Qualification Over Ariane's Lifetime

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In principle, the development programme for a launcher ends with the qualification phase, after which it enters operational service. In practice, however, the assessment of a launcher's reliability is a continuing process and qualification-type activities proceed, as an extension of the development programme (as is done in aeronautics), over the course of the vehicle's lifetime. Modifications to the launcher's design are made whenever anomalies that might have an adverse effect on the stringent reliability requirements are detected during testing, to pre-empt their occurrence in flight.

Introduction
The primary objectives of the qualification activities performed during the operational lifetime of a launcher are:
- to verify the qualification status of the vehicle
- to resolve any technical problems relating to subsystem operations on the ground or in flight.

Before focussing on the European family of launchers, it is perhaps informative to review just one or two of the US efforts in the area of solid and liquid propulsion in order to put the Ariane-related activities into context.

The casings of the solid-propellant boosters on the Space Shuttle, for example, are systematically recovered for technical inspection and re-utilisation. While the economics of the re-utilisation can be questioned, the technical inspections have highlighted major anomalies not previously detected in ground testing, including leakage of the rear joint, deterioration of the interior of the nozzles, abnormal erosion of the internal thermal protection, etc. All of these anomalies could have led to failures. The test programme for the Shuttle's cryogenic engine (SSME) has a testing rate higher than during the engine's development phase. During the ten years following the first flight, a test programme clocking up over 300 000 s of running time was carried out. In 1993 alone, over 37 000 s of testing was conducted.

Similarly, the RL10 engine on the Centaur stage of the Atlas launcher has been the subject of an ongoing improvement programme. About 5000 tests were performed before the first flight, and 4000 during the subsequent ten years.

On-going qualification activities of a similar nature were started for the Ariane-3 and 4 launchers in 1986, and for Ariane-5 in 1996. They can be classified into two main categories: 'regular' and 'one-off'.

Ariane-3/4 accompanying activities
Regular activities
These activities are mainly devoted to verification of the qualification status of the various launcher subsystems. They include the following work packages:
- Periodic sampling of engines: one HM7 and one Viking per year, tested to the limits of the qualification domain. As an example, from 1984 to 1994, 25 turbo pumps and HM7B engines were sampled in 240 tests, totalling 75 000 s of running time. Other equipment – such as onboard computers, guidance platforms, flight-control electronics, separation thrusters, pyrotechnic components and servo-motors – was also sampled and tested up to qualification boundary conditions.
- Detailed and systematic analysis of flight data, to reveal any possible anomalies and also to update and improve the various mathematical models representing the behaviour of the launcher (Fig. 1).
- Inspection of solid-propellant boosters recovered after flight (Fig. 2), to detect any manufacturing deviations and possible weaknesses.

One-off activities
These activities stem from the results of flight-data analysis and launcher subsystem acceptance testing. They can be as important as the new definition and qualification of a

