OPERATIONS OF THE ARIANE 4 THIRD STAGE
FOR SPACE DEBRIS PREVENTION

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ABSTRACT
Operations are performed by the ARIANE 4 third stage during the payload separation and avoidance phase to preserve the structural integrity of the tank common bulkhead. Modification of the ARIANE 4 launcher third stage have been developed in order to avoid tank fragmentation afterwards due to the pressure effects resulting from vapourization of LOX and LH2 residuals. The paper describes the investigations which led to this modification and the operating mode of the on-board devices.

1. EVENTS IN ORBIT
ARIANE 4 is a three stage vehicle with optional strap-on boosters (solid and/or liquid), designed for GTO, SSO and LEO missions.

![Diagram of ARIANE 4 versions](image)

**FIG. 1: ARIANE 4 VERSIONS**

While the spent lower stages fall naturally into the ocean, the upper composite is injected in orbit. (See viewgraph 2.)

In a general case (dual launch, GTO), there are four new objects in orbit: the two satellites, the SPELDA upper part with the upper adaptor and the largest part composed of the cryogenic third stage (H10), the Vehicle Equipment Bay, the lower adaptor and the SPELDA lower part.

![Diagram of ARIANE 4 tank configuration](image)

**FIG. 4: H10 TANK CONFIGURATION**

After burn-out, the H10 is still a hazardous space object because of the significant amount of LOX and LH2 residuals (typically 280 kg) which can generate fast pressure build-up in both parts of the tank. The common bulkhead configuration imposes that the difference of pressure between both sides stays within the specified limits.
The pressure evolutions have therefore to be well predicted to safely perform, by means of the roll attitude control system (SCAR), all the programmed manoeuvres leading to the payload separation and ending with the H10 avoidance phase.

A and B: Orientation of composite (3rd stage + payload) by 3rd stage roll and attitude control system (SCAR)
C: Spin up by action of SCAR (2)
D: Separation of upper spacecraft. Then spin down (1) and reorientation by action of SCAR
E: Upper SPELDA jettisoning. Reorientation as requested by inner spacecraft.
F: Spin up and separation of inner spacecraft.
G: 3ru stage avoidance maneuver (spin down, reorientation of 3rd stage, spin up at 5 rpm and Lox valves opening).
Note: Spacecraft separations can also be accommodated under a 3 axis stabilized configuration.

FIG. 5: SCAR PHASE

When the H10, with the VEB, is definitively abandoned on its final orbit, pressure relief valves are expected to control the pressure build-up still generated by the residual propellants.

FIG. 6: ARIANE 4 3rd STAGE PRESSURANT GAS VENTING SYSTEM

As time passes, the third stage and SPELDA are slowly deorbited because of the aerodynamic drag. All the objects in orbit are tracked by NORAD. The status of ARIANE third stages is the following:

<table>
<thead>
<tr>
<th>DECAYED</th>
<th>LOST</th>
<th>EXPLODED (DESIINTEGRATED)</th>
<th>CURRENTLY TRACKED</th>
</tr>
</thead>
<tbody>
<tr>
<td>L01 - L03 - L04</td>
<td>L08 - V14</td>
<td>V16</td>
<td>ALL OTHERS</td>
</tr>
<tr>
<td>L07 - V08 - V19 - V20 - V21 - V28</td>
<td>(1) DEBRIS STILL TRACKED OUT OF 400 INITIALLY CATALOGUED</td>
<td></td>
<td>(EXCEPT L02 - L5 - V16 - V18 - V36 - NO ORIENTATION)</td>
</tr>
</tbody>
</table>

9 2 1 38

Reference: ESA bulletin of space objects - issue 13 - Jan 93

FIG. 7: STATUS OF ARIANE 3rd STAGE TRACKING BY NORAD (ARIANE LAUNCH STATUS: V55 - DEC 92)
The tank break-up of V16 in SSO, several months after the launch, has been identified during this tracking.

FIG. 8: COMPUTER SIMULATION OF THE EVOLUTION OF FRAGMENT ORBITS FROM THE ARIANE V16 UPPER STAGE EXPLOSION

The important space pollution which resulted from the above explosion led to the decision of determining its origin in view of designing preventive measures.
The investigations, which were conducted by CNES and ARIANESPACE, in relation with NASA / NORAD permitted to determine the cause of the break-up. They allowed to exclude the batteries and the pyrotechnic tank destruction system as possible causes of the explosion. The more probable cause identified is either a tank wall rupture resulting from a thermal random cycling or a bulkhead rupture resulting from an overpressure on one side because of a possible leak in a propellant circuit.
It was therefore concluded that the more appropriate measure consists in rendering the tank fully inert by means of a complete draining just at the end of the mission.

