Possible Future European Launchers – A Process of Convergence*

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The FESTIP system studies were drawing to a conclusion at the end of 1998 and the main findings are outlined in this article. The concept recommendations issued to guide the definition of tasks for the Future Launchers Technologies Programme (FLTP), which is expected to take over European activity in this field from 1999 onwards, are also discussed and put into context.

Introduction

Europe has so far responded to the changes in the launcher market by applying an evolutionary approach to its Ariane family of expendable launchers. Successive launcher versions have been developed which have progressively integrated the best European technologies available into a proven system architecture. The most recent member of the family, Ariane-5, is now entering commercial service and will keep Europe competitive in the short term. To this same end, improvements to Ariane-5 are already being planned that will make it even more powerful, more flexible, and less costly (see the article on Ariane-5 Evolution, in this Bulletin).

The same kind of approach is being followed in the USA with the EELV, but they are also striving towards a breakthrough with reusable launchers. Their goal is to drastically cut launch costs, and their hope is to make space access a routine operation. It is therefore extremely important that Europe establishes its approach to reusable launchers as soon as possible and prepares itself technologically to take up this new challenge. It was for that purpose that the Future European Space Transportation Investigations Programme (FESTIP) was established in 1994, with four primary goals:

– to determine which launcher system concepts could become technically feasible for Europe in the near future
– to check whether these launchers would be commercially attractive, and to assess their development costs
– to identify which technology developments would be required to pave the way for these launchers in Europe
– to already start technology development in those areas in which the technical requirements are common to most future launcher concepts, such as structures, materials, aerodynamics, propulsion, and heat management.

FESTIP system requirements

The choice of concept will be very dependent on the top-level requirements placed on the future launchers. There may be particular European requirements that cause our choice to diverge from the American, Russian, or Japanese preferences. The top priority for Europe is to preserve its competitiveness on the launchers market in the medium term, and consequently the initial version of the Future European Launcher must be designed for commercial missions. Certain design constraints associated with governmental missions (e.g. missions to the Space Station, man on board) should not be imposed on the Future European Launcher because that would penalise its commercial competitiveness. In addition, payload recovery from orbit back down to Earth is not yet seen as a significant commercial market demand.

The top-level system requirement is therefore to obtain the lowest possible specific recurrent launch cost, well beyond what can be achieved through improvements to expendable launchers. Reusability is seen only as a means of achieving this reduction, but not as a requirement in itself. Semi-reusable compromises are therefore possible.

It is difficult today to predict the launch market prevailing in 20 to 30 years' time. As it is planned to start development of the Future European Launcher no earlier than 2007, it is not realistic to start investigating a single preferred configuration in detail at this stage. Nevertheless, we still need to define accurately now the critical technological requirements that will enable these future launchers to be realised.

* Based on a presentation made at the Third European Symposium on Aerothermodynamics for Space Vehicles, ESTEC, Noordwijk, The Netherlands, 24-26 November 1998.

In the FESTIP system study, this apparent contradiction was solved by defining performance requirements for concept comparison purposes only, which were arbitrary but realistic. All concepts of interest were designed according to these requirements. Then families of concepts were defined with common technological needs and the most attractive families were chosen. The tolerance to performance requirement changes of the concept feasibility and of the concept families comparison was then verified.

The following performance requirements were applied within FESTIP to the design of possible launcher concepts:

– 2 tons of payload in polar Low Earth Orbit (LEO)
– 7 tons of payload in equatorial LEO.

Two major additional system requirements were that:

– the Future European Launcher will operate from Kourou, to take advantage of the exceptional position of the European spaceport
– the launcher is required to have a full abort capability in case of single engine failure, allowing the launcher and its payload to be safely recovered for maintenance and re- launch.

Design standards were established to ensure comparability between the concepts, based on those technologies that we thought could be developed and validated in Europe by 2005. Standardised margins were defined at each system or subsystem level according to the technical uncertainties, assumptions were made regarding element reusability, and an operational scenario was established based on a very conservative assumption of 24 missions per year.

The programmatic assumptions are very important for the concept selection. By the time development of the new European launcher is assumed to start in 2007, US competitors may already be offering launch services with a reusable vehicle. Europe's technological ambitions are therefore limited by the need to have the main launcher technologies validated by 2007, taking into account present European know-how, and the expected near-term budget for technology preparation. A reasonable goal for Europe is therefore to have its future launcher operational by 2017-2020, with stepwise development strategies in place to preserve the more ambitious, longer term goals.

Generally speaking, the design and economic assumptions made in the FESTIP system study were much more conservative than is normally the case elsewhere for reusable launchers, in order to be sure that, even when taking such a prudent view, it is still worthwhile for Europe to be engaged in this new reusable-launcher endeavour.

Concept pre-selection

All possible reusable launcher concept families were considered equally at the beginning of the system study. However, in order to limit the scope of the study, those concepts that could not satisfy the main requirements or programmatic constraints presented above were not subjected to a concept design study within FESTIP. This was the case, for example, for:

– Air-breathing SSTO concepts
  These Single Stage to Orbit concepts were eliminated on the grounds of technological difficulty (as was the NASP concept in the USA).
– Concepts using existing/ planned commercial aircraft to carry an upper stage
  These concepts are not tolerant to performance requirement changes, because the carrier aircraft introduces a performance limitation and constrains launcher performance growth potential (even with the largest existing aircraft, the An-225, the expected payload is only 5 to 7 ton in equatorial LEO).
– Concepts based on parachute recovery (e.g. Kistler-type concepts)
  Parachute recovery was found to be incompatible with the masses to be recovered with the various concepts. In addition, the hazards associated with ground impacts after launch from Kourou are incompatible with the reusability objectives of FESTIP concepts, which are mandatory to ensure commercial viability.

