The Engineering Design of Engine/Airframe Integration for the SÄNGER Fully Reusable Space Transportation System

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ABSTRACT

In Germany the Ministry of Research and Technology (BMFT) initiated in 1986 study work at industry focused on "Determining of the principal features and results as Starting Points for German Industry in the Development of Future Hypersonic Transport-Aircraft with a view to Possible Hypersonic Aircraft Projects. Then, after the start of the newly initiated German Hypersonics Technology Programme in 1987 the Two-Stage-To-Orbit (TSTO) transportation system became the reference concept of the German Hypersonics Technology Program. The new concept adopted the simplified denomination "SÄNGER II".

An overview on the concept study work having been done within an international design team will be discussed with specific emphasis on the selection of the combined cycle engine concept, the propulsion operational modes and the results of the engine/airframe integration. Major experimental (EFD) and computational (CFD) results from the detailed intake, combustion chamber and nozzle design will be shown. For the experimental proof of the performance of the operational combined cycle (turbo-ram/scram) engine system under real environmental conditions several flying testbeds had been pursued together with Russian partner companies. The major achievements and "lessons learned" will be discussed.

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1.0 THE GERMAN HYPERSONICS TECHNOLOGY PROGRAM (1988-1995)

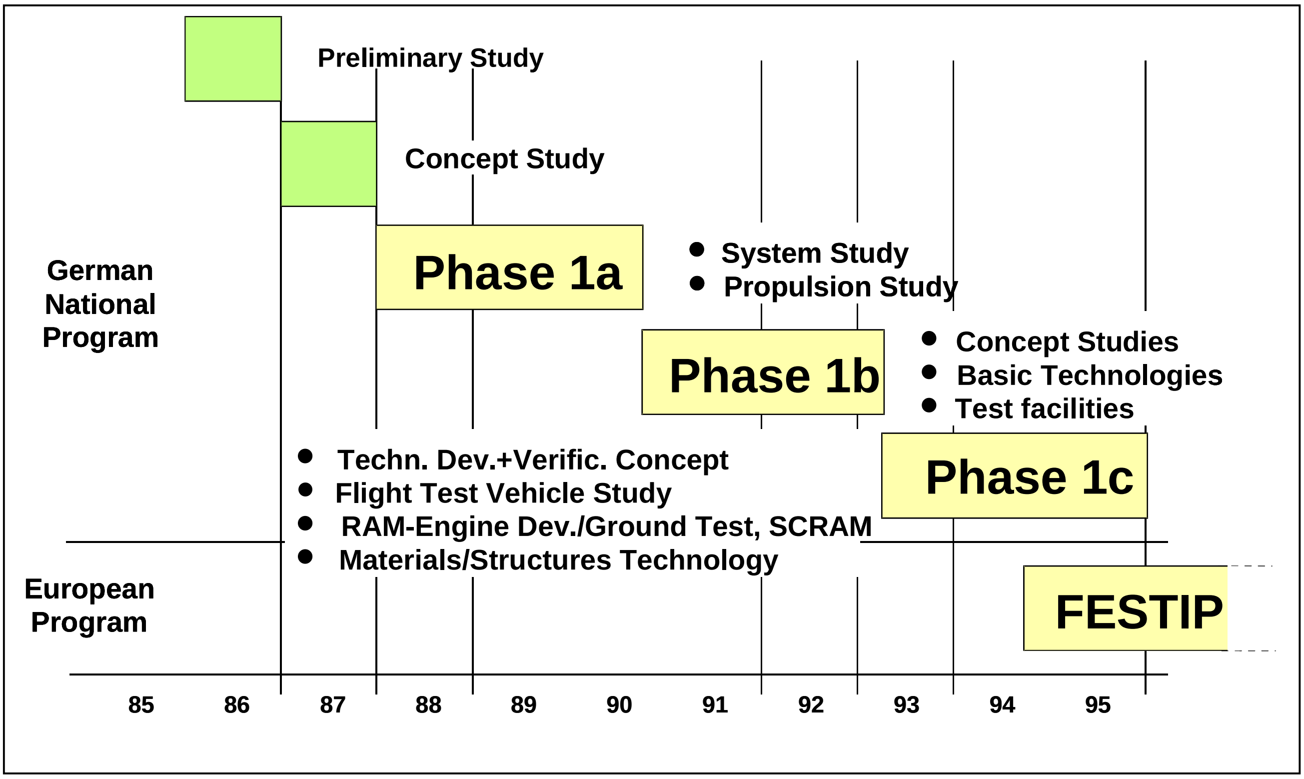


Fig. 01 SÄNGER/HTP: Schedule of the German Hypersonics Activities

In Germany efforts dedicated to these Key-Technologies were initiated during 1987-1995. They were undertaken by international cooperation within the **German Hypersonics Technology Program.** After having performed extensive System Concept Study work the decision was made to select a TSTO concept ("**SÄNGER**") as **Leading Reference Concept** for the development of the above listed "Key-Technologies" in three major time frames. At the end, mainly to shortcomings of the national budget, the program was transferred as a starting point to an ESA initiated international European program named **FESTIP** (Future European Space Transportation Investigations Program).

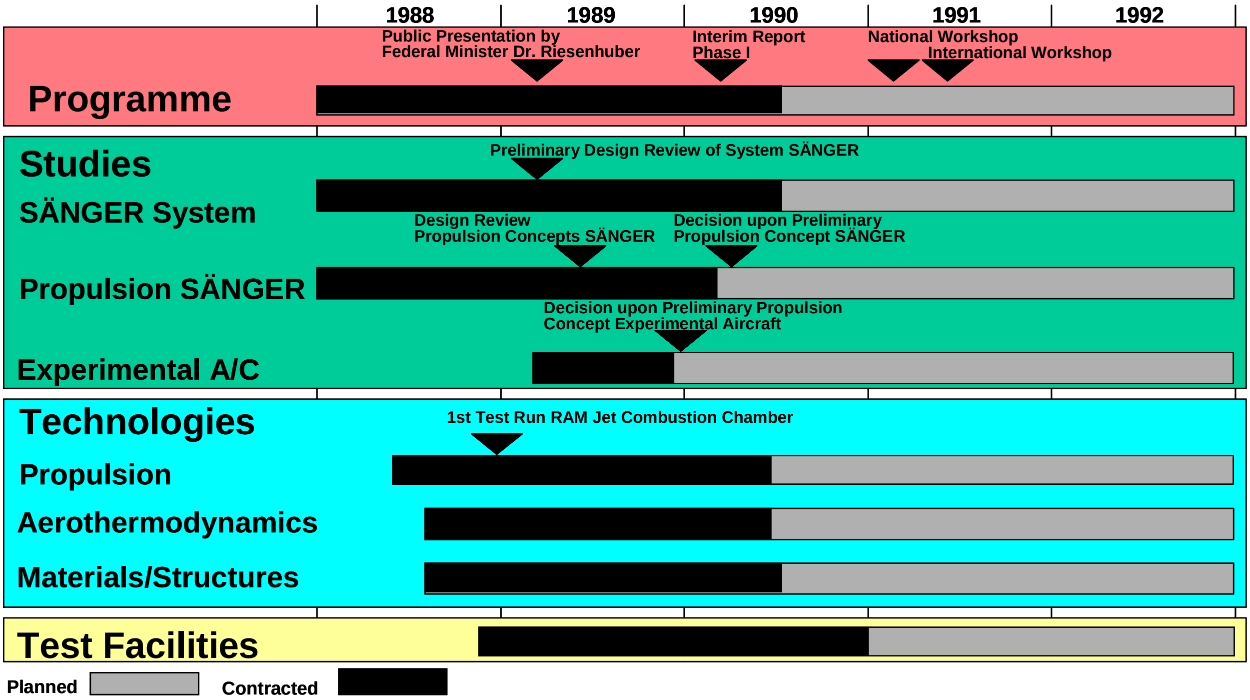


Fig. 02 Sänger/HTP: Time Schedules for Phase I (Status Phase I)

This Figure shows the time schedules for the activities already completed or planned in Phase I of the program. The most important milestones and reviews in the beginning of the Hypersonics Technology Program were:

- Jan. 89: preliminary design review of SÄNGER space transportation system
- Feb. 89 public presentation of the HTP by the Ministry
- May 89 preliminary design review of the SÄNGER propulsion system
- Jan. 90 selection of the propulsion concept for an experimental aircraft (HYTEX)
- Feb. 90 Interim report on Phase I

The program in Phase I was structured in three main activities:
- Studies (SÄNGER system, SÄNGER propulsion system and experimental aircraft)
- Technology development (propulsion, aerothermodynamics and materials & structures)
- Test facilities (since about one decade no progress in experimental test facilities!)

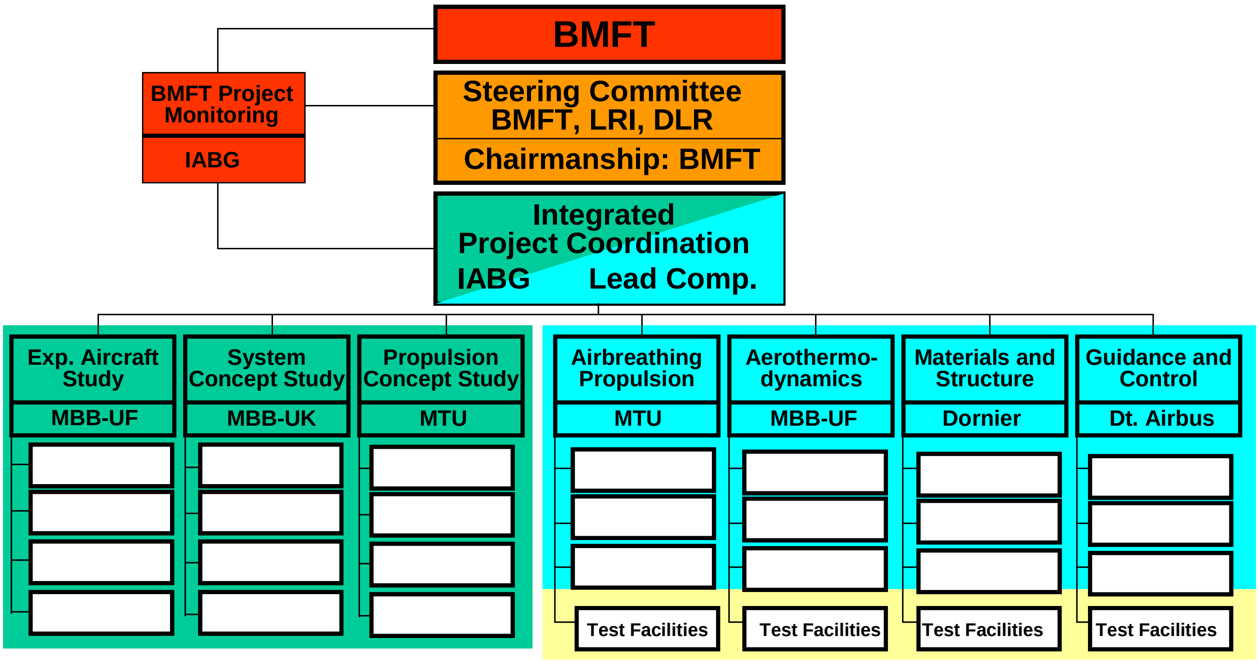


Fig. 03 HTP: Organization and Partners (Phase I)

This Figure gives an overview of all participating companies, divisions and institutions involved directly or in a supporting role. "Working Groups" were established in the individual most important technology areas, which represent an important instrument for cooperation and for exchanging experience and information between the companies, universities and research institutes.

