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ISTRA: AN AIR-BREATHING BALLISTIC SPACE TRANSPORTER FOR EUROPE

P. A. Kramer and R. D. Bühler

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16. Abstract With increasing transport requirements, reusable space transporters again receive serious consideration in Europe as successors to the "Ariane" family. The paper deals with a hydrogen-ramjet-propelled, 1-1/2-stage reusable ballistic space transporter with vertical take-off and landing and using liquid hydrogen/oxygen rockets. This novel concept was developed in a theoretical study at the University of Stuttgart. The results are compared with recently published studies of several other European space transporter concepts. The data derived for the "Istra"-concept are: 15.4 Mg payload into low Earth-orbit, 155 Mg gross lift-off mass, 10% payload ratio, which represents a 56% propellant saving, and 44% reduction in dry mas (structure and engines) compared with comparable two-stage pure rocket concepts.

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ISTRA: AN AIR-BREATHING BALLISTIC SPACE TRANSPORTER FOR EUROPE[1]

P. A. Kramer and R. D. Bühler[2]

1. Introduction /237*

According to recent investigations, Europe will experience increasing transport requirements in low Earth-orbit (LEO) in the 1990's [1]. A transport class of 15 Mg in LEO has been identified for commercial satellites. With the anticipated high launch frequency, at least partially reusable space transporters are again receiving serious consideration as successors to the booster rocket family named "Ariane" [15].

This report introduces a novel space transporter concept, developed at the University of Stuttgart and compares the results with recently published studies of several other European space transporter concepts. This project is a part of the Special Investigations Area 85 and has been supported by the Deutsche Forschungsgemeinschaft (DFG) [German Research Society] and the Commonwealth of Baden-Württemberg since 1971.

2. The Concept of Istra[3]

Air-breathing space transporter concepts have been and are being generally investigated in conjuction with two-stage winged

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*Numbers in right-hand margin indicate pagination in original.

[1]Speech at the annual convention of the Deutsche Gesellschaft für Luft- und Raumfahrt (DGLR), Stuttgart, October 5-7, 1982. DGLR copy 82-075.

[2]Licensed engineer P. A. Kramer and Professor R. D. Bühler, Ph.D., Institue for Space Propulsion, University of Stuttgart, Pfaffenwaldring 31, D-7000 Stuttgart 80, West Germany.

[3]German acronym for "Integrale Staustrahl-Rakete" [Integral ramjet rocket]

aircraft with horizontal take off and landing. Literary source [4] compares the concept in this report with primarily American studies of the last 10 to 15 years involving such investigations. This shows how the high construction expense of air-breathing space transporters as described above nearly eradicates the advantages of air-breathing engines--lower propellant consumption than with rockets of similar thrust.

The concept of "Istra" is based on a 1-1/2-stage reusable ballistic round-trip space transporter with vertical take off and landing.

The engine consists of separately installed dual ramjets working in parallel and rockets using liquid hydrogen (LH_2), liquid oxygen (LOX) and air. The ramjets build a ring out of 28 modules, which are grouped around a central, reusable ballistic rocket unit, as Figure 1 shows. /238

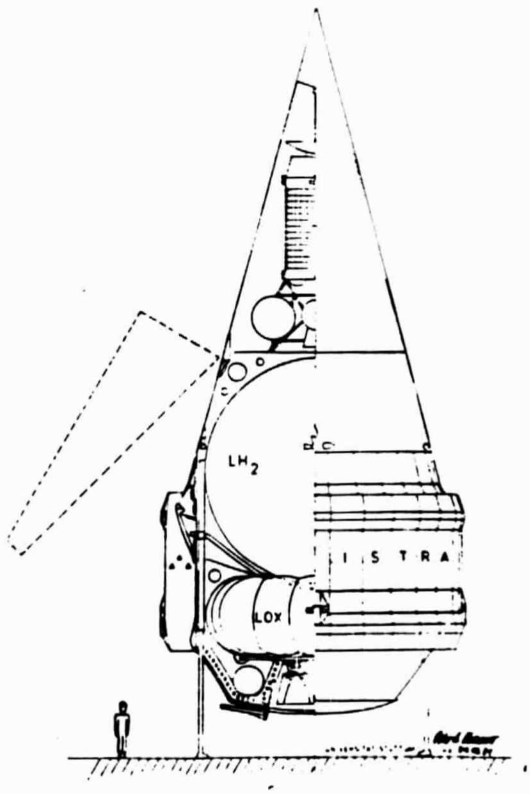


Figure 1: Basic construction of the "Istra" integral ramjet rocket

The central rocket unit was originally designed by the firm Messerschmitt-Bölkow-Blohm [8,9]. Rocket engines of this design were replaced by mainstream high-pressure rocket engines with dual-positioned jets and were transferred from the periphery into the base of the system behind flaps in the heat shield.