Initial convergence for air-breathing propulsion

A large number of air-breathing engines are possible candidates for the propulsion of the first stage of a Two Stage to Orbit (TSTO) launcher. Since it was impossible to perform concept design studies for each engine type, a pre-selection was required, based on technical and programmatic considerations. In order to compare the various propulsion systems objectively, the views of European specialists in the field on the relative merits and challenges of each approach were solicited. The results of this consultation with respect to technology applicability, allowed the air-breathing propulsion technologies to be ranked according to the effort required and time to availability (Fig. 1).

Propulsion systems for which European industry has no practical experience in comparable or related systems (e.g. LACE and air collection) have not been retained. If a development decision is to be prepared for 2007, it does not seem reasonable to start now exploring a brand new (for Europe) technological field with unknown design difficulties and uncertain system benefits.

All things considered, the most realistic air-breathing engine for a near-term European TSTO launcher was found to be an advanced large turbojet for operation up to Mach 4.

Concept design studies

The FESTIP system work included the iteration of the technical features of each launcher concept until the system requirements and design standards were met with the required margins, and its design was self-consistent (i.e. no discrepancies remained between the design features assumed or calculated in each speciality). Detailed studies were performed for the following attributes: structural design, propulsion, aerodynamics, flight mechanics, design layout, mass and budgets, performances, RAMS, subsystems. In addition, the operations aspects were analysed for each concept, and detailed development and operational cost assessments were made.

Eight concepts were eventually chosen for detailed design studies. They represent all of the concept families that passed the pre-selection process and are potentially compliant with our requirements:

(i) Concept FSSC-1: SSTO rocket winged body, vertical takeoff, horizontal landing in several variants:

- staged combustion engines with 150 bar chamber pressure
- staged combustion engines with 245 bar chamber pressure
- tri-propellant engines.

(ii) Concept FSSC-3: SSTO rocket vertical takeoff, vertical landing

(iii) Concept FSSC-4: SSTO rocket winged body, horizontal takeoff from sled, horizontal landing

(iv) Concept FSSC-5: SSTO rocket lifting body, vertical takeoff, horizontal landing; two variants, with aerospike and staged-combustion engines

(v) Concept FSSC-9: TSTO fully reusable rocket, vertical takeoff, horizontal landing

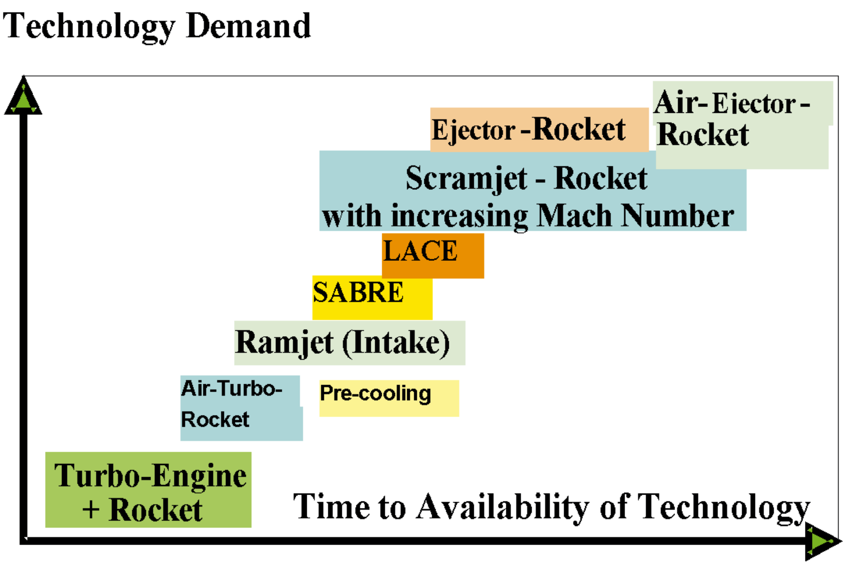


Figure 1. Technology ranking for air-breathing engines

(vi) Concept FSSC-12: TSTO fully reusable with air-breathing first stage; two variants: simple geometry and cross-feeding, advanced aerodynamics geometry

(vii) Concept FSSC-15: suborbital single-stage rocket; four variants: once-around, half-around, trans-Atlantic hopper with today's technology, and trans-Atlantic hopper with advanced technology

(viii) Concept FSSC-16: TSTO rocket concept family: stepwise development from semi-reusable to fully reusable; semi-reusable variants studied for several technology levels, while the fully reusable concept features a siamese geometry.