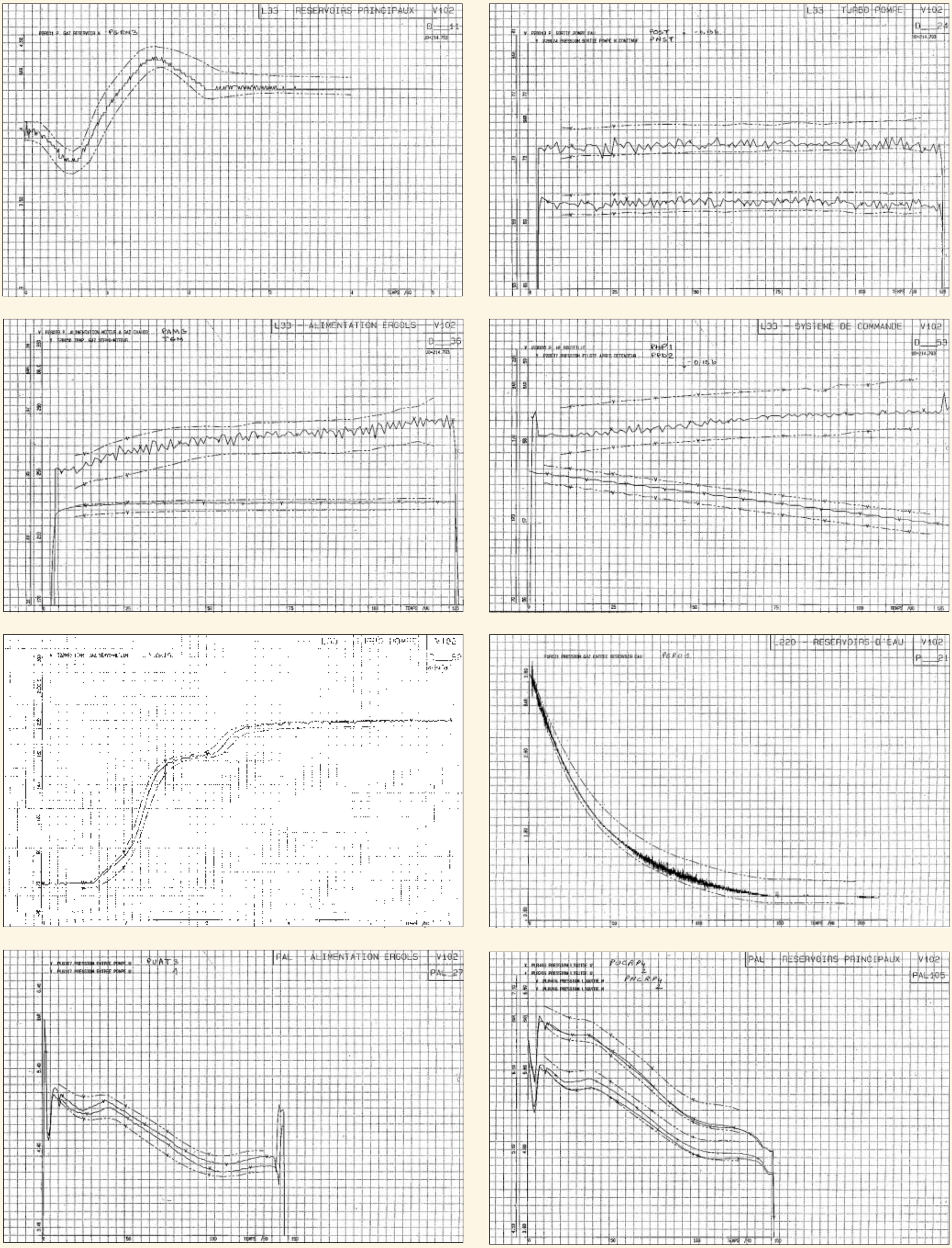


Figure 1. Between 500 and 800 parameters, depending on the Ariane launcher version, are measured, transmitted by telemetry and exploited after each flight. They constitute a valuable database that helps in detecting deviations and improving the mathematical models that simulate the launcher system’s behaviour

Figure 2. Post-flight inspection of Ariane-4 solid boosters at the Guiana Space Centre provides important information that cannot be communicated by telemetry alone: behaviours of thermal protection, nozzles, fields joints, etc.

pump bearing for the oxygen turbo pump on the HM7 engine, the qualification of a new nozzle throat for the Viking engine, or the qualification of new raw materials in the booster's solid propellant (Fig. 3).

In addition, cases of component obsolescence or supplier failure can arise, making it necessary to find replacements and qualify them for flight application. Problems of this nature have already been encountered and successfully dealt with in various areas, including electronics components, the Viking engine regulator, and composite structural materials.

Experience gained
These accompanying activities have highlighted several potential failure sources on the Ariane-3 and 4 launchers, allowing appropriate preventive measures to be taken:

– V22 : During long-duration tests on the Viking engine, a risk of blow-by on the regulator was detected. To eliminate it, a procedure for in-vacuo filling of the regulation circuit was established.
– V31 : To avoid damage caused by internal over-pressurising of the water tank on the L220 first stage, an extra valve was added.
– V33 : Poor liquid-propellant booster separation was observed. To correct it, the attachment fittings on the main stage were modified.
– V43 : Following the 'uncoupling' of the HM7B engine hydrogen pump, flights were suspended until a bleed valve preventing any pump cavitation had been qualified.
– V60 : Sampling tests on the separation rocket revealed a risk of a hot gas leak in the event of non-synchronised ignition sequences for the redundant pyrotechnic systems. These had to be modified to eliminate the risk.

