DOCUMENT

CV M-Class Internal Review

CROSS SCALE

Technical and Programmatic Report

prepared by Review Team

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1 INTRODUCTION

Cross Scale is a Cosmic Vision M-Class candidate mission that has been reviewed in frame of the down-selection for the Definition Phase. The review has been conducted according to the procedure defined in document SRE-PA/2009/013, between September 1st and September 22nd.

This report summarizes the major findings on the most critical issues and associated risks identified by the review team.

2 BOARD COMPOSITION

The board composition is listed hereafter in Table 1.

Table 1: Board Composition and Functions

Name	Function	Directorate	Short
A. Gianolio	Chair	SRE-PW	AG
F. Burger	Chair Deputy	TEC-SYP	FB
P. Falkner	Secretary	SRE-PAP	PF
R. Biesbroek	Board Member / Mission Analysis	TEC-SYE	RB
P. Poinas	Board Member / Thermal	TEC-MIT	PP
B. Fransen	Board Member / Structure	TEC-MSS	BF
C. Philippe	Board Member / AOCS	HSF-EFS	CP
L. Popken	Board Member / TT&C and Data Handling	SRE_PAI	LP
B. Gramkov	Board Member / Payload	SRE-PBP	BG
D. Martin	Board Member / Payload	SRE-PAI	DM
R. Tosellini	Board Member / Programmatics	SRE-MP	RT
F. Safa	Observer	SRE-PA	FS
T. Passvogel	Observer	SRE-PT	TP
M. Taylor	Observer	SRE-OS	MT
A. Masson	Observer	SRE-OS	AM
A. Wielders	Observer / Payload Study Manager	SRE-PAP	AW

3 TECHNICAL – SYSTEM AND PLATFORM

3.1 System requirements

The Science Requirements Document (Sc_RD), despite not being formally subject to this review, has been checked. It has been noted that the Sci-RD is focused on measurement requirements. It has also been noted that science requirements are properly translated into technical engineering requirements

The Mission Requirements Document (MRD) has been reviewed and the following points have emerged:

- The onboard data storage volume requirement (driving the development of mass memory up to 1 Tbit) should be revisited.
- The MRD requirement of a 125m-distance-knowledge at electron scale cannot be properly traced back to the Sc-RD. This requirement drives the need for the inter-spacecraft link (ISL), but inconsistencies in the accuracy definition in different ranges have been identified. Additionally, the requirement could possibly be fulfilled by means of ground ranging.

The review team recommends that the requirement be reviewed and fully justified by the scientific community and the need for the ISL be duly justified.

The review team furthermore considers that the MRD should be updated prior to entering the subsequent phase.

The review team recommends a trade-off of the "science per buck" be performed by the scientific community, in order to identify the impact to the scientific return of a reduction of the number of satellites or of the payload complement.

The mission analysis is well prepared and well advanced in relation to the project status. The CREMA provided by ESOC is covering the mission in detail. If collision avoidance manoeuvres are considered as estimated maintenance manoeuvres, then a 100% margin should be applied. It is suggested in a later phase to confirm collision avoidance margins, but this poses no risk to the study as the Δv's are very low compared to other manoeuvres.

3.2 System design

The major design drivers identified by the review team are:

- The number of spacecraft (driving cost, integration time, stiffness of the stack/dispenser).
- The number of science instruments (driving schedule, complexity and AIV/AIT)
- Five different payload configurations (driving complexity of AIV/AIT)
- The 15 rpm spin (driving the development of a star mapper and proper balancing of the spacecraft).
- The target orbit of 10 x 25 Re (driving the need of a transfer propulsion stage).
- The data volume (driving the onboard data storage and development of 1 TBit mass flash memory)
- The data downlink (driving on board power and development of a toroidal X-band antenna)

- The inter-spacecraft link (driving development of the ISL equipment and mission complexity).
- The EMC requirements driving selection of materials, processes and driving integration, testing and calibration.

The review team considers the first four drivers to have a high impact on the mission design. Should a mission simplification be required, it is recommended to initially focus the task on those four points.

From the assessments of the architecture design, the solution proposed by TAS appears to be more suitable to fit the mission requirements. However it will need to undergo a thorough structural and mass assessment, since a stack of 7 spacecraft on top of a propulsion module is a first that was never developed nor flown before.

