PROJECT DESIGNS OF ALTERNATIVE VERSIONS OF THE SL-86 2-STAGE HORIZONTAL TAKE-OFF SPACE LAUNCHER

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Abstract

This paper describes studies of three versions of a 2-Stage to orbit horizontal take-off launcher. An initial design study was performed, which determined the basic shape of the aircraft together with weight, and aerodynamic information. This was given to the 31 Master students working on the project, who were given individual responsibility for the design and analysis of major parts of the aircraft. The orbiter was designed to use a carbon fibre structure, protected by a thermal protective system and should take a 4½ ton payload into Low Earth Orbit, from a payload bay of similar cross-section to the Shuttle. The booster vehicle has a cranked delta wing and a recess on the upper surface to accomodate the orbiter, which is launched at Mach 4 at 25 KM altitude. The project showed that the concept was feasible but highlighted several problem areas, which were addressed by a subsequent MSc thesis. The main changes were the introduction of a canard foreplane and larger turbo-ramjets to the booster, which gave considerable improvements. The third version had more power, and separation at Mach 5.

Introduction

The College of Aeronautics adopts a practical approach to the teaching of aircraft design. Students will only be awarded an MSc. degree if they have proved that they have the ability to produce workable, realistic designs in which all of the major problems have been addressed. This ability is assessed by means of annual group projects in which relevant aircraft types are studied, in this case a space launcher.

The past few years have seen renewed interest in orbital launch vehicles. The Space Shuttles, despite the tragic loss of the Challenger have given valuable service. Soviet and European launchers have lifted many satellites into orbit. All of the current launchers have been expendable with the exception of large parts of the Space Shuttle. Current launchers require extensive ground facilities and long periods of launch preparation. Heavy lift vehicles such as Shuttle, will be required, to build the proposed space station, but flexible smaller-lift vehicles will also be required. Extensive literature searches and discussion with various members of industry led to the initial Cranfield Project(1). This process will be described below, together with a summary of work on two further developments and a study of using the upper stage to support an orbital laboratory.

Launcher Requirements

The choice of a horizontal take-off followed from the requirement for flexible, relatively low cost and low noise operations from existing airfields. The launcher should be completely re-usable and have quick turn-rounds. The specification was formed by the author, together with Industrial input. The first decision made was to aim for a low-risk strategy, with 2-stages and separation at Mach 4.

The envisaged missions

Space station, platform and satellite re-supply and servicing.

Satellite launch, repair and recovery.

Rescue missions.

Space research and development.

Booster stage

Separation at about 80,000 ft altitude at Mach 4.

Horizontal take-off and landing from 747-size airfields.

Use of turbo ramjets with fuselage-stored cryogenic fuel.

It may be necessary to augment take-off, transonic and boost phases with power from the orbiter's engine/s. Cross fuelling will be needed.

There should be 500 miles of cross-range performance.

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Orbiter

Payload to be 4.5 tonnes to Low Earch Orbit with bay of similar cross-section to shuttle. There is to be limited on-orbit manoeuvring so that the orbiter could be used for limited re-supply or rescue missions.

Two-crew operation.

Power is to be provided by liquid rocket motor(s).

Initial Group Project Programme

A conceptual design study was performed by the author, which determined the basic shape of the aircraft together with weight, aerodynamic and loading information[2]. Thirty-one students were then allocated the responsibility for the detail design of a major part of the aircraft, such as a major structural component, a flying control surface or a mechanical system such as fuel, environmental control or the control systems. Each student was expected to act as designer, stressman and draughtsman for his component.

The nature of the project also involved those students following our aerospace engineering course option in such areas as thermal protection, trajectory, orbital manoeuvring, rocket propulsion, payload support and docking. The project was managed to an exacting eight month programme by means of twice weekly project meetings, where students reported on progress, received advice and instructions for subsequent work. The most important role of the meetings however, was that of a forum where design compromises were resolved and students gained an appreciation of the problems being encountered on other parts of the aircraft.

The knowledge gained during lectures, project meetings and discussions with members of staff, was augmented by several valuable visits and external lectures.

The initial programme ended after 8 months, with the submission of voluminous project theses containing detailed drawings and calculations. It has been estimated that at least 30,000 manhours were spent on the programme, which produced version 1 of the SL 86 and gave the students considerable design experience.

Description of the SL86 Version 1

Figure 1 shows the booster-orbiter configuration at separation, whilst Fig. 2 is that of the booster alone.

Booster

The booster utilises 4 underslung Rolls-Royce project turbo-ramjet powerplants. The wing is set low to allow integration of the orbiter into its upper surface. Twin fins and rudders are used to give clearance to the orbiter's rocket motor. The rudders give yaw control to the whole aircraft configuration, whilst pitch and roll are provided by wing trailing-edge elevons. A conventional tricycle undercarriage is used. The fuselage contains cryogenic liquid hydrogen and oxygen, and is shaped to accommodate the orbiter, and it's structure will be largely fabricated from Titanium alloy. Both liquid Oxygen and hydrogen are to be cross-fuelled during the pre-separation burn of the orbiter's rocket motor. This is to ensure full orbiter tanks at separation. Figure 3 shows the hydrogen cross-feed system.

The wing recess for the orbiter led to complex geometrical interfaces, which were accurately defined by our CAD system. The reduction in wing depth in this region led to strength and stiffness problems. A multi-spar wing construction was used, and was manually stressed to give an input into the LUSAS finite element structural analysis, (see Fig. 4). Progressive runs were used to optimise the wing structure. This was the method used for the structure of both vehicles. Figure 5 shows the installation of the booster turbo-ramjets.

Orbiter

The large fuselage contains a 4-man flight deck, liquid oxygen and hydrogen tanks, a scaled space shuttle main engine and the payload bay. (Fig. 6). The cross section of the latter is similar to that of the space shuttle and can accomodate 8 passengers in a transport role. The structure will be 'warm' with composite construction, capable of working at 180°C, with a thermal protection system to limit temperatures to this value. Aerodynamic yaw control is by twin fins and rudders whilst pitch and roll are controlled by elevons. A reaction control system is used for control where aerodynamic surfaces are unsuitable (Fig. 7). The aircraft uses a conventional tricycle landing gear. The orbital manoeuvring system (OMS) uses two small rocket motors. The fins and flying control surfaces presented considerable structural problems as the thermal protection system occupies up to 25% of the local depth. This considerably reduced the structural depth, with consequent mass increases. This effect is shown in Fig. 8, which illustrates the attachment of the elevon. The environmental control system is based on a crew of 4 on a three-day mission. On-board power is supplied by auxilliary power units and fuel cells, the latter which supply water as a by-product. The landing gear uses lightweight twin-wheel units. The payload bay will accommodate a standard ESA space lab short module or other payloads up to a maximum of 4.5 tonnes. A manipulator arm has been designed to fit in the payload bay, which also provides storage for two man manoeuvring units. Access to the payload bay is by means of a powered lanyard attached to a submerged rail between the airlock and payload bay.

