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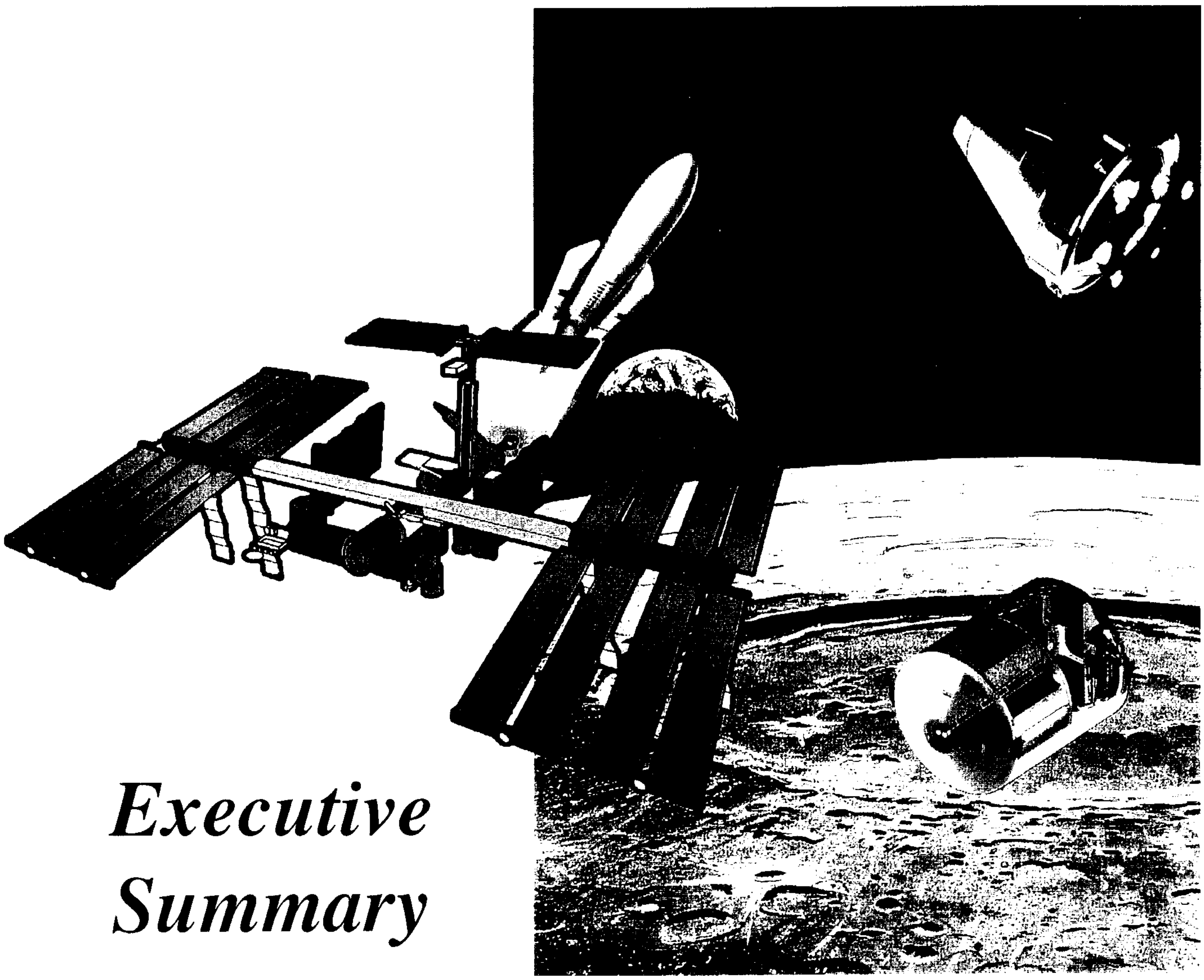
Evolutionary Space Station Systems for an International Exploration Programme
EVE Study



Executive Summary

SD-RP-AI-0224

September 1997

EXECUTIVE SUMMARY

TITLE: EVOLUTIONARY SPACE STATION SYSTEMS FOR AN INTERNATIONAL EXPLORATION PROGRAMME (EVE)
ESA/ESTEC Contract: 12180/96/NL/FG

DRL Item or D.R.D. No:

SIGNATURE AND APPROVALS ON ORIGINAL

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EUROPEAN SPACE AGENCY CONTRACT REPORT
The work described in this report was done under ESA contract. Responsibility for the contents resides in the author or organisation that prepared it.

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DATA MANAGEMENT:

DOCUMENT CHANGE RECORD

ISSUE-DATE	REASON FOR CHANGE	AFFECTED PARAGRAPHS
01 15-SEPT-97		

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1. FOREWORD

This Executive Summary has been prepared by Alenia Aerospazio, with contributions by Aerospatiale, for the European Space Agency in accordance with the requirements of the ESTEC contract 12180/96/NL/FG, covering the analysis and selection of the European ISS systems and technologies which might be adapted for application to an International Exploration Programme.

