N89-12612

THE SEPARATION TEST IN VACUUM OF THE ARIANE 4 PAYLOAD FAIRING

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ABSTRACT

This paper describes the separation tests performed during the qualification test programme of the ARIANE 4 Payload Fairing. As the first fairing structure to be developed using carbon-fibre technology, two separation tests of a flight standard fairing were performed under vacuum conditions. The primary objectives of these tests were to verify compliance with the vehicle imposed requirements and to establish the behavioural characteristics of the fairing structure itself.

INTRODUCTION

ARIANE 4 is the latest increased lift version of the European family of launch vehicles. In order to optimise the volume to weight ratio of the correspondingly larger payload fairing, the structure was developed using carbon-fibre technology as opposed to the aluminium skin/stringer construction of previous ARIANE fairings.

Having protected the payload during ascent through the earth's atmosphere, the fairing is jettisoned from the launch vehicle, whilst still in the accelerated phase, at the end of 2nd stage burn. Separation is effected by means of releasing a tension band, (the Horizontal Separation System), which attaches the fairing to the vehicle's 3rd. stage. This is followed within milliseconds by the activation of a linear explosive device, (the Vertical Separation System), which acts along the longitudinal axis of the fairing, separating it into two halves and ejecting them laterally away from the launch vehicle, (and thus the payload).

In order to fulfill the clearance requirements, a detailed dynamic analysis determined that a relatively low radial stiffness was required for the fairing halves. The separation system therefore imparts a correspondingly high amplitude "flexing" motion into the fairing structure during separation. Precise evaluation of this behaviour was thus necessary to ensure that no part of the fairing structure impinges on the payload volume and launch vehicle structure after jettison, (and to verify the mathematical model used to predict the behaviour of all subsequent fairing configurations). It was therefore considered necessary to perform separation tests under conditions representing as far as possible, those in flight. To avoid any influence from aerodynamic drag during separation, it follows that such a test had to be performed under vacuum conditions.

The tests were also performed in a 1g. environment, (simulation of operational acceleration loads of approx 3g. not being possible), and at ambient temperature conditions as opposed to the elevated in-flight temperatures. The effect of the axial acceleration was subsequently analytically superimposed on the test results, and the effect of the lower test temperatures on the fairing structure represents worst case conditions with respect to the clearance achieved, due to the corresponding increase in structural stiffness.

Due to the size of the test object which has a diameter of 4m. (13ft) and a height of 9.6m. (31.5ft), the test was performed in the Dynamic Test Chamber at ESTEC in the Netherlands; currently the largest vacuum chamber available in Europe. Views of the fairing before and after separation are given in FIGS. 1 and 2 respectively.

In addition to verifying the various performance requirements, it was to be shown that no permanent deformation of the fairing structure occurred following two consecutive separation tests. As a result, two such separation tests were performed during August and October 1984.

FAIRING DESCRIPTION

The test item consisted of the Qualification Model Fairing, which was a "medium length" version of the three design options. The overall height of this fairing is thus 9.6m. (31.5ft) with a diameter of 4.0m. (13.1ft).

The fairing takes the form of two symmetrical half shells, (designated T and TN), joined together in the vertical plane and attached to the launch vehicle at it's base.

The test item was built to the full flight standard configuration with the exception of some minor points mentioned in the following paragraphs.

A summary description of the various major subsystems of the fairing follows.

STRUCTURE

The fairing structure consists essentially of a lower cylindrical section with a height of approx. 5.0m. (16.4ft), a Front Cone of height approx. 3.7m. (12.1ft), with a spherical section Nose Cap of height 0.9m (3ft) forming the apex of the fairing. The Cylinder and Front Cone sections are produced from an aluminium honeycomb core/Carbon Fibre Reinforced Plastic face sheets construction, whilst the Nose Cap is a more conventional aluminium skin/stringer design. An aluminium Separation Ring is attached to the base of the cylindrical section to provide the mating interface with the vehicle's upper stage.

A layer of cork is bonded to the outside surface of the Front Cone and Nose Cap sections to protect the payload and fairing from kinetic heating during launch.

The entire external surface is then coated with a white electrostatic paint. The test model was only painted on the TN-Half, the T-Half being left in order to observe any possible effects of separation on the surface of the structure itself.

SEPARATION SYSTEMS

The fairing is connected to the launcher by means of a steel tension belt which maintains a circumferential tooth of the Separation Ring, in a corresponding groove at the vehicle interface. The steel belt is tensioned by means of two tension bolts located diametrically opposite each other. At the instant of separation, the two tension bolts are cut by pyrotechnic bolt cutters. This action effectively disconnects the fairing from the launcher and this assembly is thus known as the Horizontal Separation System (HSS).

Almost simultaneous with this release, (with less than 2msec. delay), the Vertical Separation System (VSS) is activated. During the launch phase, the VSS acts as the structural connection between the two fairing half shells. Upon detonation of the explosive device within the VSS, the two halves are separated and jettisoned laterally away from payload and launcher, (ref. FIG. 3).

As the fairing is ejected whilst the vehicle is still in an accelerated phase at the end of 2nd. stage burn, the VSS must impart sufficient separation energy to avoid any risk of impacting the payload or vehicle following separation.

Correct sequencing of the HSS and VSS activations is ensured by a pyrotechnic system initiated from a central distribution manifold from which Confined Detonating Fuses relay the detonation to the respective separation systems.

