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MANNED SPACE CAPSULES

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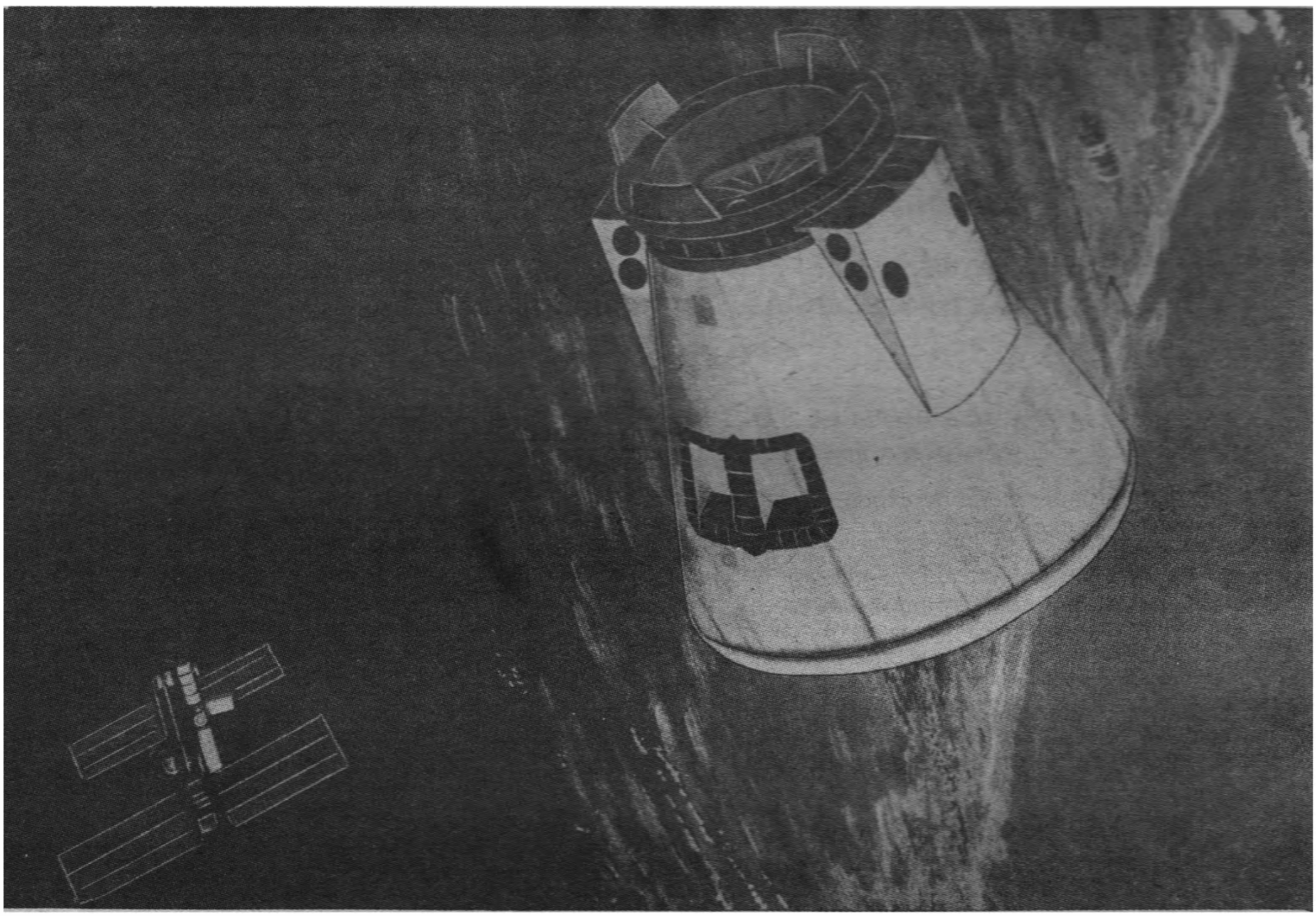
An MRC Rescue Capsule leaves the Freedom Space Station and begins re-entry into the Earth's atmosphere. *(NASA)*

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MULTI-ROLE CAPSULE – AN INTRODUCTION

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Despite the introduction of more sophisticated re-entry systems such as the Space Shuttle, there is still a role in the space infrastructure for manned semi-ballistic capsules. The Multi-Role Capsule (MRC) study explored the potential of such capsules in a European and international context.

This introductory paper presents the background to the MRC study, reviewing the various infrastructure roles for capsule and discussing other capsule concepts currently under evaluation. It also presents the main comments received by the study team since the results of the sudy were made public.

1. INTRODUCTION

This special issue of the JBIS is devoted to a presentation of the results of the Multi-Role Capsule (MRC) study. This independent study reviewed the potential for manned capsules of the type extensively employed by the American and Russian programmes in the 1960s and still used by the Soviet Union as the means of transporting men to and from the space environment. Despite the advent of more advanced re-entry systems such as the Space Shuttle, the simplicity and mass efficiency of capsules still makes them the optimum technical approach in many applications.

This introductory paper starts by exploring the background to the MRC Study in terms of the concerns of the study team. That is the areas of space activity in which it was foreseen that capsules could play an important role and the proposals (capsule or otherwise) which had been made to fulfill those roles. The paper then presents a brief outline of the MRC study results and concludes with a discussion of some of the main comments that have been made regarding the study's conclusions since they were made public at the IAF conference in Brighton last October (1987).

2. BACKGROUND

Before considering the Multi-Role Capsule concept, one should consider the background that was under consideration during the project's genesis. The team that generated the concept were concerned about aspects of both the American and European infrastructure, and four main areas were investigated:

(i) European manned space infrastructure;
(ii) European microgravity requirements;
(iii) An escape system for the US/International Space Station;
(iv) An escape system for a European space station.

This section considers each of the areas in turn. The discussion reflects the most recent events at the time of writing (at the conclusion of the study). However this update does not significantly alter the main concerns that influenced the MRC study team and the subsequent events have only put the proposal into a clearer context.

2.1 European Manned Space Infrastructure

Over the past four years there has been an increasing acceptance within the European space community that Europe must undertake the development of a manned infrastructure if it wishes to improve its ability to exploit the space environment. This belief has led to the establishment of the Columbus and Hermes programmes, Columbus providing the in-orbit elements and Hermes providing the manned transportation system to reach them.

The Columbus programme originated as a German/Italian study which explored in some detail by expanding the Spacelab technology and hardware to provide a permanent orbiting laboratory. The results of these national studies were widely reported and the conclusions, and the rationale behind them, were well understood by the European Space community generally when the American offer to join the Space Station programme was made. The national study could then form the basis of a European wide programme that elegantly combines exploitation of the opportunity created by cooperation on a major American programme with the establishment of an autonomous European facility.

It is perhaps somewhat unfortunate that many of these desirable features found in the Columbus programme history were not also to be found in the Hermes programme. Hermes originated in national studies conducted by France but unlike Columbus, the results of early study work were not so widely disseminated, and many of the fundamental conclusions have not been fully justified. Even the choice of approach remains unexplained: of the three alternatives,

(i) Capsule on a general purpose launcher;
(ii) Winged aerospaceplane on a general purpose launcher;
(iii) Specialist manned launch system,

the Hermes study selected the winged aerospaceplane. This is a most surprising and controversial choice, because whereas the other two options have been successfully implemented, the American X-20 (Dynasoar) programme (which is the only publicised attempt at the second option) failed to meet even the most modest objectives.

Hermes has also not managed the happy trick of contributing to the overall infrastructure as well as enhancing European autonomy. It has not found any role in the context of the Space Station programme and it has even had some difficulty in managing the servicing roles in the autonomous European infrastructure.

Because of the lack of understanding about Hermes goals and the logic behind its trade-off decisions, the examination of alternatives is an effective tool for those outside the Hermes study team to explore the requirements and potential technical solutions of the transportation element of the European manned infrastructure.

2.2 European Microgravity

One of the main impacts of the "Challenger" loss and the subsequent grounding of the Space Shuttle fleet was the delay in launching the European "Eureka" platform and a lack of flight opportunities thereafter. This has caused a build-up of European microgravity experiments which have no immediate opportunity to fly and one solution to this problem is the use of capsules.

There are a number of capsule studies underway in Europe all intended to fly microgravity experiments and return them to Earth. This type of mission is frequently flown by both China and the USSR, indeed both countries are now marketing space on their flights and have been successful in acquiring European orders.

One of the most mature European proposals is TOPAS (Transport Operation of micro-g Payloads Assembled on Scout). This is a German-Italian programme and is exploring the potential of a small capsule based on an American (General Electric) design, which would be placed in orbit by a Scout rocket launched from the San Marco platform. The Scout rocket is also American, being constructed by LTV.

The payload of this capsule would be about 100 kg and it could remain in orbit for between 2 days and two weeks. The capsule would then re-enter and parachute to a land recovery. Possible recovery sites include the Sahara, Saudia Arabia and Australia.

TOPAS has a limited capability primarily due to the restrictions placed on the system by the Scout launcher. Both Germany and Italy have study programmes underway to consider the next step.

Aeritalia (Italy) have been considering a concept that would be launched by an uprated version on the Scout giving about twice the payload. This capsule is called Carina.

Carina is cone shaped re-entry vehicle 1250 mm in diameter and 1350 mm high. The payload mass is 150 kg and the capsule can provide 150 Watts of power for the mission life of up to 21 days. Power is supplied from a combination of solar arrays and batteries. The system would also provide 150 kbps telemetry and an on-board memory capability of 128 Mb.

A German study, lead by Dornier Systems, has examined a larger capsule concept called Raum-Kurier (Space Courier). The capsule is a "Gemini" type cone 2 meters in diameter and weighing 1.1 tonnes. It is launched into a 300 km 55° inclination orbt for 7 days. A solid propellant retromotor initiates the recovery, return is on-land and uses conventional parachutes. The payload weighs 600 kg and has 0.7 m^3 volume. It is supplied with 150 Watts of power and has a data rate of 2 kbps. Launch systems options are being left open with China's Long March looking favourite for the early launches. The USSR and the American AMROC are also potential options.

Raum-Kurier is seen as the starting point for the longer-term exploitation of capsule and re-entry technology. The design incorporates growth capability with respect to unmanned and manned utilization such that by a step-by-step learning process improved capsules can be developed with minimization of development risk and development costs. A possible improvement of the unmanned capsule would be to add an expendable solar power module to the baseline design to allow longer mission durations. The manned capsule design will be characterized by higher safety requirements and perhaps lift-controlled entry trajectories to improve the oberational flexibility and to decrease the loads.

There are common features to all these proposal which limit their effectiveness as complete microgravity laboratories. The payload on all is small, the best is Raum-Kurier which has half the payload of Eureca. The flight times are limited to a couple of weeks. None is capable of flying biological experiments or the large packages needed by some materials experiments. However the need for any microgravity capability as soon as possible is now so pressing that at least one of these systems is likely to be developed.

2.3 US Space Station Escape Vehicle

In the renewed examination of Space Station safety in the light of the lession learnt from the Challenger accident, NASA proposed that an Escape Vehicle be added to the Space Station. This contingency facility would to an extent replace the safe haven philosophy (which had been the earlier approach) and gives greater coverage of possible contingency situations including:

- Return of injured or ill crew members.
- Escape from a severely damaged station.
- Return capability in the event of loss of STS operational status.

The Escape Vehicle is designated Crew Emergency Return Vehicle (CERV).

Having identified a requirement to be able to evacuate the Space Station Crew in the event of an emergency there are a number of alternative approaches.

The MRC study considered that an escape vehicle permanently attached to the Space Station represented the most attractive approach. The study identified four other possible approaches open to NASA and these are summarised below:

Approach (1) **Modified Apollo Modules**

Technical Risks:	**Major Refurbishment; almost complete rebuild.**
Cost:	New Service Module; new Docking Adaptor; refurbishment; overall cost close to baseline system.
Operational:	Atmosphere incompatability; Parts and spares availability; No expansion capability.
Advantages:	Proven re-entry system.
Conclusions:	Many technical problems and little cost reduction.

Approach (2) Permanently Attached Orbiter

Technical Risks:	Modify orbiters for six months – orbit staytime.
Cost:	New Orbiter; Orbiter Mods to entire fleet; overall cost significantly greater than baseline system; all the financial impact of five orbiter fleet with capac-

	ity unchanged.
Operational:	Only one orbiter attached and if used as ambulance remaining crew have no escape; station crew must contain two shuttle pilots; little expansion compatibility.
Advantages:	Proven re-entry system.
Conclusions:	More expensive and has operational problems.

Approach (3) Shuttle Rescue Mission

Technical Risks:	No major risks.
Operational:	Two week plus delay before reaching the station; no capability if Shuttle System is grounded.
Advantages:	Almost no cost impact; proven re-entry system.
Conclusions:	Delay time unacceptable in almost every hazard situation; lack of system level redundancy also a problem.

Approach (4) Ground Launched CERV

Technical Risks:	Modify an EV for CERV delivery.
Costs:	Overall cost comparable to baseline.
Operational:	Delay time of around two weeks (as bad as a Shuttle rescue mission).
Advantages:	Reduction in nominal delivery costs.
Conclusions:	Delay time unacceptable in almost every hazard situation.

All these other approaches were judged to have serious if not insurmountable problems. NASA's studies seem to be coming to similar conclusions although at the time of writing these were still under evaluation and a final decision had not been arrived at.

There is a considerable background of work in the United States addressing "From Orbit" escape systems. A review in "Space Station Crew Safety Alternatives Study" [1] identified 13 past proposals from US companies. These fall into two classes: deployable devices where the heat shield is in some way deployed (e.g. by inflation or unfurling) and rigid where the escape system is a conventional homogeneous system. Most of these proposals date back in concept to the 1960s and tend to suffer the same problems in the light of Space Station evacuation:

- They are for only one or two crew members compared with an initial Space Station crew of eight.
- They required new technology development (especially the deployable types).
- They are somewhat crude devices putting the crew member at higher risk than would normally be acceptable.

Three of these concepts are worth further attention because derivatives of them are being proposed for CERV. Firstly there is the Apollo Escape concept consisting of a modified Command Module. A rescue version of the Apollo was produced for the Skylab programme by modifying a CM/SM such that it could carry five men. In the event that the transport Apollo attached to Skylab was unable to return, the rescue Apollo would fly to the station with a crew of two and pick up the three men stranded in orbit and return to Earth. Problems on the second manned mission actually lead to the first stages of launching this rescue craft, although in the event it was not required.

The General Electric MOSE system was considered in the mid-seventies. It was a very simple system adapted from the Discovery type of capsule which has been extensively used on American programmes. In the light of actual Space Station requirements a more sophisticated version providing a shirtsleeve environment and accommodating six men is under evaluation.

The third proposal which is under consideration is the use of a lifting body (or a winged vehicle). This has the advantage of a lower g level on crew members which can be beneficial if injuries have been sustained. It also allows a runway landing which would speed access to medical facilities again if injuries or illness were involved. The disadvantage is the additional cost of the system, the technology problems associated with in-orbit storage, and the complexity in flying the system.

The NASA studies have explored the capsule requirements. The basic requirements are for an Escape System, a safe haven and a method of returning ill or injured crew members. Based on the experience of Antarctic bases and submarines it is estimated a crew member will need to be evacuated from the Space Station on average once every 4 years.

A number of other missions were also identified. These were all related to contingency situations such as recovery of a stranded EVA astronaut or a backup-crew delivery-system should the STS system be grounded for any period. These additional missions are still under examination.

2.4 European Space Station Studies

Europe's first manned space programme was Spacelab which is a pressurised laboratory which flies within the payload bay. When the Americans offered involvement in the Space Station Programme the most logical contribution was to modify the Spacelab system to provide a laboratory module which would attach to the Space Station allowing much more experimental time and space. A further development would be the attaching of a resource module to a pressurised laboratory to create a Man-Tended Free Flying (MTFF) facility. As already discussed these two laboratories form the basis of the Columbus programme.

However, the Columbus programme will fall short of being an autonomous European Space Station which would demonstrate a complete capability in manned spaceflight and provide guaranteed European access to the Space environment. Two ESA funded studies have been conducted to explore developing Columbus technology to produce an independent European Space Station. These are the "Long Term Evolution" (LTE) study and the "Study Towards European Autonomous Manned Spaceflight" (STEAMS).

2.4.1 Long Term Evolution Study

The "Study on Longer Term Evolution Towards European Manned Spaceflight" was conducted for ESA by a team under the leadership of MBB/ERNO. It examined the requirements for an autonomous European Space Station and included an examination of the escape vehicle requirements.

The study performed a requirement breakdown starting from the role as Station Rescue System. From this six primary missions were identified:

- Station escape.
- Stranded EVA crewmember rescue.
- Crew rescue from secondary system.
- Attached safe haven.
- Detached safe haven.

- Contingency crew delivery system.

A secondary mission not related to its safety role was also identified: this was as a cargo return system at the end of its life in orbit. An Escape Vehicle would not necessarily have to conduct all these missions to be a viable system.

A number of preliminary designs were generated covering a range of technical solutions. As a result of comparing these preliminary design concepts the study arrived at some preliminary conclusions with regard to the escape vehicle:

- Station escape (including ambulance) is an essential mission.
- EVA crew member rescue was worth considering further.
- Rescue mission to systems other than Space Station would need infrastructure level consideration.
- Attached safe haven had a minor impact and was recommended for inclusion.
- Detached safe haven was worth considering further.
- Contingency crew delivery has a major impact at infrastructure level and needs careful investigation.

2.4.2 S.T.E.A.M.S.

The "Study Towards European Autonomous Manned Spaceflight" was conducted for ESA by a team under the leadership of Aerospatiale. Like the LTE it considered an autonomous European Space Station but with a different emphasis considering a more direct utilisation of Columbus elements. It also considered the requirements for an Escape Vehicle and arrived at five mission options (mission having a slightly different meaning in the context of this study compared with LTE).

Missions 0–3 were all variants on crew evacuation but with different degrees of flexibility over aspects such as relocation, duration and landing philosophy. Mission 4 is the same as the secondary mission described in the LTE study; namely cargo return at end of life.

Unlike the LTE study STEAMS did not consider a range of system capabilities, rather it centred on a single approach using a small capsule. Two possible configurations were proposed and Fig. 1 shows the baseline design. The study did identify a number of critical technology issues related to the Escape Vehicle these were:

E.V. LIFE DURATION:
- Monitoring/maintenance of critical components (activation readiness should be permanent).
- Ageing of materials for re-entry capsule (thermal shield, structures etc).

E.V. ROBUSTNESS and RELIABILITY:
- E.V. should be able to operate in aggressive environment (alert/evacuation phase).
- Reinforced, hardened and reliable design.

E.V. LOW WEIGHT/LOW COST:
- Simplicity of design.

E.V. "AMBULANCE" FUNCTION:
- Medical support inside a small vehicle.
- Acceleration/shocks limitation (aerodynamic shape, landing system).

2.4.3 Further Studies

European work on space station Escape systems is continuing with a special ESA funded study devoted to an "Escape Vehicle for the Autonomous Presence of Man in Space". This study has just started under the industrial leadership of Aerospatiale with MBB and CASA as study participants. This work should refine the requirements for escape systems from the European infrastructure viewpoint and identify the technology and financial factors that need to be addressed.

3. MULTI-ROLE CAPSULE OVERVIEW

It was a discussion of the above background that lead a group of British Aerospace engineers to propose examination of a manned vehicle with a multi-role capability. The intention was that this would be able to fulfil many of the European requirements for the 1990s and also provide a valuable contribution to the USA Space Station Programme in addition to Columbus elements. The study was started in April 1987 and the

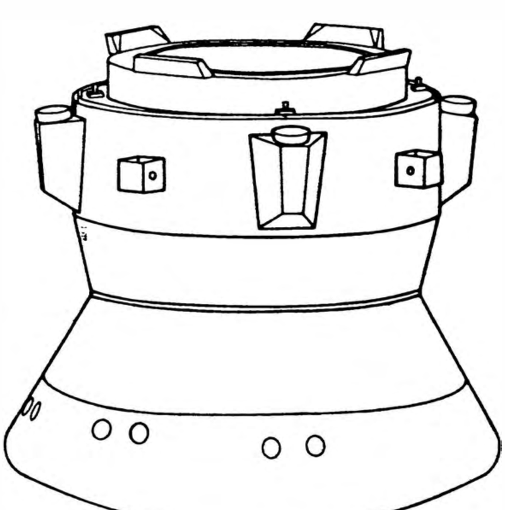

Fig. 1. Aerospatiale Escape Vehicle Concept

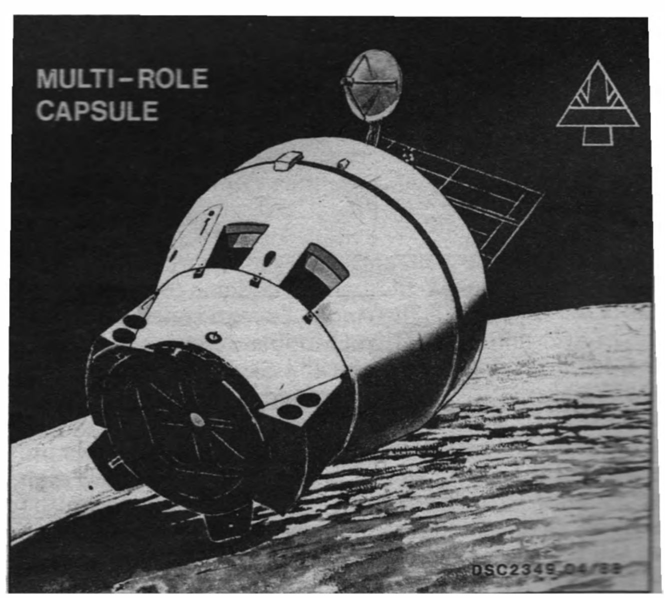

Fig. 2. MRC on Orbit View

bulk of the work was completed in about six months. The results were presented at the IAF conference in Brighton in October 1987.

The study centred on a semi-ballistic capsule concept similar in many respects to American manned spacecraft of the 1960s but employing more advanced avionics and structures technologies. The configuration, shown in Figs. 2 and 3, featured a conical re-entry vehicle with a

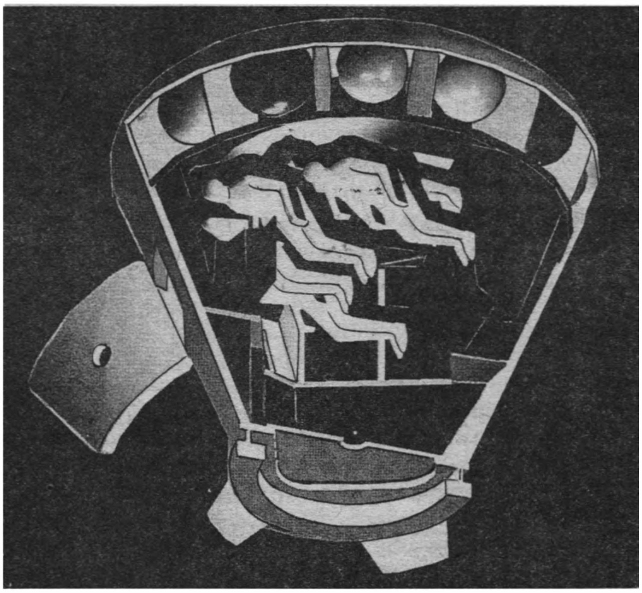

Fig. 3. MRC Internal View

Space Station standard docking port at the apex. The study baseline design features are summarised in Table 1. Figure 4 shows a comparison between the MRC concept and past capsule designs.

TABLE 1. MRC Design Features.

Mass	7 tonnes in orbit.
Size	4 m diameter 8.3 m long (solar array deployed)
Crew	4 normal, 6 escape
Payload	250–500 kg (carried in cabin) (1500 kg unmanned microgravity)
Life	5 day active (+ 1 day contingency) >2 years on-orbit store
Recovery	Semi-Ballistic re-entry; parachute to ocean splashdown

The capsule was designed to be launched into Low Earth Orbit by Ariane 4. After a mission of up to five days it would re-enter the Earth's atmosphere. The conical shape together with an offset centre of gravity allows the capsule to fly a semi-ballistic trajectory which lowers the acceleration forces to about three times Earth gravity and also permits a degree of control as to where the capsule lands. After the capsule has completed the high velocity part of the descent it would deploy parachutes to slow down to a safe speed. It would splashdown in the ocean in the same way as the American Mercury, Gemini, and Apollo capsules. The weight on return is about 5.5 tonnes. The capsule is divided into two modules; the Descent Module and the Service Module.

The Service Module is a cylinder structure that attaches to the back of the Descent Module. It houses a solar array for the generation of electrical energy and various communication antennas. It is discarded before re-entry into the Earth's atmosphere.

The Descent Module, which is the only part of the spacecraft to return to Earth, has three sections. The forward cabin has a docking port, control thrusters, hygiene and galley facilities. The mid cabin houses the crew couches and the control equipment. The rear cabin houses the batteries, the propellant and air tanks, and a payload bay for mounting mission specific equipment.

Three versions of the MRC were identified each intended to fulfil a different role. These were:

	VOSTOK/ VOSKHOD	MERCURY	GEMINI	SOYUZ	APOLLO	MRC
ORIGIN	USSR	USA	USA	USSR	USA	UK
OPERATIONS	61 - 63	62 - 63	65 - 66	67	68 - 75	94
CREW NORMAL CONTINGENCY	1 3	1 -	2 -	1 - 3 -	3 5	4 6
ORBIT MASS (TONNES)	5 5	1 4	3 7	6 7	22 0	7 0
LIFETIME (DAYS)	5	1	14	18	12	5
RECOVERY	BALLISTIC LAND	BALLISTIC WATER	SEMI BALLISTIC WATER	SEMI BALLISTIC LAND	SEMI BALLISTIC WATER	SEMI BALLISTIC WATER
CONFIGURATION	RE ENTRY SPHERE + INSTRUMENT SECTION	CAPSULE + RETRO PACK	RE-ENTRY MODULE + RETRO MODULE + EQUIPMENT MODULE	ORBIT MODULE + DESCENT MODULE + SERVICE MODULE	COMMAND MODULE + SERVICE MODULE	DESCENT MODULE + SERVICE MODULE

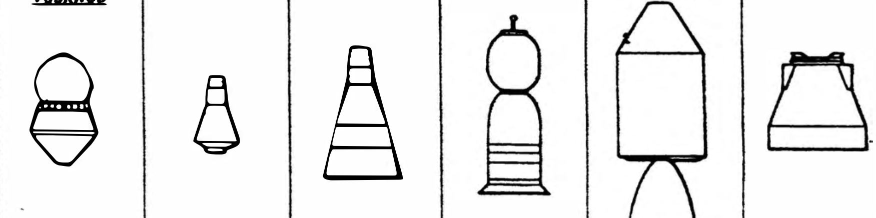

Fig. 4. Capsule Comparison

(i) Four-man General Manned Transportation.
(ii) Six-man Escape System.
(iii) An Unmanned Microgravity Laboratory.

