FRACTURE CONTROL IN THE EUROPEAN SPACE AGENCY

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In the last decade, manned space programs, with all their associated safety issues, have boosted in Europe the role of fracture control techniques for space applications. All payloads to be carried inside the cargo bay of the American Space Shuttle, are subject to stringent fracture control requirements, to ensure the safety of the crew. In view of the numerous activities of the present and envisaged in the near future: Space Station, Ariane V, Hermes, requiring fracture control; the European Space Agency is performing many tasks concerned mainly with technology and management aspects.

INTRODUCTION

Fracture control has been applied in nuclear and aircraft industries since many years but only during the last ten years its application to space became important in Europe because of the American Space Shuttle program.

All payloads to be carried on the Space Shuttle require the application of fracture control procedures to prevent catastrophic failures that endanger the life of the astronauts and/or the loss of the shuttle itself. Spacelab has been the first ESA program to use fracture control and after that many other payloads have been developed by industries/universities using it.

In the ministerial conference in Rome in January 1985, the European Space Agency long term programs have been approved to strengthen the European space policy.

To increase the European competitiveness on the launcher market in the 1990.s, the Ariane V program has been approved, see

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fig. 1. Such a launcher will be able to place in low orbit 15 tons of payload and it will be man-rated. A key element of this launcher is constituted by the large cryogenic engine HM-60, see fig. 2.

To become independent in the manned space flight, the reusable plane Hermes, see fig. 3, has been proposed. This vehicle will be mounted on an Ariane V launcher. Furthermore the natural continuation of the Spacelab program will be pursued ESA with the participation to the American Space Station in the frame of the Columbus program, see fig. 4. The Columbus will be attached at the beginning to the US station and will later be detached and become a free flyer.

All these challenging future programs require a coordinated and balanced fracture control policy in order to optimise the research and development funds that will be available and to focus the European industry effort in this area.