Main objectives of the study were:

- Review of Moon Mission Scenarios w.r.t. the International Moon Exploration Scenario
- Analysis of European ISS systems / technologies and selection of few items which may be proposed as ESA contributions to an International Moon Programme taking into account also Mars applicability
- Assessment of ISS use as a testbed for the selected items
- Definition of a global plan for ESA initiatives to ISS and Moon.

The coherence of the study "Evolutionary Space Station Systems for an International Exploration Programme - EVE" with respect to the parallel study "Adaptive Space Station Systems for an International Moon Programme - ADAM" was guided by the EVE focus on the analysis of the Moon mission scenarios with particular regards to Phases 3 and 4 of the International Moon Exploration Scenario, and by a top-down approach from the Moon mission scenarios' requirements to the potential adaptation of European ISS elements/technologies.

ESA/ESTEC Study Manager was Mr. A. BICHI.

Main contributors to the study were:

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2. INTRODUCTION

The main objective of the performed study "Evolutionary Space Station Systems for an International Exploration Programme (EVE)" is to identify European technologies and/or items under study or development for use in the International Space Station Programme that could be adapted and regarded as potential European candidates for application to an International Moon Exploration Programme.

Different Moon mission scenarios have been reviewed at the light of current plans for lunar exploration, and reference architectures have been examined to sort out the functional and performance requirements of the various infrastructure elements.

A parallel process has been performed taking into account the functional and performance requirements of the European contributions to the International Space Station, to identify the most suitable candidates for adaptation to Moon applicability.

3. MOON MISSION SCENARIOS

During the last years, a renewed interest in lunar exploration has been shown at world-wide level and a variety of mission scenarios has been discussed. At the beginning of 1994, an important contribution to the exploration of our satellite was given by the Clementine mission, that provided invaluable information concerning the topography and the element distribution and abundance in the lunar regolith, opening up new exploration paths in the vicinity of the lunar South pole for the search of ice in permanent-shaded craters.

In the same year, at the 1st International Lunar Workshop held in Beatenberg, Switzerland, ESA presented a 4-step scenario for a return to the Moon (see Table 3-1), that was then endorsed as reference International Moon Exploration scenario by the International Lunar Exploration Working Group (ILEWG). The plan proposes starting with probes soon after the turn of the century and moving rapidly toward a crewed lunar base that could be in place before 2020 [1]. The Declaration of the Workshop, reaffirmed at the "2nd International Lunar Workshop", held in Kyoto, Japan, in 1996, made it clear that "rich opportunities are offered by the exploration and utilisation of the Moon" and emphasised the uniqueness of the Earth-Moon system and the potential of the Moon as a natural long-term space-station [2, 3].

Phase I Lunar Resource Explorer	Chemical inventory of the Moon including water, carbon High resolution mapping of the surface. Inertia investigation of the polar region. Technology development for later phases	Polar Orbiter Satellite & Orbiter and polar lander
Phase II Permanent robotic presence	Telepresence (including poles and farside), remote chemical analysis, geophysical observation and survey, assessment of the environment, install pilot radio astronomy instrument, active seismology, resource exploration	Rover system with unlimited range and lifetime (possible supply of new experiments serviced by rover)
Phase III First use of lunar resources and environment	Oxygen production, investigation construction techniques, investigate life support, first biological experiments including eco-systems, install large astronomical instrument (VLFA)	Materialab Biolab VLFA
Phase IV First human outpost	Build-up lunar outpost, install scientific laboratory, install sub-mm interferometer, geological investigation, improve outpost capabilities	Initial human mission (most likely at high latitude)

Table 3-1 International Moon Exploration Scenario

The first phase of the proposed scenario - *Lunar Resource Explorer* - , whose reference timeframe could be from 2000 to 2005, focus on the robotic exploration of the Moon to gather a resource inventory and to acquire a full and detailed knowledge of the lunar surface, and also to demonstrate key technologies for the next phases.
Typical mission scenarios in this phase include an orbiter/lander mission like the recently proposed Euromoon-2000, that foresees a landing mission of a 1250 kg spacecraft on the rim of the Aitken Basin near the lunar South pole. Other planned missions in this phase are the Lunar Prospector (USA) and the Lunar-A (Japan), scheduled for launch in the next months [4 - Appendix 1].
The infrastructure size estimation for these missions is 1 ton spacecraft with few hundreds kg P/L landed on lunar surface that can be satisfied with an AR5-class launcher.

The second phase - *Permanent Robotic Presence* - focus on robotic operations on the lunar surface including telepresence, remote chemical analysis, resource pilot plant demonstration, pilot radio astronomy instrument installation. Mission scenarios to support these objectives should foresee extended operation range/lifetime rover missions with a robust robotic autonomy capability and surface means logistic resupply missions.

The third phase - *First Use of Lunar Resources/Environment* - focus on the exploitation of in-situ resources with particular regard to lunar Oxygen, and on the installation of large astronomical instruments.
Typical mission in this phase would have to land laboratories/plants for material production and to support the build-up and operations of automatic astronomical observatories. Further significant life-science experimental activities would be required in preparation of the outpost development.

The infrastructure size estimation for phases 2 and 3, whose reference timeframe could be from 2005 to 2015, is a 2-3 ton spacecraft with the capability to land about 1 ton P/L on the lunar surface and requiring multiple AR5-class launches.

