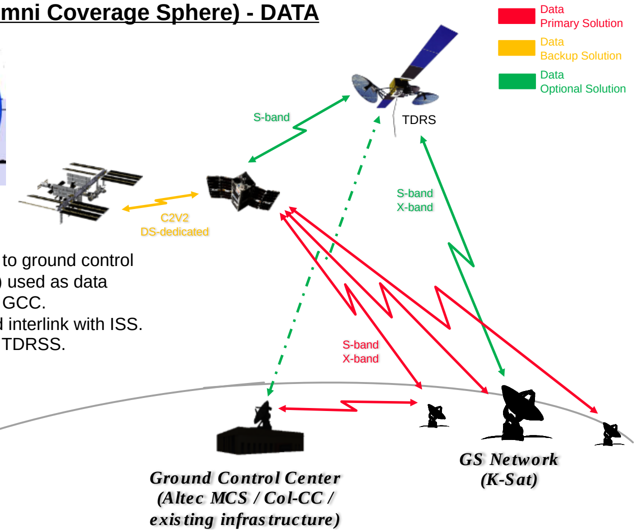


Far-range ops (out of Omni Coverage Sphere) - DATA

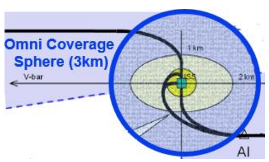


Data

Primary: S-band / X-band link to ground control network (e.g. K-SAT) used as data relay network for the GCC.
Backup: C2V2 / DS-dedicated interlink with ISS.
Optional: S-band interlink with TDRSS.



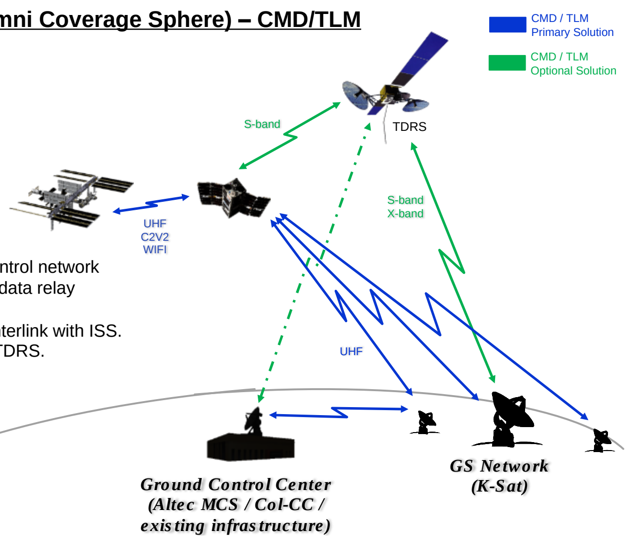
Proximity ops (inside Omni Coverage Sphere) – CMD/TLM



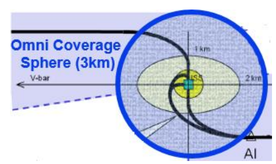
Commands & Telemetry

Primary: UHF link to ground control network (e.g. K-SAT) used as data relay network for the GCC;
UHF / C2V2 / WIFI* interlink with ISS.
Optional: S-band interlink with TDRS.

*to be assessed with more documentation (e.g. 3D coverage pattern)



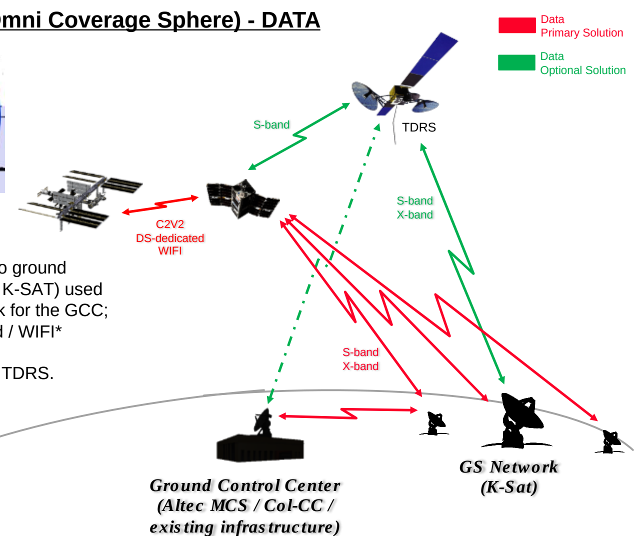
Proximity ops (inside Omni Coverage Sphere) - DATA



Data

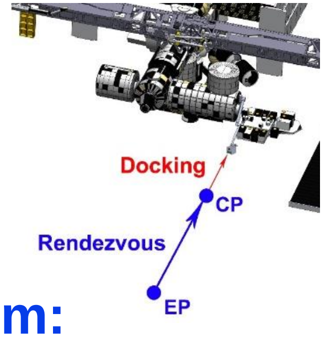
Primary: S-band/X-band link to ground control network (e.g. K-SAT) used as data relay network for the GCC;
C2V2 / DS-dedicated / WIFI* interlink with ISS.
Optional: S-band interlink with TDRS.

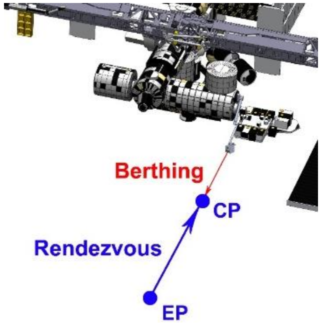
*to be assessed with more documentation (e.g. 3D coverage pattern)



Docking

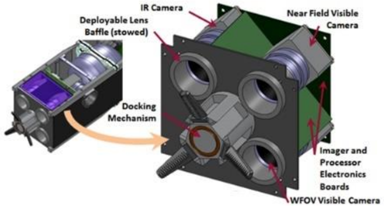
- **Main capabilities to be performed:**
  - To achieve capture – condition of no escape;
  - To achieve rigid structural connection;
  - To establish the connection of data, power and possibly propellant interfaces (scheduled only for a long-term implementation of the multi-purpose platform).
- **Strategies identified:**





EP – Ending Point (Far-Range Rendez-vous phase)
CP – Capturing Point (Retrieving phase)

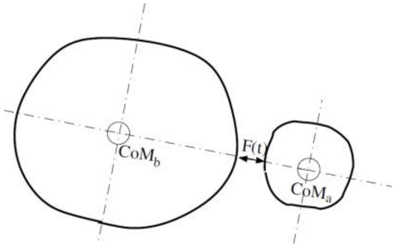
- **Mating mechanism:**
  - A docking station (DS) shall be installed on the JEMRMS. It includes a device similar to the docking mechanism installed on-board the spacecraft that utilizes electro-magnetic forces to dock with the DS, and three finger grippers to firmly lock the vehicle to the DS.



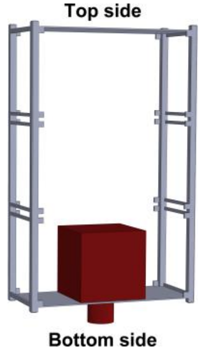
Docking Mechanism

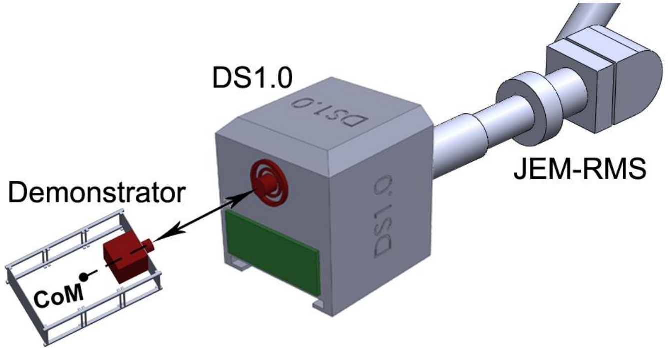
Docking system

- **The baseline design selected for docking operations is the RPOD module.**
  - **Its position w.r.t. the mass distribution of the satellite must be selected in such a way that momentum exchanged at contact with the docking station is prevented or reduced. For this reason, the direction along which the docking occurs should go through the CoMs of both bodies.**



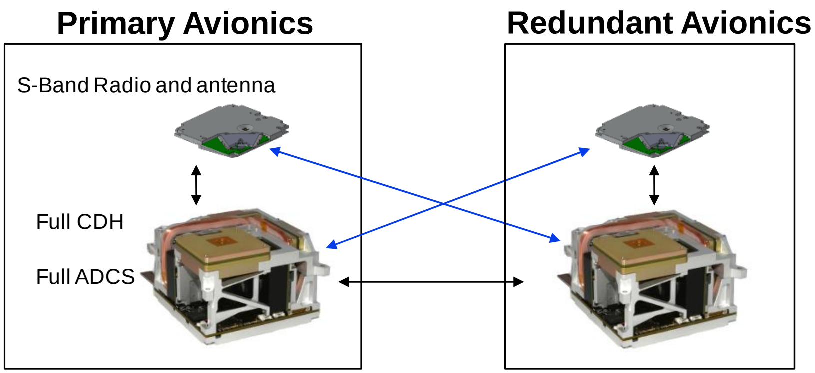
  - **According to the current deployment technologies, the system should be placed on the bottom of the satellite, the only area available for allocating an extra volume.**





Safety critical functions

- **Example: AOCS**
  - **Need: Fault tolerance or Design for minimum risk – Type of hazard: collision with ISS most likely catastrophic hazard (TBC by safety reqs. assessment)**
  - **Safety Critical function: Attitude Determination and Control**
    - **Example of Fault tolerance approach selected: redundancy**



Redundant Communication Systems

- Allow for the vehicle to be commanded in case of failure on Primary Comm
- If primary CDH or ADCS fails, Comm can relay commands to the redundant CDH/ADCS System with full actuator control

Redundant Avionics

- Always in communication with the Primary system.
- Can take over immediately in case of a fault
- Provides back up to attitude sensor and actuator failures
- Provides redundant storage for mission data

    - **Fault Tolerance approach: diversity**
      - **Propulsion system can take over in case of actuator (RWs) failure**
  - **Robust solution combining redundancy and diversity at system level**

System Requirements - Level 1

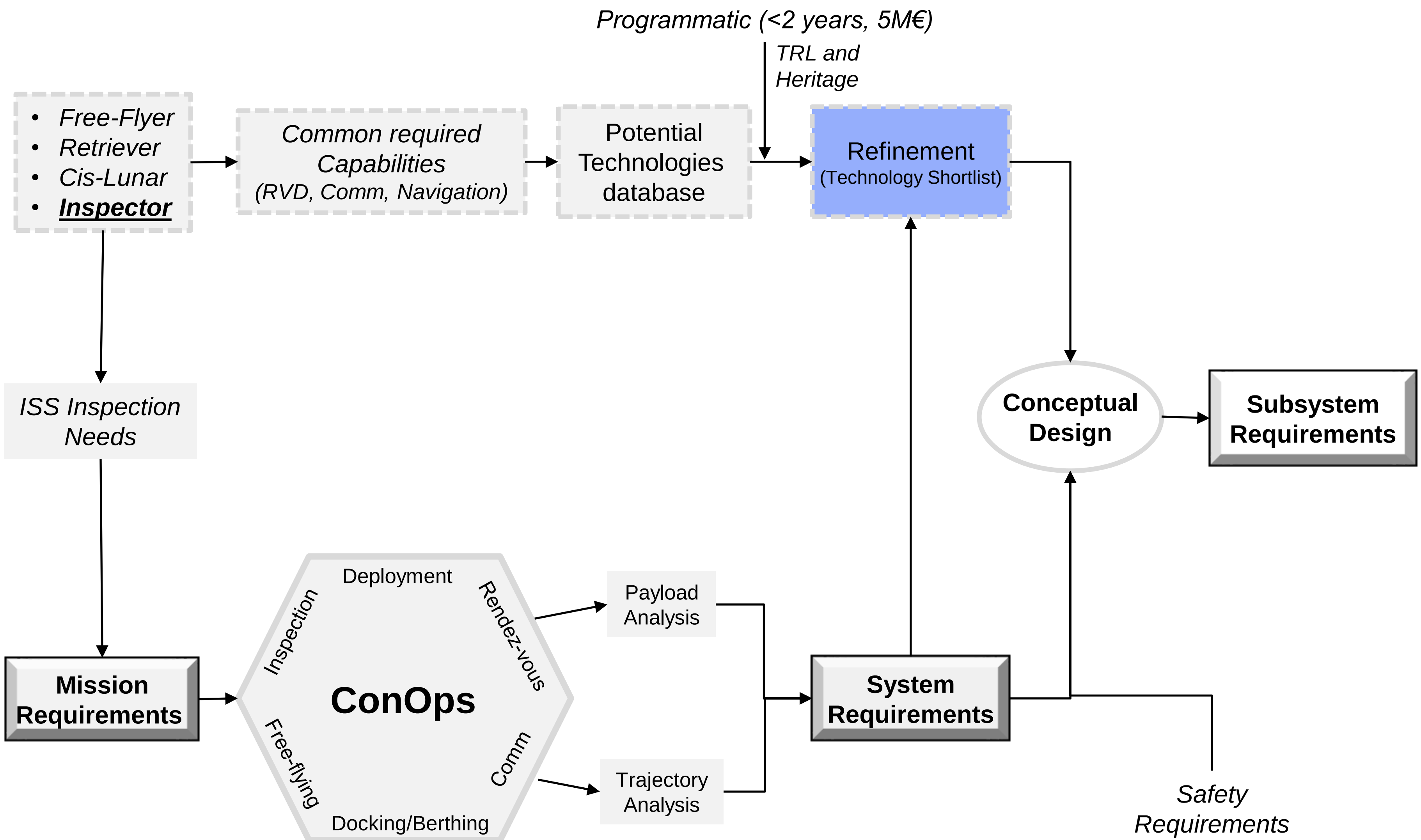
The System Requirement for the Demonstration Mission, are grouped in:

Operational	Functional	Interfaces
Deployment	Power Distribution	Structural
Navigation	AOCS	Mechanical / Docking
Rendez-vous and Berthing	DATA Handling	Electrical
Inspection	Life time	Communication
Retrieval inside ISS		Control

Resources	Environmental	Safety
Physical Properties	Load	Mission
Power Consumption	Thermal	Design
Data Rate	Pressure	Functions
Propellant Refilling	Outgassing	Operations

Technology short-list

CubISSat Work Logic Diagram



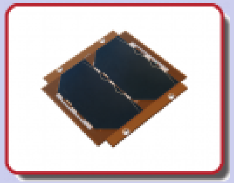
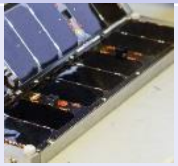
Structures

- **Multiple Technology options on the market**
  - There is no envisaged need of technology development because the current available structures are fully developed and qualified for LEO operations and major launch vehicles
  - Examples of available 6U technologies shown

NAME	COMPANY NAME	ORIGIN	TRL	# Mission	HI	TR	PHOTO
Intrepid 6U	Tyvak	USA/EU	7*	0*	1	7	
6-Unit CubeSat Structure	ISIS	EU	7	0	1	7	

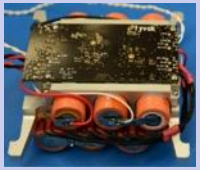
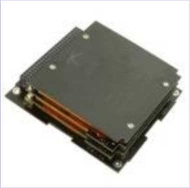
Power Solutions: solar panels

- **Several high TRL Technology options**
  - **Design will be customized to specific needs of the demo mission but several options available (including EU solar cells suppliers and integrators)**

NAME	COMPANY NAME	ORIGIN	TRL	# Mission	HI	TR	PHOTO
NanoPower Solar P110-A/B	Gomspace	EU	9	<2	1	9	
2U Double-Deployed Solar Panels	Clyde Space	EU	9	<2	1	9	
Multifunctional Fixed-Body & Deployable Side Panels	TYVAK	USA/EU	9	>=5	1.5	13.5	

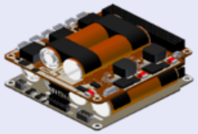
Power Solutions: batteries

- **Several technology options available off-the shelf and with high TRL**
  - **TRL > 9 shown hereafter**

NAME	COMPANY NAME	ORIGIN	TRL	# Mission	HI	TR	PHOTO
Integrated Battery Pack	TYVAK	USA/EU	9	>5	1.5	13.5	
NanoPower BPX	Gomspace	EU	9	n/a	n/a	9	
CubeSat battery	Clyde Space	EU	9	n/a	n/a	9	

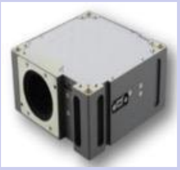
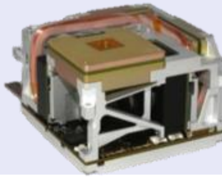
Power Solutions: PCDU

- **Technology options available off-the shelf**
  - **Tyvak Endeavor solution integrates PCDU and OBDH functions**