Ariane-5 accompanying activities
Qualification of the Ariane-5 launcher is still in progress, but the production of the first set of operational launchers is already well under way. Consequently, Ariane-5 accompanying activities were started in 1996, based on the experience gained from Ariane-3 and 4 and retaining the distinction between regular and one-off activities that has proved so effective.

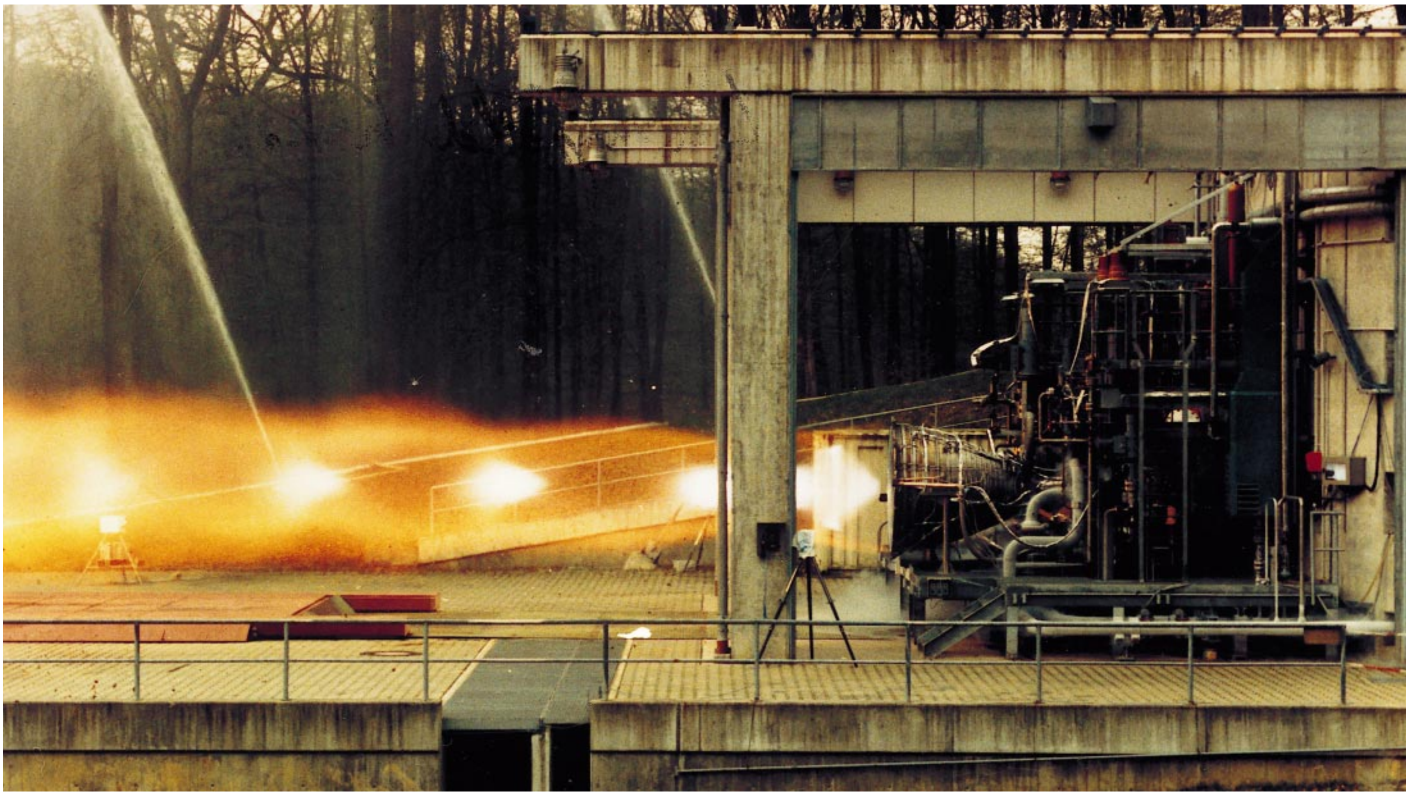
Regular activities
The types of recurrent activity supporting the Ariane-5 programme are similar to those for Ariane-4. There are, nevertheless, key differences stemming from two factors:
– the higher reliability target set for Ariane-5
– the development of new engines for Ariane-5.

