Title: A Concept for a Microgravity Experiment Recoverable Satellite "MERS"

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Need

Experimentation under conditions of microgravity is a fundamental need for society today. Such research provides knowledge which can have far-reaching humanitarian, scientific and commercial impacts and the International Space Station (ISS) currently provides the main opportunity for this. Political events in 2014 have demonstrated how fragile the reliance on the ISS is and that more robust, secure, longer-term solutions need to be found for conducting long-duration microgravity research.

Mission Objectives

The MERS mission has the following objectives, which may be listed in the order of priority below:

1. Provide an environment suitable for longer-duration microgravity experiments.
2. Provide the ability to retrieve microgravity experiments for analysis after completion in orbit.
3. Provide continuity of service long after the ISS ceases operation.
4. Improve the worldwide knowledge and practice of re-entry.
5. Provide temperature stability of ±0.25°C to a crystal growth experiment.

Concept of Operations

The MERS system aims at operational simplicity and responsiveness. Given that recovery of experiments via atmospheric re-entry is a complex and challenging undertaking, it is important that the MERS system should be kept as simple as possible in all other respects. Figure 1 depicts the broad operational concept conceived for the MERS mission.

A MERS spacecraft containing a number of microgravity experiment compartments is launched; it spends about 2 months in LEO while the experiments run; its orbit is then lowered and it is prepared for re-entry, it re-enters and the experiments are retrieved on ground.

From the business case viewpoint, selection of the launch vehicle for MERS balances keeping the system as flexible as possible (by making it compatible with shared launches to a variety of orbit heights and inclinations) with keeping the MERS spacecraft as simple as possible (by designing it for a particular orbit). Flexibility allows ride-sharing and launch cost reduction, while a dedicated launch as primary passenger on one of the emerging, new launch vehicles allows spacecraft cost reduction and launch on demand which would be attractive to customers.

MERS is being designed to operate in a circular orbit in the 400 to 500km altitude range. This allows it to share launches with a range of co-passengers, while keeping the power requirements constrained to a manageable range. It is also a reasonable height from which to de-orbit using a commercial system and then undertake re-entry without having to wait a long time.