SL86-VI Performance and Problems

Drag estimates were made for both vehicles separately, but the drag of the mated configuration was difficult to determine. Conservative assumptions were made to allow for this. Performance calculations showed that the aircraft combination could achieve the conditions of separation at Mach 4 at 80,000 ft altitude. The author's initial calculations, however, were optimistic in terms of fuel required for the acceleration and supersonic climb. With the available fuel volume in the fuselage, this limited the pre-separation cross-range to 230 miles rather than the 500 miles specified.

The above problems were aggravated by the manufacturer's reduction of turbo-ramjet thrust by 13%. These factors led to an extra LOX requirement of some 17 tonnes for the booster. One solution would be to scale-up the booster to cater for this take-off mass increase.

The low thrust output from the turbo-ramjets also led to a very long take-off run, a slow climb and acceleration, and an inability to go quickly through the transonic region without using the rocket motor. Some flight conditions had marginal longitudinal control.

The main mass growth beyond target was in the orbiter fuel system, because doubts about the effects of cryogenic fuels on carbon-fibre structure led us to non-integral tanks. This reduced the problem of the relative thermal compression of the fuselage tanks relative to the fuselage, because flexible mounts could be used. The differential expansion over the lengths of the hydrogen and oxygen tanks were 6 and 3 cm respectively. The orbiter mass growth was compensated for by better than predicted fuel burn for the orbiter.

Table 1 summarises some of the main performance parameters and dimensions for both the booster and orbiter.

These show that if increase in booster power were achieved and the booster mass was maintained at 250 tonnes, a payload of 4.5 tonnes could be inserted into LEO, giving a payload fraction of 1.8%.

It can be seen that several significant problem areas had emerged, but the basic concept offered considerable potential. It was decided to continue the study to design alternative versions to remedy the problems.

Improved Mach 4 booster, SL 86-V2

Layout Changes-booster

Canard

These are shown fully by Molnar(3) and summarised by Fielding(4).

The booster delta wing configuration is longitudinally unstable during flight and the limited control authority of the trailing edge surfaces dictated that the aircraft required a canard for stabilisation and manoeuvrability. It is long coupled and all moving, with an elevator comprising 30% of the area, over the whole span. The static stability margins for both approach and cruise, stick fixed, were calculated and plotted along with control parameters. From the plot, the smallest tail size to achieve the requirements was chosen. An analysis was also undertaken for other segments of the flight profile to check the tail size and static margin. A considerable amount of juggling of wing and fuselage components was required to limit the range of C G locations.

Control during the descent and landing phases indicated the need to use the canard and the trailing edge surfaces to produce low take off and landing velocities. Landing with the booster only gives a static margin of -9%. The changes of C G and aerodynamic centre, with and without the orbiter, gave a large number of stability conditions. The most stable being 10% after separation. This requires the use of active control technology to keep the aircraft stable.

Powerplant

An improved turboramjet with an additional thrust of 30% was provided by Rolls Royce of Bristol. This paper engine superseded that which was originally provided for the SL86. A 500 kg reduction in the engine mass was achieved by the use of improved carbon fibre intake and operation at higher combustion temperatures. These changes had a dramatic effect on the aircraft performance. The extra thrust meant that the orbiter rocket motor was not required for transonic boost and supersonic climb. This produced considerable fuel savings and eliminated the need to have risky cross-fuelling between both vehicles. One by-product, however, was that more liquid hyrogen was required. This necessitated an increase in the booster fuselage diameter from 4.3 to 5.4 metres. An additional liquid hydrogen tank was placed in the booster rear fuselage and replaced the redundant LOX tank of version 1 (Fig. 9). A 1.37m plug placed in the central fuselage enabled the orbiter to be repositioned forward towards the nose. Apart from improving the mated vehicles' overall CG, there was additional clearance around the booster control surfaces.

Fins

The fins were repositioned further outboard and incorporated into the wing tips to provide stability for low speed flight. The reconfiguration improved the relative distance between the booster and orbiter fins, hence reducing the aerodynamic interference drag and also the risk of a collision at the point of vehicle separation.

The wing tip (wing-fin) has also a moving control surface which acts as both a rudder and an elevon. From take off to separation and additionally in the case of an aborted separation the SL86-V2 will be flying in the mated configuration. As the orbiter is rigidly attached by 4 hard points to the booster, effectively four fins will provide the yaw control (two each on booster and orbiter).

Drag Estimates

The estimation of the SL86-V2 drag was an area of much uncertainty, with an aerodynamic assessment of the combined 1st and 2nd stages required. These two vehicles were aerodynamically blended as efficiently as possible, with appropriate fairing at the significant aerodynamic interfaces. DATA sheet prediction methods were used for the booster and wind tunnel results used from a similar configuration to the orbiter. Drag estimates are plotted on Fig. 10, together with the thrust from the 30% larger turbo-ramjets. The

College of Aeronautics has a computer program called DELTA, based on a Lockheed method. This gives results for flight Mach numbers up to 2.0, and the results are also plotted on Fig. 10. The vehicle was slightly outside the geometric limits of the program, and the results are conservative. Further comparisons were made with an ESA two stage to orbit study of similar configuration to the SL86. These, again, showed the initial assumptions to be conservative. More work is required in this area.

SL86-V2 Performance

With the uprated turboramjets, an immediate benefit noted was the improvement in the thrust/drag map with surplus thrust available over the whole flight regime up to Mach 4. As stated above, this removed the necessity for the use of the orbiter's main rocket engine and therefore inflight cross fuelling. This had an effect on the vehicle CG whereby 24,000 kg or LOX was not required. However, the additional fuel burn of the uprated engines required an additional 12,000 kg of LH_2. This had a net result of given an overall configuration of 237,000 kg, 13,000 kg below spec. weight.

The reduction in the SL86 mass and uprated engines enabled the booster to fulfil its mission, achieving Mach 4 at 25.0 km in 27.15 minutes, covering 1216.35 km (760 miles). This cross range was an improvement on the specified 500 miles, with the flexibility of greater orbital manoeuvres. (see table 1).

The vehicle's take off and landing performance was improved with the introduction of the canard foreplane. An aborted separation dictated an emergency landing in the mated configuration. This was achieved with a reduction in the landing speed, by fuel dumping of the LOX and the use of fuel management. This reduced the required field length, enabling conventional runways of 747 capacity to be used.

SL86-V2 Orbiter

The orbiter remained mainly unchanged from that designed for the SL86. The subject of alternative thermal protection systems was addressed, assessing some new improved concepts currently under consideration for Hermes and the TSTO.

The status of the Hermes design was that it was assumed that the internal structure will be worked to 250°C. The latest studies on 'HORUS' the TSTO upper stage have indicated that the lower surface temperatures are about 100°c lower than for the shuttle. These two facts indicate areas for possible improved TPS systems.