Technology from modern aircraft developments, currently available or planned for the the near future (for example [10]), was adapted for the LH_2-ramjet engines with subsonic stream flow and variable geometry and for the central rocket unit. The gross lift off mass of "Istra" amounts to only about 155 Mg. The entire design was intended for a relatively simple reusable system for European conditions.

Figure 2: "Istra" flight sequence

Figure 2 shows the flight sequence: Vertical lift off with rocket engines, at $M \geq 1$ ignition and parallel operation of ramjets to about $M = 2$, disengaging of the rocket engines and acceleration alone through ramjets up to stage separation at about $M = 6.5$ at altitudes in excess of 40 km. There the ramjet ring separates and is sheltered with parachutes. The central rocket unit continues to accelerate to LEO (200 km), unloads the payload, turns, brakes with rocket thrust and returns with the heat shield preceding it on a ballistic course to the Earth's surface. Landing takes place on landing struts with rocket thrust.

In addition to this 1-1/2-stage concept, a purely single-stage design was calculated in detail for purposes of comparison.

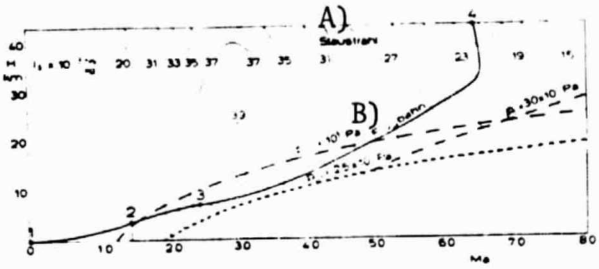
3. Analysis Technique

The method of analysis, as well as the assumptions and conditions surrounding it, have been published in previous reports [2 to 4, 6]. It will be dealt with only briefly here.

The basic idea is an approach to calculating orbit as in rocket technology: Vertical start and largely ballistic ascent with gravity deflection. The engine for this pronounced acceleration mission should work at fullest possible thrust, so long as no critical boundaries, in particular regarding structure stress, are exceeded. In such a situation the engine must be throttled. This procedure contrasts otherwise usual system concepts for air-breathing engines, which generally utilize a trajectory specification in the form of a high Mach-number combination (for example, constant ramming pressure). Such a specification simplifies propulsion calculation, since the power of air-breathing propulsions is dependent not only upon the flight altitude as with rocket propulsions, but also very much upon the actual Mach-number.

This specification, on the other hand, impedes technical realization, since the engines must be used up for maximum thrust, while nearly always being throttled, in order to follow this "unnatural" course. Beyond that, it is not possible to maintain this course without additional significant aerodynamic lift.

Figure 3 shows the two different types of paths. One path with $p_{dyn} = 1 \times 10^5$ Pa (= 1 bar) is mentioned frequently in the literature. At high Mach-numbers it leads to excessive combustion chamber pressures in the ramjet engines. This necessitates very speedy stage separation or conversion to supersonic flow.



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Course 1 Rocket launch 2 Ramjets on 3 Rockets out
4 Stage separation

Figure 3: Trajectory profile "Istra" over the isolines of the specific impulse of the ramjet engines. Boundary lines for dynamic pressure and ramjet-combustion chamber pressure
Key: A) Ramjet B) Trajectory

In project "Istra", on the other hand, a complete engine data bank is set up beforehand for every conceivable flight situation and every engine stage. Thus, any arbitrary trajectory can occur during flight regardless of stage. Figure 3 includes a field of isolines of the specific impulse of the ramjet engines.

At the end of a trajectory calculation, when sufficient payload is available, the engine stress is checked. A trajectory course is set as the intersection, once again using the data fields of the engine data bank, to determine the manner and duration of the critical load.

Figures 4 and 5 plot combustion chamber pressure (static) and temperature (total) along two typical paths. The flatter path occurs when the rocket engine is reconnected parallel to the ramjet engine before stage separation to increase thrust. This effect was optimized in the results described in [7]. As

Figure 4 or 5 shows, no excessive stress occurs in the ramjet combustion chamber. In particular, combustion chamber pressure remains below 15 x 10^5 Pa (≈ 15 bar).

