

This work was written as part of one of the author's official duties as an Employee of the United States Government and is therefore a work of the United States Government. In accordance with 17 U.S.C. 105, no copyright protection is available for such works under U.S. Law.

Public Domain Mark 1.0

<https://creativecommons.org/publicdomain/mark/1.0/>

Access to this work was provided by the University of Maryland, Baltimore County (UMBC) ScholarWorks@UMBC digital repository on the Maryland Shared Open Access (MD-SOAR) platform.

**Please provide feedback**

Please support the ScholarWorks@UMBC repository by emailing [scholarworks-group@umbc.edu](mailto:scholarworks-group@umbc.edu) and telling us what having access to this work means to you and why it's important to you. Thank you.



## PHOENIX AND CLUSTER II—TOWARDS A RECOVERY FROM THE LOSS OF CLUSTER

R. Schmidt\*, C. P. Escoubet\* and M. L. Goldstein\*\*

*\*Space Science Department of ESA, Keplerlaan 1, NL-2200 AG Noordwijk, The Netherlands*

*\*\*Code 692, NASA, Goddard Space Flight Center, MD 20771, U.S.A.*

### ABSTRACT

The four-spacecraft Cluster mission was to aim, for the first time ever, at 3-dimensional measurements of small-scale processes (scale lengths ranging from a few hundred to thousands of kilometres) in the magnetosphere and the solar wind. The four spacecraft were identically equipped with a state-of-the-art set of instruments to measure fields, particles and the composition of the plasmas along their highly eccentric, polar orbit. The launch took place on 4 June 1996. Unfortunately, the launcher blew up at an altitude of about 3700 m due to a major malfunction of its guidance system. The spacecraft were lost in this accident. The scientific community is trying to recover from this tragic loss by actively pursuing two alternatives for a replacement mission. As an immediate step towards a recovery, the European Space Agency has already given the go-ahead to industry to assemble the Cluster spare spacecraft and negotiations for a launch vehicle are underway. The scientific community prepares the case for a decision by the relevant funding authorities to either rebuild the Cluster mission or to build for small satellites carrying as many of the original Cluster instruments as possible.

©1997 COSPAR. Published by Elsevier Science Ltd.

### INTRODUCTION

ESA's Cluster mission was to be a four-spacecraft mission to study the interaction between the solar wind and the Earth's magnetosphere in unprecedented detail. Cluster would have allowed, for the first time, to make truly three-dimensional measurements of both large- and small-scale phenomena in the near-Earth environment. Cluster was to be launched by Ariane-5 - the first time that four identical spacecraft would have been launched on a single launch vehicle and it was to be the first flight of ESA's new generation launcher.

It was planned that Cluster, together with the Solar and Heliospheric Observatory (SOHO) constitute the Solar Terrestrial Science Programme (STSP), the first Cornerstone of ESA's Horizon 2000 long-term science programme. Cluster and SOHO measurements were to be co-ordinated with an international fleet of spacecraft through the Inter-Agency Consultative Group to form a unique set of data on the interaction between the Sun and the Earth.

## THE CLUSTER SPACECRAFT

Each of the four cylindrically shaped spacecraft measured 3 m in diameter and was about 1.2 m high. The launch mass was 1250 kg, 650 kg of which was fuel to propel the spacecraft from the geostationary transfer orbit into the final polar orbit. The launch configuration, i.e. two stacks of two spacecraft, weighed more than five tons. The spacecraft in their deployed configuration were dominated by their four wire booms (50 m each) belonging to the electric field and wave instrument. The sensors of fluxgate and search coil magnetometers were each mounted at the tip of a 5 m radial boom. For telecommunication purposes there are also two axial boom antennae.

The plan was to inject the spacecraft into a Geostationary Transfer Orbit (GTO) on a single Ariane-5 launch vehicle. They would have been transferred in pairs to their mission orbits (apogee 19.6 Earth radii and perigee 4 Earth radii) through a series of propulsive manoeuvres. The large quantity of propellant, more than half the spacecraft's mass, required to perform these complex manoeuvres, was a major factor in the spacecraft design. The selection of the final orbits was such that the spacecraft would have flown in a tetrahedral formation when crossing regions of scientific interest, this being the optimum formation to achieve the mission's scientific objectives. Relative distances between the spacecraft would have been adjusted in the course of the mission depending on the spatial scales of the structures to be studied, varying from a few hundred kilometres to a few Earth radii. The spacecraft were supposed to be spin-stabilised at all times, with attitudes ensuring a solar-aspect angle of approximately 90 degrees - the optimum for power and thermal-control subsystems.