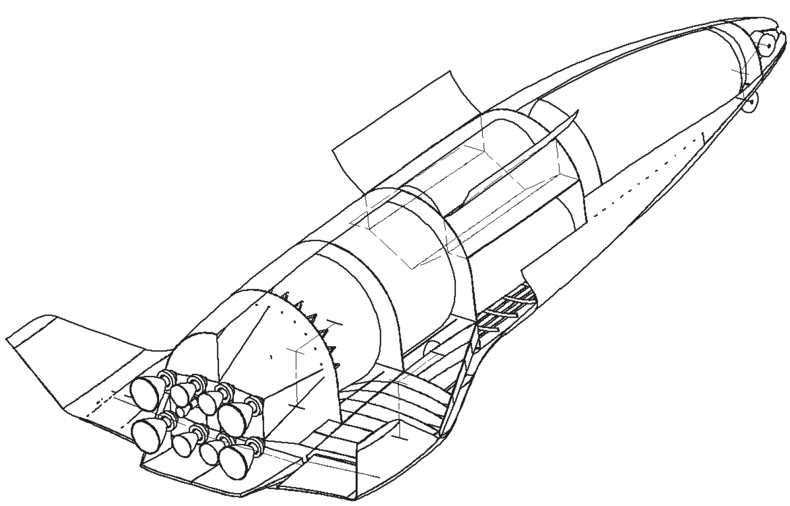
Findings for each concept

Detailed findings are available to European industry in the FESTIP reports. The major findings can be summarised as follows:

FSSC-1 (Fig. 2)

The winged-body SSTO concept will certainly

Figure 2. FSSC-1



become commercially attractive at some point in the future. For it to be technically feasible, however, a more advanced technology than presently available in Europe is required. The main problem with SSTOs is their sensitivity to the assumed technology level, making the time when the technology level will be sufficient in Europe to design an SSTO vehicle very difficult to predict accurately.

Comparing the different variants of FSSC-1, we found that:

– The performance gains obtained with higher-pressure engines do not pay off when engine reusability constraints and operating costs are considered.
– With the present study constraints, the tri-propellant engines lead to a heavier, more complex and less reusable concept, which is found not to be cost-effective.

Figure 3. FSSC-3

Figure 4. FSSC-4

igure 3. FSSC-3

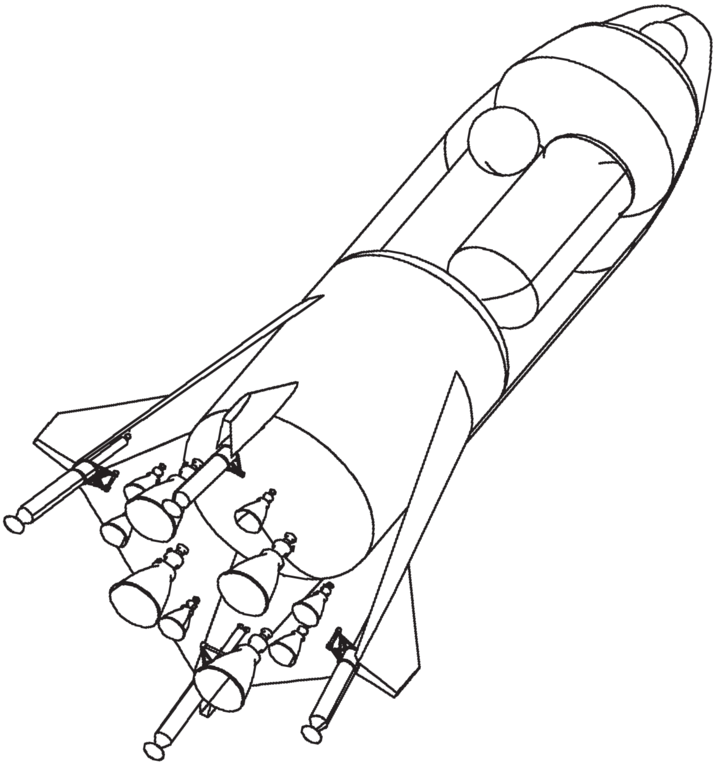
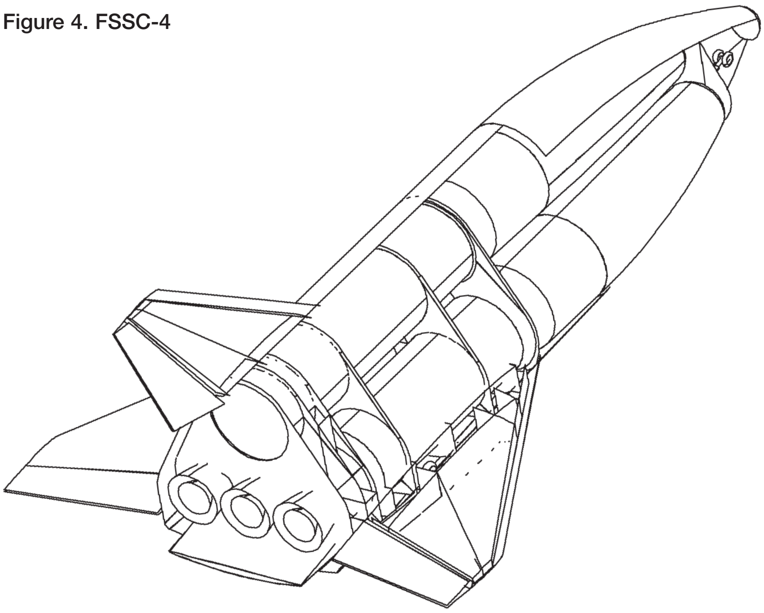


Figure 4. FSSC-4



FSSC-3 (Fig. 3)
The correct internal layout and geometry is difficult to determine for this concept, and needs to be further consolidated by wind-tunnel testing. The orbital performance of such concepts is relatively high for their dry mass, but the cross-range manoeuvring and guidance during re-entry are also problematic. The landing accuracy requires special attention, with consequences at system level. The complexity of the propulsion systems leads to high development costs (use of aerospike propulsion could have advantages). Specific launch costs are not significantly lower than for a winged-body configuration. The overall impression when comparing this vertical-landing concept with other winged concepts was that the absence of wings generates more design problems than it has advantages (this, however, is a very subjective judgement, validity of which could be limited only to the FESTIP configurations).