NAME	COMPANY NAME	ORIGIN	TRL	# Mission	HI	TR	PHOTO
ENDEAVOR (Cortex-A8 C&DH)	Tyvak	USA/EU	9	>=5	1.5	13.5	
NanoPower P31US Power Supply	Gomspace	EU	9	>=2	1.2	10.8	
3rd Generation 3U EPS	Clyde Space	EU	9	>=5	1.5	13.5	
CORTEX 130 Electrical Power Card	Andrews Space	USA	9	>=2	1.2	10.8	

Attitude and Orbit Control

- **Technology options**
  - **ADCS Integrated Solutions shown. No need of new development is envisaged**

NAME	COMPANY NAME	ORIGIN	TRL VALUE	# Mission	HI value	TR	PHOTO
MAI-100 ADACS	MARYLAND AEROSPACE	USA	9	<2	1	9	
Cube ADCS	Cube Space	EU	8	<2	1	8	
XACT	Blue Canyon Technologies	USA	9	<2	1	9	
Inertial Reference Module (IRM)	TYVAK	EU	9	>=5	1.5	13.5	

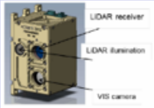
Attitude and Orbit Control : GNSS receiver

- **Reliable Technology options available off the shelf**
  - **No specific development is needed**

NAME	COMPANY NAME	ORIGIN	TRL	# Mission	HI	TR	PHOTO
SGR-05U - Space GPS Receiver	SURREY SATELLITE TECH	EU	9	>=2	1.2	10.8	
SGR-05P-Space GPS Receiver	SURREY SATELLITE TECH	EU	9	>=2	1.2	10.8	
OEM615™ Dual-Frequency GNSS Receiver	NOVATEL	EU (Canada)	9	>=5	1.5	13.5	

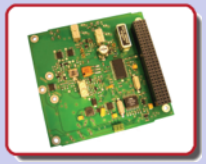
Attitude and Orbit Control: relative navigation

- **Technology options**
  - **Tyvak RPOD integrated system developed for NASA CPOD: based on ISL ranging and VIS+IR cameras with image recognition algorithms;**
  - **Cosine HyperScout for hyperspectral imaging: high optical quality in the NIR range, reduced amount of data to be downloaded and processed;**
  - **No detailed information on the JENOPTIK and CSEM technologies available so far.**

NAME	COMPANY NAME	ORIGIN	TRL	# Mission	HI	TR	PHOTO
RPOD VIS and IR camera Module	Tyvak	USA/EU	7*	<2	1	7	
DLEM SR military laser rangefinder module	JENOPTIK	EU	8	<2	1	8	
Flash LiDAR	CSEM/FBK	EU	8	<2	1	8	
HyperScout	Cosine	EU	7*	<2	1	7	

Telecommunications

- **High TRL Technology options shown**

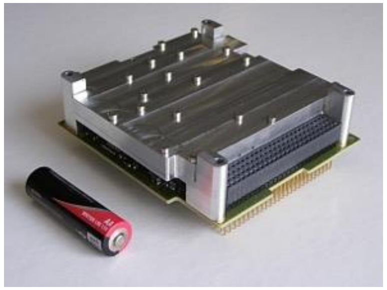
NAME	COMPANY NAME	ORIGIN	TRL	# Mission	HI	TR	PHOTO
S-BAND Transceiver	TYVAK	USA/EU	9	>=5	1.5	13.5	
UHF Transceiver	TYVAK	USA/EU	9	>=5	1.5	13.5	
ISIS VHF downlink / UHF uplink Full Duplex Transceiver	ISIS	EU	9	>=2	1.2	10.8	
NanoCom AX100	GomSpace	EU	9	>=5	1.5	13.5	

Telecommunications

- **X-band not currently available at ISS but it is for TDRSS. Options exist in the market for future implementation / direct Tx to ground**
  - **Tyvak solution is a transceiver module flying in 2017 (TRL7). Specs in table below**

Specification	Value
Modulation scheme	GMSK
Symbol rates	100 kS/s to 2 MS/s
RF power	0 dBm to 30 dBm
DC power	<10 W average < 14 W peak
Tuning Range	8025 MHz to 8200 MHz
Dimensions	8 x 4 x 1 (cm)

  - **Syrlinks solution EWC27 X (8GHz) - flown on GomX-3**



Data Handling

- **Multiple Technology options available on the market with high TRL**
  - **no technology development envisaged at this stage**
  - **Tyvak Endeavor solution integrates PCDU and OBDH functions**

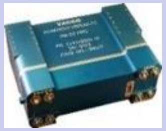
NAME	COMPANY NAME	ORIGIN	TRL	# Mission	HI	TR	PHOTO
NanoMind A712D	GomSpace	EU	9	>=2	1.2	10.8	
CubeSat Kit Motherboard (MB) REV C	Pumpkin	USA	9	>=5	1.5	13.5	
ENDEAVOR (Cortex-A8 C&DH)	Tyvak	USA/EU	9	>=5	1.5	13.5	

Propulsion (initial trade)

Type	Technologies	Most promising solutions	Advantages	Disadvantages
Cold/warm gas	7 identified > 50% TRL 7 or higher	Vacco Ind. (USA) multiple options ETIAS NanoPS SF6 cold gas (CanX2 flight) NanoSpace (EU) HPGP (Prisma satellite mission 2010)	Simple, reliable technology. Good heritage. “Green” propellant available (e.g. R134a, GN2) Small, precise thrust, high specific impulse and efficient use of the propellant. Thrust range 0.05 – 200 N	Most off-the-shelf solutions in the US but Ongoing development in EU
Monopropellant	5 identified (aerojet still in development)	Busek’s BGT-X5 NanoAvionics SSPT	Simple, reliable technology On-going developments for 6U in EU	Mostly Hydrazine-based (safety critical, toxic, not allowed on multiple launchers)
Bipropellant	1 technology TRL 6	Tethers Unlimited HYDROS	“green” propellant (H2O)	More complicated system, TRL 6
Electrostatic (Ion / Ionic Liquid / Hall Effect)	9 technologies 2x TRL 9 (Busek BHT-200 and BET 1mN)	Busek Co. Inc. leader with high-TRL solutions Accion Systems	Several options with TRL > 8 Some developments in Europe (Fotec)	Very High power (5 to 200W peak) low thrust All COTS US-based
Electromagnetic (PPT)	2 technologies 1x TRL 9	Busek BmP-220 (TRL9) MarSpace PPT (TRL7)	Mars Sapce System (EU) qualified for within ESA program	High power, low thrust

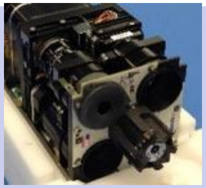
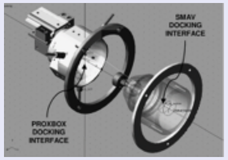
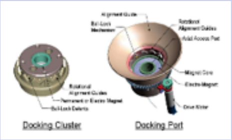
Propulsion

- **Cold-gas technology options available with TRL 7**
  - **Vacco CPOD MPS will fly in Q4 2016 and 2017**

NAME	COMPANY NAME	ORIGIN	TRL	# Mission	HI	TR	PHOTO
Nanosatellite Micropropulsion System	MicroSpace s.r.l	EU	7	<2	1	7	
ADN Micro Propulsion System	VACCO ind	USA	7	<2	1	7	
CPOD Micro Propulsion System	VACCO ind	USA	7	<2	1	7	
MEMS Thruster Module	NANOSPACE	EU	8	<2	1	8	
JPL MarCO Micro CubeSat Propulsion System	VACCO ind	USA	7	<2	1	7	
NanoPS	UTIAS/SEL	EU (CND)	8	<2	1,2	9.6	

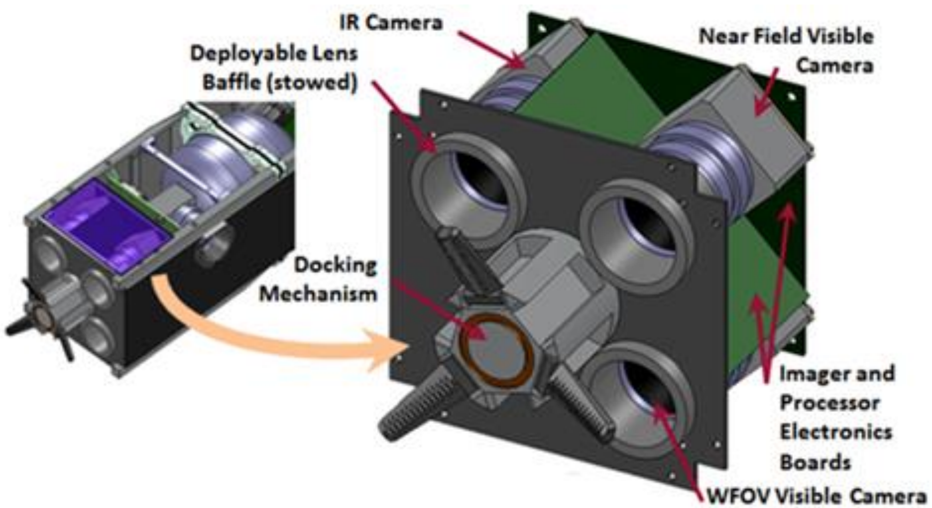
Docking Systems

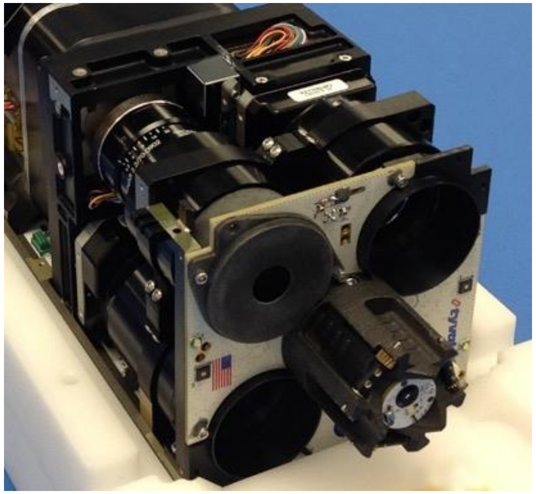
- **Technology options**
  - **Tyvak RPOD docking system unique development in the market. First flight Q4 2016. Docking demo in 2017, providing a “first” in this class of nanosatellite subsystems.**
  - **Full technology development not necessary, however a careful adaptation to ISS requirements has to be performed. The same on-board docking mechanism can be used on the MPEP platform.**

NAME	COMPANY NAME	ORIGIN	TRL	# Mission	HI	TR	PHOTO
RPOD Module	TYVAK	EU/USA	7*	<2	1	7	
ARCADE docking mechanism	Università di Padova	EU	5	<2	1	5	
NASA Magnetic Capture Docking System	NASA	USA	5	<2	1	5	

Docking System: RPOD module description

- **The RPOD module developed for NASA CPOD houses:**
  - **four imagers (narrow field of view visible, wide field of view docking visible, wide field of view IR, and narrow field of view IR)**
  - **fiducial LEDS**
  - **the docking mechanism**
  - **electronics for image processing**
- **The docking mechanism utilizes miniature motors to actuate a three finger latch on each vehicle for the final mechanical mating**





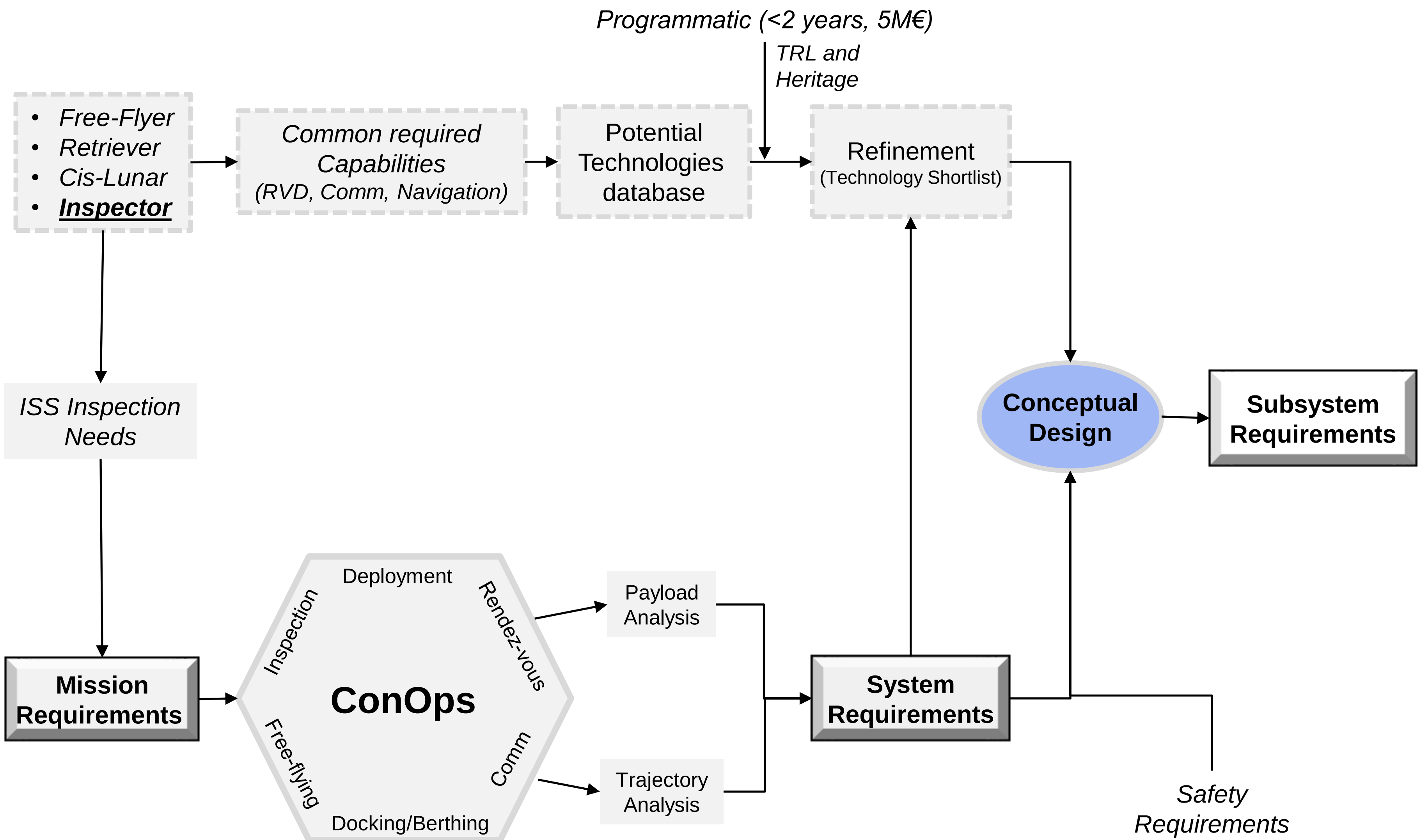
Deployment systems

- **6U Technology options available on the market**

NAME	COMPANY NAME	ORIGIN	TRL	# Mission	HI	TR	PHOTO
Tyvak Nanosatellite Launch Adapter System	Tyvak	EU\USA	9	>=5	1.5	13.5	
Canisterized Satellite Dispenser (CSD) (6U)	Planetary Systems Corporation	USA	9	>=2	1.2	10.8	
6-POD CubeSat Deployer	ISIS	EU	7	<2	1	7	

Conceptual Design

CubISSat Work Logic Diagram



Interface Requirements Definition

The spacecraft is defined as a Multipurpose Cubesat capable of accommodating specific ISS experiment payloads and operating them in the open space enviroment while flying around the ISS framework.