Controlling four spacecraft in a co-ordinated manner required new operating procedures. Mission control would have been performed by ESOC, the Agency's Space Operations Centre in Darmstadt, Germany, via ESA's ground station network, with support from NASA's Deep-Space Network. The sheer volume of data - about  $10^{12}$  bits collected in two years - required new handling procedures. The scientific data were to be distributed by ESOC using CD-ROM as a medium to the Principal Investigators, Co-Investigators and the network of eight national data centres (6 in Europe, 1 in USA and 1 in China) that form the Cluster Science Data System (CSDS). The operations scenario called for science operations to be carried out by the Joint Science Operations Centre at RAL, Didcot.

## THE LAUNCH FAILURE

On June 4 1996, after a short break in the countdown due to bad local weather conditions, Ariane-5 appeared to rise flawlessly, producing a tremendous cloud of smoke and vapour. The flight trajectory was nominal up to an altitude of 3.5 km, when the sudden swivelling of both solid booster nozzles forced the launcher to tilt sharply. The intense aerodynamic loads on the launcher structure resulted in the break-up of the launcher which caused the self-destruction of all launcher elements. Parts of the Cluster spacecraft were dispersed throughout the swampy area around the launch pad. Subsequently, an Inquiry Board has determined the accident to be attributable to the flight software and has made recommendations to correct the anomaly.

Shortly after the failure, the Cluster project proposed to the Cluster community to refurbish quickly the Cluster structural model using the spare experiments and make it ready for flight within about a year. This spacecraft, considered to be the first of a new fleet, was named Phoenix. The Principal Investigators supported this proposal but strongly emphasised that a single-spacecraft mission could not by no means achieve the scientific objectives of the four Cluster spacecraft.

On 17 and 18 June 1996 a Science Working Team meeting was convened which re-confirmed the Cluster scientific objectives as timely and being the next step in space plasma physics. After extensive discussion on the recovery scenario, a resolution was prepared listing two possible options for a new mission, which would recover either all or most of the original scientific objectives of Cluster. The name *Cluster II* was chosen for the new mission.

## THE RECOVERY ACTIVITIES

Following the destruction of the four Cluster spacecraft a recovery action was immediately initiated and ESA, after receiving approval from the Space Science Programme Committee (SPC) at their meeting on 2 and 3 July 1996, decided firstly that Phoenix, based on Cluster spare parts be made ready for flight within one year and secondly that studies be initiated to explore ways to implement either option 1 or 2. The results of the studies and launch options for Phoenix will be presented at the next SPC meeting on 27 and 28 November 1996.

### Cluster II

A single Phoenix spacecraft cannot meet the primary Cluster objectives. The key objective of Cluster was, and still is, to understand processes at small to medium scales and to relate them to global dynamics. These Cluster objectives remain the highest priority for the exploration of space plasmas, and can only be achieved with four closely spaced spacecraft. To this end, a longer term strategy is being studied named Cluster II, which has two options.

Option 1 is to re-fly the Cluster mission: this option would use four re-built Cluster spacecraft and would totally recover the scientific objectives of Cluster and a substantial portion of the ESA Solar Terrestrial Science Programme (STSP). This is the highest priority option and is the one which best exploits previous investments.

The manufacture of all units including the experiments will take some time despite being existing designs, and thus the first Cluster II spacecraft could only be ready for a launch by the end of 1998. The other spacecraft would come off the production line up until 2000 at approximately six monthly intervals. The spacecraft could be launched individually in series, taking up any spare capacity of already manifested launches. The final fleet would then converge to undertake the Cluster science, in the year 2000. Alternatively, all spacecraft could be launched together on one launch vehicle according to the original Cluster mission scenario.

Option 2: From the scientific point of view it is absolutely clear that the repetition of the original Cluster mission carries the highest priority. However, sufficient funds cannot easily be found within ESA to rebuild, launch and operate the spacecraft. The member states of ESA will certainly also have difficulties to fund the nationally provided elements of the scientific payload. It is therefore very important to look into cheaper ways for the implementation of a four-spacecraft mission. Thus, option 2 is to re-build one Cluster spacecraft, Phoenix, and to launch it together with three or four potentially smaller spacecraft provided in a special programme with national agencies. For this option, the SPC delegations took an action to study alternative strategies which could produce a cheaper mission. This might include subsets of the original payload complement integrated on cheaper national mini satellites. Various single or multiple launcher options are also being considered which might necessitate minor modifications to the final Cluster II orbit.