Within the depth of definition of the study there was very little technical difference between the two manned versions, apart from the number of seats. The unmanned microgravity version has some differences, mostly removing equipment not required in this role.

The study outlined a development programme assuming the Ariane 4 launcher. The main aim was to explore the earliest possible operational date, and to demonstrate that the system could be available in a timeframe compatible with the identified roles on the US Space Station. A summary of this programme is shown in Fig. 5. It assumed a Phase A start at the beginning of 1988 and leads to the first flights, including one manned flight, in 1993, ie a total development programme of just under six years.

launch system development programme. A more detailed account of the selection criteria is given in "Rationale and Requirements for the Multi-Role Capsule" a companion paper in this issue.

The launch team appreciated that some modifications to the launch system would be required both to accommodate the new payload and more generally to manrate the launch system. Details of the identified modifications are discussed in "Multi-role Capsule System Description" also a companion paper in this issue. At the time of the study the team could foresee no problems in implementing these modifications as they were essentially the same modifications proposed by the early Hermes programme (when its launch system was Ariane 4). The reasons for the move of Hermes from Ariane 4 to Ariane 5 were given as the increased mass of Hermes, which took it well beyond Ariane 4's capability (even after stengthening), and the bending moments generated by Hermes on the launcher during the ascent

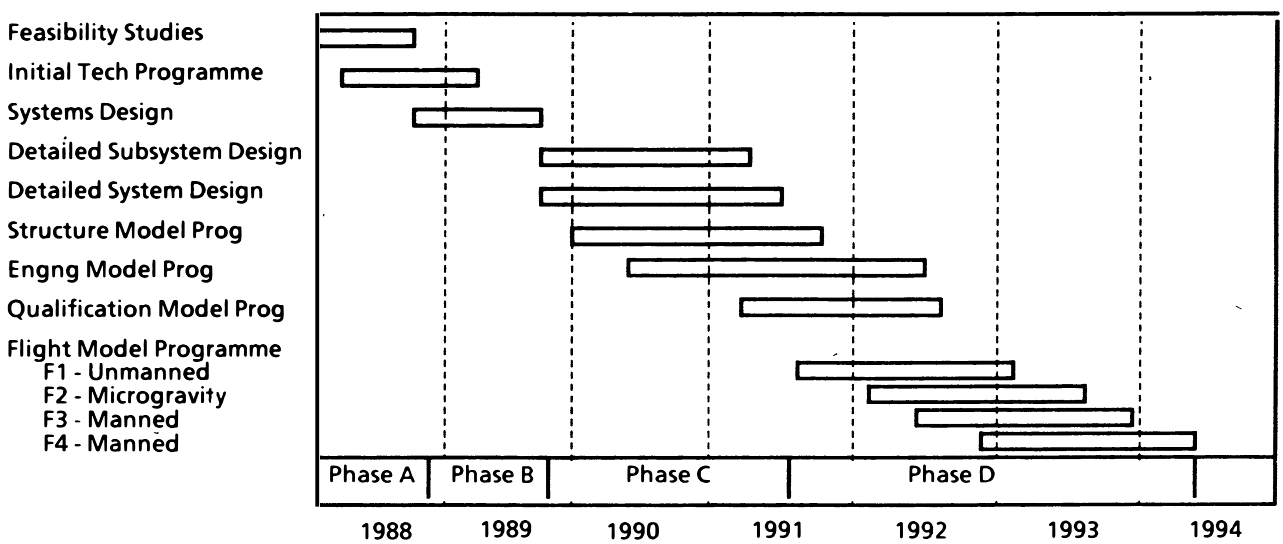

Fig. 5. Development Programme

4. REACTION TO THE MRC CONCEPT

Since the MRC concept was first revealed to the public at the IAF conference in Brighton during October 1987 there has been considerable comment on the proposal. Many people have been attracted by the relatively low development cost of the programme, the early operational date and the possibility of a valuable transatlantic link. From this point of view there have been many favourable comments.

However there have also been a number of concerns expressed about the concept as proposed and three of these merit consideration in an overview of the MRC potential:

(i) The selection of the launch system.
(ii) The selection of the sea-based recovery.
(iii) The extent of technology development.

4.1 Launch Vehicle Selection

The study selected Ariane 4 as a launch system for the MRC because it allowed for earlier operational flights and decoupled programme success from a parallel new

in the atmosphere. Neither of these problems arose in the case of the MRC, and the original Hermes work on Ariane 4 was considered valid.

Discussions since the study was made public have revealed a concern that the Ariane 4 launch system was designed as an unmanned system and the reliability was reduced in accordance with this role to increase the commercial competitiveness of the vehicle. It was felt by some that the degree to which this philosophy had been applied was such that it would not be practical to raise the reliability to that required for a manned launch. Thus the feasibility of the selected launch system must be considered an open question.

Unfortunately this is not an easy question to resolve as the only way of establishing the feasibility of man rating is for the Ariane industrial team to identify those items that contribute to the comparatively low reliability and then to identify alternatives that would raise reliability to a level acceptable for manned flight. This exercise was beyond the scope of the MRC study.

While the use of the Ariane 4 must remain in question a number of relevant points should be born in mind:

(i) The higher than acceptable failure rate of the Ariane family has lead to many of the reliability issues being addressed in any case.

(ii) None of the Ariane failures has been potentially catastrophic in the sense that sufficient warning of the failure would have been available for the crew to use escape systems and procedures to safely return to Earth.

(iii) It is difficult to conceive that there is a fundamental problem in the Ariane system that could not be addressed by alternative components or increased inspection and monitoring.

This concern does not effect the suitability of Ariane 4 to launch the unmanned microgravity version of the MRC. Nor does the argument apply to manned launches on the alternative launch systems, Ariane 5 and STS.

4.2 Recovery Operations

A second issue which has been queried by a number of commentators is the selection of sea-based recovery as opposed to land-based recovery.

The study assumed that recovery could be accomplished by a single vessel and a helicopter, and that an entire carrier task force (such as was used in the 1960s for capsule recovery) would not be required. This reduction in effort is the result of knowledge about achievable touch down accuracies which eliminate the need for any major search operations.

A similar approach has been suggested by NASA's Johnson Space Center. As part of the CERV programme they are considering off-shore recovery as opposed to recovery operations in the deep ocean. The capsule would descend to within a kilometer of a coastal recovery facility and the necessary helicopters and boats can then be sent out to recover the capsule and crew.

The issues raised in connection with sea recovery are the cost and the availability of suitable craft if the use of national navies are assumed. These are valid concerns and were not fully addressed by the MRC study and would require further investigation before a satisfactory conclusion could be drawn.

In addition to the general operational concerns there were some additional comments with regard to the suitability of a sea recovery when the capsule is used as a crew ambulance to return injured crew members. There are three factors to consider:

(i) The time from landing to hospitalization.

(ii) The difficult handling of incapacitated crew members.

(iii) The adverse and in some cases dangerous effect of seasickness on certain injuries and illnesses.

The current conclusion is that the landing technique should be judged on open issue. Both sea and land recoveries have been extensively used and the technical feasibility of either is beyond doubt. The land recovery would require a small increase in system mass to accommodate cushioning rockets to soften the final impact, but this would not be sufficient to alter the overall conclusions about the capsule's potential. A more detailed study would be required to conduct a trade-off to find the optimum approach.

4.3 Technology Acquisition

A persistent comment is the lack of technology advancement inherent in adopting a capsule approach. Mostly this comment has been made in the context of preparaton for advanced aerospaceplane such as HOTOL. This subject is covered in "Rationale and Requirements for the Multi-Role Capsule" (Paragraph 7.5) but one point is worth emphasising.

There is a widespread perception in Europe that there is essentially no knowledge and experience in the field of hypersonics. This is an erroneous view; the military programmes in both France and Britain have acquired an extensive background in this technology. For example the uncertainties that exist on the HOTOL programme are confined to the chemical reactions of the atmosphere with some of the new reusable materials at the specific conditions HOTOL will experience. This kind of data can only be obtained by a specialist test vehicle designed to accurately match the specific re-entry characteristics of HOTOL.

The common criticism voiced that Hermes is a essentially precursor to a HOTOL type programme whereas an MRC approach is of no value, is not valid. Neither are an essential precursor, indeed the benefit of either is very small in terms of directly applicable technology.

5. CONCLUSIONS

The MRC study showed that manned capsules still have many missions that they can effectively perform, both in a purely European and in an international context. The feasibility design produced by the study was judged to have successfully scoped the technical and financial aspects of such capsules. Indeed it went further and showed a single design could be expected to undertake all the roles identified. The approach outlined merits more consideration, particularly by Europe as a means of meeting infrastructure requirements in a cost effective manner with low technical risk.

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RATIONALE AND REQUIREMENTS FOR THE MULTI-ROLE CAPSULE

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The Multi-Role capsule (MRC) is a concept for a recoverable capsule capable of working in unmanned and manned modes. It would be launched on Ariane 4, and be capable of carrying up to six men or 1500 Kg of cargo. It would undertake a number of roles, supporting space station programmes with crew delivery and emergency crew return, other missions could include independent manned operations and as an unmanned microgravity laboratory. The concept has been the subject of a preliminary study to establish the feasibility and potential. The paper discusses the reasons why the MRC study was undertaken and the rationale for setting the system requirements.

1. INTRODUCTION

It is becoming convential wisdom within Europe that an independent manned access to space needs to be acquired sometime in the 1990's. The arguments for a European independent "man in space" programme are very similar to those for Ariane as an independent unmanned access, that is reliance on outside launch capability carries the risk of European priorities being subordinated to those of the launcher nation. It is not the intention of this paper to remake the case for a European manned launch system but to review the approaches available to achieve this objective and to establish the minimum useful requirements on such a system.

The study produced a requirement specification which embodied the results of the infrastructure investigation described above. The feasibility of this specification was then demonstated by the development of a feasibility design. This concept for a semi ballistic capsule is called the Multi-Role Capsule (MRC).

2. STUDY RATIONALE

2.1 European Infrastructure

There has been considerable study work conducted on an independent European manned system on the Hermes programme. Hermes is a winged aerospaceplane launched on Ariane 5, which is specified as being capable of carrying a crew of three and a useful payload of around 2.1 tonnes.

The study was conducted to re-examine from first principles the best method of achieving an initial European manned infrastructure. This has been studied in some depth by the Hermes project, based around an Ariane 5 launched Spaceplane. There were two reasons for conducting the MRC study despite the advanced state of the Hermes studies.

2.1.1 A Changing Role

The first reason is the changing role of Hermes as the study progresses. There have been major changes recently introduced in the Hermes concept most, notably the deletion of the external cargo bay, and the addition of a full crew ejection capability. This is primarily a result of a changing perception of Hermes role, it is now primarily seen as a means of servicing Columbus elements, particularly the Man Tended Free Flyer (MTFF) and any independent European Space Station. Despite the magnitude of these changes the Hermes concept was not revisited at a fundamental (blank sheet) level.

2.1.2 Infrastructure Definition

The second reason is a better definition of the rest of the Infrastructure. At the inception of the Hermes project in 1982 there was very little understanding of what other infrastructure goals Europe would have in the 1990's. Five years later we have a much clearer picture and so we can review the effectiveness of Hermes to fulfill a useful role in the overall infrastructure.

Figure 1 shows a diagram of the main thrust of European infrastructure developments in the 1990's. There are four main thrusts to European programme in the 1990's these are.

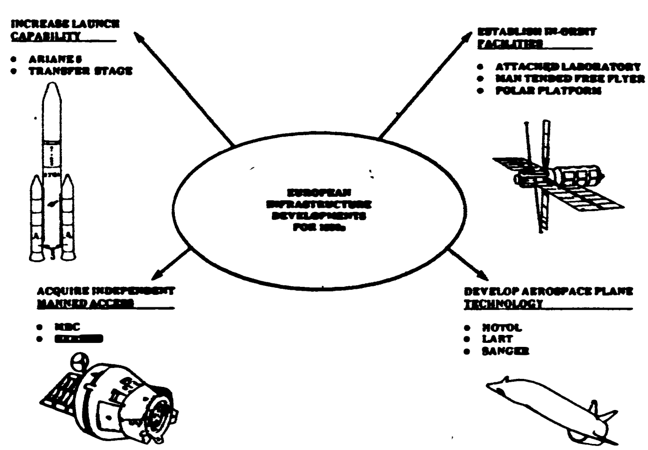

Fig.1 European 1990's Infrastructure

- i Columbus as a part of the NASA space station and as an independent facility.
- ii Expansion of the independent European launch capability with Ariane 5.
- iii The development of an advanced aerospaceplane to

ensure Europe continues to have economically competitive launch systems in the next century.

iv The estabishment of an independent manned capability.

One of the main objectives of the independent manned capability is to acquire the complete range of technologies and management skills in Europe to exploit as manned spaceflight becomes increasingly important in the overall space capability of a major space power. While this objective is independent from the other infrastructure goals there are significant interactions between them. These can be summed up as follows:

Launchers: It is clear that Europe will need to exploit its existing launch capability (Ariane) for its first independent manned missions since developing a from scratch system has neither technical nor economic merit. The launching of manned systems can be very demanding on launch systems and the possible impact must be fully assessed.

Columbus: It is clearly an important feature of any manned space transportation system that is developed that it can support the in orbit infrastructure that will be created by the Columbus programme. This will give Europe a credible independent capability to conduct a full range of low Earth orbit operations.

Aerospaceplane: The main activity during the 1990's in this area will be the development of an advanced launch system for operation soon after the turn of the century. The role of a manned programme in the 1990's would be to support this activity with technology development.

Apart from the question of technical compatibility with the extensive infrastructure Europe hopes to put in place, there is also a question of cost. All these developments are expensive programmes, running to several billion accounting units each. They are all crucial to maintain a European foothold in the space industry particularly the new developing areas in microgravity exploitation. It is therefore important that the development funds are spent efficiently only meeting real requirements. Hermes is not only expensive in its own right but it is significantly affecting the Ariane 5 costing by increasing the launch vehicle size and specification beyond what is required for its other missions.

2.2 Support To International Space Station

With the Columbus pressurized laboratory Europe has demonstrated that it is possible to create a system whose development both, enhances European goals for a measure of independence and the maintenance of a competitive space industry, while at the same time enhancing the overall western space capability in a significant and useful way. The development of a European manned launch system offers a similar opportunity.

Europe has a need for an independent manned launch system and manned whereas the United States has a need for a contingency launch and crew return system. Were the United States to develop this, then it would be merely duplicating capabilities that it already has within the STS system, whereas if Europe developed the system it would provide Europe with many capabilities that it does not have and badly needs in addition to assisting the International Space Station effort.

For the safe operation of the Space Station NASA has identified the need for a contingency return system that is attached to the space station to allow immediate escape from the space station and return to Earth in the event of an emergency. The system called CERV is not (at the time of writing) in the four baseline Space Station work packages, but is the subject of an independent study and development programme.

The provisional requirements for CERV have been released by NASA. These include the capability to undertake the following nine missions:

- Mission 1 – (Baseline mission) to return Station crew to the Earth in the event of a station abort decision.
- Mission 2 – Space Station Contingency, that is the provision of a safe haven retreat.
- Mission 3 – Crew Ambulance, that is the ability to return sick or injured crewmembers to the earth for medical attention.
- Mission 4 – EVA Crewmember Rescue, that is the recovery of crewmembers who have detached from the Station during EVA and have no means of return
- Mission 5 – Unmanned Delivery to the Space Station, that is the ability to launch the CERV to the space station by launch systems other than the STS.
- Mission 6 – Crew delivery to the Space Station, that is the delivery of crew to the Space station in the event of a temporary loss of STS.
- Mission 7 – Space Station Cargo Return, that is the return of cargo from the Station to the Earth in an unmanned mode.
- Mission 8 – Crew Rescue from Damaged STS, that is rendezvous with a damaged but orbiting Orbiter to recover the crew.
- Mission 9 – Temporary Space Station Contingency Departure and Immediate Return.

The MRC study was aware of NASA's interest in such a system but was not familiar with the contents of the draft specification. Thus the study derived its own set of requirements for a Station Escape Vehicle and incorporated these into the MRC design. The studies assessment proved to match the NASA specification very closely with the exception that Mission 4 (EVA Crewmember Rescue) and Mission 8 (Crew Rescue from damaged STS) were omitted. When the requirement for these missions was known the design was revisited and it was found that requirements from the European needs had influenced the overall requirements such that these unforeseen missions could be conducted without any alteration to the feasibility design.

2.3 Microgravity

There are two aspects to space transportation systems, the delivery of payloads to orbit, and the return of payloads to the Earth's surface. Ariane has given Europe the first half of this but currently it has no capability for return. This has a particular influence on Europe's ability to do microgravity research, which currently is seriously compromised.

Return capability is an integral part of any manned spaceflight system. Thus it is reasonable to explore the use of any independent European manned system to also provide an independent microgravity research facility.

2.4 Independent European Space Station

Europe is already examining the possibility of the establishing of an independent Space Station as a long term objective. This is understudy as an evolution of the Columbus programme with crew delivery by Hermes. Should this ever be undertaken as a programme then a rescue system similar to the CERV (discussed above in section 2.2) would be required. Since the MRC study included the complete CERV requirements in the system specification, it could of course meet this European need when it arises.

3. REQUIREMENTS

3.1 Reference Missions

The following were the missions that were considered when the MRC specification was determined.

3.1.1 Independent Missions and Technology Flights.

The first class of missions were the missions independent of other elements in the European in orbit infrastructure. These include the test flights, which will prove the independent launch capability, and technology proving flights during which the various techniques required for a full capability in manned spaceflight such as EVA and in orbit construction. Later technology flights could be used to qualify components of the Aerospace plane or other projects intended for the beginning of the next century.

Another mission that could be undertaken in an independent role is a guest visit to the Soviet Mir Space Station (or its successor). Whether or not this particular mission is undertaken, it illustrates that a system such as the MRC, or Hermes, would give Europe the ability to participate in international manned space programmes on an equal partner basis.

3.1.2 Space Infrastructure Support

The main role of the MRC within the overall infrastructure is to support the manned in orbit infrastructure. This is currently foreseen as having two elements, a laboratory attached to the USA Space Station, and a European Man Tended Free Flyer (MTFF) microgravity laboratory. Later an independent European Space Station could be envisaged.

The MRC could have two roles associated with European involvement in the Space Station. The first is as the escape system (CERV) allowing the crew to return to Earth in the event of a catastrophic Space Station malfunction or the grounding of the Space Shuttle system for any reason. If Europe undertook to provide this element it would mean a continued commitment to European involvement in the programme as (with the current MRC specification) the life boat would probably need to be replaced every two years.

The second Space Station role would be a second means of crew delivery. This second access capability is not a technical requirement of the Space Station programme although it would give a fallback mode that allows the Space Station to continue reduced operations in the event of another grounding of the STS. However the main value of a European crew delivery mission would be for prestige as it emphasizes the strength of its partnership in the programme.

The Columbus Man Tended Free Flyer has two possible methods of servicing, either from the USA Space Station, or by the independent European manned launch system (Hermes or MRC). Even if the Space Station is selected as the best operational method the independent servicing capability is still important to ensure Europe has full control over this important facility. Later it may prove desirable to establish an independent European permanently manned space station and this will clearly need a fully independent logistics and crew supply capability.

The European independent manned access capability would need to support manned operations in orbit until a fully man rated operational European aerospaceplane exists, which,with a suitable overlap,means around 2005. To leave the long term options open for the expansion of the European independent activities it should be assumed that the system shall be able to support a 12 man facility as an upper limit, while be optimized around a 4 man station.

ECLSS	Open ECLSS	Closed ECLSS
Oxygen	990	500
Air makeup	400	400
Water	7670	3070
Hygiene etc.	1000	1000
Misc	100	100
Other		
EVA consumables	80	80
Personal effects	240	240
Propellant	1990	1990
Thermal fluid	20	20
Repair parts	1200	1200
Payload	3000	3000
TOTAL	16690	11600

There are two support roles that the MRC is intended to undertaken. They are crew transportation and a contingency crew return system (lifeboat), the same roles as envisaged for the USA/International Space Station. A third possible role of logistics support was not included in the requirements for the MRC alone. The reason for this omission can be seen from consideration of the logistics requirements for a 3 man permanently manned station.

Thus the annual requirements for supplying a permanent facility is well over 10 tonnes. If 4 crew rotation flights a year are assumed (ie at 90 day intervals) then more than 3 tonnes of payload each flight must be carried. This would have increased the payload requirement of the system by 300 per cent with a corresponding impact on the overall system. It was decided that the logistic supply activity would not be included in the MRC requirements. The available methods of conducting supply missions are discussed further in section 5 below.

3.1.3 Unmanned missions

Before the MTFF becomes operational (about 1997) Europe's main microgravity facility will be the Eureka platform. This is an unmanned satellite that is launched by the Shuttle, boosts itself into a higher orbit then conducts around six months of microgravity experimentation. It is then recovered, refurbished and reflown with a new payload.

However the "post-Challenger" Shuttle programme does not appear to offer as many flight opportunities for Eureka as originally hoped for nor is it given the priority that Europe would have liked. Thus, there appears to be a gap between Europe's desires for microgravity research and the actual capability they possess to conduct them. ESA have already started to explore the possibility of an Ariane launched returnable capsule as a means to fill this gap.

It was decided to include the possibility of an unmanned microgravity version of the MRC in the specification. This would give a substantial capability for microgravity research which is totally under European control.

3.2 Study Goals

From the above discussion the study identified a total of eight infrastructure roles that the Multi-Role Capsule should undertake. These are:

i Independent European Manned Access To Space
ii Manned Spaceflight Technology Development
iii Unmanned Microgravity Laboratory
iv US Space Station Escape System
v US Space Station Contingency Access
vi MTFF And Polar Platform Servicing
vii European Space Station Crew Access
viii European Space Station Escape System

In addition to conducting the above roles, the study set out with the following major goals for the system:

Early operations - It was felt that there was an urgent need to start European manned spaceflight as soon as possible. It is clearly going to be an important feature of space capability by the turn of the century and Europe has considerable catching up to do to become a credible supplier and operator of manned spacecraft.

Minimize development cost - As discussed above the funds available for such a programme are likely to be limited and the best value for money approach needs to be adopted.

Maximize potential utlization - The main goal of the system is to open up opportunities for Europe so the design should be such that it maximizes the potential uses of the system.

4. SPECIFICATION

This section describes the main features of the technical specification that the MRC study worked to.

4.1 Payload

The specified payload for the MRC was set as 1500 Kg all contained in the pressurized cabin. This figure is used to size the MRC structure and equipment such as the recovery system, the capability required during an Ariane 4 launch is reduced to 1000kg. The payload includes the crew's personal effects and spacesuits for all the crew, but not the provisions or personal equipment employed during the flight in the MRC itself. A cargo bay, with dimensions at 1.8m x 1m x 0.5m, is also included in the specification, capable of supporting up to 500 kg of mission specific payload when carying a maximum crew.

The maximum crew size was specified as a nominal four men with a maximum of six men for some missions which do not include the use of the main cargo bay. This figure is determined by a several independent considerations. Most identified independent and other early missions required a crew of between two and four men. The longer term needs for a European independent manned infrastructure are less clear however the specified capacity is the minimum to supply crew for the twelve man station, while not being oversized to support a smaller (and more likely) three to six man station.

The crew size must also consider the lifeboat role. There is a need for a lifeboat on the NASA Spce Station which could have a crew of six to eight, as well as one any future European independent station. A crew size of six would allow two lifeboats to support the Space Stations as foreseen in the next decade. Two is the minimum number of lifeboats in any cases because if the crewmember ambulance mission is undertaken an escape provision must remain at the station. Major expansion of the Space Station (up to 18 crew) could be undertaken with only a third lifeboat. The need for consideration of the long term is of particular importance in the case of the lifeboat role. It is an expensive item and it would considerably add to expansion costs if the lifeboat system needed replacement. With the six man crew the MRC could fulfill the role until the in orbit infrastructure, and the launch system operations are sufficiently advanced to provide crew escape provisions by more sophisticated methods. This could mean that MRC would be still in operational use until the middle of the next century.

4.2 Mission

The maximum mission duration was set at six days including any contingency, with an additional requirement to be able to be stored on orbit, while docked to a space station, for a period of up to two years. The life support system was required to carry consumables for 24 mandays.

The six days flight and 24 mandays consumables requirements were determined by missions, with up to a four man crew, for five days (plus one day contingency). This would be sufficient for independent missions with time for technological development activities (such as experimental EVAs). Also early support flights with a two men crew would have additional contingency to resolve teething problems associated with early facility operations. The requirements for six man crew escape (or even six man crew delivery) are well within this capability.

The two year on orbit storage time was determined by the lifeboat role. The technology required for the operation of such a capsule after a prolonged period exposed to the space environment is the most significant area of technological uncertainty. The maximum proven for the Apollo capsule was 86 days on the Skylab mission, and the Soviet Union has been replacing the Soyuz crew delivery spacecraft every six months or so. The two year requirement is therefore a technological goal and longer storage time would be desirable if possible.

4.3 Launch Vehicle

Ariane 4 was selected as the primary launch system. The reasons for this choice were as follows:

* It decouples the development of a new launcher from the development of a new manned system. This considerably reduces the technical risk in both programmes.

* The considerable development experience

with the basic Ariane would make the launcher easier to man rate.

* The use of Ariane 4 allows for a continuation of commercial and unmanned support launches by Ariane 5 in the event of a major technical hold in any of the manned launches.
* It allows an earlier start to manned development flights. 1993 being a possible first flight date.

The basic philosophy in integrating the MRC with Ariane 4 is to adopt a Soviet approach, that is the Capsule and its crew are essentially passengers with very limited monitoring and no control over the launch vehicle, which is flown by ground control as with an unmanned flight. The alternative approach used by the Americans with the crew as pilots with a control option was not selected in view of the extensive changes it would generate to the existing Ariane system. It was judged that there was little difference in the safety of either approach.