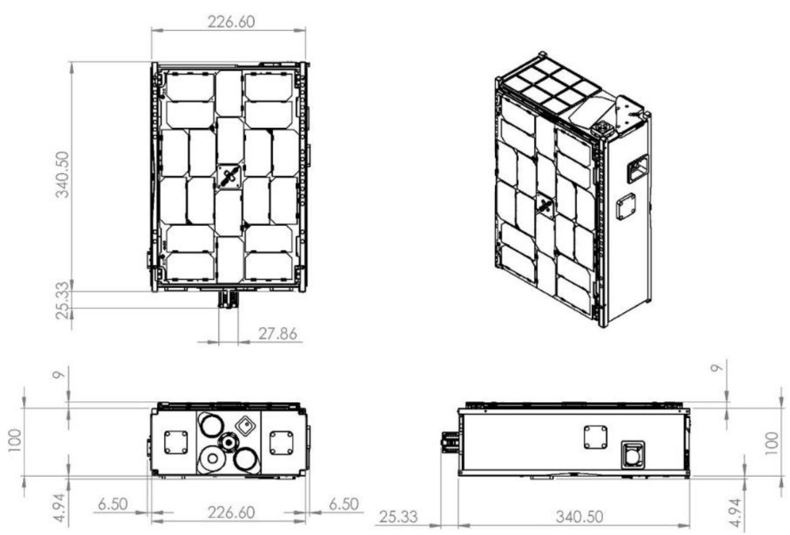
Objective of the Interface Document Definition (IDD)

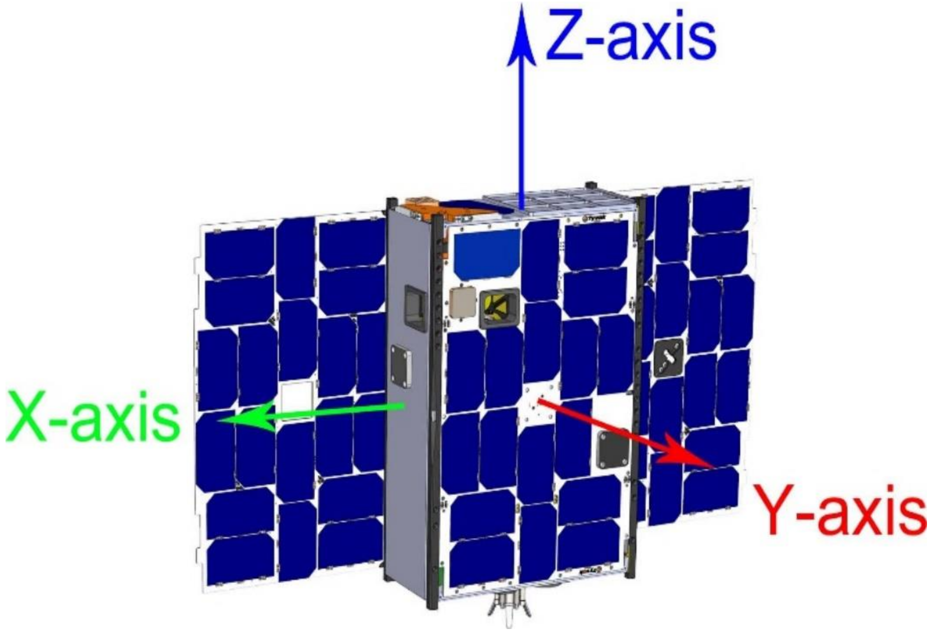
To define physical, functional and enviromental design requirements associated with payload safety and interface compatibility with the Multipurpose CubeSat.

Spacecraft Physical Descriptions

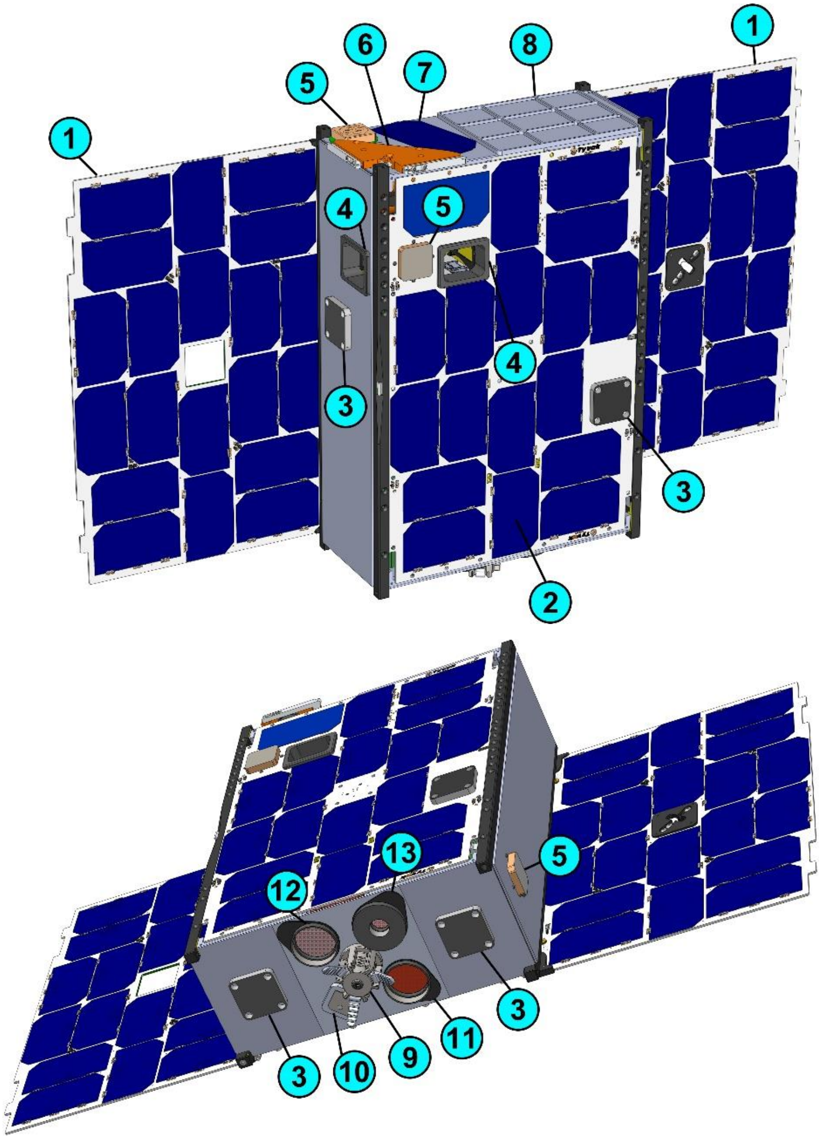
- **General dimensions**
  - **6U pico satellite**
    - **Maximum mass=12 kg**
    - **Compact configuration dimensions:**
      - **X= 226.60 mm**
      - **Y= 100 mm**
      - **Z= 340.50 mm**

- **CoG located within determined distance from the geometric centre:**
  - **4.5cm, along X**
  - **2cm, along Y**
  - **7cm, along Z**



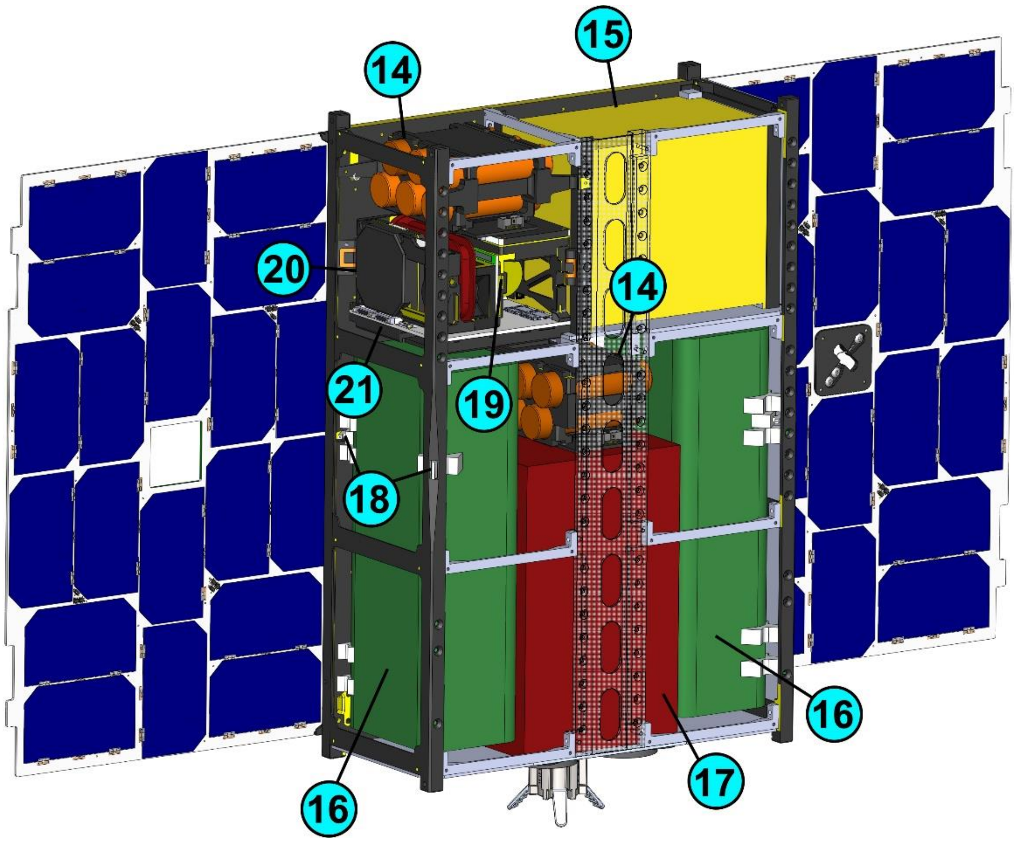


Spacecraft System Descriptions



1. Deployable / Retractable Solar Panels
2. Body Mounted Solar Panel
3. S-Band Patch
4. Star Tracker Aperture
5. GPS Patch
6. UHF Antenna System
7. Sun Sensor
8. Payload Lid
9. Docking Mechanism
10. ISL Patch Antenna
11. 35mm IR Camera
12. 50mm IR Camera
13. 70/120mm Visual Camera

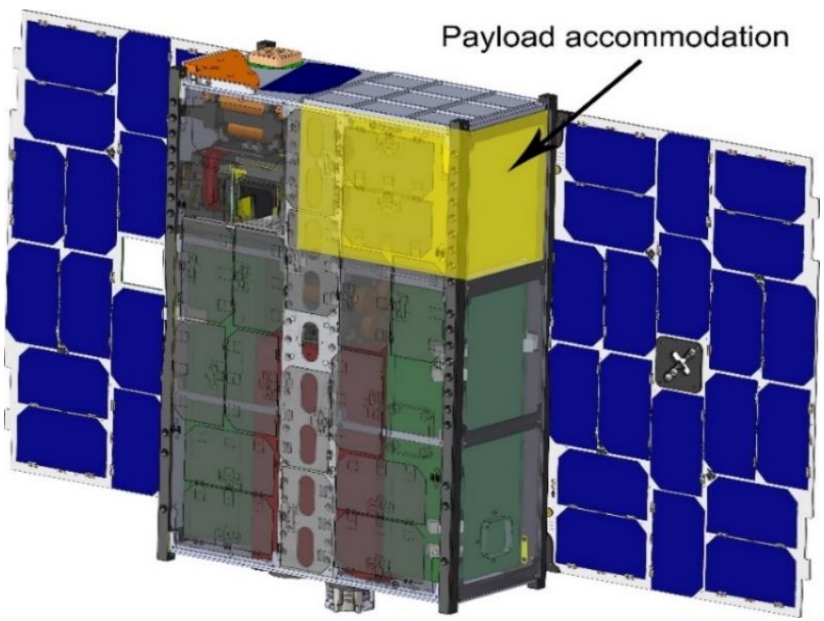
Spacecraft Internal Subsystem Distribution

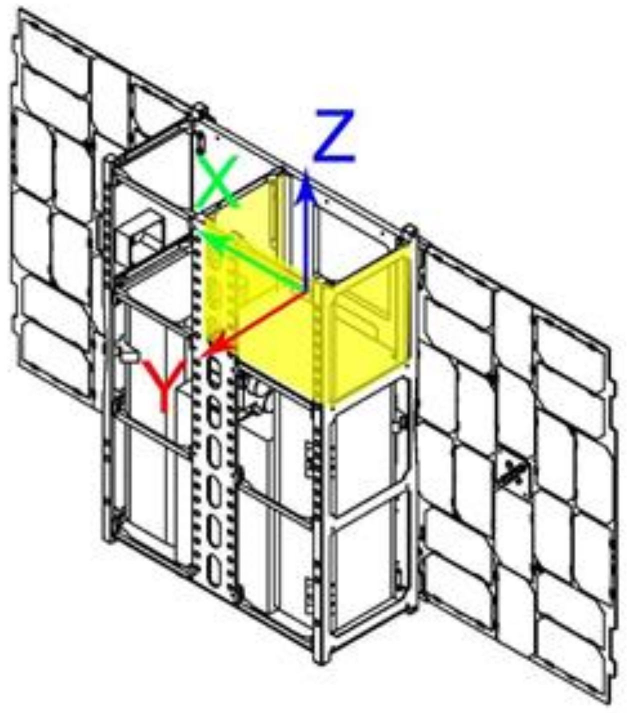


- (14) Battery Module
- (15) Payload Envelope
- (16) Propulsion Module
- (17) Enhanced RPOD Module
- (18) Cold Gas Thrusters (8)
- (19) ADCS Module
- (20) Inertial Reference Module (IRM)
- (21) GPS Receiver / S-Band Transmitter

Payload Accommodation

A slot dedicated to payloads accommodation is available in one of the corner of the structure in order to ensusre the hosting of a wide variety of different payloads

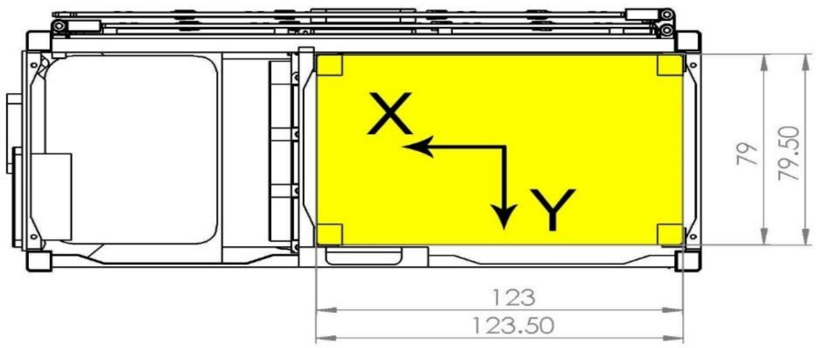


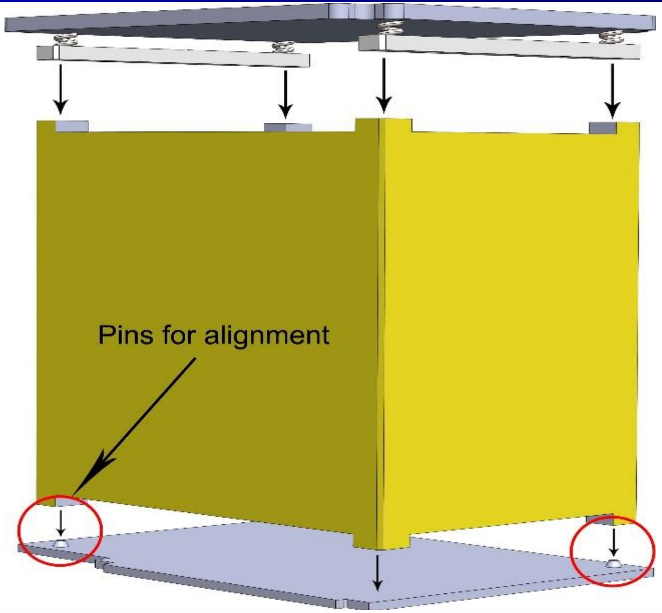


Payload Accommodation

Payload Vertical sliding on four lateral rails

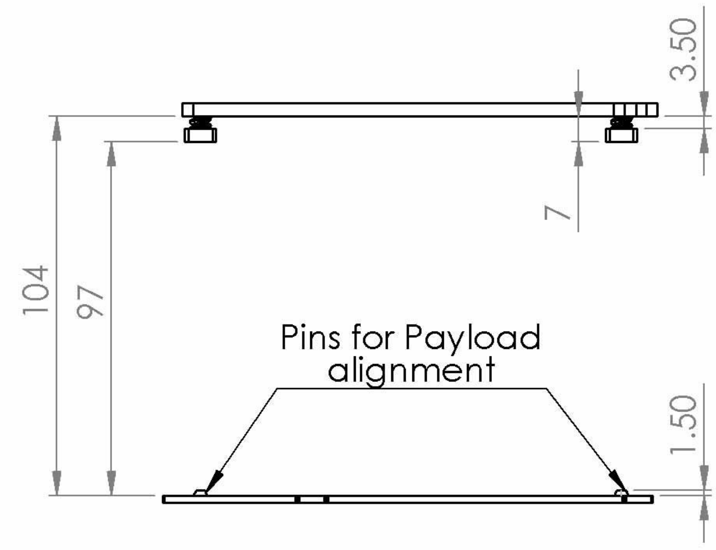
- Clearance 0.25mm between payload and rails





- Limitation of Payload displacements due to the presence of the clearance
  - 2 pins for alignment on the bottom plate

- Prevention of vibrations occurring during the launch phase
  - Damping system on the closing plate



Potential Payloads for Multi-purpose applications

Payload	Application
RF payload	Wifi Survey
UV- Vis Spectrometer	Solar Spectrum /Astrobiology reseach
Hyperspectral Imager	Chemical and material detection
Leak detectors (e.g. Ammonia)	Support to health status and inspection
Dosimeter /Fast neutron	Radiation environment monitoring/mapping
Astrobiological payload: With and w/o shielding	Efficiency of shielding material/water on bio-P/L
Small reparing/servicing tools	Automatic operation/reparation/ Target catching

Spacecraft Operations Overview

The launch, on-orbit installation and operation for TBD weeks is the standard service provided by the consortium

- The payload representative will be notified of the status of its hardware
- TBD working days prior to payload activation, the payload representative will be notified and shall ensure his support for flight operations

- **Schedule**

The individual Interface Control Agreement (ICA) between the Service provider and the Payload provider will coordinate payload schedule

