PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

The Ariane Programme [and Discussion]

M. Bignier, J. Vandenkerckhove and G. M. Webb

Phil. Trans. R. Soc. Lond. A 1984 **312**, 83-88
doi: 10.1098/rsta.1984.0052

Phil. Trans. R. Soc. Lond. A **312**, 83–88 (1984) [83]
Printed in Great Britain

The Ariane programme

By M. Bignier and J. Vandenkerckhove
European Space Agency, 8–10 *Rue Mario Nikis*, *Paris*, *France*

The Ariane programme was decided upon in 1973. It was made a European concern after a proposal from France.

Ariane 1, launched for the first time on 24 December 1979, was qualified after three successes from four flights. The Ariane 3 version will fly in mid-1984 and Ariane 4 at the beginning of 1986. The main specifications of these programmes will be described. Their economic interest is shown by the number of orders and options already received. A new launcher will be useful before the end of the present century and relevant studies have started; of the engine in particular.

Introduction

The decision to develop Ariane was taken during the spring of 1973 at the Brussels Ministerial Conference after having been sponsored by France as part of a political package deal, which also included Spacelab and Marots.

The objective of the programme was the provision of an independent launch capability, in particular for geostationary telecommunications satellites, for which the launcher was optimized. Europe wanted to be able to launch operational satellites and N.A.S.A. could not guarantee this. Symphony was launched with the proviso that it would only be experimental. It is fair to add that at that time the commercial prospects of becoming competitive on the world market were largely overlooked.

The performance objectives were particularly well selected: 1600 kg in geostationary transfer orbit (g.t.o.) corresponding to satellites of up to 1000 kg, thus anticipating the needs of users a decade in advance.

A brief history of Ariane 1

Ariane 1 was an E.S.A. programme managed by a Programme Board, which decided on funding and objectives and monitored all development and construction activities. However, unlike other E.S.A. programmes, the management was delegated to C.N.E.S., which acted as prime contractor for the development activities.

In turn, C.N.E.S. placed contracts with European industry, in particular (the present arrangement) with: SNIAS, industrial architect (system level) and main contractor for the first and third stages; SEP, main contractor for propulsion (all stages); ERNO, main contractor for second stages; MATRA, main contractor for the equipment bay; and CONTRAVES, main contractor for the shroud. Subcontracts were widely distributed, Ferranti being responsible for the inertial guidance platform and M.S.D.S. for the flight programme.

The development programme was somewhat limited and relied to the maximum possible extent on hardware that had already been developed. Costs amounted to roughly one billion (10^9) dollars, *without any previous stage flights* and with only four qualification flights of the complete vehicle.

Flight history

The first flight, LO-1, occurred in December 1979, with complete success. The second, LO-2, failed in May 1980, as the result of unstable combustion in one of the first-stage motors, which led to a comprehensive programme of testing and to the decision to test-fire all Viking motors for acceptance. The last two flights, LO-3 and LO-4, which were launched respectively in June 1981 and December 1981, were again complete successes, which launched operational E.S.A. satellites, Meteosat and Marecs 1, as well as an Indian experimental satellite, Apple.

Before qualification, which was announced early in 1982, E.S.A. also decided to order seven additional Ariane 1 rockets, the so-called 'promotion series', the first of which, L-5, due to launch E.S.As Marecs 2 and Sirio 1, simultaneously, failed in September 1982, just before reaching orbit; the failure was a result of a gear problem in the turbo-pump of the third stage. After this, not only were the necessary improvements introduced in the gear box, but in addition, the programme was subjected to a thorough review and many other measures were taken. These steps led, in June 1983, to the successful injection of E.S.As E.C.S.-1 together with a small amateur radio satellite, Amsat (which, however, was subsequently struck by the third stage), into orbit by L-6. The last firing, L-7, in October 1983, was a complete success; it put Intelsat V, with a mass of 1834 kg in g.t.o., about 15 % higher than the original performance objective, into orbit.