FLIGHT INSTRUMENTATION

A full compliment of the normal flight instrumentation for operational launches was also installed and checked out during the separation tests. This comprises :

- One displacement transducer per half fairing to record separation distance as a function of time.
- Two linear potentiometers per half fairing to monitor the radial flexing motion of the structure during separation.
- One Gyrometer per half fairing to measure the angular velocities of the separating structure about all three axes.
- Pyrotechnic status signals to verify the instants of pyrotechnic ignition, bolt cutting and pyrotechnic connector separation.
- One accelerometer was also installed at the base of the VSS on each half fairing to monitor acceleration levels. (Whilst not belonging to the definition of normal flight instrumentation, these are being flown on the initial technological launches and as such were also mounted during this test).

SOFT TENSION BELT RELEASE SYSTEM

In order to reduce the shock levels imparted to the vehicle at fairing separation the Soft Tension Belt Release System was developed. This system consists essentially of one hydraulic actuator installed within each half HSS tension belt assembly.

Activation of this device some 5 secs. prior to fairing separation has the effect of reducing the HSS tension from the launch tension of 10 tonnes to 2 tonnes, thus reducing the stored energy in the HSS, (and Vehicle interface), at the instant of separation. This device was installed and tested prior to the second separation test for comparison purposes.

CABLE STOWING SYSTEM

The function of the Cable Stowing System is to retain the deployable part of the instrumentation cable against the structure of the fairing halves during launch and ascent. It also has to resist the shock of separation but subsequently to gradually release the cable during separation, to enable instrumentation data from the fairing to be transmitted to the vehicle over a separation distance of approx. 6m (19.7ft).

As such a separation distance could not be achieved in these tests, a short section of cable was installed on the fairing, without the interface connectors, to verify that the method of fixation could withstand the separation shock.

TEST OBJECTIVES

The objectives of the separation tests can be summarised as follows :

- Fulfilment of the clearance requirements with respect to payload volume and vehicle envelope during separation.
- Verification of the structural integrity of the fairing and its equipment, (including fixations), during separation.
- Correct functioning of the pyrotechnic as well as Horizontal and Vertical Separation Systems.
- Validation of the in-flight separation measurement plan.
- Validation of the finite element model to be used for fairing separation analysis.

TEST CONFIGURATION

FAIRING INSTALLATION

The fairing was installed in the Dynamic Test Chamber, (DTC), mounted to a structure which simulated the vehicle interface, known as the Adjacent Structure, (AS). The AS was in turn mounted on the seismic structure of the DTC, at a location of 400mm. (16in.), from the chamber centreline, (ref. FIG. 4). This then enabled a free flying distance of at least 2m.(6.5ft) of one half (the TN-Half) fairing, which was required to ensure sufficient data was obtained to characterise the fairing's behaviour following separation.

CATCHING SYSTEMS

In order to restrain the fairing halves following the separation and free-flight, fairing catching systems were installed in the DTC for each half fairing. These consisted of :

Horizontal Fairing Catching System (HFCS)

This system consisted essentially of a catching net which was used to absorb the energy of the separated halves and prevented them from impacting with the wall of the DTC. The nets were attached to the chamber by means of hydraulic dampers and were tied back towards the wall to provide the required uninterrupted free-flying distance for each half fairing. The various catching systems were designed in such a way that it was the HFCS that first influenced the flight of the fairing halves, and was thus the limiting factor in determining this distance.

Bounce Back Restraint Device (BBRD)

The aim of the BBRD was to retain the half fairing against the catching net after separation and to prevent them from bouncing back from the net and onto the mounting structures in the centre of the chamber. To achieve this, each device consisted essentially of four nylon cords attached near the corners of the cylindrial section of the half fairing.

These ropes passed through a jaw clamping mechanism before being attached to the DTC wall by means of elastic ropes and a pulley arrangement. The design of the BBRD was such that the nylon ropes passed freely through the clamp jaws during separation, without influencing the fairing behaviour, but could not be pulled back in the opposite direction after the fairing was caught in the net.

Vertical Fairing Catching System (VFCS)

The VFCS consisted simply of two nylon cords for each half fairing, suspended from the underside of the DTC lid and attached to the fairing at the bottom of the conical section. The lengths of the cords were determined to allow an unimpeded free flight but to avoid an excessive drop onto the chamber sub-floor and toppling of the separated half fairing.

MEASUREMENT PLAN

In addition to the flight instrumentation mentioned above, a series of test instrumentation was added to the fairing to define its behaviour during separation. Due to the geometric constraints of the DTC, this instrumentation was concentrated on the TN-Half fairing, this being the half which was capable of sufficient free flying distance. The more important measurement systems can be summarised as follows :

ELECTRO-OPTICAL CAMERAS

As the most critical aspect of the test was to define the precise motion of the fairing half-shell during separation, (in order to subsequently validate the mathematical model), an accurate, high speed, 3-Dimensional trajectory measurement system was required.

The SELSPOT Electro-Optical Camera, (EOC), system was developed and specially adapted for this purpose by SELCOM AB, Gothenburg, Sweden. This system consists of a number of Light Emitting Diodes, (LEDs), attached to the fairing structure; each one being measured by a pair of infra-red sensitive cameras, thus enabling the 3-Dimensional trajectory to be computed. The system operates on the principle of pulsing the LEDs at high frequency with a defined sequence, resulting in a number of discrete measurement points.

A total of 6 cameras were used for this test, to monitor 12 measurement points on the fairing. This combination results in a sampling rate of 833 HZ for each measurement point.

The LEDs are connected to LED Control Units, (LCU), which act as a distribution unit for pulsing the LEDs. The complete system is controlled and monitored by an Administration Unit, which in turn interfaces with a computer for command input and data storage.

