ASSEMBLY OF LARGE SPACECRAFT: THE XEUS MISSION

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Abstract

XEUS represents the next logical step forward in X-ray astrophysics after the current set of missions have been launched and completed their operational lives. The scientific objectives of XEUS are so demanding that the mission probably represents significant technological challenges compared to past astrophysics missions. The development and ultimate success relies heavily on the capability of the International Space Station (ISS) to enable large spacecraft assembly. In this paper we describe the key characteristics of the mission, and the XEUS assembly sequence at ISS is described and finally robotic technology development needs are identified for enabling the XEUS mission.

1. Introduction

XEUS : The X-ray Evolving Universe Spectroscopy mission represents a potential follow-on mission to the ESA XMM cornerstone currently nearing completion. The XEUS mission was considered as part of ESA's Horizon 2000 plus program within the context of the International Space Station (ISS). The original mission concept has arisen through extensive discussions by the European Scientific Community particularly at the Workshop held at Leicester University UK in July 1996. At this international workshop the foundations for the "Next Generation of X-ray Observatories" was laid. With XMM due for launch in early 2000, with a mission duration of 5-10 years, it is not too early to consider the post XMM era. At the turn of the century two great X-ray observatories will have embarked on their astrophysics programs – XMM and NASA's AXAF and thus the requirements of XEUS must take account of the key thrusts and potential discoveries from both these powerful missions.

The XEUS mission aims to place a permanent X-ray observatory in space with a telescope aperture equivalent to the largest ground based optical telescope currently built to date – essentially the equivalent of the Keck Observatory for X-ray astronomy in space. By making full use of the facilities available at the ISS in the next century and by ensuring in the XEUS design a significant growth and evolution potential the overall mission lifetime of XEUS could be well over a quarter of a century. The power of this observatory will be such that for the first time detailed imaging spectroscopy studies in high energy astrophysics of objects associated with the evolution of the early universe will be undertaken.

2. The Scientific Rationale for XEUS

The aim of XEUS is to study the astrophysics of some of the most distant and hence youngest known discrete objects in the universe. The specific scientific issues, which XEUS aims to address, can be summarized as follows :

- To measure the spectra of objects with a redshift z >4 at flux levels below 10^{-17} erg cm^{-2} s^{-1} . Note this is at least a 100 times fainter than XMM.
- To determine from the X-ray spectral lines the redshift and thus age of these objects
- To thereby establish the cosmological evolution of matter in the early universe

To achieve these demanding aims a large X-ray telescope will need to be developed. An X-ray mirror with an effective collecting area at 1 keV (~1 nm) of 30 m^2. This calls for a large collecting area, in effect a large mirror of the order of 10 meters in diameter. On one hand such mirror dimension can not be accommodated within actual launch fairing. On the other in-orbit deployment techniques can not be used to obtain such mirror: it would be too complex and the deployment itself too inaccurate. To solve this dilemma, it was proposed to make use of the International Space Station as an assembly base for the XEUS Mirror completion.

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Thus the XEUS mission is conceived in a two essential mission build-up phases:

- A first phase during which the two XEUS constituent spacecraft are launched: the mirror spacecraft and the detector spacecraft.
- A second phase during which the XEUS mirror spacecraft visits the International Space Station for growth.

3. The XEUS Mission Profile

The XEUS spacecraft consists of two free flying spacecraft: a detector spacecraft (DSC) and a mirror spacecraft (MSC) separated by ~ 50 m and aligned in the low earth orbit by an active orbital control and alignment system. In the current baseline scenario it is envisaged to launch the "zero growth" XEUS mated pair (MSC1+DSC1) directly into a Fellow Traveler Orbit (FTO) to the ISS using an Ariane 5 or similar launcher. The FTO is a low earth orbit, altitude ~ 600 km with an inclination similar to the ISS. The mated pair will decouple in FTO and the DSC1 will take up station 50 m from the MSC1. After alignment validation and normal spacecraft/payload checkout the "zero growth" astrophysics observation program can begin. The MSC will point at a given target field and maintain a stable attitude while the DSC1 will maintain the focal distance and alignment with respect to the MSC1 so that the field image as measured by the DSC1 detectors remains stable.