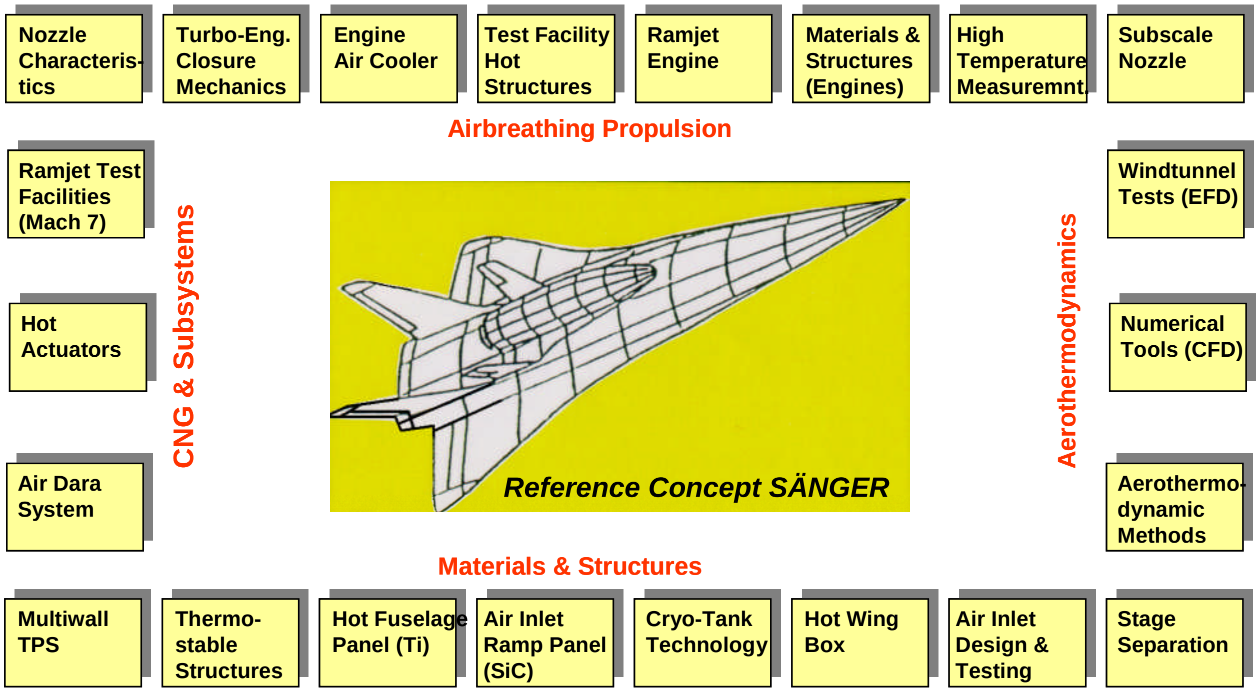


Fig. 04 German National Hypersonics Technology Programme
Technology Tasks in Phase Ia und Ib (1988-92)

The Hypersonics Technology Program was initiated 1988 and sponsored by the German Federal Ministry for Research and Technology (BMFT). The Figure gives an impression which technical tasks were investigated in the four most critical technical disciplines:

- Airbreathing Propulsion
- Materials & Structures
- Aerothermodynamics
- Guidance Navigation Control and Subsystems

Apart from national interest stimulated by the HTP in the various areas of industry , science and the universities, initial contacts have also been established with many foreign countries who would like to join in the development and testing of the advanced necessary technologies towards a new space transportation system.

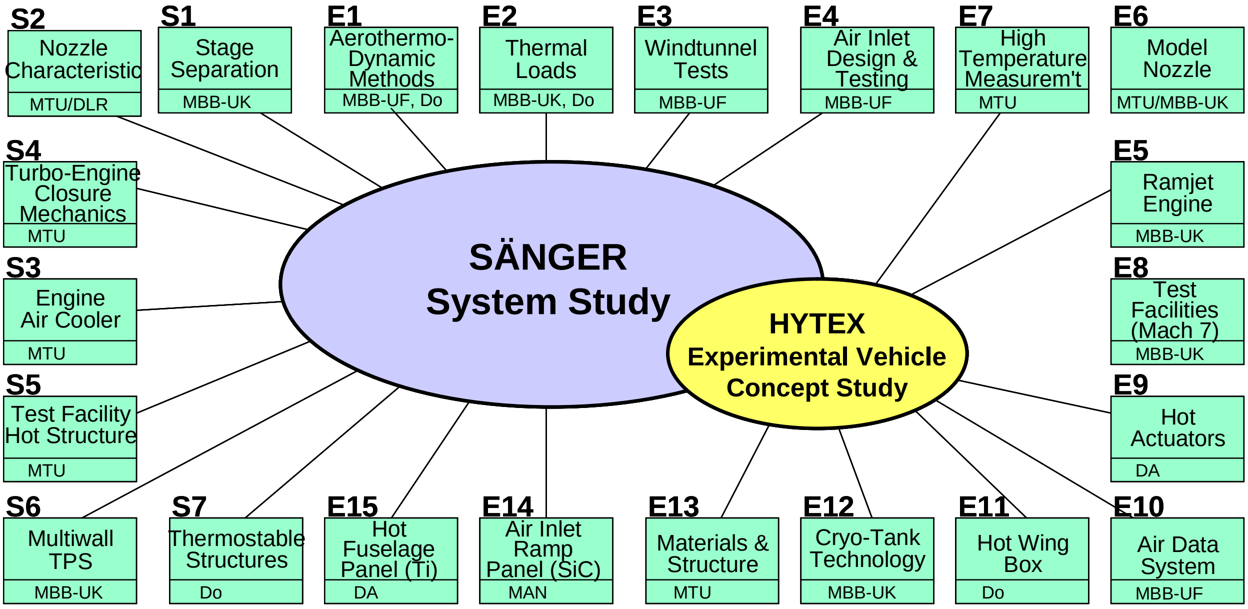


Fig. 05 **The German Hypersonics Technology Programme**
Phase Ib (1. 7.1990 - 31.12.1992)

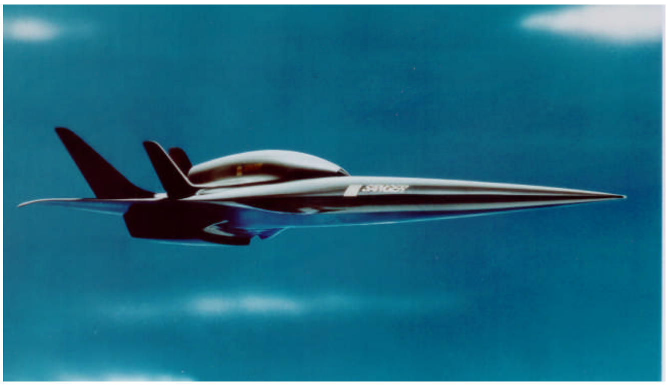
In the beginning of the HTP only German partners started in Phase Ib with a comprehensive assessment of the state of the art in the technology tasks shown. The figure shows the responsibility of participation institutions to the main technology tasks under investigation and development.

Lead industrial companies (MBB, MTU and Dornier), participating Universities (Aachen, Braunschweig, Munich, Stuttgart), the German Aerospace Research Establishment (DLR) and the German Research Foundation (DFG) were supporting the program in intensive cooperation.

All activities shown in the technology work break-down structure were directly derived from the needs of the SÄNGER reference conception and its experimental technology demonstration and verification vehicle (HYTEX).

2.0 THE TWO-STAGE-TO-ORBIT (TSTO) SPACE TRANSPORTATION SYSTEM SÄNGER

- **lower stage (hypersonic Aircraft) up to M < 6.8**
- **upper stage (Re-Entry vehicle)**
  - **HORUS for men and payload**
  - **HORUS-C unmanned**
- **100% reusable**
- **liquid hydrogen propulsion system (Turbo-Ram combined cycle)**
- **horizontal take-off and landing from European airfields**



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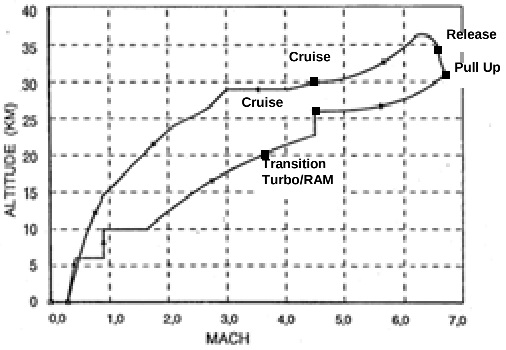
SÄNGER System Study (1988-91)
Hypersonic experimental vehicle study (1989-95)
Propulsion system study (1988-1990)
BMFT-sponsored Hypersonic Technology Program (1988-1995)

Fig. 06 Sänger: Two-Stage-to-Orbit System (TSTO)

SÄNGER was a design of a fully reusable TSTO winged space transportation system providing full European autonomy in space transport. The two-stage concept allows a maximum operational flexibility:

- It could be the only system which allows launches from European airports into all orbital inclinations (because of its cruise capability)
- The total launch mass should be less than 500 tons (B-747 class vehicle)
- For launch and landing conventional airport facilities were foreseen without any special launch assist installations (e.g. sled, trolleys ..)
- The first stage could have a large design commonality with a global hypersonic transport plane (but it turned out that at least at that time there was no interest on a civil or military transport A/C)
- During the SÄNGER development studies the upper stage for cargo was no longer envisioned

	FIRST STAGE	SECOND STAGE
LENGTH HEIGHT WING SPAN PAYLOAD	86.43 m 16.8 m 43.2 m 115 Mg	32.45 m 5.41 m 17.7 m 7 Mg
PROPULSION Number Thrust Propellant	Turbo/Ramjet 5 1300 kN (Mach 1.2) LH2 / 134 Mg	Rocket 1 1500 kN LOX/LH2 / 83 Mg
TOTAL WEIGHT	435 Mg (incl. 2.stage	115 Mg



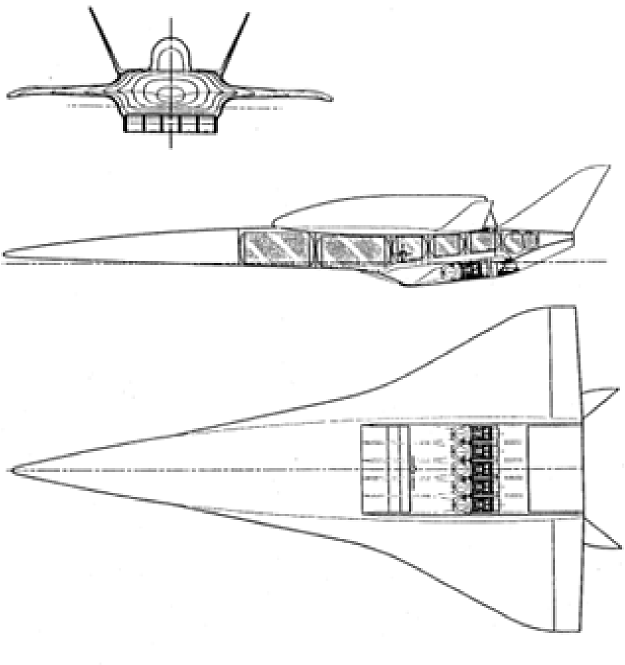


Fig. 07 SÄNGER: Compilation of Main Characteristic Data (Config. 4/92

This Figure shows the SÄNGER mission flight profile, the SÄNGER system's main geometrical dimensions and the SÄNGER TSTO system planform configuration.

Widely differing design requirements for the propulsion components with far-reaching consequences for the performance of the overall propulsion system resulted from the design of the mission flight path:

- The air intake will be designed for the highest Mach number of the ramjet operation (about Mach 6.8)
- The transonic speed (approx. Mach 1.2) result in the main design criteria for the turbo engine
- The design of the afterburner and ram combustion chamber unit is determined by the Mach number at which transition from turbo to ram operation occurs (approx. Mach 3.5)
- The extreme operation range requires a high degree of nozzle adjustability determined by the thermodynamic design of the turbo engine and the maximum Mach number. In addition, the basic drag level particularly in the transonic range – proved to be critical due to the unlined nozzle outlet area.
- Special attention was needed for the switching mechanism due to the transition from the different propulsion modes.