The fourth phase - *First Human Outpost* - foresees the installation of a human outpost on the Moon, requiring large-scale surface operations for the outpost build-up and development and for the operations of systems supporting autonomous life there, such as oxygen production, life support and environmental control systems.
The infrastructure size estimation points at a 10-20 ton spacecraft capability both for crew and cargo, implying the need of an Heavy Lift Launch Vehicle.

Starting from the SYSTEMSI Study review [5], potential mission scenarios to meet the objectives of each phase have been analyzed, and a sort of road map has been proposed according to four major strategies: Science, Utilization, Settlement, and Toward Mars (Figure 3-1).

The outputs of the performed analysis have been summarised using Scenario Forms in which the following areas are addressed [4 - Appendix 2]:

-	Strategy	:	main strategic objectives
-	Basic Assumptions	:	mission type / cooperation scheme
-	Description of Mission Scenario	:	mission objectives / time frame / phasing
-	Required Infrastructure	:	elements identification
-	Operational Characteristics	:	logistic needs / degree of automation
-	Programmatics	:	timescale / cost projection.

A system-level functional analysis has been performed to individuate the required infrastructure elements for each scenario. Table 3-2 shows the required elements in case the Utilization strategy is selected.

UTILISATION SCENARIO							
		SU-01	SU-03	CU-01	CU-02	CM-02	CM-06
MISSION PROFILE		2	6	2/4.2	4.2	8	8
Transportation Infrastr.	Medium Lift Launch Vehicle	X	X	X	X	X	X
	Heavy Lift Launch Vehicle				X	X	X
	Shuttle or RLV					X	X
	Orbit Transfer Stage	X	X	X	X	X	X
	Automatic Scientific Lander		X	X			
	Unmanned Logistic Lander			O	X	X	X
	Manned Lander					X	X
	Crew Module					O	O
	Crew Transport & Reentry Module					X	X
	Cargo Automatic Return Module		X		O		
LEO Infrastructure	Assembly & Servicing Facility		O		O	X	X
	Sample Storage / analysis facility		O				
	Propellant storage				O	X	X
	Crew training facility					O	O
	Crew quarantine facility					O	O
Lunar Orbit Infrastr.	Data relay satellites		X	X	X	X	X
	Lunar transport node						
	Automatic orbiter	X					

Table 3-2 Utilization Scenario Required Infrastructure

4. MISSION PROFILES

For a proper identification of the infrastructure elements relevant to Transportation, LEO and LLO segments, a key point is to analyse different mission profiles to launch, transport, land, and possibly return to Earth, the required elements.

When travelling to/from the Moon, various intermediate steps can be considered, corresponding to an "energy level", transfers between each step being performed through orbital manoeuvres:

- LEO or GTO orbits: they can be used as intermediate parking orbits before transfer towards the Moon, either for operational reason (checks, accuracy, preparation) or due to launcher performance constraints (e.g. needs for in-orbit assembly).
- LTO orbit: this is the transfer orbit from Earth influence sphere to Moon influence sphere.
- LLO orbit: a Low Lunar Orbit, reached by a braking from LTO, can also be used for Lunar Landing preparation (e.g. site final selection, orbit correction, etc.,...)
- ETO: in case of a return from the Moon, the Earth Transfer Orbit is the opposite of LTO one.

The manoeuvres to be performed to transfer between these levels are summarised, in terms of ΔV, in the following table.

	Transfer Manoeuvres m/s
LEO - LTO	3150
GTO - LTO	1200
LTO - LLO	870
LLO - Moon	2100
Moon - LLO	1920
LLO - ETO	870
ETO - LEO	3150

Table 4-1 Required Delta-Vs

When combining the various possible intermediate steps, 9 families of operational profiles have been identified, the most complete of which is shown in Figure 4-1.