Technically the Ariane 4 vehicle is quite suitable for launching the MRC type system, however there would be some alterations required. Some of these are the usual alterations for man rating a launcher, covering the amount and type of telemetry, the launch abort procedures, and the analysis of the aerodynamics etc., of the new payload.

In addition to these, there would be a need to strengthen the structure of the upper two stages. Although the quoted payload capability into low Earth orbit (with four liquid boosters) is over 9 tonnes, in practice structural limitations set an upper limit of 6 tonnes with the current design. This is a little light for a system meeting the specification outline and so it is assumed that strengthening of the launcher will be required. The impact of these changes on the payload capability is uncertain and so the specification on the MRC was set at 7 tonnes. This was sufficient to meet the specification and should be well within the capability of the modified Ariane 4. Hopefully sufficient margin will remain to give considerable orbital flexibility.

A disadvantage with this choice of launcher is the restrictive diameter of the third stage (2.5 m.), which provides a major configurational constraint. The configuration derived by the study shows that this disadvantage can be overcome.

The payload provisions will have to be altered which involves the addition of two new elements. The existing Vehicle Equipment Bay (VEB) would need extensive alteration or replacement to accommodate the following:

* All the payload mass is tranferred via the VEB to the third stage.
* The interface with MRC (including the separation system) is significantly different from the existing interface.
* The man rating will probably involve some changes in the electronic outfitting of the launch system which is housed in the VEB.

The other change is the replacing of a faring with an escape system. This would be used to pull the MRC from the launch system in the event of an emergency requiring a crew escape.

It is possible that later the MRC would be required to be launched on Ariane 5, sharing with another payload or additional module (this possibility is discussed further in section 5 below). This should not prove technically very difficult if a special adapter is constructed between the MRC and the Ariane 5 upper stage. The other payload rides within this adapter in a similar manner to the Lunar Module on the Apollo/Saturn 5.

Another possible launch system is the STS. The use of the Shuttle would be to deliver rescue capsules to the Space Station. These would be mounted in the STS payload bay attached to Airborne Support Equipment (ASE). In this role it would be launched unmanned. The study did not consider this launch system in detail, but did keep the MRC dimensions compatible with the payload bay.

4.4 Interfaces

The main interfaces apart from those associated with the launch system are those required for operations with the Space Station/Columbus. This necessitates the inclusion of a Space Station Docking/Berthing port, which has a 1.3 m square hatch, a connection ring about 2 m in diameter and maximum dimensions from tip to tip on the guidance plates of about 2.3 m. This is much larger than previous manned systems have been required to accommodate and has a profound influence on the overall configuration.

The operations at the Space Station also require that the MRC has a grapple point for the Space Station manipulator system (this has been assumed to be the same as the Shuttle's RMS). Its location has to be such that the manipulator can place the capsule on to a berthing port.

A desirable feature that was included in the MRC specification was the inclusion of a cold gas reaction control subsystem for control when close to other manned systems to prevent damage from the hot gas thrusters.

4.5 Safety

The main safety feature of the MRC during the launch phase would be a solid rocket escape tower of the same type used on Mercury, Apollo, and Soyuz, as discussed in section 4.3 above. These have proven to be an effective means of crew escape in the event of a problem with the launch system, particularly on Soyuz where they have been used during real emergencies and have saved the crews' lives.

The provisions for decompression, and cabin environment contamination rely on each crew member having a pressure suit which would be worn during launch and other critical operations. Because every crew member has a pressure suit there is no provisions for Shuttle type rescue enclosures.

Contingency supplies include survival packs, medical packs, repair tools and a contingency allowance of the life support consumables. In this regard the provisions are very similar to the practice of Apollo and Space Shuttle.

Normal good design practice for safety is of course assumed. This involves having redundancy on all the life critical items and so far as is practicable avoid colocating redundant units. Potential hazardous components that represent either an explosion or toxicity hazard are located outside the pressurized volume. The design would also avoid materials that can propagate fire, outgas, or have other undesirable properties.

4.6 The Microgravity Laboratory

This was assumed to be a minimum modification from the manned version. With the removal of the seats and other systems not needed on an unmanned flight the payload was raised to 1.5 tonnes on an Ariane 4 launch, still all housed in the pressurized volume. This payload will however need about 1kw of power and thermal conditioning which will involve the incorporation of additional systems.

5. ARIANE 5 VERSION

There are two major compromises inherent in the above specification. First the maximum mission lifetime of only 5 days in orbit operation, this was deliberately set as short as possible for the prime missions to allow the use of simple storage techniques for the consumables which are easier to design for the long on orbit storage. The second compromise was the omission of the logistics role for the reasons already discussed in section 3.

It is not certain whether either of these are crucial omissions or not, but it is possible to improve the system with an additional module. Originally the study aimed to explore this option to demonstrate the expansion potential of the MRC concept when placed on the new launch system. However when this was under consideration the options and possibilities that opened up were so many and the work needed to refine the uncertain requirements given the current definition of the infrastructure precluded the derivation of a set of requirements or a configuration within the resources allocated to the study.

For the study a 15 tonne payload capacity was assumed. The extension options are unlikely to develop as well as Hermes as the capabilities would be very similar. Without Hermes, which drives the 21 tonne requirement, Ariane 5 could be returned to the commercially optimum 15 tonnes. Given the main MRC system has a mass of 7 tonnes this leaves around 7 tonnes for any extension module.

The optional nature of an Ariane 5 version should be stressed. The basic MRC on Ariane 4 can meet the fundamental requirements for a European manned transportation system as already discussed. If detailed consideration of the infrastructure requirements leads to the decision that an expanded system capability has an independently justifiable role, then the option is open.

The study foresaw three main missions that an expanded MRC could undertake, in addition to some secondary missions. Each tended to drive requirements in a different direction and it was not possible to prove these could be met by a single system by generating a feasibility design.

The first mission as an extended independent flight for technology development. The need for such missions given the Columbus programme is small unless special orbits, or some other special requirements. The most likely configuration for this mission would be a pressured module which would about double the habitable volume, increasing the consumables and power to give a mission life of around three weeks.

The second mission is a MTFF servicing mission (also applicable to an independent space station) delivering both the crew and the supplies in one launch. For this mission an Ariane 5 launch was used to launch the MRC and an extension module together. This module would need both a pressurized and external payload area. A first estimate of the payload capacity suggests that such a module should easily carry the 3 tonnes identified for this mission in section 3.1.2.

the third mission was the servicing of unmanned platforms particularly the Columbus Polar Platform. The polar orbit reduces the available payload but in this case there is no need for a pressurized area and if optimized for this mission, an MRC and extension module could have a payload of over 2 tonnes, which is consistent with mission requirements.

6. PROGRAMME

The study assumed a specific programme for development and utilization. This is shown in Fig.2. The programme assumed a maximum utilization of the potential by undertaking all the design missions.

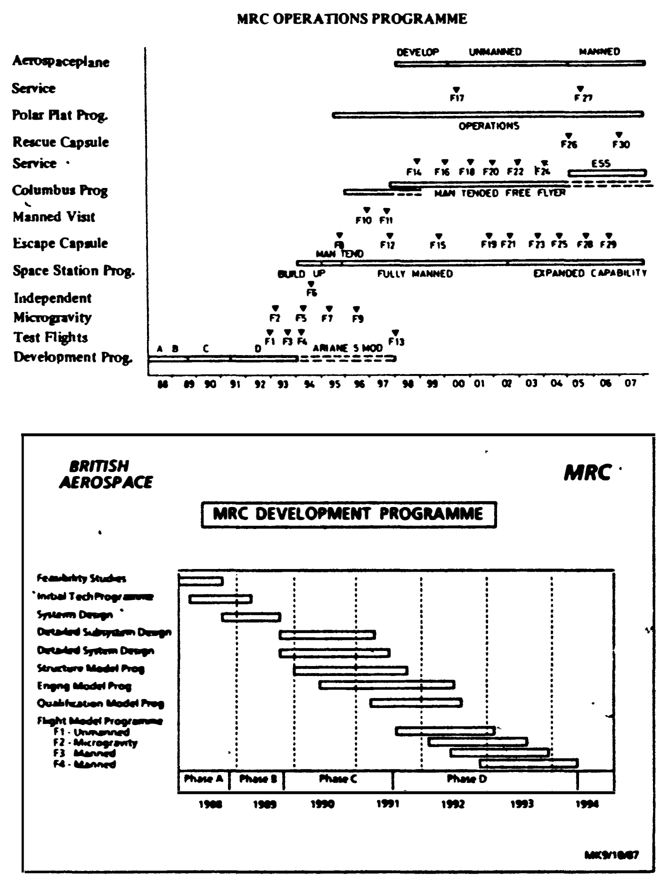

Fig.2 MRC Programme

The development programme from the beginning of Phase B to launch of the first test flight is just over four years long. This may appear short when compared with the durations proposed for other programmes (such as Hermes or Columbus), but the complexity of the system is not as great and this programme is considerably longer than the time spent developing similar systems in the 1960's.

It was assumed that the programme would start in the fourth quarter of 1988 which leads to the first flight in 1993. This flight would be unmanned but fly the manned version, the second flight is also unmanned by flys the special microgravity laboratory version. Then in the fourth quarter of 1993 the first manned flight is undertaken as a further test of the system. A second manned development flight is conducted in 1994 before the system is judged ready for operation.

The overall operations programme indicates the system would have about flights a year over a fifteen year period. The main use would be as an escape system for the various space stations with eleven of the thirty flights. The table 1 gives more detail of the flights. It also identifies three contingency missions that may call for capsules to be constructed and held in readiness.

TABLE 1 Mission Model

No.	Date	Crew	Launch	Mission
Development				
STM	1991			Structural testing
EM				System Development
QM	1992			System Qualification
Flight Models				
F1	1993	0	A4	Development
F2	1993	0	A4	Microgrvity
F3	1993	2	A4	Development
F4	1994	4	A4	Development
F5	1994	0	A4	Microgrvity
F6	1994	4	A4	Independent mission (e.g. Mir Visit)
F7	1995	0	A4	Microgravity
F8	1995	0(6)	A4	ISS Rescue capsule
F9	1996	0	A4	Microgravity
F10	1996	3/4	A4	ISS Visit (System Demonstration)
F11	1997	3/4	A4	ISS Visit (Crew Supplement For MTFF Operations)
F12	1998	0(6)	A4	ISAS Rescue Capsule
F13	1998	2	A5	A5 Development
F14	1998	2	A5	MTFF Service
F15	1999	0(6)	A4	ISS Rescue capsule
F16	1999	2	A5	MTFF Service
F17	2000	2	A5	Polar Platform Service
F18	2000	2	A5	MTFF Service
F19	2001	0(6)	A4	ISS Rescue Capsule
F20	2001	2	A5	MTFF Service
F21	2002	0(6)	A4	ISS Rescue Capsule
F22	2002	2	A5	MTFF Service
F23	2003	0(6)	A4	ISS Rescue Capsule
F24	2003	2	5	MTFF Service
F25	2004	0(6)	A4	ISS Rescue Capsule
F26	2004	0(6)	A4/A5	ESS Rescue Capsule
F27	2005	2	5	Polar Platform Service
F28	2006	0(6)	A4	ISS Rescue Capsule
F29	2006	0(6)	A4	ISS Rescue Capsule
F30	2007	0(6)	A4/A5	ESS Rescue Capsule
Contingency capability				
C1	1996	4	A4/A5	Crew Supply for ISS & ESS
C2	1999 on	2	A5	MTFF or PP service
C3	2005 on	2(6)	A4/A5	Aerospaceplane Rescue

After a further independent manned flight, probably a guest visit to the MIR station, the first Space Station support flight occurs at the end of 1995 and is an unmanned mission to supply the first lifeboat just before permanent manned operations begin. This lifeboat is assumed to be replaced every 18 months. Two visits are also included in the programme, one, after a years operation of the Space Station facility, as a goodwill visit and technical demonstration. The second visit sends a four man crew to expand the Space Station capability during the in orbit construction and commissioning phase of the MTFF, when the workload is likely to be heavier than the standard Station Crew could be expected to handle.

Once in operation two servicing missions a year would be conducted in the programme. An Ariane 5 version is assumed, which effects the programme in that an addition technology development flight using the Ariane 5 at the end of 1997.

The unmanned flights of the microgravity laboratory are assumed at the rate of one a year after the first flight in 1993. These stop in 1996, in anticipation of the MTFF becoming operational in the following year which would become Europe's main microgravity Laboratory.

7. HERMES

Since support of the manned in orbit infrastructure is the primary objective of the Hermes system (Fig.3), a comparison of Hermes and the MRC is appropriate. The question that needs to be addressed is does Europe need both? The answer is somewhat complex.

The Hermes concept is for a spaceplane which is placed into orbit by Ariane 5, it would then return in the same manner as the Space Shuttle gliding to a landing on a conventional runway. It would then be turned round for a reflight.

The Hermes in its most recent form is optimized for the servicing of the MTFF or European Space Station. Its crew is now three reduced from an earlier four or six, this was partly to reduce mass and partly to allow the crew to be located in an ejectable cabin during launch. Behind the cabin is a pressurized payload area, which has 18 cubic meters for payload storage and 8 cubic meters living space. Behind the payload area is the airlock that also has the docking port for connection to the facility to be serviced.

The total payload capabiity is quoted as 3 tonnes but this includes margins and payload packaging and this gives a useful payload of 2100 kg. It has a long mission duration capability of three months.

7.1 Launch Vehicle Impact

As with all aerospace plane solutions its mass compared with its payload mass is high, the total mass is around 21 tonnes for about three tonnes of payload including crew. This has meant that it has greatly exceeded the original capability planned for Ariane 5 (15 tonnes) this has lead to a continuing series of proposals to increase Ariane 5 payload mass to chase Hermes' growing mass.

The current margin (as available to the author at the time of writing) on the Hermes system is 2.6 tonnes in 18 tonnes (Launch mass less payload) or 14.5 per cent. For a system at this level of definition this is a narrow margin and there must be some risk that the overall mass budget of 21 tonnes may be exceeded. This means that Ariane 5 may need further uprating or that the payload capacity of Hermes would need to be reduced. Neither a desirable option.

7.2 Space Station

There are two potential missions that could be underta-

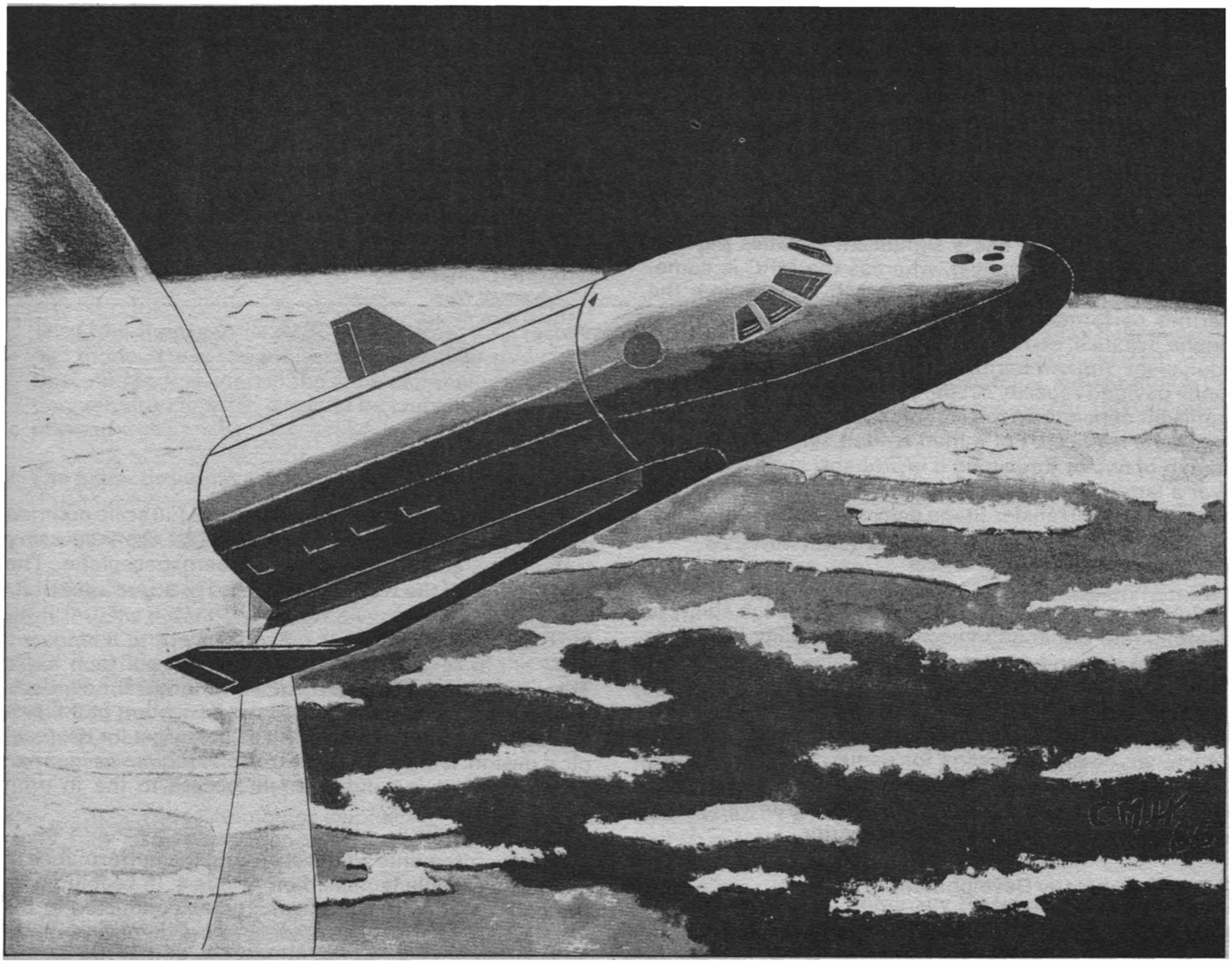

Fig.3 Hermes

ken by a European manned launch system. One is guest visits, acting as a secondary crew delivery system. There is very little difference in the effectiveness of either Hermes or MRC to fulfill this role.

The second is a lifeboat for contingency crew return. Hermes is not suitable for this job for several reasons:

* It is not designed for extended in orbit stays (modification to achieve this carry a high technological risk)
* It requires a skilled pilot to fly it during re-entry
* It is an expensive asset to perform this role
* It will not be available early enough

By contrast MRC has the lifeboat role as one of its primary missions and has none of the above problems.

7.3 Columbus Support

Whether the Columbus remains as the MTFF or expands to an independent European space station there are four main support roles, Module delivery, Crew transportation, Logistics supply and Rescue. There are several options (see Fig.4) though all need the development of a specialist upper stage for the delivery of the main Columbus elements, and the development of some form of ballistic capsule. The latter is an important point, that a lifeboat system would require development in addition to Hermes if an independent European station were to be established. This additional cost would be essentially the same as the development cost of the complete MRC system as outlined in this paper.

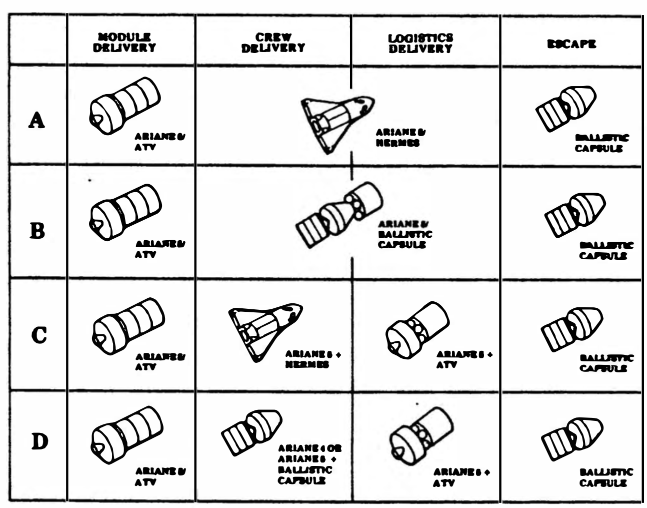

Fig.4 European Space Station Transportation Options

Both MCR and Hermes can act as a crew transportation system, the main difference being in the number of crew. The MRC maximum crew capability is set as six (the original Hermes crew size) as compared with the current Hermes crew of three. For servicing the MTFF three is probably sufficient, however a crew of only three, especially if one needed to be a trained pilot, would restrict European options at the turn of the century.

Another fundamental difference between Hermes and MRC is that Hermes has a significant logistics payload capability (18 m^2,3 tonnes), whereas the MRC is somewhat limited (1 m^2, 500 kg). The MRC can match the Hermes performance with an extension module and an Ariane 5 launch, so the systems could be judged roughly equivalent (remembering that MRC requires only 15 tonne payload capacity Arian e 5). Whether three tonnes is sufficient depends on the complexity of the eventual system to be serviced. For a man tended system or a small station of two or three men it is probably sufficient, however a larger system would be more effectively supplied by an Ariane 5 Transfer Stage delivered logistic module.

7.4 Independent Operations

Both Hermes and MRC would give Europe the ability to demonstrate a manned spaceflight capability. They are both able to conduct the main identified missions, i.e. technology demonstration and development a guest visit to Soviet Station. Hermes does have one advantage over the baseline MRC in that longer flight times are possible which can be an advantage for some of the technology development. If this longer mission is felt necessary then, as with the logistics capability, an Ariane 5 and an extension module would address this disparity.

7.5 Technology Development

One of the prime features of the Hermes system is the large amount of new technology that would need to be developed to complete the programme. Europe will need to expand the technologies that its industry is capable for exploitation in the early years of the next century, particularly by the Aerospaceplane (e.g. HOTOL). Table 2 shows the developed technologies against three main infrastructure programmes; Columbus, MRC and Hermes.

The Columbus programme, which is not primarily intended as a technology development in its own right, never the less does provide a degree of appropriate technology development. The MRC would provide some additional technologies but in some areas the experience gained. HERMES provides a much fuller range of technology development. It should be noted that the same or better range of technology advancement could be obtained from a smaller pure experimental vehicle without attempting to meet infrastructure roles.

TABLE 2 Technology Development

Technology	Columbus	MRC	Hermes
Space Medicine	X	X	X
Robotics	X	–	–
EVA	–	X	X
Hypersonics	–	/	X
Fuel Cell	–	–	X
ECLSS	X	X	X
Turnaround	–	–	X
Flight Avionics	–	/	X
In Orbit Comms	X	X	X
Advanced Prop.	–	–	–
Cyro Tank/Struct.	–	–	–

(X = extensive / = limited)

It is a debatable point as to whether a full scale manned vehicle would be needed to provide the necessary technology advancement for an aerospaceplane. The conclusions of the HOTOL study tend to argue against it.

8. CONCLUSIONS

This paper intended to explain the rationale for conducting the MRC study and explain the derivation of the system specification that was used as the target for the technical design. It is assumed that Europe requires a manned programme giving independent access to the in orbit infrastructure.

The requirements were set around the performance of a ballistic capsule launched on Ariane 4. In keeping with the conclusion with American studies conducted in the sixties, particularly those leading to the demise of the X-20 Dyna-Soar programme, it was found that the performance of ballistic capsule on an expendable launch system is about three times better than an aerospaceplane as well being more cost effective with low launch rates. Thus the MRC can offer effective infrastructure support, while using a smaller and existing launch system. This reduces the technical risk, development and operation costs, as well as being operational much earlier.

There are a number of options in the longer term with regards to support of independent European facilities and with the technology developments which will be required for the support of the advanced launchers. It was not within the scope of the MRC study to trade off these options, but even if it is not judged that a vehicle meeting the MRC specification can contribute to these areas there are sufficient unique roles for such a vehicle to provide a justification for its development.

This paper represents the author's private work and the views expressed in the paper are those of the author and do not necessarily represent those of British Aerospace plc.

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MULTI-ROLE CAPSULE SYSTEM DESCRIPTION

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The Multi-Role capsule (MRC) is a concept for a recoverable capsule capable of working in a manned and unmanned mode. It was the subject of a feasibility study within British Aerospace. It has a two module configuration, a Descent Module contain the crew and major systems and a jettisonable Service Module with equipment that is only required in orbit. It would be launched on Ariane 4, and be capable of carrying up to six men or 1500 kg of payload

The paper describes the feasibility design at system and subsystem level.

1. INTRODUCTION

The Multi-Role Capsule (MRC) concept is the result of a study into the potential of a European manable capsule in the context of the anticipated 1990's infrastructure. This paper describes the main technical features of the MRC feasibility design that was produced to demonstrate the viability of the concept. The study goal was to produce a feasibility design of sufficient detail that reasonably accurate assessments of

- i) The technologies involved
- ii) The performance,
- iii) The cost,

could be made. To accomplish this the feasibility design was taken down to unit level for all subsystems. It should be noted that few trade offs were conducted during this process, therefore the results presented here are deemed to represent a workable system, although not necessarily an optimum.

The Multi-Role Capsule was designed to undertake eight infrastructure roles. They include all the European requirements for payload recovery and manned space access. They also include all the missions that NASA has identified for the Crew Emergency Rescue Vehicle (CERV) element of the Space Station. the CERV was not in the initial Space Station plans, but is now under study in the United States and is generally agreed to be an essential part of the Space Station programme. The eight roles are:

- i Independent European Manned Access
- ii Manned Spaceflight Technology Development
- iii Unmanned Microgravity Laboratory
- iv US Space Station Escape System (CERV)
- v US Space Station Contingency Access
- vi MTFF and Polar Platform Servicing
- vii European Space Station Crew Access
- viii European Space Station Escape System

There are clearly advantages to multi-role systems. Although the development process is a little more complex set of system requirements, and the resulting product is a little off optimum for any particular mission, the increased utilization of the final product can lead to very substantial savings.

2. SYSTEM REQUIREMENTS

The MRC study started by merging the mission requirements of the identified infrastructure roles to obtain the overall specification the capsule would need to meet. The main requirements identified are discussed in this section.

The in-orbit mass will require to be under 7 tonnes to meet the likely performance of Ariane 4. There is also a maximum diameter requirement of 4 meters. This is determined by a need to restrict the hammerhead on the launch system and also to aid integration into space station configurations.

The crew should nominally be four for a launch case with six during an emergency return only. The provision should also be available for between 250 and 500 Kg of payload.