The next two launches under the promotion series are also Intelsat V satellites, with L-8 now scheduled for February 1984† and L-9 for two months later. The last two Ariane 1 rockets will subsequently be used for C.N.E.Ss Spot and E.S.As Giotto.

The whole programme so far, which has remained reasonably well within the budget (at least below the 120 % mark), has slipped behind schedule by about 18 months in total. It has achieved five successes from seven attempts. This compares favourably with other programmes: three from eight for Atlas Centaur and seven from twelve for Tital III, which subsequently demonstrated 89 % reliability over 54 launches and 94 % reliability over 122 launches, respectively.

Ariane 1 is a three-stage satellite launcher of simple classical design. Its lift-off mass is 210 t and its height 47 m. The first two stages have, respectively, four and one Viking motors, which use storable N_2O_4–UDMH propellants, but the third-stage motor, HM-7, uses cryogenic propellants (liquid hydrogen and oxygen). The launch range is at Kourou, in French Guiana, only 5° N above the Equator, which enables the maximum advantage to be taken of the Earth's rotation for g.t.o.

Improved versions: Ariane 2, 3 and 4

The development of improved versions of Ariane (figure 1) are in progress. The aims are to:

(i) improve cost effectiveness by taking advantage of scale; in particular, it will be possible to launch two PAM-D-sized satellites simultaneously, by means of a special structure, Sylda;

(ii) launch larger and heavier satellites in the future;

(iii) improve reliability by means of additional redundancies; and

(iv) provide more volume for the satellite designers.

† L-8 was successfully launched on 4 March 1984.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