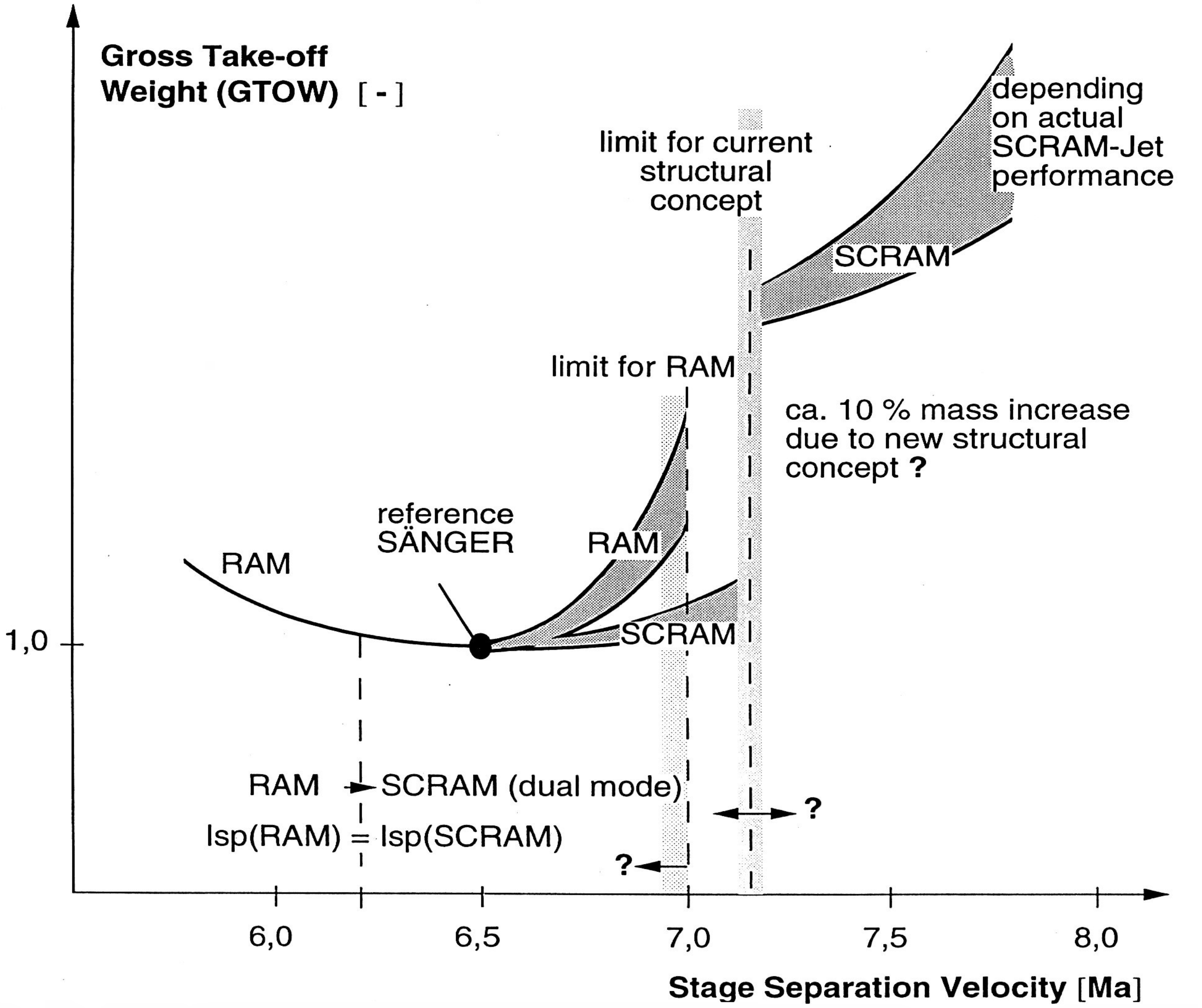
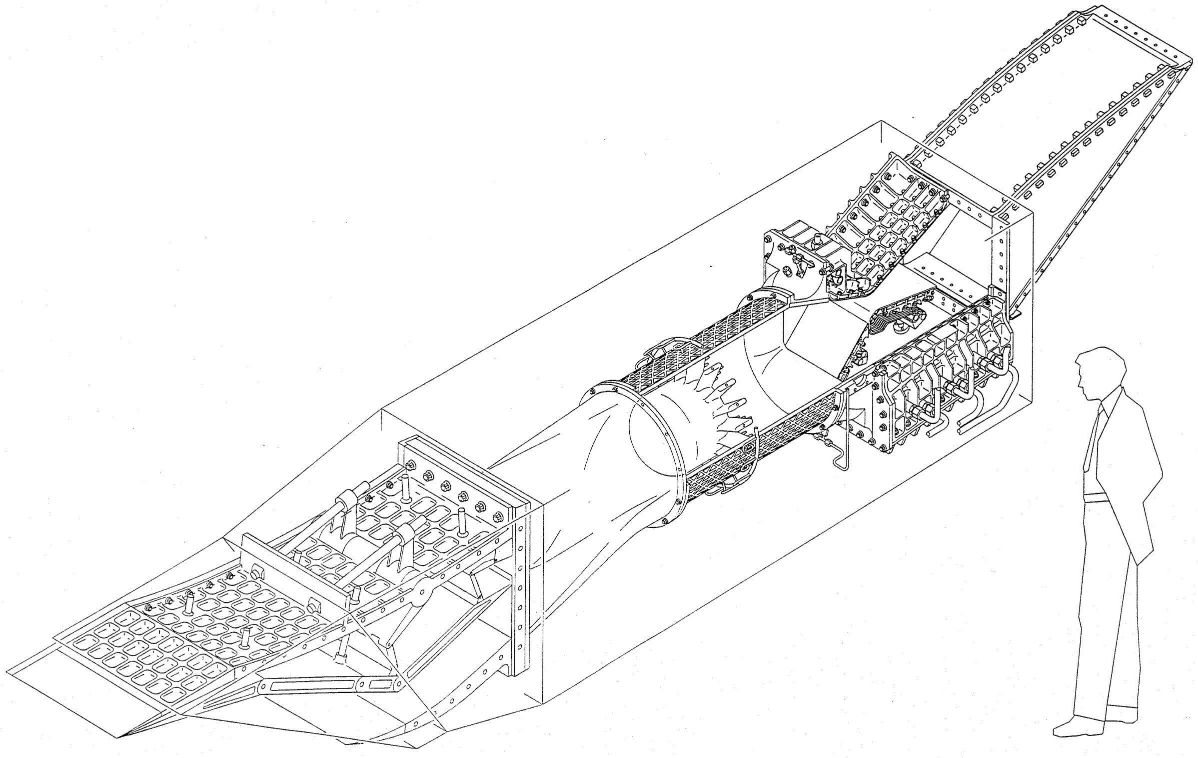


Fig. 08 SÄNGER: Rationale for Optimum Stage Separation Machnumber

The optimum stage separation velocity is difficult to find without having a given concept, especially for airbreathing propulsion systems. Of course the concept refinement is highly influenced by the staging parameters.
For the SÄNGER vehicle the rational for a stage separation velocity in the order between Mach 6 to 7 was based on the following logic:

- The technological limit for a realistic (=affordable) structural concept was assumed at around Mach 7 (e.g. active cooling, TPS for 1. Stage!)
- Scram propulsion seemed to be out of the technological reach (performance data were at least questionable assumptions)
- Between Mach 6.5 and 7 ram propulsion seemed to be superior against scram

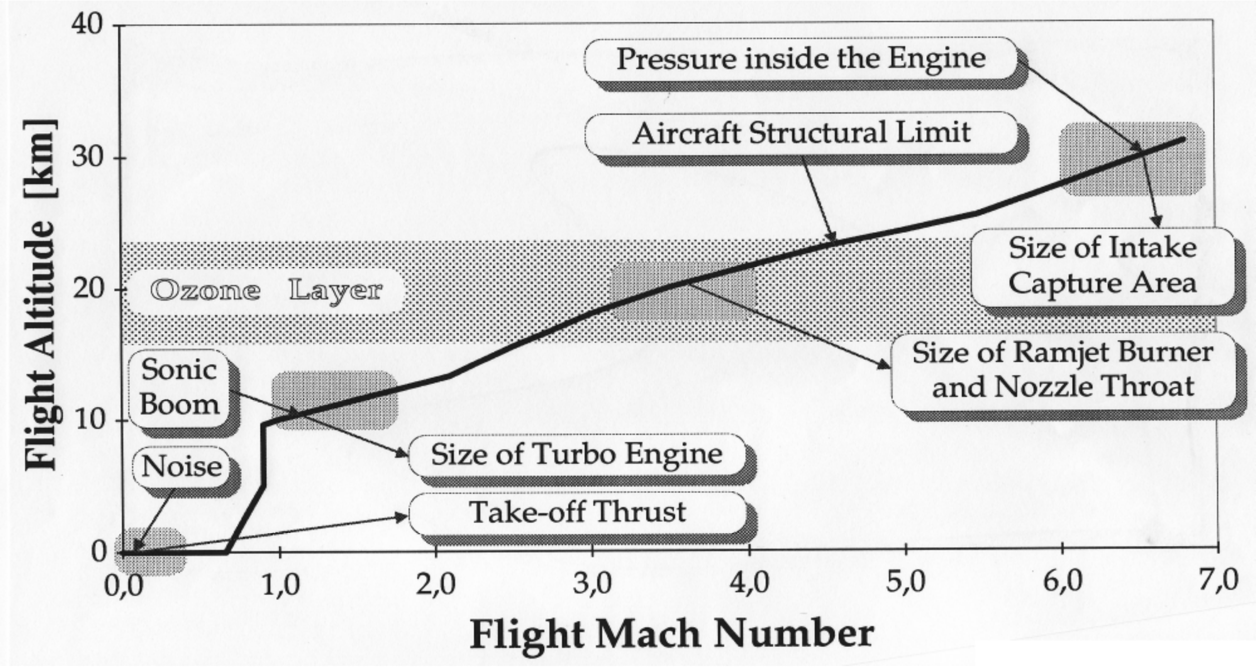


Courtesy to MTU

Fig. 09 SÄNGER: Turbo-Ram Propulsion System

The possible engine configuration is shown in the Figure. Based on a combustion chamber diameter of 50 cm the total length of the complete engine is about 8 m. With the exception of the intake (which was firstly designed for a 30 cm combustion chamber) all components have been designed built and tested in ground facilities.

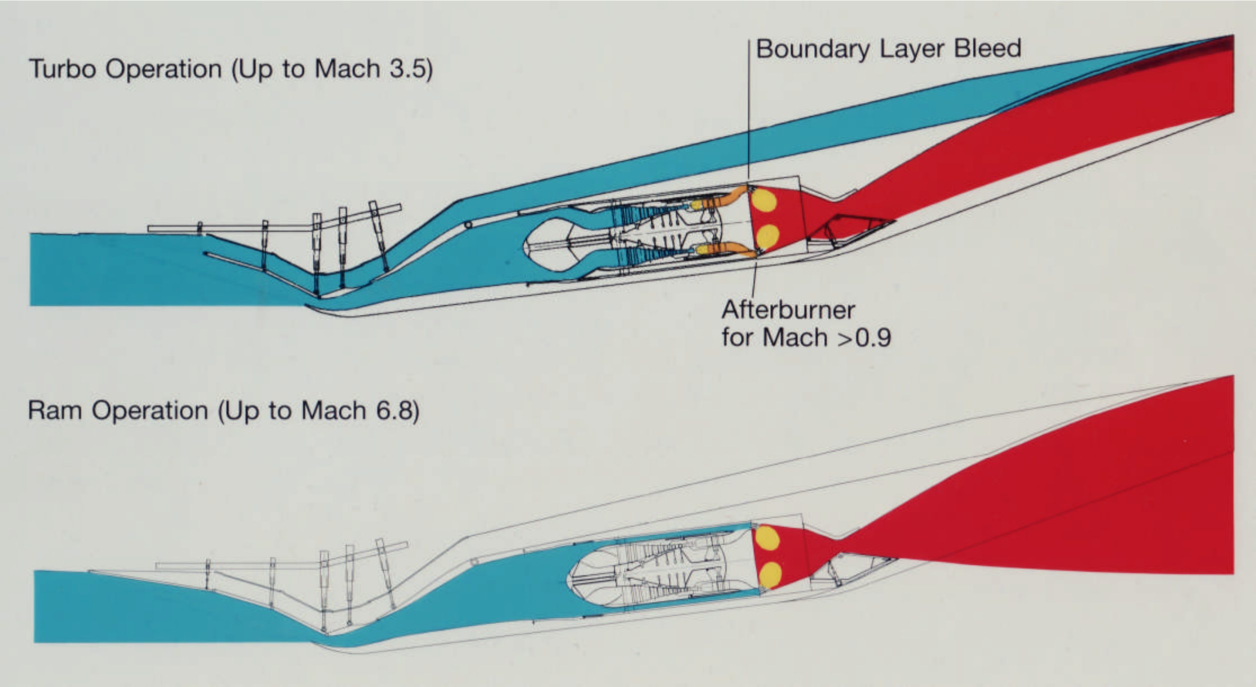
The complete engine (including the large intake) was planned to tested in the free jet test facility APTU at AEDC in Tullahoma, Te., operating up to about Mach 5 in 1996.