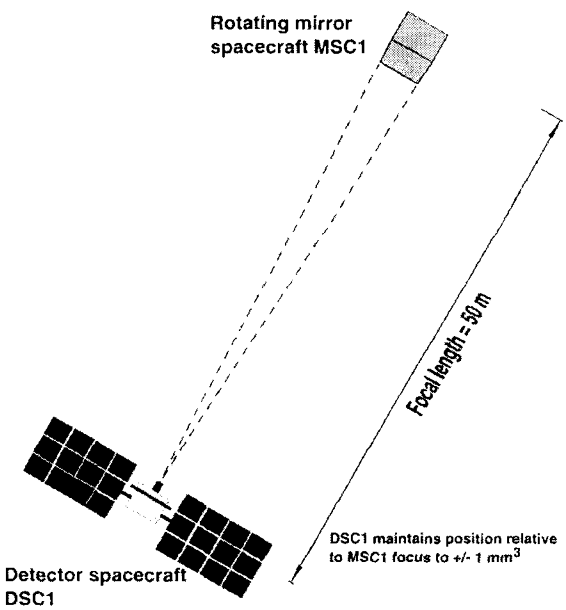


Figure 1; Detector Spacecraft – Mirror Spacecraft relative orbit station keeping

It must be stressed that XEUS is in this scenario completely autonomous from the ISS. In the initial launch "zero growth" configuration the MSC1 will contain only the two inner annuli of the telescope filled with 32 petals. Despite the XEUS initial collecting area is huge (~6 m^2 at 1 keV) a growth capability is crucial for achieving the ultimate scientific goals of the mission.

The pair of XEUS spacecraft can dock in orbit and, through the use of the orbit control system (OCS) on DSC1, the pair can perform an orbit change and come to the vicinity of the ISS. At this point the two docked S/C pair are able to wait for up to one year, following the ISS from a safe distance, until the Mirror sectors are uploaded by Shuttle to the ISS. Prior to the docking to the ISS, the DSC1 will separate from the MSC1, and then the MSC1 will approach and dock to the ISS. As far as possible, docking technology developed for the Automated Transfer Vehicle (ATV) will be used. The DSC1, after de-docking from the MSC1 the DSC1 will undergo a controlled de-orbit.

4. The Mirror Spacecraft (MSC1)

A key characteristic of XEUS is the large X-ray mirror aperture. The MSC capitalizes on the successful XMM mirror technology and the industrial foundations, which have been already laid in Europe for this program. Unlike XMM however, where a heavily nested mirror was fabricated from closed shells, the XEUS mirror is divided into annuli, with each annulus sub divided into sectors. The initial mirror aperture is dictated by the fairing diameter, that is 4.4 meters in outer diameter. At the center of MSC, a diameter of 1.2m is reserved for the ISS docking port accommodation and S/C avionics. To reach the science goals, additional mirror surface needs to be added. The ISS is used as an assembly base to complete on-orbit the mirror spacecraft by adding new sectors to it. That growth is essential to push the spectroscopic limits to the highest redshifts and therefore the youngest objects.

Because mirror petals are very sensitive to contamination each petal will be protected from contamination during launch, maneuvering and docking with the DSC1 and while in the vicinity of the ISS by hermetically sealed doors. The operating temperature of each petal must be maintained constant so as to prevent deformations of the highly accurate mirror plate surfaces. While each petal contains an integrated stray light and thermal baffle as part of the unit, the MSC1 will operate as a spinning spacecraft rotating about its major axis at 1 degree/second. This will ensure an uniform temperature around the circumference of the spacecraft. In addition the MSC1/2 contain large thermal baffles to shield the mirror from direct sunlight.

The MSC will be flying in low earth orbit but will not actively control its orbit during observations. The MSC1 will have a complete AOCS, compatible with the requirements for docking to the ISS. Major orbit changes, e.g. for visiting the ISS, will be performed using the DSC1 OCS after docking to the DSC1. The pointing direction of the MSC1 will be restricted due to stray light, thermal and power reasons. The angle between the telescope pointing and the sun-vector will always be in the range 90 – 120° during the observation phase of the mission.

Figures 2 shows the MSC1 in cross section.