The SL86-V2 performance calculations indicated a mass saving of 13,000 KG for the combination. This could be used to given an orbiter mass allowance to 128,000 KG so that payload into orbit could be increased. The increased mass would require re-sizing of the orbiter and it is not obvious what percentage payload increase would follow, but it might be the order of 500 KG. Another alternative would be to scale down the booster, but the safest course would be to keep the saving as a safety margin on the booster design.

Improved Mach 5 booster, SL86-V3

After reconfiguring the SL86-V2 by installing turboramjets of a further 25% additional thrust, initial performance calculations indicate that a 250,000 kg vehicle could achieve a Mach 5 separation at 25.5 KM altitude, in 23.04 minutes. This vehicle is termed SL86-V3.

There is a mass penalty of 6218.5 kg for the increased engine mass and a fuel mass saving due to increased thrust. However, an additional 12,445 kg of fuel is required from 24 KM to 25.5 KM with the increase in Mach Number from 4-5.

This gives a total vehicle mass of 249,477 kg with 522 kg surplus. However, a re-design of the booster fuselage is necessary to accommodate the additional 6741 kg of LH_2 required.

The SL86-V3 can thus be utilised as a Mach 5 vehicle at the present specification, with an increased payload to orbit, because the orbiter will be required to produce a smaller amount of ΔV due to of the increased Mach No. and altitude at separation.

Various studies have suggested that the optimum use of turboramjets is up to about Mach 7, above which greater inefficienty is present due to limited ramjet thrust. Preliminary studies showed that the physical size of the required engines made it impossible to fit them in the SL86's position. A fuselage location would be required, thus leading to a new configuration.

Separation at speeds above Mach 4 could lead to signficant kinetic heating problems on the booster. This should be investigated.

Remaining Areas of Uncertainty

The stage separation manoeuvre is an area of much uncertainty. However, it is proposed that the upper stage is slightly elevated by hydraulic means, relative to the booster. The aerodynamic forces provide adequate lift to initiate and maintain a safe separation manoeuvre. At the point of separation the trajectory of the orbiter is initiated by the flight path taken by the booster. It is proposed that some form of clamp or rail system would restrain the orbiter in its elevated position at four points, the rocket engine's thrust initiating and maintaining the separation manoeuvre. The repositioning of the booster fins further outboard along the span has removed the difficulty due to the original proximity of the fins of the booster and orbiter. It should be noted that the orbiter rocket motor is gimballed, thus providing a powerful pitch control, should it be required. The late B.R.A. Burns of BAe, who was HOTOL Manager, was kind enough to assess the initial SL86 concept. His main criticisms concerned the wing tip fins, particularly those of the orbiter. He felt that the high loads, and requirement for thermal protection would make it almost impossible to provide adequate structure and a cool environment for the actuators. Initial calculations showed that it was just possible to provide enough strength and stiffness. The actuators could be placed in the wing tip. This would lead to rather remote drives, but should be possible. Another problem was the suck-down effect on tip fins of wing lift and control deflection. The outward cant of the booster fins should help, and could be copied on the orbiter. It was thought that the titanium fuel tanks were risky because of hydrogen embrittlement. Other commentators expressed concern about working composite structures to 180°C. These problems are common to the Hermes programme and are being addressed in research projects.

The outstanding uncertainty is in the area of aerodynamics. The simple methods used should be checked by wind tunnel and computational fluid dynamics. It may be necessary to develope a retractable fairing to fill the recess on the booster's wings after the orbiter's separation.

Discussion

The SL86-V2 a booster with uprated turboramjects of 30% over the SL86 offers the capability of launching 4500 kg of payload into low earth orbit. Separation of the orbiter to take place at Mach 4, 25,000 m altitude, with a configuration 13000 kg below spec. weight.

The vehicle has an acceptable take off and landing performance, capable of using 747 type runways, and handling qualities as expected for this size and type of vehicle.

The SL86-V3 is an alternative uprated booster with a larger engine of some 60% increase in thrust over the SL86. This vehicle configuration appears to offer greater versatility and would warrant a more detailed investigation for a future design. A payload of 4500+kg can be launched into low earth orbit, with separation of the orbiter taking place at Mach 5, 25500 m altitude.

The booster configuration would require a re-assessment with a need to determine the optimum fineness ratio due to the additional fuel requirement. Mach 5 would subject the structure to a more severe temperature environment, necessitating consideration of some form of thermal protection system in the higher temperature area.

The SL-86 orbiter formed the basis of a further group project for 7 spacecraft engineering students. The students designed an orbital laboratory, called LABSPACE, which was to be supplied by the SL-86. The latter was to be capable of staying in orbit for 28 days, considerably more than the original orbiter. The requirements for this study were described by Bowling[5]. It was shown that the SL-86 would be a suitable vehicle.

Conclusions

The basic SL-86 concept was sound, but it had a number of shortcomings. The overall performance of the SL86-V2 is satisfactory, meeting the specification with a 13,000 kg undermass at 237,000 kg.

The SL86-V3 meets the specification, however with new engines and a much reconfigured fuselage. It's payload to orbit should exceed the SL86-V2's. The studies have shown several areas where future research would be profitable.

The design programmes fulfilled their aim of providing powerful means of training designers. The use of challenging and interesting projects was a means of investigating many of the problem areas of such aircraft, and produced some good detail design work.

The 39 students involved in the projects experienced many of the problems of an industrial project and learnt how to tackle a difficult job. Their theoretical and practical training makes them well placed to make significant contributions to the Aerospace Industry.

References

1. Fielding, J P "Design Study of a 2-stage Horizontal Take-Off Space Launcher". Aerogram Vol. 5, No. 1, November 1987, Cranfield Institute of Technology.

2. Fielding, J P "DES 8600 - Two Stage Horizontal Take-off Space Launcher". Design Specification. July 1987, Cranfield Institute of Technology.

3. Molnar, S "Investigation into Refinements to the SL86 2 Stage to Orbit Space Launcher". Research Thesis, September 1988, Cranfield Institute of Technology.

4. Fielding, J P & Molnar, S "DES 8842 - Development of Improved Versions of the SL86 Space Launcher, January 1989, Cranfield Institute of Technology.

5. Bowling, T S "DES 8708 - European Labspace, ELS - Group Project Specification", October 1987, Cranfield Institute of Technology.

