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Space Plane Concept Overview

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– National Aerospace Laboratory, Japan –

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Abstract

Having considered a number of possible future space activities and analysing their implications for future launch vehicle requirements in terms of economics, technological and policy aspects by overcoming the disadvantages of the current launch system, the development of the low-cost fully reusable new space transportation system to and from lower earth orbit, as driven by the clear need for affordability and operational flexibility, would be key issue.

For such advanced systems, the spaceplane integrated by hypersonic airbreathing propulsion system, optimally configured as single stage or two stage to orbit, horizontal take-off and landing system, would be potentially one of promising options.

In Japan, National Aerospace Laboratory of Science and Technology Agency (NAL) has initiatedthe Spaceplane Program since 1987 to define the concept and to mature the required hypersonic technologies as well as to provide a base of research and development capabilities in critical disciplines for the development of future space transportation system.

The present overview paper will discuss the current activities on NAL spaceplane research program, with an emphasis on the vehicle system concept powered by hypersonic airbreathing propulsion system.

I. Introduction

Japan's policy for future space transportation system development was deliberated by the Consultative Committee on Long Term Policy under Space Activities Commission, and Advisory Committee on Space Plane under Research and Development Bureau of Science and Technology Agency in 1987 [1)-3)].

Future fully reusable spaceplane with low operational cost as driven by the clear need for affordability and operational flexibility optimally configured as horizontal take off and landing system, would become required as the successor of the current systems to be phased out around 2010$^+$. The corresponding decisions for the development would then be taken around the year of 2000.

Based upon the program plan discussed by the Advisory Committee, basic Space Plane R&D program scenario is schematically outlined in Figure 1.

The program consists of *planning phase*, *Technology Readiness Verification Phase* and *Experimental Space Plane Development Phase* to promote the research and development based on the time-phased scenario to attain the goal of fully reusable spaceplane development in the 21st century.

National Aerospace Laboratory of Science and Technology Agency has initiated Spaceplane Program to define the spaceplane system concept and to develop the related hypersonic technology bases for the future development of new space transportation system, configured as full-reusable, single stage to orbit (SSTO), horizontal take-off and landing system as Japan's leading reference concept, since 1987. [4)-5)]

Key technology research objectives and issues in the respective research technology fields such as aerodynamics, structure and materials, guidance and control, computational fluid dynamics, manned flight and airbreathing propulsion are summarized on Table 1.

The current status of the Spaceplane Program is in technology maturization phase, to provide technology as well as to provide bases of R&D capabilities in critical disciplines, which would also identify and develop technology to increase future spaceplane mission performance and to enable new missions.

The present overview paper will summarize the current activities on NAL spaceplane research with an emphasis on the vehicle system concept powered by hypersonic airbreathing propulsion system.