The dispenser solution of Astrium, despite yielding a lower spacecraft mass, is less credible due to the low detailing effort and already built-in “rescue measures” like the use of Lunar resonance in order to counterbalance launch mass problems.

In the Astrium study a modified LISA Pathfinder Propulsion Module is proposed. Lessons learnt from LISA Pathfinder (where the PM was “adapted” starting from a Eurostar 3000 platform) are not addressed (underestimated design modifications, cost overruns, delays in schedule, Eurostar commercial satellite not in line with ESA standards). In fact the changes needed for Cross Scale are so substantial (diameter 937 to1666, COG for P/L from 545mm to 2000mm, P/L mass from 500 to 1800 kg, additional large power subsystem) to suggest, or rather require, a new development.

The Astrium stick model FEM yields a lateral frequency of 14 Hz only, thus requiring a stiffening of the propulsion module. This implies a mass penalty on top of the 3500 kg currently estimated thus making the overall system not compliant with the launcher lift capability.

The Astrium design carries several inconsistencies that are likely to bring the total mass of the spacecraft beyond the lift capability of the launch vehicle.

In comparing the two industrial studies, the review team considers the TAS one more solid and carrying a medium risk compared to the high risk of the Astrium one.

3.3 Spacecraft design

In analysing whether the proposed spacecraft design is compliant with the requirements, the review team noted the following points:

- In the EADS study the carrier + S/C lateral Eigenfrequency is not compliant with the Soyuz requirement (14Hz instead of 15Hz + 15% margin) and the assessment is based only on simplified modelling.
- The stiffness of the TAS design is driven by the stacked CFRP cylindrical segments that are interconnected from bottom to top to form a central tube. The central tube

with a diameter of 1666 mm provides good overall stiffness of the design but the availability of a qualified launch adapter in this size is unclear.

- A lateral frequency of 17.5 Hz is based on a well-defined preliminary FEM. This frequency could be confirmed by the modal analysis with the provided FEM.
- Throughout the study, the sizing of the PM as well as the sizing of the base satellite structure was driven by the stiffness requirements, while trying to minimize mass. A verification of strength has been omitted, implying a potential need for mass increase during the definition phase.
- (TAS): The deep notch to 0.055g for the TAS design should be compliant with the equivalent sine loads derived from CLA. In case the notch is deeper than the equivalent sine spectrum, it shall be verified that the computed COG loads are below the quasi-static design loads. This shall be confirmed by preliminary CLA in the definition phase, which implies a potential risk in the sense that there might be a future need to strengthen the structure at the cost of an increased overall mass.
- (EADS): The relatively high COG position for the EADS design at 2.47 m above spacecraft to launch vehicle interface plane, relatively high bending moment at the spacecraft base
- (EADS): The re-use of the LISA PF PM, originally designed for a 937mm adapter, requires serious modifications of the PM in terms of diameter and shape (becomes conical) to become compatible with the 1666 adapter. From a design point of view, now it seems more logical to design a new PM from scratch with a lower COG position.
- Lateral Frequency Requirement: The lateral frequency requirement for the Cross Scale configuration on Soyuz-Fregat 2-1B equals 15 Hz, which is rather high as compared to for instance the Ariane-5 requirement (10 Hz). Given the high COG position of the configuration, this frequency requirement might be hard to meet and potentially could increase the structural mass in the definition phase.
- The Soyuz performance estimated by ESOC should be verified by Starsem. This could have a large impact on the spacecraft wet mass and is therefore a risk.
- (EADS): The use of the 35-m Ground station mandates the use of X-band. The impacts on the spacecraft and mission design of adopting X-band must be assessed by Astrium, whose design is based on S-band.
- Should the ISL prove to be necessary, the use of the same antenna both for the communication subsystem and the ISL is considered too high an element of risk and should be avoided.
- The assumed data compression factor of 10 is extremely high, while 4 to 5 is more realistic. Data compression will come at a price of additional processing resources depending upon the data and required reduction.
- FEM and TMM have been provided for TAS, only a very simplified structural information by EADS. Both EADS and TAS thermal designs are preliminary with more detailed modelling effort by TAS. The EADS thermal modelling is just enough to estimate the radiator area and heater power demand.
- The EADS concept does not consider additional power needed by the HPGP propulsion system (for heating up before operation).