## Phoenix

Phoenix will be based on the Cluster Structural Model equipped with the flight spare units of the experiments and sub-systems prepared for the original Cluster mission. New equipment will be manufactured in certain cases where there are not sufficient available, for example the harness, radial boom, wire booms, etc. Phoenix will be identical to the original Cluster spacecraft and using extensive knowledge available from the previous programme, will be fully integrated and tested by mid-1997. This spacecraft will therefore be available for launch in the last quarter of 1997.

The case for the launch of a single Phoenix spacecraft into a 'Cluster-type' orbit in the immediate future rests upon two central arguments: (a) primary investigation using modern high-resolution plasma and field instrumentation of key magnetospheric regions, principally the high-altitude dayside cusp, and (b) co-ordinated observations with a number of key spacecraft which are currently operational or which are due to be launched in the immediate future, and with the new ground-based infrastructure which was timed for Cluster. Four major agencies (ESA, NASA, the Russian Institute of Space Research, IKI, and the Japanese Institute of Space and Astronautical Science, ISAS) have co-ordinated their missions in the field of solar terrestrial science in order to study large scale magnetospheric processes. This programme has been augmented by an unprecedented network of ground based observatories. The four point Cluster measurements were an important element in this global programme. A single spacecraft will be able to recover some, but not all, of these objectives.

The primary driver in the choice of orbit intended for the original Cluster mission was that it should pass through the high-latitude boundary of the Earth's magnetosphere in the vicinity of the dayside cusp. Most of the information on this region which is presently available was derived from measurements made by the ESRO HEOS-II spacecraft during 1972 - 74. These data were sufficient to provide the first evidence of time-dependent solar wind-magnetosphere coupling processes at the magnetopause boundary (then termed "flux-erosion events"), and also indicated, via the discovery of the "entry layer", that this region was probably a primary site of solar wind plasma entry into the Earth's plasma environment. There is therefore no doubt that a single spacecraft with Cluster-class instrumentation will provide major new insights and information on this key region, though not, of course, of the same order as would have been provided by the four-point information from Cluster itself.

A second major area of activity which will uniquely become possible with the Phoenix spacecraft launched in the immediate future will be co-ordinated observations with the large number of magnetospheric-related spacecraft which are either currently operational or which are planned to become so over the next 1 - 2 years. Phoenix would fill a gap in the global coverage of the magnetosphere created by the loss of the Cluster mission. The four-point Cluster measurements were an important element in this global programme. A single spacecraft would be able to recover some, but not all, of these objectives.

Initially, in addition to the central scientific reasons outlined above, it is also undoubtedly the case that the early flight of a single Cluster spacecraft will also provide much operational information which would be useful in preparing for a Cluster reflight. One aspect of this involves the experience which would be gained of instrument and spacecraft operation in orbit. Another concerns the new information which would be gained of the plasma conditions on the Cluster orbit, which would significantly aid further definition of an optimum science data gathering plan.

## OUTLOOK

All parties involved in the recovery activities are preparing their arguments for the meeting of the Science Programme Committee on 27 and 28 November 1996. It is expected that the committee will make a decision on how to go about the launch of Phoenix and whether or not to implement a Cluster II mission based either on option 1 or 2. The decision will not be easy in view of the potential impact of Cluster II on the overall science programme of ESA. As there are no free funds available to execute Cluster II, all cost will have to be born out of a fixed budget leading to potential delays of other science missions in the future. The Cluster community feels, however, that the scientific contributions of Cluster, having been one of ESA's cornerstone missions, to the progress of space plasma physics would have been of paramount importance and a re-flight of the mission would be extremely important for the future of this discipline. The impact of a loss of a mission of such a magnitude on space science in general is also acknowledged by representatives from other disciplines and therefore it is hoped that the decisions by the relevant committees will be in favour of a recovery mission.

## ACKNOWLEDGEMENTS

The authors are very grateful for the contributions by Prof. S.W.H. Cowley to the justification for the single-spacecraft Phoenix mission.

## REFERENCES

A detailed description of the scientific payload, spacecraft and operational systems is in press. It will be published in Space Science Reviews, January 1997.