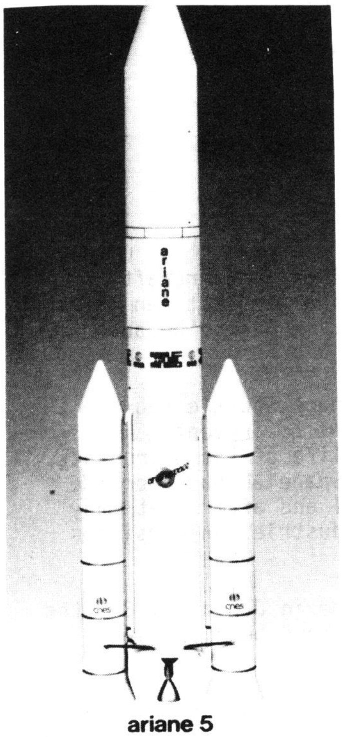

Figure 1 Ariane V, man-rated launcher

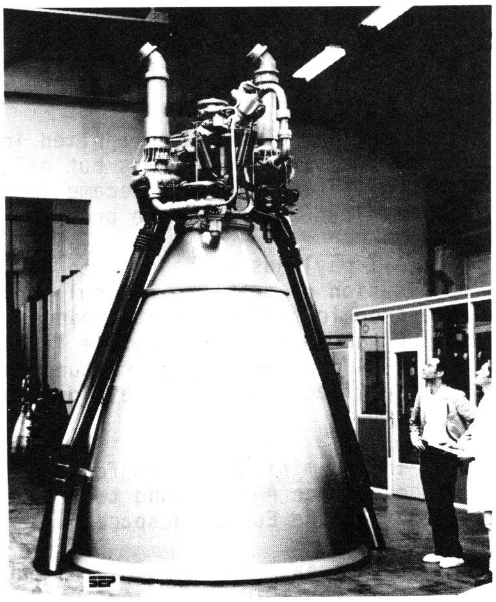

Figure 2 HM-60 engine for Ariane V

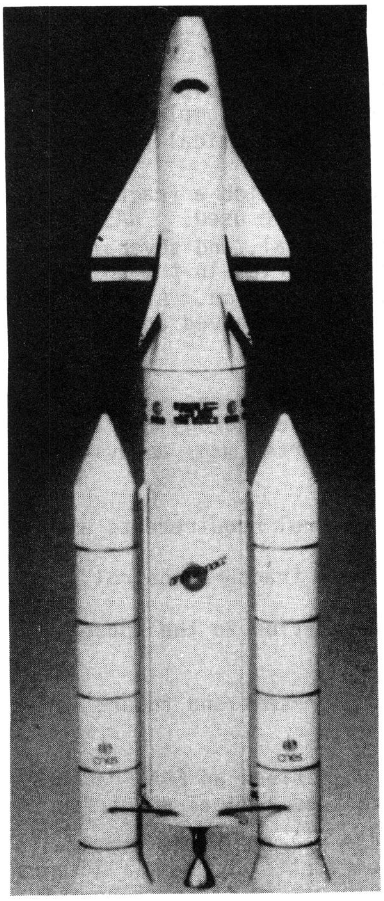

Figure 3 Hermes, manned reusable space plane

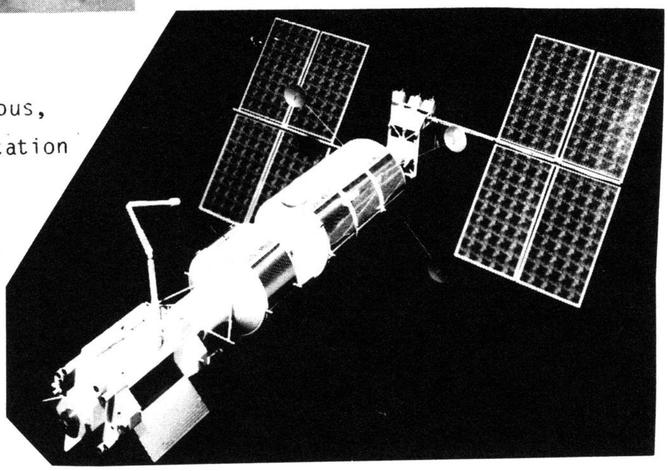

Figure 4 Columbus, the ESA Space Station

FRACTURE CONTROL MANAGEMENT

A successful fracture control program is multidisciplinary since failure in a structure is often the result of a complex interaction of metallurgical, mechanical and chemical parameters.

Spacelab was the first ESA project for which a fracture control plan and a fracture control board were used. NASA fracture control requirements are very general, and several interpretations have been made by the industries in the United States and Europe generating a confusing situation. Also universities and research centers have been involved and they need clear indications on the way to proceed.

To cope with present problems of proliferations of fracture control plans and prepare fracture control technology for future programs, the European Space Agency has started many activities aiming at:

- providing cost effective fracture control requirements and guidelines
- streamlining and unifying the European fracture control policy
- creating a European exchange of information in the space domain on fracture matters
- standardising analytical tools
- giving Europe extensive autonomy for present and future programs

To carry out the above mentioned objectives an ESA Fracture Control Board has been established to act as a focal point for all the fracture control issues. The ESA policy is thus basically formulated in the Fracture Control Requirements document. To make the fulfillment of such requirements even easier, a Fracture Control Guidelines document will also be issued. These documents will both be agreed by NASA to standardize the approach.

Furthermore there is a deep involvement of the European Industry in workshops and technical meetings. The creation of an Industry Advisory Group will take place in order to keep a direct contact with most of the Industries, not only with the one involved in a project. Such contact with the Industries will allow for easy exchange of technical information between Industries, create a common material European Database, and obtain a feed-back concerning problem areas to be investigated by ESA.

The ESA Fracture Control Board will deal directly with NASA/JSC regardless of which NASA center is responsible for the payload. ESA is working very closely with NASA/JSC on standardization of analytical tools for crack growth analysis. Furthermore ESA has a number of technological contracts to improve the Fracture Control technology (see next paragraph). In Fig. 5, the complete ESA management scheme is shown.

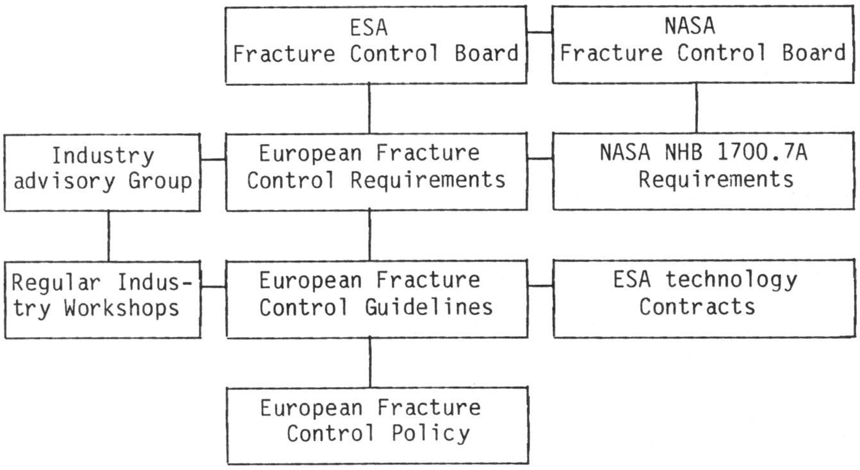

Figure 5 ESA Fracture Control Management

For the Ariane V, which will be designed as man-rated, and possible for the Hermes only the ESA requirements will exist. Such requirements have not yet been formulated, but a number of areas where simplifications can be made have been identified (i.e. 14 gr loose piece requirement), even if compatibility with NASA is needed.