- Thorough analyses of requirements were carried out by both TAS and EADS study teams with due consideration of similar missions (SCOPE, CLUSTER, THEMIS, MMS, MagCon). However some areas were not properly covered: the EADS study for example simply reports the Concurrent Design Facility (CDF) findings on the radiation assessment.

The review team considers that the limited level of maturity of the structural design could lead to an increase of the mass budget.

The review team considers the uncertainty on the Soyuz performance to be a potential show-stopper and recommends this issue to be clarified as a matter of urgency.

3.4 Resource budgets

- The harness mass budget in the TAS-F design is marginal.
- Allocation of balancing mass is not evident in the TAS-F budget.
- The accommodation of all subsystems and instruments boxes on both TAS and EADS spacecraft is questionable due to the limited space and volume available. A detailed analysis of the number of boxes and their effective accommodation taking into account e.g. harness bending radius and connectors has not been done.
- In the TAS design the power available is limited by the height of the solar panel and is marginal. An increase of power has a big impact on the mass budget.

The review team considers the mass, volume and power budgets to be very critical elements that could jeopardise the design proposed by both contractors.

3.5 Margins

- The typical 20% mass system margin is considered in the budgets provided, but equipment level 5/10/20 % margins are unclear, i.e. not identified or replaced by averaged numbers.
- Both design solutions, with the required 20 % system margin, come to within a few kg of the launch vehicle lift-off capability
- The stiffness requirement on the stack could drive the structural mass leading to a significant mass problem.
- The TAS-F solution has baselined a transfer without lunar resonance.

The review team considers the margins at equipment level insufficient and recommends clearer mass budget with margins to be provided.

The review team also observes that, whilst the current design in the TAS solution foresees seven structurally identical spacecraft, the mass budget criticality could be eased by strengthening the lower spacecraft and lightening the upper ones. This obviously poses limitations in the AIV and a proper trade-off should be performed.

The review team also recommends a trade-off to be performed by TAS on the use of lunar resonance due to the potential mass saving of up to 200 kg (at the cost of a 5-month increase in transfer time and increased radiation levels).

4 TECHNICAL - PAYLOAD

4.1 Payload Definition

The assumptions made during the industrial studies were based on a Payload Definition Document (PDD) dated Feb-2009. The definition of the instruments has however evolved in parallel with the assessment studies, leading to the update of, inter alia, power and mass budgets. Some changes resulted in lower values, but some in considerably higher values, as for example in the case of the Fields ACDPU mass.

An effort will be needed to consolidate the requirements and ensure consistency at system level.

For what concerns the power estimates, care should be taken to estimate primary power (i.e. correctly include DC-DC conversion losses and add margins).

The review team expresses concern on the inconsistency between spacecraft and payload interfaces that could become a show-stopper, especially for the mass budget.

4.2 Maturity and Heritage

All instruments have basic flight heritage, however most of them rely on modifications, mainly to reduce mass and power consumption and to cope with obsolescence of electronic components. These modifications are not considered critical at this stage, as for most of these alternatives exist (for instance if an ASIC development fails).

The two rather new developments are the common processors Fields Data Processing Unit (DPU) and Central Particle Processor (CPP). Whereas the Fields DPU's architecture is already well defined, the CPP design is still rather immature. In particular, redundancy is not foreseen and is it unclear how much processing power will be required to compress the complex datasets in order to reduce the data volume. Currently the link budgets assume a factor 10 compression, which has not been achieved on real data without considerable loss of information, and which may require a considerable amount of processing power.

The review team considers the technology readiness of the payload adequate to this stage of the project and sufficient to proceed, with the exception of the CPP, the design and budgets of which should be defined prior to proceeding into the subsequent phase.

Due to the high number of payload unit interacting amongst themselves, the review team recommends all interfaces to be properly documented prior to proceeding.

4.3 Development Schedule and resources

No instrument development schedule was provided, but given the expertise of the various instrument groups and the fact that they rely heavily on existing designs, no major problem is foreseen. Exceptions are again the common processors. The risk is mitigated in a first instance as specific development activities are foreseen in the TDP. Nevertheless interfaces need to be agreed as soon as possible and representative prototypes of the processors delivered to the instrument teams. The capability of the providers of the processing units to deliver the all models at the required time both to the spacecraft contractor and to the payload consortium has to be properly assessed.