Table 1 Performance and Dimensions

		SL86-V1	SL86-V2	SL86-V3
Target Masses				
Maximum design (take off) mass	(both stages)	249,800kg	237,800kg	250,000 kg
Maximum landing mass (emergency)	(both stages)	167,000kg	132,653kg	139,800 kg
Maximum mass	(orbiter)	115,000kg	115,000kg	115,000 kg
Maximum design (take off) mass	(booster only)	135,000kg	122,000kg	130,000 kg
Maximum landing mass	(booster alone)	135,000kg	92,415kg	98,000 kg
Maximum landing mass	(orbiter)	22,000kg	22,000kg	22,000 kg
Performance				
COMBINATION Take-off field length at max. AUM		3826m(11662ft)	2185m	
BOOSTER NORMAL landing distance		3714m(11320ft)	2091m	
ORBITER landing distance		3203m(10510ft)$_2$	3203m	3203m
COMBINATION ABORT LANDING DISTANCE		3772m(11496ft)^{2}*	3000m	
MACH. NO. AT SEPARATION		4	4	5
SEPARATION ALT.		25km	25km	25.5km
MAX. CROSS RANGE PRIOR TO SEPARATION		364km(230 Miles)	1216.35km (760 miles)	1177km
TIME PRIOR TO SEPARATION		21mins	27.15mins	23.04mins

ALT. OF ELLIPTICAL TRANSFER ORBIT PERIGEE	100km	COMMON TO ALL VERSIONS
MACH. NO. IN TRANSFER ORBIT	26	
TIME FROM SEPARATION TO TRANSFER ORBIT	6mins 10secs	
ALTITUDE OF LOW EARTH ORBIT	300km	
PAYLOAD INTO L.E.O.	4500kg	
PAYLOAD BAY SIZE	4.5m dia. by 4.5m long	
Dimensions		
BOOSTER WING AEROD. REF. AREA	548.6m^2	
WINGSPAN	31.5m	
OVERALL LENGTH	61.0m	
ORBITER WING AERO REF. AREA	164m^2	
WING SPAN	16.8m	
OVERALL LENGTH	32.74m	