FSSC-4 (Fig. 4)
The feature distinguishing this concept from FSSC-1 is its horizontal takeoff from a sled. This is actually very beneficial, because it reduces the thrust required at takeoff, and therefore engine mass and cost. In addition, the classical centre-of-mass problems can be more easily solved. The use of the sled at takeoff to avoid needing heavy landing gear is seen more as a psychological barrier than a technical difficulty. This takeoff mode is very innovative for a space launcher and other innovative inherent technical features of the concept are the aeroshell structure and rear payload integration, which are beneficial in terms of reducing recurrent operating costs.

FSSC-5 (Figs. 5, 6)
The design team was disappointed to discover that this concept, inspired by the Venturestar geometry, cannot be made both feasible and economically viable with the technology presently available or foreseeable in the near term in Europe. The tanks are heavy and complex and the thrust-to-weight ratio achieveble with the aerospike engine is a major unknown. An attempt was therefore made to replace the aerospike engine with conventional high-pressure staged combustion engines, but the result was not very promising from an economic point of view.

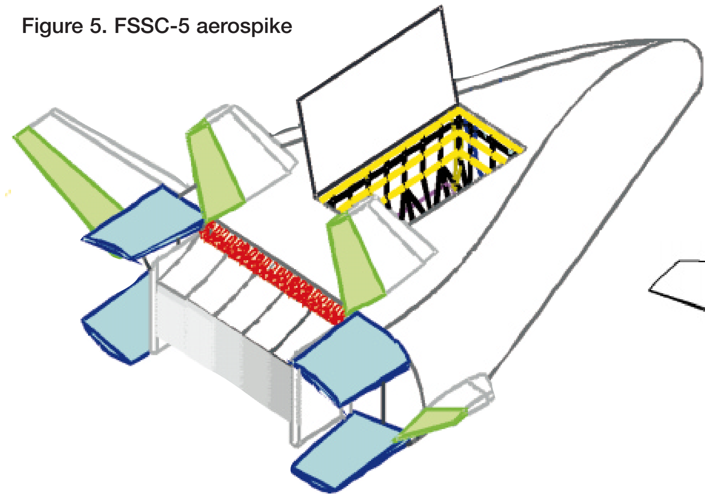


Figure 5. FSSC-5 aerospike

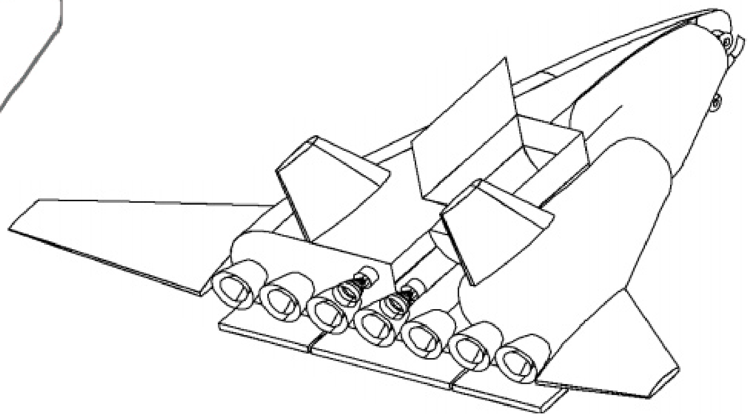


Figure 6. FSSC-5 rocket

FSSC-9 (Fig. 7)
This concept was found to be technically within reach, its design being rather conservative, but it was not fully compliant with the abort requirements. The development and operations costs were high mainly because the concept was not totally optimised. The lessons learned from this concept were integrated into the FSSC-16 design to try to obtain a more attractive TSTO concept.

FSSC-12 (Figs. 8,9)
This TSTO concept was the only air-breathing concept studied within FESTIP. The staging at Mach 4 is an optimisation to limit the technological challenge of the air-breathing engine, but creates integration problems with two stages of comparable dimensions. Robust design solutions have been found, but development costs (including the new engine) are very high, and the operating costs not very attractive. This concept has, however, the best capabilities for launch abort.

FSSC-15 (Fig. 10)
This concept is a single-stage fully reusable launcher, which does not reach orbital velocity. Its ascent phase is immediately followed by the ejection of a kick stage which boosts the payload to its final orbit, while the reusable stage immediately re-enters. The amount of propellant required on board the launcher is therefore much lower than for an SSTO, and the concept yields higher performances and is more robust to technological assumption uncertainties. Several variants of this sub-orbital concept have been studied, with the following results:

- The once-around or half-around variants are nearly the same size and involve the same technological challenge as the fully orbital SSTO. Consequently, they can be considered particular operating modes of a full SSTO concept, offering increased performance capabilities.
- The trans-Atlantic hopper seems very attractive from a development and operational cost point of view. This concept is a specifically European option, as its feasibility relies on the availability of potential landing sites in ESA Member State territories at the right geographical locations around the world. Technical feasibility seems to involve no fundamental difficulties, assuming only very limited improvements to today's European know-how. More advanced technologies can be integrated later for performance improvement.