The active life should be five days with an additional day capability for contingency (six days in total). In addition to this a two year on orbit lifetime in a storage or hibernation mode was specified. This was primarily a technologicial concern and if later studies show this could be extended then this would be highly desriable.

The system would be required to deliver crews to and return them from orbit and orbiting space systems notably space stations. It is required to support limited EVA activity, one nominal and one contingency two man EVA being specified.

The system was specified as a semi-ballistic vehicle with a nominal splashdown in the ocean. In a contingency case the capsule should be able to touchdown on land without major injury to the crew. The landing accuracy during an automatic re-entry should be to within two kilometers of a designated point. Recovery is to be accomplished with a single ship and helicopter.

A more detailed account of the rationale for the derivation of the system requirements is given in reference 1.

3. DESIGN

3.1 Configuration

The MRC has a two module configuration as shown in

Figs. 1 and 2. A Descent Module that has the pressurized section and is the section that returns from orbit. Attached to the rear of the Descent Module is the Service Module which contains equipment which is only required while in orbit and can be jettisoned before re-entry. The Service Module also acts as the adapter to the VEB on the Ariane launch system.

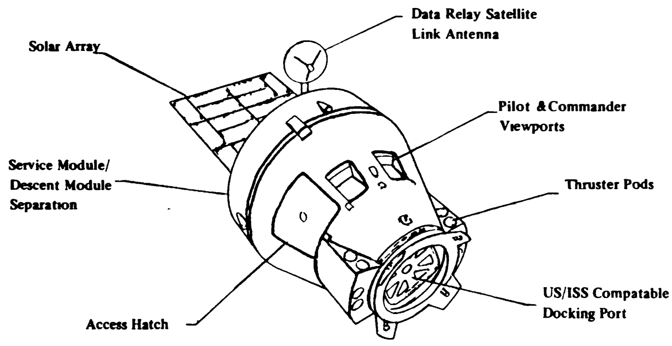

Fig.1 General View of MRC

Figure 1 shows the orbital flight configuration of the MRC with the arrays and antenna deployed. The nominal attitude would be Sun locked, with the Sun along the Z axis, that is full on solar array (which has a fixed position). When manoeuvres or other tasks require a different attitude the spacecraft is powered from batteries which can then be re-charged during periods of Sun pointing. In this respect the MRC has adopted a very similar strategy to the Soviet Soyuz spacecraft.

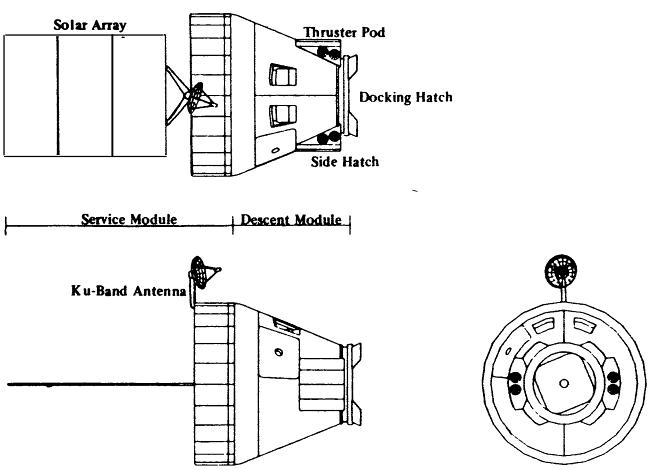

Fig.2 Three Views of MRC Orbital Configurations

3.1.1 Descent Module

This is a cone shaped structure 4 meters in base diameter and 3.6 meters high. At the front end is a Space Station compatible docking port. Two pods behind the port contain the main thrusters and recovery parachutes. Another unpressurized area at the base houses the propulsion and ECLSS consumables.

The majority of the Descent Module is devoted to the pressurized cabin. This is divided into three compartments, the forward compartment which houses the galley and hygiene. The mid compartment contains the main crew area. The rear cabin houses the batteries and a mission specific payload area 1.8 x 1.5 x .75 meters. In the Space station lifeboat role (whether the International/US Space Station or an independent European Station) the payload bay would house an additional two seats allowing a total six crew to return in the event of an emergency.

The main crew area in the mid cabin can contain up to four seats. Two of these are nominally passenger seats and two are nominally pilot seats although the MRC can be flown by one man or even fully automatically. The two pilot seats have forward facing viewports and a control console. Most of the MRC equipments are housed in this area in a U shaped equipment bay which act as a floor and lower walls to the mid cabin area. A side hatch opens into this area which is used for access into the vehicle on the launch pad, and as the egress/ingress for EVA while in orbit. The side hatch also achieves compliance with the Space Station safety requirement for two independent methods of entering any area.

The docking port, which is compatible with the standard Docking/Berthing port on the International-United States Space Station, drives the configuration of the forward section of the capsule. The guidance vanes on the port are placed symmetrically to aid the re-entry aerodynamics this means the hatch is placed at an angle of 22.5 degrees to the spacecraft axis. This also effects the docking angle and means the internal local vertical is 22.5 degrees away from the local vertical of the Space station system that has the docking port guidance vanes set asymmetrically.

The microgravity laboratory version would be unmanned, however the main configuration and equipment remains essentially the same. The main experiments would be mounted in racks which are mounted in the same locations as the seats. Up to six of these racks can be carried, each carrying up to 200 Kg. The forward compartment which normally houses the hygiene and galley would in this case carry secondary experiments.

Figure 3 shows the interior arrangement of the four man transport, with two payload racks mounted in the payload area. The view also shows the propellant, and gas storage tanks in the lower unpressurized area.

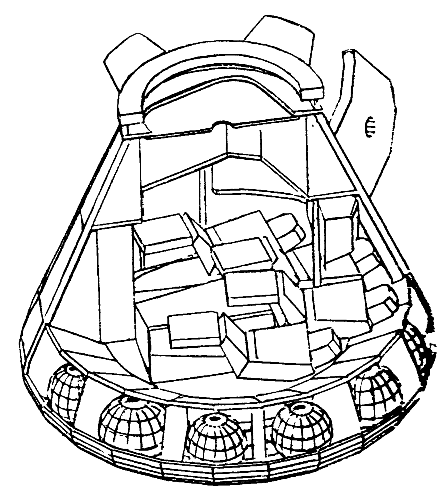

Fig.3 Interior View of 4 Man Version

3.1.2 Service Module

The service module is a cylinder 4 meters in diameter and 1 metre high. It houses the cold gas reaction control system, the solar array, the DRS link antenna, and some other electronic boxes.

The solar array has three ridged panels (five in the microgravity laboratory version) and deploys after separation from the launch system along the X axis. This direction was selected because it does not impact on the overall diameter in the YZ plane which allows the MRC to be easily integrated into the Space Station architecture.

The DRS Link antenna is also deployable after separation form the launch vehicle . It swings through 180 Deg. such that the support boom is pointing along the Z axis. A two axis pointing mechanism is then used to keep the antenna pointing at the DRS satellite. The antenna can not track the DRS under all attitude conditions the field of view being over a complete hemisphere. However the link with DRS is only intended for use when the mission activity demands it, so this restriction is not considered critical.

The Service Module is jettisoned before the de-orbit burn, by firing the four explosive bolts that hold it to the Descent Module.

3.2 System Budgets

3.2.1 Mass

The most critical aspect of the concept was judged to be the system mass so a significant proportion of the study effort was devoted to a detailed mass analysis. Table 1 gives the subsystem level breakdown for the Ariane 4 launched manned version of the capsule.

The study placed this major emphasis on achieving a realistic mass estimate for two reasons. Firstly, mass has been the main "Achilles Heel" for past proposals for manned launchers and must be considered a key issue in any assessment of feasibility. In particular the selection of design launcher was judged to increase the mass sensitivity.

The second reason for the attention to mass is that since the parametric costing techniques that were to be used are largely dependent upon mass. These techniques are proven to be surprisingly accurate providing the mass data used accurately reflects the final system mass. Thus the accuracy of the cost estimate largely depends upon the realism of the mass estimate.

From the start the study maintained a multi level margin approach with an identified margin at every level where a requirement specification will eventually be placed; that is at system, subsystem and equipment levels. The system budget in Table 1 shows two columns, the first has the raw estimated mass for each subsystem (being the addition of the unit mass estimates) the second column showing the subsystem masses after unit and subsystem level margins have been added giving the subsystem specification mass. A detailed mass breakdown is given in Appendix A.

The total available margin (raw estimate to system specified maximum) is 22 per cent of the 7 tonnes available. Of this 8 per cent was been distributed to the subsystems and equipments. The total margin held by the subsystems is generally greater than 10 per cent and in many cases exceeds 20 per cent typically 5 per cent of this is held at the subsystem level and the rest distributed to equipment, based upon their level of definition. The consumables have a 5 per cent allocation as these are considered well defined. The payload allowance has no margin as the specified is assumed to contain its own margin.

TABLE 1 System Mass Breakdown

SUBSYSTEM	SUBSYSTEM ESTIMATE MASS (kg)		SUBSYSTEM SPECIFIED MASS (kg)		SUBSYSTEM MARGIN %
Mechanical					
Structure	895		1000		11
Thermal Protect	631		730		14
Thermal Control	64		80		20
Mechanisms	313		350		11
Propulsion	164		10		22
POPS	64		70		9
Recovery	236		270		13
Mech.Fittings	21		25		16
Electrical					
Data Management	48		55		13
S-Band Comms	18		20		10
Audio Comms	24		30		20
Ku Comms/Radar	128		145		13
Guilde.Nav. & Con	70		80		12
Power	271		310		13
Habitability					
ECLSS	185		210		12
Galley & Hygiene	71		90		22
Fittings	237		270		12
Loose items	75		85		12
Caution & Warning	36		45		20
	------		------		
TOTAL DRY MASS	3551		4075		
Consumables	930		977		5
Payload	1000		1000		
Margin	1519	(22%)	948	(14%)	
			------		------
SPEC MASS IN ORBIT	7000		7000		
	------		------		
Escape Tower	756		950		20
	------		------		
LAUNCH MASS	7756		7950		
	------		------		

The study concluded that these margins were sufficiently healthy to give a high degree of confidence in the feasibility of an in orbit specification mass of 7 tonnes.

3.2.2 Power

Table 2 shows the system level power budget indicating the average power consumption for each subsystem. A similar margin philosophy was used for power as described for the mass budget. A 10 per cent margin is held at subsystem level with specification values being rounded up to the nearest 5 watts. A minimum of 10 per cent was deemed necessary at system level in fact the study had identified a 16 per cent margin.

4. LAUNCH SYSTEMS

4.1 Ariane 4

Ariane 4 was selected as the primary launch system for the MRC. The reasons for this choice are that it allows for

TABLE 2 System Power Budget

	Oper. Power	Duty Cycle	Aver. Power	Spec. Power
Thermal Control	200	.5	100	110
Propulsion	5	1.0	5	10
Data Handling	60	1.0	60	70
S-Band Comms	20	.8	16	20
Audio Comms	30	.8	24	30
Ku-Bands Comms	90	.2	18	20
GNC	90	1.0	90	100
Power	50	1.0	50	55
ECLSS	50	1.0	50	55
Galley/Hygiene	20	.4	8	10
Fittings	120	.7	84	95
Caution & Warning	5	1.0	5	10
			------	------
TOTAL (Watts)			550	585
Margin			+150	* 115
			------	------
Specified Average Power (Watts)			700	700
			------	------

+ Total Margin 21%
* System Level Margin 16%

an earlier start to the programme and yet has less risk than reliance on a new launcher development. The Ariane 4 would need some modifications for this new role, some of these would be changes related to man rating and others are associated with the new payload.

Man rating woud require changes in the monitoring and control functions during the vehicles flight. The telemetry system would require some expansion to allow the additional data (including audio) from the MRC. The vehicle safety destruct system would also require either modification or even removal to allow the MRC to escape from a failed launcher without the additional hazard of an explosion. A review of the equipment reliability would need to be undertaken and some lower reliability equipment may require some redesign as a result of this review. In addition to these hardware changes, a higher level of quality monitoring and increase safety constraints on launch operations would also be introduced.

There are two major modifications required due to the MRC payload configuration. The first is the removal of the payload shroud because, to allow the escape system to operate, the capsule can not be enclosed. The escape system covers the upper part of the capsule protecting the docking port and other sensitive equipments located there. The lower part of the capsule and the Service module are exposed. The Service Module is mounted on an inverted cone launch vehicle adapter which provides the interface with the third stage of the Ariane. The new aerodynamic configuration would require analysis which is beyond the scope of this study, but it is not expected to lead to any significant hardware changes. The hammerhead configuration required by the large heat shields and capsule aerodynamics is similar in extent to the existing fairing. The capsule is symmetric so the large bending moments that can be caused by winged vehicles on expendable launchers are avoided.

Figure 4 shows the MRC in its launch configuration with the escape system and VEB/third stage.

The electronic equipment would also require to be

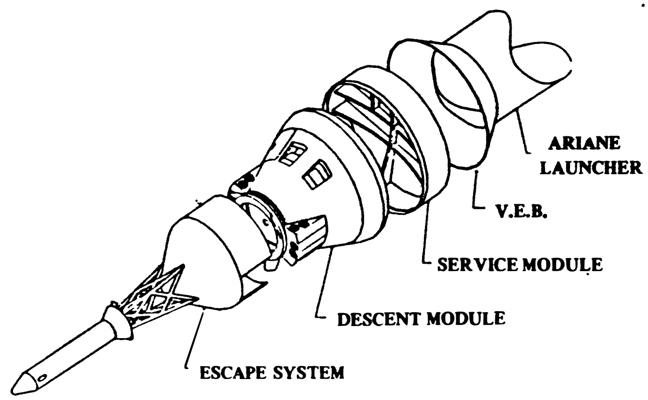

Fig.4 MRC Launch Configuration

relocated as the Vehicle Equipment Bay (VEB) is located in the lower part of the fairing on the standard Ariane 4. These electronics would now be located in the MRC launch vehicle adapter.

The other major change associated with the MRC as a payload, would require a significant revision of the hardware on the second and third stages. Although the theoretical performance of Ariane 4 with four liquid boosters is over nine tonnes into Low Earth Orbit, in practice structural considerations on the second and third stages limit the maximum payload to 6 tonnes. It would therefore be necessary to strengthen the launcher structure to take a heavier payload.

The launch pad would also require some modifications and additions to allow crew access to and from the capsule, including an escape provision. A number of options were identified with regard to the Launch pad:

- i Modify the LA2 pad (which is the existing operational Ariane 4 launch pad) for manned operations. This has a disadvantage in that the MRC adaptions and operations could effect the unmanned commercial operations.
- ii Refurbish and modify the LA1 launch pad. This is the original Ariane launch pad which is currently planned to be decommissioned.
- iii Construct a new manned launch pad.

A comprehensive trade off on these was beyond the scope of the study, however the second option (refurbish LA1) seemed the most attractive and was used as the baseline operation assumption.

Unmanned launches of the microgravity laboratory or escape capsule delivery to Space stations is assumed to be undertaken on the same pad and with very few changes to the procedures or hardware. In this case however the escape system would be omitted and a different boost protection system employed.

4.2 Escape System

The Escape System, which is considered part of the launch system, is designed to provide a means to detach the descent Module and carry it away from the launch system. It is able to be used at any time after the crew are in the capsule and the launch site cleared of ground personnel until the end of the second stage burn. After the second stage burn the vehicle will have reached sufficient altitude to separate and descend without assistance in the event of a launch system failure. A secondary function of the Escape System is to provide thermal protection and streamlining to the forward region of the capsule (the docking hatch and thruster pods) during the atmospheric phases of the ascent.

The Escape system consists of the following elements:

- Main rocket subsystem
- Separation rockets
- Tower structure
- Shroud

The main rocket system is a large (around 600Kg) solid propellant rocket, with four angled nozzles to minimize the impingement on the MRC in the event of firing. It is sized to provide sufficient impulse to lift the Descent Module to a height of 2000 meters, which is sufficient height to allow separation from the Escape System and the deployment of the descent parachutes for a landing in the normal way. The motor burn pattern would be tailored to limit the maximum acceleration to 7 g

Following a normal launch the Escape System would be jettisoned using three small rockets at the top of the main rocket system. These rockets are angled to ensure that the MRC/Launcher stack does not collide with the Escape System during the jettison manoeuvre. These motors are also used to separate the Escape System from the Descent Module after firing the main motor during an abort.

4.3 Alternative Launch Systems

4.3.1 Ariane 5

It is possible that manned launches of the MRC would be required on Ariane 5, for more advanced infrastructure support operations. As currently conceived Ariane 5 would be man rated as part of its development programme so that it could support HERMES missions. Thus no changes over the current definition of Ariane 5 would be required for the MRC.

The Ariane 5 system has a variety of upper stage options. For the MRC this would be the manrated stage designed for Space Station delivery missions. This is currently the subject of two independent studies, ARIES and ATS. The delivery capability of these vehicles would be in excess of 15 tonnes.

As with Ariane 4 the MRC would need to be exposed during launch so that the Escape System can operate if necessary. This system would be identical to that already described for Ariane 4.

A launch system adapter would be needed, this would be a cone shaped structure from the upper stage of the Ariane 5 to the Service Module. The interface with service module would be identical to those on the Ariane 4 adapter and no charges to the MRC are foreseen. The study assumed that an Ariane 5 launch would involve a second payload. The adapter would be configured to provide a significant payload envelope below the MRC. This second payload would be mounted on the standard payload adapter.

A second launch mode on Ariane 5 would be when there is no crew, for example the delivery of an escape capsule to the International Space Station or a European Independent Station. In this case the capsule can be contained under the normal payload fairing as part of a payload stack for delivery to the space station by the ARIES or ATS upper stage.

4.3.2 STS

It is assumed by the study that even if the MRC did have a role to play in the International Space Station programme as the CERV, then it would be launched by one of the Ariane variants as part of the European contribution. If an STS launch is a requirement the dimensions of the MRC system are compatible with the Shuttle orbiter payload bay, but the study has not examined the details of this launcher option.

5. SUBSYSTEMS DESIGN

5.1 Mechanical Subsystems

5.1.1 Structure

5.1.1.1 Descent Module

The main shell of the capsule is made from aluminium skinned honeycomb sandwich sections bonded together to form the external cone structure. The launch loads from the Service Module are carried through four equispaced pyro bolt fittings and eight snubber pads into load frames attached to the internal surface of the main shell.

The interface to the escape tower is through a further four pyro bolts at the upper end of the load frames. At this height a stiff ring is fixed to the load frames and to the main shell. From the base of the main shell, the pressure vessels surfaces continue through an aluminium sandwich panel lower cone floor into a hemispherical aluminium pressure dome, both fastened to machined aluminium alloy rings and supported at intervals by the load frames. The load frames are split at the base of the cone to maintain a continuous pressure shell at this level.

At the top of the main shell, a machined aluminium alloy ring is bonded to the sandwich shell to form an interface to which the docking hatch assembly is bolted completing the pressure vessel.

The heat shield forms an aerodynamic base to the capsule using a CFRP/Kevlar skinned honeycombe panel support clear of the pressure hull from the lower sections of the load frames. It is designed to crush on impact to minimize shock levels within the capsule.

Where the access hatch is fitted one of the load frames will have to be substantially removed, and suitable reinforcement added locally to redistribute the loads. A similar approach using local reinforcement will be required for the windows and other egress ports as required in the main shell structure.

Facilities for the attachment of the thermal protection systems is required on the upper surfaces to limit temperature excusions during launch, and on the base for attachment of the ablative thermal shroud.

5.1.1.2 Service Module

The Service Module is made as a CFRP skinned sandwich structure bonded in sections into a machined alluminium alloy ring forming the upper half of a pyrotechnic line charge separation device, the lower half remaining with the launch vehicle after separation. At the four pyro bolt and eight snubber locations to the capsule, additional reinforcement is provided to spread the load peaks as uniformly as possible into the service module cylindrical structure. Within the cylinder, a series of aluminium skinned flat sandwich panels are suspended to provide mounting area for the service equipment including attachment of the Solar Array.

5.1.2 *Propulsion Subsystem*

It was possible to study this area in some detail since the technologies employed and their utilization are well understood. Very little new equipment is foreseen as necessary for the MRC propulsion requirements to be realised. This level of definition help the favourable assessment of the MRC feasibility as the propulsion system including the propellant accounts for a considerable proportion of the system mass as well as being the performance constraining subsystem in many cases.

To allow the MRC to carry out its nominal mission, the propulsion meet the following requirements:

* Provide a large delta V (around 100m/sec) capability over a relatively short duration to affect a re-enter manoeuvre.

* Provide an altitude control capability during re-entry to allow the desired angles of attack to be achieved.

* Provide an efficient altitude and orbit control capability whilst in orbital flight.

* Provide a vernier thrust and low contamination altitude control capability during proximity operations and docking manoeuvres at the man-tended free-flyer (MTFF) or MSS and any other spacecraft.

In addition the subsystems must provide a large margin in operational flexibility whilst being reliable and inherently safe, especially if the MRC is to have the rôle of a lifeboat for evacuation purposes. This must be achieved while meeting the on orbit storage requirement of two years.

The combination of these requirements, coupled with the MRC concept of a Descent Module and jettisionable Service Module has resulted in two independent subsystems, one of which uses MMH and NTO as the propellants and used for the re-entry manoeuvre and altitude and orbit control, it is called the Primary Integral Propulsion subsystem (PIPS), and a cold gas reaction control subsystem for proximity and vernier operations called the Proximity Operations Propulsion Subsystem (POPS).

5.1.2.2 *Proximity Operations Propulsion Subsystem*

Gaseous Nitrogen was chosen as the propellant for the cold gas RCS because it:

* will not contaminate the surrounding environment
* is easily storeable with a wide thermal margin
* low cost (compared with He)
* provides a reasonable Isp
* has been flight qualified (e.g. MMU)

Essentially any inert gaseous substance is suitable for the cold gas RCS, however, Nitrogen is considered the best option, principally because considerable experience has been gained with unmanned as well as manned systems.

The POPS provides the necessary propulsion requirements when the MRC is within 500m of the Space station or other sensitive system. The Nitrogen gas is stored at 276 bar within two pressurant tanks mounted within the Service Module. These tanks are 0.6m diameter spherical pressure vessels using the same technology as employed in existing spacecraft helium pressurant tanks. They store 21 kg. of nitrogen which provides a total delta V of 17 m/sec.

The POPS schematic is shown in figure 5.

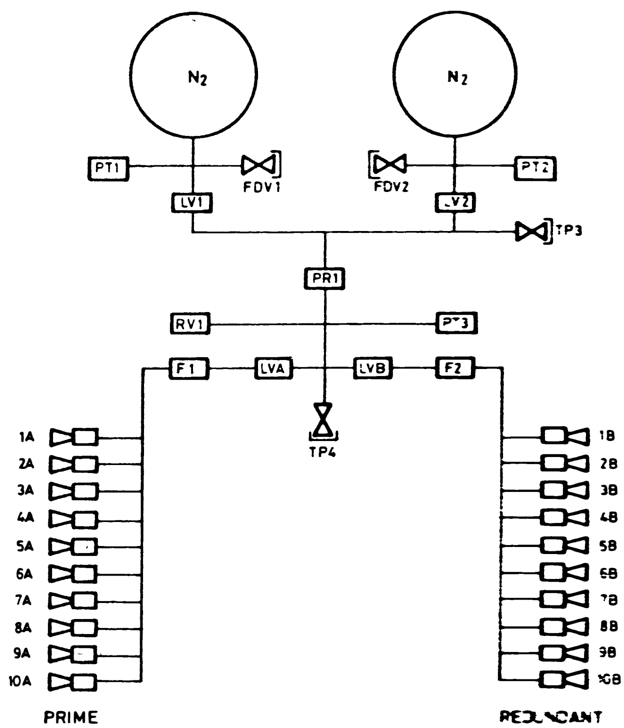

Fig.5 POPS Schematic

Each tank is connected to a separate fill/drain valve and pressure transducer for propellant management and measurement. One LV per tank allows a particular tank to be used and a common manifold directs the Nitrogen to an internally redundant pressure regulator which regulates the pressure downstream to 15 bar.

Two gas latch valves then allow the Nitrogen to be directed to either the primary or redundant thruster branches. The latch valves at the Nitrogen supply and the thruster valves provides a triple redundant barrier to the Nitrogen for the minimization of any leakage.

Each thruster branch contains ten 30N thrusters with an Isp of 65 seconds, and are configured in pairs on the exterior of the SM thruster pairs.

5.1.2.2 Primary Integral Propulsion Subsystem

For all other altitude, orbit control and re-entry propulsion requirements, a bipropellant subsystem was chosen which uses Mono Methyl Hydrazine (MMH) as the fuel and Nitrogen Tetroxide (NTO) as the oxidiser. The reasons for this choice are as follows:

* easily storeable and will not degraded or evaporate for extended periods of time (flight proven in-orbit life exceeds seven years)
* provides an excellent Isp for a non-turbo pump, a pressure fed, propulsion subsystem.
* very considerable flight experience on spacecraft, both manned and unmanned.
* relative low cost and risk.

Thus the choice of bipropellant subsystem is because considerable experience has been achieved and a significant inventory of equipments are available to support its uses.

The Primary Integral Propulsion Subsystem consists of twelve, 400N thrusters used for all pitch, yaw and roll manoeuvres during non-proximity operations and atmospheric re-entry. The arrangement of the 12 thrusters also allows a re-entry manoeuvre to be performed at the termination of the mission using the four, forward facing, yaw thrusters. The thrusters are pressure fed with propellant by use of separate pressurant supply.

The subsystem schematic is shown in figure 6. It is based on the bipropellant subsystem used by communication satellites, but uprated for manned activities and allowing full testing to be performed prior to flight operations. The pressure fed, bipropellant system was chosen, rather than a more efficient (i.e. greater Isp) turbo pump system, principally because it offers much greater reliability and safety with reduced complexity and cost.