A schematic of the measurement set up is shown in FIG. 5, whereby Cameras 1A and 3A were installed on a central tower structure inside the fairing and Cameras 2B and 4B were attached to the inside wall of the DTC. Cameras 1A and

2B thus acted as a pair viewing one quadrant of the cylindrical section of the fairing, whilst 3A and 4B monitored the other quadrant. These measurement points were achieved by mounting a "double" LED arrangement of which, one was installed on the inside surface and the other adjacent to, but on the outside surface of the fairing.

Pulsing this pair of LEDs simultaneously, enabled a measurement "point" on the fairing structure to be seen by a camera pair, one of which was installed inside and one outside the fairing. Cameras 5A and 6B were both attached to the underside of the DTC lid, monitoring LEDs attached to the outside surface of the fairing Front Cone.

CINE CAMERAS

In order to obtain a general visual impression of the fairing behaviour during separation, four 16mm cine cameras, each equipped with a 94° wide angle lens, were installed outside the DTC, viewing through optical view ports. The cameras had a film speed of 150 frames/sec. and were controlled by a single control unit providing synchronisation with each other and the ignition signal. For the second separation test, one of these cameras was relocated inside the DTC to improve its viewing angle. A special sealed container with outlets for the control and pressure lines to pass through feed throughs in the DTC wall, was produced to protect the camera from the vacuum conditions.

BREAKWIRES

To establish the sequence of separation of the two halves, over the entire length of the fairing, at the instant of separation, a series of Breakwire assemblies were bonded across the joint between the two half shells. Each assembly provided timing information over displacements between the half fairings of 0,40 and 60mm, enabling accurate assessment of the separation sequence both along the fairing's length and comparison of the two separating joints.

STRAIN GAUGES

In order to establish the stresses induced in the fairing structure as a result of separation and the subsequent flexing modes, 24 strain gauges were attached to the TN-Half fairing. The locations were selected as those areas indicated by the analysis as being the most critical, some of which were re-located for the second test based on the evaluation of the data from the first test.

SHOCK ACCELEROMETERS

High frequency shock accelerometers were attached to the major interfaces of the pyrotechnic and separation systems; (i.e. pyrotechnic manifold, VSS detonator blocks, VSS end seals at the opposite ends to the detonators, and the bolt cutter housings). The purpose of these was to establish the event timings of the pyrotechnic system, to verify the correct sequence of operations.

Similar accelerometers were also installed on parts of the fairing catching systems to establish impact times and thus correlate the free-flying times established with other measurement systems.

MEASUREMENT ACCELEROMETERS

In order to obtain an indication of the low frequency acceleration levels, a total of 15 measurement accelerometers were installed at various locations on the TN-Half fairing. Of primary interest were the areas of the VSS separation joints and the highest point on the Nose Cap.

CLEARANCE DETECTORS

As a supplementary source of verifying the clearance requirement with respect to the vehicle interface, clearance detectors were bonded to the support structure onto which the fairing was mounted. These took the form of simple moulded polystyrene blocks extending to the limits of the forbidden volume, within which no part of the fairing structure may pass during separation. These would have provided immediate indication had this volume been breached.

SHOCK MEASUREMENTS ON ADJACENT STRUCTURE

In addition to establishing the fairing behaviour, an indication of the shock levels induced into the vehicle, at the instant of separation, was also obtained.

A total of nine high frequency accelerometers were attached to the Adjacent Structure to monitor in particular the levels experienced close to the fairing mounting interface, around its complete circumference.

IGNITION SYSTEM

The ignition of the pyrotechnic system was initiated by a start command entered on the computer keyboard of the EOC system, resulting in a trigger signal being sent to the Ignition Control Unit (ICU). This signal in turn closed power relays within the ICU which simultaneously provided the ignition current to the pyrotechnic detonators and recorded a "time zero" signal on each of the magnetic tape recorders of the data management system, as well as each cine film. This signal was thus used as a timing reference for subsequent data evaluation.

TEST OBSERVATIONS

a) A detailed visual inspection performed following the first separation test, indicated some anomalies. The TN-Half fairing structure, (inner face sheet and honeycomb core), had ruptured along a row of fixing inserts close to the axis of symmetry. The rupture extended along a length of approx. 1.5m (5ft) from the base of the fairing. Detailed evaluation of the instrumentation results revealed however, that the failure did not occur during the free-flight of the half-shell, but after being restrained by the catching nets. The position of the nets and stiffness of the support points were modified for the second test. The damaged area of the fairing was replaced and no such failure occurred during the second test.

b) Three rivets from the lowest aluminium stiffener of the Nose Cap, adjacent to the VSS had broken loose. Localised shock loading due to separation was clearly higher than expected in this area. These rivets were subsequently replaced with steel bolts and again no such problems were observed during the second test.

c) Some structural damage was observed in the area of the Bolt Cutter fixations which resulted in some parts becoming loose during separation. This area was also strengthened to avoid the possibility of any loose parts impinging the payload volume and this modification was successfully verified by the second test.

d) Failures were encountered on both displacement transducers during the first test. The principle of operation of these transducers is of a thin cable attached to the vehicle interface. This is then extended from a pulley within the transducer which is attached to the fairing structure. As the cable extends up to 2m (6.5ft) during fairing separation, the resultant output of the potentiometer within the transducer provides an indication of displacement versus time.

The problem encountered during the first test was that both cables broke at the attachment interface with the vehicle, immediately on separation.

The geometry of the attachment point as well as that of the cable outlet and pulley arrangement was modified for the second test, resulting in successful functioning of both units.

e) The fixations of the Cable Stowing System did not withstand the separation shock and the cables broke loose from the attachment points. Modifications were made for the second test but the cables again separated from the fixation brackets.

(Note: This system was subsequently redesigned and retested at sub-system level before becoming qualified for flight).