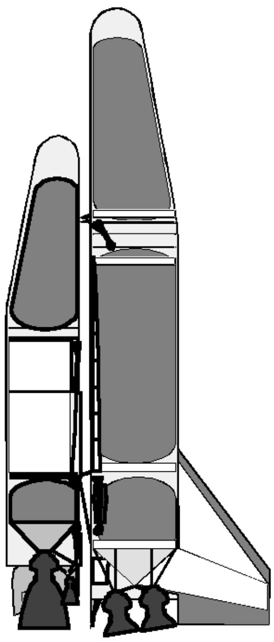


Figure 7. FSSC-9

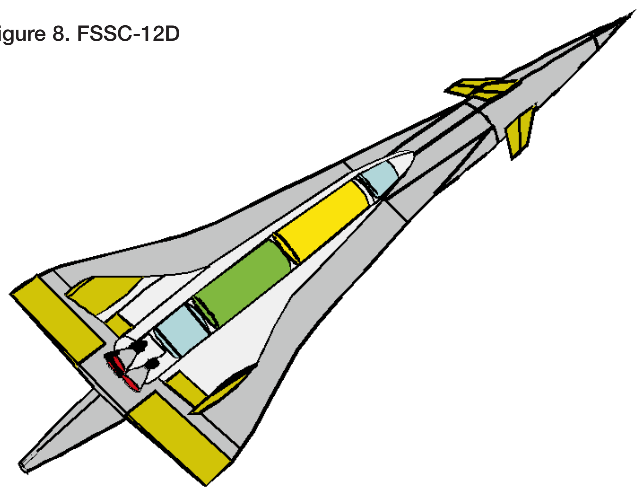


Figure 8. FSSC-12D

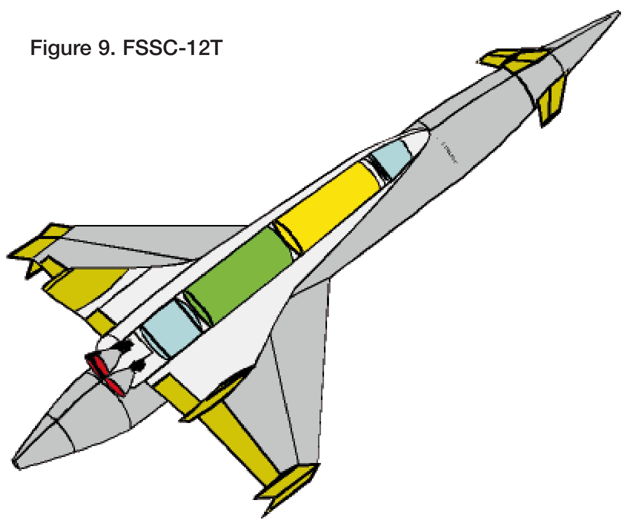


Figure 9. FSSC-12T

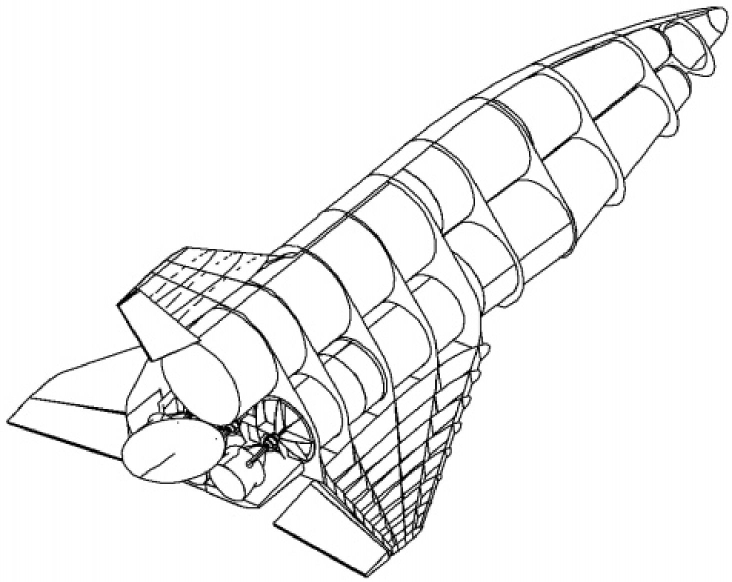


Figure 10. FSSC-15

FSSC-16 (Figs. 11,12)
The semi-reusable version of this concept could become feasible in the near term. However, the assumed use of an Ariane-5 core stage imposes performance capabilities of a level comparable with Ariane-5. The double launch may not be the optimal strategy for a reusable launcher, and a very high level of performance may be inadequate for constellation replenishment missions. Improved adaptability of the concept to changing mission requirements calls for a new expendable stage, and then the development costs need to be reassessed. The projected operational costs show a moderate improvement with respect to present expendable launchers. The fully reusable version can be developed at a later stage, using the first stage developed for the semi-reusable version. More advanced technologies will be required, however, to achieve a fully reusable concept able to reach a stable orbit. It is still unclear in how far the siamese concept can be applied, since it puts an additional constraint on the performance levels achievable in the long term.

Concept selection criteria; global comparison and preferred concept families
The selection criteria for the concepts to be studied further during the FLTP are:
- Concept technical feasibility in Europe, assuming an affordable technology preparation phase until the planned development decision in 2007.
- Affordability of the concept development (using Ariane-5 as a comparative reference).
- Recurrent-launch-cost projections compared to competitors.
- Adaptability of the concept to the potential evolution in market needs.