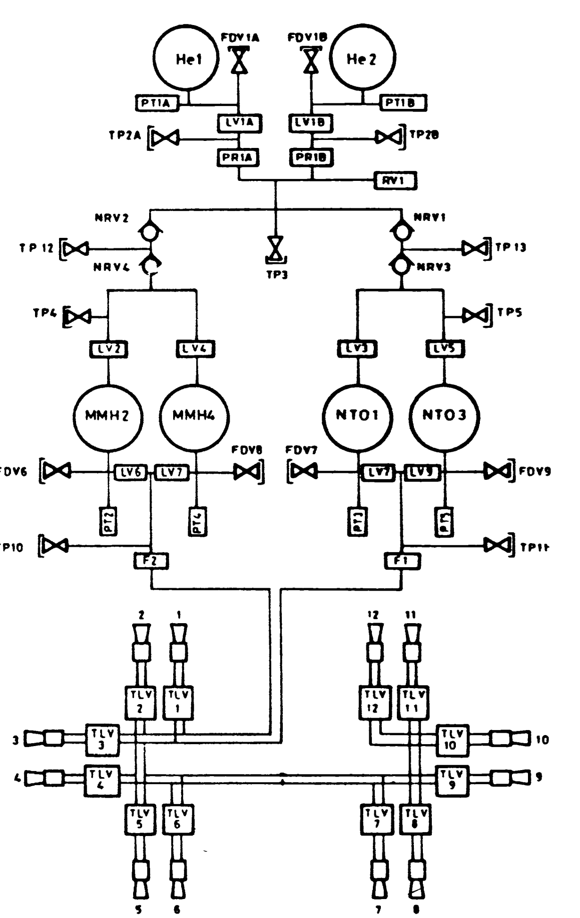

Fig.6 PIPS Schematic

Around 6 kg of Helium is stored within two tanks at a pressure of 276 bar, as measured by the pressure transducers (PT) and is initially isolated by the use of two high pressure gas latching valves (LV), one per helium tank. When these LVs are opened, the helium is regulated down to 17.5 bar by the series redundant pressure regulator (PR). Because the use of regulated helium pressurant over a long period of time is not yet a flight proven technology the helium supply represents a redundant system and any one tank can meet the mission needs.

A second set of low pressure latch valves (LV), once opened allow the helium to pass into the propellant tanks to maintain flight pressurization of the propellant tanks. Any over pressurization can be vented through the use of two relief valves (RV) placed in series for redundancy. Two non-return valves (NRV) are also placed in series in each half of the subsystem and ensure that a potentially catastrophic mixing of propellants is eliminated by allowing the helium to pass into, but no fluid (propellant or pressurant) out of, the propellant tanks. As a further inhibit to possible propellant mixing upstream of the tanks, during all altitude control manoeuvres the latch valves (LV) should be closed, since propellant sloshing will occur at these times. These LVs would only be opened during large translational manoeuvres, such as the reentry burn.

The maximum total propellant load of 700 Kg is contained within four spherical titanium tanks 0.7 meters in diameter, located around the periphery of the Descent Module. This propellant load provides sufficient propellant to meet the identified mission needs. At the base or outlet of each tank is a surface tension propellant management device which governs the flow of propellant from the tanks without introducing helium bubbles into the liquids. This is required to work in the gravity range +3g to −.5g, the negative g loading case is important as this condition arises during the de-orbit burn. Such management devices have been successfully developed and do not represent a technical risk.

At a pressure of 17.5 bar, as measured by each tank's pressure transducer (PT), the propellant is initially prevented from reaching the prime and redundant thrusters (which are housed in one branch) by latch valves placed immediately downstream of each tank. After each thruster and its pipework has been vented, these latch valves are opened to prime the thruster lines.

Activation and use of a thruster occurs when first the latch valves immediate upstream of the thruster are opened. These extra latch valves are included to ensure that should a thruster fail to open, it can be isolated from the rest of the thrusters without the complete loss of all thrusters. This philosophy of individual thruster isolation differs from normal satellite practice of two isolatable branches, although heavier it provides a higher degree of redundancy and means a thruster failure has less impact on subsequent mission planning.

The thrusters are located within two separate pods on the upper section of the Descent Module, as shown in Fig. 1. All four forward facing yaw thrusters would nominally be used for the re-entry burn, although this manoeuvre can be performed safely and with sufficient precision using either the two prime or two redundant thrusters.

The thrusters are based on those used during the Apollo programme, and of those used extensively today in a large variety of bi-propellant unmanned spacecraft. The thrust is around 400 Newtons and the specific impulse is 3060 Nm/kg. The size of the thrusters (0.55m x 0.25m dia.) placed a major configurational constraint on the MRC, however, the initial evaluation showed the thrust level was required for control during re-entry and the relatively high Isp gained from the large nozzles benefited the de-orbit burn propellant consumption.

In addition to the described components, fill and drain valves and test ports are provided to allow filling, purging and draining. Filters are incorporated to collect any debris and orifices are used to trim the propellant flow to allow the correct mixture ratio to be achieved.

5.1.3 Thermal Protection System

The Thermal Protection System (TPS) protects the MRC from frictional heating during ascent and re-entry. It consists of two major elements:

* launch protection shielding
* re-entry shielding.

The launch protection shielding consists of a layer of insulation material (baselined as cork), covering the external surface of the Service Module. Initial studies suggest that cork would also suffice as the thermal protection for the upper surface of the Descent Module.

The re-entry protection system consists of a large ablative heat shield permanently mounted to the underside of the Descent Module. This material was baselined as a resin compound of the type used by the Gemini and Apollo programmes although the use of more advanced materials would be examined in later studies to achieve a greater mass efficiency.

5.1.4 Thermal Control Subsystem

The Thermal Control Subsystem (TCS) of the MRC is designed to maintain all the SM and PM subsystem equipments within the flight operational temperature limits throughout all phases of a mission.

Between the outer metal surface of the Descent Module on which the thermal protection is mounted, and the pressure hull is a layer of Multi-Layer Insulation (MLI). This thermal blanket, coupled with the TPS, ensure that the rate of heat flow between the Descent Module and the external environment is minimized and kept relatively constant.

Heat produced by the electrical equipment, payloads and the crew is rejected and dissipated from the Descent Module by means of the active water/gycol loop also used by the ECLSS to maintain the atmosphere at the correct temperature. The water loop uses pumps to circulate the water through the environment control subsystem and the equipment cold plates. Then the warmed water is carried to the Service Module thermal radiator via the DM/SM umbilical connector. The thermal radiator is essentially the outer surface of the SM with several loops of water pipes on the internal surface. The rate at which heat is dissipated could be controlled by adjusting the water flow rate as necessary.

Water/Gycol was selected over Freon for safety reasons as the system is largely located within the pressurized cabin.

Equipments mounted on the SM, such as the POPS, are maintained at the correct temperature with MLI blankets and locally placed heaters and thermistors. These passive control techniques are well proven on previous manned and unmanned spacecraft.

5.1.5 Recovery Subsystem

The MRC recovery subsystem is based largely on the equivalent Apollo subsystem and operational technique, principally because it has demonstrated the level of reliability necessary to support operational manned system. The recovery system consists of:

* Main parachutes (4 off)
* Drogue parachutes (2 off)
* Float stabilizers
* Homing beacon

All components of the recovery subsystem are configured around the docking port and above the main pressurized cabin, with each main and drogue parachute packed within individual containers.

During the terminal descent phase the recovery subsystem will be used as follows:

i At 10 KM altitude, pyro bolts would be fired to blow-off the external covers and exposing the parachutes canisters.
ii The two drogue parachutes would be released at intervals of a 2-3 seconds apart, by use of mortar devices. The mortars ensure that the parachute is far enough away from the Descent Module to facilitate successful deployment. These provide the initial decellerating force slowing the capsule to the velocity at which the main parachutes can be deployed.
iii At approximately 3 Km altitude, the redundant pyro bolts holding the two drogue parachutes would be fired, again at discrete intervals, which would jettison the drouge.
iv The four main parachutes are then deployed slowing the capsule to around 10 m/sec descent speed. The parachutes are sized such that should one fail then a safe landing speed is still obtained.
v After splashdown, floatation devices would be automatically inflated ensuring that the Descent Module floats upright.
vi The recovery beacon is automatically activated.

5.2 Electrical Subsystems

The electrical subsystems include the electrical and electronic components that supply and control power, data and commands. A block diagram is shown in figure 7 which shows the overall system electrical architecture down to unit level. This shows the functional links (except prime power supply) and indicates in which module (Descent or Service) in which the unit is mounted and to which

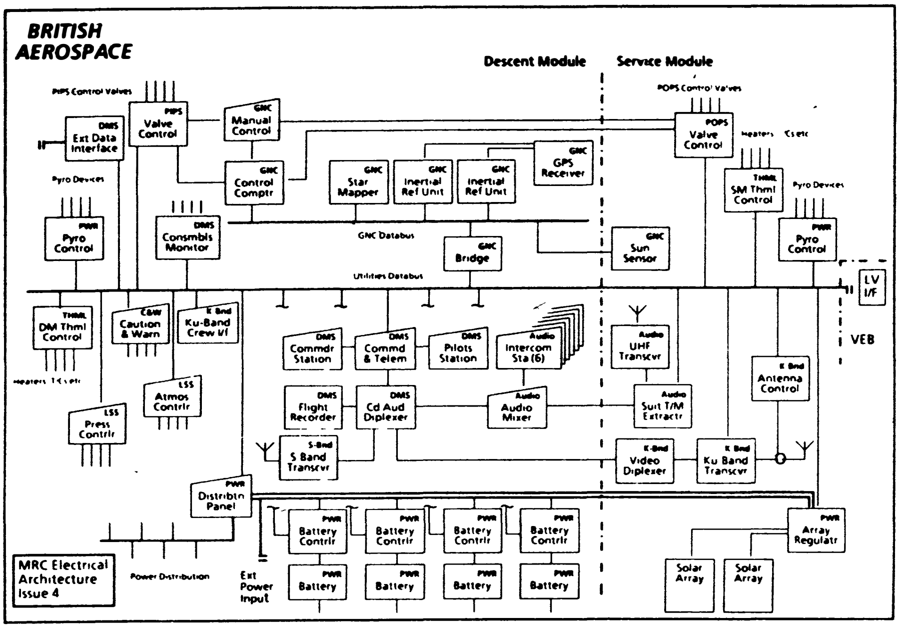

Fig.7 MRC Electrical Architecture

subsystem it belongs. A more detailed description of each subsystem is given below.

5.2.1 Data Handling and Control

The data handling subsystem is based around a relatively low speed serial databus (probably either a 1553 or OBDH standard). This Utility databus is connected to all the units that require to receive commands or distribute data. The exception to this are the Guidance, Navigation and Control Subsystem that has an independent databus which is connected to the main utility databus via a bridge interface.

The main controller of commands and telemetry is the aptly named Command and Telemetry Unit (CTU). Commands can be issued via the CTU from three sources

i The S-band or DRS communication subsystem
ii The pilots or commander's station (these commands are required to be authenticated and authorized before being executed)
iii From the manual override controls on the CTU itself.

A fourth source of commands, which do not go via the CTU, is the control computer which is part of the Guidance, Navigation and Control subsystem. The computer in the GNC is capable of controlling an entire flight giving the Multi-Role Capsule the capability for total autonomous flight. These commands enter the utility databus via the interface bridge.

5.2.2 S-Band Communications

This is the general communications subsystem on the MRC. It carries audio and telemetry and telecommands. The unit uses an S-Band transponder with internal redundancy which is fed through two onmi-directional antennas mounted on the external surface of the Descent Module. Communications are fed direct to ground stations and coverage available depends upon the availability and location of suitable ground stations.

5.2.3 Audio Communications

This carries the internal audio communications within the MRC and interfaces these audio signals with the RF communications subsystems. Each of the crew station (including the two contingency crew in the payload area) has an intercom mounted by the couch. This can allow communication through headsets, either within pressure suits or worn externally when in shirtsleeves.

The audio subsystem also has a UHF transceiver for communication with EVA astronauts in pressure suits. This handles both audio communications and suit telemetry.

5.2.4 DRS Communications Link

This link which is separate from the S-Band link is for capsule to ground communications via a Data Relay Satellite system. This has the advantage of being available at all times and having a higher data rate, sufficient to add real time video images to the Audio and telemetry data. It is entirely located in the Service Module.

The frequency of this system would either be K-Band or Ku-Band dependant upon the definition of the DRS system. For the purposes of the MRC feasibility study this detail was not of any significance.

The signal is transmitted via a steerable dish antenna which is deployed after separation from the launch system. The dish diameter is 0.6 meters and is pointable over a complete hemisphere.

As with the similar system on the Space Shuttle Orbiter, it is envisaged that this subsystem can also be used as a radar during tracking and rendezvous manoeuvres.

5.2.5 Guidance, Navigation and Control

The Guidance Navigation and Control (GNC) subsystem provides the following functions:

* Attitude determination
* Attitude control
* Orbit determination
* Orbit adjustment and transfer
* Space Station withdrawal manoeuvres
* Space Station proximity manoeuvres
* De-orbit manoeuvre
* Control Hypersonic semi ballistic flight
* Subsystem status monitoring
* Failure monitoring
* Manual control over attitude and position control
* Provision of Position and attitude data

The primary source of attitude and position data are two hot redundant Inertial Reference Units (IRU) this uses laser gyroscopes and accelerometers, and supplements these with signals from the Global Positioning System (GPS) to provide up dates to calibrate and correct the internally derived information. The accuracy of this system is specified as attitude to 1 degree and position to within 100 meters.

Two other secondary sources of attitude are provided. There is a Sun sensor to aid attitude control when in a Sun pointing mode, this is mounted on the Service Module. The second unit is a star mapper system which views forward out of the left thruster pod. This supplies supplemental attitude information of higher accuracy than obtained by the IRU, it is also used during rendezvous manoeuvres.

The data from these sensors is fed to the GNC databus which is a height speed parallel bus controlled by the GNC computer. The bus is connected to the utilities data bus by a bridge interface unit.

The GNC computer is the prime control system. It carries the flight programme and is capable of controlling the mission completely autonomously. Detailed sizing of this computer ws beyond the scope of the study but provision was made for a capacity equivalent to a typical 32bit mini computer.

The computer would directly link with the valve control electronics of both the POPS and the PIPS which are the actuation systems for both position and attitude control. In addition there is a manual controller that also interfaces with the Valve control electronics providing a manual flight mode, overriding computer control. In the event of a GNC subsystem failure it is possible using visual guidance from the viewpoint for either the pilot or commander to conduct a de-orbit manoeuvre and a controlled re-entry although in this case the landing accuracy is lost.

5.2.6 Power

The power subsystem is required to generate and distribute around a kilowatt of power during the orbital operation phases of the MRC missions.

The primary power generation source is a solar array which extends from the rear of the Service Module, with rechargable batteries as a secondary power source. The technology trade off was between fuel cells and solar arrays. Fuel cells would be slightly lighter and provide potable water, however the cyrogenic storage was judged to be a major high risk technology for extended in-orbit storage and the fuel cells are considerably more expensive than an equivalent solar array. A further positive advantage to solar arrays is that while attached to a space station the capsule can be self powered for its housekeeping and monitoring functions and not impinge on the Station power budget. This not only helps the space station power budget but in the event of an emergency the MRC would be at a full state of readiness no matter what the history of the station's power subsystem during the emergency.

The solar array has an area of around 12 square meters providing 1000 Watts when the spacecraft is orientated such that sunlight is full on the array.

The secondary power source are four batteries, each with a separate charge/discharge controller. The Battery Control Units (BCU) and Array Regulator keep the power bus at 28 Volts. The batteries selected were a Nickel Cadmium type as opposed to Nickel Hydrogen. The batteries are sized for the re-entry cases when they can be run down to very low depth of discharge without worries about the effect on the recharge ability. In this situation the weight advantage associated with Nickel Hydrogen are largely negated. The safety, cost and technical risk considerations also all favoured the use of Nickel Cadmium. The batteries are mounted within the rear section of the pressurized cabin around the payload area.

The final unit in the power subsystem is the distribution panel mounted as an overhead console in the pilots and commanders control area. It contains the circuit breakers, power bus monitoring and the distribution circuitry.

5.3 Habitability Subsystem

5.3.1 Environment Control and Life Support

This subsystem controls the atmospheric environment within the pressurized cabin such that a comfortable and safe shirt sleeve environment is maintained. The cabin pressure is maintained as a nitrogen/oxygen mix at sea level pressure, which is compatible with existing Soviet, American and European manned systems.

The subsystem is separated into two distinct and separate elements. One controls the oxygen and carbon dioxide content of the air, the other controls the cabin pressure. Figure 8 shows a functional block of both elements.

The Atmosphere Control draws in air from various points within the cabin. The water is first separated out using a condenser system and the water placed in a storage tank, the water is not re-used and presumed stored until its removal during post recovery operations, an alternative would be to provide an overboard dump. After the water is removed the air is past through a LiOH/Activated Charcoal canister, which the study assumed would be of the same design as the one used on the American Space Shuttle Orbiter. The capsule would carry a total of twelve such canisters of which two are used at any one time. The replacement of canisters would be a manual operation during active flight.

After the removal of carbon dioxide and odours a measurement of the partial pressure of oxygen. If this is below the desired level then gaseous oxygen is added. The oxygen is stored in a gaseous form at room temperature in high pressure bottles of the same design used by the propulsion subsystems for the helium pressurant and the

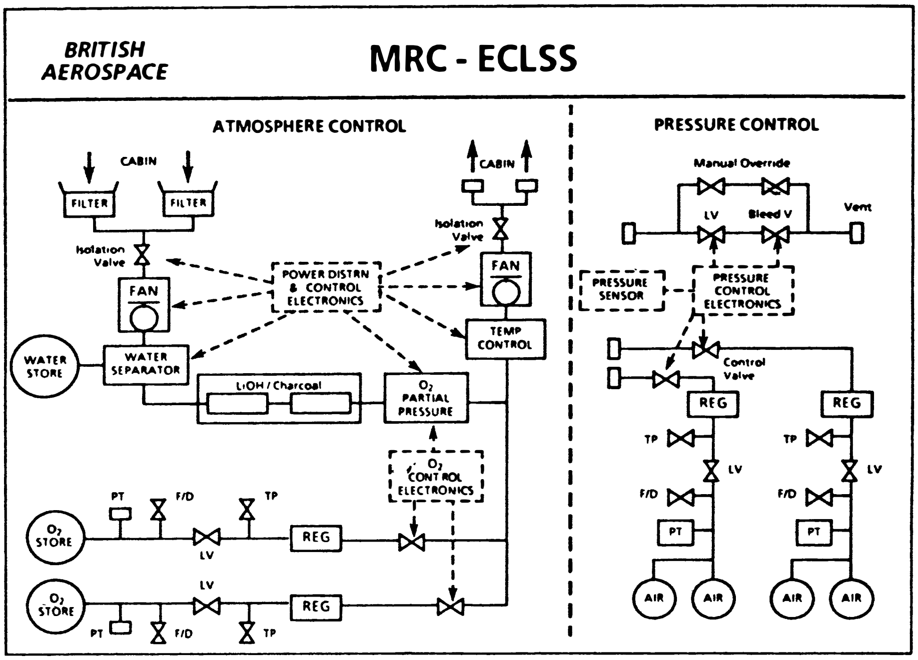

Fig.8 MRC ECLSS Schematic

nitrogen gas propellant. There are two such bottles which have independent plumbing. The total mass of oxygen carried is 24 kg, sufficient for 24 mandays.

After the temperature of the air is controlled to the desired temperature, it is re-introduced into the cabin.

The pressure control system monitors the pressure of the cabin and if it falls below the nominal level introduces more air from a gasses supply. The air is stored in four high pressure bottles (as described above) which are plumbed to provide two independent systems. The total air carried is 43.5 kg which is sufficient to make up the losses expected due to leakage over six days, and provided two complete cabin repressurizations from a vacuum (one for a nominal EVA the second as a contingency). The pressure control also provides an overboard dump allowing a controlled depressurization of the cabin for EVA, or the removal of atmosphere contamination.

5.3.2 Galley and Hygiene

The galley and hygiene facilities are mounted in the forward section of the pressurized cabin. This area is comparatively spacious due to the need to accommodate the large hatch of the standard docking port and this space has been put to use by providing more civilized facilities than available on earlier systems of this class e.g. Apollo or Soyuz.

The galley is mounted on the right side of the cabin. It provides the storage for food a potable water as well as a preparation area where food can be heated and water (hot or cold) added. The trash storage area and the hand washing facility are also here.

The toilet facility is located on the left of the cabin. It was based upon the same principles as the facility provided on the Space Shuttle and would be suitable for use by both male and female crewmembers. During use a privacy curtain can be used to visually separate the forward section from the rest of the pressurized cabin, this will also assist the separate air flow system for the forward cabin to help control odours.

5.3.3 Fittings

This subsystem is a collection and control point for general miscellaneous fitted items that do not form part of a major subsystem. It includes cabin furniture, including the couches and privacy screen for the forward section of the cabin. General stowage facilities, cabin lights, and the cabin floor are also included here as are the externally mounted grab handles and navigation lights.

5.3.4 Loose Items

This subsystem is a collection and control point for the miscellaneous items required for the flight which are loose and independent. They include the loose emergency equipment (oxygen masks, ground survival kit, life vests etc.), a tool kit, video recorder, tape recorder, and the flight manuals.

5.3.5 Caution and Warning

This subsystem contains safety related equipment which is not functional integral with other subsystems. Prime among these is the fire detection and control equipment consisting of sensors and fixed and portable extinguishers. In the event of a fire the cabin atmosphere is likely to be contaminated with toxic gases. Initially the crew can use the portable oxygen supplies to avoid breathing the gases, they can then enter pressure suits while the cabin atmosphere is vented into space. A repressurization with clean air from the pressurized store. This sequence is the same as procedure on the Space Shuttle orbiter.

The subsystem also contains a secondary atmosphere monitor system to provide a check on the functioning of the ECLSS. In the event of a failure of the control systems on the ECLSS the atmosphere can be maintained by manual operation of the control valves using the data supplied by this secondary unit as a guide.

The subsystem also contains a monitor electronics unit to measure the status of certain life critical items such as the position of the hatches.

6. MICROGRAVITY VERSION

Most of the infrastructure roles identified for the MRC are manned missions and can be conducted with the standard vehicle with all the changes in configuration between missions being confined to the outfitting of the payload area. However the unmanned microgravity laboratory will require a more extensive reconfiguration of the basic system to effectively undertake the mission. Some of these differences have been identified when relevant during the preceding discussion. This section covers the philosphy behind the Microgravity version and summarize the changes to the configuration identified for the feasibility study.

The study confined itself to producing one configuration that minimized the modification to the manned version while achieving a useful mission capability. The aims of this part of the study were:

i To show that such a system were possible without any requalification.
ii To establish the performance likely for such a system.
iii To ensure any aspects of system design that can facilitate the microgravity role are incorporated.

It may be that further modifications may prove effective in an improving payload, power and microgrvity environment but at additional development cost. Clearly further studies and definition of the financial environment would be required to identify the optimum system.

The modifications identified are:

- 2 additional panels on solar array giving 1Kw of power to payload
- Additional batteries and control units
- Add payload data acquisition subsystem
- Delete Subsystem – Audio
  – Caution and Warning
  – Galley and Hygiene
  Equipment – Commander and Pilot Stations
  – GNC Manual Control
  – DRS Crew Interface
  – External data Interface
  – Crew couches
- Add 6 main payload canisters in place of crew couches
- Add Secondary payload mounted in forward cabin in place of Galley and Hygiene

The usable payload would be around 1500 Kg. Main payloads would be housed in canisters that would be mounted in the same position as the crew couches (using the same interface). Smaller "Get away Special" type payloads could be mounted in the forward cabin in the place of the Galley and Hygiene equipment.

The mission duration would be determined by the payload's impact on the ECLSS. If a life science mission is flown which consumes oxygen then the mission life would be limited to around two weeks. If the requirement is restricted to maintaining cabin pressure with no oxygen consumption then the mission could be extended to a few months. If the mission is flown with the cabin unpressurized then six months or more would be possible.

7. CONCLUSIONS

The study produced a technical configuration for the MRC that demonstrated the feasibility of one system that could meet the infrastructure roles. Clearly with many successful manned capsule programmes in the past there is little question as to the general feasibility of the approach, however there are special features of the MRC concept that need investigation.

Where the Infrastructure roles have generated requirements that were not requirements of past capsule projects (e.g. long in orbit storage) then alternative technological approaches have been identified. Although detailed subsystem trade offs were not conducted the overall result is workable and proves technical feasibility.

The second area of concern is in the ability to meet the mass requirements. This is both an area of technical concern and has an impact on the financial assessment. The level of detail and the margin philosophy employed in combination are believed to have accurately scoped this notoriously difficult issue.

REFERENCES

1. MRC Rationale and Requirements (see page 58).

This paper represents the author's private work and the views expressed in the paper are those of the author and do not necessarily represent those of British Aerospace plc.

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APPENDIX: MRC MASS BREAKDOWN

This appendix contains the detailed mass breakdown for the Multi-Role Capsule (MRC), down to unit level.

As with all programmes a mass margin between the estimated mass and that specified is required, to allow for uncertainties in design and build. From the outset the MRC study employed a sophisticated mass margin philosophy to ensure;

a) The overall margin is adequate for the design status
b) Any areas of major concern are identified
c) Initial subsystem specification values are available for subsystem level feasibility studies.

The margin philosophy allocates a margin at every level of breakdown for which there is a requirement specification (i.e. System, Subsystem and equipment). This is done even though at this stage in the project the lower level specifications do not exist.

The actual percentages applied were as follows;

i) Equipment level

Mass derived from existing units	2% to 5%
Mass estimated from parametrics etc.	5% to 15%

ii) Subsystem level

A minimum margin of 5% was allocated at subsystem level (in addition to the sum of equipment margins). This being a suitable value for the early stages of a project. Where subsystems have a previous history (on other projects) for large mass excursions from original estimates a larger mass margin was used.

iii) System level

A further margin is required at system level to cover uncertainties at system level. The minimum acceptable margins at this level depends upon the programme status, in the judgement of the study suitable margins would be.

Contract Start – Freeze of system spec – 8%
Preliminary Design Review – Freeze Sub system Spec – 5%
Critical Design Review – Freeze Manuf. Drawings – 2%

Therefore the MRC study, being at an early stage, looked for a System level margin greater than 8%.

A point to make about the system level margin is that it only covers uncertainties in meeting the system specification it does not cover changes in those requirements. In systems where customer requirements strongly influence the engineering design (such as communications satellites) the best approach is have a further customer margin identified. However the MRC which is essentially a transport system with little direct engineering input from the customer this customer controlled margin is assumed included in the quoted payload capability.