TEST INSTRUMENTATION RESULTS

The results of the various methods of instrumentation are summarised below, with both separation tests being combined, as the measurements for both tests were essentially the same.

Measurement data has been quoted where it is considered meaningfull to do so. Much of the data however was used to validate the mathematical model to be used for the separation analysis of all subsequent ARIANE 4 launches. The results of this correlation are outside the scope of this paper.

ELECTRO-OPTICAL CAMERAS

The 3-Dimensional trajectories of all measurement points were successfully obtained from both tests. Whilst all points were important to characterise the fairing's behaviour, the critical points are the bottom corners of the half-shell, at the HSS/VSS interface. It is in this area that the "flexing" motion of the fairing during separation is most extreme.

These measurement points are thus the most critical with respect to verifying that the clearance requirements of the payload and vehicle are satisfied. This flexing motion can be explained by considering FIG. 6 which indicates the forms taken by the circumference of the base of the fairing during separation. In addition to being jettisoned away from the vehicle, the two sides of each fairing half-shell are also projected radially outwards by the force of the separation system. It thus follows that these points, having reached a maximum amplitude, will tend to return inwards. The relationship between separation velocity, flexing frequency and amplitude is thus clearly critical in determining the clearance margins during separation.

The plot of the trajectory of measurement point A of FIG. 6, in the horizontal separation plane, is indicated in FIG. 7 and is typical for both corners of the half-shell. A typical minimum clearance between these points and the payload volume was determined as approx. 350mm (14 in), which results in a satisfactory margin of safety when considered in a parametric separation analysis.

Measurement data was obtained over a horizontal free flight distance of 2m (6.5ft) within a time of 350msecs. before contacting with the catching system. As this corresponds to almost one complete cycle of the flexing motion, (Ref. FIG 7), confidence is achieved that the fairing motion can be fully characterised.

The trajectory traces of the measurement points also clearly indicated discontinuities at the instant of fairing rupture during the first test. These correspond to the instant of the second maximum amplitude of flexing, at which time the measurement points on the axis of symmetry of the half-shell are tending to be pushed back towards the centre of the DTC due to the resilience of the catching net. The failure therefore, did not occur during free-flight but as a combination of the flexing motion and the restraint of the catching system.

BREAKWIRES

Data obtained from the Breakwire signals indicated that complete separation occurs between 2.5 and 4msecs. after ignition, with the base of the fairing tending to commence movement marginally before the upper part.

The results were consistent with those indicated by the EOC system and also the sense of rotation established by the gyrometers. Both sides of the fairing separated simultaneously as expected. These results applied to both separation tests.

STRAIN GAUGES

All strain gauges yielded sufficient data to establish correlation with the dynamic analysis in all areas. Information obtained from the strain gauges also assisted in verifying the cause of the structural failure experienced during the first separation test.

The time of an instantaneous discontinuity in the outputs of strain gauges located adjacent to the failure line, are identical with that obtained from the electro-optical system correlating to the moment of the second maximum displacement.

Data obtained from the second test, including the area repaired after the first test, indicated no abnormally high strain levels.

SHOCK ACCELEROMETERS

The pyrotechnic timing sequence established from both tests, by means of the shock impulses, confirmed correct operation of this system. Activation of the two HSS Bolt Cutters and VSS detonation occurred simultaneously, (within 0.1msec.), approx. 0.5msec. after manifold ignition. An impulse on the VSS end seals at the opposite ends of the detonator blocks was recorded 1.3msec. later, which is consistent with an expected detonation velocity of the VSS of 6500m/sec. (21000ft/sec.).

Additional shock accelerometers attached to various parts of the catching systems confirmed that the impact occurred at the catching net before the vertical support ropes influenced fairing trajectory. The time of impact also agreed within 6msecs of that computed from the EOC system, when considering the available free-flight distance.

MEASUREMENT ACCELEROMETERS

Sufficient information was obtained from the low frequency accelerometers to provide inputs to the dynamic analysis.

CLEARANCE DETECTORS

Detailed visual inspection of the polystyrene clearance detectors revealed that no part had been touched during separation, thus confirming that the minimum clearance requirements with respect to the vehicle interface, had been satisfied.

SHOCK MEASUREMENTS ON ADJACENT STRUCTURE

The high frequency accelerometers attached to the Adjacent Structure indicated peak levels of approx. 800g. in the area adjacent to the VSS, during the first test.

The effect of the reduction of the tension in the HSS for the second test, from 10 tonnes to 2 tonnes, as a result of the Soft Tension Belt Release Test, was to reduce the corresponding shock levels to approx. 400g.

FLIGHT INSTRUMENTATION RESULTS

DISPLACEMENT TRANSDUCERS

As discussed under Test Observations above, correct output data was obtained during the second test. This data agreed very closely with that obtained from the SELSPOT system.

LINEAR POTENTIOMETERS

The linear potentiometer system, developed to monitor the flexing motion during separation, functioned correctly during both tests. Maximum amplitudes of 500-600mm (20-24in) were indicated, again correlating with values measured by the EOC system.

GYROMETERS

Both gyrometers also functioned correctly yielding data compatible with that computed from the EOC system.

The ability of the unit itself, (as well as the fixation to the fairing structure), to withsland the separation shock, was thus also verified.

EVENT STATUS SIGNALS

The status signals included as part of the Flight Instrumentation, assist in verifying that these events actually occur in flight and that the relative timing of the events are correct. The results again produced data compatible with other measurement systems by indicating Bolt Cutter functioning 0.5msecs after manifold ignition and pyrotechnic connector separation 20-30msecs later.