Milestone/Activity	Launch -/+ months
Contract Signing	L- 12
Interface Control Agreement Start	L- 11.5
Payload Deliveries: Functional Description, Interface Drawings, Declared Material List	L- 10
Service provider starts ISS safety process	L- 10
Payload delivery: Thermal Model or equivalent data	L- 9
Upload manifesting	L- 9
Payload delivery: Flight operations description	L-6
Payload handover to service provider	L-3
Payload Environmental tests and Functional test within Multipurpose CubeSat test bed	L- 3 to L- 1
Certification for flight and handover to launch authority	L-1
Launch	L-0
Payload installation into Multipurpose CubeSat	L+3
Payload operation	L+3 to L+TBD
TBD: Payload returns to payload provider	L+TBD

Spacecraft Operations Overview

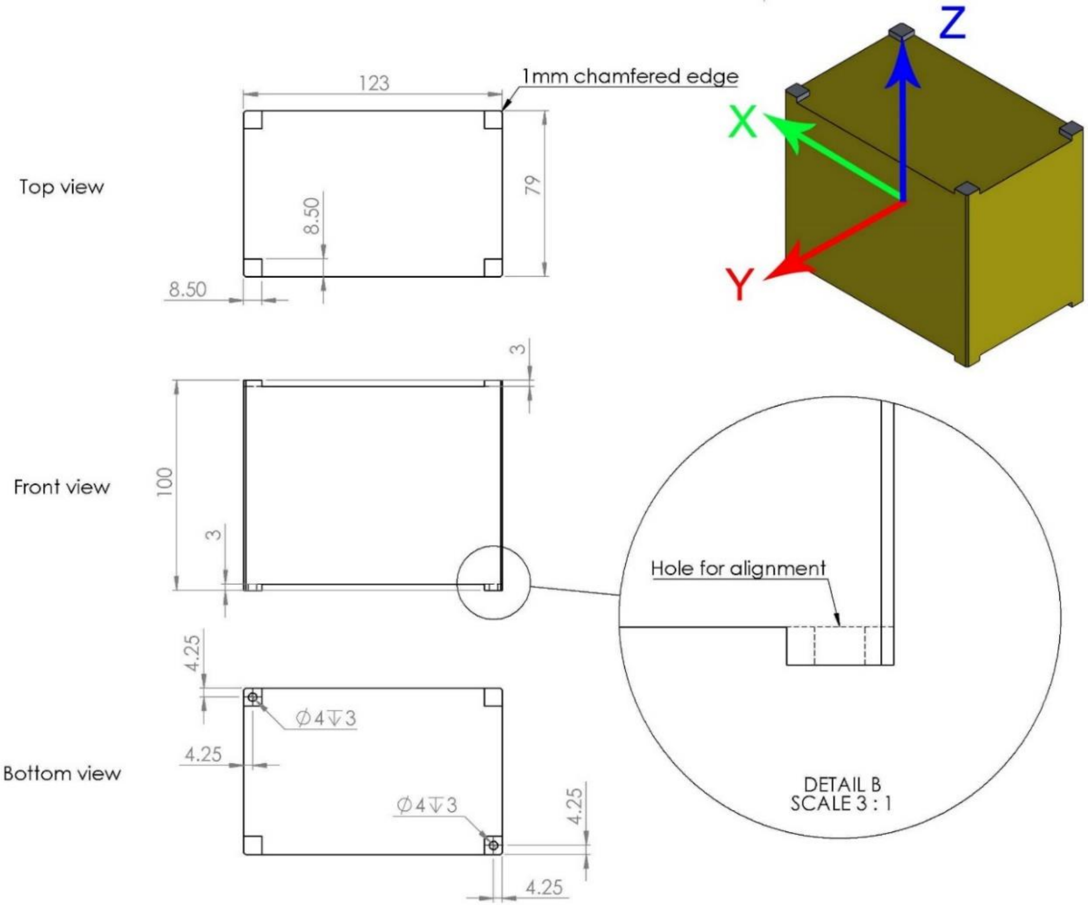
- **Ground Operations**
  - **Payload Delivery and Inspection**
    - To be performed according to ICA to the TBD facility
    - Safety and ICA requirements verification by the Service Provider (among others, NASA HFIT, mass properties, overall dimension)
  - **Payload Data Gathering for Operations**
    - Payload provider in charge of development of procedures in support of crew interaction and on-orbit assembly of the payload into Multipurpose CubeSat
    - Service provider to gather information on the payload including an overall evaluation, pictures, and other products as needed for efficiency maximization purposes (including the optimization of crew payload assembly and installation time)
  - **Payload Testing**
    - To be performed according to ICA (among others: grounding checks, bonding checks, verification of the concept of operations)
  - **Payload Packaging Delivery and Launch**
    - Service Provider to integrate the payload into a delivery package in final stowed configuration
    - Service Provider to deliver the package to the Launch facility
    - Service Provider to integrate the into the ISS visiting vehicle

Spacecraft On-Orbit Operations

Spacecraft On-Orbit Operations	
Operation	**Description**
Payload Destow	Once the launch vehicle is on orbit and berthed/docked, the crew is responsible for transferring the payload and placing it in the appropriate on-orbit stowage location until it is time to install the payload into the Multipurpose CubeSat.
Payload Assembly	Once payload deployment window is scheduled, the on-orbit crew is responsible for unpacking the payload and installing it into the Multipurpose CubeSat. The Multipurpose CubeSat with payload will be then installed onto/into Docking Station (DS) and moved externally for the deployment by means of JEM Airlock Slide Table.
JEM Operations	The JEM operations are managed by JAXA controllers. The air lock slide table retracts into the JEM airlock. The inner door is closed and the airlock is depressurized. The JEM airlock outer door is opened and the table is transitioned outside the JEM module to be accessed by the JEMRMS.
EVR Operations	The s/c shall provide bi-directional S-Band communication with ground for telemetry and commands
Payload Operations	The communication link between Ground and Payload is based on UHF for command uplink (TBC) and S-/X- band for payload and telemetry data downlink (TBC). As described in Paragraph 3.2.3, payload owners do not have direct access to the command interface. Payload data rate is limited to TBD kpbs by default, unless a different limit is agreed into ICA.

Payload Interface Requirements

- **Payload Envelope:**
  - **The Demonstrator allows for the installation of a payload which dimensions are approximately equal to 1U CubeSat form-factor.**
- **Payload Mass Properties:**
  - **The maximum gross payload mass capacity shall be 1.5kg. Any larger mass will need to be negotiated.**
  - **The center of gravity shall be located within a sphere of 1cm radius from payload geometric center.**



Payload Electrical and Data Interface

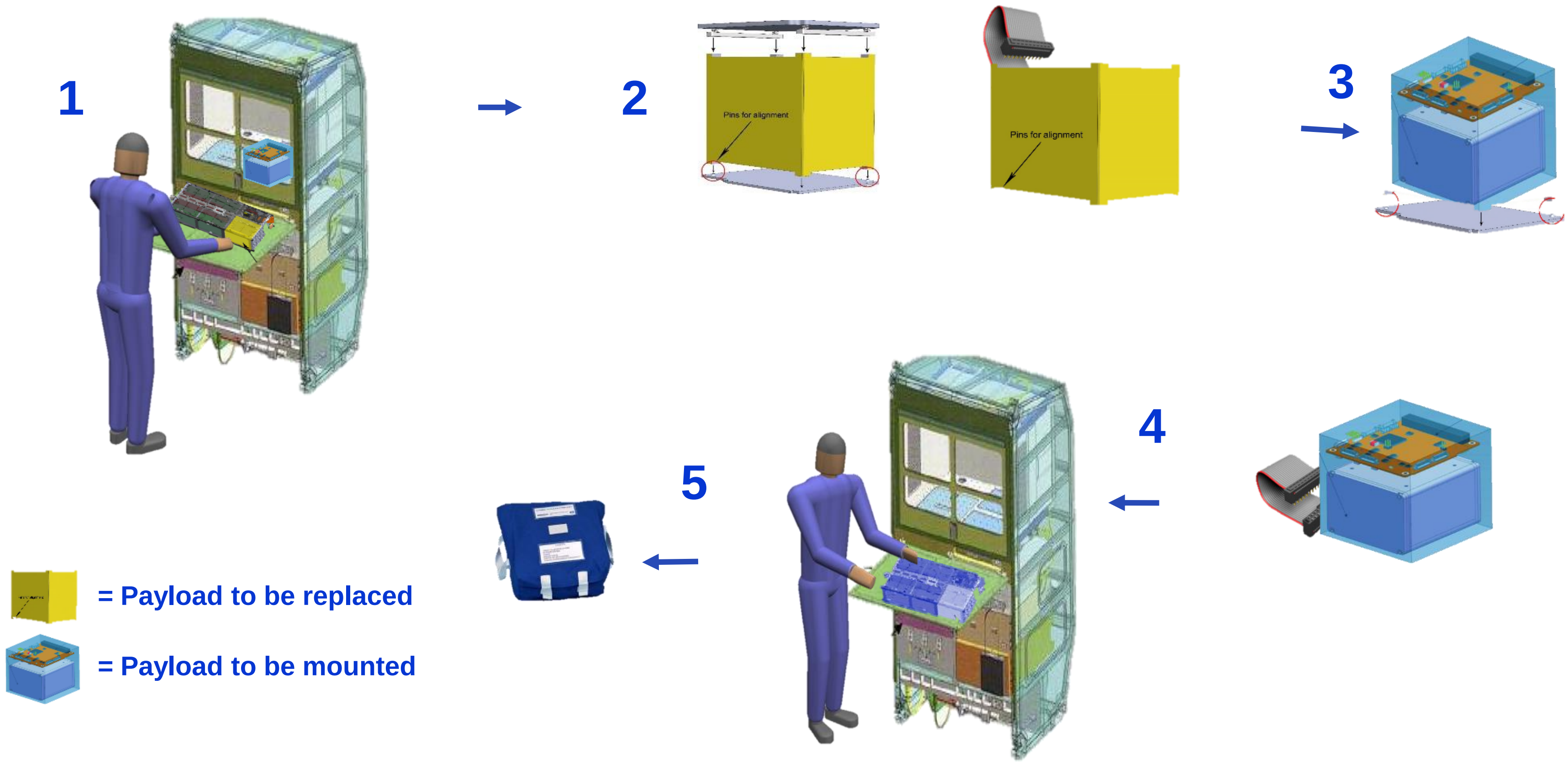
- **Electrical services are available via a Payload Interface Board (PIB), which is in installed inside the Multipurpose CubeSat.**
  - **The interface to the payload provides switchable VDC power outlets. Depending on the payload installed, multiple values of maximum power can be provided.**
- **Electromagnetic Compatibility:**
  - **The payload electrical grounding shall be in accordance with SSP 30240 Space Station Grounding Requirements (TBC).**
- **Electrical grounding**
  - **The payload electrical grounding shall be electrically bonded to the CubeSat in accordance with TBD Document.**
- **The communication link between the Multipurpose CubeSat and the ground:**
  - **The operators monitor, control and configure the satellite itself, including the payload. The data downlink includes Health and Status monitoring data for the satellite and the payload, and mission data.**
  - **Payload owners do not have direct access to the command interface, but they receive data from the Multipurpose CubeSat ground facility, in the form of (a) streaming Health and Status telemetry, related to the payload and (b) payload data.**

Command and Data Interfaces

- **Commanding**
  - **The Multipurpose CubeSat provides the capability to send commands to the payload via uplink communication. Automatic commands may also exist onboard the Multipurpose CubeSat as follows:**

- Status
- Transmit file (if any)
- Receive file (if any)
- Abort
- Power
- Reboot
- Execute
- Others (TBD)

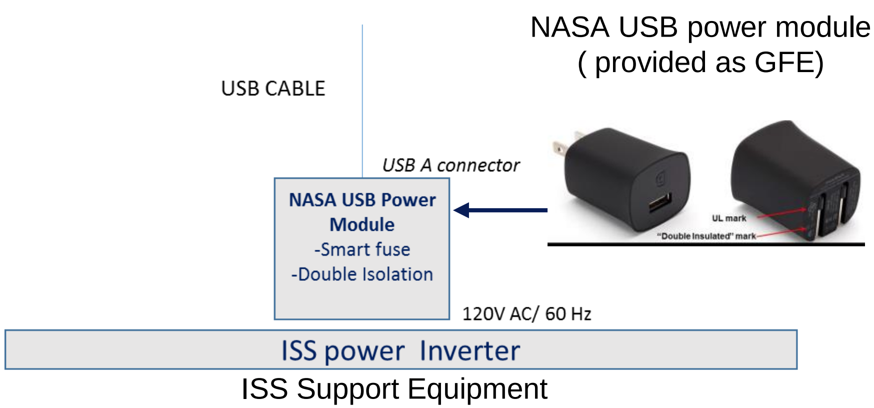
DEMO#1 Reconfigurability on Board : Payload Replacement



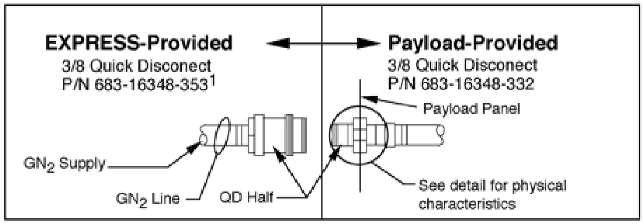
1 - CubISSat can be placed on the MWA for the P/L reconfiguration	**2 -** The lid on top of the P/L will be unscrewed and the Electrical Connector demated before sliding the P/L out from CubISSat.	**3 -** The new P/L will be aligned with the 4 rails and slided into CubISSat until its final position. The connector will be mated before closing the pack.	**4 -** CubISSat reconfiguration chek-out will be performed	**5 -** CubISSat will be stored until the next utilization

DEMO#1 Refurbishment on Board

- **Demo Battery Recharging**
  - **USB interface**
    - NASA USB Power Module (P/N SEG33124724-301), already available on-board the ISS .This power adapter (COTS item by Griffin “Power Block Universal with Charge Sensor”) is plugged in the NASA “120 VDC to 120 VAC Power Inverter” (P/N SEG33123254)→ 5V, 2A
    - It has been certified for Columbus utilization

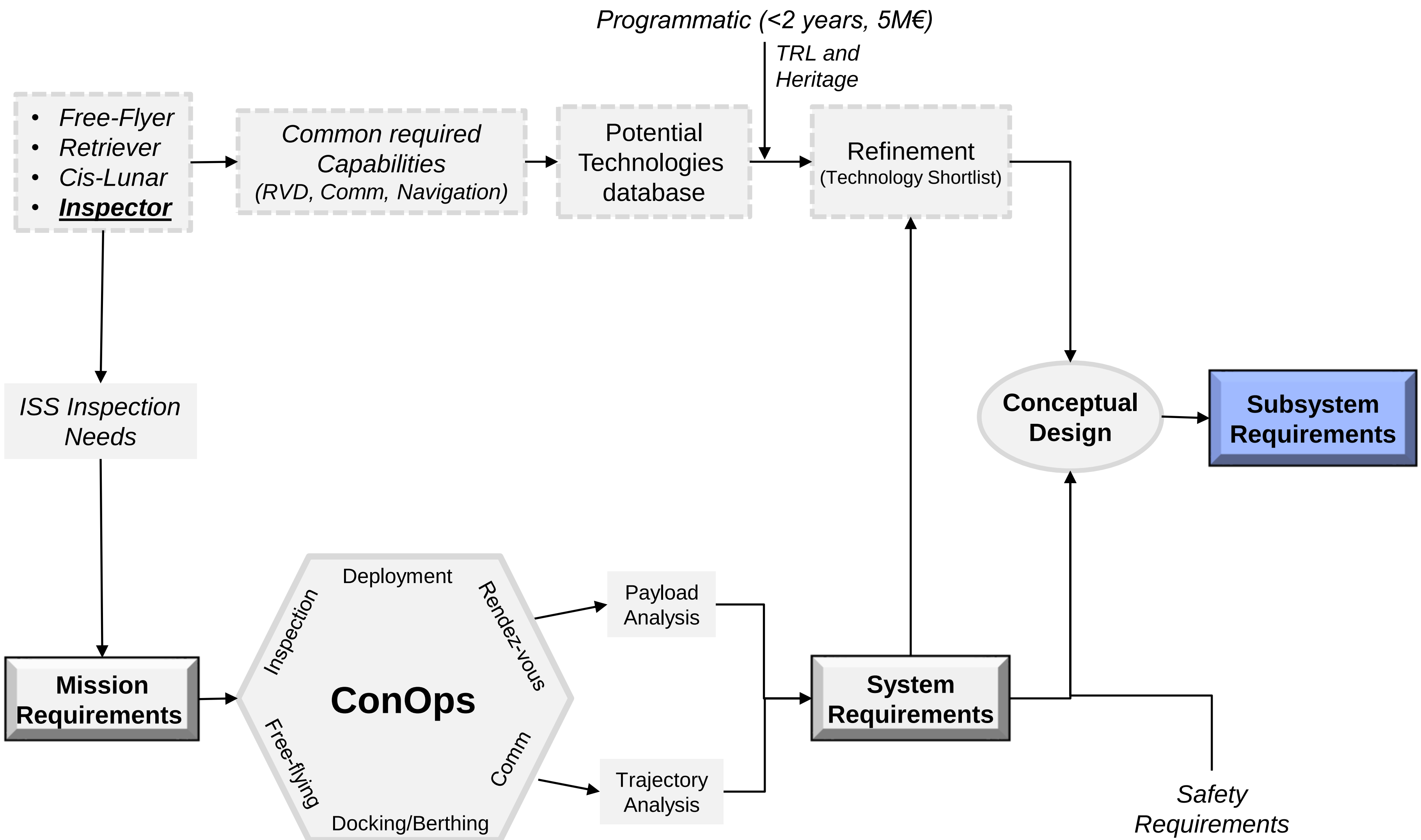


- **Demo Propellant Refilling**
  - **GN2 ISS interface**
    - The GN2 line can be used to test the potential refilling on board inside ISS for future scenarios in manned environment.
    - The Nitrogen is available as compressed gas, therefore the test has only a demostrative purpose.
    - The Propulsion system of the CubISSat shall fulfill the Safety design guidelines for the pressurized line and provide the QDs interface to the Rack (e.g. EDR2 nitrogen line interface, which is 13.78 bar)