Courtesy to Zeller/Sterr/Herrmann, ASME 92-GT-204, June 1-4,1992,

Fig. 10 Critical Engine-Design Parameters during Ascent Trajectory

The engine for a high speed transport vehicle has to be designed to meet the most critical design limitations given by the flight trajectory especially for the ascent part and the mission constraints and integration limitations as the figure shows. The size of the Turbo-engine is first of all defined by the take-off thrust requirement. The flight at higher Mach number (after transition from the turbo-to-ram operation mode) along the trajectory is performed at constant dynamic pressure according to the limitations of the airframe structure. This defines the size of the ramjet burner and the nozzle throat. Remarkable to note: The size of the intake capture area is designed for the maximum Mach number at high altitude and the pressure inside the engine. Although the intake has variable intake ramps this leads in many cases to spill-drag due to by-passing parts of the airflow at low speeds ("Intake Design Miss-match").



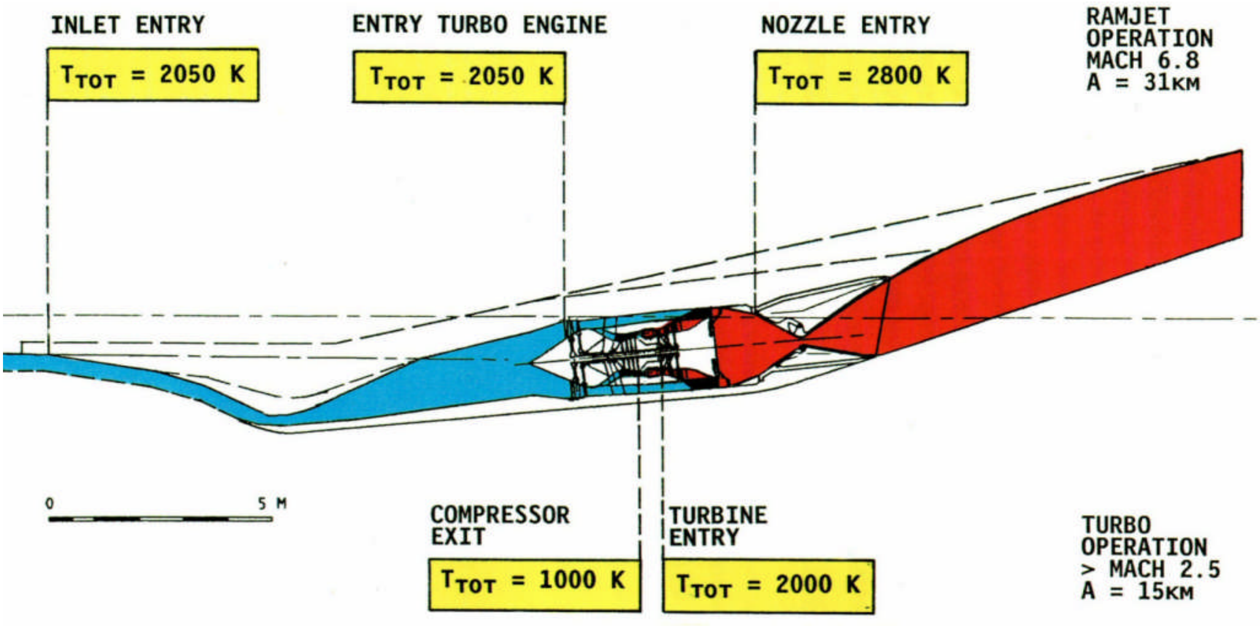
Courtesy to MTU

Fig. 11 SÄNGER: Propulsion Operation Modes

At the end of the propulsion systems study in Februar 1990 the integrated turbo/ramjet propulsion system with a co-axial flow-path was selected as baseline for all propulsion systems related conceptual design and propulsion technology development activities.

These technology work had already been started early in 1988 because independent from the final decision on the engine cycle type the most critical engine components (intake, ram combustion chamber and nozzle) the technology development work was essentially the same. But in 1990 a decission on the operational modes for the whole flight Mach number range had to be achieved.

- Turbo operation was foreseen up to Mach 3.5 with the afterburner ignited for Mach numbers greater than 0.9.
- Then the switching mechanism will close the flow-stream through the turbo engine and the flow goes around the closed turbopart in the afterburner now working as a ramjet unteilo the maximum flight Mach number of 6.8 was reached
- A separate duct was leading the forebody boundary layer in paralell to the engine flow-path to the nozzle and could be used to enhance the nozzle/afterbody expansion by blowing



Courtesy to MTU

Fig. 12 SÄNGER : Temperature Stresses in the Propulsion System

The figure shows the extreme temperature stress in the complete propulsion system. Results of work on the engine thermal balance clearly showed that the engine feasibility was mainly determined by the ability to cool surface areas subjected to extremely high temperatures. Temperatures of over 1800°C at the engine intake clearly indicate the cooling effort required for the structural components. Cooling structures for both air-cooled and hydrogen-cooled surfaces were identified during innovating design and development work wrt the thermal balance of the propulsion system.

The development of high temperature resistant, light weight materials plays a very important role for all propulsion components. Consequently:

- Materials and structures for the high temperature loaded components
- Auxiliary systems (e.g. air cooler, hydrogen pumps
- High temperature sensors and measurement techniques

were investigated in different studies.

Objectives:

- **Assessment of the impact of true temperature corresponding to flight Machnumbers up to 7 (requires "free-jet" testing)**

- **Data acquisition during test, verification and validation of design tools**

- **Impact of materials and structures on intake design and manufacturing for high temperature testing intakes with variable geometry parts (e.g. ramps with cooling, sealing, pressurizing, ...)**

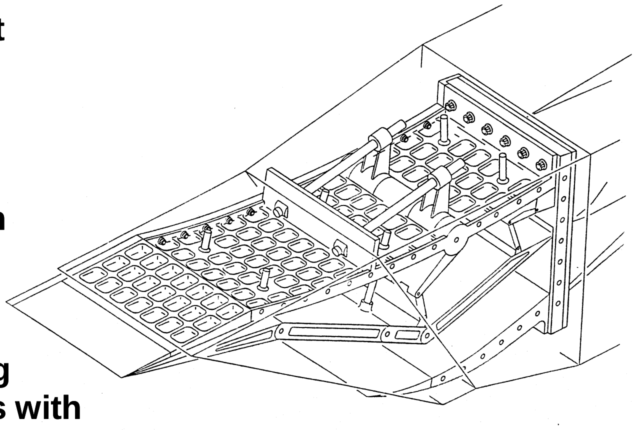
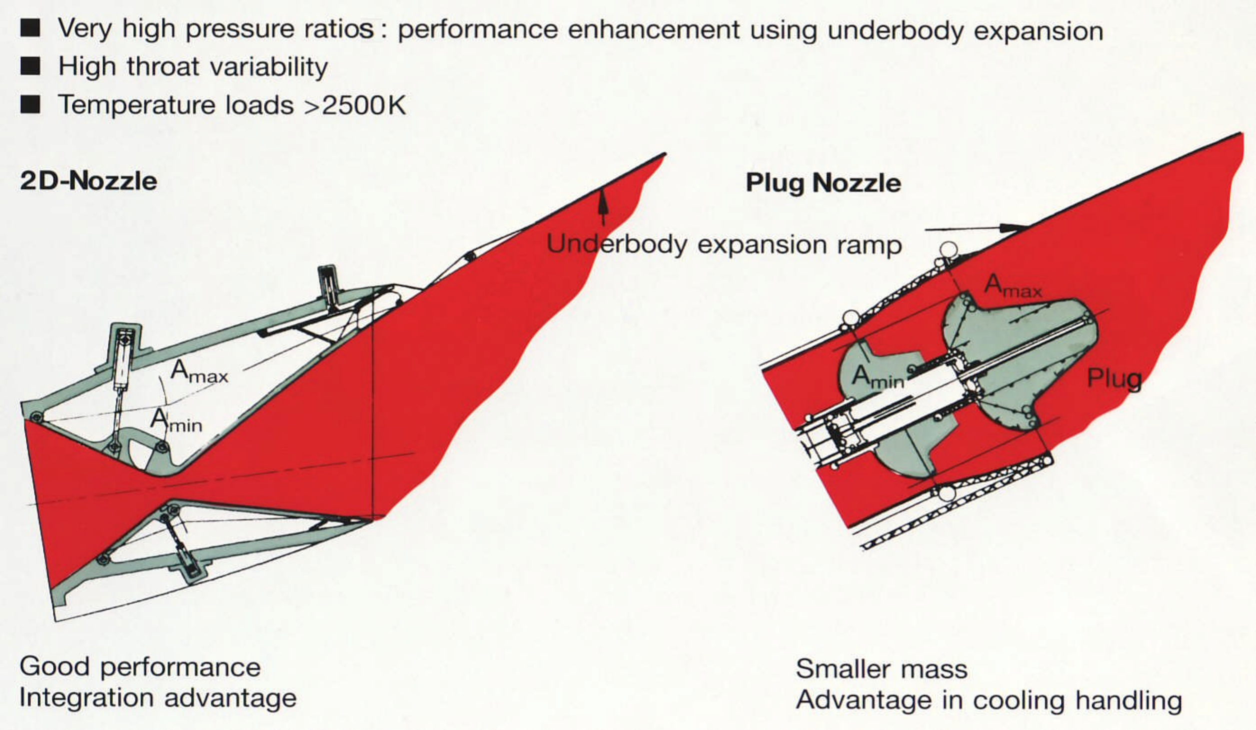


Fig. 13 Engine/Airframe Integration wrt Intake Design

Shows the Intake design to be built and flown on the hypersonic test-vehicle HYTEX RA-3. On this vehicle a possible engine configuration would have a combustion chamber of 50 cm and a total length of the complete engines of about 8m. Two windtunnel models with 2-D geometry with 1:10 scale had been designed and two of them were tested up to hypersonic speed in the German windtunnel TMK at the DLR in Cologne.

The **first** generic model with a cross flow section of 10cm x 10 cm, fixed ramps and movable side walls was tested at "cold" free-stream numbers of $M_\infty = 2.9$ and 5.
Based on this experience a **second** generic model was built with the same scale, but with boundary layer (from a flat plate simulating a forebody) without diverter duct and four movable ramps but again only in "cold" free-stream numbers of $M\infty = 4.5$, 5.0 and 5.2.
The next logical **third** step was then in 1994 the design of a full scale intake to complete the SÄNGER propulsion system. The combustion chamber with nozzle was already tested in the MBB connected pipe test facility in Ottobrunn with a 30 cm diameter scale. It was planned to integrate all three engine components in the large 50cm diameter scale in 1995 and to test the complete engine in a large windtunnel test facility up to Mach 7. The choice was made to use for this test the APTU test facility of AEDC, Tullahoma in the United States.



- Very high pressure ratios : performance enhancement using underbody expansion
- High throat variability
- Temperature loads >2500K

Good performance
Integration advantage

Smaller mass
Advantage in cooling handling

Courtesy to MTU

Fig. 14 Trade-Off for the design of a variable geometry engine nozzle concept

Test facilities had been used in 1992 for investigating combustion chambers combined with hydrogen cooled nozzles. Hypersonic nozzles have to be optimized to provide maximum thrust over a wide operational range. Two types of nozzles with variable adaptive geometry had been studies within an extensive design trade-off:

- 2D nozzles types with a rectangular cross section and
- Axisymmetric plug nozzles

To select a final nozzle concept detailed measurements were required, in particular of wrt the chemical composition of exhaust gases in the nozzle in order to obtain precise data on the nozzle thrust generation. Therefore at MTU, MBB and DLR complementary test facilities were modernized or newly built to perform more realistic ground tests.