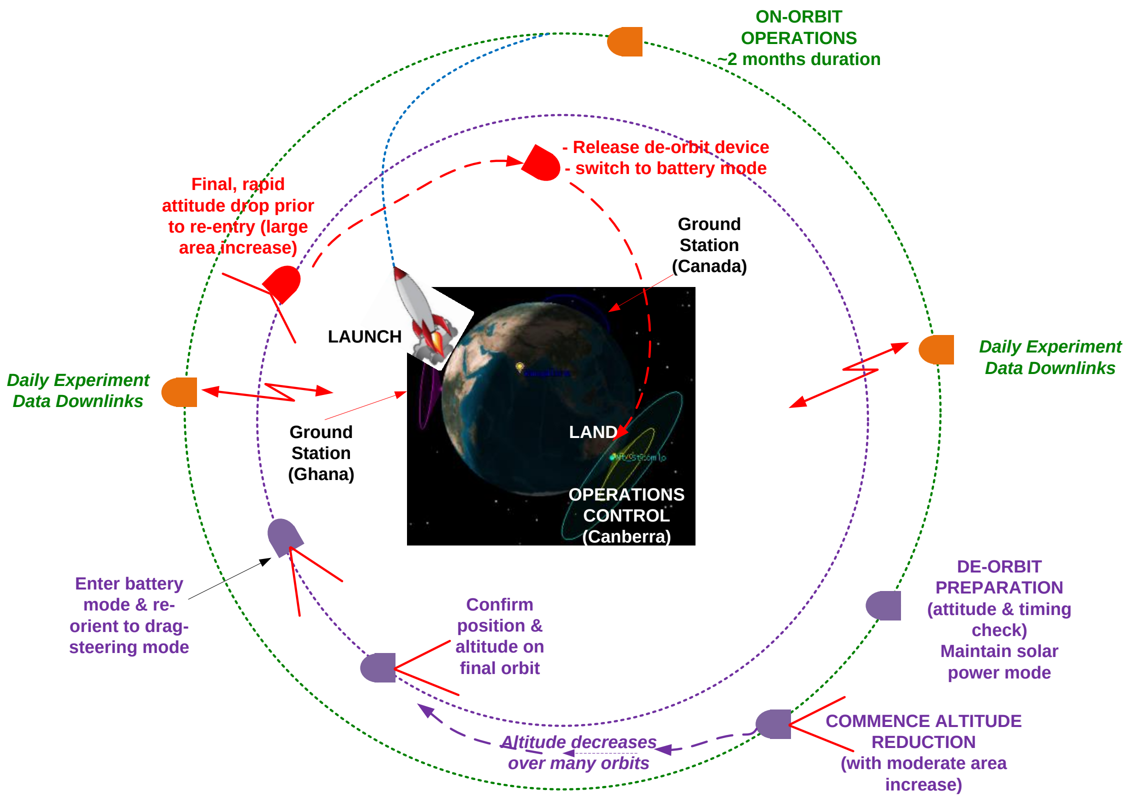

Figure 1. The MERS concept of operations

Following launch, separation and commissioning, the customer may request commencement of the microgravity experiments. The thermal control subsystem is designed to allow all experiments to function simultaneously, but if necessary, experiments will be scheduled to allow those with higher than normal power demand or heat generation.

Operations will be controlled from Canberra, Australia. The baseline concept will make use of a minimum of 3 ground stations: in Australia, Ghana and Canada. This will allow a significant increase in the daily volume of experiment data which can be downlinked and then accessed remotely via the internet. Such a concept allows the TT&C subsystem to make use of the simpler, cost-effective UHF band, which also makes MERS compatible with typical university ground stations. While the selection of this frequency band is not final, initial investigations and trade-offs show the benefit of trading data bandwidth for power and TT&C system simplicity and cost. Using a network of university ground stations and accepting the need for more complicated data management software should make the use of UHF feasible. The data volume will not be high as only low-level temperature monitoring of the experiments will be transmitted.

Once the experiments have successfully completed, MERS begins the phase of operations which distinguishes it from all other traditional microsatellites. A passive de-orbit device is deployed, which will slowly reduce the satellite's altitude by greatly increasing its area and creating a significant increase in the atmospheric drag. During this time it maintains its nominal sun-pointing attitude in order to ensure the solar power supply is available. Once the altitude is sufficiently low, a final check on altitude and orbit parameters is made from ground. When everything is correct, a last reduction in altitude is performed. Then, the drag device is jettisoned, the reaction wheels (or drag-steering) are used to arrange MERS in its re-entry attitude and the switch to battery mode is made. If the re-entry is started at the correct time, the inherently stable aerodynamic shape chosen for MERS will ensure that a landing within the very large available at Woomera, Australia is made. The internal design minimises the effects of the re-entry and landing on the experiment modules. These are then retrieved after the landing.

Key Performance Parameters

1. On-orbit thermal environment: the MERS thermal design will provide an internal payload temperature around 20°C for the period during which experiments are taking place, with a ±0.25°C control band. This temperature level allows direct equivalence with experiments conducted on the International Space Station. The stability is the advantage gained for crystal growth when convection currents are reduced or removed.
2. Thermal environment during re-entry: here, the thermal design will aim to maintain a non-operating temperature range within the experiment modules of -20°C/+50°C. This will ensure that the physical and chemical properties of the experiments are not changed, while not driving the design of the thermal protection system unreasonably. In addition, this range is compatible with most consumer electronics.
3. The attitude and stability for start of re-entry: these are critically important to ensure a controllable and predictable re-entry. The centre of mass of MERS must be closely controlled relative to its aerodynamic centre of pressure. A stable start of re-entry is achieved by using an inherently stable sphere-cone shape and the selection of a 50° cone angle which balances the ballistic coefficient with the peak heating load.
4. The maximum g and shock loads experienced by the experiment modules: these loads must be controlled so that the experimental material is not damaged. A thermal and shock isolation system has been conceived (see Ref. 1).
5. Data volume which can be down-linked: it is important that adequate data from sensors within the experiment modules can be received during the orbital part of the mission to enable the customer to have a complete picture of their experiment. Thus, in the event of a failed re-entry, critical experimental information is not lost.