* CONTROL PROBLEMS

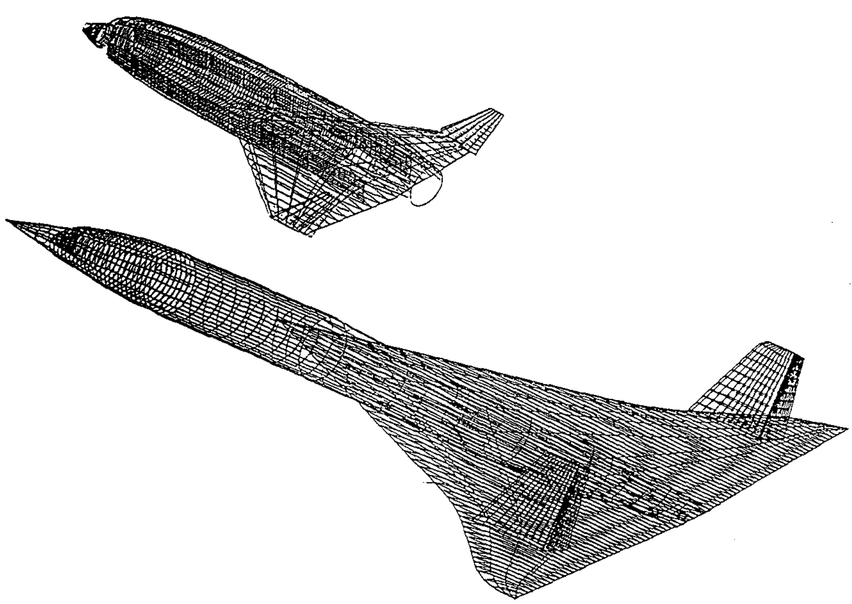


FIG.1 CAD MODEL OF BOTH STAGES OF SL86-VI

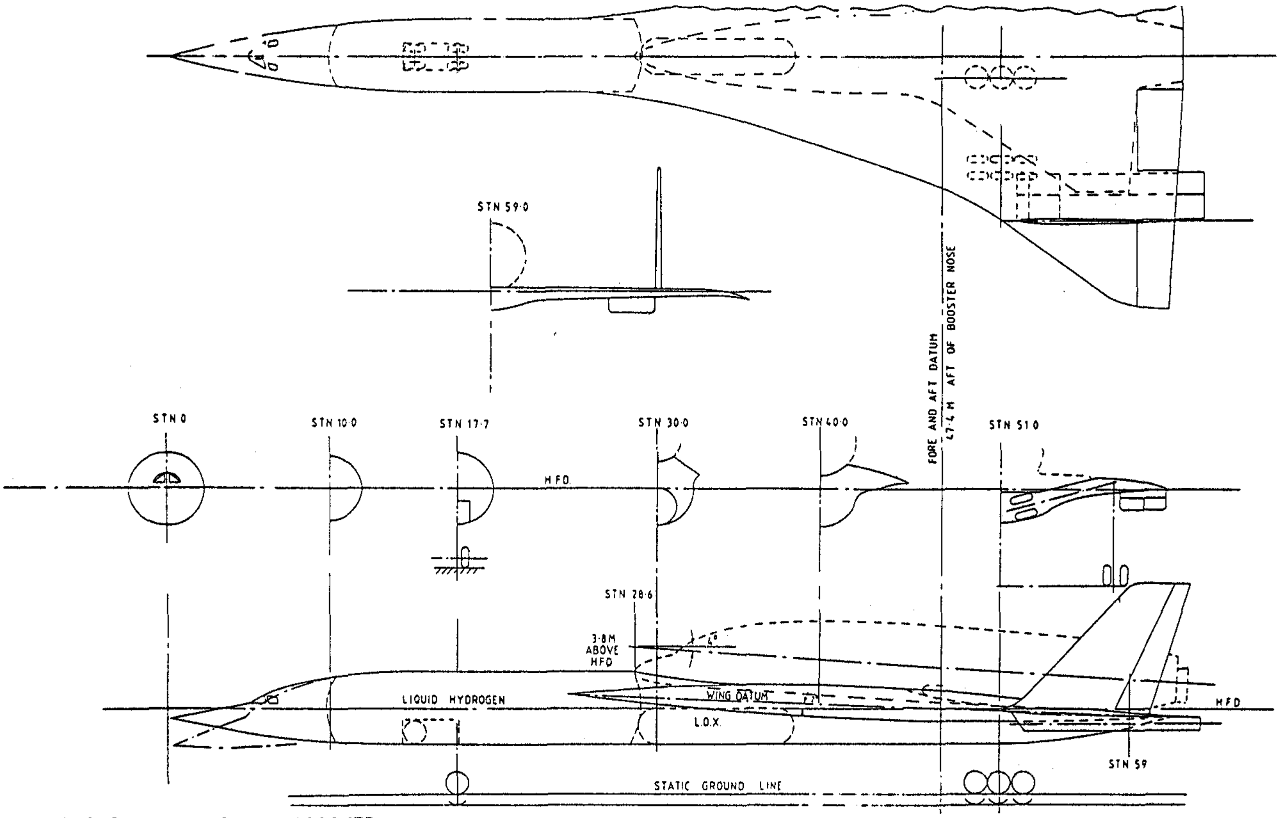


FIG.2 THE ORIGINAL BOOSTER

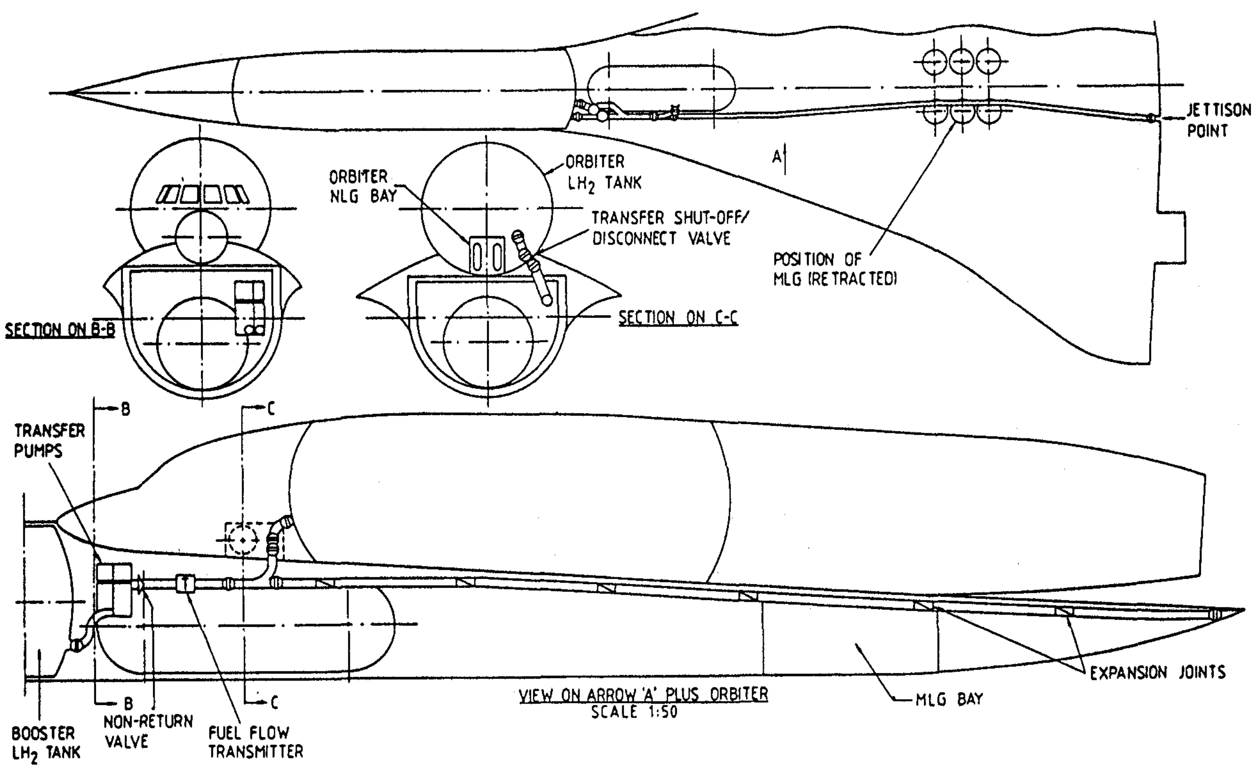


FIG.3 LIQUID HYDROGEN CROSS-FUELLING

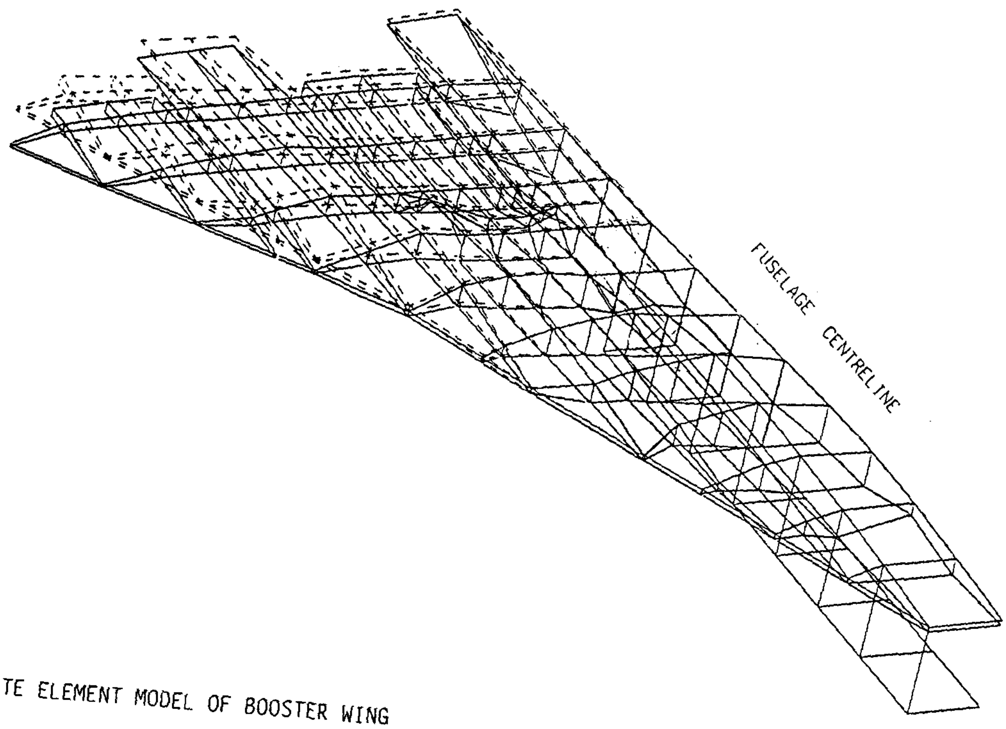


FIG.4 FINITE ELEMENT MODEL OF BOOSTER WING

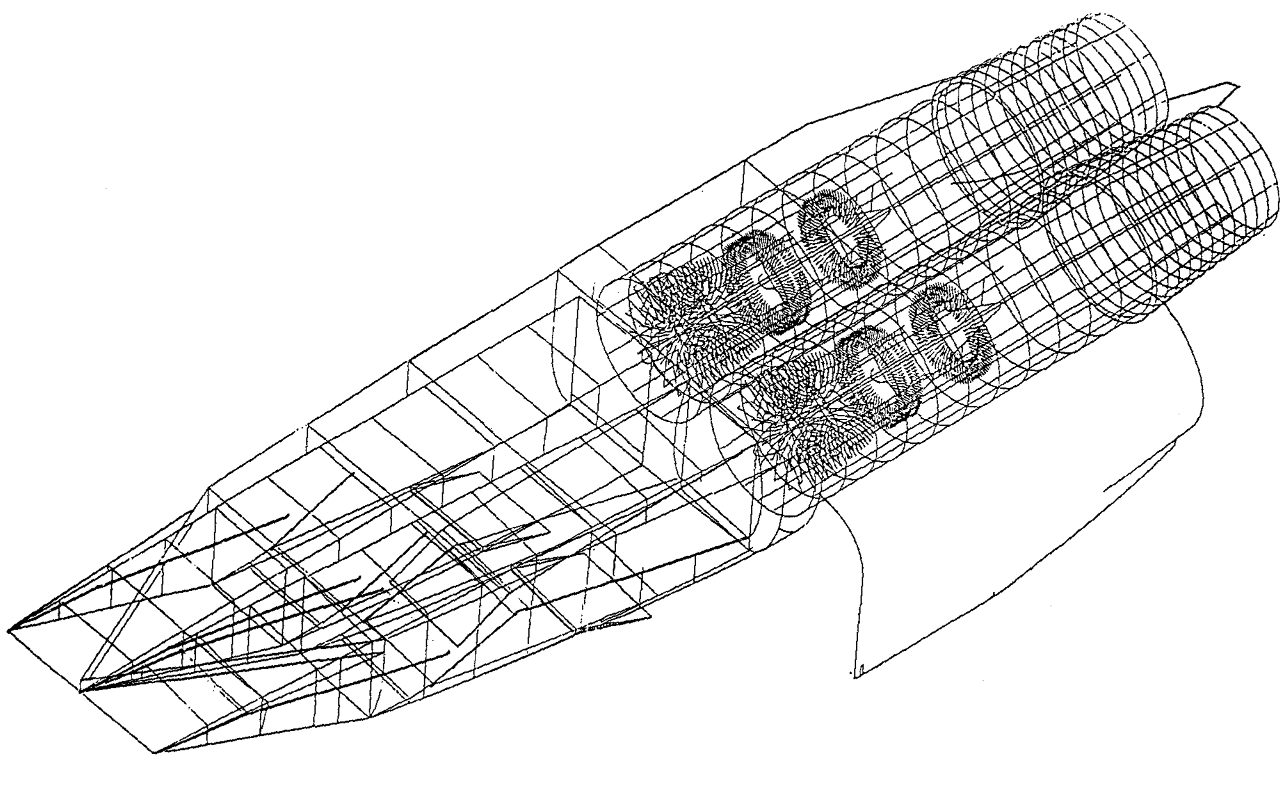


FIG. 5 BOOSTER TURBO-RAMJET ENGINE INSTALLATION

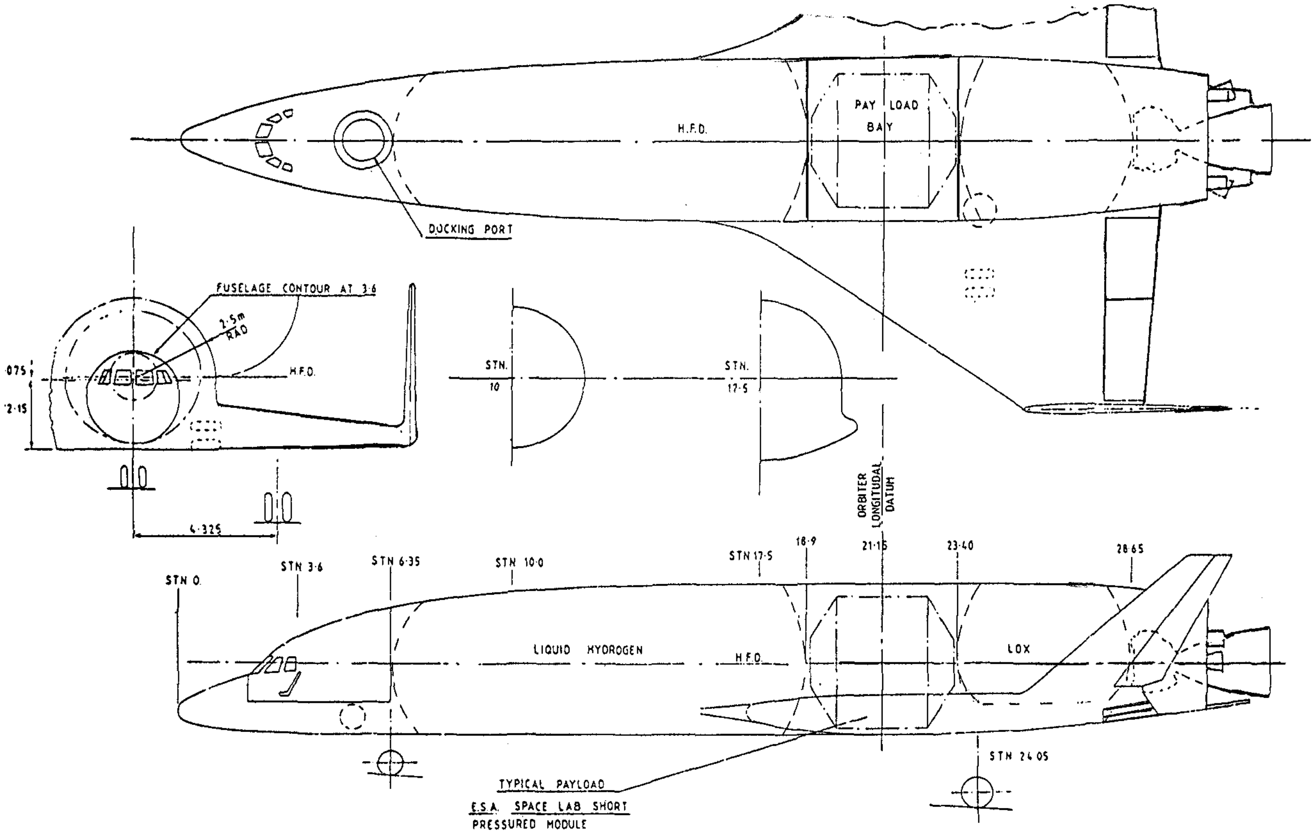


FIG.6 ORBITER FUSELAGE

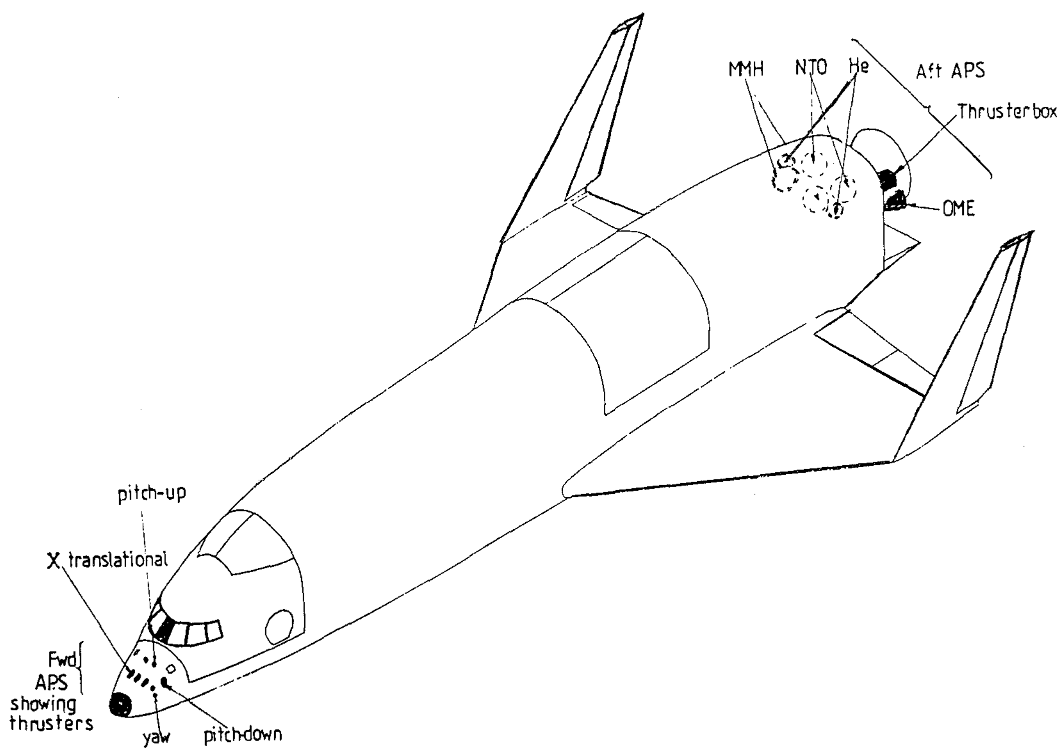
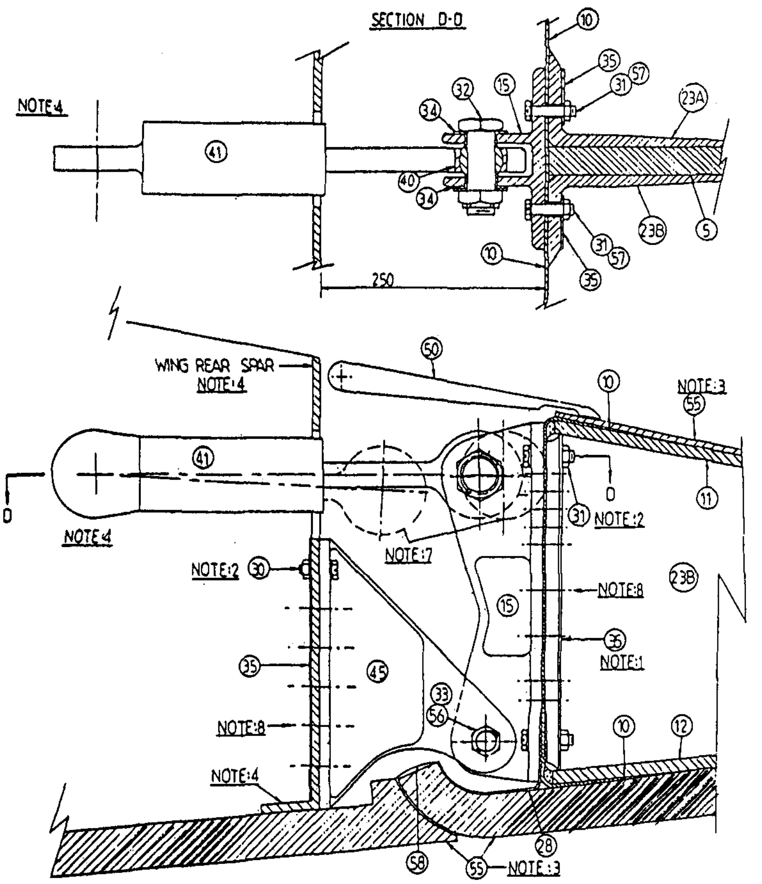


FIG.7 AUXILLIARY POWER SYSTEM (A.P.S.)



No	DESCRIPTION / MATERIAL	DRAWING No
5	RIB No5	SL86-0-E-5
10	FRONT SPAR	SL86-0-E-2