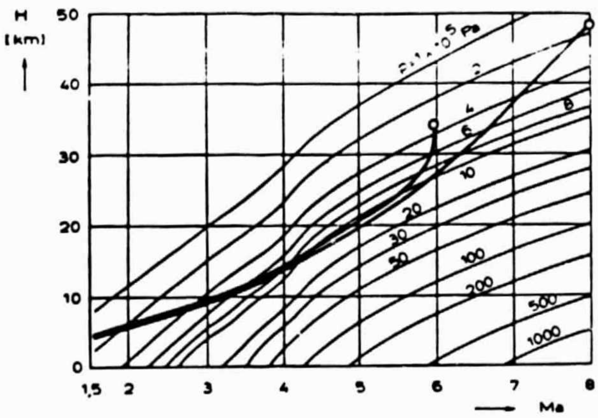

Figure 4: Two trajectory profiles up to stage separation over the isolines of the static ramjet combustion chamber pressure

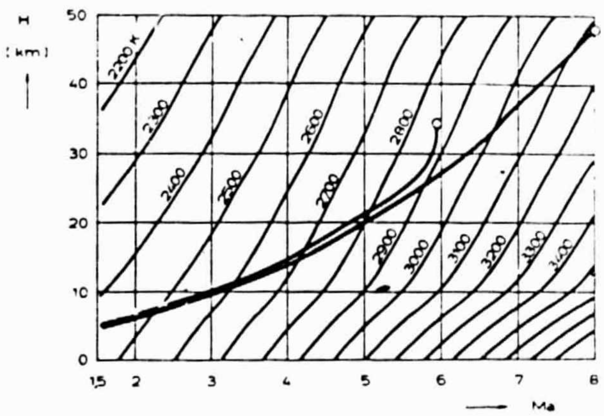

Figure 5: Two trajectory profiles up to stage separation over the isolines of the total ramjet combustion chamber temperature

An interactive design and analysis process provides interplay of system design through parameter variation and engine analysis [6]. After finding satisfactory total solutions the result can be optimized with methods as in [7]. This allows further parameters, like, for example, thrust engagement and aerodynamic lift, to be considered.

4. Results and Comparisons

If the corresponding specific impulse of the ramjet engine (thrust in seconds of propellant mass consumed, Ns/kg) along the trajectory in Figure 3 runs its course over flight time, the situation shown in Figure 6 occurs.

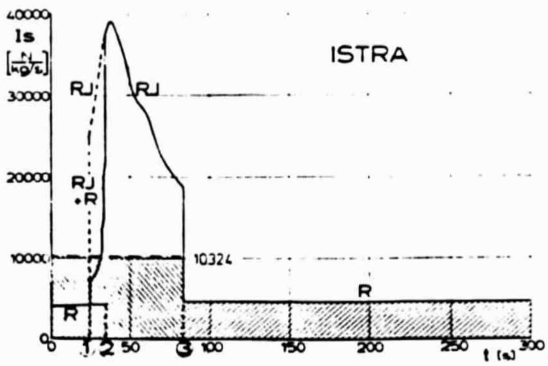

Figure 6: Specific impulse over flight time: 1. Rocket launch 2. Turn off rockets (in stages) 3. Stage separation

The dotted lines show the course of the ramjets and the rocket engines separately; the solid lines indicate the two in combination. As the rocket engines are throttled near the acceleration boundary ($b \leq 4.5 g_0$), total specific impulse increases drastically as speed increases and reaches values of nearly 39,000 Ns/kg. Then, as a result of sinking atmospheric pressure, it drops off again until stage separation.

The effective mean value which is reached for the flight up to stage separation amounts to approximately 10,3000 Ns/kg, which is about 2.6 times that of a pure rocket engine. This gain through propellant savings opposes increased expenditure due to engine mass.

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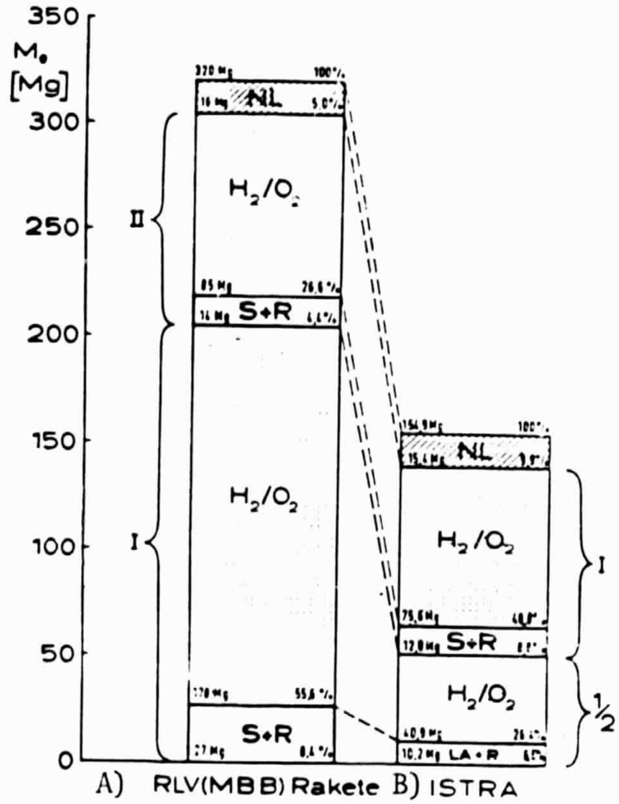

Figure 7: Mass comparison "Istra" and "RLV" rocket by MBB[1]

Key: A) RLV (MBB) Rocket 2-stage reusable

B) ISTRA 1-1/2 stage reusable

Figure 7 presents the attained payload of about 15.4 Mg and the appropriate mass distribution for "Istra" in graph form. It is compared with MBB's design for a two-stage ballistic space transporter "RVL" which is also propelled with LH_2LOX and has about the same payload [1].