Displine: MECHANICAL Subsystem: STRUCTURE

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Descent Module					
Press Cone	134.0	1	134.0	5	140.7
Bulkhead	38.0	1	38.0	5	39.9
Shear walls	84.0	1	84.0	5	88.2
Attach. Rings	13.0	3	39.0	5	41.0
Rear Cone	45.0	1	45.0	5	47.3
Rear dome	63.0	1	63.0	5	66.2
Shield support	67.0	1	67.0	5	70.4
Pod Structure	12.0	2	24.0	5	25.2
Hatch reinf.	20.0	1	20.0	10	22.0
DM Pyro fit.	35.0	1	35.0	5	36.8
Miscellaneous	154.0	1	154.0	10	169.4
Service Module					
Cylinder	124.0	1	124.0	5	130.2
Beams	20.0	1	20.0	5	21.0
SM Pyro fit.	18.0	1	18.0	5	18.9
Micellaneous	30.0	1	30.0	10	33.0
TOTALS			895.0		950.2
Margins			105.0 +		49.8 *
SUBSYSTEM SPECIFICATION MASS			1000.0		1000.0

+ Total margin held by subsystem 11%
* Subsystem level margin 5%

Displine: MECHANICAL Subsystem: THERMAL CONTROL

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Radiator	8.0	1	8.0	10.0	8.8
Bracket	2.0	1 Set	2.0	10.0	2.2
Pump	3.0	2	6.0	10.0	6.6
Pipework	7.0	1 set	7.0	10.0	7.7
Water/Gycol	10.0	1	10.0	10.0	11.0
Cold Plates	5.0	4	20.0	10.0	22.0
GS Heat Ex	2.0	1	2.0	10.0	2.2
ECLSS Heat Ex	2.0	2	4.0	10.0	4.4
Valves	4.0	1 Set	4.0	10.0	4.4
Miscellaeous	1.0	1	1.0	10.0	1.1
TOTALS			64.0		70.4
Margins			16.0 +		9.6 *
SUBSYSTEM SPECIFICATION MASS			80.0		80.0

+ Total margin held by subsystem 20%
* Subsystem level margin 12%

Displine: MECHANICAL Subsystem: THERMAL PROTECTION

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Descent Module					
DM Blankets	75.0	1 Set	75.0	10	82.5
Upper protect	90.0	1	90.0	10	99.0
Heat Shield	400.0	1	400.0	10	440.0
Paint	10.0	1	10.0	10	11.0
Service Module					
SM Blankets	36.0	1 Set	36.0	10	39.6
SM Protect	15.0	1	15.0	10	16.5
Paint	5.0	1	5.0	10	5.5
TOTALS			631.0		694.1
Margins			99.0 +		35.9 *
SUBSYSTEM SPECIFICATION MASS			730.0		730.0

+ Total margin held by subsystem 14%
* Subsystem level margin 5%

Displine: MECHANICAL Subsystem: MECHANISMS

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Docking Port					
Ring Guide	78.0	1	78.0	5	81.9
Latches	40.0	1 Sec	40.0	5	42.0
Structure	30.0	1	30.0	5	31.5
Flange/Seal	62.0	1	62.0	5	65.1
Hatch	40.0	1	40.0	5	42.0
Control Elec.	13.0	1	13.0	10	14.3
Side Hatch					
Hatch	40.0	1	40.0	5	42.0
Thermal Protect	10.0	1	10.0	15	11.5
TOTALS			313.0		330.3
Margins			37.0 +		19.7 *
SUBSYSTEM SPECIFICATION MASS			350.0		350.0

+ Total margin held by subsystem 10%
* Subsystem level margin 6%

Displine: MECHANICAL Subsystem: PRIMARY INTEGRAL PROPULSION

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Latch Valve	0.4	30	12.0	2	12.3
HP Latch Valve	2.3	4	9.2	2	9.4
F/D Valve	0.3	4	1.2	2	1.2
Press. Trans.	0.3	6	1.8	2	1.8
Test Port	0.1	11	1.1	2	1.1
Press. Reg.	1.0	2	2.0	5	2.1
Relief Valve	1.0	1	1.0	0	1.0
Non Ret Valve	0.2	4	0.8	2	0.8
Filter	0.5	2	1.0	2	1.0
Thrusters	3.4	12	40.8	2	41.6
Press Tank	16.0	2	32.0	2	32.6
Prop Tank	13.0	4	52.0	8	56.2
Pipework	5.0	1 Set	5.0	15	5.8
Control Elec.	4.0	1	4.0	10	4.4
TOTALS			163.9		171.3
Margins			46.1		38.7
SUBSYSTEM SPECIFICATION MASS			210.0		210.0

+ Total margin held by subsystem 22%
* Subsystem level margin 18%

Displine: MECHANICAL Subsystem: PROXMITY OPERATIONS PROPULSION

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Tank	16.0	2	32.0	8	34.6
Press. Trans.	0.3	3	0.9	2	0.9
F/D Valve	0.1	4	0.4	2	0.4
Latch Valve	0.4	4	1.6	2	1.6
Relief Valve	0.5	1	0.5	2	0.5
Pressure Reg	1.0	1	1.0	5	1.1
Thruster	1.0	20	20.0	5	21.0
Pipework	3.0	1 set	3.0	15	3.5
Filter	0.3	2	0.6	5	0.6
Control Elec	4.0	1	4.0	10	4.4
TOTALS			64.0		68.6
Margins			6.0 +		1.4 *
SUBSYSTEM SPECIFICATION MASS			70.0		70.0

+ Total margin held by subsystem 9%
* Subsystem level margin 2%

Displine: MECHANICAL Subsystem: RECOVERY

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Parachutes	45.0	4	180.0	5	189.0
Drouges	12.0	4	48.0	5	50.4
Flotation Collar	8.0	1	8.0	5	8.4
TOTALS			236.0		247.8
Margins			34.0 +		22.2 *
SUBSYSTEM SPECIFICATION MASS			270.0		270.0

+ Total margin held by subsystem 13%
* Subsystem level margin 8%

Displine: MECHANICAL Subsystem: MECHANICAL FITTINGS

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Grapple point	12.5	1	12.5	2	12.8
Grab Handle	0.5	4	2.0	5	2.1
Equip. Bolts	5.0	1 Set	5.0	10	5.5
Harness tiedown	1.0	1	1.0	10	1.1
TOTALS			20.5		21.5
Margins			4.5 +		3.5 *
SUBSYSTEM SPECIFICATION MASS			25.0		25.0

+ Total margin held by subsystem 18%
* Subsystem level margin 14%

Displine: ELECTRICAL Subsystem: DATA MANAGMENT

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Flight Recorder	5.0	1	5.0	5	5.3
Command & Tele	10.0	1	10.0	5	10.5
Command Stations	10.0	2	20.0	5	21.0
Com/Diplex	4.0	1	4.0	5	4.2
Signal harness	5.0	1	5.0	10	5.5
Consumable Mon.	4.0	1	4.0	10	4.4
TOTALS			48.0		50.9
Margins			7.0 +		4.1 *
SUBSYSTEM SPECIFICATION MASS			55.0		55.0

+ Total margin held by subsystem 13%
* Subsystem level margin 9%

Displine: ELECTRICAL Subsystem: S-BAND TELECOMMUNICATIONS

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
S-band TX/RX	3.0	2	6.0	5	6.3
Switch	0.5	1	0.5	5	0.5
Antenna	0.5	2	1.0	5	1.1
RF Harness	1.0	1	1.0	10	1.1
TOTALS			7.5		9.0
Margins			2.5 +		1.0 *
SUBSYSTEM SPECIFICATION MASS			10.0		10.0

+ Total margin held by subsystem 25%
* Subsystem level margin 10%

Displine: ELECTRICAL Subsystem: AUDIO COMMUNICATIONS

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Intercoms	1.0	4	4.0	5	4.2
Audio Mixer	2.0	1	2.0	5	2.1
EMU Tele extract	3.0	2	6.0	5	6.3
UHF TX/RX	10.0	1	10.0	5	10.5
Antenna	0.5	2	1.0	5	1.1
RF Harness	1.0	1	1.0	10	1.1
TOTALS			24.0		25.3
Margins			6.0 +		4.7 *
SUBSYSTEM SPECIFICATION MASS			30.0		30.0

+ Total margin held by subsystem 20%
* Subsystem level margin 16%

Displine: ELECTRICAL Subsystem: POWER

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Solar Panels	10.0	3	30.0	5	31.5
Array Deploy.	6.0	1	6.0	5	6.3
Array Regulator	6.6	1	6.0	10	6.6
Battery	35.0	4	140.0	5	147.0
Battery Control	3.0	4	12.0	10	13.2
Ground Umbilical	2.0	1	2.0	5	2.1
Control Box	15.0	1	15.0	10	16.5
Pyro Control Box	5.0	2	10.0	5	10.5
Harness (DM)	30.0	1	30.0	15	34.5
Harness (SM)	20.0	1	20.0	15	23.0
TOTALS			271.0		291.2
Margins			39.0 +		18.8 *
SUBSYSTEM SPECIFICATION MASS			310.0		310.0

+ Total margin held by subsystem 13%
* Subsystem level margin 6%

Displine: ELECTRICAL Subsystem: Ku COMMS/RADAR

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Crew Interface	5.0	1	5.0	5	5.3
Antenna control	12.0	1	12.0	5	12.6
Ku TX/RX	60.0	1	60.0	5	63.0
Video Diplexer	10.0	1	10.0	5	10.5
Antenna	21.0	1	21.0	5	22.1
Radar Elec.	20.0	1	20.0	5	21.0
TOTALS			128.0		134.5
Margins			17.0 +		10.5 *
SUBSYSTEM SPECIFICATION MASS			145.0		145.0

+ Total margin held by subsystem 12%
* Subsystem level margin 7%

Displine: ELECTRICAL Subsystem: GUIDANCE NAVIGATION AND CONTROL

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Inertial Ref.	10.0	2	20.0	10	22.0
Control Computer	15.0	1	15.0	5	15.8
Manual Control	8.0	1	8.0	8	8.6
Sun Sensor	2.0	2	4.0	5	4.2
Star Mapper	13.0	1	13.0	5	13.7
GPS Reciever	2.0	1	2.0	5	2.1
GPS Antenna	0.5	2	1.0	5	1.1
LAN Bridge	3.0	1	3.0	5	3.2
GNS LAN Harness	4.0	1	4.0	10	4.4
TOTALS			70.0		75.1
Margins			10.0 +		4.9 *
SUBSYSTEM SPECIFICATION MASS			80.0		80.0

+ Total margin held by subsystem 13%
* Subsystem level margin 6%

Displine: HABITABILITY Subsystem: ECLSS

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Oxygen Tanks	16.0	2	32.0	2	32.6
Air Tanks	16.0	4	64.0	2	65.3
Pipework	1.5	1 set	1.5	15	1.7
F/D Valves	0.4	4	1.6	5	1.7
Pressure Reg	0.5	8	4.0	5	4.2
Atmos. Cont.	51.0	1	51.0	5	53.6
Press. Cont.	20.0	1	20.0	5	21.0
LiOH Store	4.0	1	4.0	5	4.2
ECLSS Cont.	7.0	1	7.0	10	7.7
TOTALS			185.1		192.0
Margins			24.9 +		18.0 *
SUBSYSTEM SPECIFICATION MASS			210.0		210.0

+ Total margin held by subsystem 12%
* Subsystem level margin 9%

Displine: HABITABILITY Subsystem: GALLEY

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Trash Container	0.45	2	0.9	5	1.0
Water Dispenser	0.5	1	0.5	2	0.5
Food Prep	2.0	1	2.0	5	2.1
Water Store Tank	2.5	4	10.0	10	11.0
Water Heater	5.0	1	5.0	10	5.5
Washing Station	5.0	1	5.0	10	5.5
F/D Valve	0.4	1	0.4	2	0.4
Structure	11.0	1	11.0	10	11.0
TOTALS			34.8		37.0
Margins			10.2 +		8.0 *
SUBSYSTEM SPECIFICATION MASS			45.0		45.0

+ Total margin held by subsystem 22%
* Subsystem level margin 18%

Displine: HABITABILITY Subsystem: HYGIENE

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Seat	3.0	1	3.0	5	3.2
Gate Valve	1.0	1	1.0	5	1.1
Motor	4.0	1	4.0	10	4.4
Slinger Tines	2.0	1	2.0	5	2.1
Fixed Tines	2.0	1	2.0	5	2.1
Handles	0.5	1	0.5	2	0.5
Filters	0.5	3	1.5	5	1.6
Framework	10.0	1	10.0	10	11.0
Fan Separators	3.0	1	3.0	5	3.2
Urinal	2.0	1	2.0	5	2.1
Restraint	0.6	3	1.8	5	1.9
Vac. Cont. Valve	0.5	1	0.5	5	0.5
Waste Water Tank	5.0	1	5.0	5	5.3
TOTALS			36.3		39.0
Margins			8.7 +		6.0 *
SUBSYSTEM SPECIFICATION MASS			45.0		45.0

+ Total margin held by subsystem 19%
* Subsystem level margin 13%

Displine: HABITABILITY Subsystem: FITTINGS

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Privacy Screen	5.0	1	5.0	5	5.3
Couch	25.0	4	100.0	2	102.0
Grab Handles	0.5	8	4.0	5	4.2
Floor Covers	6.0	1	6.0	5	6.3
Payload Bay	50.0	1	50.0	5	52.5
Main Lighting	3.0	1 Set	3.0	10	3.3
Personal Stowage	7.0	4	28.0	10	30.8
Suit Stowage	8.0	2	16.0	5	16.8
Nav. Lights	0.5	2	1.0	10	1.1
Power Point	0.3	1	0.3	5	0.3
Miscel. Stowage	24.0	1	24.0	5	25.2
TOTALS			237.3		247.8
Margins			32.7 +		22.2 *
SUBSYSTEM SPECIFICATION MASS			270.0		270.0

+ Total margin held by subsystem 12%
* Subsystem level margin 8%

Displine: HABITABILITY Subsystem: LOOSE ITEMS

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Port. Oxygen	1.8	4	7.2	2	7.3
Survival Kit	19.1	1	19.1	2	19.5
Life vests	1.2	4	4.8	2	4.9
First Aid Kit	8.0	1	8.0	2	8.2
Tool Kit	10.0	1	10.0	5	10.5
Video Recorder	7.5	1	7.5	5	7.9
Video Camera	12.0	1	12.0	2	12.2
Sound Tape	1.0	2	2.0	5	2.1
Flight Manuals	4.0	1 set	4.0	5	4.2
TOTALS			74.6		76.8
Margins			13.4 +		11.2
SUBSYSTEM SPECIFICATION MASS			88.0		88.0

+ Total margin held by subsystem 15%
* Subsystem level margin 13%

Displine: HABITABILITY Subsystem: CAUTION AND WARNING

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
C&W Control	16.0	1	16.0	5	16.8
Fire Ex (fitted)	10.0	1 set	10.0	10	11.0
Fire Ex (losse)	5.0	2	10.0	10	11.0
TOTALS			36.0		38.8
Margins			14.0 +		11.2 *
SUBSYSTEM SPECIFICATION MASS			50.0		50.0

+ Total margin held by subsystem 28%
* Subsystem level margin 22%

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MULTI-ROLE CAPSULE OPERATIONS

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The Multi-Role Capsule concept offers reliable, low cost and safe manned access to and from space for near future European low Earth orbit activities. The operational aspects of performing a typical crew delivery to the Man-Tended Free-Flyer and International Space Station are described in outline. In addition, possible emergency contingency situations which could emerge during all phases of operation are also discussed, demonstrating the flexibility of th MRC system design.

1. INTRODUCTION

The primary function and operational philosphy of the Multi-Role Capsule Operation (MRC) is to provide a fundamentally simple, low cost and inherently safe autonomous European manned access to Low Earth Orbit (Fig.1). Development of the MRC would provide Europe with all the manned spaceflight capability to support the Manned Tended Free-flyer (MTFF) or future European Manned Space Station as well as provide an alternative access to the International Space Station (ISS). Also, because it is designed to be compatible with man-rated version of the Ariane 4 launcher, the MRC allows Europe to achieve an early manned spaceflight capability, providing valuable experience prior to MTFF operations as well as a manned or unmanned platform for microgravity experimentation.

This paper discusses in broad outline the sequence of events which would need to be performed to integrate, launch, operate and recover the MRC for principally the typical MTFF servicing mission, although references are made to other mission scenarios. Many of the techniques and procedures which are considered have been derived from the considerable experience gained from Gemini, Apollo and Space Shuttle programmes. These techniques, coupled with those specific to the MRC, will allow extremely flexible, but safe, missions to be achieved.

2. LAUNCH VEHICLE INTEGRATION

2.1 Ground Operations

The MRC consists of 3 primary elements; the Descent Module (DM), the Service Module (SM), and the Escape System (ES). Each of these constituent parts are delivered to the launch site fully assembled and tested, for final integration with each other and the launcher. The integration procedures could utilise existing facilities currently employed to support unmanned Ariane 4 operations (1). Following arrival of the flight elements, at either Cayenne Rochambeau or Cayenne Harbour and transfer to CSG, the MRC integration flow sequence and required facilities

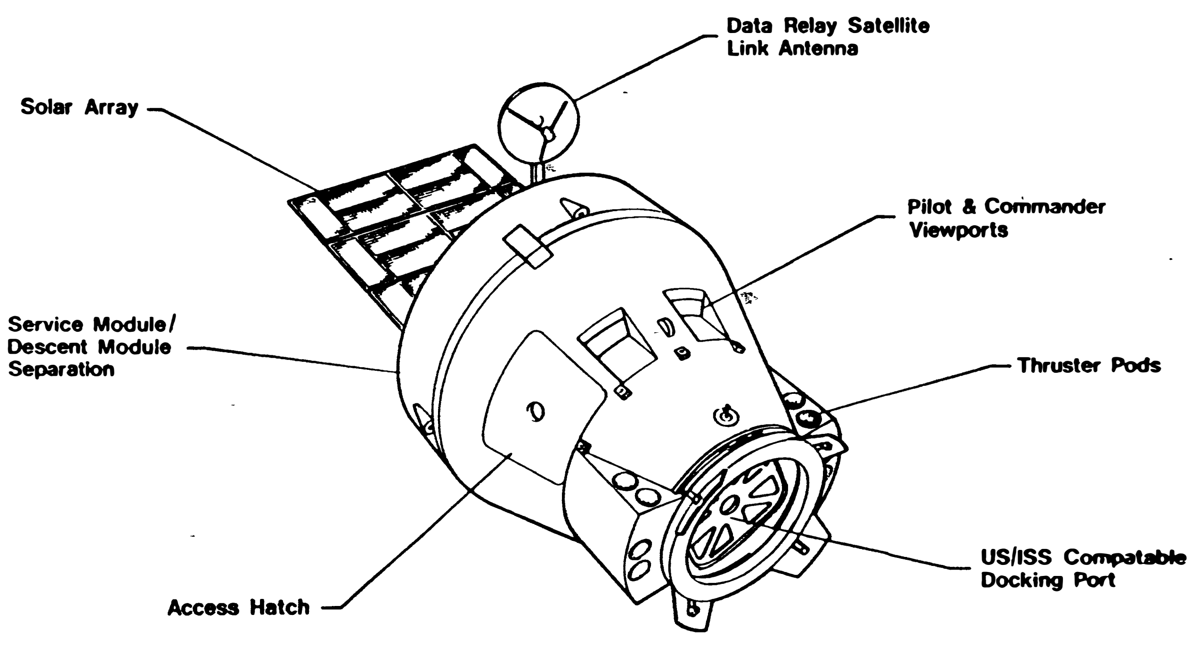

Fig.1 Multi Role Capsule

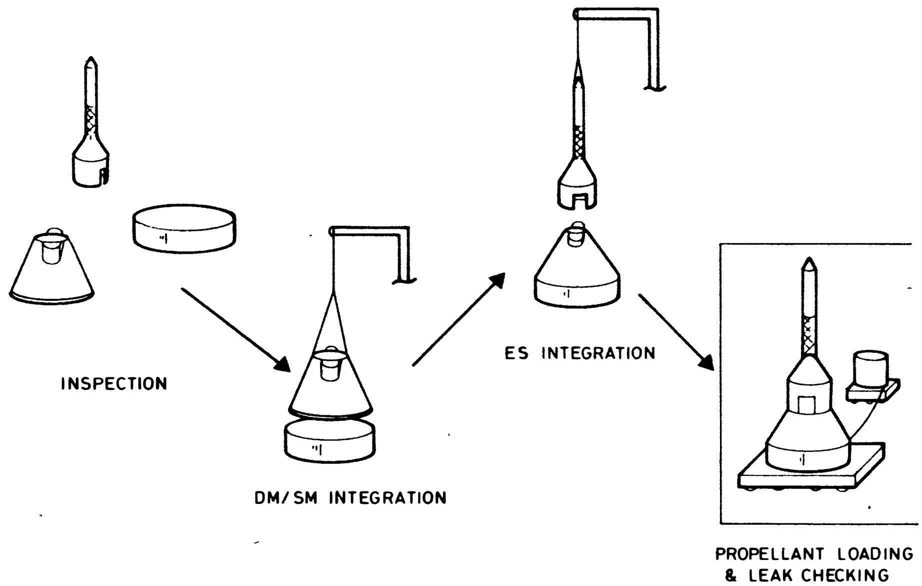

Fig.2 Integration Flow

would be as follows (Fig.2):

- Inspection of the DM and SM in buildings S1A or S1B
- Inspection and preparation of the ES solid rocket motors in building S2 or S4
- Integration of the DM and SM in building S3B followed by integration of the unarmed ES
- Basic functional testing to verify all module to module interfaces
- Propellant, atmosphere supply, pressurant and nitrogen loading
- Leak checks and final close out verification testing.

MRC specific preparation equipments would include electrical verification instrumentation, mechanical ground support equipment and payload handling and insertion equipment as appropriate.

For microgravity missions the ES would be replaced with an aerodynamic faring, unless specifically requested by the customer, and large payloads can be installed and checked at this stage.

2.2 Launch Pad Operations

The fully intregration MRC would be transported in a sealed container, primarily to protect the exposed SM equipments from the environment, to the launch pad for launcher integration. This container, which encloses the MRC below the ES tower, is a dual purpose system as it also acts as the launch pad gantry enclosure facility. Following transportation to the launch pad the MRC, within the container, is raised up the pad fixed service structure and secured to the gantry immediately above the Ariane 3rd stage. Here, the MRC is integrated to the launcher without exposure to the environment.

This launch pad operations sequence would be as follows:

- Raising the MRC in its container up to the fixed service structure and securing it above the launcher
- Integration of the MRC to the Ariane 4 upper stage
- Umbilical integrity verification
- Final MRC system checkout

Launch vehicle checkout would be esentially no different to that performed for unmanned launches except for increased levels of monitoring.

3. LAUNCH

3.1 Launch Preparation

Approximately 1-2 weeks prior to launch, any major payloads can be installed inside the DM. Loading would be through the external DM hatch. The crew couches and other personal effects, if a manned mission is to be performed, are then installed and the vehicle readied for launch.

Two hours before launch, the crew is secured within the DM and the hatch is closed. The MRC enclosure facility then splits and each half swings on the gantry arms through 90 deg. and exposes the MRC for the first time. Should a launch abort occur, the launch pad gantry would swing back and completely surround the MRC to protect the crew from potential launch vehicle propellants fumes in addition to their own pressure suits. An automatic command or manually operated actuation would blow off the hatch to allow an emergency escape of the up to 4 crew members. The crew would then board an escape basket which would slide down a wire to a safety bunker, in a similar manner to the STS launch pad escape system.

3.2 Launch Phase

Upon ignition of the Ariane 4 1st stage and Liquid booster rockets, lift-off of the MRC occurs under completely automatic control, although a crew manned override capability would exist in the event of a failure in the ECLSS or abort systems. During 1st and 2nd stage burns (Fig.3) escape from the launcher is possible by the activation of the escape tower rocket and SM/DM separation pyrotechnic devices. Command for an abort can be issued

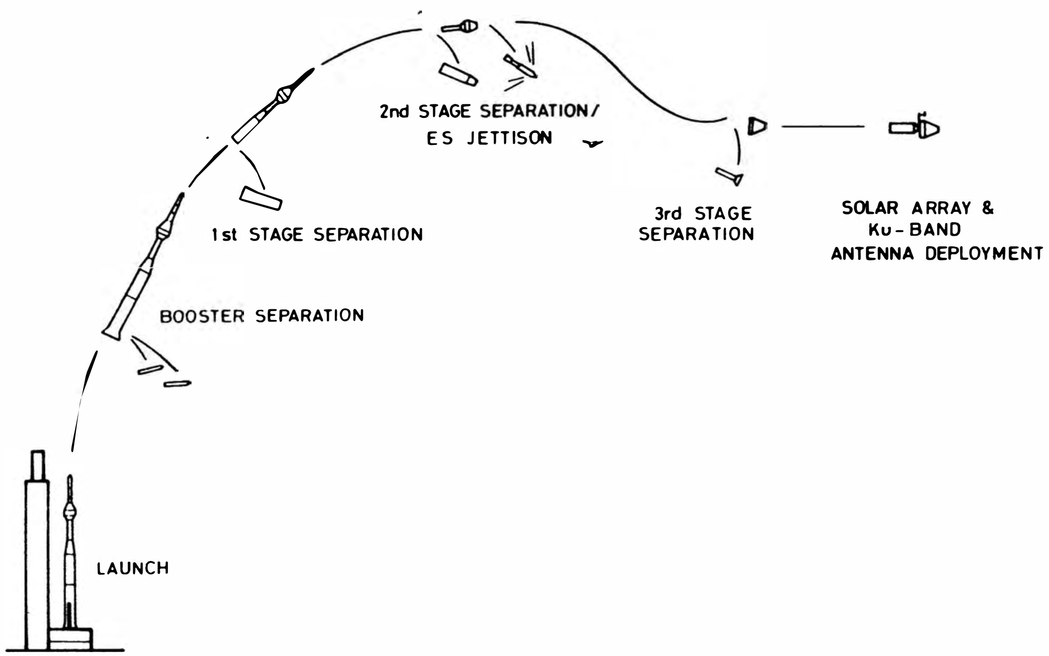

Fig.3 Launch Sequence

by the launchers avionics, ground range safety officer or MRC crew command. Telemetry and telecommand is achieved using the UHF subsystem in the MRC and relayed by the launch vehicle.