ACCELEROMETERS

One of the accelerometers of the type proposed to be flown for supplementary information on the initial technological flights of ARIANE 4 was damaged during the first test, whilst the second unit functioned correctly. Following refurbishment by the manufacture, both units were again installed for the second test and both produced correct data.

SOFT TENSION BELT RELEASE TEST

The Soft Tension Belt Release System was tested under vacuum conditions prior to the second separation test.

Instrumentation included additional strain gauges on the tension belts to monitor the tension, and shock accelerometers on the Adjacent Structure to measure the corresponding shock levels at actuation.

This system functioned satisfactorily, resulting in a final HSS tension of 2.5 tonnes and maximum shock levels recorded on the Adjacent Structure were approx. 180g. Following this test, the HSS tension was re-adjusted to the specification value of 2 tonnes for the actual separation test.

CONCLUSIONS

The aim of this paper has been to describe the separation tests performed on the flight standard version of the ARIANE 4 payload fairing during it's formal qualification test programme. A total of two tests were successfully performed during August and October 1984, by the end of which all the main test objectives had been fulfilled. Correct functioning of all aspects of the fairing, including pyrotechnic and separation systems, were verified and sufficient measurement data obtained to enable validation of the mathematical model to be used for all subsequent flight predictions.

Prior to publication of this paper, the first launch of the ARIANE 4 vehicle was successfully achieved from the Guyana launch facility on 15 June 1988. On board instrumentation confirmed the predicted separation performance of the payload fairing.

FUTURE OUTLOOK

The development programme of the payload fairing for the next generation of European launcher, the ARIANE 5, has already commenced. Due to signifiant design changes for this version, particularly in overall size, it is foreseen that similar separation tests will also have to be performed during this programme.

In order to be able to perform these tests without undue geometrical constraints from the test facility, studies have been initiated to investigate the availability of larger vacuum chambers; including those in the U.S.A.

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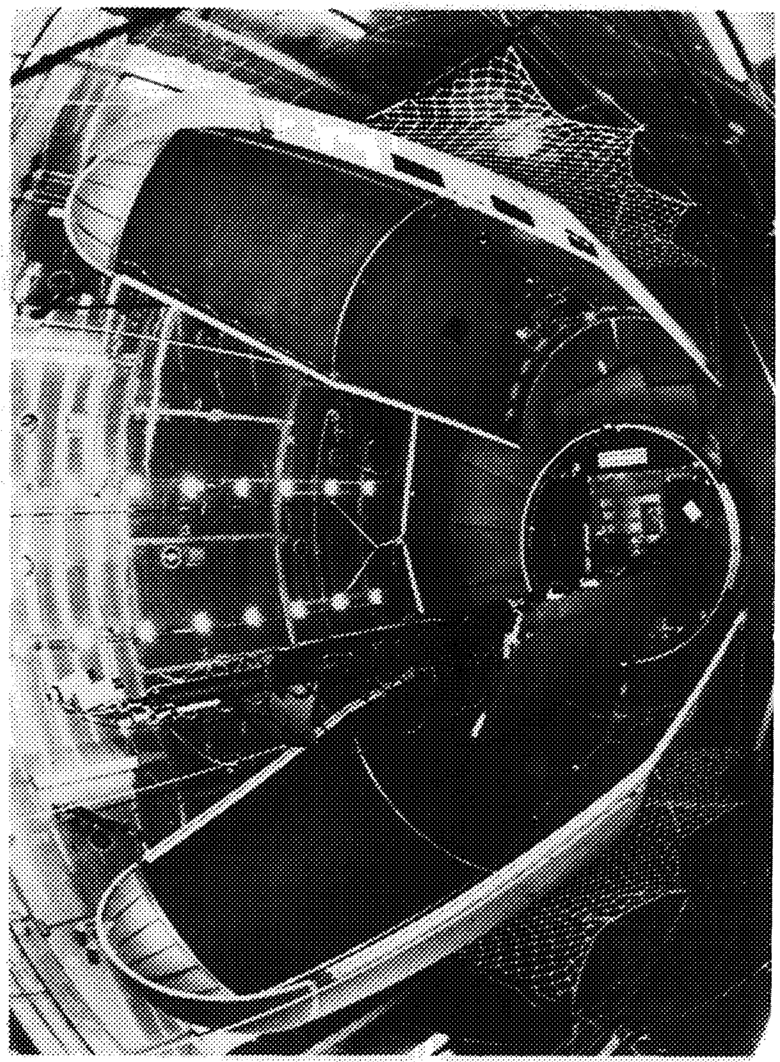