FRACTURE CONTROL TECHNOLOGY

To cope with all the challenging programs envisaged by ESA, a number of Fracture Control technologies need improvement:

a. materials properties
b. stress intensity solutions
c. crack growth prediction algorithms
d. load spectra
e. NDI
f. fracture of composites
g. probabalistic fracture mechanics
h. creep

Materials Properties

Fracture properties of materials are needed for any fracture control activity. Since the testing activities to derive the material properties are very expensive, ESA is generating together with NASA a computerized database which could be used by any Industry/University. Such a database must be kept continuously up to date for all new data which is generated in Europe and in the United States.

Stress Intensity Solution

At present Finite Element Packages in general are used to generate Stress Intensity Solutions but the main problem is the computer cost, still quite high in spite of the hardware price decreasing. Fast methods to evaluate Stress Intensity Factors are needed, especially for 3D configurations. Boundary Integrals and edge function methods are under consideration.

Crack Growth Prediction Algorithms

ESA is working together with NASA on a new computer software which will be standard for every space program. At the moment crack opening/closure effects are not taken into account in the space industry, but they are considered in the aircraft industry.

ESA is sponsoring research in this direction to verify the need to introduce retardation algorithms. Crack opening / closure is normally ignored in the crack growth prediction, which is considered a conservative approach.

Load Spectra

To predict the life of a component it is necessary to know the operational loads. Up to a few years ago only theoretical spectra were available because the Space Shuttle was not operational. ESA has sponsored a contract [2] to verify the operational spectra for the Spacelab and other payloads using measured accelerations. The result of such work is the evaluation of the load spectra used for earlier projects, and a software to estimate load spectra for an arbitrary STS payload.

Non Destructive Inspection

The initial defect sizes assumed for the fracture control are dependent on the industry NDI capability and manufacturing experience. Work is needed to have statistically meaningful results from many industries and for different component and manufacturing processes. Bolt fracture is a quite common problem which is very difficult to characterize due to the difficulty of characterizing the initial crack size. More reliable NDI are also needed, especially for future in orbit inspection. Standards to qualify NDI personnel should be set up.

Fracture of Composite

The use of composite materials is growing very fast but unfortunately at the moment we still do not have reliable algorithms to predict the behaviour of such materials. One of the basic problems with the composite is how to define a defect and its criticality. ESA has a number of contracts [3], [4], aimed to develop methodologies for acceptance criteria after manufacturing and for strength characterization.

The environment also plays an important role in the degradation of the composite properties. ESA has already implemented some Damage Tolerant Design requirements for composites, mainly concerning with proof testing. In the future it is desirable to specify detailed analytical/experimental procedures for design/verification of composite structures.

Probabilistic Fracture Mechanics

The purpose of probabilistic fracture mechanics is to estimate or bound the reliability of a component subject to cracking and to quantitatively ascertain the influence of engineering and management decisions on component reliability.

Such approach has been used mainly in the nuclear industry but applications in space should produce a decreasing of cost.

Such analysis should be used also in conjunction with the risk assessment to evaluate the overall risk of a component.

Creep

The crack propagation at high temperatures, typical problem for the HM-60 engine of the Ariane V will require a lot of testing activity to generate material data. The creep problem is new for the space industry in Europe since no man-rated engines have been developed in the past.

INTERDISCIPLINARY APPROACH

Fracture Control has been widely applied in several industries other than aerospace since many years. Every industry has developed an expertise in a particular field more relevant to its activity. In particular:

Nuclear/Energy industry: Different materials from aerospace are used nevertheless sophisticated analysis techniques have been developed in elasto-plastic regime in deriving fracture criteria and in radiation shielding. Extensive material data exchange is already existing between European industries since many years. probabilistic fracture mechanics is also widely used.

Off-shore industry: Load spectra prediction techniques are well advanced together with fast on site Non Destructive Inspections. Corrosion prevention and control is mandatory for such industry.

Civil industry: Application of fracture mechanics to non metallic material is normally carried out.

Transportation industry: Techniques to decrease the cost of automobile parts increasing the reliability using fracture control are used.

Considering the many technology areas that will be needed in the immediate future for the ESA space programs are already used or under development in other industries, a closer interdisciplinary cooperation is sought to decrease the development costs.

CONCLUSIONS

Fracture Control is growing very fast, and in view of the new future challenging programs, Columbus, Ariane V, and Hermes, ESA is trying to improve the effectiveness and reduce the cost.

Fracture control is evolving from the approach used for Spacelab towards, in the near future, more cost effective methodologies using ESA/NASA standard tool, probabilistic approach, European Material Data Base, Composite Fracture Criteria, Interdisciplinary fall-out. From the management point of view ESA is preparing a system which shall cope with the future needs grouping and focussing the European efforts in these areas.

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[3] Integrity Control of CFRP - Structural Components, Contract No. 4442/80/NL/AK with MBB/ERNO

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