Subsystem Requirements

CubISSat Work Logic Diagram



Structures

- **Preliminary Requirements**

ID	Subsystem Requirements	Traceability
DM-SS-STR-010	The structure shall provide support for all elements of the spacecraft	SR-IF-080
DM-SS-STR-020	The structure shall have a modular design to be adaptable with various subsystem configurations	SR-IF-080
DM-SS-STR-030	The structure shall withstand all loads during s/c lifetime	SR-IF-080
DM-SS-STR-040	The structure shall provide sufficient stiffness to comply with the launch vehicle requirements	SR-IF-080
DM-SS-STR-050	The structural mass shall be minimized	

Power systems

- **Preliminary Requirements**

ID	Subsystem Requirements	Traceability
DM-SS-PWR-010	ISS orbit shall be taken into account as first design driver	MR-010
DM-SS-PWR-020	Maximum eclipse duration at ISS orbit (~39 min) shall be taken into account for CubISSat battery sizing	MR-010 SR-FN-030
DM-SS-PWR-030	The power system design and sizing must take account of the radiation-induced degradation that will affect the solar cells	MR-010 SR-FN-030
DM-SS-PWR-040	The power system design and sizing must take account of the atomic-oxygen induced degradation that will affect the solar cells	MR-010 SR-FN-030
DM-SS-PWR-050	Deployable Solar Panels shall be considered for power generation in order to maximize Orbit Average Power	MR-010 SR-FN-030

Attitude and Orbit Control

- **Preliminary Requirements**

ID	Subsystem Requirements	
DM-SS-AOC-010	The S/C shall be 3-axis stabilised in a low drag attitude during free-drift trajectories	SR-FN-040
DM-SS-AOC-020	During inspection operations the AOCS system shall stabilise the payload in a ISS-pointing attitude	SR-FN-040
DM-SS-AOC-030	The AOCS system shall be able to perform orbit control manoeuvres	SR-FN-040
DM-SS-AOC-040	The AOCS system shall be able to perform Collision Avoidance manoeuvres	SR-FN-040
DM-SS-AOC-050	The AOCS system shall provide absolute orbital knowledge within 10m (TBC)	SR-FN-050
DM-SS-AOC-060	The AOCS system shall provide relative (ISS) orbital knowledge within (TBD) m	SR-FN-060

Telecommunications

- **Preliminary Requirement**

ID	Subsystem Requirements
DM-SS-COM-010	The Communication Subsystem shall be able to establish link with ISS during proximity operations for command and telemetry
DM-SS-COM-020	The ISS link shall use C2V2 S-band or UHF available band
DM-SS-COM-030	The Communication Subsystem shall be able to establish link with ESA approved GCC for command and telemetry and Ground Networks for data downlink
DM-SS-COM-040	The Ground link shall use S-band for command and telemetry and S/X-band for data downlink
DM-SS-COM-050	The Communication Subsystem shall be able to establish S-band link with TDRSS (backup TBD)
DM-SS-COM-060	The communication subsystem shall be able to receive and demodulate an uplink signal and transmit it correctly to the data handling system.
DM-SS-COM-070	The communication system shall downlink all the imagery and video data generated around the ISS.

Data Handling

- **Preliminary Requirement**

ID	Subsystem Requirements
DM-SS-OBDH-010	The On-Board Data Handling subsystem shall provide for: • command reception • decoding • encryption/decryption • processing • distribution to subsystems and components • payload interfacing
DM-SS-OBDH-020	The On-Board Data Handling subsystem shall be responsible for the execution of AOCS algorithms.
DM-SS-OBDH-030	The On-Board Data Handling subsystem shall be able to store imagery and video data for a given duration (TBD).
DM-SS-OBDH-040	The On-Board Data Handling subsystem should support most common interfaces used by COTS CubeSat components (i.e. CAN, SPI, I2C, UART).
DM-SS-OBDH-050	The On-Board Data Handling subsystem shall be provided with a software radiation tolerant computer system able to detect, avoid and repair faults caused by high-energy ionizing radiation.
DM-SS-OBDH-060	The On-Board Data Handling subsystem shall provide the capability and capacity to generate, transfer, and manage real-time and stored data for the purposes of monitoring and reporting spacecraft health and status, and payload operations.

Propulsion

- **Considerations**
  - Cold-gas technologies available with high TRL
  - Likely need customized development for accommodation constraints
- **Preliminary Requirements**

ID	Subsystem Requirements
DM-SS-PROP-010	The propulsion system shall provide the S/C with 6 DOFs manoeuver capabilities. Both position and orientation of the nozzles must be chosen according to the position of the CoM of the satellite.
DM-SS-PROP-020	The propulsion system shall provide enough propellant for all planned manoeuvres of the S/C (phasing, inspection, rendezvous and docking operations), accounting also for collision avoidance and de-orbiting manoeuvers.
DM-SS-PROP-030	The propulsion system shall have a thruster redundancy.

Docking Systems

- **Preliminary Requirements**

ID	Preliminary Docking Subsystems Requirements
DM-SS-DOCK-010	The docking subsystem shall be able to perform both docking and berthing operations, playing respectively an active and passive role during the mating phase.
DM-SS-DOCK-020	The docking subsystem shall ensure the capture of the S/C, with condition of no escape given by a rigid structural connection.
DM-SS-DOCK-030	The docking subsystem shall be able to maintain the S/C docked for long-time operations during the retrieval of the vehicle.
DM-SS-DOCK-040	The docking subsystem shall be designed to perform undocking operations, ensuring the vehicle to phase away from the docking station with sufficient separation velocity.
DM-SS-DOCK-050	The docking subsystem shall be mechanically aligned with the CoG of the satellite to prevent any torque caused by impacts during mating operations.

Deployment systems

• Technology options comparisons

Options	6-POD ISIS	CSD Planetary Systems	Tyvak 6U
Access Ports		X	X
Additional Mass			X
Power/Data Port		X	X
Purge			X
X-Y Constraint	X	X	
Z Constraint	X	X	X
6U+ Additional Volume	X		X

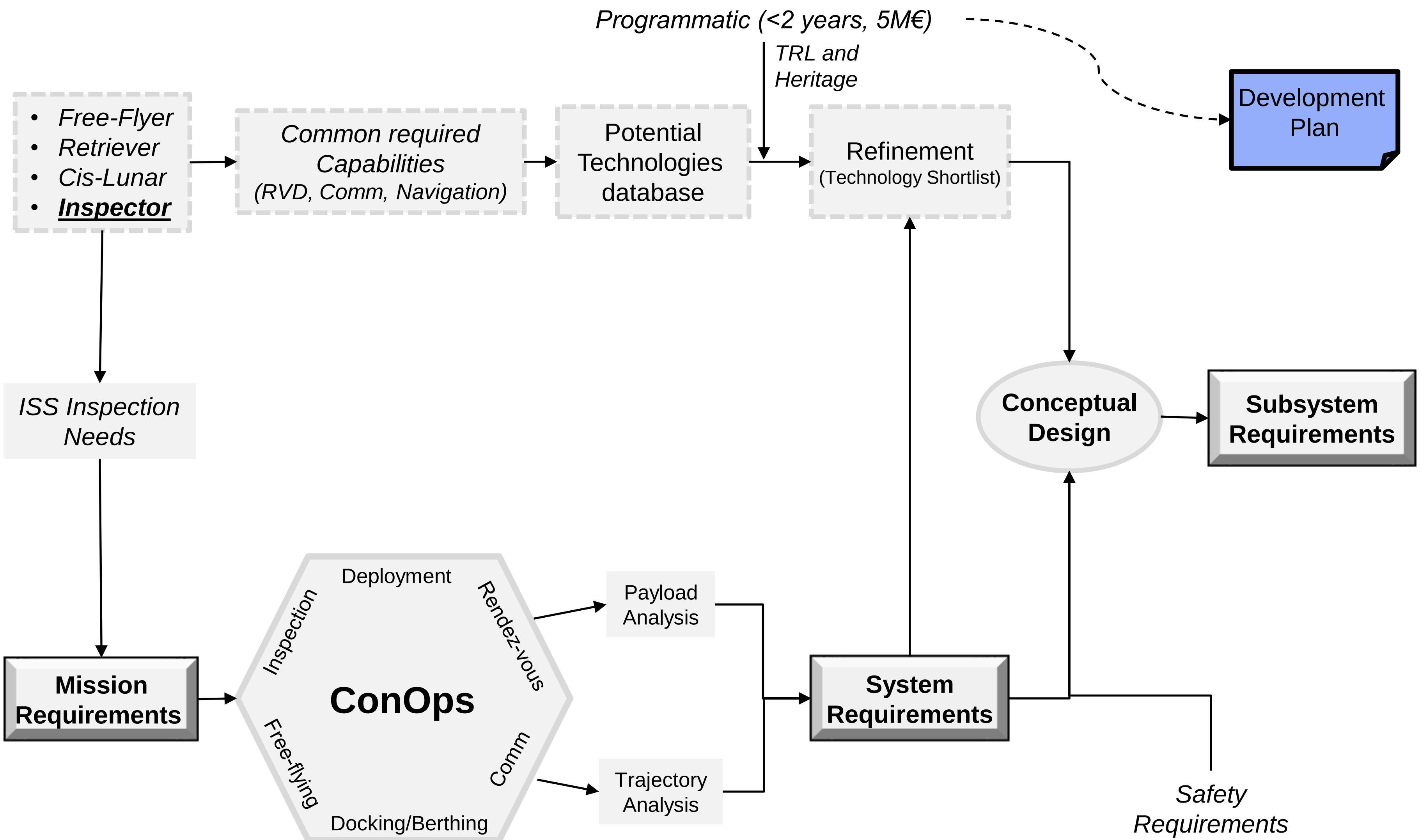
Deployment systems

- **Subsystem Requirements**

ID	Preliminary Docking Subsystems Requirements
DM-SS-DS-010	The deployment system shall accommodate a 6U-form factor nanosatellite
DM-SS-DS-020	The deployment system shall serve as mechanical interface with Launch Vehicle
DM-SS-DS-030	The deployment system shall be handled by crew on-board ISS
DM-SS-DS-040	The deployment system shall provide a mean for inspection of the S/C after integration
DM-SS-DS-050	The deployment system shall provide a mean for RBF removal after s/c integration
DM-SS-DS-060	The deployment system shall be mechanically and electrically connected to the MPEP platform
DM-SS-DS-070	The deployment system shall eject the spacecraft with a positive separation velocity < 1.0 m/s (TBC)
DM-SS-DS-080	The deployment system release mechanism shall be non-explosive
DM-SS-DS-090	The deployment system shall provide an electrical signal to verify the correct door opening upon activation

Development Plan

CubISSat Work Logic Diagram

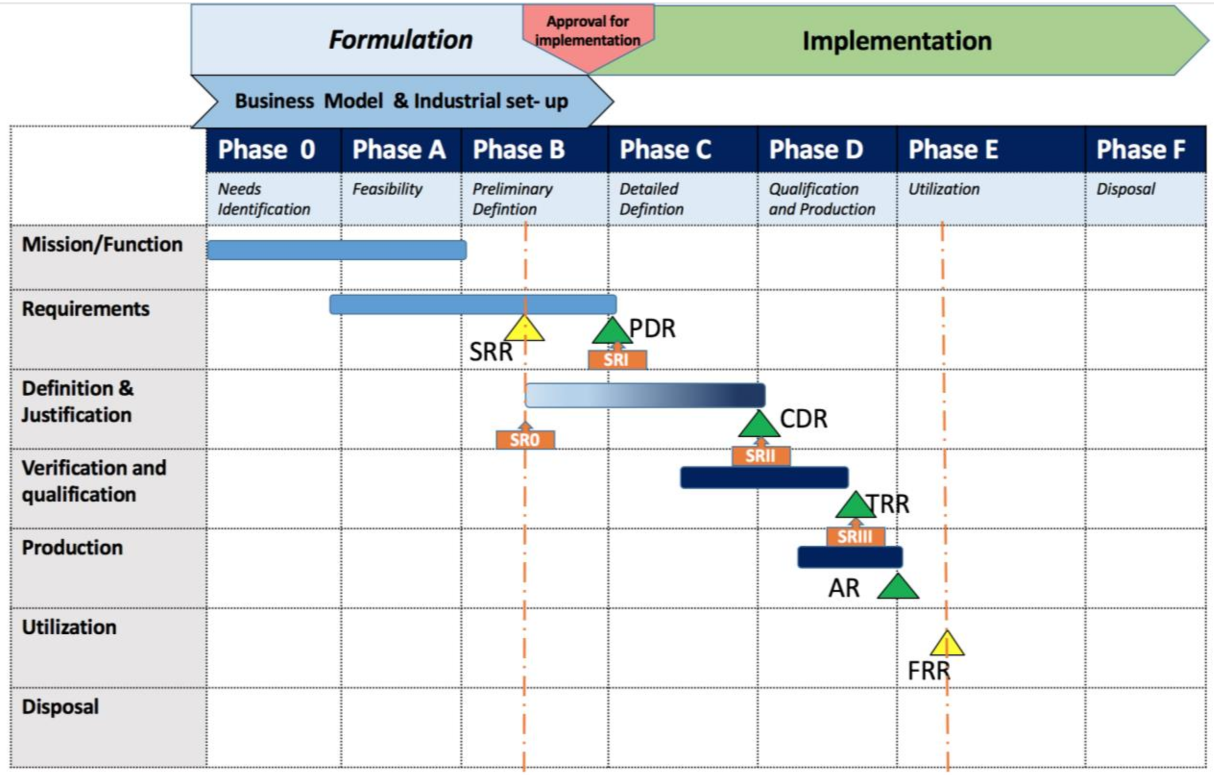


Development Plan

- **Assumptions**
  - The program starts with SRR and Safety Review, Phase 0 outcomes
  - The Development Plan takes into account:
    - Space Segment (Vehicle and Docking System (DS1.0) design and development)
    - Ground Segment (Testing, Operations plan and infrastructure development)
    - Launch Procurement Services (NOT Launch opportunity, NOR integration services)
  - Schedule, ROM cost estimate and effort are to be considered as minimum
- **Constraints**
  - 5M€
  - Development time 2 years
- **Schedule**
  - The Program Schedule is built taking into account the maturity of numerous components and targets delivery of the flight-ready vehicle and docking platform approximately 24 months (22 Months + 2 margin) after program start.