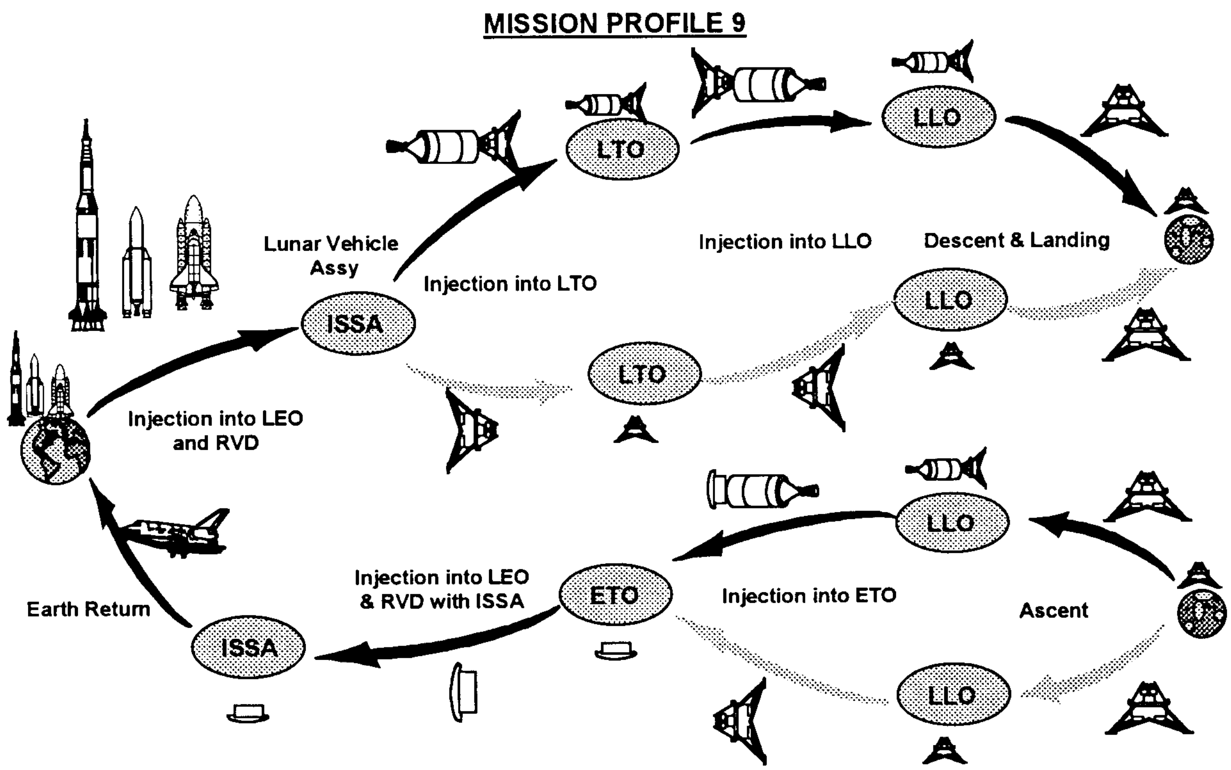

Figure 4-1 Mission Profile 9

5. EUROPEAN ISS CONTRIBUTIONS

The main objectives of this task were to review of the planned European contributions to the International Space Station and to compare the major functional and design requirements between ISS items and those which would be applicable to Moon missions to identify few strategic items and/or technologies that could be adapted to Moon mission applications.

5.1 TRANSPORT & SERVICING ISS ITEMS

5.1.1 Crew Transfer Vehicle (CTV)

The CTV baseline mission is [6] :

- to transport a crew of 4 to ISSA and perform an atmospheric re-entry;
- to reboost the space station;
- to transport up to 200 Kg of payload (in addition to the crew) ,
- to provide an "only cargo mission" with a 1.5t pressurized payload capability.

The CTV mission is an "A5 single launch" w/o fairing. The staging of the vehicle is the following :

- The LES (Launch Escape System) on the top of the CTV is used (with the help of micro extractor) for safeguard during the launch phase.
- The CTV is a bi-module : Crew Module (CM) + Resource Module (RM).
  - The CM is a two skins structure with a rear cone angle of 20° (to keep a minimum deceleration rate) and a 4.4m diameter. The pressurized cabin is the load carrying structure through which all the loads are transferred to the RM. The external structure supports the thermal protection and the aerodynamics loads.
  - The RM is fixed at the bottom of the CM and hold all the necessaries life functions. The RM is mainly composed of a cross structure and a load carrying skin between the 4.4 diameter of the CM and the 5.4m diameter of the Transfer Vehicle (TV).
- The TV is fixed at the bottom of the RM. It is a propulsive module and is composed of an external load carrying structure interfacing with A5.

5.1.2 Crew Rescue Vehicle (CRV)

The CRV baseline mission is :

- to carry back in an emergency case a crew of 6 to 8 after a TBD period attached to ISSA;
- to transport up to 200 Kg of payload in addition to the crew down from ISSA.

A CRV mission is an "A5 single launch" under fairing. As far as the staging of the vehicle is concerned, a TV can be used but the CRV can be transported with an other launcher.

5.1.3 Automated Transfer Vehicle (ATV)

The ATV baseline mission is [7] :

- to refuel and reboost ISSA from 350 km to 450 km at 51.6°;
- to deliver pressurized cargo to the Russian side of ISSA (DRM4 mission) with a 5.5t dry cargo up and down (after a 6 months attached phase to ISSA).

This nominal mission can be deviated in 4 different missions cases:
Case 1: Delivery of all types of cargo.
Case 2 : Delivery of reboost and dry cargo only (removal of platform with refuel/water/gas tanks).
Case 3 : Different mission from DRM-4 (reboost tanks not installed).
Case 4 : Different mission from DRM-4 (reboost tanks installed and filled).

The staging of the vehicle is the following :

- "Spacecraft" composed of the Ariane5/ATV separation system, the main propulsion module, the reboost section, and the equipped avionics bay.
- "Cargo Carrier" composed of an unpressurized section (platform carrying the refuelling, water and gas tanks), and the Pressurized Module.

5.1.4 Return Capsule (SPARC)

The SPARC concept [8] is not a ISSA planned item. The above values are preliminary values and show that SPARC is well suited for early Moon phases. Nevertheless it can be used for small payload re-entry (at a reduced cost) during phase III and IV.