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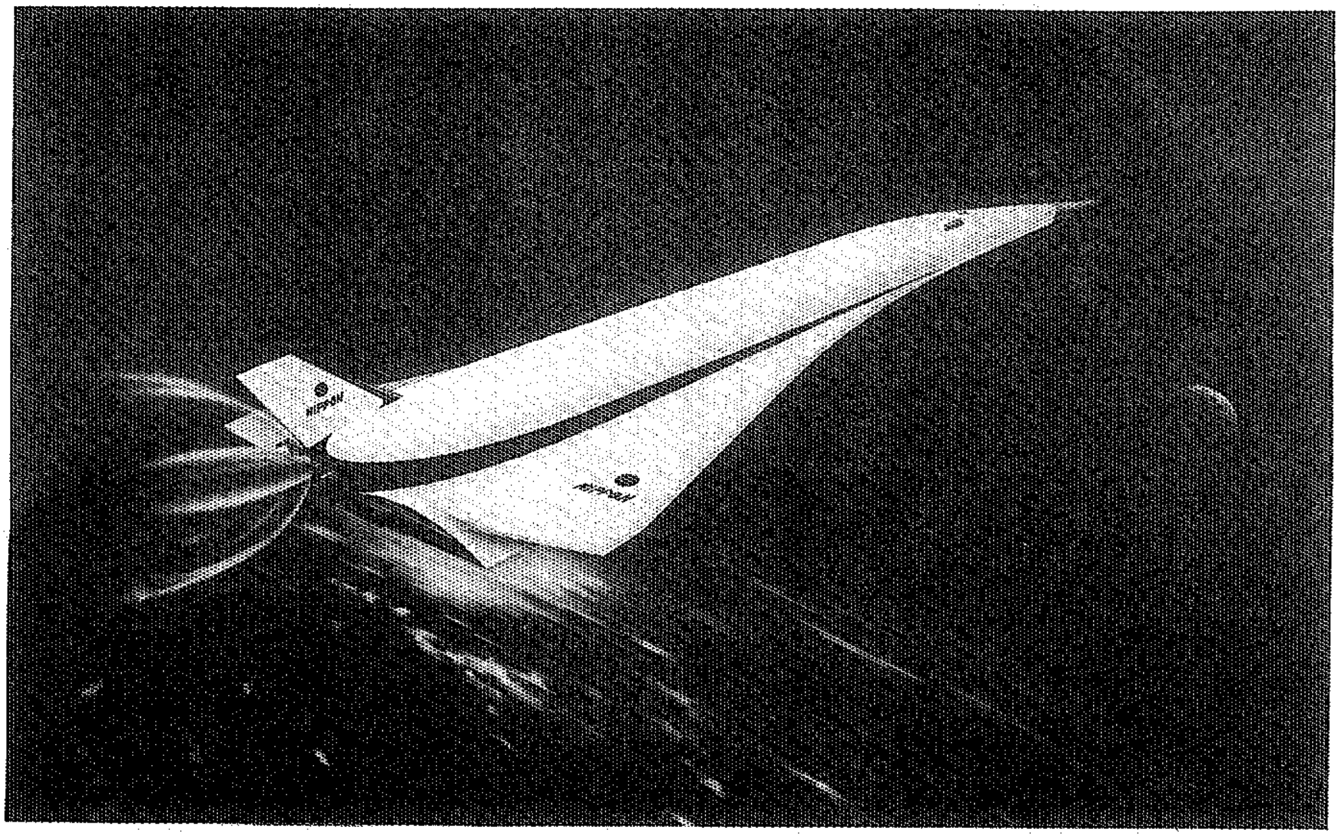
Technology Area	Objectives	Key Technology Issues
Aerodynamics	· Optimum cross range, acceleration, hypersonic stability and control, low-speed horizontal take of and landing capabilities. · High propulsive efficiency (vs aerothermodynamic heating). · Optimum Propulsion / Airframe integrated vehicle design.	· High Lift / Drag ratio (minimum drag), reentry capability, required wing planform area, sweep angle, profile. · Airbreathing / propulsion system integration design issues; stability and control, control effectiveness, interaction between Reaction Control System, forebody / inlet integration, nozzle afterbody design for hypersonic region, off-design performance, base drag reduction for transonic region ground effect for take off and landing. · Forebody (minimum drag, inlet performance longitudinal stability) / Inlet (compression efficiency, thrust induced moments, pitch / yaw sensitivity, flow capture / spillage / Afterbody·Nozzle (base drag, thrust-dependent moment).
Structures & Materials	· Weight reduction by structure design and advanced material selections for very low structural weight fraction vehicle. · High volumetric structural efficiency (Fuselage / Cryogenic Tank structure) design for high fuel weight fraction requirement. · Design for severe aerothermal loads. · Active cooling structure for wing / fuselage and propulsion (heat recovery).	· Advanced materials : Titanium - Aluminide intermetallics (Ti3Al-base (α-2), TiAl-Base (γ)) , metal-matrix composites such as Titanium-Aluminide composites , Carbon-Carbon composites, Ceramic-Matrix composites for light weight hot structure. · Coatings (thermal control, protection against *environment) designed to have high emissivity*, noncatalytic to the recombination of dissociated gases, oxidation resistance, hydrogen-compatibility. · Integral / nonintegral, pressurized structure for light weight and high volumetric Tank / Fuselage structure. · Slush Hydrogen compatibility (fuel state, material) · Loads evaluation, criteria selection, thermal control system, trajectory tailoring. · Active cooling structure by high-conductivity materials including SiC coated Niobium metal, copper-matrix composites (Cu/Gr) and beryllium-alloys (Cu / Be), , for small radius nosecone and leading edge structure.
Guidance & Control	· Vehicle performance optimization · Highly reliable and redundant guidance, control and stability for all flight phases (Takeoff, Ascent, Orbit Insertion, Deorbit Targeting, Rnadev / Docking and Deorbit Burn, Entry, Terminal Area Operations *Approach and Landing, Abort Targeting and Abort)* · Ability to abort safety at all times following an initial failure, to increase operational flexibility and reduce costs.	