The exceptionally high reliability requirement for Ariane-5 and the aim of reducing production and operating costs have resulted in a new launcher configuration that differs substantially from that of the previous generations. This new configuration required the development of two new liquid-propellant engines – Vulcain and Aestus – and a new solid-propellant booster.

Cryogenic main stage
The two features mentioned above – high reliability and new development – are both highly relevant in the case of propulsion, where a clear distinction also has to be made between two cases:
– integration of various items that undergo qualification tests individually
– qualification of the engine as a whole under extreme operating conditions (Fig. 4).

To address the first case, one Vulcain engine has been revalidated and used to test engine components in a special campaign. The second case is being covered by limit tests on

Figure 3. Ariane-4 strap-on-booster test stand in Sardinia (Italy), and a full-scale firing test sequence in 1997 to qualify a new ingredient in the solid propellant's composition



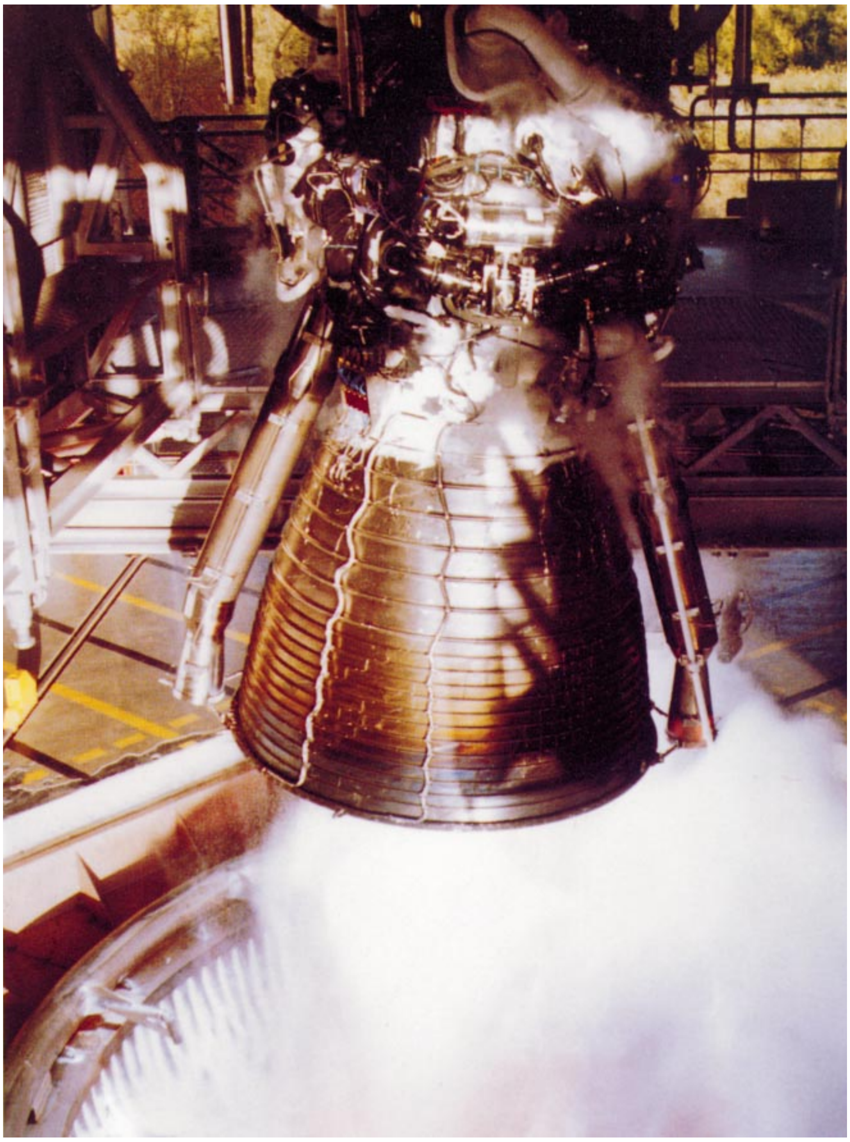


Figure 4. Test firings of the Ariane-5 cryogenic Vulcain engine in Vernon (France) and Lampoldshausen (Germany)
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one Vulcain engine per year. This rate of testing gives a cumulative running time over the five years of the campaign through to the year 2000 of about 30 000 s — nearly 1.8 times the estimated cumulative running time of flight engines (acceptance tests and flight).