5.2 SPACE STATION ITEMS

5.2.1 Columbus Orbital Facility (COF)

The COF is configured as a general purpose laboratory and is permanently attached to ISS [9]. During its operational life it relies on station resources for structural attachment, power, waste heat rejection, contamination monitoring and control and control and data communication to ground.

The external configuration is a two segment cylindrical module with an overall length of 6.6. metres. The forward cone accommodates the passive part of ISS Common Berthing Mechanism. The module is covered by a multi-layer insulation assembly for thermal insulation and by a meteoroid and debris protection system for protection against the space environment. For the on-orbit assembly of the module by the Space Station Remote Manipulator Arm (SSRMS) to Node 2 , a Power Data Grapple Fixture is attached to the outer shell.

The COF internal configuration accommodates in the 4 quadrants of the module, 8 ISPRs (International Standard Payload Racks) in lateral position, 2 ISPR's plus 2 storage racks in the ceiling and 1 storage rack in the outboard part of the floor. In addition to the 3 storage racks used for space station system and crew items storage, the COF provides storage volume for its systems, consumables and maintenance tools distributed throughout the module.

Subsystems are accommodated in the remaining floor space on hingeable structures and on panels attached to the cones.

5.2.2 Mini Pressurised Logistics Module (MPLM)

The MPLM is configured as a transportation module carried by the US Shuttle Orbiter that can be attached to ISS for a period of about 2 weeks each mission. During its operational life it relies on Shutlle or Station resources for the proper operations [10].

The structure is similar to the one utilised for COF.

5.2.3 Space Greenhouse

A Controlled Ecological Life Support System (CELSS) will be required to provide life support to crews during long-duration space missions on-board the Space Station, at the lunar outpost, or on-board a Mars spaceship.

Research activities in this field have been performed in USA, Russia, Japan, and Europe, and considerable technological progress has been made in the development of controlled environmental facilities for food, oxygen, water, and waste recycle.

The ESA MELISSA (Micro-Ecological Life Support System Alternative) system has been conceived as a micro-organism based ecosystem intended as a tool for developing the technology for future artificial ecosystems. The driving element of MELISSA is recovering the edible biomass from waste, CO2, and minerals with the use of sun light and energy source [11].

5.2.4 Robotics

Robotic support on the Moon surface is felt absolutely necessary both during the automated missions and also during missions involving a crew . The expertise developed in this field to satisfy the needs of the International Space station can be fruitfully applied to Moon mission applications previous suitable adaptations to the different lunar environment [12].

Two major steps are planned for ESA activities under the perspective of robotics support on ISS:

- the European Robotic Arm (10 meter class) mounted on the ISS Russian segment first for assembly tasks and later on for the Station servicing and maintenance operations [13];
- the flight demonstration of SPIDER robotic system (2 meter class) in the frame of JERICO experiment to be performed on board the Russian MIR Station [14].

5.2.5 Laboratory Support Equipment

Space Station laboratory support equipment might be used to support lunar surface operations like antenna or astronomical instrument pointing

The Hexapod system is intended to provide a stable pointing platform to the NASA instrument SAGE III on board the International Space Station, compensating the attitude errors generated by the ISS. SAGE III requires to be aligned along the local Vertical (Nadir pointing) to be able to look forward the Earth limb at the Sun or the Moon light through the atmosphere in order to analyse the main gas components.

The Hexapod is composed of six electromechanical linear actuators disposed so as to form three contiguous "V"'s between two reference planes as upper and lower platform; one of the two platforms is fixed to the carrier, the relative position of the other is univocally defined by the length of the six linear actuators [15].

The Coarse Pointing Device (CPD) is a pointing mechanism intended for scientific payloads which need a coarse pointing toward the Sun. It will be mounted on a specific ISS EPA, Zenith-oriented, and will allow Sun observation for periods of at least 15 minutes on average per orbit, for a total of 600 hours over a year [16].

5.2.6 Rendez-vous and Docking Technology

Another important technology that has been assessed in the frame of the study is the autonomous on orbit RVD capability with a manned station that is one of the challenging requirements for the ATV [17].
Attention is also currently devoted to the Monoeuvring Inspection Vehicle (MIV) rendezvous simulator development [18].

5.2.7 Tether Technology (TATS / TMM&M)

A tether facility - Tether Assisted Transportation System (TATS) - has been recently proposed to be installed on-board the Space Station, and a European tether mechanism has been developed (TMM&M).
The tether technology could be usefully employed also in a programme of lunar exploration to support in-orbit measurements and surface operations [19].

5.2.8 Laboratory Facilities

Laboratory facilities developed for the Space Station could constitute a valuable know-how in preparation of different Moon mission scenario applications.

The Technology Exposure Facility (TEF) is aimed at providing exposure to a wide range of technology research and development investigations [20]. The TEF will be accommodated on the ISS EXPRESS Pallet via an EXPRESS Pallet Adapter (EPA). The TEF is in the form of two "walls" consisting of instrument modules. The walls are parallel to the flight direction, and are made of up to 8 (TBC) modules in two rows of four (TBC). Between the walls runs a rail mounted arm with a fixed length stand-off bringing the second joint above the wall height. As this stand-off is fixed in all operations phases, it must respect the height envelope. With a realistic limb diameter and suitable clearances, this restricts the wall height to a maximum of 1000 mm.