11	UPPER SKIN PANEL	SL86-0-E-2
12	LOWER SKIN PANEL	SL86-0-E-2
15	ACTUATOR HINGE FITTING, TA48 FORGING	SL86-0-E-6
23A, B	INBOARD, OUTBOARD No5 RIB TO SPAR BRACKET $(0_{oc}:45_{2c})_s$	
28	LEADING EDGE TILE SUPPORT BRACKET	SL86-0-E-3
30	BOLT, NUT & WASHER MIL-T-9047, 10mmØ, 6/SIDE	
31	BOLT NUT & WASHER MIL-T-9047, 12mmØ, 10/SIDE	
32	PIN, WASHER & CASTLE NUT, S96, 38.1mm(1.5") Ø	
33	PIN, WASHER & CASTLE NUT, S96, 22.2mm(0.875") Ø	
34	BUSH, S80, 3mm WALL THICKNESS	
35	BACKING STRIP, 2.5mm THICK, TA57	
40	BEARING, ROSE RNR 24	
41	TANDEM ACTUATOR, STROKE 140mm	
45	CENTRE HINGE BRACKET, TA48 FORGING,	SL86-0-E-6
50	ELEVON SEAL PANEL	SL86-0-E-7
55	THERMAL PROTECTION SYSTEM	
56	BEARING, FAFNIR BS28ATH50M	
57	BUSH, TA49, 2mm WALL THICKNESS	
58	INCONEL SEALING STRIP	

NOTES

1. THE TITANIUM BACKING STRIPS ARE IN 3 SECTIONS PER SIDE AND ARE BONDED IN PLACE AFTER MANUFACTURE OF THE ELEVON.
2. THE NUTS ARE BRAZED TO THE BACKING STRIPS AND BOLTS ARE LOCKWIRED AFTER INSTALLATION. ALTERNATIVE TO BRAZING NUTS IS TO USE TITANIUM ANCHOR NUTS RIVETED TO THE BACKING STRIP.
3. FOR DETAILS OF THERMAL PROTECTION SYSTEM REFER H. HINDS
4. FOR DETAILS OF THE ACTUATOR MOUNTING STRUCTURE AND INNER WING STRUCTURE REFER TO J. SAGGU.
5. PART SECTION ONLY SHOWN.
6. MATERIAL SUBSCRIPT IS: C-CYCOM 3100 BISMALEMIDE UNIDIRECTIONAL CFRP 0.125mm THICK.
7. BROKEN LINES SHOW EXTENT OF ACTUATOR TRAVEL. FOR DETAILS OF ELEVON MOVEMENT REFER TO SL86-0-E-1.
8. ATTACHMENT BOLT CENTRE LINES