· Optimized trajectory, minimization of weight or size for the desired mission performance. · Design criteria for *aerospace – worthiness. self-contained onboard autonomous vehicle guidance and control designs with fault* tolerant, self-check system, AI based human / machine interface. · Optimized control and insertion to orbit, hypersonic stability and control. · Optimization of and /or interaction between aero control and reaction gas control. Control surface sizing issues ; engine out control / unstart for stability angmentation and good handling qualities throughout high q and high temperature environment and actuators (freqency requirement, hinge moment method), RCS augmentation at low q. Minimize propulsive thrust induced moments, pitch / yaw sensitivity.
Computational Fluid Dynamics	· Numerical Simulation of flight environment to compensate for the limiting capability of existing ground-based experimental facilities. · Rational vehicle design approach	· Numerical Simulation of full 3 dimensional, hypersonic aerothermo chemical-reacting flow fields both external to airframe, and internal to propulsion system especially for real-gas chemical reacting environment. (Propulsion / Airframe integration — Nose bluntness effect , forebody aerothermal loads, inlet flow field and performance, Nozzle flow field and *performance* —) · Effective for detailed design analysis for vehicle design and result interpretation.
Manned Flight	· To enhance safety and reliability for manned flight, task and performance management.	· Optimum Design of Human / *Machine interface. (Visibility, instrumentation and interactive display / control)* Abort recovery system, Development of manned flight criteria by flight simulations and / or flight experiments, Development of ECLSS to satisfy the required weight and high ambient stagnation temperature environment constraint. Participation of pilots on Spaceplane R&D in the earlier stages is key issue.
Propulsion	· Development of high perofrmance propulsion system to satisfy the *required weight and sizing constraint, operating efficiently across the* speed regime from takeoff to orbital speed. · Establish man – rated criteria for airbreather, rocket and/or combined propulsion system. · Propulsion is one of the most key enabling technology to define Space plane system configuration.	· High performance minimum weight airbreathing propulsion, Propulsion (Inlet / Combustors / Nozzles) / Airframe (Noise / Forebody / Afterbody) integration (wider ΔV capability, higher effective specific thrust Is.p. and higher thrust to weight ratio, required high thrust for acceleration against transonic drag). For SSTO Concept, scramjet engine is the only promising concept of high speed propulsion, where heat recovery cycle by injection of excess hydrogen (both regenerative cooling and recovery of internal losses) to extend SCRAM's operating limit ($M \geq 15 \sim 20^{+}$) is essential. For low *speed propulsion, accelerating to SCRAM's operating limit* ($M \geq 4 \sim 6$)*, Liquid Rocket based LACE (Liquid Air* Cycle Engine) is potentially one of promising options. · For TSTO Concept, development of minimum weight LACE with improved air-liquidification/ heat-exchange capability is essential.