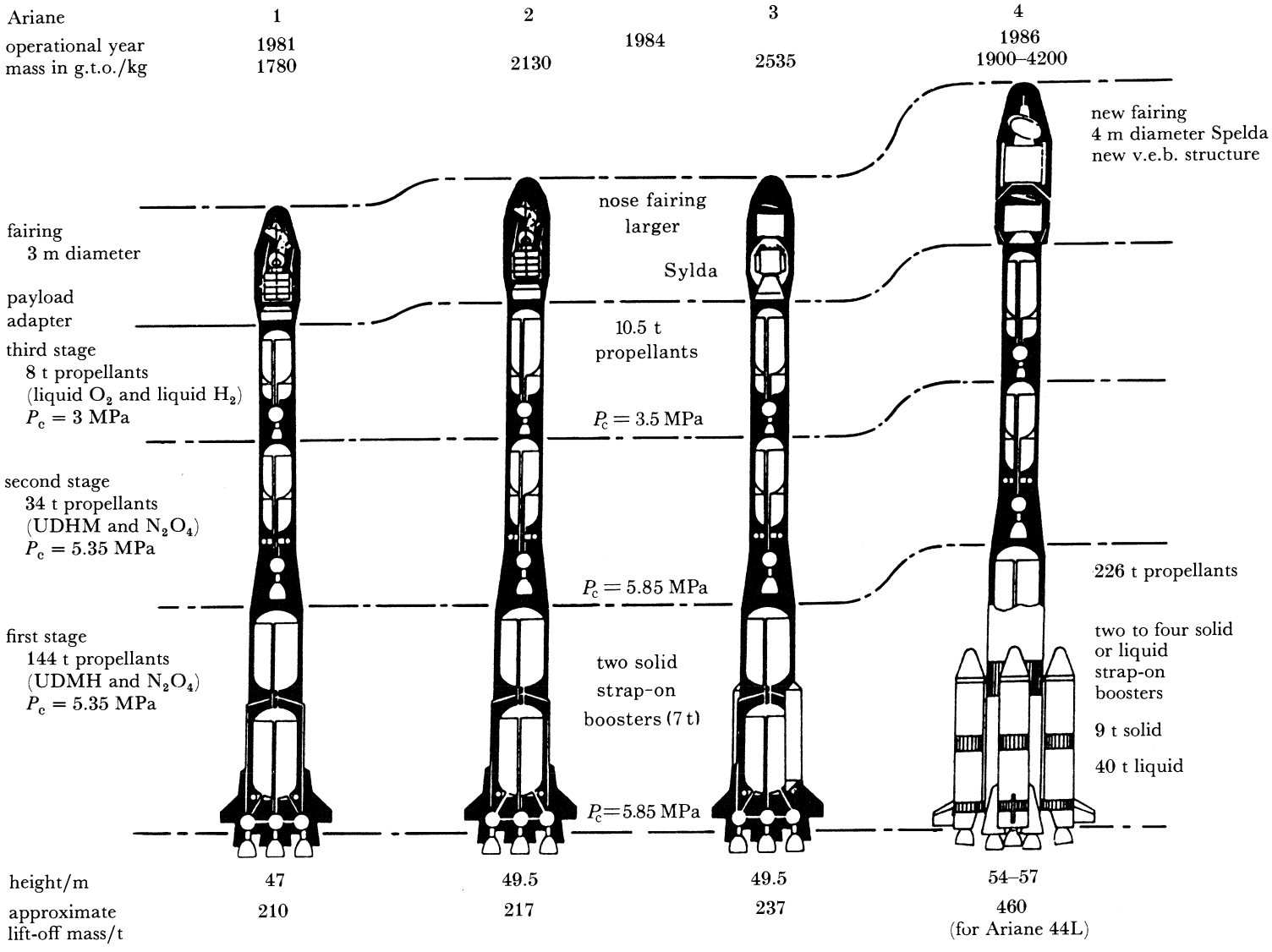

FIGURE 1. The development of improved versions of Ariane. P_c is the chamber pressure.

Ariane 2, 3

Ariane 2, 3 is a relatively straightforward derivative of Ariane 1. Its core, Ar-2, has somewhat higher performances thanks to the increased combustion pressure of the Viking motors (5.85 MPa instead of 5.35 MPa), and of the HM-7 motor (3.5 MPa against 3 MPa), together with longer third stage tanks (10.5 t of propellant instead of 8 t). The addition of two solid propellant strap-on boosters, manufactured by B.P.D., gives Ariane 3, which has a lift-off mass of 237 t and the capability to inject 2535 kg into g.t.o., a 38 % improvement in performance over Ariane 1. Ariane 3 will be needed to launch E.S.As Olympus.

The first flight of Ariane 3, L-10, is foreseen for June 1984. It will carry two operational communications satellites, probably E.S.As ECS-2 and an American domestic satellite, G-Star 1. Subsequently, recovery of the first stage by parachute for re-use after refurbishment, is also to be attempted (probably for L-13).

Ariane 4

Ariane 4 is a much enlarged derivative of Ariane 3. Its core, Ariane 40, has a longer first stage and its fairing is much enlarged (in particular with a diameter of 4 m instead of 3 m). The performance of Ariane 40 is close to that of Ariane 2, 1900 kg in g.t.o. Greater capability can be obtained by adding liquid or solid strap-on boosters (table 1). The lift-off mass of the later version is 460 t.

TABLE 1. INCREASED PERFORMANCE OF ARIANE 4 BY THE ADDITION OF STRAP-ON BOOSTERS

booster type	Ariane code number	$10^{-3} \times$ (mass in g.t.o.)/kg
two solid	42P	2.6
four solid	44P	3.0
two liquid	42L	3.2
two liquid and two solid	44PL	3.7
four liquid	44L	4.2

The first launch of Ariane 4, probably the 44PL version, is presently scheduled for early 1986 with three satellites: a Meteosat, Eurostar and Arsène. Ariane 44PL will be capable of launching Intelsat VI.

ELA-2

For launching Ariane 4, which will have a height of up to 57 m, a new launch pad, ELA-2, will be built at the range, which will also handle Ariane 3 rockets. This will allow the annual launch rate to be increased to 12.

TOWARDS COMMERCIALIZATION

Ariane is a competitive launcher.