The Fluid Science Laboratory (FSL) includes in its utilisation scope the research in the field of the transparent (liquid and gaseous) fluids submitted to different thermal, mechanical, electrical stimulations. Several replicas of the same experiment as well as long-duration experiments will be possible, availing of a rich and sophisticated diagnostics set, above all in the field of optical instrumentation [12].

Biolab is a multi-user, highly modular facility intended to allow the scientists to perform a wide ensemble of experiments in the fields of gravitational biology and space radiation effects on such small-size biological materials as plant seedlings, small invertebrates, cell cultures and micro-organisms. The lowest tier elements of the Biolab hierarchy are its Experiment Containers, hosting the biological samples [12].

The modularity architecture of the Material Science Laboratory (MSL) will permit it to successfully face on-orbit reconfiguration issues, so as to meet evolving requirements levied from the scientific users in the field of e.g. metallurgy, glasses, semiconductors [12].

The integration of a Human Physiology Research Facility in the Columbus Orbiting Facility could be pursued in cooperation with the European national agencies [12].

5.3 ADAPTABILITY TO MOON INFRASTRUCTURE ELEMENTS / TECHNOLOGIES

Out of the comparison of the main functional and performance requirements of the European ISS elements and technologies with the "corresponding" Moon infrastructure elements requirements, the following **adaptability** table has been derived:

	Moon Infrastructure Elements	**European ISSA Elements**
Transport and Re-entry Vehicle	Crew Transfer Re-entry Module (CTRM) Cargo Automatic Return Module (CARM)	CTV, CRV "Cargo CTV" SPARC (P/L up to 50kg)
Transfer Stages	Orbital Transfer Stage (OTS)	ATV, TV
Landers	Manned Lander (ML), Unmanned Lunar Lander (ULL)	ATV derivative for descent or ascent stage ?
Habitation Technologies	Habitation Module (HM)	COF, MPLM
Robotics	Robotic Arm	JERICO, TEF, ERA
Pointing Devices	Astronomical Pointing Devices	HEXAPOD, CPD

Table 5-1 European ISSA Elements Adaptability

In general, a certain adaptability (with necessary upgrades) exists between the CTRM/CARM and the CM+RM modules (CTV concept). The CTV/CRV concept (except the TV) is a potential candidate for the migration from the ISSA elements to a Moon program element. On the other hand, the TV/ATV concept for a OTS use is not recommended: the need for cryogenic propulsion prevents from any high commonality.

As for habitability aspects, the know-how and technology derived from COF and MPLM could be a starting point for the development of an habitat suitable for lunar environmental conditions .

Key technologies in support to the different objectives of the international Moon exploration scenario phases are robotics and teleoperations. Due to the fact that the launch capability limits will imply the need of in-orbit assembly of the lunar surface infrastructure major elements, automated rendezvous and docking capability will be a must.

The adaptability of the European ISS contribution has been evaluated with respect to the needs of each phase of the Moon Exploration Scenario as shown in the following table as far as Phase IV is concerned.

MOON SCENARIO PHASE IV	SYSTEM NEEDS	SUBSYSTEM NEEDS	ISS AVAILABILITY / ADAPTABILITY
Transport Infrastructure	Heavy Lift Launch Vehicle		New Launcher
	Orbital Transfer Vehicle	RVD, Cryogenic propulsion, Power generation, communications and data handling, GNC and control	ATV
	Unpressurized Lander (Scientific / Logistic)	Landing system (gears, air bag, crushable structure)	The P/L could be derived from the "Cargo CTV"
	Manned Lander	Landing system, environmental control, habitability	The habitat module could be derived from the CTV
	CARM	Thermal protection (upgraded heatshield, aerobrak.) Earth landing (ballistic parachutes, airbag, etc.)	Derived from CTV/CRV SPARC for small P/L
	CTRM	Thermal control, re-entry, life support	Upgraded CTV
Surface Infrastructure	Data Relay Satellite	Communications	YES
	Power Gener. - Nuclear Power Plant	Power Generation / Storage / Control, Nuclear technology	YES (Storage), NO (Generation, Nuclear)
	Unpress. Rover (with extended range)	Robotics, Teleoperations / Virtual Reality	ERA, JERICO, TEF
	Mining Equipment	Robotics, Teleoperations / Virtual Reality	ERA, JERICO, TEF
	Resources Production Plants	Robotics, Teleoperations / Virtual Reality, Material Laboratory	ERA, JERICO, TEF, Fluid Science Lab.
	Large Astronomical Instruments	Robotics, Teleoperations / Virtual Reality, Tether technology	ERA, JERICO, TEF, TATS / TMM&M
	Robotic Means (unloading / digging)	Robotics, Teleoperations / Virtual Reality	ERA, JERICO, TEF
	Pressurised Rover	Robotics, Habitat/ECLSS	ERA, JERICO, TEF, COF
	Habitation	Habitat, ECLSS, CELSS	COF, MIRIAM, MPLM, Greenhouse
	Laboratory	Habitat, ECLSS, Life science experiments	Biolab, COF, MIRIAM, MPLM

Table 5-2 Moon Programme Scenario - Phase IV - Elements

6. ISS AS A TEST BED

To check the "adaptability" of the selected ISS items and technologies to Moon mission scenarios, ad-hoc demonstration / evaluation initiatives could be performed in the context of the International Space Station.