2. ON-BOARD MODIFICATION

The selected modification called the "passivation" was developed in the frame of an ESA ARIANE 4 complementary development programme.

The calendar of the whole activity is the following:

- V16 launch: February 86
- H10 Break-up: November 86
- CNES/AE working group: November 86 to July 87
- Modification design definition phase: Sept. 87 to Nov. 88
- Critical Design Review of the pyro rod: July 89
- Qualification steering committee: December 89
- First flight application (V35): January 90

The energy contained in the H10 comes from the vapourization of the residual propellants. The mean values of the main parameters at engine cut-off are:

<table>
<thead>
<tr>
<th>HYDROGEN</th>
<th>OXYGEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>liquid mass</td>
<td>120 kg</td>
</tr>
<tr>
<td>gas pressure</td>
<td>2.7 bar</td>
</tr>
<tr>
<td>gas temperature</td>
<td>150 K</td>
</tr>
<tr>
<td>valve threshold</td>
<td>3.3 bar</td>
</tr>
</tbody>
</table>

The hydrogen is used for the SCAR manoeuvres. The oxygen is vented by means of the controlled pressure relief valve and gives longitudinal thrust during the SCAR phase.

The basic idea of the modification is to achieve the full depletion of the H10 tank.

To meet this requirement, valves are maintained open irrespective of the electrical and pneumatic energy available on-board.

The pressure relief valves have been fitted with pyrotechnic devices which allow definite depletion and depressurization of the tank.

The operating sequence is added to the standard one with an appropriate timing such that the difference of pressure between both tank parts still meets the bulkhead design requirements.

The LH2 pressure relief valve is linked to a venting pipe composed of two tubes which are normally sealed. The pyrod cuts the end of the two tubes. After that, the tank pressure decrease through the venting pipe.

The LOX controlled pressure relief valve is opened upon an electrical command. After that, the pyro-rod extends and blocks the valve in open position.

For the time being, the application of this passivation measure is limited to SSO and LEO missions of the ARIANE 40 version, because at first of the availability of the four additional pyro circuits which are needed (use of circuits normally allocated to boosters), then because of the critical aspect of the space pollution in low orbits. So far, this passivation measure has been successfully implemented on V35, V44 and V52.
The flight data of V52 are here under.

![Graph of H2 Tank Pressure Evolution](image)

**FIG. 12: H2 TANK PRESSURE EVOLUTION**
*REFERENCE TIME T0 (H2 ENGINE CUT-OFF)*

![Graph of H2 and LOX Valve Opening](image)

**FIG. 13: H2 TANK PRESSURE EVOLUTION**
*REFERENCE TIME T0+7000 s (H2: FIRST STAGE IONITION)*

The next application is foreseen with V59 / SPOT3 in SSO (Sept. 93). Afterwards, from V60 (Oct. 93) onwards, all the ARIANE 4 launchers will include this passivation means which will be systematically applied for all the missions, including GTO missions.

<table>
<thead>
<tr>
<th>LAUNCH</th>
<th>LAUNCHER VERSION</th>
<th>ORBIT</th>
<th>LAUNCH DATE</th>
<th>PASSIVATION SYSTEM PERFORMANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>V25</td>
<td>AR 40</td>
<td>SSO</td>
<td>JAN 90</td>
<td>OK</td>
</tr>
<tr>
<td>V44</td>
<td>AR 40</td>
<td>SSO</td>
<td>JUL 91</td>
<td>OK</td>
</tr>
<tr>
<td>V52</td>
<td>AR 42P</td>
<td>QUASI CIRCULAR (appr. 1300 km - 80°)</td>
<td>AUG 92</td>
<td>OK</td>
</tr>
</tbody>
</table>

**FIG. 14: APPLICATION STATUS OF THE ARIANE 4**
3rd STAGE PASSIVATION SYSTEM

This achievement is the ARIANE 4 contribution to the European efforts which are made for limiting the creation of space debris.