Application of these criteria to the FESTIP concepts leads to the following conclusions:

With respect to technical feasibility:
Some comments have already been given for each individual concept, but the overall conclusions are as follows. The technological challenges are high for all SSTO concepts compared to present European know-how, and there is considerable uncertainty regarding the

Figure 11. FSSC-16ASR

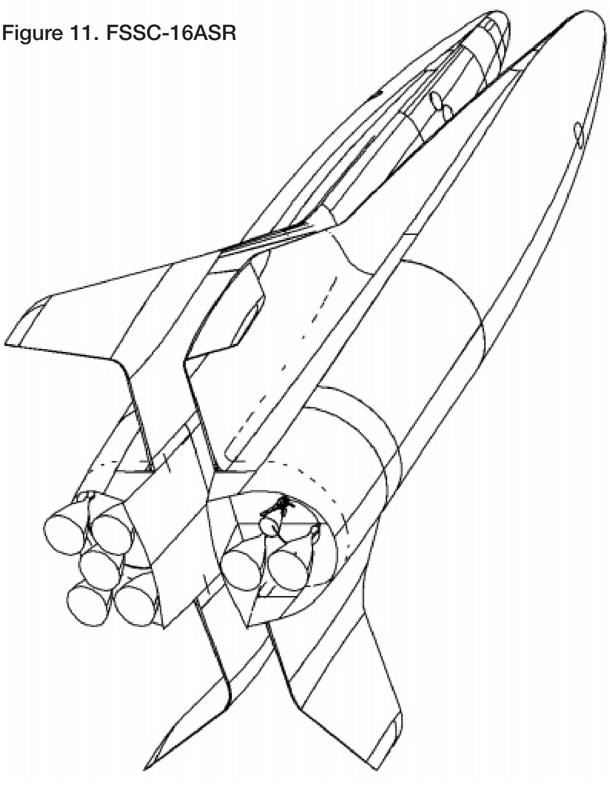
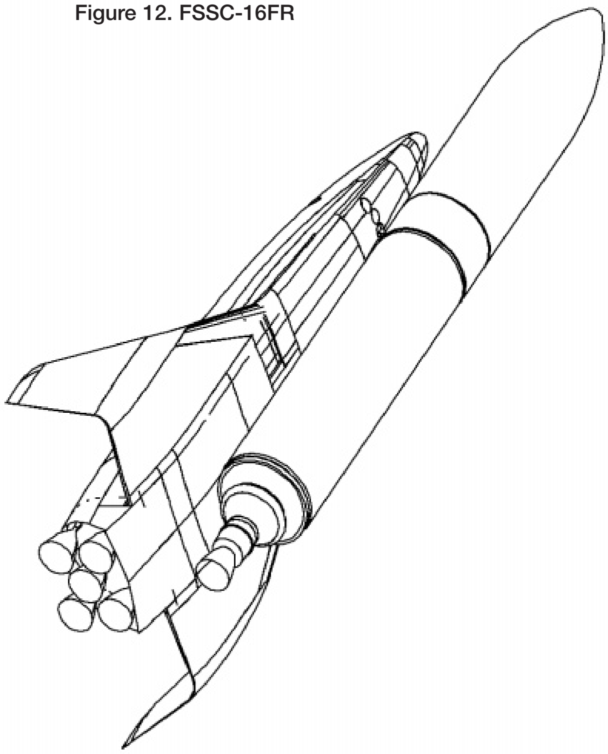


Figure 12. FSSC-16FR



final size feasible for such vehicles. It was concluded that Europe could not prepare the technologies required to start the development of an SSTO by 2007 within a reasonable budget.

A high-pressure (245 bar) staged combustion engine meeting the 60-mission reusability objective was also found to be an unreasonable target for Europe within the time constraints. Even a 150-bar chamber pressure engine was considered challenging. The most conservative approach is to adapt Vulcain engines for reusability.

With respect to affordability and cost-reduction perspectives:
A quality index proportional to the inverse of the product of specific launch cost into equatorial orbit and concept development cost, as shown in Figure 13, gives an idea of the relative economic attractiveness of the various concepts: the higher the index, the more attractive the concept from an economic point of view.

As can be seen from Figure 13:
– The air-breathing TSTO concept, although technically feasible, is not competitive.
– Semi-reusable concepts are of interest when compared to the SSTO concepts, since their higher operational cost is compensated by a lower development cost.
– The suborbital-hopper concepts are particularly interesting because they combine a low development cost and a low specific launch cost. They therefore achieve a better rating than any of the SSTO concepts.
– TSTO Concept 9 was insufficiently optimised, which explains its very poor rating. The lessons learned from that concept did, however, allow better optimisation of TSTO concept 16 FR, which achieved a better rating, but still below those of SSTOs.
– Concept 5 is an exception among the SSTOs: its poor rating results from the design problems described above.

Figure 14 shows a relative qualitative evaluation of uncertainties in design, and hence in concept costings, resulting from:
– the inherent sensitivity of each concept to the design parameters
– the uncertainties due to the amount of technological progress required
– the available design margins and backup options at system level.

With respect to adaptability to new missions:
All concepts can, in principle, be scaled to meet different performance requirements, with the exception of the FSSC-16 family where, for the reasons already discussed, the solution would be a new expendable stage, with the penalty of increased development costs.

Technology requirements for the FLTP
The FESTIP concepts comparison therefore shows that two families are particularly interesting, since they seem within reach technically for Europe in the medium term: the FSSC-16 semi-reusable and the FSSC-15 trans-Atlantic hopper concepts, both of which include a partial-reusability feature.