Future phases and milestones

- **Next Phases and respective milestones**
  - Phase B2 - Preliminary Definition –> PDR and Safety Review Phase I
  - Phase C – Detailed Definition –> CDR and Safety Review Phase II
  - Phase D – Verification, Qualification & Production –> TRR, Safety Review Phase III and AR



Work Breakdown Structure and Project Organization

- **Work Breakdown Structure**

#	Work Packages	CY 2017	CY 2018	Total Hours
1	Project Management (WBS 1.0)	276	304	580
2	Systems Engineering (WBS 2.0)	1032	256	1288
3	Payload (WBS 3.0)	1992	336	2328
4	Spacecraft design and development (WBS 4.0)	5304	3120	8424
5	Docking/Dispenser System (WBS 5.0)	2112	544	2656
6	Integration and Test (WBS 6.0)	448	2504	2952
7	Mission Operations (WBS 7.0)	200	1304	1504
8	Launch Vehicle/Services (WBS 8.0)	0	352	352
	TOTAL	**11364**	**8720**	**20084**

- **Project Organization**
  - **Customer (ESA) –> Main program sponsor and principal decision maker**
  - **Contractor –> Overall Program management and Systems Engineering**
  - **Sub-contractor(s) –> Propulsion system supplier**
  - **Vendors –> Mission Control Center and Ground Terminals Network**

Cost Estimation

- **Cost Estimation**
  - **Period of performance: January 01, 2017 – December 31, 2018 (24-month duration)**
  - **Assumptions:**
    - **Effort will be performed at the Contractor facilities**
    - **The Euro values on cost reports may vary slightly at summary levels due to computer rounding.**
    - **The materials, travels and services costs are calculated with best estimate with a 20% of margin based on Tyvak past experiences and previous study programmes**
    - **Labour cost is estimated based on the standard labour rates for project management and project engineering.**
  - **Estimating Methodologies:**
    - **Labour hour estimates were obtained by comparing work scope, time span, and deliverables from past CubeSat and NanoSat programs**
    - **Required Tyvak-purchased materials were estimated from previous purchase orders from previous and existing programs, catalog prices, and/or on-line sources**
    - **Travel requirements were derived from customer-defined SOW, and from past experience with the CubeSat and NanoSat programs**

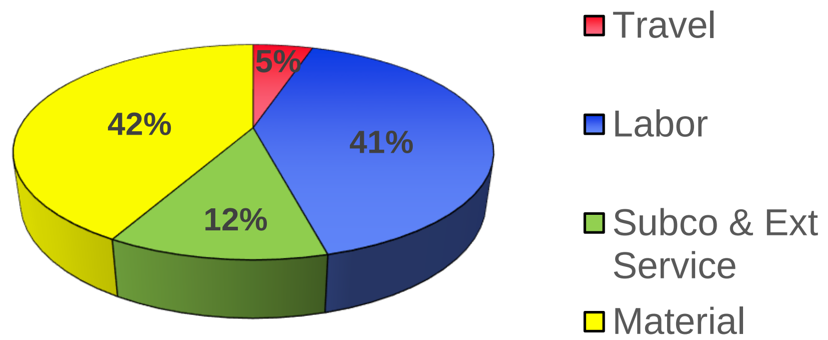
Cost Element Supporting Data

- **Cost Element Supporting Data**
  - **Indirect Costs**
    - **A value of 25% G&A over the total direct costs has been used. This is the same rate applied by European Commission to H2020 projects, and is considered common and acceptable for a small aerospace business;**
  - **Materials**
    - **Costs are estimated to prepare different versions of the models and prototypes needed for design development and for delivery. All procurements are believed to be with EU suppliers to the best of our knowledge, with few exceptions;**
  - **Subcontract and External Service**
    - **Tyvak will establish a subcontract for the propulsion subsystem;**
  - **Travel**
    - **Travel by Tyvak employees will be minimal to support this program. As needed, travel is from Tyvak facilities in Turin, Italy.**

Cost Summary

		duration (months)	ROM COST
1.0	**PROJECT MANAGEMENT**		
1.1	Program Oversight	24	€ 30.643,20
1.2	Team Coordination	24	€ 30.643,20
1.3	Program Reviews (10x)	3	€ 22.024,80
1.4	Safety Reviews	1	€ 7.341,60
2.0	**SYSTEMS ENGINEERING**		
2.1	Trade Studies and Analyses	12	€ 57.456,00
2.2	System Requirements consolidation	5	€ 23.940,00
2.3	Vehicle Modeling and Simulation	18	€ 34.473,60
2.4	Mission Modeling and Simulation	20	€ 38.304,00
3.0	**PAYLOAD**		
3.1	Payload coordination	18	€ 22.982,40
3.2	Payload imaging sensors (VIS, IR)	11	€ 84.268,80
3.3	Reconfigurable Payload Unit	11	€ 63.201,60
3.4	RPU software for P/L plug&play	17	€ 113.954,40
4.0	**SPACECRAFT Design and development**		
4.1	Bus development	7	€ 73.735,20
4.2	ems dev (CDH, EPS, ADCS, space2ground)	12	€ 126.403,20
4.3	space2space Comsys	17	€ 65.116,80
4.4	Propulsion	17	€ 179.071,20
4.5	Docking System	19	€ 236.527,20
4.6	RPO software	18	€ 120.657,60
4.7	Image recognition software	18	€ 86.184,00
4.8	Vehicle flight software	18	€ 120.657,60
5.0	**DOCKING/DISPENSER PLATFORM**		
5.1	System Design and Development	11	€ 115.869,60
5.2	Subsystem Design and Development	11	€ 115.869,60
5.3	Docking Platform Software	18	€ 86.184,00
6.0	**INTEGRATION AND TEST**		
6.1	Mission Assurance (HITL & Flatsat)	14	€ 111.720,00
6.2	Bus Subsystems AI&T	5	€ 52.668,00
6.3	Bus System AI&T	4	€ 34.473,60
6.4	Vehicle AI&T	7	€ 60.328,80
6.5	Docking Platform AI&T	6	€ 51.710,40
6.6	Docking Platform Integrated Testing	7	€ 46.922,40
7.0	**MISSION OPERATIONS**		
7.1	MO plan	12	€ 15.321,60
7.2	MCC development	17	€ 65.116,80
7.3	Ground Network Coordination	9	€ 34.473,60
7.4	UHF Ground Systems	9	€ 34.473,60
7.5	S/X band Ground Systems	9	€ 34.473,60
8.0	**LAUNCH VEHICLE SERVICES**		
8.1	Launch procurement and coordination	12	€ 15.321,60
8.2	Deployer Procurement	8	€ 30.643,20
		Labor	€ 2.443.156,80
		Material	€ 2.504.922,00
		Subco & Ext Service	€ 727.776,00
		Travel	€ 257.115,60
		TOTAL	€ 5.932.970,40

Cost Summary



Category	Value
Labor	€ 2.443.156,80
Material	€ 2.504.922,00
Subco & Ext Service	€ 727.776,00
Travel	€ 257.115,60
TOTAL	**€ 5.932.970,40**

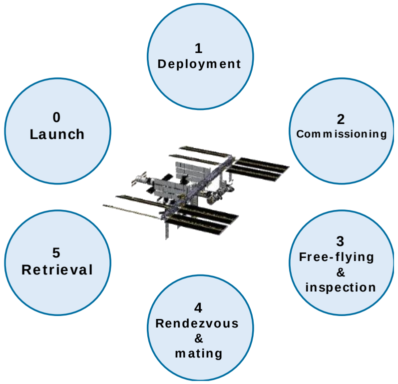
N.B. € 1.042.716,00 is entirely dedicated to the development of the DS1.0 Docking Platform

NASA Safety Review Panel Phase 0

Houston 08/06/2017

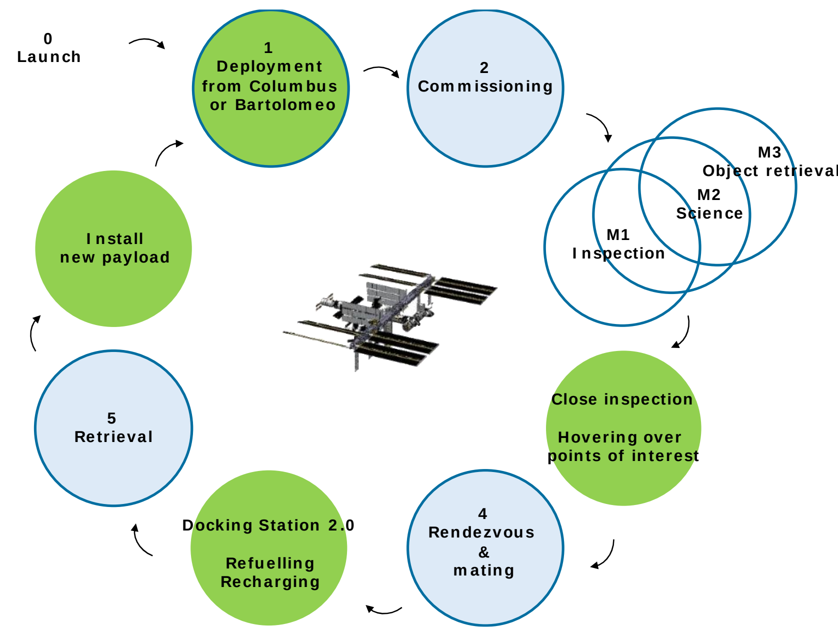
Program Strategy

- **The 1st mission is aimed at retire all risks and prove the opportunity for a future full operational ISS drone**



First Mission

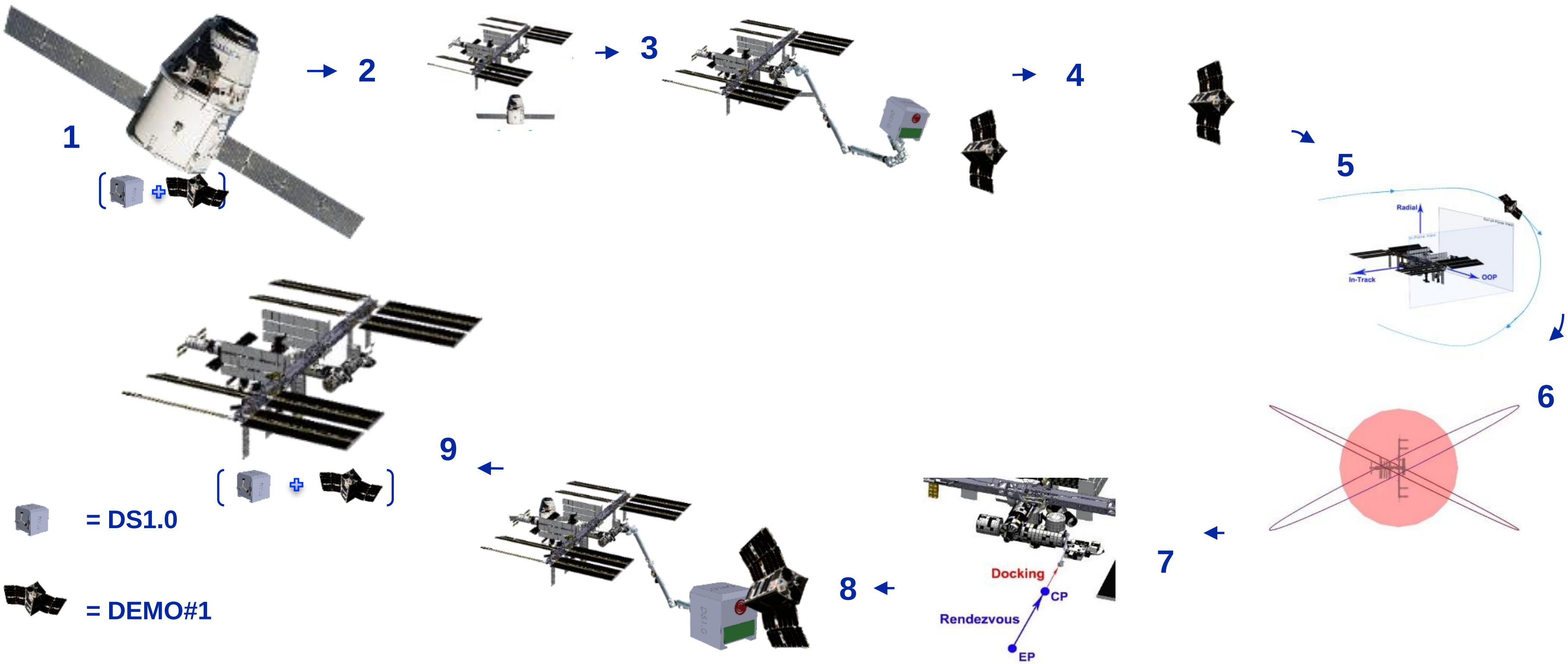
- Deployment from KIBO
- Risk retired for navigation approach & communication
- Rendez-vous and Docking demonstrator
- Docking Station 1.0: deployment and retrieval



Future Operational ISS Drone
Add enhanced capabilities

- Deployment from Bartolomeo or Columbus
- Docking Station 2.0: add power, refuelling, multiple dockings & un-dockings
- Close inspection (sub-cm resolution)
- Reusable drone: switch bw multipurpose payloads, reconfigure on-board
- Multiple deployments/retrieval

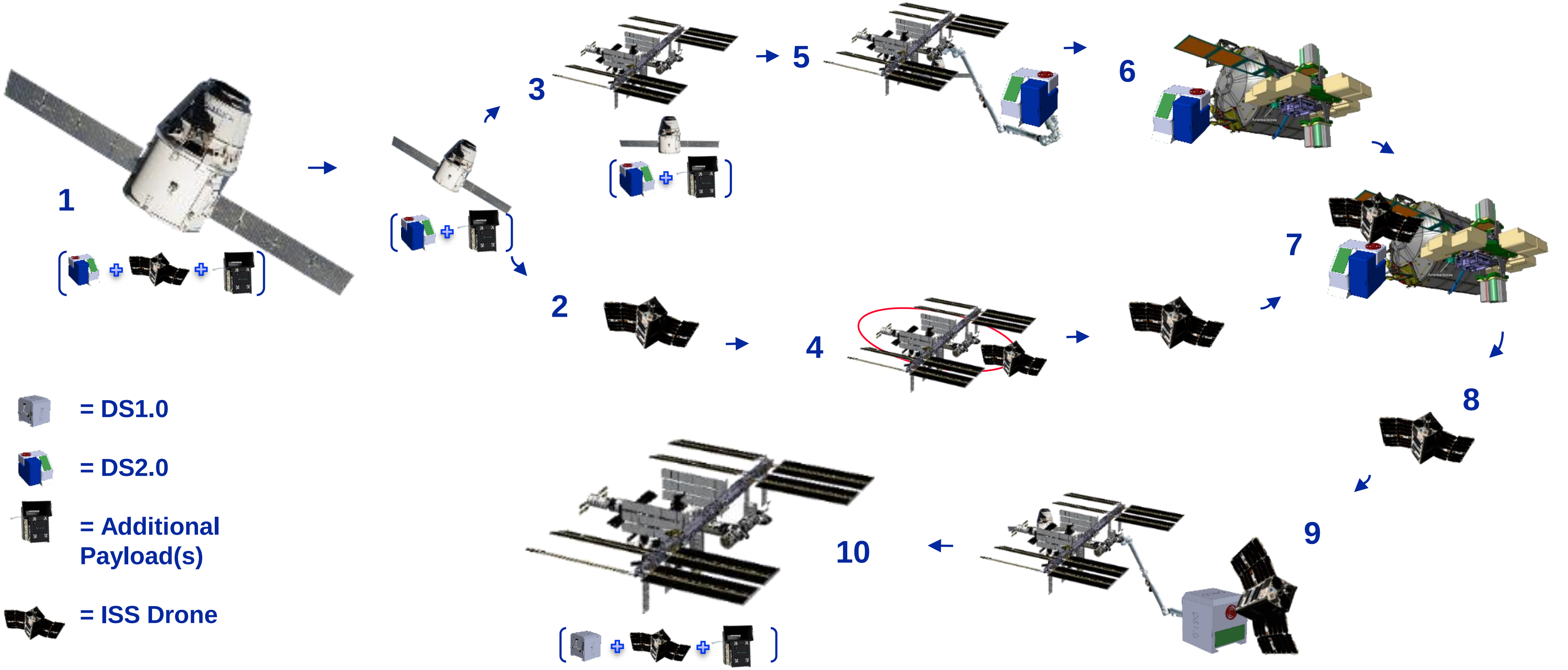
First Mission ConOps



ConOps as presented at NASA SRP0.
For further details, see ESA presentation «Multipurpose CubeSat SRPO0-TIM – 1107»

1 – DS1.0 including satellite and deployment system is delivered as cargo to ISS on board a VV.	2 - VV is berthed to ISS. DS1.0 is moved to KIBO.		3 - DS 1.0 is mounted to the sliding table of module and grappled by JEM SS-RMS. The arm is held in position. CubISSat is then deployed.	4 – Satellite activation. Commissioning Phase at few km away from the ISS. First propelled manoeuvre outside the KOS.
5 – Semi-autonomous Step-by-Step approach to ISS. RGPS navigation	6 – Start inspection orbits. RGPS and Visual-based navigation	7 – Rendez-vous manoeuvres and docking with same DS1.0	8 – CubISSat is returned inside ISS after docking with DS1.0.	9 - DEMO#1, DS1.0 and payload are stowed inside the KIBO module where Crew performs post-mission detailed inspection.

Future Operational Mission ConOps



1 – DS2.0 and ISS Drone are delivered as cargo to ISS on board a VV. Additional Payloads can be stowed on-board for later installation.	2 – ISSDrone can be released from DS2.0 while approaching ISS.	3 - VV is berthed to ISS.	4 – ISSDrone performs a specific mission (e.g. close-out inspection)	5 – DS2.0 is grappled by the SS-RMS.
6 - DS2.0 is robotically mounted onto Columbus or Bartolomeo external platforms;	7 – ISS Drone docks with the DS2.0 when it can be recharged, refuelled or retrieved inside for check-out for installation of new payloads	8 – As necessary ISSDrone can start a new mission performing un-docking from DS 2.0.	9 – DS1.0 is still available at ISS and can serve as additional / backup docking port.	10 - ISSDrone, DS1.0 and payloads are stowed inside the KIBO module where Crew performs post-mission detailed inspection.