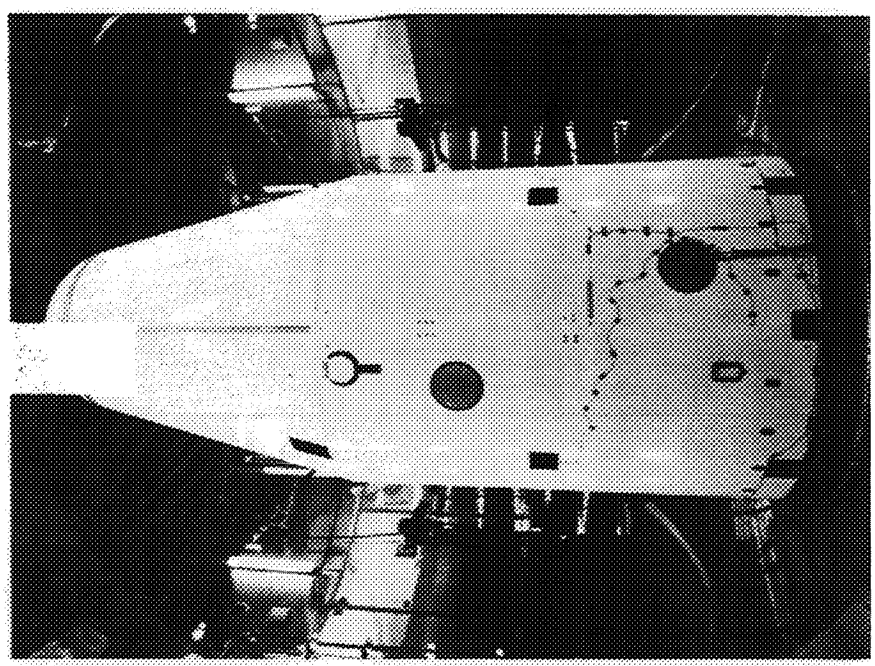

Figure 1. Fairing Installed before separation

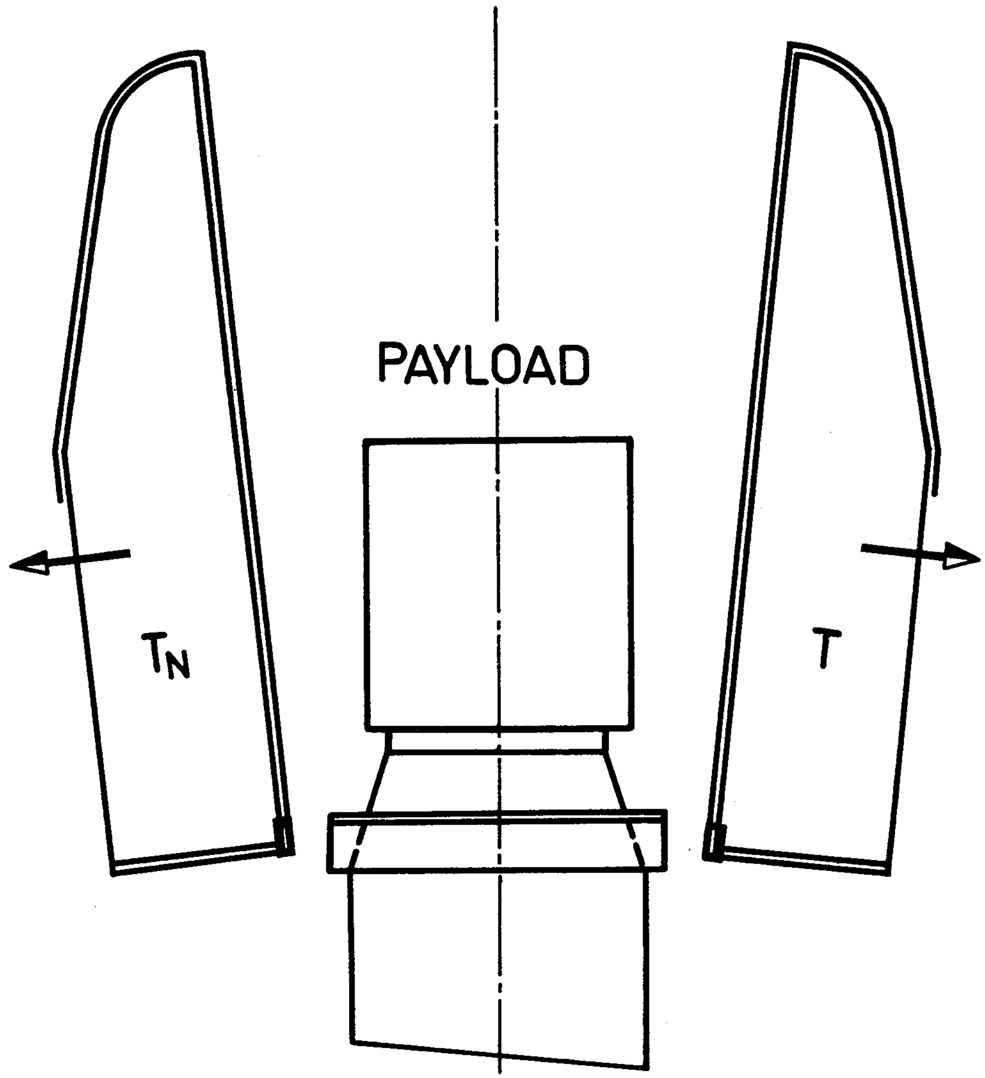

Figure 3. Schematic of Fairing separation

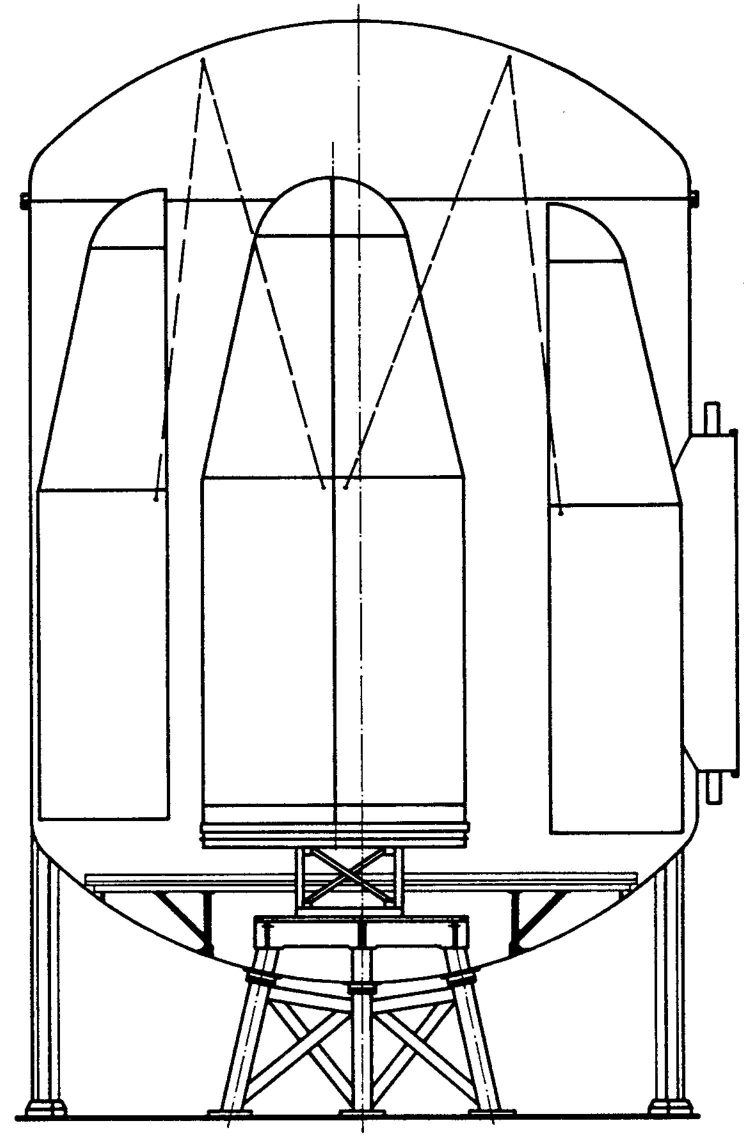