"Istra's" air-breathing half-stage (no tank staggering, only engine staggering) uses less than one-fourth of the propellant--mainly LH_2--used by the rocket booster stage of the "RLV".

LOX is used only during operation of the rocket engines. The higher stages are nearly similar. Their differences decrease as a result of varied flight conditions during stage separation.

In total, "Istra" uses about 56% less propellant than the comparison rocket. A "dimension effect" results and the overall size of the rocket is reduced. This reduces the entire dry mass (structure and engine mass) so that, in total, 44% dry mass is necessary. On the one hand, this points to the possibility of savings in development costs, while reduced propellant consumption cuts down operating costs.

Finally, Figure 8 compares this concept with other recent European suggestions on the basis of net mass at gross lift off mass [5]. Two theoretical curves for constant net masses of 13.5 Mg and 29.5 Mg intersect with two bands, which according to [1] describe the path of single- and/or two-stage ballistic transporter rockets with LH_2/LOX. Outlined symbols represent pure rocket concepts, darkened symbols those with air-breathing engines in the atmosphere.

Figure 8 enumerates the following recent European concepts: "RLV" two-stage and "RLV-5" from MBB [1]; "BETA IA" from MBB [8, 9]; a two-stage ballistic and winged system (for horizontal landing) from Dornier System [11, 12], and systems from TU Munich [13], which fall into the same area as those from Dornier System. It also includes an optimum design from Aerospatiale [14] with air-breathing booster stage and horizontal lift off. The concept "Istra" is given in 1-1/2- and single-stage versions.

As in [4], this also shows that horizontal lift off, air-breathing two-stage concepts possess no convincing payload advantages over competing rockets. Both "Istra" versions possess about 2.5 times payload capacity compared to ballistic rocket concepts with the same number of stages.

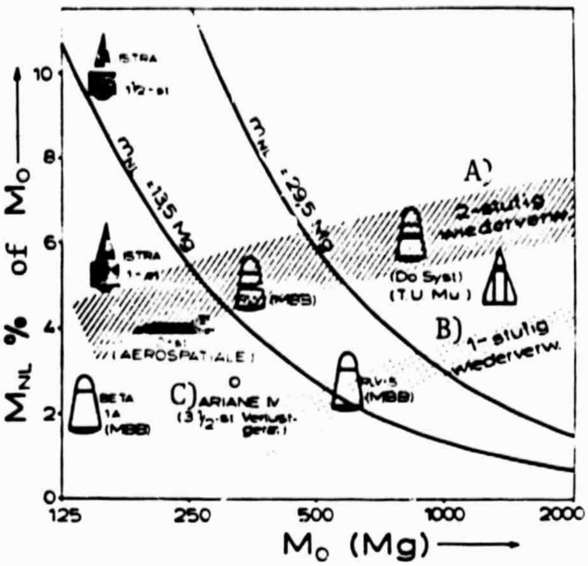

Figure 8: Payload comparison of recent European space transporter studies on the lift off mass. Outlined symbols: Pure rocket concepts. Solid symbols: Air-breathing booster engines. Key: A) 2-stage reusable B) 1-stage reusable C) 3-1/2-stage non-retrievable rocket

5. Summary

The results to date for Project "Istra" may be summarized as follows:

1. In its 1-1/2-stage version the concept "Istra" reaches approximately 10% net mass of gross lift off mass, which corresponds to about 2.5 times that of comparable rockets.

2. Propellant savings amount to about 56%, savings on dry mass (structure and engine mass) about 44%. The extent to which the latter may be converted into reductions in development and operating costs depends greatly on the development costs for the entire ramjet technology, which to date is produced and financed outside the space industry. /241

3. These results are based on assumptions of modern structure and engine technology. The necessary ramjet technology needs to be adapted from aircraft use to aerospace needs. This is not a novel idea in aerospace history.

4. Hydrogen is the suitable fuel for this use. Because of low propellant requirements in the first stage, its normal disadvantage--low specific volume density--no longer has a disadvantageous effect.

5. A relatively small 155-Mg heavy space transporter with over 15 Mg net mass in lower orbits is a very promising solution for European needs following the of non-retrievable rockets in the "Ariane" series. Future studies and technology programs supported by industry and advanced research institutes must investigate to what extent development expenditures and periods fit into European economic and time requirements.

In appreciation

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