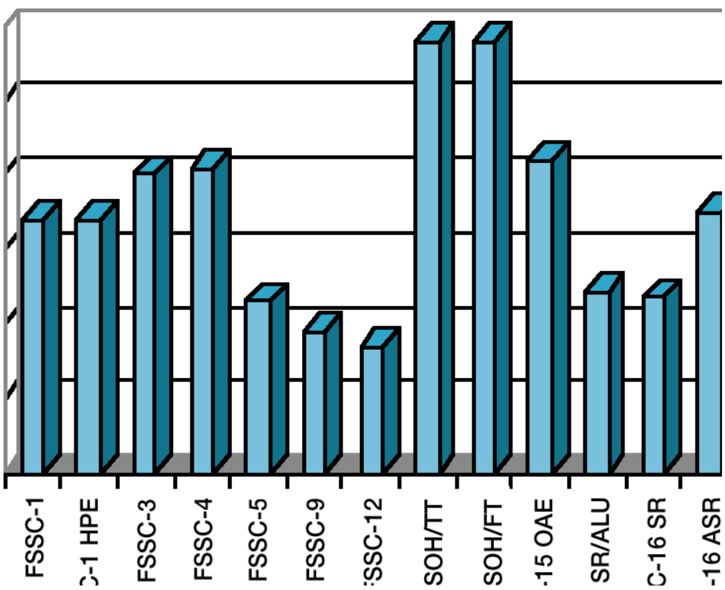


Figure 13. Economic attractiveness of the various concepts

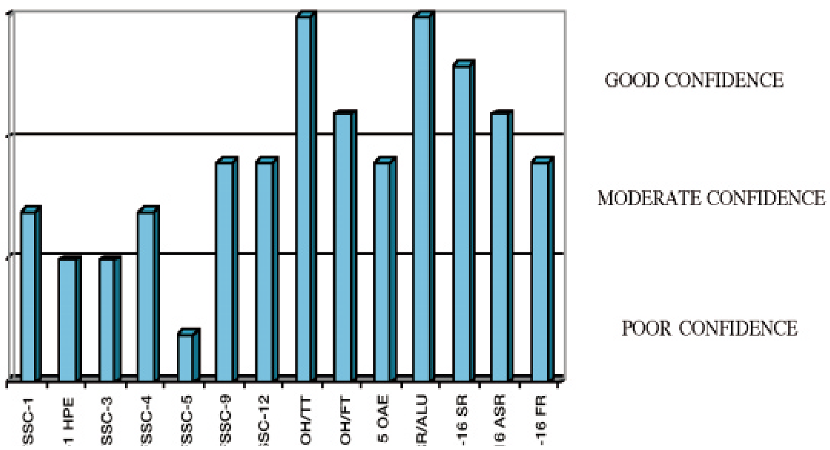


Figure 14. Design confidence as a basis for costing

The FLTP concept design effort should focus on confirmation of their economic interest and improvement of their adaptability to missions of potential interest. The FLTP technology effort should focus on the technologies needed for these two families. The detailed technological requirements for the preferred concepts are identified in a document called the “Technology Development and Verification Plan”, which proposes a development strategy, testing requirements, achievable schedule, and indicates anticipated technology-preparation costs, as well as a listing of the facilities required to support the development.

The requirements for new technologies in Europe for the semi-reusable concept mainly concern the transformation of the Vulcain motor into a reusable engine, the manufacturing of composite tanks, health monitoring, and experience in rocket-vehicle reusability.

For the suborbital hopper, the main requirements are the transformation of the Vulcain into a reusable engine, large composite primary structures, re-entry technologies (aerothermodynamics and thermal-protection systems), health monitoring, and experience in rocket-vehicle reusability. There is therefore a common core of technology requirements on which new work should be started immediately within the FLTP, while an activity is maintained over the envelope of the requirements until a definitive choice of the future launcher concept for Europe can be made.

In-flight testing requirements

In-flight experimentation, validation and demonstration will be required to gain enough confidence in the new technologies’ maturity and their integration into a functional system. Before committing to the Future Launcher’s development, it will be necessary to confirm via relevant practical flight experience that the anticipated launch-cost reductions are not unrealistic. The key objectives for the in-flight experimentation are thence:

1. To provide visible and indisputable evidence of European industry’s ability to design and manufacture a test vehicle with technical features similar to those of possible Future European Launchers.

2. To provide hands-on experience in the recurrent operation of a test vehicle using the key technologies required for possible Future European Launchers, and to provide operational data supporting a better assessment of the anticipated operational cost savings.

3. To place those newly developed technologies, which cannot be fully validated by ground testing, in a realistic working environment for their validation.

4.To motivate the European engineering teams through the near-term realisation of hardware and to offer the technology teams a challenge that is rewarded by visible in-flight success.

The major constraints affecting in-flight experimentation are:

– to consolidate conclusions in time for the possible go-ahead to develop an operational launcher, a decision presently targetted for 2007
– to maintain affordability vis-a-vis the budget available for the technology development.

To comply with these constraints, a stepwise implementation is proposed:

The first step in in-flight experimentation should address those requirements that are independent of the final concept selected, which thereby constitute a common core for in-flight testing needs. The proposed European Experimental Test Vehicle (EXTV) Step 1 shown in Figure 15 can meet those requirements.