Following 2nd stage separation the ES would be automatically jettisoned, by firing the separation motors at the tip of the ES, and the third stage ignited to inject the MRC directly into a circular orbit at the mission altitude. Separation of the third stage is performed immediately after shut down, after which an avoidance manoeuvres with the stage is performed either manually or, in the nominal case, under automatic control using the bipropellant RCS thrusters. The third stage is vented to lower its orbit and hence accelerate orbital decay and eventual re-entry.

The Ku-Band communications antenna is then deployed and locked onto the appropriate Data Relay Satellite (DRS), followd by release of the solar array. The vehicle is orientated so that the solar arrays face the Sun and replenish the batteries.

For the manned MRC missions, the crew would fold away their couches and remove and stow their pressure suits.

4. MISSION OPERATIONS

4.1 Rendezvous and Docking

The primary mission role for the MRC is to allow autonomous European manned tending or servicing of the proposed Columbus pressurised free flying module. For this and any other possible MRC missions, the rendezvous and docking procedures and manoeuvres are described below.

4.1.1 MTFF

The Ariane launch, described in section 3.2 would put the MRC in an orbit which intercepts with the MTFF. Ground tracking systems would relay to the MRC long range separation and closing rate data until the MRC onboard short range radar (L-Band) acquires the MTFF and takes over control.

At a closer range (100km), communications are established between the navigation control computers on the MRC and MTFF. From positional data received from the MTFF, orbital correctional manoeuvres are performed automatically to allow the orbit parameters to be closely matched. Additionally, these manoeuvres have the effect of reducing the velocity between both vehicles.

When the distance has been reduced to within 200m, the final RCS burns are performed to reduce the closing velocity to less than 1 m/sec. The MRC then drifts to within approximately 50m of the MTFF, at which point the cold gas nitrogren thrusters are activated to further reduce the closing rate to less than 0.5 m/sec and orientate the MRC correctly for docking.

The closing rate is progressively reduced during the terminal docking phase so that the relative velocity is arrested at about 10m from the MTFF docking adapter. Then, depending upon the configuration of the MTFF, the final soft docking could be performed either directly using the cold gas thrusters controlled by the navigation computers, or by using a MTFF based SMS manipulator (Fig.4). In the later case, the SMS end effector would be

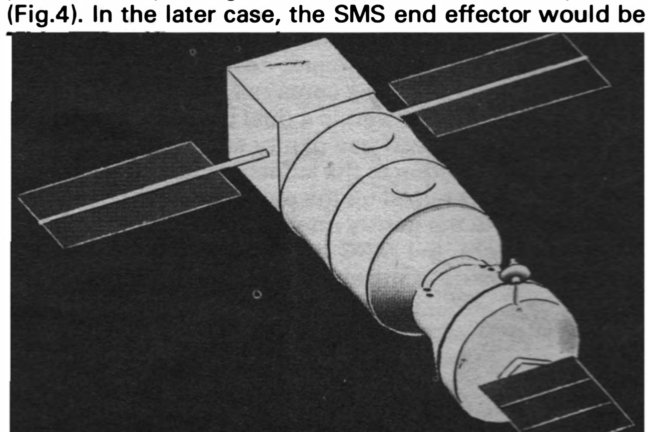

Fig.4 MRC Docked to MTFF

attached to a grapple fixture on the MRC, and then slowly the SMS would soft dock the MRC.

Once soft docking had been established and verified, the latches on the docking adapter would be activated to pull them together for the final air tight hard dock. Prior to opening the MRC hatch, tests would be performed to verify the integrity of the docking mechanical and electrical interfaces.

A limited override capability would exist to allow a manual docking to be attempted as a back-up emergency mode. In such a scenario the MRC mission commander would view the docking target on the MTFF through the hatch window and, using translational and rotational hand controller, would guide the MRC for docking.

4.1.2 International Space Station

Rendezvous and docking of the MRC to the ISS (Fig.5) would be similar to the procedure employed for the MTFF except that the RCS would be isolated at a greater distance, due to possible contamination of ISS attached payloads, and an ISS specific grapple fixture would be required.

Specific details of the reconfiguration include:

- Propulsion subsystem latching valves closed to prevent leaks or inadvertent thruster activation
- Attitude control subsystem inhibited since all attitude control is provided by the MTFF
- Communications would be routed through the MTFF communication subsystem by connection into the MTFF databus
- Power subsystem configured to trickle charge the MRC batteries to maintain them at full capacity
- Thermal subsystem configured to maintain the MRC within housekeeping flight temperature limits.

For missions to the MTFF, the MRC would act as the living quarters for the crew and, subsequently, the ECLSS would be maintained at operational status although the air supply would be provided by the MTFF. For an ISS mission the MRC ECLSS would be inhibited.

Following the MRC reconfiguration, the air pressures between the two vehicles would be equalized by the MRC

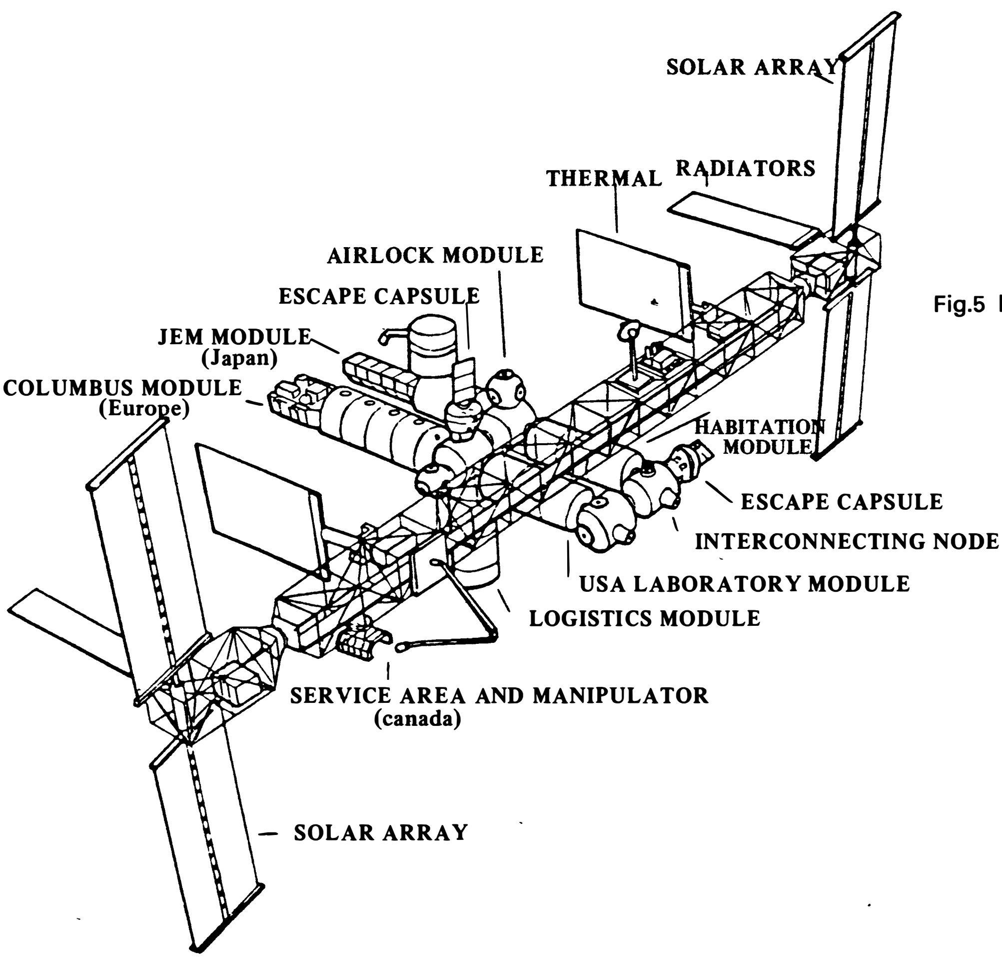

Fig.5 International/US Space Station

4.2 Orbital Activities

Once a safe docking had been verified, the MRC computers would reconfigure for orbital housekeeping operations and in a condition ready to support a possible emergency evacuation should the need arise.

relief valves, then the hatches would be opened. All payloads, fluids and any additional equipments would be unloaded. Payloads or equipments which are to be returned to Earth would be loaded into the MRC as appropriate and secured in the aft payload bay or within the forward cabin lockers.

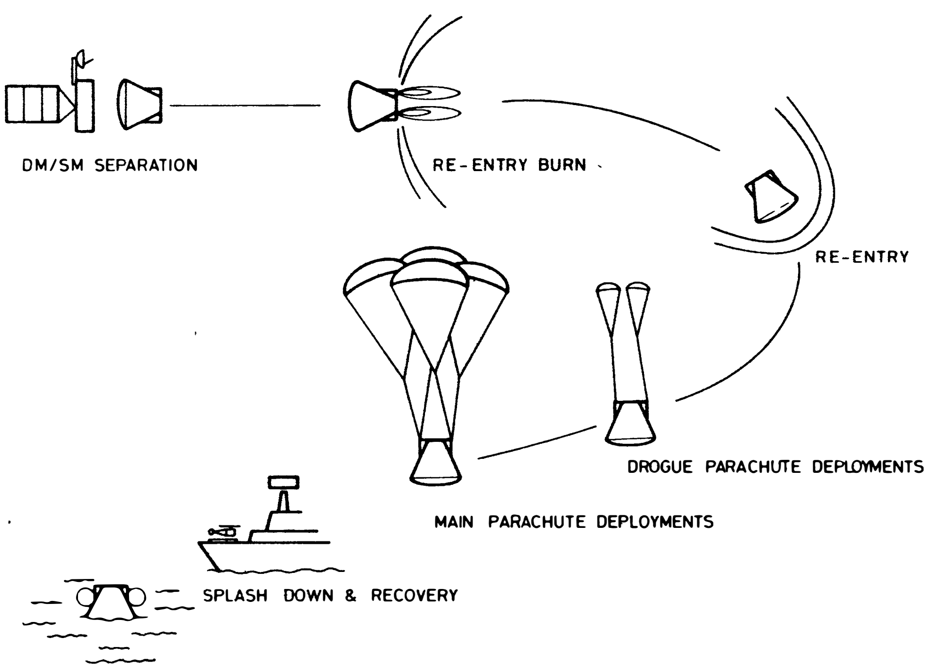

Fig.6 MRC Recovery Sequence

5. EARTH RETURN

The re-entry and recovering sequence is described in the following subsections and shown schematically in Fig. 6.

5.1 Re-Entry Preparations

At the termination of the mission all the hatches would be closed and confirmed to be air tight, and all MRC subsystems returned to full flight status. Undocking of the MRC would be achieved by releasing the docking adapter latches and then either firing the cold gas thrusters to provide the necessary separation impulse or utilising the MTFF or ISS manipulator system.

When the separation distance had reached more than 200 m the RCS would be activated and the four forward facing thrusters fired to increase the separation velocity to more than 5 m/sec.

Approximately 5-6 hours after undocking when the separation had reached 100 km preparations would start to configure the MRC for re-entry. The crew would don their pressure suits, unfold their couches into position and strap themselves in.

Once the precise re-entry and landing parameters had been computed and verified by ground controllers, the SM would be detached, by activating the four pyrotechnic bolts between the DM and SM and severing the umbilical lines. An avoidance manoeuvre is then performed by the DM.

Later, once the DM had begun entry interface, the SM gas thrusters would be vented to depletion, thus reducing its orbital altitude below the mission altitude and accelerating orbital decay. Alternatively, an ISS or future European orbital manoeuvring vehicle could be used to recover the SM and return it to the space station. There compenents, such as the solar array sensors and Ku-Band antenna, could be removed for re-use on future MRC missions or other systems. The recovered components would be returned to Earth on a subsequent MRC or STS flight.

Separation of the SM is performed prior to the re-entry burn since the RCS can be fully tested and verified before the burn takes place thus, if the SM does not separate, the MRC can return under its own control to the MTFF or ISS for repair without putting the crew at serious risk.

The DM four forward facing thrusters are then fired in the direction of flight for a period of four minutes, reducing its velocity by approximately 100 m/s. A contingency de-orbit burn can also be performed with only two of the four forward thrusters if necessary.

5.2 Atmosphere Re-Entry

Following a nominal de-orbit burn sequence the yaw pitch and roll thrusters would rotate the DM through approximately 180 degrees and place the DM at the correct angle of attack for re-entry and maintain it at the correct attitude during atmospheric flight to minimize deceleration loads on the crew. An ablative heat shield protects the module from the frictional heating during hypersonic phase of re-entry. All altitude control during re-entry would be performed automatically since this is the only phase of the mission which cannot be performed manually. The navigational subsystem has sufficient control authority during re-entry to ensure that the DM will land within 1 km of a pre-determined point.

Prior to the release of the drogue parachute, the remaining oxidiser and fuel is vented from the propellant tanks in turn, after which all propulsion subsystem latching valves are closed and the subsystem fully inhibited. This is to enhance safety during recovery operations.

At the altitude of approximately 10 km, and whilst subsonic, the drogue parachutes are deployed to further reduce the descent velocity and dampen any oscillations of the DM. When the altitude has decreased to approximately 3 km, the four main parachutes are released to reduce the terminal velocity to below 10 m/sec. If only two parachutes deploy, sufficient drag will still exist to limit the impact loads and ensures crew survival. VHF communications will be re-established during the final stages of the descent immediately following commmunications blackout.

After splashdown at the predetermined site, floatation devices will be inflated to ensure the DM floats upright and the recovery ship homing beacon activated. The DM is also designed to allow an emergency landing on the ground without significantly endangering the crew.

5.3 Recovery Operations

Recovery of the DM and its contents would be achieved by using ships that would home in on the tracking beacon. A crane on the recovery vessel would be attached to the lifting hardpoints on the DM and would lift the module from the sea and lower it onto the deck. Mass spectromer "sniffer" probes would be used to determine if any quantities of propellant remain on the PM and if so high pressure water sprays would be applied to wash the external surface.

Once it had been assured that the DM is safe the hatch would be opened and the crew could egress. The DM would then be placed in a sealed container and returned to the appropriate facility for removal of the payloads. Any components of the vehicle that could be refurbished for reuse would be removed and re-acceptance tested.

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This paper represents the author's private work and the views expressed in the paper are those of the author and do not necessarily represent those of British Aerospace plc.

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THE RE-ENTRY ENVIRONMENT OF THE MULTI-ROLE CAPSULE

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This paper describes the structural loading and thermodynamic environment experienced by the baseline Multi-Role Capsule during re-entry from orbit and for a proposed asymmetric alternative configuration.

The baseline Multi-Role Capsule follows the same re-entry philosophy as the Amercian Gemini and Apollo capsules. It has a symmetrical conical body with a spherical section base which acts as the heatshield. The C of G is offset allowing the vehicle to trim at an angle of around 20 deg and this results in a Lift to drag ratio of around 0.35 at hypersonic speeds with g levels around 2.5.

Many of the Multi-Role Capsule missions are greatly facilitated by lowering the g levels experienced during re-entry. To explore the possibility of a more benign re-entry, an alternative capsule shape was analyzed which can be trimmed to fly at higher angles of incidence giving a higher L/D ratio. This was achieved by a asymmetric conical body which produces an offset C of G and at the same time allow higher angles of incidence. The alternative shape can fly at 39 deg incidence giving a lift-to-drag ratio of 0.55. This lowers the peak g levels experienced to 1.6 and significantly improves the achievable cross-range.

1. INTRODUCTION

Probably the most important part of the mission of a capsule transportation system is the re-entry into the Earth's atmosphere. During the hypersonic and supersonic flight phases the kinetic energy of the orbital flight is dissipated in aerodynamic heating. The capsule functional requirement is to survive this heating while retaining sufficient control of the flight to permit a final landing in the designated landing site.

If a pure ballistic re-entry is undertaken then typically accelerations of 10 g are experienced and the degree of control is limited. These accelerations are incompatible with the requirements generated by many of the identified missions such as return of injured crew members or fragile microgravity samples. Thus the Multi-Role Capsule needed to adopted some form of aerodynamic lift to reduce the loads experienced.

The Multi-Role Capsule baseline design follows the same semi-ballistic re-entry philosophy as used by the American Gemini and Apollo capsules. It has a symmetrical conical body with a spherical section base which acts as the heatshield. The center of gravity of the capsule is offset from the geometric center causing the capsule to trim to an angle of incidence which provides lift.

This paper describes the analysis of the re-entry of the Multi-Role Capsule baseline design and an alternative body configuration intended to permit flight at much higher angles of incidence to raise the lift-to-drag ratio and thus reduce the loads experienced.

2. CAPSULE DESIGN

2.1 Baseline Design

Figure 1 shows the baseline Descent Module for the Multi-Role Capsule. It has a symmetric conic forebody and a spherical section base, its diameter is 4 meters and the cone angle (which determines the angle of inci-

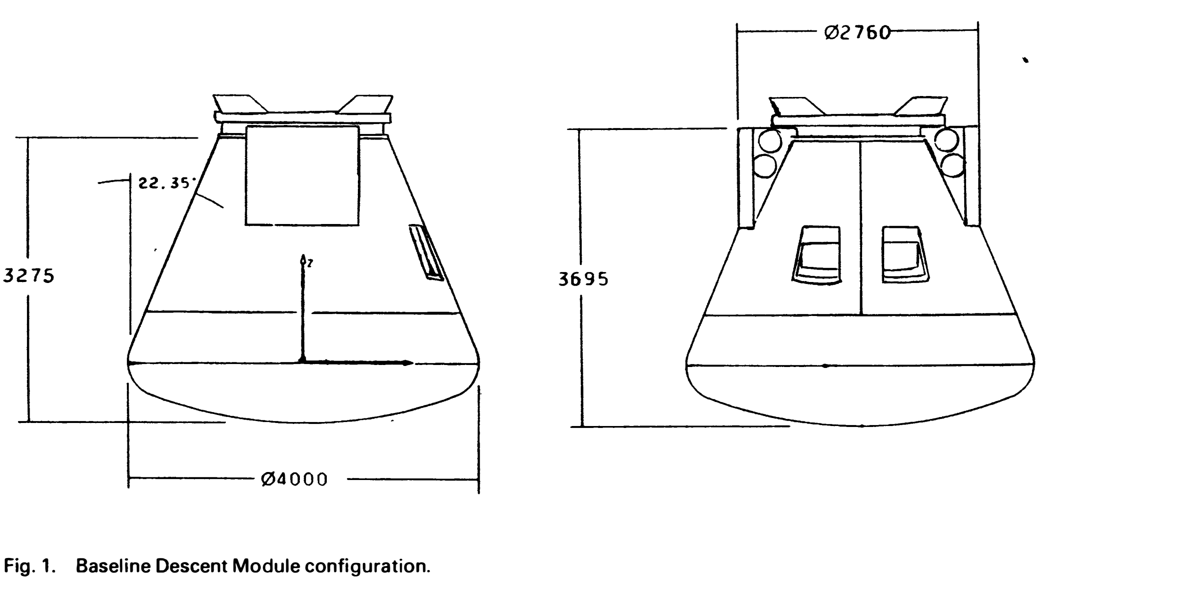

Fig. 1. Baseline Descent Module configuration.

dence) is 22 deg.

Figure 2 shows the lift-to-drag coefficients evaluated on the base area as calculated from modified Newtonian flow theory for a spherical section base. Angle of incidence is defined as the angle between the velocity vector and the axis of symmetry of the base.

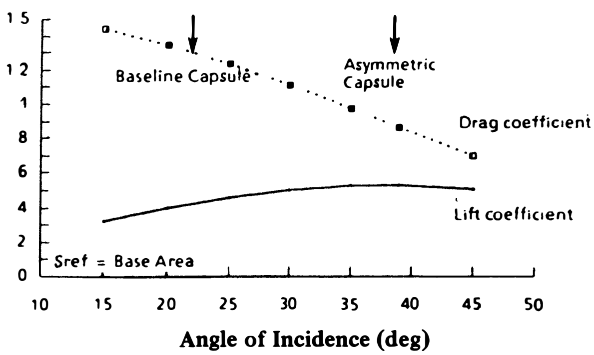

Fig 2 Lift and drag coefficients vs angle of incidence.

The values correspond closely to the wind tunnel derived for Apollo [1]. The lift coefficient remains fairly independent of incidence above 30 deg, but the drag coefficient falls with increasing incidence, giving potentially high lift-to-drag (L/D) ratios above 45 deg incidence. These high L/D are generally difficult to realize however, due to difficulty of trimming the vehicle (maintaining the vehicle at the desired angle of attack). From Fig. 2 it can be seen that the baseline capsule with its 22 deg angle of incidence gives an L/D ratio of 0.32.

2.2 Asymmetric Design

As will be shown in Section 3 the baseline symmetric conic configuration gives around 2.5 g. This is adequate for the roles identified for the MRC but further improvements in loads and capsule cross-range capability would be highly desirable especially for the following considerations.

- Some microgravity experiments particularly protein crystals produce fragile products that could be damaged by high accelerations.
- There is a concern about accelerations seen by injured personnel. It is clearly desirable that these are minimized in the case of fractures and internal injuries.
- The increased cross-range would considerably increase the flexibility of the system allowing quicker return from orbit to a designated touchdown site. This would be especially valuable in contingency situation.

The study developed an alternative aeroshell shape that was designed to significantly improve the angle of incidence. This deviated from a symmetrical conic to an asymmetric conic with one side vertical as shown in Fig. 3. This design not only produces a natural offset C of G but also allows the vehicle to fly at much larger angles of incidence before the relative wind impinges on the conical forebody which is undesirable from heating considerations. The overall base diameter was also increased to 4.5 meters which maintains compatibility with the Shuttle and Ariane 5, but the effect on an Ariane 4 launch would need to be evaluated. With this configuration a trim angle of 39 deg is achieved and from Fig. 2 this corresponds to an L/D of 0.55.

This alternative configuration would not alter the overall complexity of the MRC system; the asymmetric shape being as easy to manufacture as a symmetric shape. The only major system impact identified is the effect of the asymmetric shape on the launcher stack aerodynamics which the study has not addressed.

3. RE-ENTRY ENVIRONMENT

The re-entry environment for both configurations is shown in Figs. 4 to 8.

Figure 4 shows the deceleration experienced by the baseline capsule during the re-entry. The peak deceleration occurs at around Mach 7 with a value of 2.4 g. In contrast, Fig. 5 shows the deceleration for the asymmetric design which also reaches a peak at Mach 7 but in this case only 1.6 g. This difference is due to the difference of angle of incidence. This point is further illustrated by

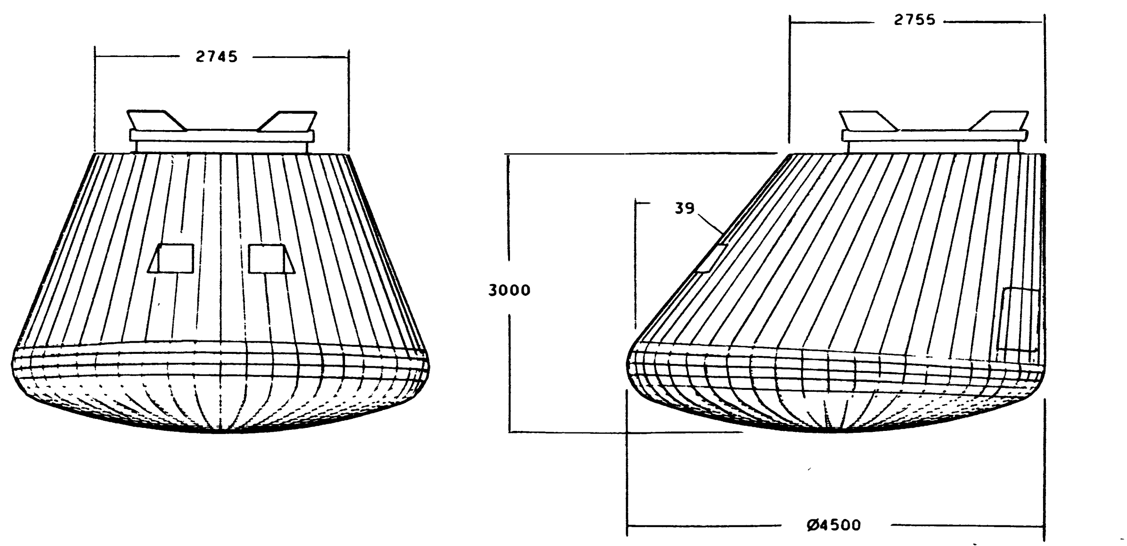

Fig. 3. Asymmetric conic alternative Descent Module configuration.

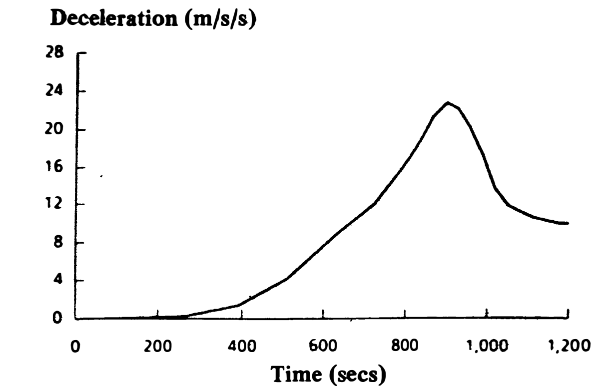

Fig. 4. Deceleration history of baseline (symmetric) configuration

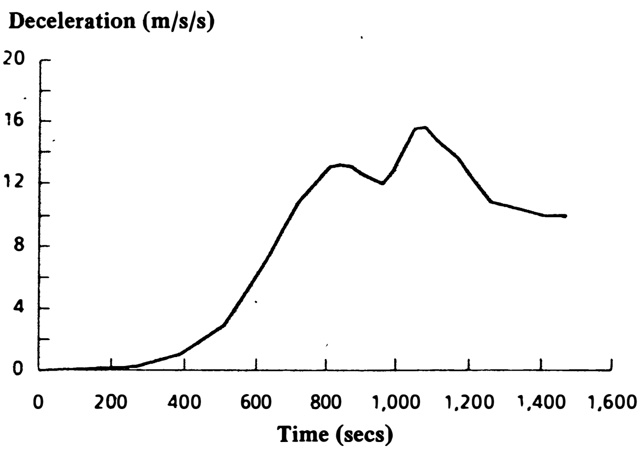

Fig. 5. Deceleration history of the alternative (asymmetric) configuration.

Fig.6 which shows the relation of maximum g load against angle of incidence.