Critical equipment for the stage and propulsion system (pressurisation/bleeding units, electro-valve units, feed valves and liquid-helium subsystem, flexible element, damper systems, etc.) will undergo dedicated qualification programmes followed by inspection.

Storable-propellant stage

The case of the Aestus engine on the storable-propellant stage is different. It is ignited in flight and operated for about 1000 s under conditions that are difficult to reproduce on the ground. The ratio of cumulative running times on the ground, with one test campaign a year, to those cumulated in flight will therefore be much lower than that given above for the Vulcain engine.

Aestus engine testing is, however, performed on a near-annual basis, with the engine undergoing nominal acceptance testing followed by short- and long-duration tests under varying operating conditions. The results of all of these tests serve to confirm the durability of the engine's performance.

The propellant tanks and high-pressure vessels will also undergo acceptance and destructive testing (fracturing) for the purposes of comparison with the qualification margins. Other items of equipment such as the pressurisation unit and electrical servo-motor will be subjected to their own qualification programmes periodically.

Solid-booster stage

As far as the solid-booster propulsion system is concerned, the initial development testing serves primarily to freeze the definition of the boosters and above all the casting production procedures and hardware acceptance criteria. The limited number of ground tests – five development and two qualification – is insufficient for accurate definition of the available margins, especially since the internal ballistics are different in flight and during ground testing. Recovery of flight specimens for inspection is therefore extremely important, as these provide the data needed for accurate definition of the actual margins for the features considered most critical (thickness of thermal protection, nozzle parts, field joints), which cannot be determined by in-flight measurements alone. Moreover, despite the fact that the booster definition is frozen on qualification, procedures and raw materials are bound to evolve over time, without it being possible to assess the impact of this on available margins.

The boosters from at least two Ariane-5 launches per year will therefore be recovered for inspection and at least one full-scale booster firing will be performed on the test stand at the Guiana Space Centre.

Other launcher systems

Other launcher systems will be sample-tested on a regular basis, including:

– electrical systems: onboard computer, inertial reference unit, flight control electronics, etc.

– attitude control system: thrusters, tanks with membrane, hydrazine feed valves, etc.

– pyrotechnic systems

– nozzle actuator units for the solid-propellant boosters and the cryogenic main stage.

Sampling will proceed on the basis of how critical a given item is. Items will undergo qualification testing followed by inspections. Limit tests will be conducted on the electronics components, together with a destruct inspection.

One-off activities

These can be divided into two groups:
– actions to address observed anomalies
– actions in cases of component or material obsolescence.

In the case of performance deviations being observed in flight (or during sampling tests), the prime aim is to arrive at a thorough understanding of the problem and thence define the most effective solution.

Experience gained under earlier Ariane launcher programmes has demonstrated the importance of taking prompt action to deal with cases of material obsolescence, particularly:
– the procurement of materials, ingredients, semi-finished products and units
– electronic components.

Hardware obsolescence or the withdrawal from the market of the relevant supplier can affect items in either category. Moreover, the risk of such obsolescence problems occurring is increasing as a result of industrial restructuring on an international basis and the nature of the launcher components themselves. Electronic equipment is particularly prone to such problems. Such changes will inevitably lead to the need for the period substitution of certain items, the replacements for which will also require the necessary re-qualification.

Conclusion

The considerable experience acquired in the development and operation of the Ariane-1 to 4 series of launchers has demonstrated that flight failures can be prevented by conducting the accompanying activities that have been described here. With more than one hundred flights to Ariane's credit, Ariane-4 currently enjoys the highest reliability record in the market: 0.966 according to the AMSAA model. These accompanying activities are set to continue throughout the lifetime of Ariane-5, with the systematic analysis of flight data combined with the sample-testing of critical items from the production line. The goal is to ensure that Ariane-5 has an even higher reliability throughout its lifetime than its predecessor.

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