6.1 ATV DEMONSTRATION INITIATIVES

From the analysis described in the previous paragraph, two types of evolutions from ATV are envisaged [7]:

- **Vehicle for LEO assembly** —> **ATV enhancement**
- **1t class lunar lander** —> **ATV technology derivation**

The non exhaustive following list counts up the necessary modifications:

- ATV enhancement for LEO assembly
  - Main and AC upgraded propulsion (to handle 20t stage weight instead of the nominal 9t cargo carrier)
  - Upgraded guidance and control (RVD + robotic arm)

- ATV derived technologies for Lunar Lander
  - Main and AC upgraded propulsion and variable thrust capability
  - Upgraded guidance and control (transfer and landing phase)
  - Upgraded navigation (transfer and landing phase)
  - GNC vision based dedicated to the LTO-LLO transfer and the Moon landing phase

Two ways for demonstration initiatives for or using ATV are available :
- **Demonstration of specific technologies during an ATV Logistic Flight**
- **Specific ATV missions for procedures and technologies validation / rehearsal**

Demonstration of Specific Technologies During an ATV Logistic Flight

- **Candidates:**
  - propulsion : variable thrust
  - Lander configuration (e.g. architecture with more engines)
  - vision based GNC
  - LLO deorbit and Lunar descent simulation
  - new power generation (e.g. deployable solar arrays)

- **Advantages:**
  - marginal cost : main mission is the logistic flight, paid by the station
  - several flight opportunities : at least one per year

- **Drawbacks :**
  - constraints from ISS could reduce the possibilities of testing
  - the modifications of ATV for the demonstration should not reduce the logistic performance
  - the demonstration part of the flight should not impact the POMS of the Logistic mission

Specific ATV Missions for Procedures and Technologies Validation / Rehearsal

- **Candidates :**
  - LLO deorbitation : procedures, software, sensors
  - Lunar descent : procedures, software, sensors
  - new power generation (e.g. deployable solar arrays)
  - upgraded attitude control
  - robotics means for servicing

- **Advantages :**
  - no constraints from ISS operational environment
  - use of a "standard ATV" as a test bed : limited cost at hardware level
  - some commonalties could exist with other ATV evolutions : free-flyer, service vehicle, ...

- **Drawbacks :**
  - cost of launch
  - using an AR5 for testing the enhanced ATV only could be not mass efficient

For launch cost reason, the recommended way for demonstration is to make use of already planned ATV logistic flights. Figure 6-1 shows the proposed planning for the implementation and demonstration of ATV derived technologies for an automatic lander (it has been assumed a nominal ATV logistic flight average rate of 0.7/year).

ATV derived technologies for an automatic Lander

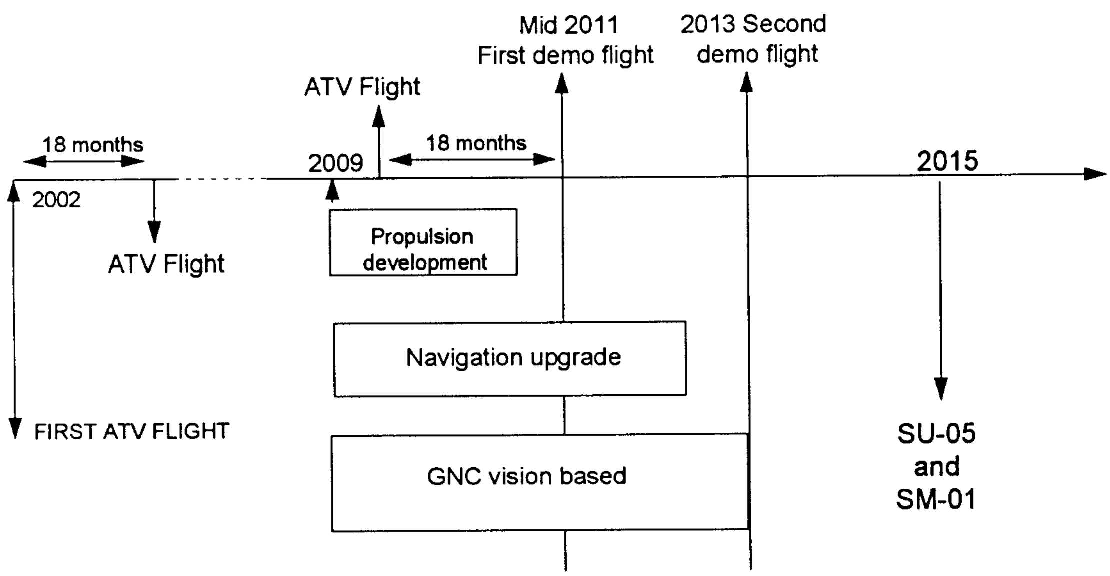

Figure 6-1 ATV Demonstration Initiatives

6.2 CTV DEMONSTRATION INITIATIVES

The applicability of the CTV to Moon mission scenarios is critical. Necessary modifications include:

- Thermal protection sizing for atmospheric re-entry from Lunar Return Trajectory
- Increased mission duration (up to 2-3 weeks) will request a technology change for power generation (solar arrays or/and fuel cells)
- Re-entry GNC to be adapted for return from Moon trajectory : narrow corridor, higher loads and torques
- Crew accommodation and interfaces to be evolved to cope with Lunar environment constraints (1/6 g)
- Pressurised volume to be validated for several depressurization / pressurization (CM will act as an airlock for the Moon surface)
- Structure and lightening (the CTV is designed with large mass margins, thanks to AR5 performances in LEO, but the mass budget will be much more constraining for a Moon mission)

- Power generation (increased ECLSS duration, increased computer performances, increased reliability...)