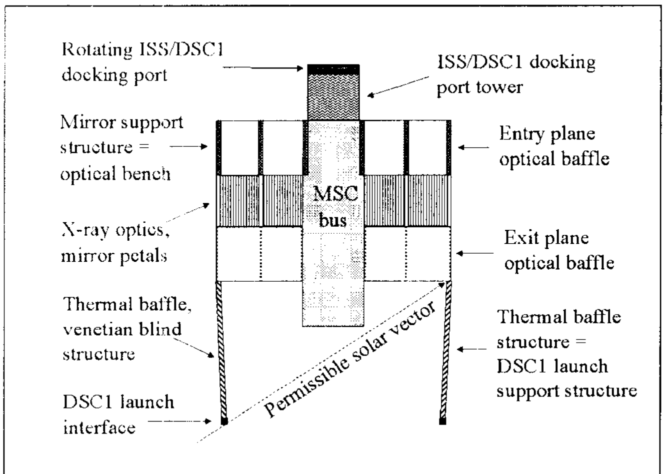


Figure 2: MSC1, cross section

5. The Detector Spacecraft (DSC1)

The DSC1 will be tracking the focus of the X-ray telescope on-board the MSC1 to within ± 2 mm. This implies that the DSC1 will be flying in a non-Keplerian orbit. The orbital characteristics of this MSC1-DSC1 tandem pair is summarized in Table I.

Table I :Orbital Characteristics of the DSC/MSC

Parameter	Specification
Altitude	600 km
Eccentricity	0
Inclination	51.6 deg
Period	97 min
Maximum eclipse	35.5 min
Node spacing	24 deg
Node precession	-4.5 deg/day
De-orbit dv	256 m/s
Altitude change dv	0.54 m/s/km
Plane change dV	132 m/s/deg
Earth angular radius	66 deg
Range to horizon	2831 km

Figure 3 shows a perspective view of DSC1 looking at the anti-solar side, which shows the instrument thermal radiators.

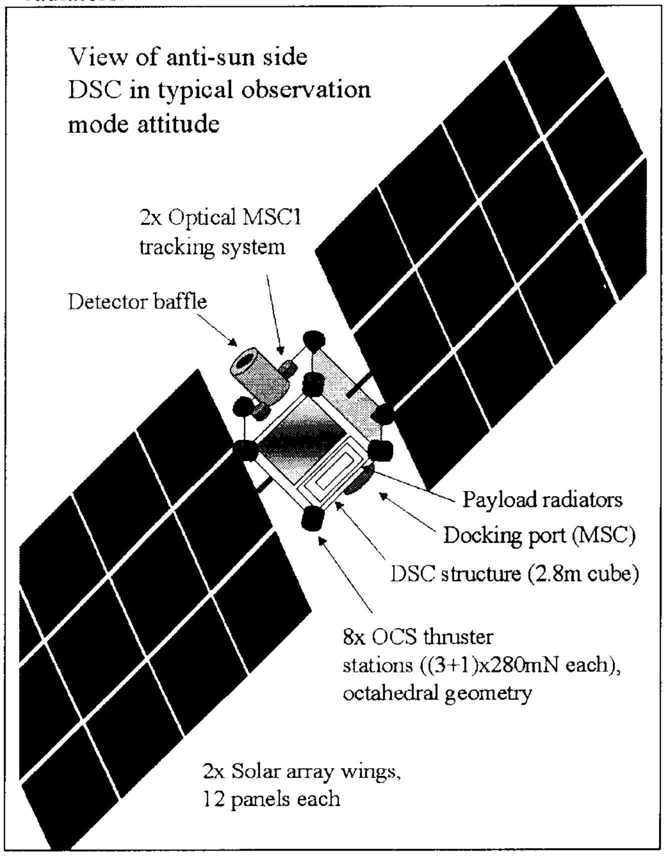


Figure 3: DSC1, perspective view

The payload of DSC1 will include three X-ray imaging spectrometers. This payload has not been subject to a detail study.