Space Segment Description

The MERS spacecraft described here is for a 50kg class, scalable proof of concept mission. An initial system trade-off led to the decision that the complete MERS spacecraft should be re-entered, rather than attempting to re-enter the experiment modules separately. The external configuration will be determined by the final choice on flight attitude and heat shield angle. The geometry of the MERS spacecraft is shown in Figure 2. Configuration 2 in Figure 2 is the current working baseline. In this configuration, the solar array would be integrated into the conical surface of the cooler section of the heat shield, while the flat, anti-sun side would form the main radiator surface. Thermal analysis confirms this area is adequate to maintain approximately 20°C inside MERS. Bear in mind that the solar array does not need to function during or after re-entry; it must only maintain structural integrity. Attitude control is performed using micro reaction wheels. This anti-sun side must then be thermally decoupled from the internal compartment prior to re-entry (see Ref. 1). Configuration 3 is also under consideration. This configuration would use a novel concept whereby passive drag steering is achieved via 4 fin-antennas attached to the leeward side of the spacecraft. These would double as antennas during the orbital phase, but would most likely need to be jettisoned prior to re-entry. The solar array would be more complex, as it would have to be on the non-Earth-facing half of both the windward and leeward sides of the heat shield.

The cut-away view shows how the experiment modules are located to have the greatest mechanical and thermal isolation from the external environment. The main heat shield has a simple sphere-cone shape and a high TRL-level carbon phenolic material. The omni-directional antenna(s) will be located on the leeward (radiator) surface.

The mass of MERS is calculated to be 46.0kg. This includes a 20% design margin on all of the standard equipment. In a number of critical areas, namely the heat shield, the internal structure and the internal shock and thermal isolation system, a margin of 30% has been applied.

The preliminary design for the MERS power subsystem foresees a COTS solution with a 30 W-hr battery being recharged via an approximately 0.4m^2 solar array, with 28% cell efficiency and an 80% packing factor (to allow for the curved surface).

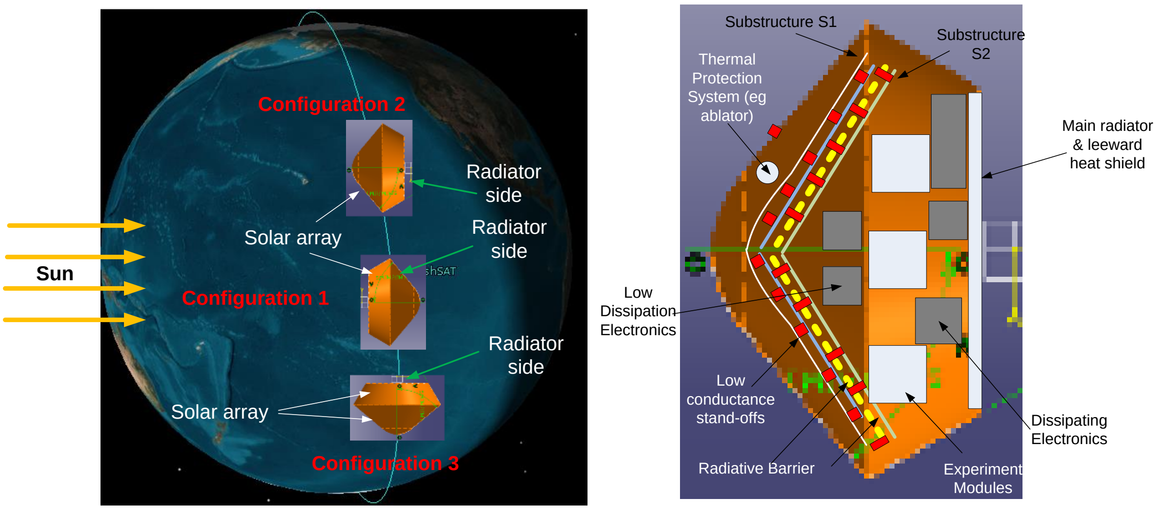

Figure 2 – MERS flight configurations and internal cut-away view

The MERS TT&C subsystem is likely to have a full duplex VHF/UHF transceiver. Configurations being explored for the antenna(s) include separate monopole antennas or dual dipole antennas. An overall Eb/No of 63.72 has been calculated for the complete link with the UNSW ground station. Final choices for modulation and polarisation are being investigated.