FIG.8 ORBITER ELEVON MOUNTING

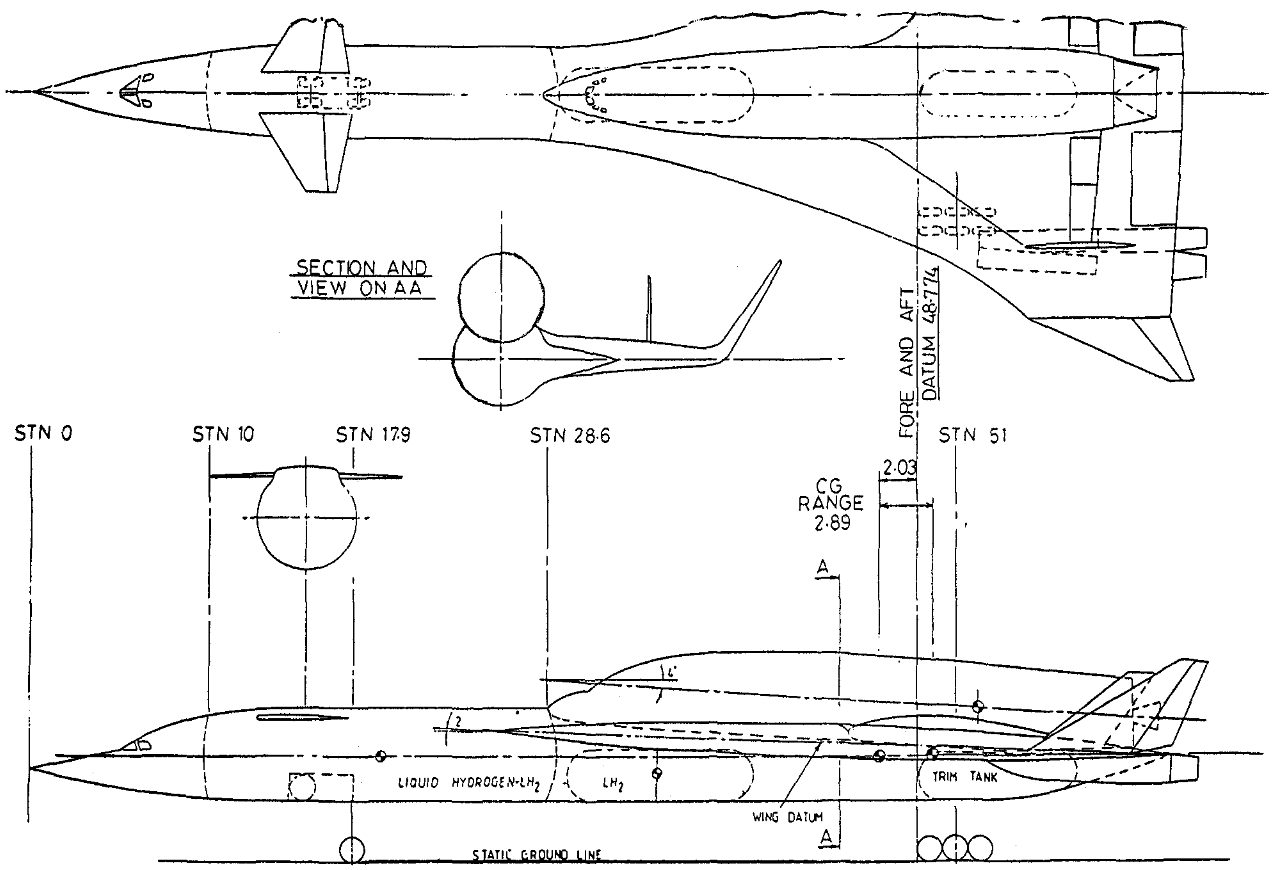


FIG.9 SL86-V2 BOOSTER AND ORBITER

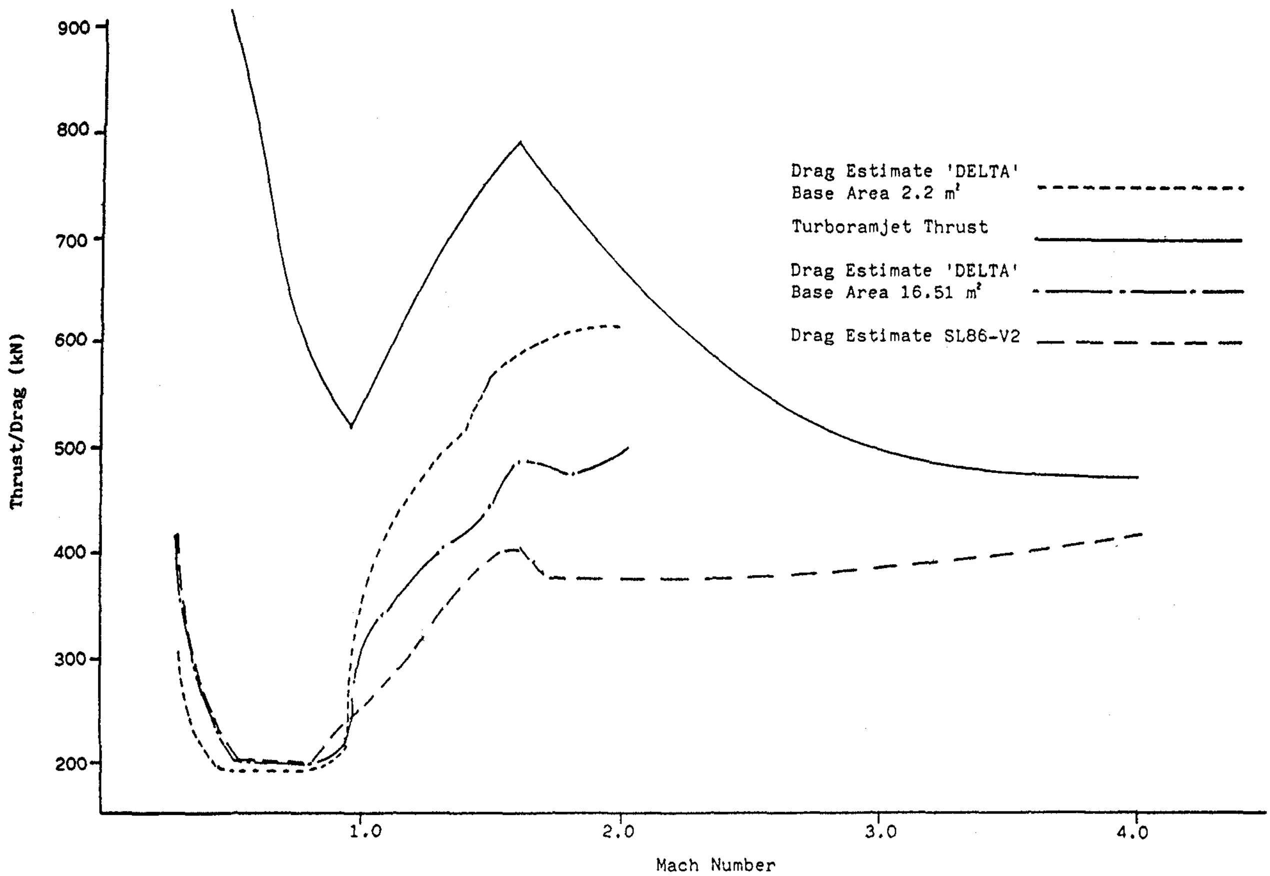


FIG.10 SL-86 V2 THRUST AND DRAG PREDICTIONS