Figure 4. Configuration of Fairing in DTC

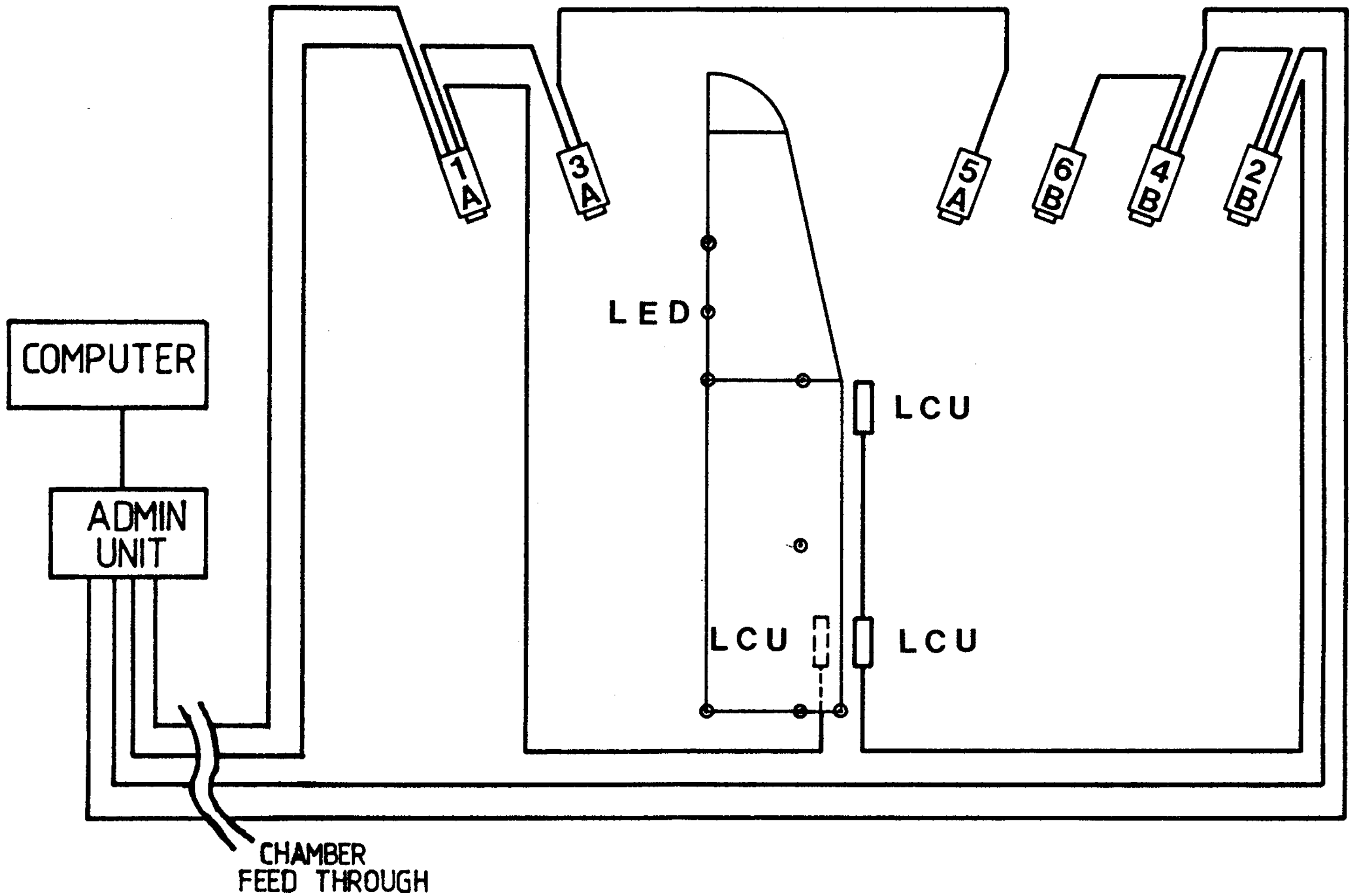

Figure 5. Electro-optical Camera system set-up

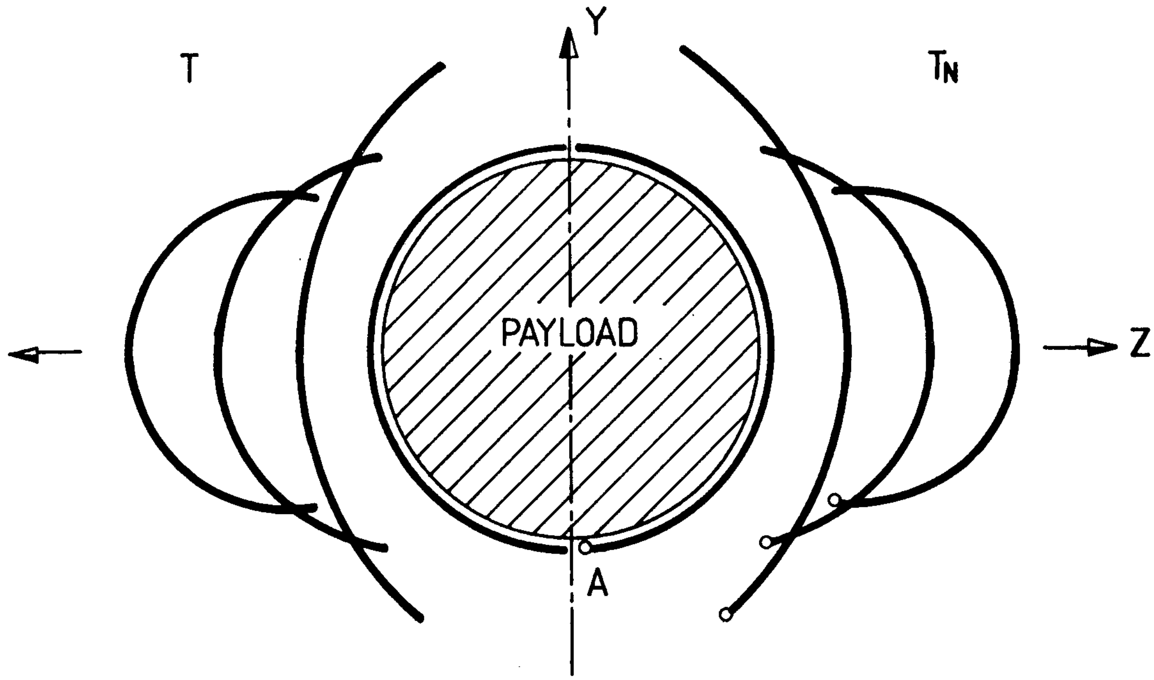

Figure 6. Fairing flexing motion during separation

