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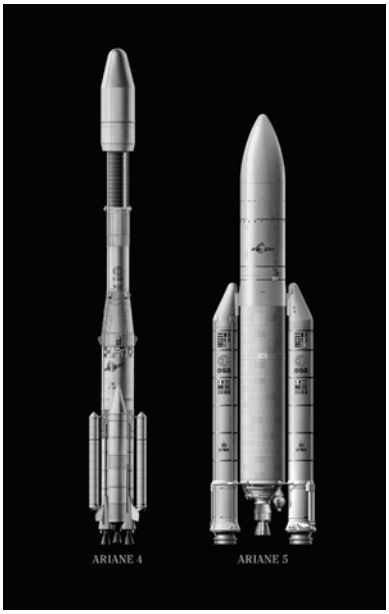
The current crop

ARIANE V

When the Ariane 4 was introduced in 1988 it was able to launch the 'leading edge' communication satellites two at a time, but the trend was towards ever heavier satellites and so Arianespace promptly set out to develop the Ariane V to supplement and later to succeed it. The HM-60 Vulcain engine developed by the Société Nationale d'Etude et de Construction de Moteurs d'Aviation (SNECMA) together with the Société Européenne des Propulsion (SEP) for the hydrogen powered core had 112 tonnes of thrust.[1] It was to be augmented by two solid boosters for a lift-off thrust of 1,140 tonnes. These SEP-built motors were 10 times larger than any previously made in Europe, being comparable to those of the Titan IVA.[2] The storable-propellant Aestus second-stage engine supplied by Daimler–Benz Aerospace had 2.7 tonnes of thrust.[3,4] The Ariane V was to put 18 tonnes into low orbit, or 6 tonnes into geosynchronous transfer orbit.[5,6] The plan was to share the launch fee of about $130 million between two payloads. Competitiveness on cost was essential, because when the development began Arianespace had expected the competition to be the 'old' US vehicles, whereas since then the Americans had announced plans to build a new range of launchers with a view to cutting the cost to $80 million per flight, and there was new competition from Russia's Proton and China's Long March, both of which seemed likely to be able to offer bargain prices.[7] However, it appeared that the booming market would be able to accommodate them all. When it was conceived, the Ariane V was also to have carried astronauts on the Hermes spaceplace, and therefore was required to have a high level of reliability – the goal was for a 98.5 per cent overall success rate, with the figure for the first stage being 99.95 per cent.[8,9] However, Hermes was cancelled in 1993 for financial reasons. In April 1994, with Ariane V engine trials about to begin, Arianespace hoped to fly the début mission in October 1995, and make the first commercial flight in early 1996.[10] The company was so confident in the vehicle that it issued a guarantee: ''If a satellite is lost during the launch phase – whether the failure is caused by the



A comparison of the configurations of the Ariane 4 and Ariane V.

launcher, or the satellite – the customer will be granted a free launch for a replacement satellite similar to the lost spacecraft."[11,12]

Disastrous début

In June 1995, after faulty software delayed the final static test firings of the Vulcain engine, the first Ariane V was postponed from November 1995 to January 1996, and in September it was slipped to late April 1996.[13,14] The second one was to launch in September with Intelsat 709 as a demonstration funded by Arianespace, as a precursor to the first commercial mission with PanAmSat 6 in early 1997. The mounting delay was due to oil and propellant leaks suffered in testing the first stage, some of which necessitated significant modifications. The payload for the first vehicle was a stack of four Cluster satellites, each weighing 1.2 tonnes, which had been developed by the European Space Agency to monitor the Earth's magnetosphere.[15] Fortunately, they did not need to be launched on a specific date.[16] After the loss of Intelsat 708 on a Long March 3B on 14 February 1996, Intelsat 709 was withdrawn and dispatched on an Ariane 44P on 15 June to plug the gap, and the European Space Agency's Atmospheric Re-entry Demonstrator assigned in its place.[17]

The début mission on 4 June 1996 appeared to have an excellent start, with the vehicle lifting off when the solids lit some 6 seconds after the main engine had ignited, but 30 seconds later it suddenly toppled over, and the auto-destruction system destroyed it at a height of 12,000 feet. In fact, the vehicle had already started to disintegrate as a result of the aerodynamic stress imposed by the increasing angle of attack, which was in response to the three engine nozzles being commanded to slew 'hard over' as a result of the failure of the inertial reference system. As the European Space Agency's press release wryly observed, the flight "did not result in validation of Europe's new launcher".[18] This is an interesting study in software engineering, due in part to an unwarranted reliance on heritage from its exceptionally reliable predecessor. Early in the development of the Ariane V, it was decided to reuse as many components of the Ariane 4 as possible in order to cut costs. In particular, the inertial reference system that had proved itself was carried over. The part of the software at issue was used prior to launch to initialise the inertial reference system and also, on the Ariane 4, to facilitate a rapid realignment of that system in the event of a last-minute hold in the countdown. While this realignment function served no rôle on the Ariane V, it was retained for commonality reasons, and allowed (as on the Ariane 4) to operate for approximately

40 seconds after lift-off.[19] Simulations had indicated that the software would function properly in the new vehicle, but no tests were made using real hardware to confirm this. It was discovered that flaws in the specification and design of the software had resulted in the total loss of guidance and attitude data.[20,21,22,23] In particularly, no thought had been given to the values that certain variables might take. Also, as the Ariane V rose more rapidly than its predecessor, its horizontal acceleration was five times faster, and a variable conversion between a 64-bit floating point value and a 16-bit signed integer resulted in an overflow condition as a result of producing a number higher than could be represented this way, and the software crashed. The software was written in Ada, and only some of the software variables were protected against overflow – a decision that had been agreed to by all the project partners. The others were expected to be either physically constrained, or small enough with a large margin of safety. This logic proved to be faulty for the Horizonal Bias, the variable that caused the exception in the inertial reference units. As guidance system flaws are difficult to identify (because hardware cannot be accelerated to high speed in a laboratory!) this represented another classic mistake. The investigation noted that the 'culture' was based on protecting against random hardware failures, and both of the inertial reference units had the same flawed software. Consequently, in the space of 20 milliseconds at T + 30 seconds, the backup and then the primary unit both raised an overflow exception and the guidance system, which was left to 'fly blind', ordered the Vulcain engine of the core and the nozzles of the strap-ons to gimbal over to their limit.[24,25] The investigation issued 40 recommendations, including revising the management to assign Arianespace overall responsibility for the embedded software.[26] The modifications included redesigning the shroud for smoother aerodynamics, structural reinforcement to eliminate the buffeting that had been observed near the base of the vehicle, and more effective thermal protection for the solid strap-on separation points.

Trying again

The launch of the second qualification flight of the Ariane V had been scheduled for June 1997, in time for the Paris Air Show, but by early 1997 it was clear that making the modifications would take longer.[27,28] The flight on 30 October was a partial success, in that although the upper stage performed the geosynchronous transfer orbit burn, the orbit did not have the planned parameters. The payload comprised two satellites supplied by the Centre National d'Etudes Spatiales in France, one of which had the physical characteristics of a typical large communications satellite and was fitted with sensors to record the stresses of launch.[29]

Ariane 4 finale

In view of the delay in introducing the Ariane V, an order was placed to manufacture a further 10 Ariane 4 launchers, although the largest payloads would either have to wait or be offloaded to other providers.[30,31] As it happened, however, the Ariane 4 was idle for four months in mid-1998 as a result of the late delivery of the satellites.[32] Nevertheless, Arianespace managed to catch up by flying 10 missions in the final four months of the year. In May 1999 the company announced that it would phase