6. The Activities at the ISS

In the current baseline scenario it is envisaged that the mated XEUS pair (MSC1 +DSC1) will arrive in the vicinity of the station from FTO and the MSC1 will then dock at the ISS using the same docking port as ATV on the Russian segment. This rendezvous with the ISS, which will take advantage of the evolution of the XEUS orbit with respect to the ISS, will occur on a timescale of ~ 4-5 years after initial launch of MSC1 and DSC1. At the ISS the MSC1 is grown to MSC2.

The top level activity envisaged at the ISS after the MSC1 has docked with the ISS can be summarized as follows:

- Insert the 8 sectors into MSC1 mirror support structure. Note that each mirror sector is ~ 1700kg. Figure 4 shows a mirror sector extracted from the transport container.

- Deploy the thermal baffle elements to the MSC2 as indicated in figure 7.
- Perform checkout of MSC2.
- De-dock MSC2 and move it to the ISS safety perimeter
- Transfer MSC2 orbit to FTO.

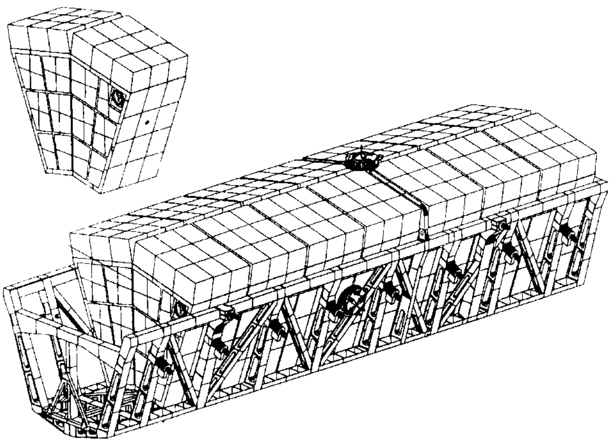


Figure 4: Mirror Sector Transport Container for eight mirror sector

6.1 Preparatory Activities

Likewise the European ATV, the MSC1 will dock to the Russian service module. The service module will be, at the time of MSC1 visit, the only site at ISS that can accommodate a large and heavy S/C such as MSC1 for a period of up to 2 months and offering sufficient free area around the S/C for its assembly. It is also the only module equipped with reflective targets used for ATV docking.

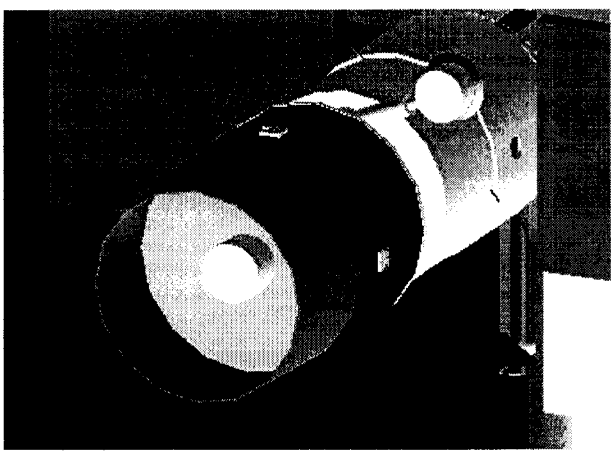


Figure 5: MSC 1 docked at the Service Module

The European Robot Arm (ERA) will be used to support the mirror sector assembly activities that will take place on the Russian Segment side. ERA is stored on the science power platform. To support the assembly task, an ERA basepoint on the service module will be installed. Fortunately the necessary fixation interface is available on the external diameter of the service module, and can be used to connect an ERA basepoint

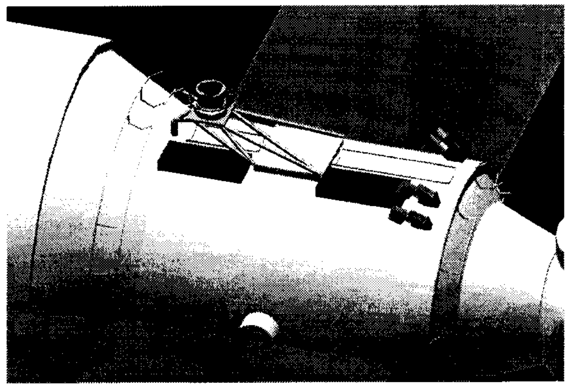


Figure 6: ERA basepoint attachment concept on the Service Module

Once the MSC1 has docked to the service module, the ERA can relocate onto the service module basepoint and a visual inspection of the MSC1 can be done to assess its general status.