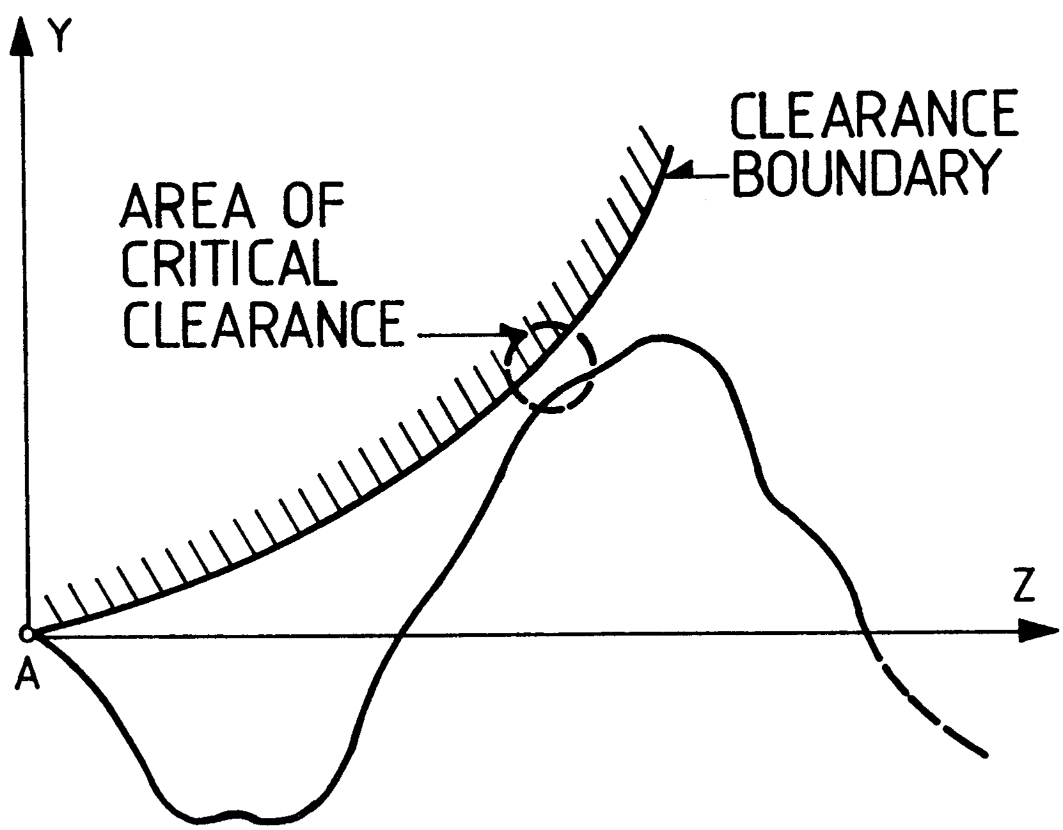

Figure 7. Trajectory of critical point

Session VIII

ANALYTICAL/EXPERIMENTAL HEAT TRANSFER

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