A second parameter of interest is the achievable cross-range since a high cross-range allows greater operational flexibility and allows more precise control of the landing position. Cross-range is achieved by rolling around the velocity vector. The bottom line cross-range is achieved by rolling only when the flight path angle becomes positive (to avoid skipping). The analysis assumed a heat shield which is not ablative but reradiates heat (a worst case) with a temperature peaking at around 2350 K in the baseline case with an achievable cross-range of 0.28 deg (31 km).

Higher cross-range is achieved by decreasing the (negative) flight path angle at which rolling commences. The effect is to increase the cross-range, but at the expense of higher temperatures. By contrast, the peak decelerating forces are completely unaffected by the steeper trajectory.

Figure 7 shows a plot of cross-range against radiation temperature of the baseline configuration. The maximum achievable cross-range is around 1.2 deg (130 km) with a corresponding peak temperature of 2500 K.

Figure 8 shows the same plot for the asymmetric configuration. This can achieve much higher cross-ranges, capable of over 3 deg (330 km); while the peak temperatures are lower for a corresponding cross-range. These range from 2200 K at low values (under 1 deg) to 2400 K at 3 deg.

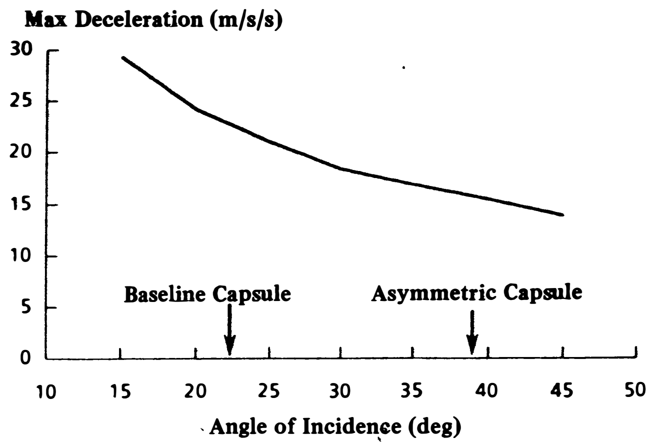

Fig. 6. Peak deceleration vs angle of incidence

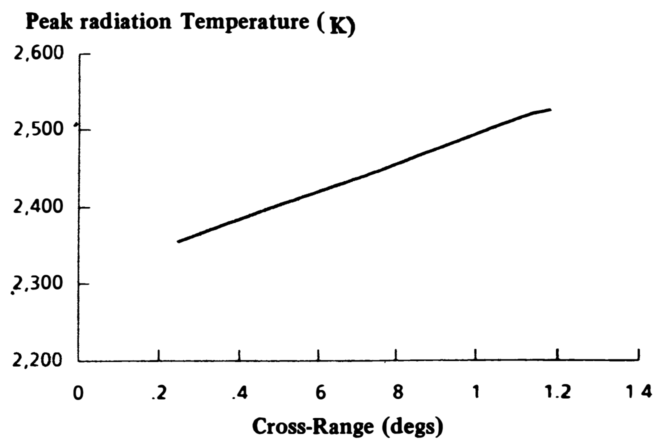

Fig. 7. Peak temperature vs cross-range for baseline capsule.

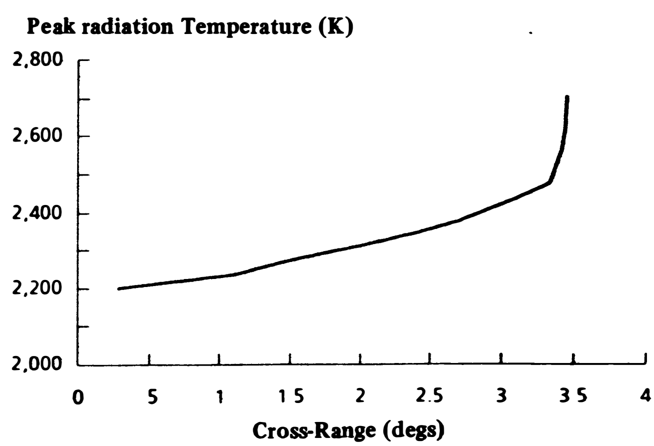

Fig. 8. Peak temperature vs cross-range for asymmetric capsule.

Although the Multi-Role Capsule baselined an ablative heat shield in fact modern ceramic materials such as carbon-carbon and carbon-silicon-carbide have been shown to withstand temperatures of 2500K to 3500K without serious oxidation or catalytic degradation and could be considered.

4. CONCLUSIONS

Provisional analysis of the baseline capsule design which is trimmed to fly at 22 deg will achieve a L/D ratio of 0.32. During re-entry the deceleration loading was found to be 2.4 g and the maximum stagnation point temperature was found to be 2350 K.

While these values are entirely consistent with the projected missions, it was desirable in some cases to lower the decelerations and an alternative asymmetric shape, intended to improve and re-entry performance, was also analysed. This achieved an L/D ratio of 0.55 which reduced the peak deceleration to 1.6 g. This is a considerable improvement and merits further consideration in later phases to the programme.

A cross-range of 1.2 deg for the baseline MRC, and 3 deg for the asymmetric alternative, could be achieved with only a moderate increase in the stagnation point temperature. The predicted temperatures were low enough for later phases to the programme to consider the use of radiative materials as opposed to ablative materials which were adopted as the baseline.

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This paper represents the author's private work and the views expressed in the paper are those of the author and do not necessarily represent those of British Aerospace plc.

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MULTI-ROLE CAPSULE : PROGRAMME AND COSTS

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The Multi-Role Capsule concept faces major challenges in meeting cost and schedule targets to enable it to fulfil the infrastructure roles foreseen in the original requirement effectively. To explore these areas a programme proposal was created covering both the development and subsequent utilization. This indicated that the timescale goals and production assumptions should be achievable. The development and production costs were assessed using parametric cost modelling techniques.

1. INTRODUCTION

The Multi-Role Capsule (MRC) Study was intended to explore the potential for a manned, semi-ballistic capsule to fulfil a variety of roles required in support of the Space Infrastructure envisaged for the 1900s and beyond. The technical feasibility of such a vehicle has been demonstrated in a number of systems dating from the late 1950s. The important question regarding the use of such vehicles in the 1990s is whether they can provide reductions in cost, risk and schedule in support of expanding infrastructure requirements.

This paper addresses cost and programmatic aspects of the MRC concept. It presents a programme exploring the ability of the system to meet infrastructure roles at the proper time. Cost estimates were produced using parametric costing techniques in an attempt to reduce vehicle development and productions costs, and these schedule and cost estimates were used to explore the impact of MRC on overall space Infrastructure developments.

2. PROGRAMME

2.1 Development Programme

The development timescale is one of the most challenging aspects of the MRC proposal. There are three key requirements to be met if MRC is to fulfii its designated roles:

- The need to provide microgravity experiment opportunities in the immediate future (before full operation of the US/International Space Station).
- Experience arising from use of a recoverable vehicle which could be applied to an advanced, recoverable Space Transportation System (such at HOTOL) needs to be available before 1995.
- Permanent occupation of the US/International Space Station is currently planned for 1996, and the CERV (Crew Escape & Rescue Vehicle) System will need to be operational at that time.

There is therefore a requirement for the system to provide a microgravity facility by 1994 and to be operational as a man-rated vehicle by 1995. This implies a six year development programme, including test flights.

Two approaches were used to establish whether a six year programme could be met. A high-level development programme outline was used to establish that time would be available for critical engineering operations. In addition, past programmes were examined to give pervious experience in meeting the goals.

Fig. 1 shows a bar chart for the main activities

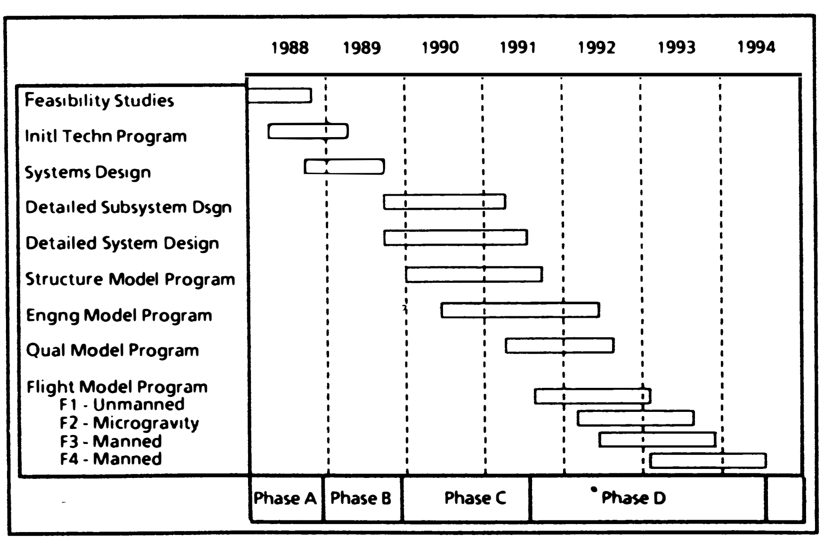

Fig. 1. Proposed development programme.

foreseen for development. A conventional four-phase programme was assumed (shown at the base) with the main design and construction activities shown. The flight model bars include the time taken for delivery as well as to conduct the flight.

The development programme was assumed to start with Phase A studies and a technology proving programme beginning in 1988. This start date has not been kept, but continuing ESA and NASA studies are covering much of the groundwork required. However, there will still be a need for an initial period in which potential contractors respond with proposals for system development.

The next phase of the programme (Phase B) defines the system level design to the point of issue of subsystem specifications. One year has been allowed for this activity, on the assumption that the requirements are more akin to those used in satellite systems rather than complex manned systems like the Space Shuttle or Space Station. By modern standards MRC is a relatively simple system without many of the subsystem interactions which can complicate the system design phase.

The programme continues along a classical development path with a Phase C containing subsystem detail design. The assumption of 21 months for Phase C followed similar considerations to those involved in Phase B. The tightest part of the programme is the construction of a Structure Test Model just three months after the start of Phase C. To achieve this, detailed structure design activity will be required in Phase B, and parallel construction and design would be needed in Phase C. This method of working has been used successfully in the past, but demands close co-operation between contractor and customer.

The Engineering Model construction is also carried out during the Phase C programme. This model is intended as a system level design tool to explore subsystem interactions. Integration would start nine months after the start of Phase C and like the Structure Model would involve parallel assembly and design.

Both Structure and Engineering Models are intended as a means of risk reduction and do not form part of the System Qualification. The standard of build in either of these models does not have therefore have to fully reflect the final flight design. Both mechanical and electrical qualification testing is carried out on a dedicated Qualification Model, which would need to be of flight standard. The assembly of this Qualification Model would begin three months before the start of Phase D as a means of reducing the overall development time.

Phase D culminates in the construction of the Qualification Model described above and the delivery of four Development Flight Models. The construction, delivery and flight of each model takes 21 months (assuming components with long delivery times have been ordered early). The total time allowed for the completion of Phase D is two and one half years.

Four Flight Models are included in the flight development programme. The first is an unmanned flight of the manned configuration to prove the system prior to flying with a crew, and corresponds to initial flight tests on earlier capsule programmes. The second flight is an unmanned test flight of the microgravity version. Although a test flight, it is assumed the real payloads could be flown, relieving some of the pressure on the European microgravity programme. In the plan presented this flight would take place in early 1993. The development test flight programme would then be complete with two manned test flights to prove all system functions including EVA, rendezvous and possibly docking operations. In this programme, the first European astronaut – independently launched – would fly at the end of 1993.

The conclusion of the initial planning exercise was that, with a small amount of risk associated with early start of the Development and Qualification Model assemblies, the six year goal was achievable. The assumption has been made that no changes in system requirements are implemented after the start of Phase B, and that funding is provided on an "as required" basis rather than an "as provided" basis with artificial constraints.

In this respect the MRC development programme would have to follow the management trends of major programmes in the 1960s rather than the national of the 1970s and 1980s. Comparison with programmes such as the Space Shuttle and Space Station/Columbus are not really valid. The development philosophy follows more closely that of commercial communications satellite programmes – typically achieving 2½–3 years from contract award (effectively the start of Phase B) to first launch. The corresponding time for MRC is a little over four years, giving some confidence in the outlined programme.

A further test of the programme's viability is a comparison with the time taken to develop similar systems in the 1960s. The relevent dates for Mercury, Gemini and Apollo are given in Table 1. The Mercury programme is not considered valid for the purpose of comparison mainly because of the simplicity of the system, the lack of interaction with other elements, and the reduction in safety to a level unacceptable by today's standards.

TABLE 1. 1960s capsule programmes with number of months from contract award shown in brackets.

	Contract award	First unmanned flight		First manned flight	
Mercury	Feb 1959	Nov 1960	(22)	May 1961	(28)
Gemini	Dec 1961	Apr 1964	(28)	Mar 1965	(39)
Apollo	Nov 1961	Feb 1966	(63)	Oct 1967	(71)
MRC (proposal)	Nov 1988	Jan 1993	(49)	Dec 1993	(57)

The Apollo capsule is the system closest to the MRC concept in specification and as can be seen took significantly longer than the MRC programme outlined here. However, there are a number of special features evident in the Apollo programme which tended to stretch the development of the CSM:

- The Apollo specification was altered after the contract award to take account of the Lunar Orbit Rendezvous decision.
- The Gemini programme was introduced to act as an Apollo precursor.
- The Apollo 1 fire delayed the programme for at least one year while major redesigns were carried out.

The Gemini programme is therefore probably the best guide to the sort of programme envisaged for MRC. Its complexity and size are a little below MRC, but not to a disproportionate amount. The comparison suggests that a total of six years from the start of project definition to an operational system is not unrealistic.

2.2 Utilization Programme

The study also considered a utilization programme. This exercise had three goals:

- To illustrate the various roles the system could fulfil.
- To examine potential conflicts in the programme due to the multi-role requirement.
- To scope likely production requirements.

The study assumed that all the roles identified for MRC were exploited. In practice this is an unlikely assumption, but represents a "worst case" demand. The programme presented here was derived during a series of iterations, taking into account the need for a uniform production rate.

The utilization programme is shown in Fig. 2. This shows the interactions with other infrastructure programmes, such as the Space Station. Table 2 gives the nominal assumed missions as a sequential listing. The early operational flights are unmanned microgravity missions, flown at a rate of one per year. In addition, an independent manned mission is included in 1994 – possibly as a guest visit to Mir.

In 1995, support to the US/International Space Station begins with the launch of the first CERV. A second CERV is launched in 1997. CERV replacement launches then occur every 18 months – rather frequent replacement for an emergency vehicle, but representing a "worst case" demand. There are also two manned launches to the Space Station, one in 1996 and a second in 1997. The first visit is intended as a demonstration of independent European manned access to Space, the second to provide supplementary crew during operations to set up the Columbus Man Tended Free Flier (MTFF). With the Space Station operational, microgravity missions are assumed to be required no longer, and unmanned missions cease after 1996.

The MTFF would require servicing by the MRC with an attached servicing module at a rate of about one flight per year. This would use an Ariane 5 launch, and a test flight of this launch system is scheduled for 1998. The Ariane 5/MRC launcher could also be used to service the Polar Platform with a flight every six years. The study also identified three contingency missions, requiring additional capsules to be held in a state of readiness on the ground. The first mission is a contingency-crew delivery-system to the Space Station should the primary logistics vehicle (the Space Shuttle) become temporarily non-operational. The second is to allow an unscheduled service of the Polar Platform or MTFF. The final contingency mission would provide rescue capability in support of test flights of a manned aerospaceplane.

TABLE 2. Maximum mission model.

No.	Date	Crew	Launcher	Mission
Development				
STM	1991	—	—	Structural testing
EM	1992	—	—	System development
QM	1992	—	—	System qualification
Flight Models				
F1	1993	0	A4	Development
F2	1993	0	A4	Microgravity
F3	1993	2	A4	Development
F4	1994	4	A4	Development
F5	1994	0	A4	Microgravity
F6	1994	4	A4	Independent mission (eg. Mir visit)
F7	1995	0	A4	Microgravity
F8	1995	0(6)	A4	ISS rescue capsule
F9	1996	0	A4	Microgravity
F10	1996	3/4	A4	ISS visit (demonstration)
F11	1997	3/4	A4	ISS visit (crew for MTFF ops)
F12	1998	0(6)	A4	ISS rescue capsule
F13	1998	2	A5	A5 development
F14	1998	2	A5	MTFF service
F15	1999	0(6)	A4	ISS rescue capsule
F16	1999	2	A5	MTFF service
F17	2000	2	A5	Polar Platform service
F18	2000	2	A5	MTFF service
F19	2001	0(6)	A4	ISS rescue capsule
F20	2001	2	A5	MTFF service
F21	2002	0(6)	A4	ISS rescue capsule
F22	2002	2	A5	MTFF service
F23	2003	0(6)	A4	ISS rescue capsule
F24	2003	2	A5	MTFF service
F25	2004	0(6)	A4	ISS rescue capsule
F26	2004	0(0)	A4/5	ESS rescue capsule
F27	2005	2	A5	Polar Platform service
F28	2006	0(6)	A4	ISS rescue capsule
F29	2006	0(6)	A4	ISS rescue capsule
F30	2007	0(6)	A4/5	ESS rescue capsule
Contingency Capability				
C1	1996 on	4	A4/5	Crew supply for ISS/ESS
C2	1999 on	2	A5	MTFF or PP service
C3	2005	2(6)	A4/5	Aerospaceplane rescue

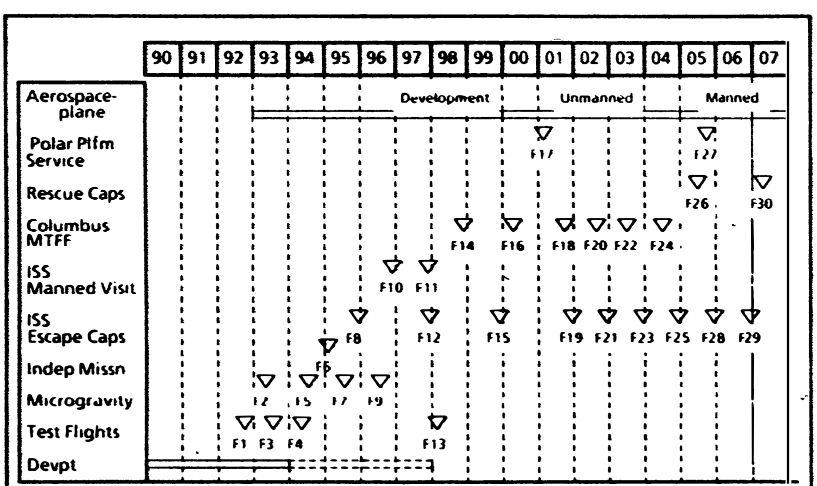

Fig. 2. Maximum utilization programme.

The conclusions of the utilization programme study are:

- Even with maximum utilization, the flight rate is not more than two per year. Many of these would have an extended orbital life, and the benefits of a reusable system are not obvious.
- The Space Station escape role (CERV) and the infrastructure servicing role have a significant utilization over a long period (~ 15 years).

3. COST

Cost estimates for development and production of MRC were made using parametric cost analysis at both system and subsystem level, using a multilevel object-oriented program (CAPCOST) based on Cost Estimating Relations originally derived for the NASA Space Station studies, but modified in the light of British Aerospace experience. The structure of the CAPCOST programme is illustrated in Fig. 3. The purpose of CAPCOST was to investigate potential cost saving measures in the vehicle design such as the multiple use of common components. One cost saving measure which it is difficult to assess with a parametric model using mass as the principal component is the impact of increasing mass margins and using less demanding technology as a consequence. This may have a significant impact, particularly on production costs.

TABLE 3. Development cost estimate.

	MAU
Flight Hardware	
Structure	133
Active thermal	7
Propulsion	27
Power system	27
GNC	70
Data and communication	218
ECLSS	164
Recovery system	14
System test	52
SE&I and management	93
	805
Support equipment	
GSE	66
Simulators	7
Test Programme	
Test capsules (3)	300
Flight support	331
Launchers (3)	219
Total development	1728

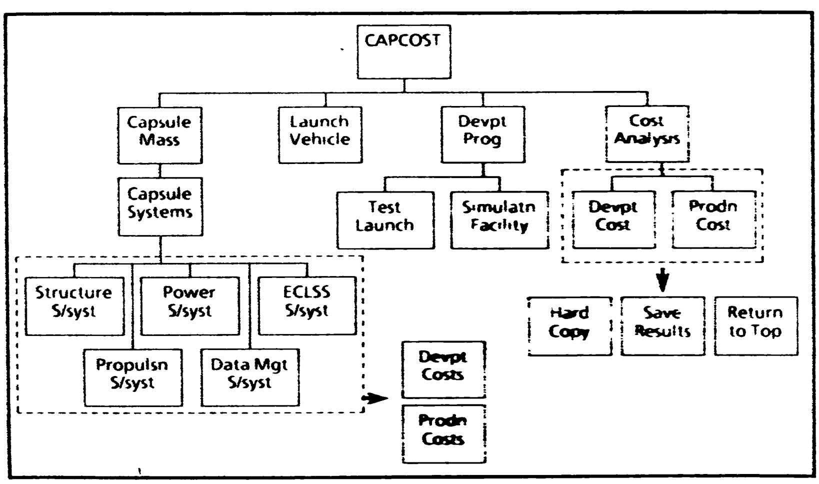

Fig. 3. CAPCOST structure.

3.1 Development

The MRC development costs were estimated assuming the programme outlined in Section 2, including one unmanned and two manned test flights. The estimate is shown in Table 3. The total cost is about 1.7 billion ESA Accounting Units. This is in general agreement with top level experience from previous capsule programmes (see Fig. 4).

3.2 Recurring Flight Cost

The recurring flight costs are also estimated by CAPCOST and are shown in Table 4. The flight support costs are somewhat variable, depending on the nature of the mission and the extent of the ground support and tracking requirement imposed. The cost of capsule hardware looks somewhat high, but with a production run of 16 capsules learning factors would bring the average cost down to about 75 MAU, and it is possible that by exploiting high mass margins further cost reductions could be achieved.

4. EUROPEAN SPACE INFRASTRUCTURE IMPLICATIONS

One argument in favour of developing a European Multi-Role Capsule is that it can act as an interim manned carrying vehicle in developing a European Space Infrastructure without diverting excessive resources from the primary objective of setting up an operationally affordable transportation system for the early years of the 21st Century. The currently proposed Hermes is expected to cost in the region of 5000 MAU to

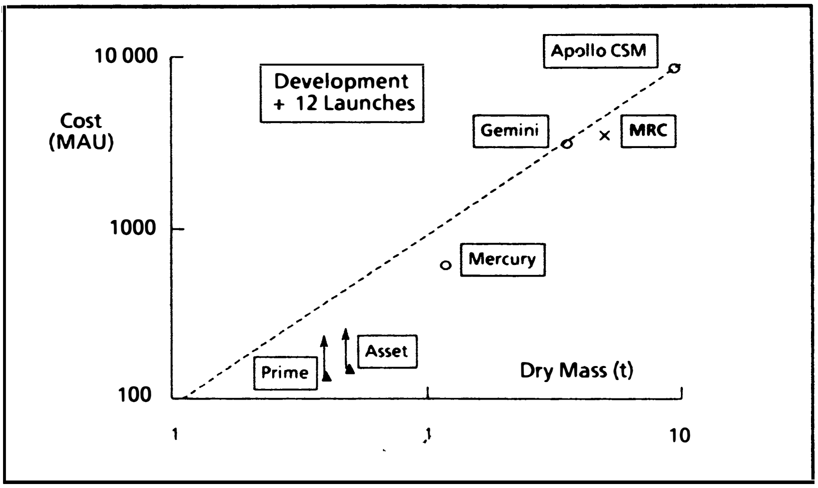

Fig. 4. Comparison of MRC cost estimate with other programmes.

TABLE 4. Recurring cost estimate.

	MAU
Flight Hardware (first unit production)	
Structure	19
Active thermal	6
Propulsion	4
Power system	7
GNC	12
Data and communication	17
ECLSS	11
Recovery system	2
Integration and test	11
SE&I and management	11
	100
Flight support	10
Launcher	73
Total flight cost	183

develop, and will have a recurring flight cost of about 120 MAU. It seems unlikely that Europe will be able to afford more than two or three launches per year, and that the size of the low Earth orbit facility that it will be able to support will be minimal. To compete effectively with US capabilities in the early 21st Century, Europe will require a substantial reduction in launch costs, and will have to invest in a reusable and cost-effective space transportation system such as HOTOL in the same period as is having to pay for the expensive operations associated with Hermes and a Man-Tended Free Flier.

Developing the MRC as an alternative to Hermes would save about 3000 MAU in development costs. Table 4 suggests that the recurring flight cost of MRC would be higher than Hermes, but a production run of perhaps 15 capsules, or some attempt at reuse of hardware, could be expected to bring the unit price down to about 75 MAU. In addition, with the launch capacity of Ariane 5 it would be possible to launch a capsule and an expendable Logistics Module in tandem, so that support flights to a Man-Tended Free Flier or an initial, autonomous European Space Station would be no more expensive than launching Logistics Support Modules on separate flights to Hermes. It seems probable, therefore, that in the period from 1997 to 2005, the unit flight cost of MRC operations would not be different from that for Hermes. In the short term there would be less pressure to exploit a very expensive investment to the full before starting on a successor vehicle, and in the long term the existence of the MRC would save costs associated with providing an Escape Capsule for an autonomous European Space Station.

Successful exploitation of the space environment demands not simply the capability to carry out operations in orbit, but the capability to afford such operations. Manned launch systems using expendable launch vehicles are likely to provide only an interim, expensive access to low Earth orbit, providing experience before more economical launch systems become available. There is a strong case, therefore, for keeping ambitions and risks low during this interim period, and adopting a well-tried route that the MRC programme offers.

5. CONCLUSION

The Multi-Role Capsule concept has the attraction of providing a short-term and relatively low-cost route for Europe to enter Man-in-Space operations, while providing a long-term component of its eventual European Manned Space Infrastructure. To be successful, there are challenges in meeting cost and schedule targets to fulfil these roles effectively. This paper has explored the cost and programmatic issues and has indicated that the timescale goals and productions assumptions are achievable.

This paper represents the author's private work and the views expressed in the paper are those of the author and do not necessarily represent those of British Aerospace plc.

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