Orbit/Constellation Description

The MERS spacecraft is the sole orbital element. Selection of its orbit is critical for a number of reasons. These include the business case, the power requirements which result from the visibility of MERS for data transmission and very importantly, the ease with which the orbit can be lowered and re-entry commenced, keeping in mind that one of the customer requirements was that no propulsion system is allowed.

The 46kg launch mass means that all the launchers currently on the market have greatly more performance than is needed to put MERS into its target orbit. Therefore, launch as a secondary payload must be expected and this is why the power and thermal subsystems have been designed to allow orbits with different inclinations in the 400-500km altitude range. Figure 3 shows the orbit, the minimum ground station configuration and the typical coverage obtained (between 20 and 40 minutes per day, spread over 3 to 6 passes per ground station).

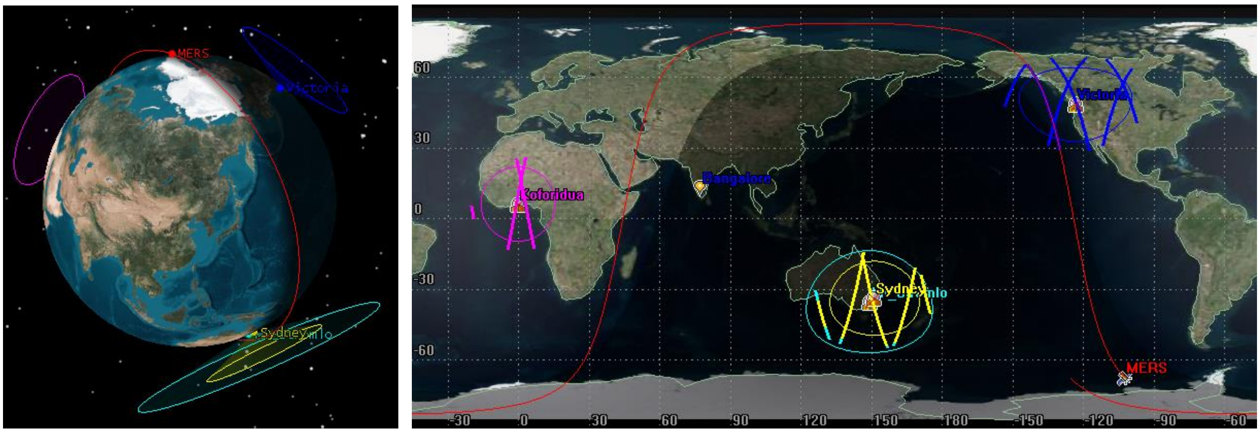

Figure 3 – Minimum MERS visibility: 3 ground stations and 400km orbit altitude

Implementation Plan

UNSW Canberra would lead the implementation of the MERS spacecraft, at least for the development and protoflight phases. Promising discussions have been held with potential industry and government partners in Europe and Japan. Software tools for re-entry trajectory and heating prediction, power profile modelling and link budget estimation have been developed at UNSW Canberra. A number of key technology developments have been identified. These are the heat shield with solar cells embedded in it, the combined heat shield-radiator for the leeward side and potentially, the drag-inducing antenna concept. These represent the top technical risks. On the programmatic side, there is the need to orchestrate the ground station network and the organisation and funding of a meaningful sub-orbital flight experiment. A benefit of the proposed MERS concept is that it is self-disposing and will add no further debris to LEO.

Estimation of the total life cycle cost is challenging, because MERS is a very unique spacecraft. While as much cube- and microsatellite technology as possible is used on MERS, the costing must reflect the extensive testing required and the specialised shape of the spacecraft. The Small Satellite Cost Model developed by the Aerospace Corporation has been used as a starting point and modifications have been made where appropriate. The final prediction (including all non-recurring costs, 1 qualification and 1 flight unit, testing, integration, management, flight support and launch is $15.46M. Of this, $5.9M is for the qualification and flight units. A bottom-up analysis in a fully university environment leads to an estimate of $3.04M for the two units. These two figures bracket the likely MERS cost range.

References

1. Tuttle, S.L., "Thermal design of a recoverable microsatellite", accepted for the 44th International Conference on Environmental Systems, 13-17 July 2014, Tucson, Arizona.