Despite the heritage of the instruments, in consideration of the high number of instruments to be delivered in various models and of the tight system schedule and in the absence of a payload development plan, the review team considers the payload development schedule a high risk.

The review team recommends the payload consortium to provide a detailed development plan to verify compatibility with the system schedule.

5 TECHNOLOGY READINESS

For all Cosmic Vision M-class candidate missions the current TRL level required is 4 to 5, with TRL 5 to be definitely reached at the end of phase-B1 (end 2011).

The elements that have been identified that require further development are:

- Star mapper for 15 rpm (currently 10 rpm)
- Inter-spacecraft ranging system (ISL)
- Toroidal X-band antenna
- Mass flash memory for up to 1 TBit

None of the above developments are considered critical or technology-wise challenging, no new technology inventions are required but simply further development is desirable in order to reduce the schedule risk.

Off ramps have been identified for the four areas above, should any of the technology developments encounter problems:

- For the 15 rpm star mapper: reduced science return by spinning at 10 rpm (existing technology)
- Inter-spacecraft ranging system (ISL): ground based ranging (trade-off recommended anyway)
- Toroidal X-band antenna: accept reduced downlink data rate
- Mass flash memory up to 1 TBit: less flexibility of data selection (regions of interest).

The review board considers the development risk relative to technology low and the technology readiness to support a launch in the nominal 2017-18 timeframe satisfied.

6 PROGRAMMATIC REVIEW

6.1 Development plan and schedule risk

The model philosophies proposed by the two contractors are very much driven by the cost cap and schedule assigned to the mission. These two drivers are leading to a minimalistic approach in terms of number of models and the partially parallel integration of 6 S/C (TAS) up to 8 S/C (Astrium). Given the very high number of actors involved in the development, interface management and AIV, a more classical model philosophy would significantly reduce the overall risk.

6.2 Development schedule:

The development schedule for a launch in 2017 is overoptimistic and would require 1 year more time for integration.

The critical path is in the required parallel integration and verification of 6 to 8 spacecraft and in the timely availability of the high number of instruments in different models.

On the instrument side, CPP and ACDPU require a very early delivery to the instrument consortium for development and early verification of the individual instruments and to the spacecraft for the EM and real-time test-bench activities. In the absence of a detailed payload schedule, this is considered an element of high risk.

All science instruments would require a very streamlined delivery process with no delay to allow for the proposed stacked AIV/AIT. This is considered as high risk for the schedule.

6.3 Schedule robustness versus ESA implementation constraints

The schedule for 2017 is not realistic and hence not robust versus ESA implementation constraints. An early instrument AO is required for a more defined and final payload complement.

6.4 Schedule margins

Both industrial studies provided only a top-level schedule showing a generic 6-month schedule margin between FAR and launch. The review team considers the schedule for a launch in 2017 overoptimistic and considers that at least one additional year for integration would be required.

Despite both Contractors declaring compliance with the launch date of end 2017 and including a 6-month schedule margin, their schedules present common and multiple risks with a high probability of occurrence. The schedule risk is therefore rated high.

7 CONCLUSION AND RECOMMENDATIONS

On the basis of what exposed above, the key findings are summarized hereafter:

- the mass budget is critical in both designs, much more in the Astrium one, where further definition of the structural design may lead the current architecture to exceed the launch vehicle lift capability
- the AIV process for seven spacecraft is challenging and the full implications of dealing with such a high number of subsystem and payload has not been fully explored by the contractors nor reflected in schedule and margins
- the credibility of the schedule provided is low, at least one additional year may be necessary

The review team recommends the following tasks to be performed in preparation or during the following definition phase:

- Assessment of the inter-spacecraft distance knowledge and accuracy requirements
- Review need for the ISL (derived from the above)
- Trade-off of the “science per buck” identifying the impact to the scientific return of a reduction of the number of satellites or of the payload complement.
- Trade-off the number of science instruments and of science configurations
- Detailed structural design and verification of structural loads
- Confirm launch vehicle lift-off capability
- Detailed box allocation analysis
- Streamlining and optimisation of Payload to derive at lower number of configurations for the various scales and to lower the number of overall P/L items
- Review payload interfaces and consistency with system design
- Detailed CPP design
- Detailed definition of interfaces between payload units
- Payload units development plan
- Define margin allocation at subsystem/unit level and apply it
- Higher download capabilities as currently foreseen and could relax the on board data storage volume.