Endorsement of NASA Safety Panel

- **Two meetings have been finally scheduled:**
  - ***Safety Technical Interchange Meeting*: aimed to introduce the Project & Payload Concept, present identified Safety Critical Topics and Safety Approach and jointly elaborate identified Safety Critical Topics with Open Safety Approach;**
  - ***Working Group Meeting*: aimed to walk through an initial attempt from ESA/Tyvak to elaborate SSP documentation (SSP 50808), receive guidelines on the interpretation of the safety requirements set or the implementation procedures and provide guidance for preparing the safety data required for subsequent safety reviews.**

Main outcomes from SRP0

- **Mission scenario**
  - S/C deployment strategies - from VV and ISS - might be implemented. In both cases, the safety of the ISS shall be kept as main driver.
  - Redundancy of propulsion system with respect operational control shall be covered with respect to autonomous flight. Generally speaking, the s/c shall be two failures tolerant for the collision hazard from a safety perspective.
  - No major objections to the use of nitrogen as first choice for propulsive gas. However, the use of xenon or other inert gases might be investigated.
  - Hazards to the ISS Environmental Control and Life Support System (ECLSS) shall be addressed.
  - The Panel agreed with ESA favourite comms approach: establish communications with the s/c prior its deployment as per VVs current standard undocking processes.
  - The Panel confirmed that, wrt the applicable safety requirements, the CubeSat free-flyer exhibits characteristics of both payload and system. Despite this, it should be treated as a system, with SSP 50021 being applicable rather than SSP51700. NASA agreed that a tailored requirements matrix will need to be developed for the s/c to support the future Phase-I safety review.

Main outcomes from SRP0

- **Navigation Approach**
  - The Panel underlined the need of a strong definition of the design provisions associated with a rendezvous, mating/docking, and retreat, including the associated commanding inhibits, from a safety perspective.
  - Design/operational details associated to the docking system will also need to be addressed.
  - The Panel recommended to consult with the ISS Vehicle Office representatives regarding the docking system design aproach.
  - The Panel considered the return of the s/c inside the ISS at completion of DEMO Mission as doable, advising to study equipment such as SAFER to gain a better understanding of the requirements needed.

Main outcomes from SRP0

- **Critical Functions**
  - The Panel advised that the state vector associated with ISS and visiting vehicles can be made available to support the development of navigational strategies and should be coordinated with NASA Safety engineers.
  - The Panel indicated that navigation strategies associated with fault tolerance requirements and navigation rules should be addressed for each phase of the CubeSat mission, including failure tolerance/redundancies of the spacecraft systems with respect to free-flight maneuvers.
  - NASA confirmed that the C2V2 system supports video streams. It was agreed to investigate how to provide ESA with more detailed information about the C2V2 interfaces.
  - NASA clarified that hazardous commanding can only be done through S-band (UHF is not certified for this in conjunction with ISS operations); furthermore, the Panel advised to use an ISS certified Control Center as the command source since this would simplify the safety evaluation/certification.

Main outcomes from SRP0

- **Program Strategy and Approach**
  - **The Panel discussed the first demo mission strategies, enhanced capabilities for future operations, and program strategies for future missions. No safety issues or concerns were indicated at this time.**
- **Preliminary Design Overview**
  - **The Panel recommended that the CubeSat design team consult with the NASA battery team regarding battery requirements and selection, particularly since spacecraft preparations will conducted inside the ISS environment.**
  - **The Panel advised to prepare the requirements set by systems, so as to ease their establishment and review with NASA.**

Main outcomes from SRP0

- **Safety Considerations**
  - The Panel agreed that SSP 50021 safety requirements are not inclusive to the CubeSat free-flight phase, indicating the applicability of SSP 50808 requirements will require clarification via development of a requirements applicability matrix. NASA will provide ESA with a correlation matrix between SSP 50808 and 50021.
  - The Panel further clarified that the vehicle will need to meet two fault tolerance with respect to the collision hazard. ESA will also need NASA ISS assistance/guidance with respect to safe free-flight navigation trajectories.
  - The Panel advised ESA to specifically evaluate time to re-contact/collision of ISS in case of failure(s) throughout the approach/docking operations. It was agreed to organize a separate teleconference on this topic at a later point in time.
  - The Panel advised to carefully consider the response after losing 1 FT, clarifying that in some instances the appropriate response being to not retreat/abort but to press-in. The Panel advised to consider the risk progression and sources throughout the entire approach and docking operations, paying extra attention to the transition between modes.
  - A fault tolerance approach is preferred by the ISS safety community rather than Design for Minimum Risk (DFMR) approach.
  - The Panel recommended that ESA conduct working group meetings with NASA, as needed, to resolve any questions or design issues/concerns prior to the Phase-I safety review.

Main outcomes from SRP0

- **Conclusions**
  - **Following a poll of the Technical and Panel representatives present, the Panel concluded that no significant technical or safety issues/concerns are indicated at this time for the ESA Multipurpose CubeSat Free-flyer preliminary design approach, and concurred with preliminary planning approach for the ISS demonstration mission.**

Backup Slides

Propellant consumption for different holding points

Point #	Relative Position			Propellant Utilization	
	R [m]	S [m]	W [m]	Hold [g/hr]	Translation [g/hr]
1	-290	0	0	100	68
2	0	0	-290	33	42
3	0	-290	0	1	42
4	0	0	290	33	68
5	290	0	0	100	98
6	0	290	0	1	-

Reference system relative to ISS:
R ------ Radial
S ------ Along-track
W ------ Cross-track

R-bar is from 4 to 198 times more demaning than V-bar.

Imagery capturing details

- **The sensor has a uncompressed data rate of 6 Megabytes (roughly). This is by multiplying the pixel array size (2048 x 1536) by a 10-bit depth for each pixel. Now, since the data is stored in 8-bit bytes, so a 10-bit pixel is really stored in a 16-bit (2 byte) container.**

- **For video sharing, different frame rates can be used, 5-10 frames per second would be a good approach.**

- **For compression techniques, LZW (lossless compression) or JPEG2000 (lossy compression) algorithms will be used.**

- **The performance of compressing, like most techniques, is highly dependent on the scene captured. If the image is completely black or white, the file will be VERY small, if there is a lot of variation in the image, it will be much larger. That being said, typical image sizes for the system used are between 1.2MB and 2MB, depending on the scene.**

Imagery Data downlink

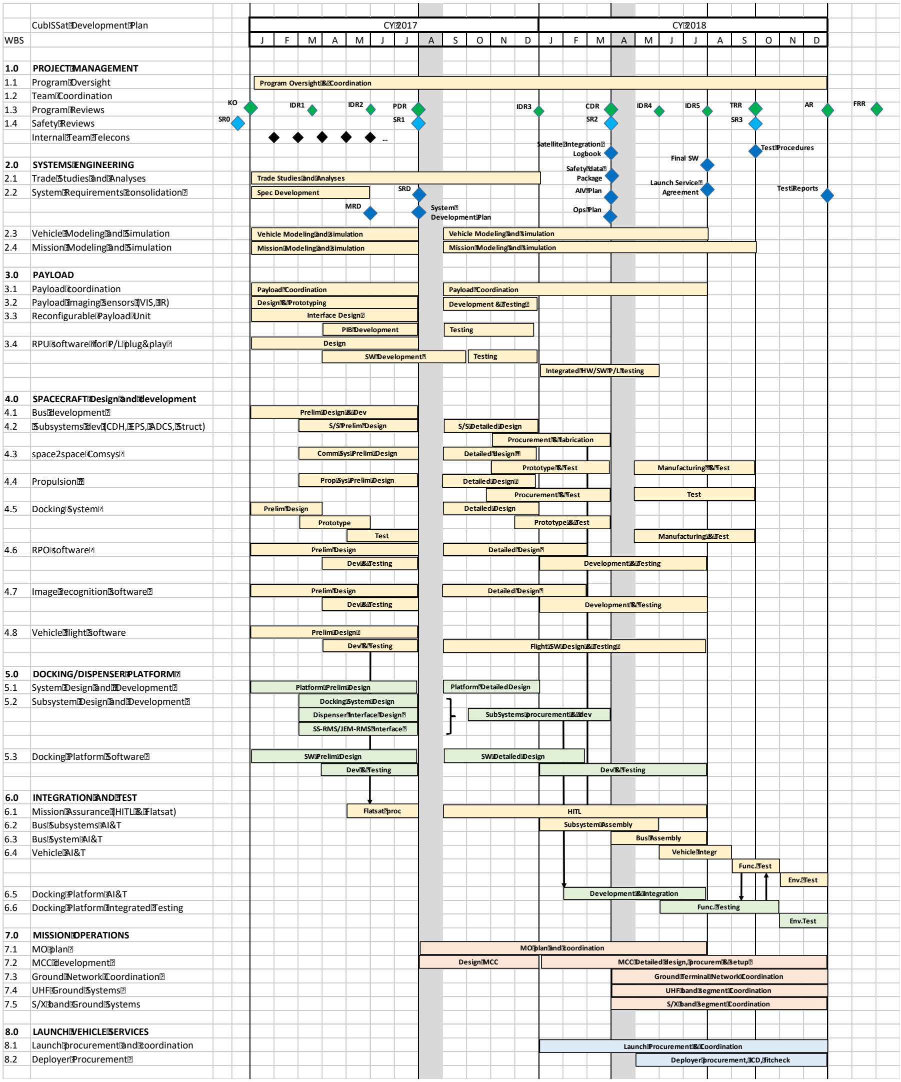
Tyvak modified RPOD (2048*1536)*10 bits		
fps	Data rate w/o compression (Mbps)	Data rate w/ compression (Mbps)
5	252	80
10	503	160
15	755	240
30	1510	480

Communication types

- Express Logistic Carrier (ELC) Wireless
  - Type: Wireless 802.11n
  - Freq: 5.25 – 5.35 GHz
  - Expected data rate: 26-63 Mbps
- UHF communications
  - Type: a form of Space to Space Station Radio (SSSR) link
  - Freq: 414.2/417.1 MHz
  - Exp data rate: 8 kbps
- S-Band communications using TDRSS
  - Type: either Single Access (SA) or Multiple Access (MA) modes
  - Freq: SA on 2265 MHz TX - 2085.7 MHz RX, MA on 2287.5 MHz TX - 2106.4 MHz RX
  - Exp data rate: <300 kbps (SA), <100 kbps (MA)
- Common Communications for Visiting Vehicle (C2V2) (S-Band)
  - Freq: 2.29-2.3GHz
  - Exp data rate: ~10 kbps (within ~30 Km) and ~80 kbps (within ~10 km)

Example: K-SAT global network

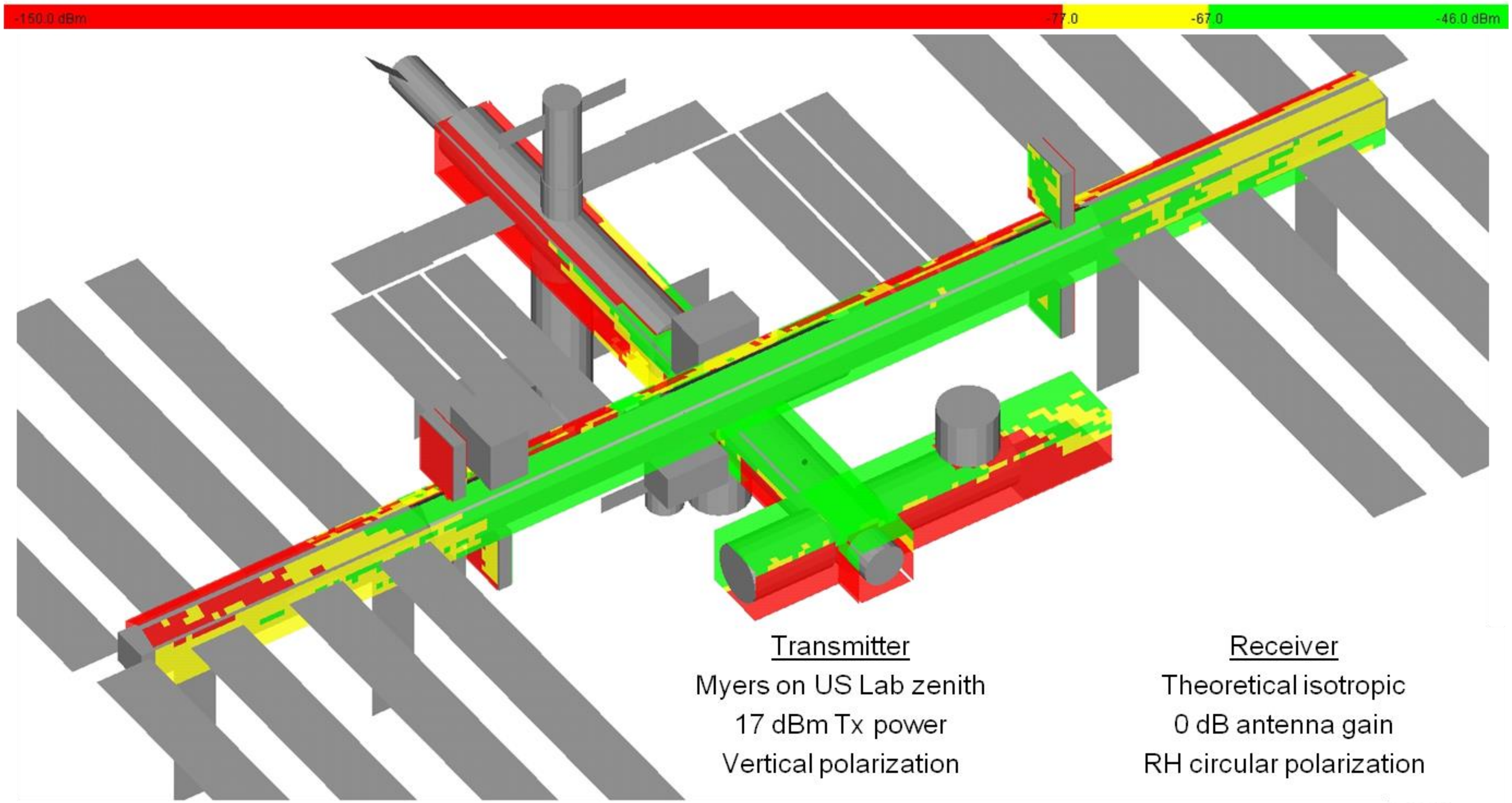
Development Plan - Schedule



Deliverable Documentation Items

Document Name	PDR	CDR	TRR	AR
Mission Requirements Document (MRD)	Issue	Control	Control	Control
Mission Analysis Report (MAR)	Issue	Maint	Maint	Maint
System Requirements Document (SRD)	Issue	Control	Control	Control
System Design Report (SDR)	Issue	Control	Control	Control
Environmental Design Specification	Issue	Control	Control	Control
Space Debris Mitigation Document	Issue	Maint	Maint	Maint
Space-to-ground Interface Control Document (SGICD)	Issue	Control	Control	Control
Space-to-Space ICD (SSICD)	Issue	Control	Control	Control
Declared Lists for Parts, Materials and Processes (DLs)	Issue	Control	Control	Control
Satellite Mechanical Analysis Report	Issue	Maint	Maint	Maint
Satellite Thermal Analysis Report	Issue	Maint	Maint	Maint
Satellite AOCS Analysis Report	Issue	Maint	Maint	Maint
COTS User Manuals	Issue	Maint	Maint	Maint
System Development Plan (SDP)	Issue	Maint	Maint	Maint
Payload-Platform Interface Control Document (ICD)	Issue	Control	Control	Control
Product Assurance Plan (PAP)	Issue	Maint	Maint	Maint.
Satellite Test Procedures		Issue	Maint	
Satellite AIV Plan		Issue	Maint	
System Verification Control Matrix (VCM)		Issue	Maint	Maint
Non-Compliance Reports (NCRs)		Issue (as needed)	Issue (as needed)	Issue (as needed)
Request For Waivers (RFWs)		Issue (as needed)	Issue (as needed)	Issue (as needed)
Safety Data Package		Issue	Maint	Maint
Satellite Integration Logbook (SIL)		Issue	Maint	Maint
Mission Operations Plan		Issue	Maint	Maint
Ground Segment Acceptance Test Procedure			Issue	Maint
System End-to-End Test Procedure			Issue	Maint
Satellite Test Reports				Issue
Ground Segment Acceptance Test Report				Issue
System End-to-End Test Report				Issue

Coverage Zones
EWC Antenna Coverage with 0 dB Receive Antenna Gain (Zenith View)