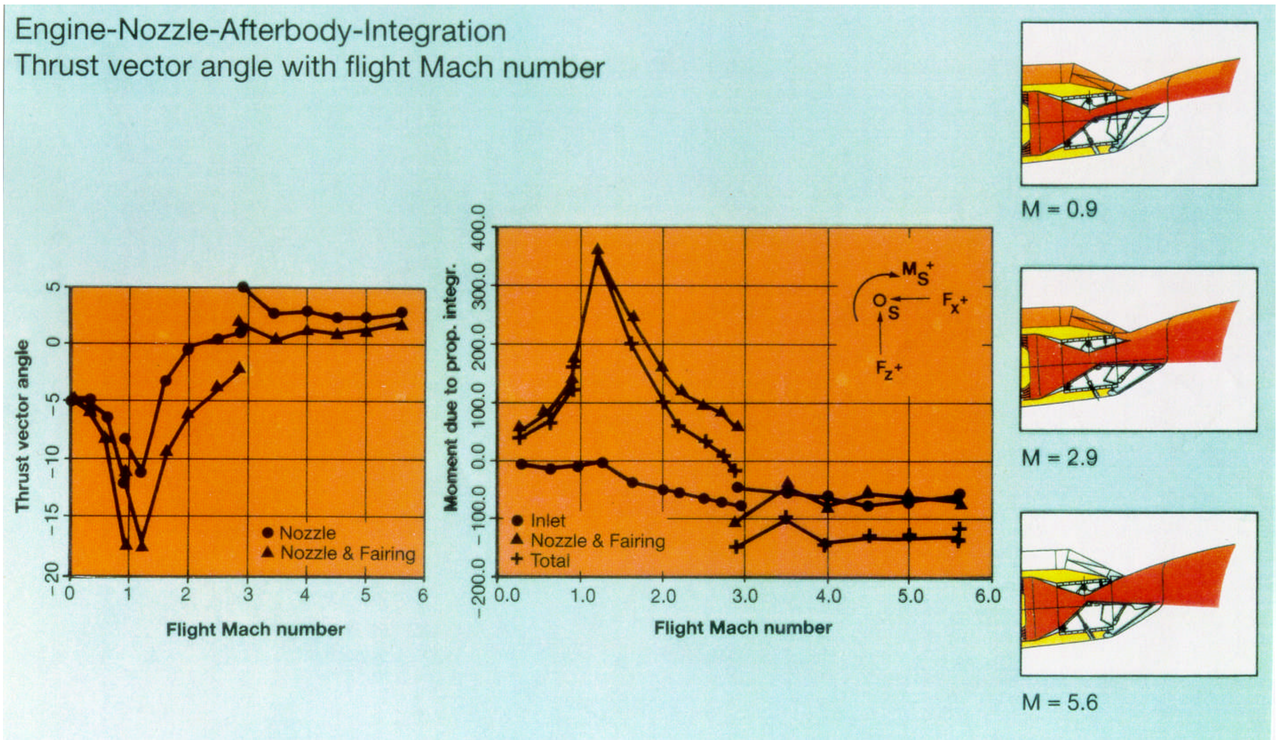
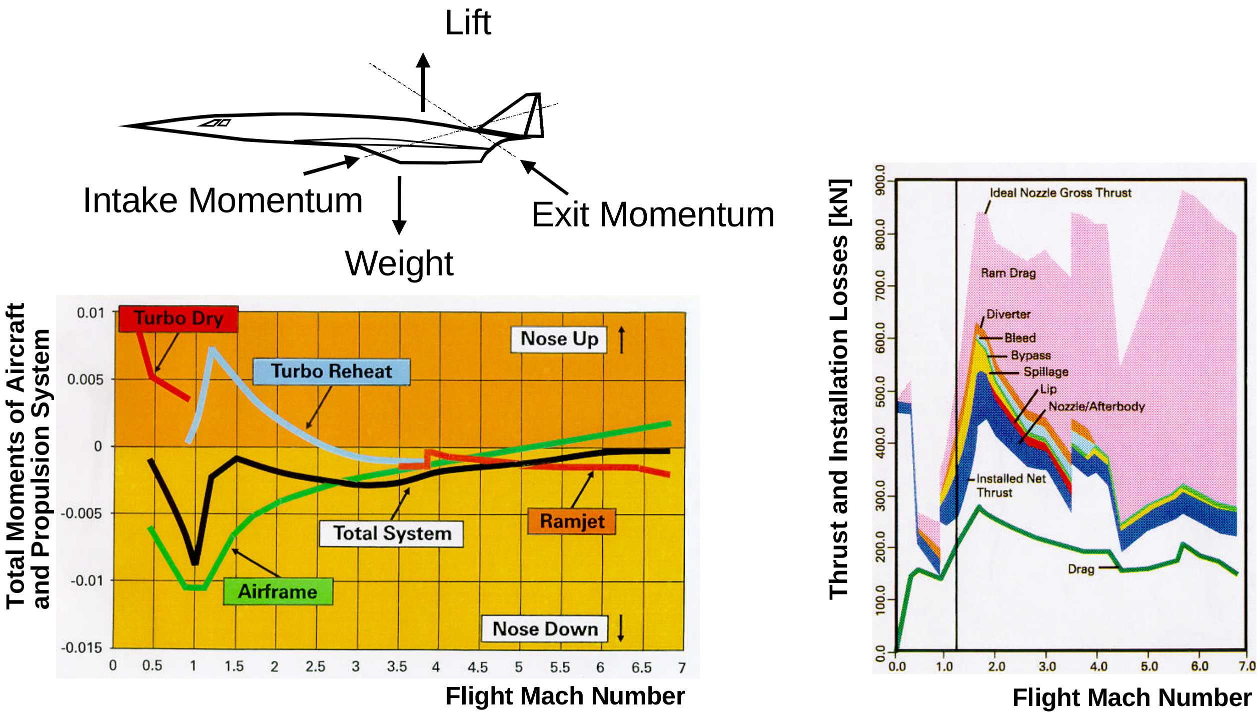


Fig. 15 "Key Technologies": Impact of Thrust Vector Angle and Longitudinal Pitching Moment due to a SERN Nozzle/Afterbody Integration

In addition to the engine airframe integration effects on drag is its effect on the longitudinal moment of the flight vehicle. Therefore these propulsion system's induced effects have to be optimized together with the aerodynamic flight mechanics and flight performance together with the design of the airframe. It has already been discussed that the forces acting at the intake as well as the nozzle and after-body expansion rate are not in line with the flight direction. Due to the strongly asymmetric design of the intake and nozzle and due to the great distances between the components of the propulsion system and the center of gravity of the vehicle, the resulting moments are in the same order of magnitude as the aerodynamic moments of the aircraft itself. The Fig. shows the impact of the Turbo- and ramjet-effect during operation. During low subsonic, transonic und low supersonic flight the compensation of the nose-up generated pitching moment by aerodynamic controls would result in additional trim-drag. Therefore the design of the shape of the airframe ("Camber") can balance the nose-up moment to some extent. The same process works for supersonic speed in the opposite direction.



Courtesy to Heitmeir/Lederer/Herrmann, AIAA-92-5057, December 1-4,1992,

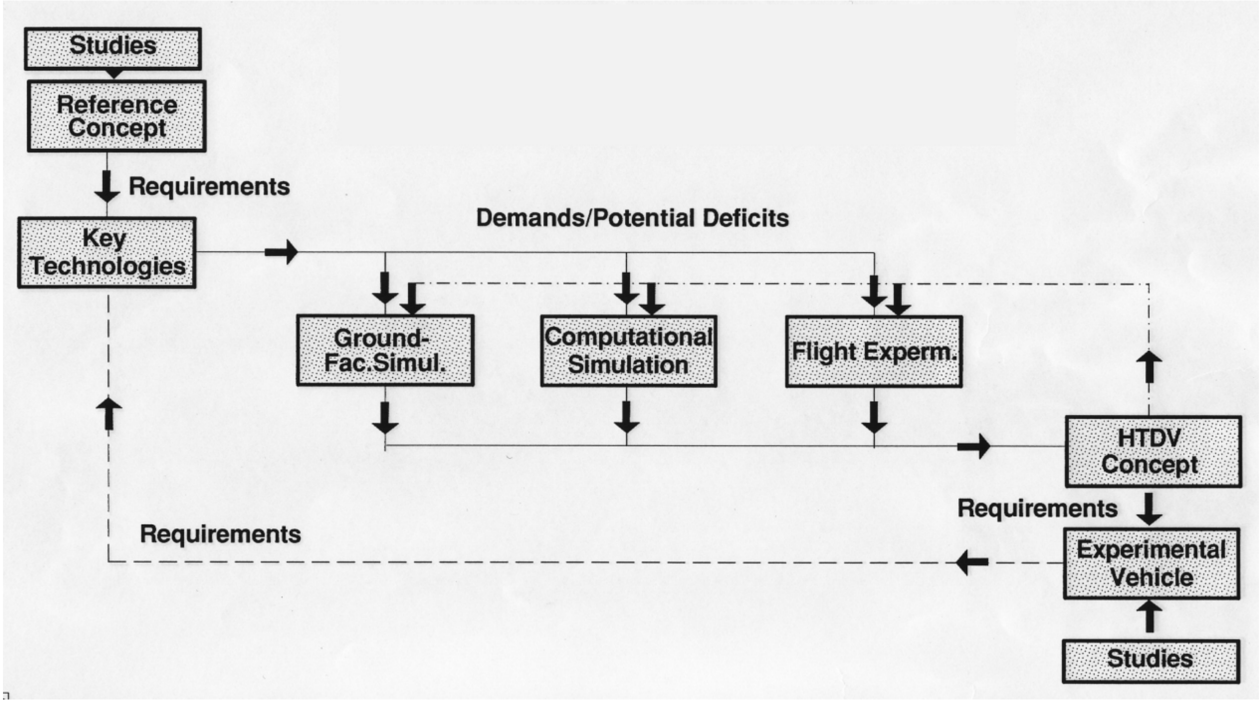
Fig. 16 "Key Technologies": Engine/Airframe Integration wrt Thrust-Drag and C_{m0}

This viewgraph shows schematically the major aerodynamic forces acting on an aircraft with an integrated airbreathing engine. There are very high forces at all engine components and the resulting net-thrust to accelerate the vehicle against the aerodynamic drag is a small difference of nearly equally high numbers. This becomes specifically true at transonic speeds (e.g. "show-killer" for the NASP). There is a high sensitivity with regard to nozzle-aft-body-integration, losses due to the intake-installation and the real gas effects at hypersonic speeds beyond Mach 5. The impact of forces related to the engine on the pitching moment of the total vehicle is important (e.g. trim-losses). The conclusion is that the **propulsion system and the airframe have to be optimized together**.

The figure on the right side shows the results from the SÄNGER first stage analysis of ideal nozzle gross thrust, installation drag brake-down, the installed net thrust and the overall vehicle drag. **Please note:** Installation losses due to propulsion integration are of the same order as vehicle drag.

In the previous figure the impact of the resulting thrust vector direction (Intake and Nozzle) on the overall pitching moment. On the left side now is shown the total moment's balance for SÄNGER. These propulsion system's induced effects had to be optimized together with the aerodynamic flight mechanics and flight performance together with the design of the airframe. Due to the strongly asymmetric design of the intake and nozzle and due to the great distances between the components of the propulsion system and the center of gravity of the vehicle, the resulting moments are in the same order of magnitude as the aerodynamic moments of the aircraft itself.

3.0 THE TECHNOLOGY DEVELOPMENT AND VERIFICATION CONCEPT (TDVP)



Courtesy to Hirschel, AIAA-93-5072, Nov.30-Dec. 3,1993,

Fig. 17 HTP: The Hypersonics Technology Development and Verification Concept (HTDV)

After having identified a large number of most critical "Key-Technologies" during the early study work in the Hypersonics Technology Program a strategy was needed for the development of these so-called "enabling" technologies which were mandatorily required to design develop and finally build a future viable new space transportation system which could compete with the available expendable rocket based. That means to lower the cost for payload to orbit.

<u>This strategy named HTDV follows has four basic phases:</u>

1. Definition of mission requirements for the new STS
2. Conceptual design of a potential system reference concept
3. Identification of the enabling concept dependant "Key-Technologies"
4. Verification of the new technologies using experimental (EFD), computational (CFD) and finally flight testing to reach the technology readiness level 6 (NASA definition)

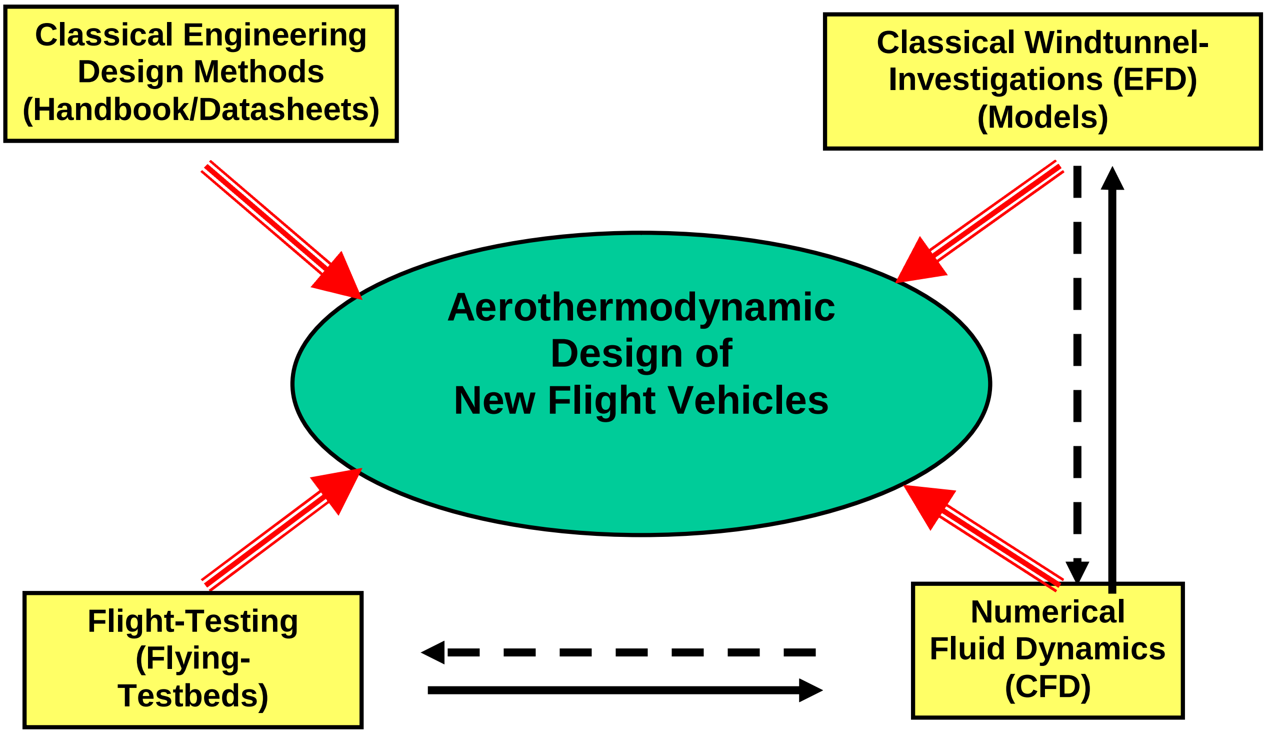


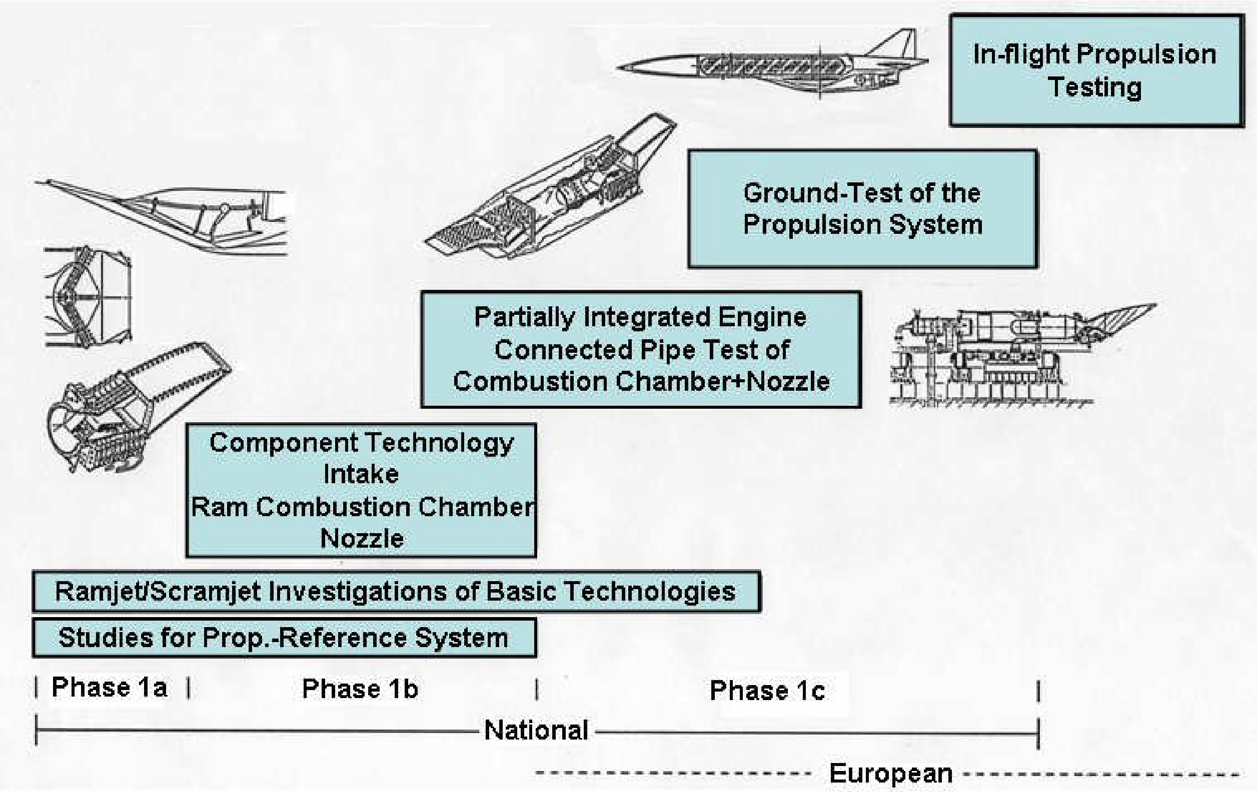
Fig. 18 Aerothermodynamic Design & Development Tools

Most of the design efforts up to the late 70th were still relying to a large degree on windtunnel testing.

But the large number experimental efforts has led to the assessment of large databases which had been used consequently by engineers in research institutes and aircraft industry to establish empirical procedures, so-called datasheets, which allowed to predict aerodynamic coefficients in a complementary way to much more costly experiments.

By that time more powerful computers came up and fully theoretical methods (Computational Fluid Dynamics, CFD) became more and more powerful. Starting with the solutions of potential flow in the late 60th ("e.g. "Panel Methods"), these methods were extended to solutions of the Euler and Navier Stokes Equations soon. The remaining major problem was code validation and, more specifically, the numerical simulation of viscous flow. But the capabilities of the available ground testing facilities were, concerning the simulation of high speed, only limited.

The only way to get reliable aerodynamic data is flight testing, being in Europe in most cases too expensive and time consuming but very successfully performed in US.



Courtesy to Heitmeir, IAF-94-V.5.554, October 9-14,1994,

Fig. 19 SÄNGER: Strategy for the Propulsion System Development

A general strategy for the development of this impressive SÄNGER propulsion system concept was established from the beginning of the technology work 1988 in a Phase 1a.

It led to the development of the engine components in Phase 1b and finally ended with successfully performed tests of a partially integrated propulsion system (Ram combustion chamber and 3D Nozzle) in the ground test facility up to Mach=7 at MBB in Ottobrunn.

Several flying test-beds were proposed to validate the propulsion system or at least some of its component by flight testing.

At the end of 1994 the propulsion system development suffered a setback. A government decision was taken that the program had to be finished strictly by the end of 1995. Due to the cancellation of the Hypersonic Technology Program, this nearly complete engine remained a dream of its design engineers – and the existing hardware went to the German museum.

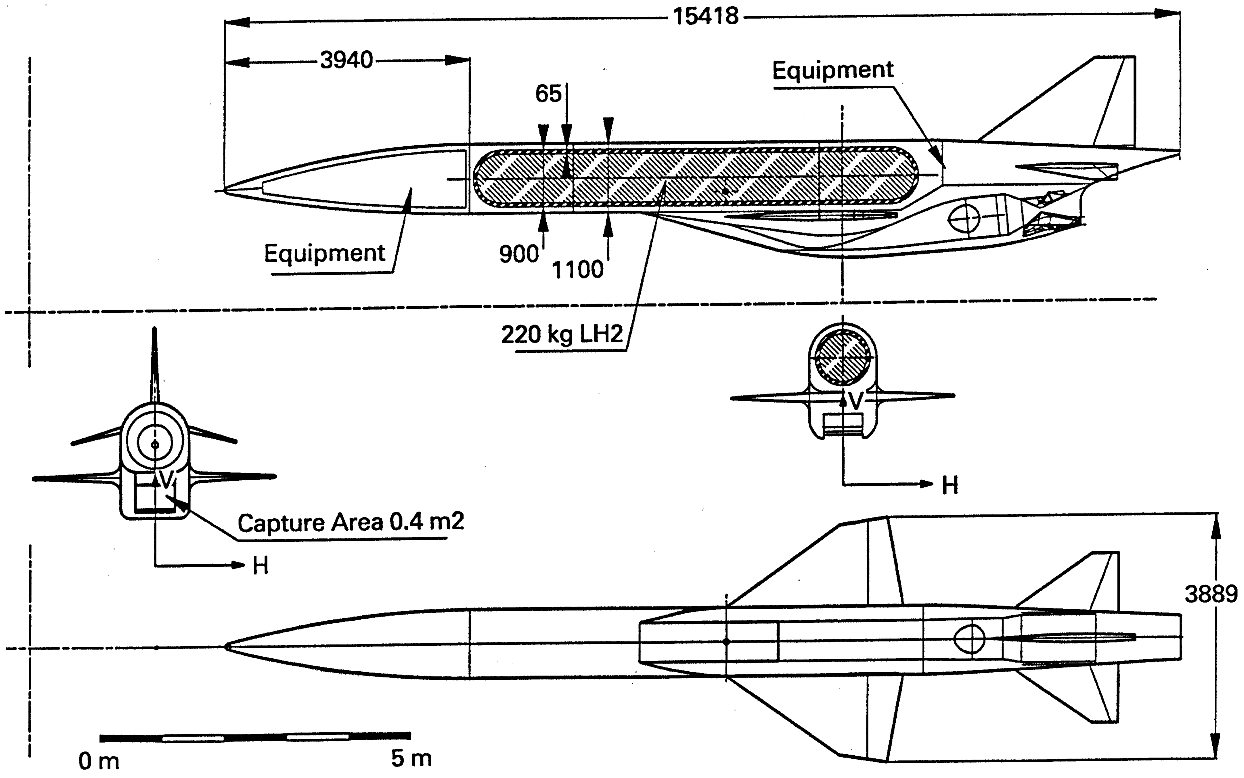


Fig. 20 Hypersonic Flight Test Vehicle: HYTEX R - A3

The study of alternative flight test vehicles started in Phase 1a and continued in Phase 1b. It was devoted to investigate not also technically **feasible** but also **affordable** alternative concepts of flight test vehicles and in that context to look for possibilities of international cooperation. This should lead to the result that existing flight hardware, available in other countries, could be used.

As a result of this international cooperation HYTEX R-A3 was defined as a reference vehicle concept with rather maximum test objectives representative for a SÄNGER-like complete propulsion system (due to volumetric constraints with the exception of hydrogen as fuel):

- HTO, transition turbo/ram, $Ma_{max} > 5$ and horizontal landing)
- Stability and control could be demonstzrated
- The thrust vector at different Mach-number and different equivalence ratios for the ram jet propulsion system (combustion chamber with 600 mm diameter) integrated with the airframe of the HYTEX R-A3 seemed feasible.

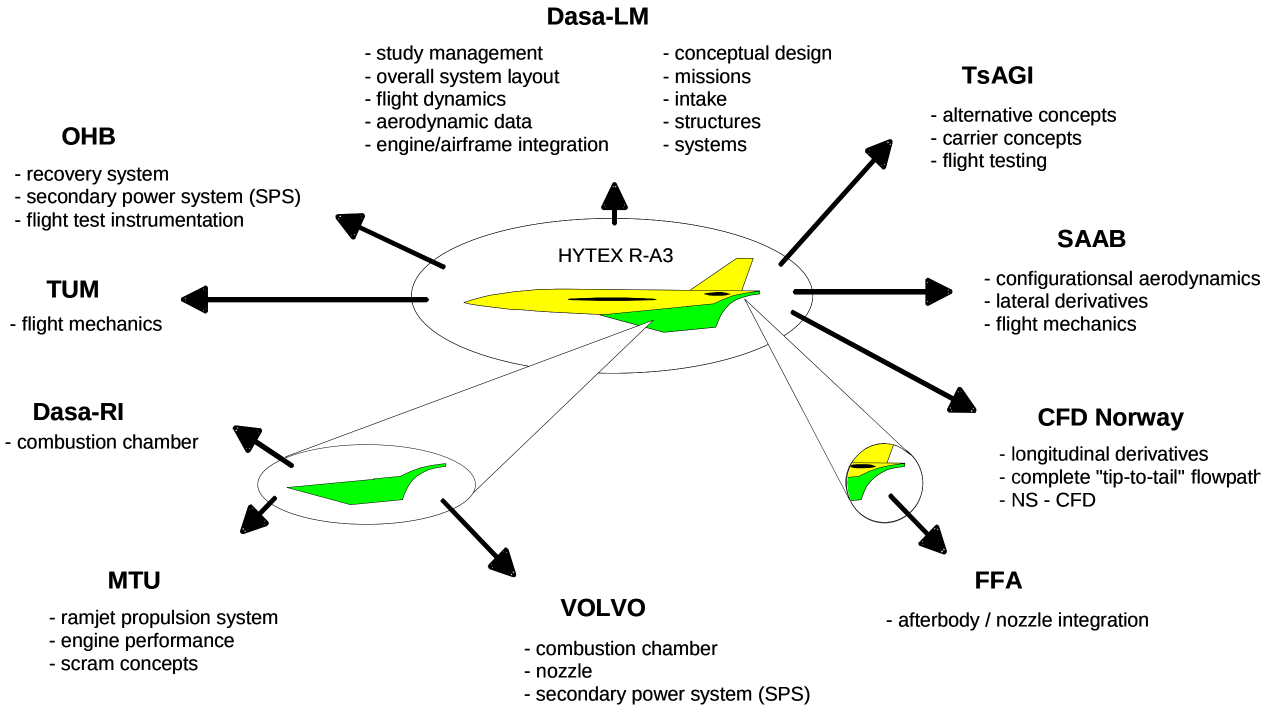
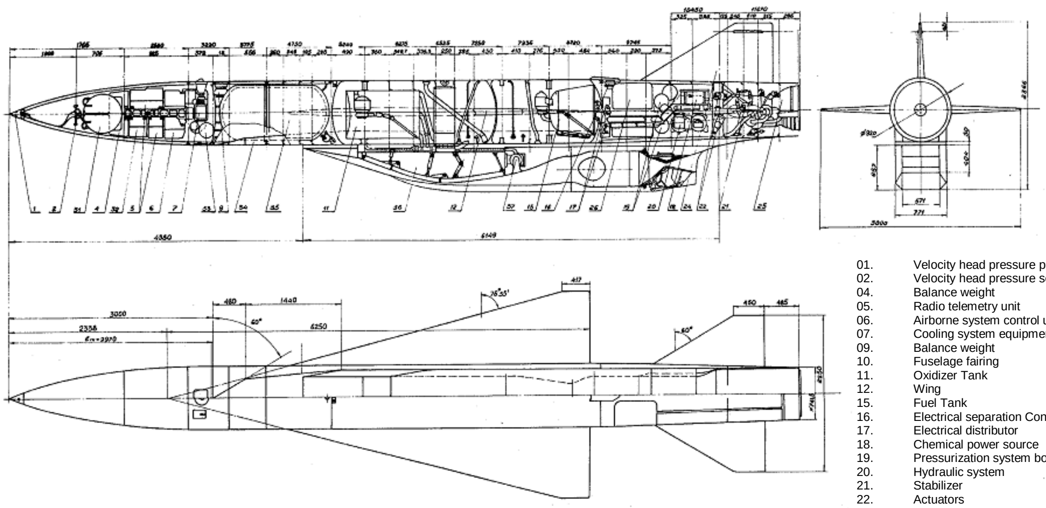


Fig. 21 Study of Alternative Concepts and Configurations of Hypersonic Flight Test Vehicles - Cooperation with Partners in Phase Ic (Status: April 1994)

International partners involved were from Sweden and Norway for theoretical parts and from Russia as far as testing possibilities are concerned. Also Cooperation with France was regarded in parallel in an additional study which was offered to CNES in France and BMFT in Germany.



01. Velocity head pressure pick-up
02. Velocity head pressure sensors
04. Balance weight
05. Radio telemetry unit
06. Airborne system control units
07. Cooling system equipment
09. Balance weight
10. Fuselage fairing
11. Oxidizer Tank
12. Wing
15. Fuel Tank
16. Electrical separation Connector
17. Electrical distributor
18. Chemical power source
19. Pressurization system bottles
20. Hydraulic system
21. Stabilizer
22. Actuators
24. Dorsal fin
25. Liquid propellant rocket engine
26. Parachute container
31. RAMJET nitrogen cooling system storage tank
32. RAMJET control unit
33. High-pressure helium bottle
34. RAMJET and its service lines fairing
35. Thermal-insulated LH2 tank
36. Studied RAMJET module
37. RAMJE fuel system pump

Fig. 22 RADUGA D2 with Integrated Turbo-Ram Engine for Flight Testing

01. Velocity head pressure pick-up
02. Velocity head pressure sensors
04. Balance weight
05. Radio telemetry unit
06. Airborne system control units
07. Cooling system equipment
09. Balance weight
10. Fuselage fairing
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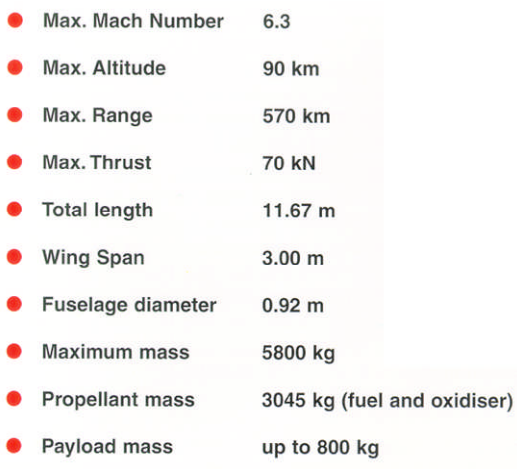


● Max. Mach Number	6.3
● Max. Altitude	90 km
● Max. Range	570 km
● Max. Thrust	70 kN
● Total length	11.67 m
● Wing Span	3.00 m
● Fuselage diameter	0.92 m
● Maximum mass	5800 kg
● Propellant mass	3045 kg (fuel and oxidiser)
● Payload mass	up to 800 kg

Four Variants for “Step-wise” Approach planned:

Variant 1:	**Variant 1:**	**Variant 1:**	**Variant 1:**
RADUGA D2 HFT as an aerothermodynamic flight experiment in 1996 (basic version)	Basic Version of variant 1 plus implementation of a recovery system	RADUGA D2 HFT with adaptation of a Scramjet (Dasa/MTU/TsAGI)	RADUGA D2 HFT with adaptation of a Ramjet

**Fig. 23 Alternative Designs for Hypersonic Flight Test Vehicles
Study Stage III (January 1995- December 1995)**

Mainly due to cost at the end of all study work on alternative flight test vehicles for hypersonic speed the RADUGA D2 remains as the only affordable concept. The most important characteristics of this vehicle will be summarized. The missile can be launched under the Russian Tupolev Tu-22M3 at low supersonic speed (Mach = 1.7). It can reach a maximal Mach number about 6.3. It is a design from the late 60th and has flown many times for military purposes.

The main modification for the cooperative effort were related to fly small scale propulsion modules investigated in the Russian test facilities at TsAGI and CIAM and now mounted under the fuselage of the missile. A small hydrogen tank was integrated in the nose area.

The picture show the RADUGA missile which was exported from Russia to OHB in Bremen.

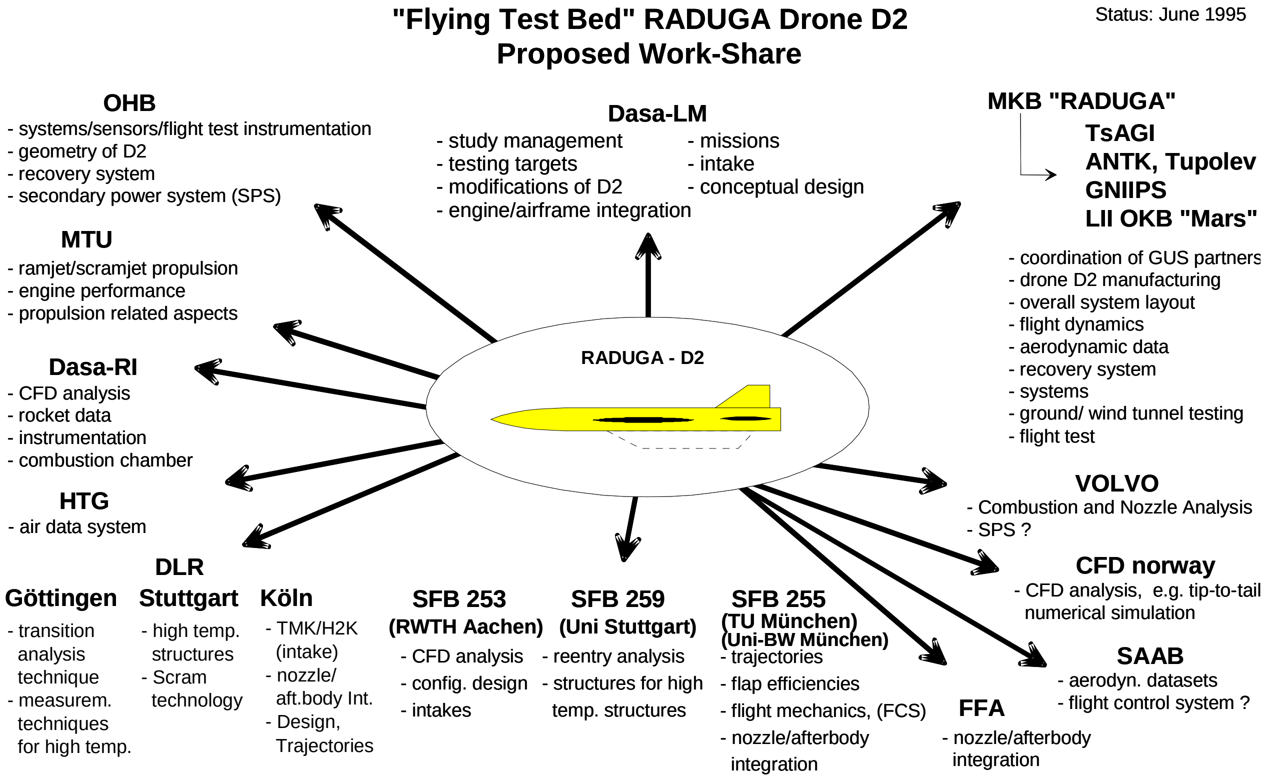


Fig. 24 Study of Alternative Concepts and Configurations of Hypersonic Flight Test Vehicles Phase Ic

For the RADUGA D2 flying testbed an agreed work-share of international institutions of industry, research institutes and universities is shown in the next figure. The activities cover all technical disciplines needed for launch, flight demonstration after separation from the carrier aircraft at supersonic speed, data acquisition and transmission to the ground and recovery of the vehicle on ground. It should be mentioned that the German OHB had already received a real hardware of the RADUGA missile D2 from the Russian partners which can be seen in Bremen exposed to visitors. Unfortunately the program was cancelled end 1995. Ten years later a similar experiment has been flown in the US using a Pegasus first stage carrying the X-43A being launched from a B2 which required a Budget one ordered of magnitude higher than the European/Russian approach.

4.0 MAJOR RESULTS AND LESSONS LEARNED

Major achievements at the end of Phase Ia und Ib (1989-92):

Propulsion:

- LH2-Ram-Combustion-Chamber up to M = 7
- Ram-Combustion Testfacility with unique gas generator up to M = 7
- Intake-Models tested at hypersonic speed
- LH2-cooled 2-D Nozzle and tests integrated with the ram-combustion chamber

Materials and Structures:

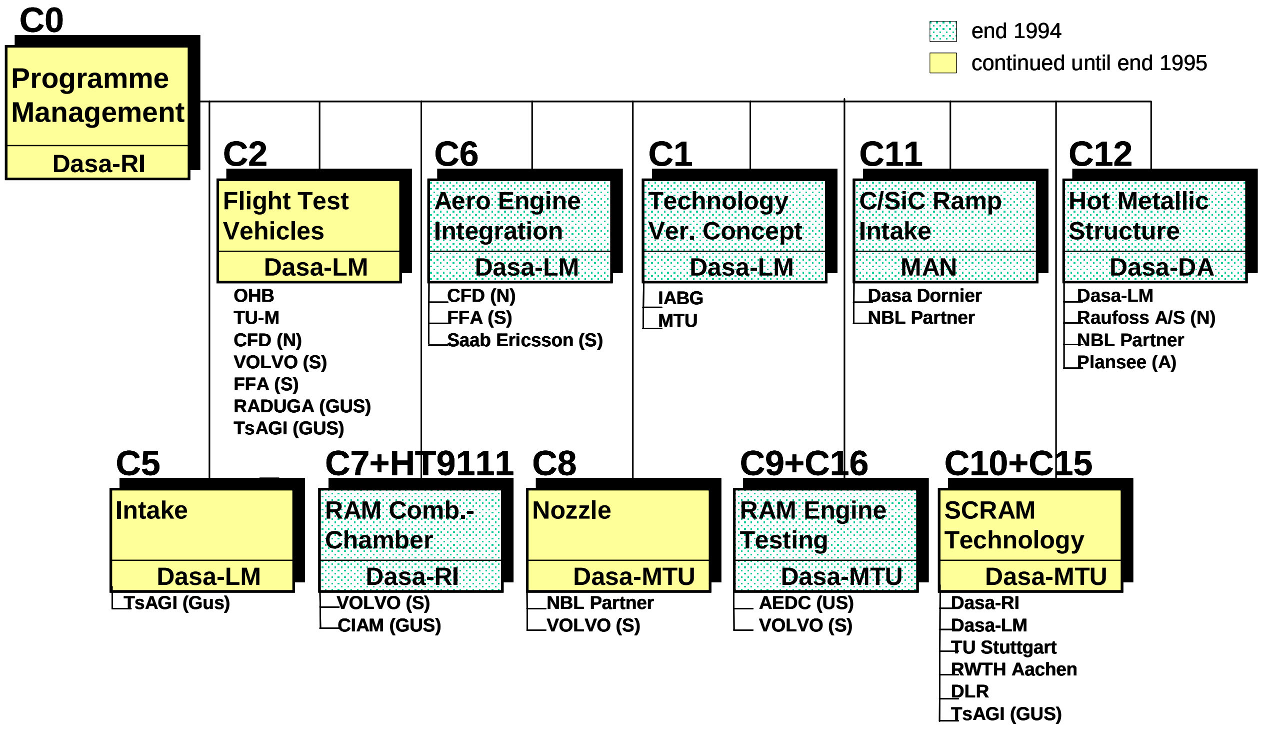
- Intake Ramp using C/SiC for high temperatures
- Hot Metallic Structures (based on Titanium) for wing- and 3-D body-panels

Aerothermodynamics:

- Development and validation of approximate prediction methods
- Numerical and experimental simulation of external and internal flows
- Numerical and experimental simulation of stage separation

Flight Control and Systems:

- Air-Data-Sensor-System for acquisition of data at hypersonic flight
- Hot Actuator Systems



*) HTP, initiated 1988 and sponsored by the German Federal Ministry for Research and Technology (BMFT)

Fig.25 Program Activities in Phase Ic (1993-1995)

The third and last part of the German National Technology Program in Phase I was Phase Ic. The conceptual and technological investigations of Phase Ia and Phase Ib have shown that the SÄNGER concept – apart from some not yet verified assumptions – seems to be at least technically feasible. To foster the basis for this statement and taking into account some budgetary constraints the work in Phase Ic had to be concentrated on a few most important technical issues. The chart shows all the remaining 10 "projects" having started finally with some delay in mid March 1993. All but two tasks (C1 and C11) were undertaken in cooperation with international partners. Only the yellow marked Projects "survived" the budget cut in 1994:

C2	Investigation of the Flight Test vehicle RADUGA D2
C5	design and development of the 50 cm Intake
C8	Design and development, manufacture and test of the nozzle including the expansion ramp for the 50 cm ram engine combustion chamber
C10	Design and development, manufacture and test of four different model combustion chambers with exchangeable fuel injectors for connected pipe tests at CIAM (Russia)

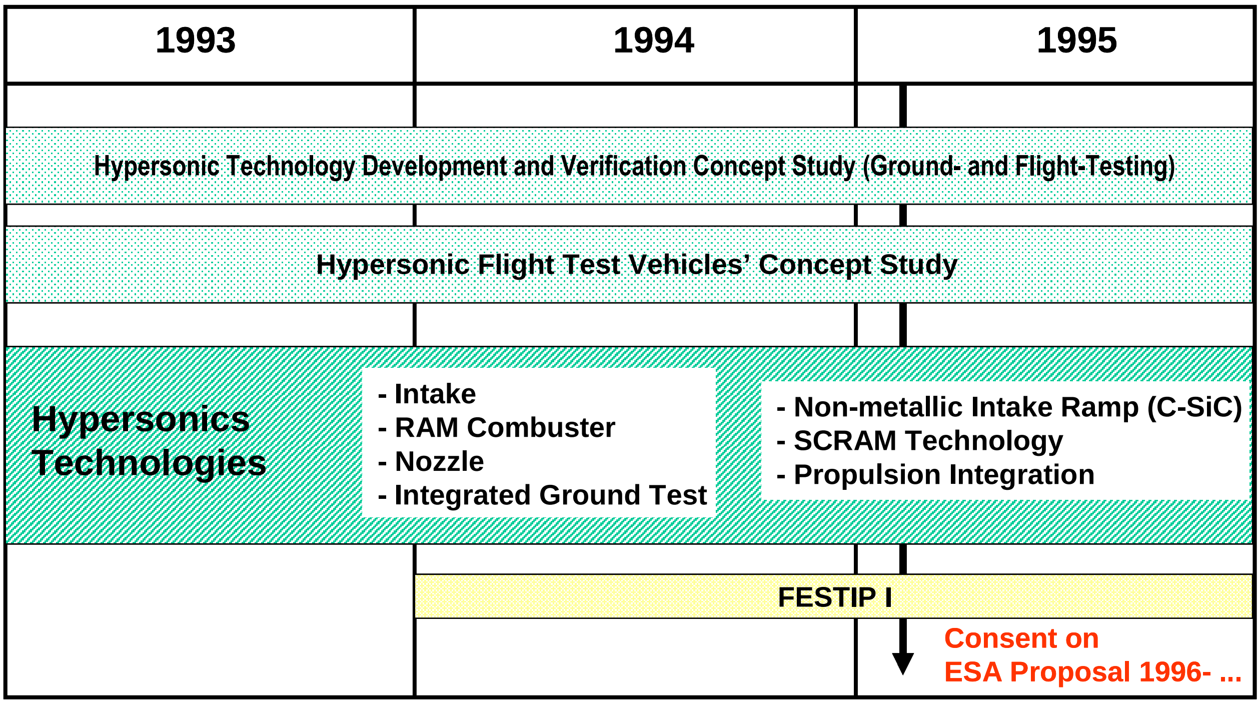


Fig. 26 **HTP - Planned Activities in 1993 -1995 (Phase Ic)**

The German Hypersonics Technology Program Phase 1 (1988-1995) was a very comprehensive technology effort. Unfortunately, very close to the final step of ground testing the SÄNGER propulsion system in a large scale model in a free jet test facility in the US, the program was terminated (as initially planned for 1995).

Transition from the Hypersonics Technology Programme (HTP) to the Future European Space Transportation Investigations Programme (FESTIP) was then the only way to maintain continuity for the engineering team at Ottobrunn as well as for any continuation of successful cooperation with many international contacts which were established during the HTP, although the airbreathing propulsion technology was no longer subject of the technology work

Major Achievements to reached by Phase Ic*)

Propulsion:

- Intake model ETM3, operating in a windtunnel at hypersonic speed
- Propulsion system, including intake, combustion chamber and nozzle, investigated in a large test facility (CIS, US) up to M=7
- SCRAM combustion chamber, tested in small scale in test facility

Materials and Structures

- Hot metallic structures for wing-body and integral tank, verified on ground
- Intake ramp, based on ceramic matrix materials, tested at high temperatures
- Design tools, validated to a reliable degree, validated by ground tests

Aerothermodynamics

- Design tools, validated to a reliable degree, validated by ground tests
- Numerical and experimental simulation of external and internal flows
- Advancement of the methodology for propulsion integration

Flight Control and Systems

- Sensor systems for data-acquisition in flight up to M = 7(8)
- Simulation and component testing of critical systems

And:
- Establishment of a "Technology Development and Verification Concept" for a Step-by-Step demonstration of "Key-Technologies"
- Proposal for a concept of a feasible flight test technology demonstrator with a broad based modular design concept, to be build and tested in international cooperation (ESA)

***) bold : reached end 1995**
Italic: terminated due to budget cuts

BMFT-Initiative terminated end 1995

- 440 MDM spent including funding from German Industry, Research Institutes and Universities
- Sänger Turbo-Ram propulsion system not completed (intake)

Major Know-How gained:

- Rationale for the selection of the SÄNGER reference propulsion system
- Trade-offs for alternative airbreathing combined propulsion cycle engines
- Development of Engine/Airframe integration techniques
  (e.g. intake, internal flow duct, nozzle, B.L. diverter/internal duct,...)
- Development of propulsion hardware components
  (intakes, combustion chambers, nozzles)
- Database from windtunnel testing of SÄNGER and HYTEX Models
  (DLR-TWG, -TMK, -H2K, FFA-S4, -T1500, TsNIIMASH-U4M)
- Database from windtunnel testing of propulsion components
  e.g. intakes, combustion chambers, Nozzle concepts (DLR, Dasa, TsAGI)
- Structural Design Concepts and selected hardware components developed and tested
  (e.g. tanks, flaps, insulations, TPS, ...)

		Budget Planned		Budget Spent
Phase 1a + 1b (1988-92)	- BMFT[1]	220		200
	- Industry	30-40		40
	- DLR[2]	90		80
	- DFG[3]	20-30		
		370		32
		2/93	7/94	
Phase 1c (1993-95)	- BMBF	145	95	70
	- Industry	35	25	20
	- DLR			
	approx.	40	40	40
	- DFG			
		220	160	130
Phase 1, total (1988-95)		**590**	**530**	**450**

[1] German Ministry for Research&Technology, [2] German Aerospace Institute, [3] German Research Society

Fig.27 HTP / Budget (Currency in Mio DM)

Concluding Remarks:

After 7 years of intensive international cooperation the German national Hypersonics Technology Program was abandoned. Mainly three major periods of activities characterize the initiative:

First	After intensive configurational trade-offs the TSTO system concept SÄNGER was chosen to identify the most critical "Key-Technologies" which are mandatorily needed to realize this advanced European next generation fully reusable Space Transportation System. The SÄNGER fist stage concept was based on an airbreathing propulsion system which seems to be the best way to a fully reusable system. So the stage separation Mach number and altitude seem to be achievable. For the upper stage it was assumed to relay on the re-entry technologies developed at the same time in the European HERMES program.
Second	Based on this identified most critical "Key-Technologies" a Technology Development and Verification concept was established and in four technical disciplines were working groups established: - Propulsion technology - Materials and structures - Aerothermodynamics - Flight Control and Systems Resulting from these activities hardware was designed built and tested
Third	In the last phase of the program the activities were concentrated first of all on the propulsion system components (e.g. intake, combustion chamber and nozzle). Mainly due to the conclusion that propulsion engine/airframe successful integration only could be proved by flight testing a number of flight demonstrator concepts were investigated some of them with intensive cooperation with Norway, Sweden und Russia.

After the termination of the Hypersonics Technology Program it was decided to turn over all the technical know how and engineering experience into the new Future European Space Transportation Initiative Program (FESTIP) which was initiated by ESA in 1995.