The FESTIP EXTV is a relatively small rocket-propelled vehicle (4.2 tons dry mass, 10 tons gross take-off mass), designed for frequent flights at speeds up to Mach 4. It takes off horizontally using its own propulsion, and lands horizontally. Its main purpose is to acquire experience in the recurrent use of high-speed reusable rocket vehicles. This know-how is

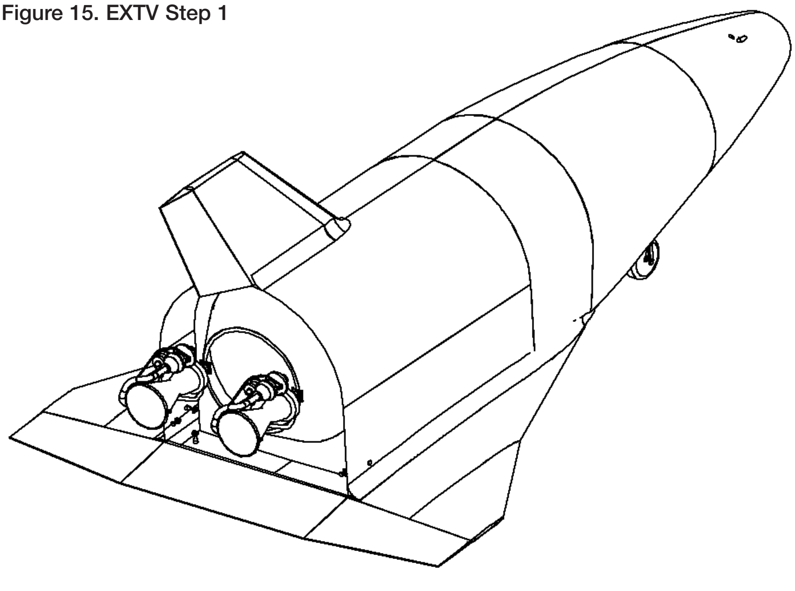


Figure 15. EXTV Step 1

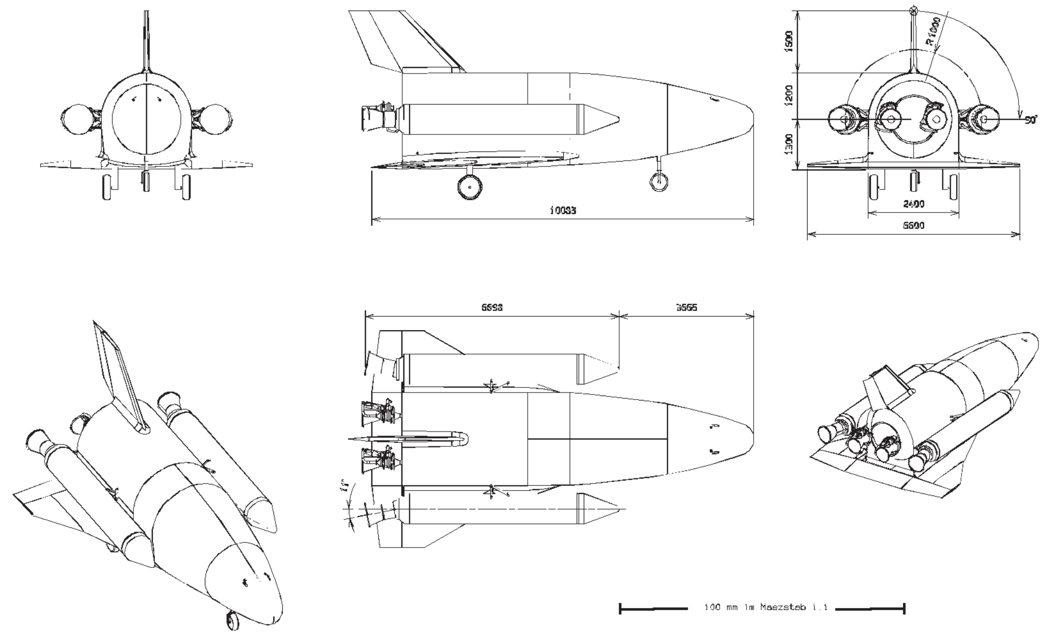


Figure 16. EXTV Step 2

urgently needed because it has implications not only for the design of future launchers, but also on our judgement as to whether their development is worthwhile. Meeting these core in-flight test needs must therefore be one of the priorities of the FLTP.

Should the suborbital-hopper finally be chosen as the preferred concept for the operational launcher, a second in-flight-experimentation step will be needed to address high-speed technologies. For this, a modified EXTV fitted with additional solid boosters and thermal-protection systems, as shown in Figure 16, can be used.

Finally, if later on for other than economic reasons the Future Launcher is required to have a full orbital capability, additional in-flight testing will be required in a third step to demonstrate a complete re-entry and a safe landing. A vehicle with a similar shape and approximately the same dimensions as the EXTV (but without main propulsion) could be placed on top of a Soyuz launcher to meet these additional needs.

Conclusion

The FESTIP system study has allowed us to identify which families of concepts are most likely to enable Europe to retain its commercial competitiveness on the world launch market. We have concluded that the concept families that could be technically within Europe's reach include partial reusability features, and that these families have the potential to yield commercially competitive launchers. Two options will be analysed further during the FLTP: the semi-reusable TSTO and the suborbital hopper.

The technology requirements for these concepts have been identified and the development needs are rather modest and therefore consistent with the expected funding until the final decision on the Future Launcher's operational development, by 2007. In-flight experimentation for reusable rocket operation in a relevant flight domain is mandatory before this decision can be made. These activities together form the nucleus of the Future Launchers Technologies Programme (FLTP) to be started in 1999.