Closely after the MSC1 docking to the ISS, the 8 mirror sectors will brought to the ISS by a single Space Shuttle launch. The required 8 mirror sectors will be accommodated on one dedicated transport container (TC). That transport container will be handed over by the Shuttle RMS to the Space Station RMS using the nominal payload hand-off procedure.

Figure 7: Transport Container handed over by the Shuttle RMS to the SSRMS

A power and data grapple fixture (PDGF) will be mounted on the TC such the SSRMS can deliver survival power to the mirror sectors. The SSRMS will transfer the transport container to the Z1 truss. Z1 truss is the only area in ISS whereto a container of such size (nearly 12 meters in length) and mass (nearly 15tons) can be stored. Once the transport container is mechanically and electrically mounted on Z1 structure, the SSRMS will relocate to the Zarya module (ex FGB).

At this stage, all preparatory tasks are completed and the MSC1 upgrade to a MSC2 can start.

6.2 The Mirror Sector Assembly Activities

From its basepoint on Zarya, the SSRMS will get the transport container stored on Z1 and transfer it to near the service module, at a hand-over pose.

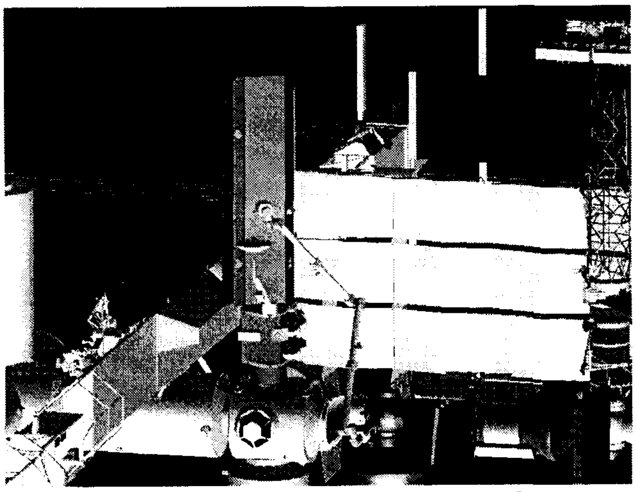


Figure 8: SSRMS relocated on ZARYA PDGF gets the TC for transfer to the Service Module vicinity

Once arrived at its hand-over pose, the SSRMS drives will be disabled, and its brakes applied. ERA will then transfer to the hand-over pose, and get from the transport container held by the SSRMS a mirror sector.

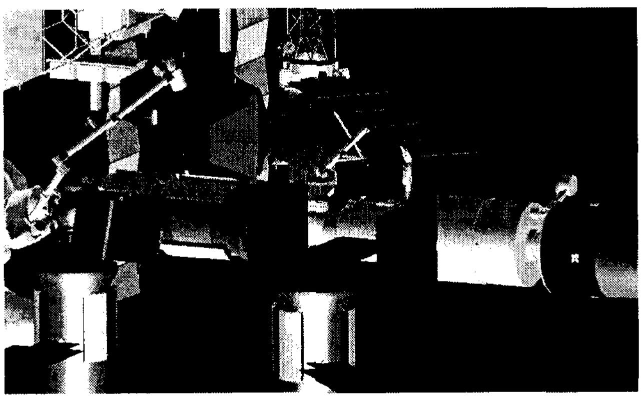


Figure 9: ERA extracts the first mirror sector from the transport container

The mirror sector will be extracted by ERA from the transport container, transferred to MSC1 and installed on the MSC1.

ERA will actuate thermal "knifes" releasing a split bolt mechanism that will mechanically attached the mirror sector to the MSC. Once the safety of the mechanical fixation of the mirror sector has been verified, ERA will release the mirror sector. The mirror sector, which is mounted on a rotary structure, will then be rotated by 180 degrees. A new mirror sector slot is presented, for the next mirror sector engagement. That rotary structure is essential to install all mirror sectors by ERA based on one basepoint only.

Once the last mirror sector is installed on the S/C, the transport container is stored back on the Shuttle for return to ground.