Due to the present uncertainties on the CTV development schedule, it was not considered realistic to propose any schedule for the implementation of CTV upgrades for lunar application.

6.3 ROBOTICS DEMONSTRATION INITIATIVES

According to the International Moon Exploration Scenario [1, 2], lunar surface operations will be performed in a robotic way (automatic operations and/or teleoperations) during the first three phases. A robust robotic capability will also be required in Phase 4 to support the activities performed by the crew.

The expertise developed in this field to satisfy the needs of the International Space station with ERA, JERICO, and TEF will constitute the starting point to develop robotics systems that can operate in the hostile lunar environment.

Among the potential demonstration initiatives, it is worth to underline that the European Space Robotics will see in the next years (i.e., 1998-1999) two important milestones:

- the use of the European Robotic Arm (10 meter class) on board the ISS Russian segment first for assembly tasks and later on for the Station servicing and maintenance operations;
- the flight demonstration of SPIDER robotic system (2 meter class) in the frame of JERICO experiment to be performed on board the Russian MIR Station.

Ad-hoc simulation activities on-board the Space Station will allow to test the use of a robotic arm to perform specific tasks like grappling, moving small objects, performing electrical and mechanical connections, etc., typical of a robotic arm placed on a rover or on a lander.

The more demanding robotic support required to install larger astronomical arrays on the lunar far side or to prepare the site for the Moon Outpost development will likely be derived from terrestrial civil engineering construction means.

As for the validation of the tether technology, a ASI / ESA / Russia demonstration mission is scheduled to be flown in 1998 on the Russian Progress-M vehicle in one of its routine servicing flights to the MIR station.

6.4 HABITAT TECHNOLOGIES DEMONSTRATION INITIATIVES

An essential item of the lunar surface infrastructure required to support crewed mission operations is the one providing Habitation functions. Know-how derived from the COF, MPLM, and ATV C/C could constitute a valuable background for the design of the Habitation Module, of the Manned Lander, and of the Manned Rover.

It must be pointed out, though, that the Life Support and Habitability functions must be completely designed because they are not provided by the COF or by the MPLM. The same applies to resources provision that, except for data processing, are supplied by ISS.

In addition to simulation and testing of the necessary H/W, a manned mission to the Moon will benefit from simulation activities performed on-board the Space Station in the following fields:

- Environmental (reduced gravity, radiation exposure, temperature gradients, artificial ecosystem)
- Human-related (habitability, human factors, EVA, IVA)
- Technological (ECLSS, EVA Suit)

7. RECOMMENDATIONS

Few European contributions to the International Space Station seem to have the potential to be adapted for reuse within an International Moon Exploration Programme:

- ATV
- CTV
- Robotics Technology
- Habitat Technology

Simulation and testing activities of both H/W and technologies are required due to the complex nature of the International Moon Exploration Programme proposed scenario. Moreover, during any mission scenario definition, the choice between different potential alternatives is affected by strategic planning and timing decisions. From this point of view, the development of proper simulation programmes is necessary to better understand different options and for a coherent evolution of Moon exploration / exploitation mission scenarios.

It must be stressed that simulation and testing activities on-board the Space Station and/or in the ISS environment are seen as complementary to the ground-based ones.

As for the **ATV**, two potential evolutions are envisaged: a vehicle for LEO assembly and 1t class lunar lander.
It is recommended to test the required ATV enhancements/modifications during the already scheduled ATV logistic flights duo to the additional marginal costs and the frequent flight opportunities.
Suggested demonstrations include the propulsion subsystem, the vision-based GNC, LLO deorbit and Lunar descent simulation, and new power generation systems.

As for the **CTV**, possible enhancements are suggested for the thermal protection during re-entry phase and upgraded GNC and ECLSS. Due to the present uncertainties on the CTV development schedule, we considered that it is not realistic to propose any schedule for the implementation of CTV upgrades for lunar application.

The **robotics technology** is considered of utmost importance to support surface operations in any phase of the International Moon Exploration Scenario. The expertise developed in this field to satisfy the needs of the International Space station with ERA, JERICO, and TEF will constitute the starting point to develop robotics systems that can operate in the hostile lunar environment.

An essential item of the lunar surface infrastructure required to support crewed mission operations is the one providing **habitation functions**. Know-how derived from the COF, MPLM, and ATV C/C could constitute a valuable background for the design of the Habitation Module, of the Manned Lander, and of the Manned Rover.

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