(i) Its capability meets, almost ideally, the requirements of planned geostationary satellites (up to 1400 kg for Ariane 3 and 2500 kg for Ariane 4), which represent 80 % of the market; of the order of $10 billion until 1990, which represents roughly 200 satellites to launch over six years.

(ii) Its price is substantially lower than that of comparable expendable launchers: Delta, Atlas Centaur and Titan III, as well as some of the Shuttle's upper stage combinations, namely STS/PAM-A and IUS.

For the very important class of 600–800 kg satellites in g.E.o., i.e. half an Ariane 3 or STS/PAM-D or Dz, and with the promotional price of the Shuttle for the period 1985–1988, it is grossly comparable; somewhat lower or higher, depending on the specific case.

(iii) It is available during a period in which there is a shortage of launch capacity.

(iv) It also presents a number of specific advantages, such as high accuracy in placing satellites in orbit (equivalent to a likely increase in satellite lifetime of about 7.5 months), or no extra costs for long payloads; however, the available diameter is smaller than that of the STS.

It is clear that Ariane has introduced real competition in the launcher business; its main competitor during the coming years will be the Shuttle. In the long run, however, this could change; on the one hand because the STS pricing policy will be modified after 1988 (perhaps towards more comprehensive charging) and, on the other, because initiatives are likely to be taken to commercialize unmanned expendable U.S. launch vehicles (e.l.vs). Finally, it is becoming increasingly realized that astronauts are not an asset for the majority of missions, and in the United States some consideration is being given to the development of an advanced expendable launcher, while Japan and China are developing their own capability. The Russians have shown interest, for at least one example (Inmarsat) in selling launch services.

This analysis is supported by the verdict of many users. Beyond the promotion series, firm orders have already been given for the launch of 24 satellites, in addition to which nine options have been taken. Many of them, which add to the first three Intelsat V satellites in the promotion series, are for non-European satellites, often from private U.S. carriers, another three Intelsat Vs, two G-Stars, one Arabsat, one Westar, two Spacenets and two SBTSs.

To commercialize Ariane, a private firm, Arianespace, was created in 1980, with a capital of 179 million French francs, and with the following tasks: sale of launch services; purchase of launchers; performance of launch operation; and maintenance of production and launch capability. Arianespace is the first commercial company to sell satellite launches in the world. The development tasks, however, remain the responsibility of C.N.E.S., which also provides technical support to the firm.

The objective of the programme is to launch at least five or six Arianes per year from 1984 onwards (a majority carrying two satellites), with a high degree of reliability and dependability. This is a major challenge, which requires special measures beyond the development phases. A comprehensive industrialization effort is presently in progress aimed at streamlining the manufacture of the critical hardware. In a number of instances, product improvement efforts are already under consideration, as much of the equipment will continue to be used on Ariane 3 and then Ariane 4.

Beyond Ariane 4

While Ariane 4 is expected to meet needs until 1995–2000, plans are already being studied at C.N.E.S. and E.S.A. to develop its successor, emphasis being placed on cost effectiveness and reliability; in particular, the development of a high-thrust cryogenic motor, HM-60, is being proposed to the E.S.A. Member States, since such an engine will be needed irrespective of the final configuration, and its development time is of the order of 12 years.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Discussion

G. M. Webb (*Commercial Space Technologies Ltd, Hanwell, London, U.K.*). Is not Dr Vandenkerckhove's expression of E.S.As total reliance on the HM-60 cryogenic rocket engine as 'needed independently of the final configuration' a little incautious in the face of developments in advanced engine design currently taking place in certain British and German companies?

J. Vandenkerckhove. At present only one cryogenic rocket engine, HM-7, which is used on the Ariane third stage, is available in Europe. Its thrust is not sufficient for use on the first or second stage of a large launcher; therefore a higher thrust motor, more advanced than the Viking, is needed. Optimization studies show that the choice of the vehicle configuration does not significantly influence the choice of its thrust level, around 90 t, to inject 12–15 t in l.E.o.

The development of cryogenic HM-60, with this thrust level, is presently being proposed to E.S.A. Member States.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES