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SÄNGER II, A Hypersonic Flight and Space Transportation System

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ABSTRACT:

The paper presents the actual design status of the SÄNGER Advanced Space Transportation System which comprises a hypersonic aircraft as first stage (EHTV). This vehicle (European Hypersonic Transport Vehicle) has been conceived for a dual purpose: to serve as the first stage of a launch vehicle with cruise capability, which is required to reach the space station orbit (28.5 deg) from Europe, and in the same basic configuration as passenger plane with some 230 passengers (business class) for a range of more than 10 000 km. The optimum cruise speed seems to be Mach 4.4 in 24.5 km altitude for economic and environmental reasons. The maximum speed for the launcher stage will be Mach 6.8 in 31 km altitude before separation of the upper stage. The EHTV uses turboramjet engines with 350/400 kN thrust level and liquid hydrogen as fuel. The design and performance characteristics of the vehicle will be described, as well as the programmatic aspects.

1. INTRODUCTION

SÄNGER is representing a new generation of space transportation systems winged reusable vehicles. For the first time, a real cooperation of aeronautics and astronautics is required to realize such a system.

Moreover, one of the inherent features of the SÄNGER project is to realize two major future challenges: a new space transportation system, and a hypersonic transport aircraft - with only one development program and investment - a real synergy effect!.

This is feasible because SÄNGER is a two-stage vehicle (FIG. 1) comprising a first stage with turboramjet engines and cruise capability. The cruise capability is required if Europe seeks real autonomy - and that means launches directly from a European airport. Vertical launches are not feasible from Europe due to safety reasons. So only horizontal launch from airports are possible. This fact plus the required cruise range is the geopolitical logic behind the SÄNGER concept.

SÄNGER also features the modern trend to separate manned space operations and (unmanned) cargo/satellite launches. It is neither practical nor necessary to employ pilots in launching unmanned payloads. SÄNGER for this reason has two different upper stages (FIG. 2). HORUS, the manned, winged vehicle with small payload for space station supply missions and crew exchange, and CARGUS, the expendable ballistic upper stage for LEO payloads up to 15 Mg.

The new vehicle concept was named SÄNGER to honour the famous German engineer and scientist who

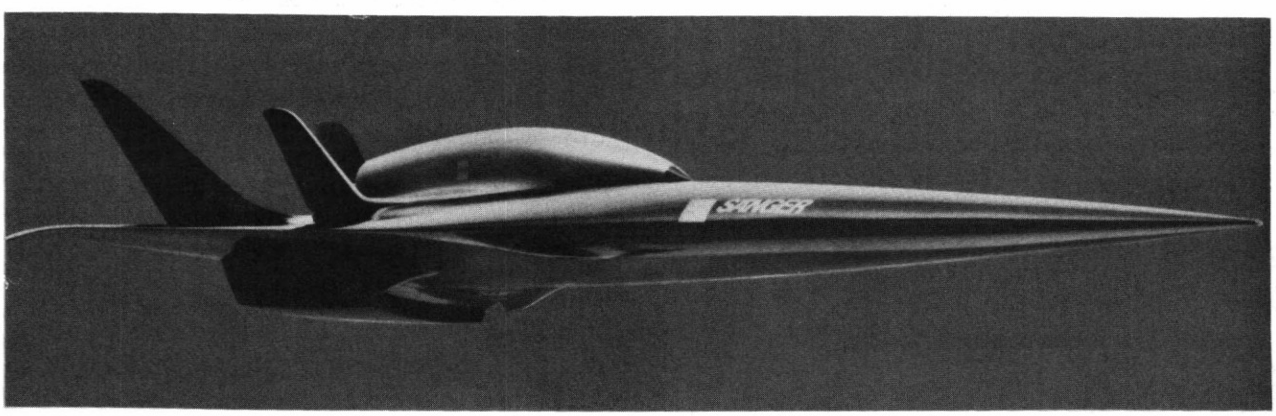

FIG. 1: SÄNGER Space Transportation System with HORUS second stage for manned space operations

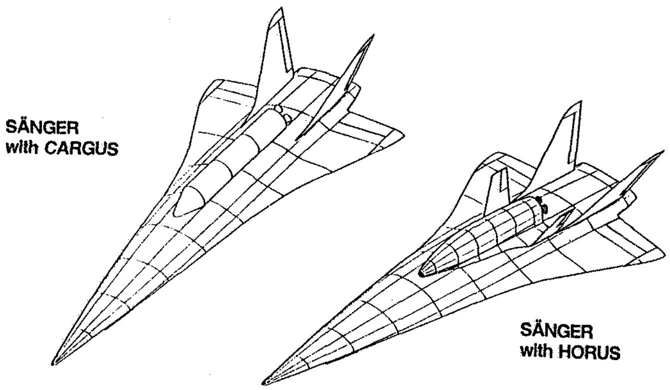

FIG. 2: SÄNGER hypersonic first stage vehicle configuration with the two upper stages

made essential contributions to rocket and ramjet propulsion; he also conceived the first hypersonic winged vehicle.

The SÄNGER concept was originated by MBB in 1985/86 and let to a feasibility study contract by the BMFT, the German Ministry for Research and Technology, in 1987. Since early 1988 a comprehensive 2.5-Year System Definition Study has been started. Four MBB Divisions are cooperating with other German Companies (Dornier, MTU) and Institutes (DFVLR). In parallel, a five-year hypersonic technology program has been initiated.

This paper gives the design status of SÄNGER as of early 1988, and concentrates on the first stage, the so-called EHTV (European Hypersonic Transport Vehicle).

2. SÄNGER CONFIGURATION AND CHARACTERISTICS

FIG. 3 provides a classical three-side view of SÄNGER with the HORUS upper stage. The main data are summarized in TABLE I. The launch mass is comparable with present large aircraft and should not pose problems to existing runways.

The first stage is configured for 100 Mg propellant mass (liquid hydrogen) which meets both the launch vehicle requirement (upper stage mass of 76 - 91 Mg with 2 x 3500 km range) and the passenger plane requirement (35 Mg payload and range of more than 10 000 km).

The HORUS payload of 3300 kg for the Space Station supply and crew exchange mission is sufficient and compatible with a bi-monthly mission for a continuously manned European Space Station.

The CARGUS payload capability of 15 Mg is large enough for the launch of space station modules and

TABLE I : SÄNGER II Main Data Summary

TOTAL LAUNCH MASS		340 Mg
	Vehicle length	84,5 m
	Wing Span	41,4 m
	Hypersonic L/D	4.8 - 5.5 (5°)
FIRST STAGE (EHTV)	Total Mass	259 Mg
	Nominal Net Mass	149 Mg
	Maximum Propellant Mass (LH_2)	100 Mg
	Engine Thrust (ground)	5 x 300 kN
	Max.Speed (at Separation)	Mach 6.8
	Cruise Range	2 x 3500 km
SECOND STAGE HORUS	Total Mass	87.7 Mg
	Nominal Net Mass	22.2 Mg
	Propellant Mass (LOX/LH2)	65.5 Mg
	Engine Thrust (vac)	1 x 1500 kN
	PAYLOAD	(2 - 4) 3.3 Mg
SECOND STAGE CARGUS	Total Mass	61 Mg
	Nominal Net Mass	6 Mg
	Propellant Mass (LOX/LH2)	55 Mg
	Engine Thrust (1 HM.60)	1050 kN
	PAYLOAD	5 -15 Mg

platforms, as well as for the launch of GEO spacecraft: either one satellite with 26 Mg, or two spacecraft with 1.2 Mg each.

Although it was not evident at the beginning of the studies, it could be proven that the same vehicle design and size can be used for both the space transport and hypersonic aircraft. However, there are operational differences which are shown in TABLE II.

The turboramjet propulsion system can fly economically both with Mach 0.8 (dry turbojet operation) and Mach 4.4 (ramjet operation). Due to the lower mass at take-off the engine thrust level can be lower for the HST vehicle which is compatibel with its much greater operational use (4 flights per day, vs. 1 or 2 flights per month for the STS-version). This results in some 20 000 flights for an HST and only 300 to 400 for the STS-version.

The main difference in requirements is the speed: while the HST is designed for Mach 4.4 cruise speed, the STS first stage needs to accelerate to Mach 6.8 before separation of the upper stage. Although this high speed applies only for few minutes the thermal design has to be updated by active cooling of the air inlet and by passive thermal protection of the lower fuselage and wings.

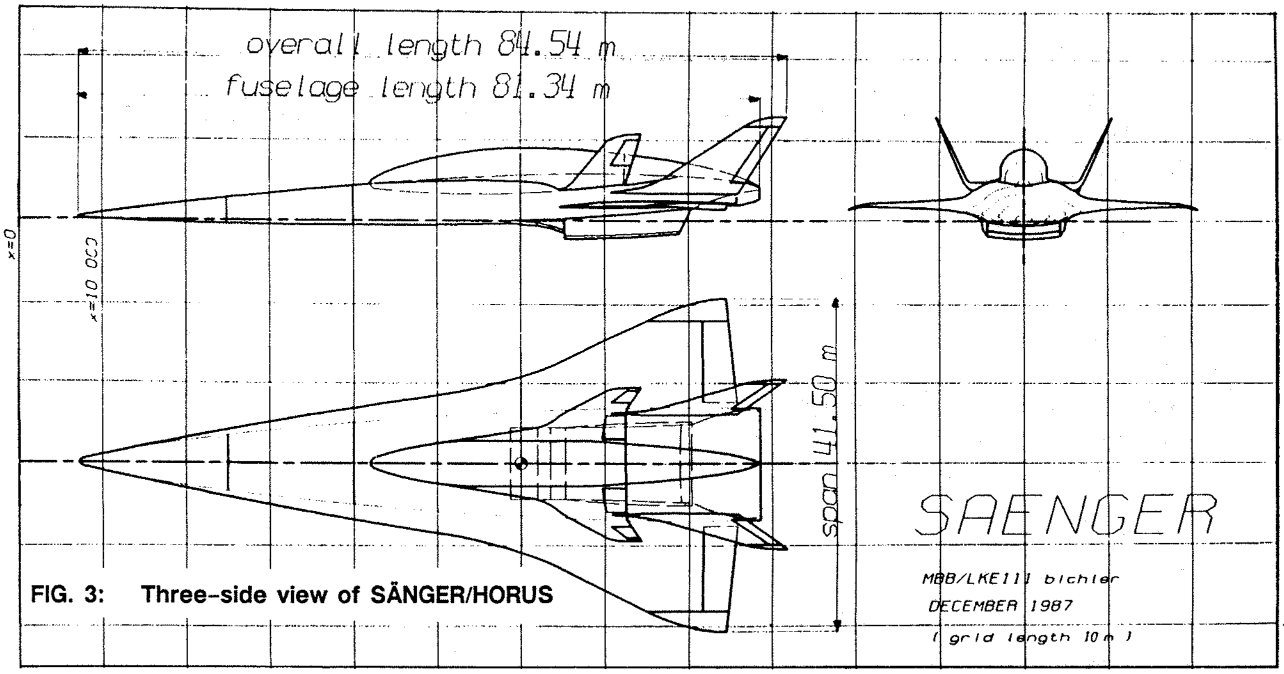

FIG. 3: **Three-side view of SÄNGER/HORUS**

The EHTV net mass (or Operating Weight Empty in aircraft language) is relatively conventional with 54 % of the take-off mass. This compares to 47.5 % of the B.747 and 42 % of the CONCORDE (FIG. 4). The hydrogen tanks require a larger fuselage and accordingly more mass. A real "spaceplane" or single-stage-to-orbit vehicle like the US NASP (X-30) or the British HOTOL concept requires a net mass share of some 17% in order to reach a satellite orbit. And this despite the fact that the vehicle has to withstand the mechanical and thermal loads during atmospheric re-entry with Mach 25! This is to illustrate the required difference in technology level required for a hypersonic aircraft and a spaceplane.

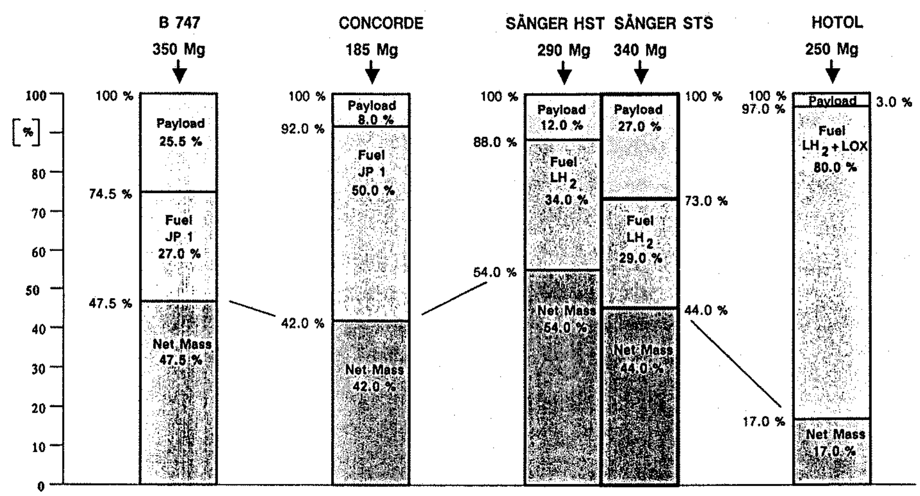

FIG. 4:

Mass comparison of different aircraft/aerospace vehicles

TABLE II : EHTV OPERATIONS and LIFETIME

	PASSENGER TRANSPORT	LAUNCHER STAGE
Cruise Speed	**Mach 0.8/ 4.4**	**Mach 0.8/ 4.4/ 6.8**
Flight Range	**10 500 km**	**2 x 3500 km**
Flight altitude (max)	**24 500 m**	**31 000 m**
Operational Lifetime	**15 years**	**25 years**
	20 000 flights	**300 - 400 flights**
	55 000 hours	**1000 - 1500 hours**
Thrust level at take-off:	**300 kN**	**350 kN per engine**
Payload	**230 Pax + 10 Mg Cargo**	**91 Mg HORUS**
		66-76 Mg CARGUS

3 PROPULSION AND TRAJECTORY

The ascent trajectory of a hypersonic transport is quite complex and needs a careful optimization together with the engine system characteristics.

For SÄNGER-EHTV a turboramjet combination has been selected due to the maximum performance of the ramjet system at high speeds. FIG. 6 shows the baseline system design with parallel arrangement of ramjet and turbojet, however, with a common variable air inlet. The location of the turbojet engine in the lower position has the advantages of better access and allows to lead the boundary layer through the ramjet duct.

The ascent trajectory (present reference, not yet fully optimized) is depicted in FIG. 5 and the related drag/thrust characteristics in FIG. 8. FIG. 7 shows the specific propellant consumption.

Phase 1: Take-off and ascent to 13 km altitude with dry turbojet thrust to Mach 0.9.

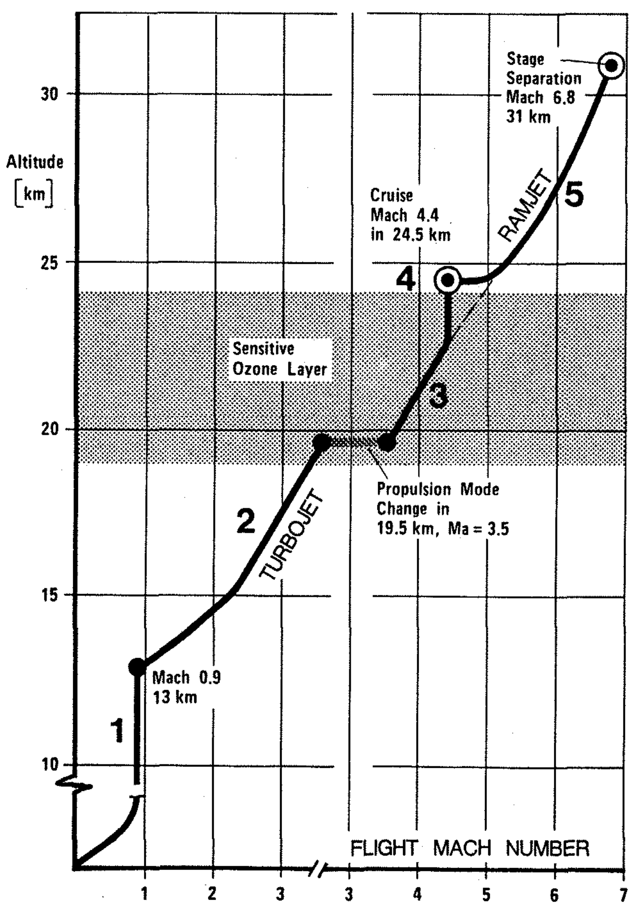

FIG. 5: Ascent trajectory of SÄNGER (Preliminary Reference)

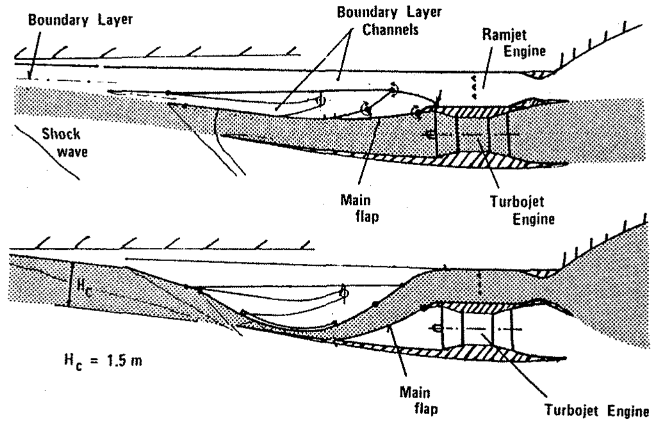

FIG. 6: EHTV turboramjet propulsion concept

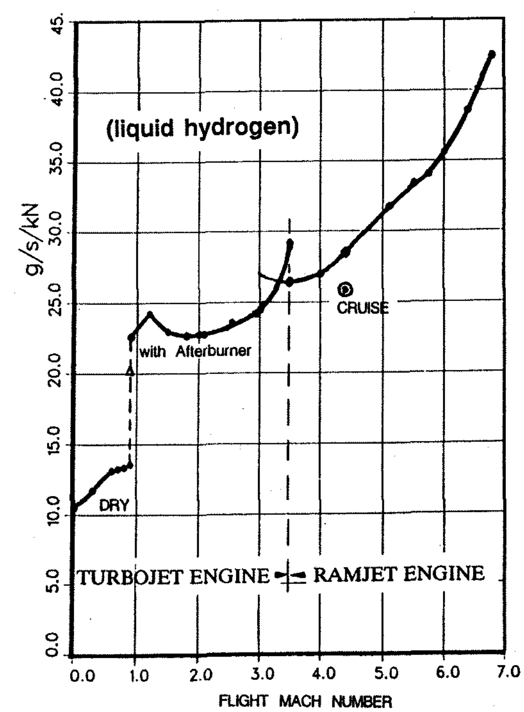

FIG. 7: Specific propellant consumption

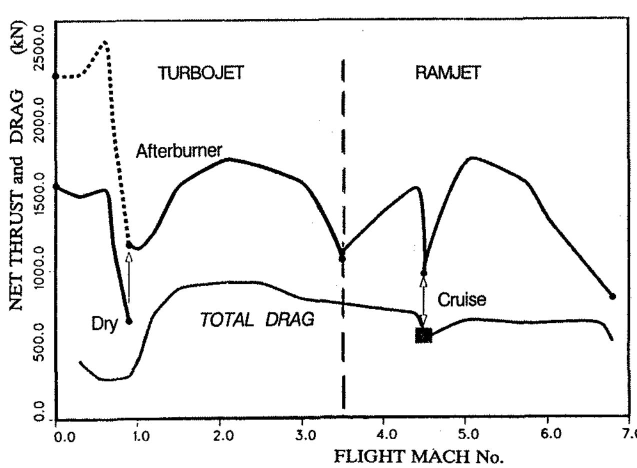

FIG. 8: Total net thrust and aerodynamic drag vs. speed (cf. FIG. 5)

Phase 2:Afterburner switch-on and acceleration to Mach 3.3 in 19.5 km altitude.

Phase 3: Change to ramjet engine operation and ascent to 24.5 km altitude at Mach 4.4.,

Phase 4: Cruise in 24.5 km altitude to the desired geographical latitude including turn maneuver due East.

Phase 5: Acceleration to Mach 6.8 in 31 km altitude and subsequent separation of the second stage.

Phase 6: Return flight to launch site.

FIG. 8 illustrates that max drag/thrust conditions occur around Mach 2 in 13 to 15 km altitude.

The cruise altitude of 24.5 km has been selected as compromise between performance (engine Isp or specific fuel consumption), speed and thermal heating, above the more sensitive part of the ozone layer.

This altitude and the speed of Mach 4.4 should also not cause any concern regarding the ground noise problems.

FIG. 10 shows the overpressure on ground vs. altitude and speed. The EHTV pressure level is only one third of the value considered as acceptable limit (1 lb/ft^2 or 45 N/m^2) compared to the CONCORDE which is some 50% above this value.

The cruise speed of Mach 4.4 seems also to be a good economic optimum for commercial transport, as discussed in the next chapter.

FIG. 11 shows the analysis of the pressure conditions at stage separation (Mach 6.8) which certainly is a crucial issue for this vehicle. The result is that a positive separation pressure builds up between the two vehicles. A shock-tunnel model test at the DFVLR Facility in Göttingen is shown in FIG. 12.

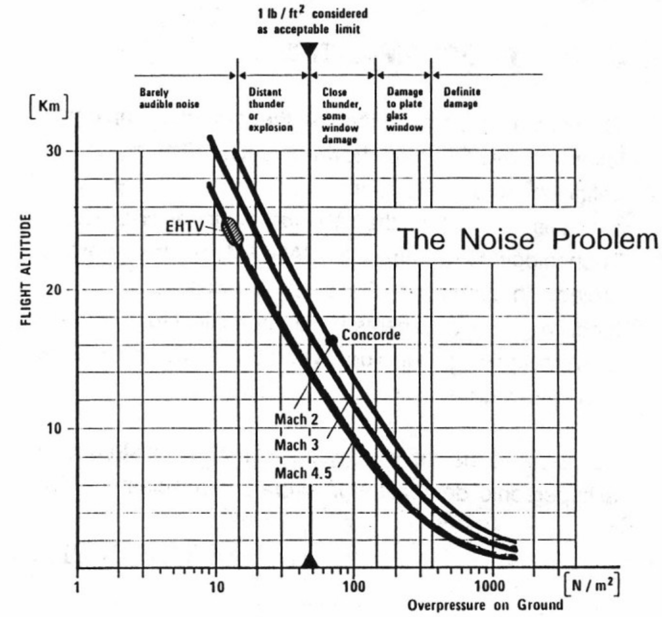

FIG. 10: Overpressure (noise) on ground vs. flight speed and altitude

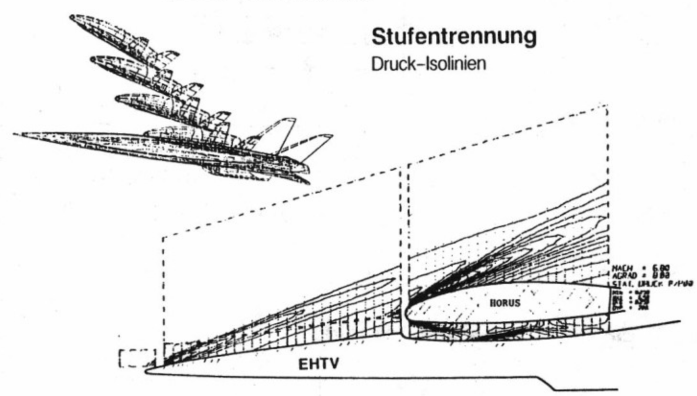

FIG. 11: Stage separation pressure conditions

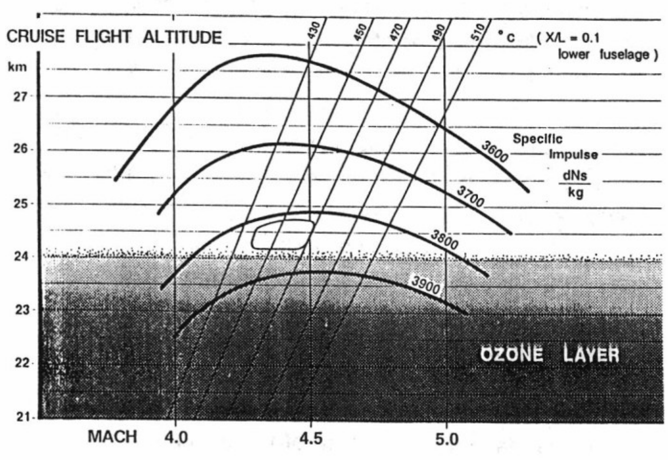

FIG. 9: Definition of the cruise flight speed and altitude

FIG. 12: SÄNGER test model in the DFVLR shock tunnel Göttingen at Ma = 6.8

4. PROGRAMMATICS

The overall program plan for the potential implementation of SÄNGER is shown in FIG. 13. The system definition and propulsion system design are actual activities as part of the German National Hypersonics Technology Program with SÄNGER as the reference project. In parallel to the study activities a number of technology developments have been initiated in the area of airbreathing propulsion hypersonic aerothermodynamics, as well as in material and structures.

As part 2 of the technology program the construction of a hypersonic demonstrator aircraft is anticipated which should – as a flying teststand – allow the verification of aerothermo-dynamic calculations and ramjet propulsion performance beyond Mach 3.

The realization of SÄNGER could be initiated by the mid-90ies, when the funding requirements for the European projects ARIANE 5 and HERMES have passed the peak, and the results of the 8 year technology program have created a solid basis for the development.

It is essential from our viewpoint to have SÄNGER available as early as possible (not later than 2006) in order to reduce the cost of space transportation essentially. Without SÄNGER a real manned European space program is not feasible financially: One launch of ARIANE 5 plus HERMES will cost more than 150 Mio. European Accounting Units (equivalent to some 200 Mio. Dollar) limiting those launches practically to 2 per year. SÄNGER will do the space station support and crew exchange role for about 21 Mio $ per launch (some 10%), allowing 6 flights per year for one third of the annual cost. Also the launch cost for unmanned payloads would be reduced to one third of ARIANE 5. The investment for the development of such an advanced launch system like SÄNGER is rather high, but the essential reduction in launch cost does pay-off economically.

The specific feature of the SÄNGER concept is the potential use of the first stage with minor modifications as a hypersonic passenger plane. This is envisaged not earlier than 2010 (see FIG. 13). There are good reasons to assume that it will be attractive to fly within three hours from Frankfurt to Tokyo or Los Angeles. Four trips are feasible per 24 hours, including 3 h ground time between the flights. The economics of hypersonic traffic depend almost completely on the price of liquid hydrogen. Presently it is 1 Dollar/lb in the US, if it will be reduced by a factor of two (which is considered realistic with respect to improved production processes and growing quantities) then the price for a ticket will be the same as presently on a B. 747. One HST replaces three Jumbo-Jets in transportation performance. Independent from technical and environmental criteria it has been found that Mach 4.4 is the most economic cruise speed providing a maximum of seat-miles per day.

The last FIG. 14 is a view into the future: a HST-230 flying with Mach 4.4 at the rim of the atmosphere.

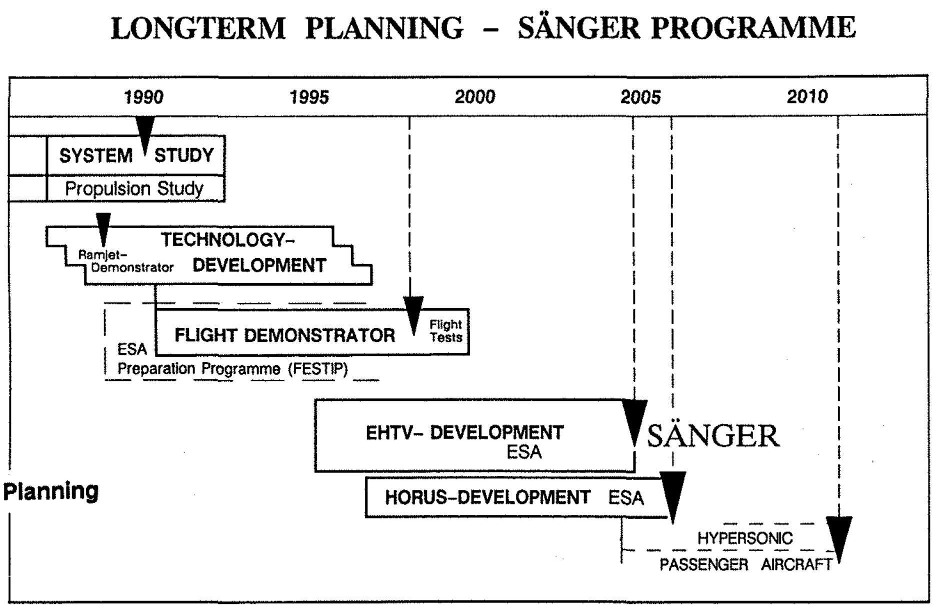

FIG. 13: Longterm Planning

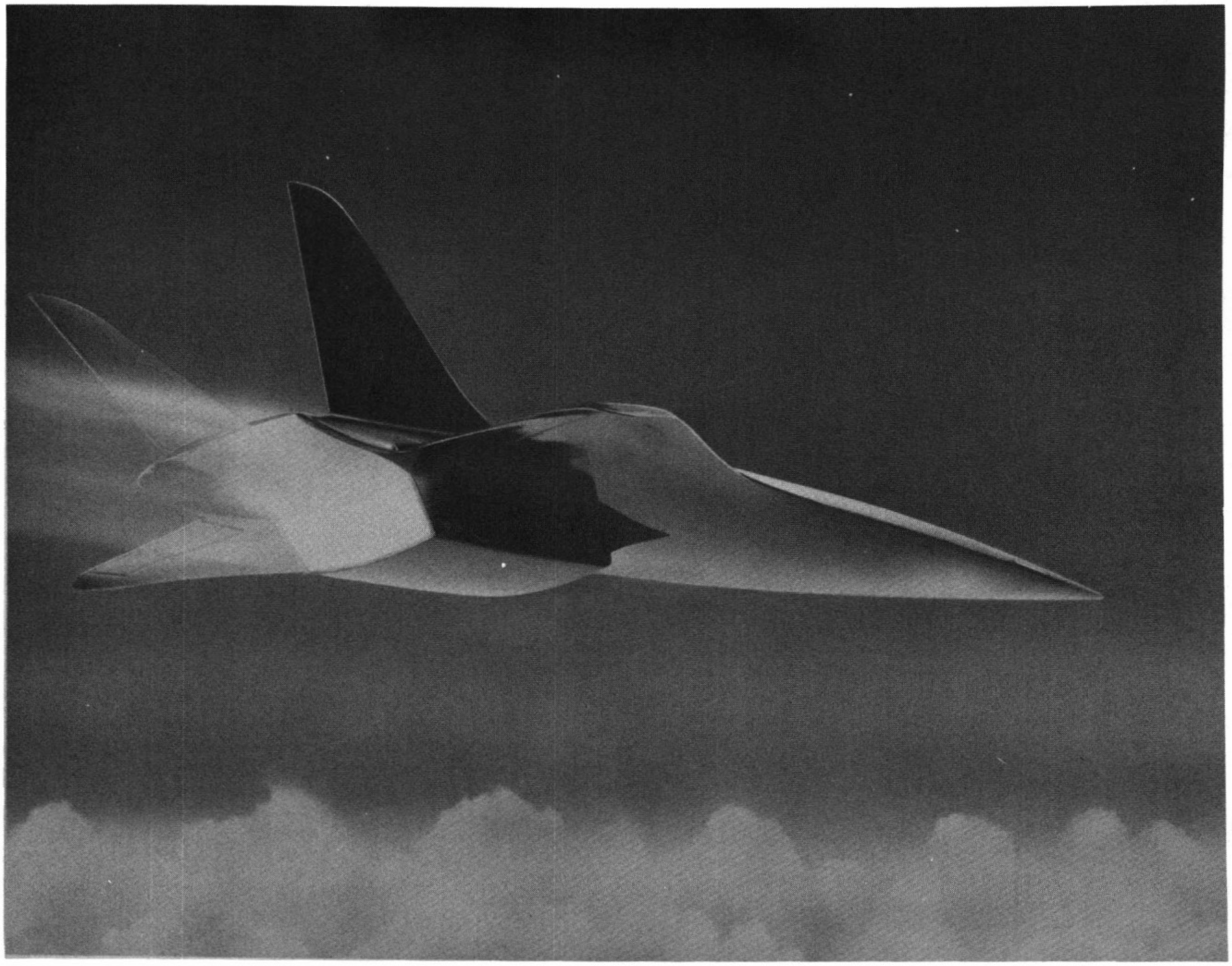

FIG. 14: HST cruising with Mach 4.4 in 24 500 m altitude in three hours (block time) between Frankfurt and Tokyo