Transmitter
Myers on US Lab zenith
17 dBm Tx power
Vertical polarization

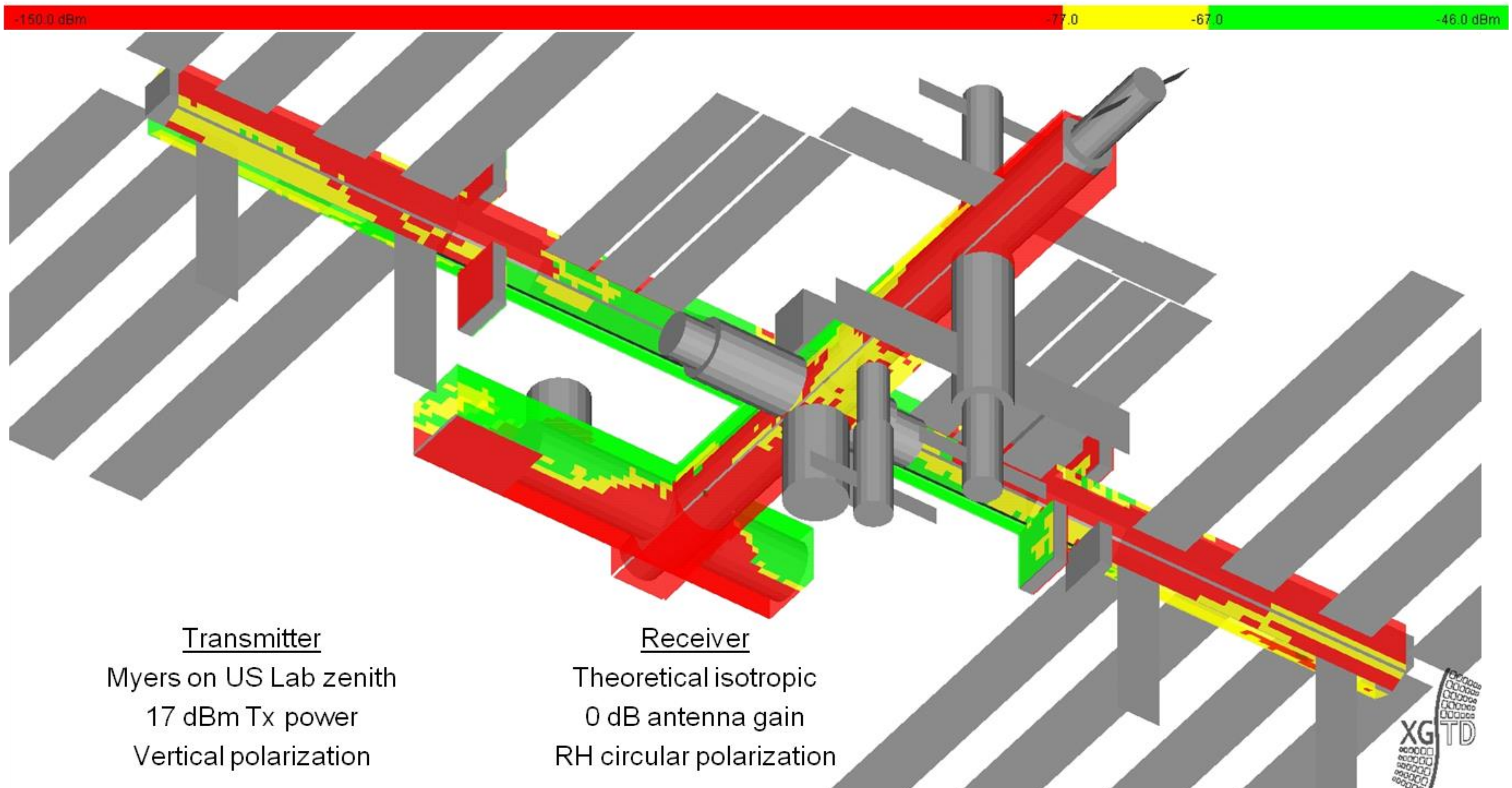
Receiver
Theoretical isotropic
0 dB antenna gain
RH circular polarization

Colors depict receive power levels from the EWC US Lab antenna at various locations along the ISS

Green = -46 to -67 dBm, Yellow = -67 to -77 dBm, Red = -77 to -150 dBm

Receiver sensitivity = -72 dBm (based on Ubiquiti test data)

Coverage Zones
EWC Antenna Coverage with 0 dB Receive Antenna Gain (Aft View)



<u>Transmitter</u>
Myers on US Lab zenith
17 dBm Tx power
Vertical polarization

<u>Receiver</u>
Theoretical isotropic
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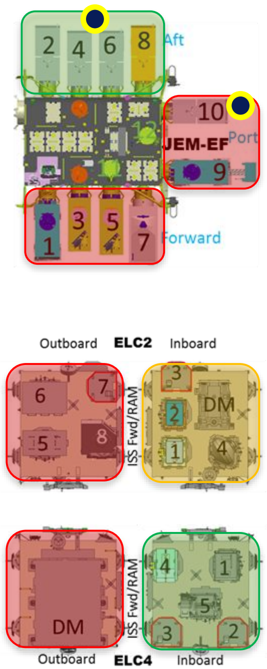
Baseline EWC

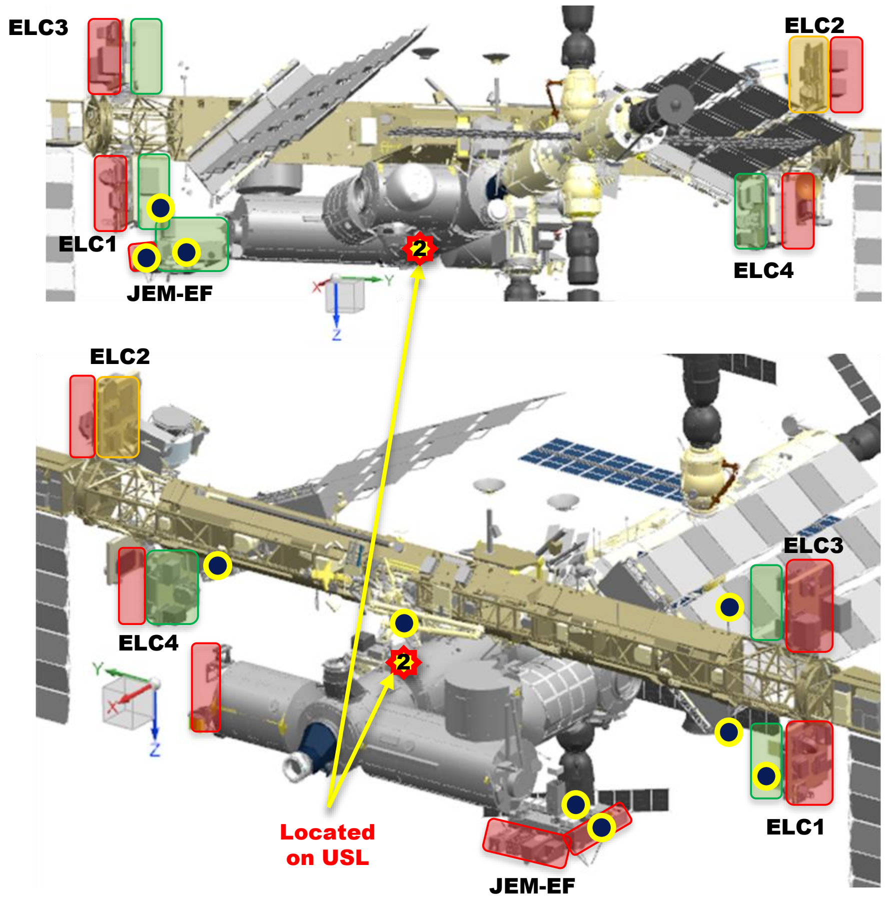
Payload Site Coverage*

- Full Coverage
- Partial Coverage
- Potential Coverage w/Deployable Antenna

- Wi-Fi User
- EWC Antenna (qty)

*Wi-Fi Coverage is also available at locations between antenna and covered payload site.



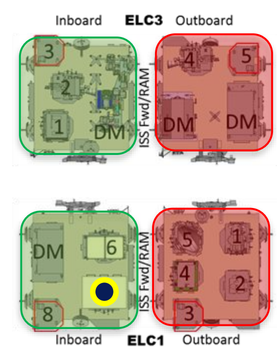


Service Provided

- Wi-fi - 802.11N
- 50 Mbps per WAP (shared)
- 100 Mbps per WAP w/MIMO (shared)

After increased rates implementation:

- Wi-Fi – 802.11AC *(2019-20)*
- 150 Mbps per WAP (shared)
- 300 Mbps per WAP w/MIMO (shared)



EWC Components

- Two Zenith Antennas
- Two Nadir Antennas
- Two USL WAPs

Planned users within coverage zone

- NREP (JEM-EF aft) – 8 Mbps
- MUSES (ELC Starboard Nadir Inboard) – 20 Mbps
- 4 EHDCs (ETVCG CPs) - 8x4 (32 Mbps total)

“Full” Coverage EWC

Payload Site Coverage*

Full Coverage

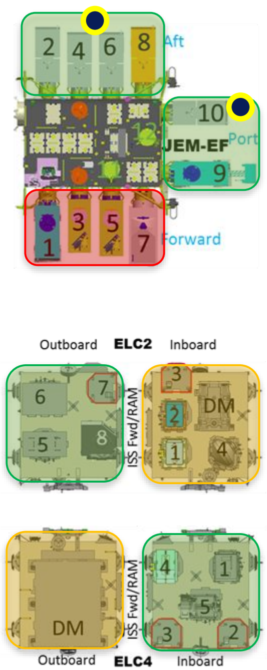
Partial Coverage

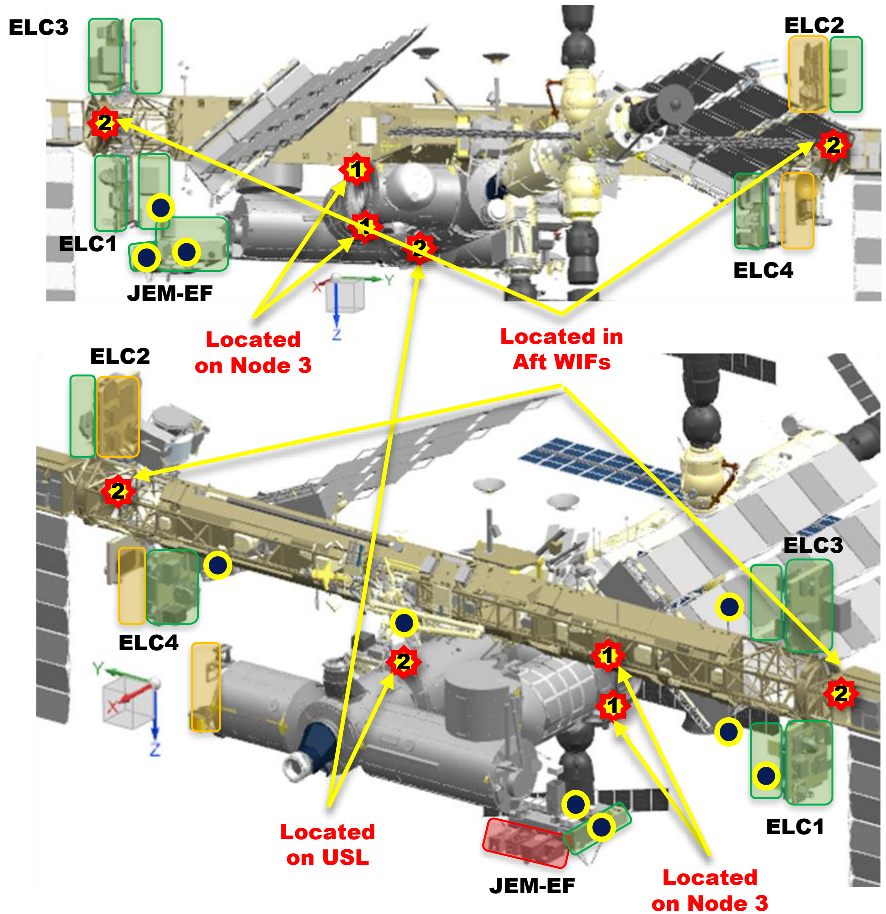
Potential Coverage w/Deployable Antenna

Wi-Fi User

EWC Antenna (qty)

*Wi-Fi Coverage is also available at locations between antenna and covered payload site.





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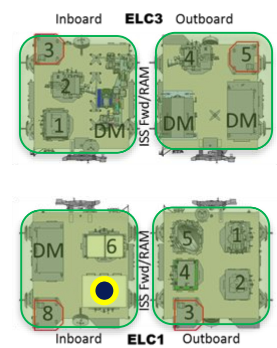


EWC Components

- Baseline EWC
- Node 3 EWC *(2017)*
- Outboard EWC using EHDCs on C2V2-like booms *(2017-18)*

Planned Users within Additional Coverage Zones

- NREP (JEM-EF aft) – 8 Mbps
- 2 Port EHDCs (ETVCG CP8&9) - 8x2 (16 Mbps total)
- ECOSTRESS – 3-20 Mbps

Technical Considerations

- Requires ethernet and power cable runs
- Thermal environment with EHDC design

"Full" Coverage EWC w/CP EHDCs

Payload Site Coverage*

Full Coverage

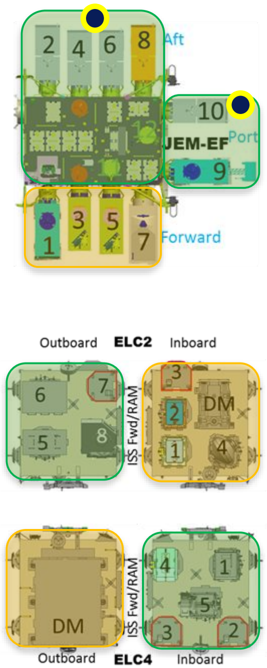
Partial Coverage

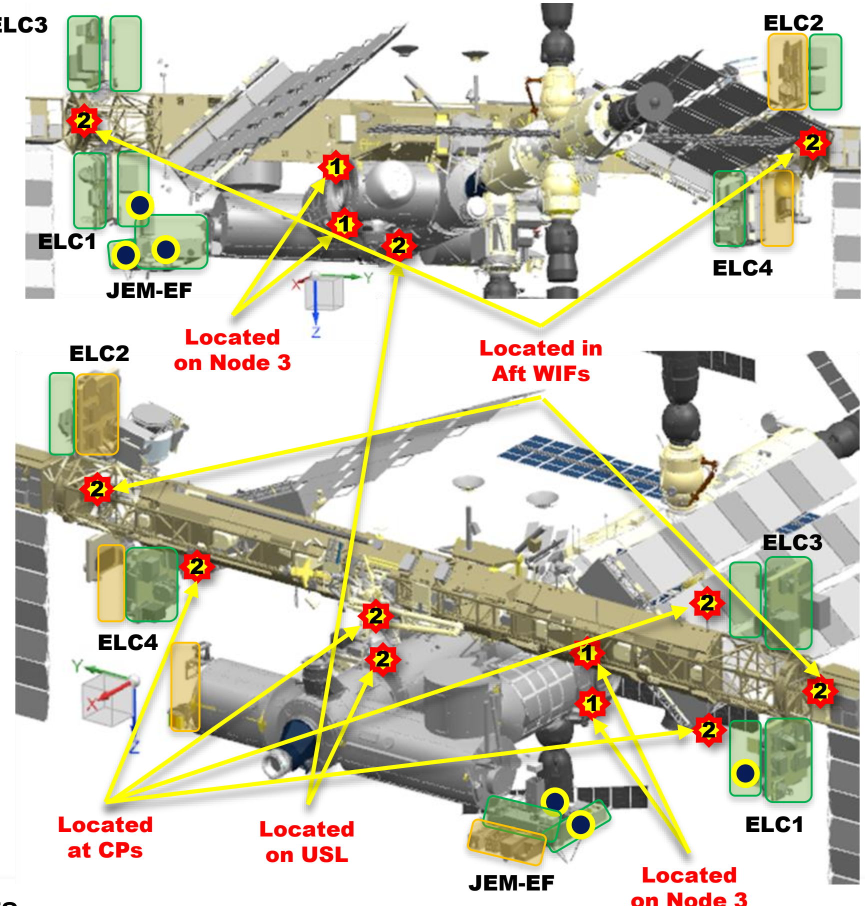
Potential Coverage w/Deployable Antenna

Wi-Fi User

EWC Antenna (qty)

*Wi-Fi Coverage is also available at locations between antenna and covered payload site.





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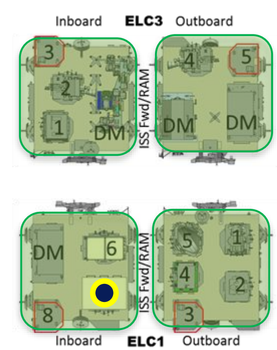
- 100 Mbps per WAP w/MIMO (shared)

After increased rates implementation:

- Wi-Fi – 802.11AC *(2019-20)*
- 150 Mbps per WAP (shared)
- 300 Mbps per WAP w/MIMO (shared)



EWC Components

- Full Coverage EWC
- EHDCs at four camera ports (CPs) *(2017-18)*

Benefits

- Eliminates four system users of Wi-Fi freeing up bandwidth for more payloads
- More WAPs equals more capacity (# users, data rates) and more robustness in failure scenarios
- Improved ISS spehrical coverage for mobile users and non-payload sites
- Maximize camera investment

Technical Considerations

- Requires additional ethernet cable runs
- Thermal environment with EHDC design
- Coverage varies with camera pointing