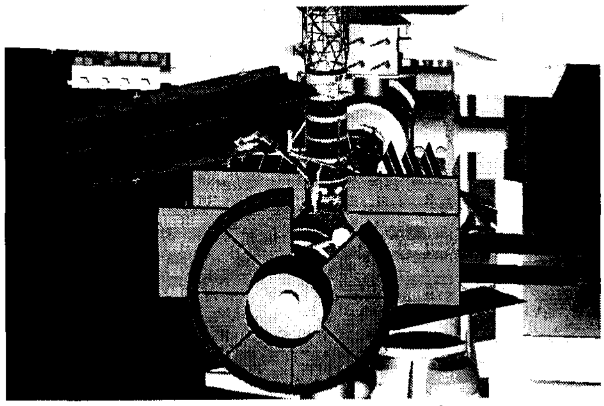
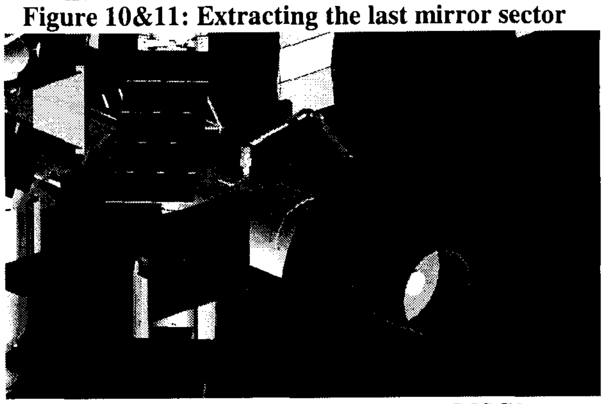


Figure 10&11: Extracting the last mirror sector



from the TC and placing it on the MSC2

The MSC2 assembly is near complete. Electrical connections of the mirror sectors to the S/C still need to be performed by EVA, with the support of ERA.

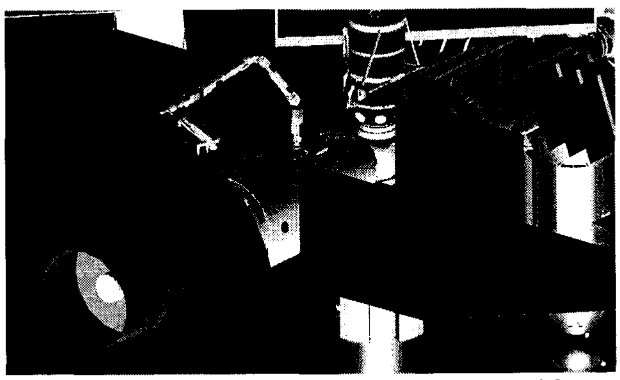


Figure 12: Electrical connection by EVA with support from ERA

Finally the thermal baffles will be deployed, and interconnected at their end by EVA to rigidify the overall structure. Once completed, the MSC2 status is overall checked. This terminates all ISS related support activity. The MSC2 is ready for un-docking from ISS and rendez-vous with the new DSC.

7. Conclusion

The Xeus mission baseline assembly scenario was presented. This baseline strategy allows Xeus to take advantage of the ISS as an in-orbit assembly facility, while minimizing the complexity of the tasks and resource demands required of the ISS. The Xeus mirror spacecraft completion is feasible within one shuttle up-load to ISS, and the required assembly time will fit within a Shuttle visit to ISS. This enables to minimize the mission build-up impact on the required ISS resources as assembly can take place in less than 11 days.

The XEUS mission represents an ambitious project full of new approaches and technologies. At the spacecraft and mission level a number of technical and logistical issues need to be addressed: For the robotics part, the following technology area needs to be investigated in near future:

- Dynamic & control interaction between the SSRMS and the ERA
- Approach and insertion strategy for the mirror sector onto the MSC2
- Launch attachment mechanism for the mirror sectors in the transport container
- In-orbit fixation mechanism for the mirror sector on the MSC2

After this initial analysis of the in-orbit assembly of the Xeus mirror spacecraft, no serious technology showstopper could be found. The ISS proves to be an enabling infrastructure to support ambitious new space science missions.