Table 2. Key Technology Research Objectives



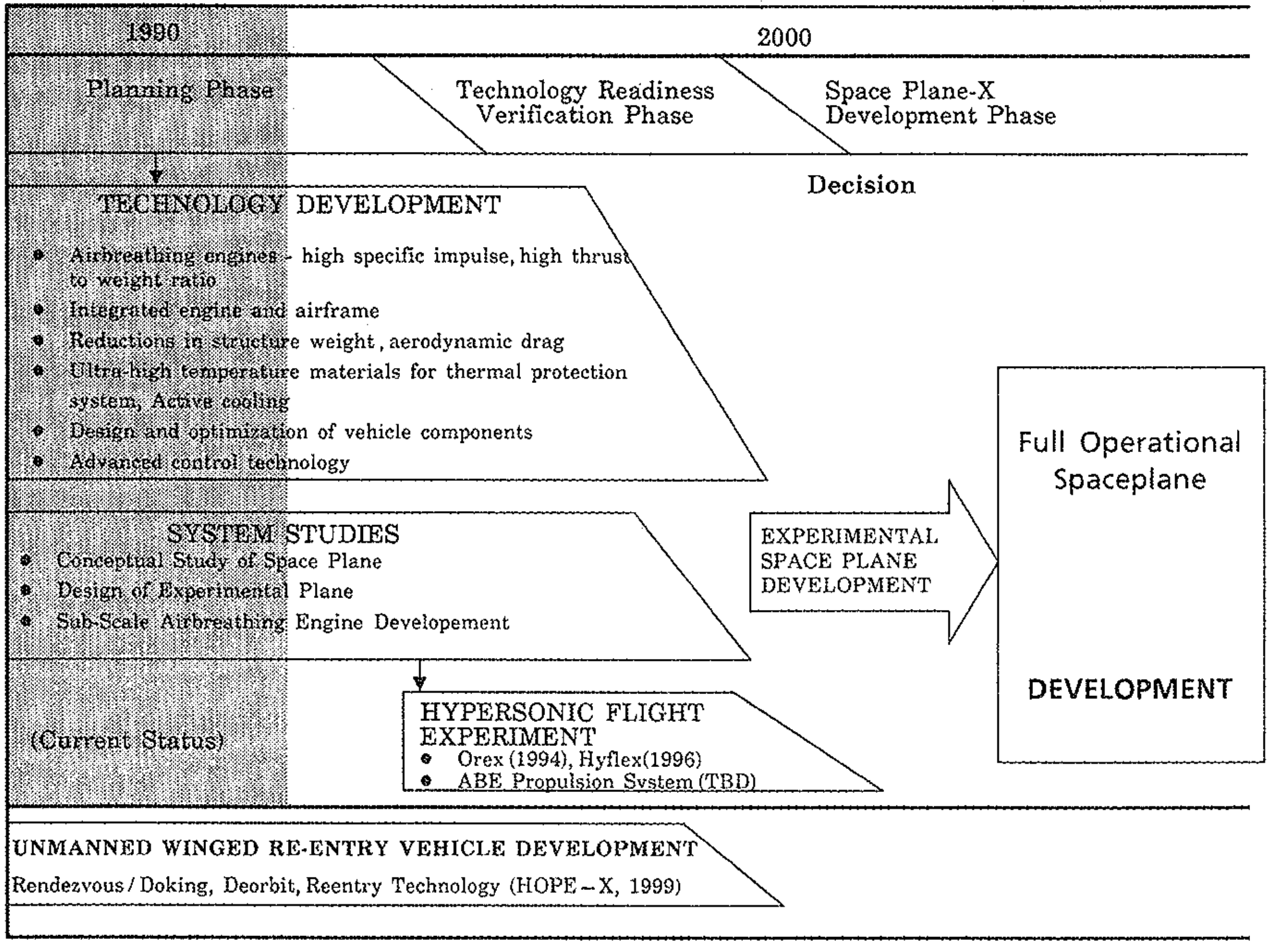


Figure 1. **SPACE PLANE R&D PROGRAM SCENARIO**

II. Spaceplane Concept

Future spaceplane reference concepts are being pursued by the respective countries as summarized in Table 2. Among these categories, our concept and key design features in achieving the mission objectives are characterized by vehicle reusability with advanced airbreathing propulsion system in priority.

Table 3 summarizes the key requirement in achieving the spaceplane object.

The key issues for the spaceplane are to reduce operational cost as well as to improve operational safety, reliability and comfortability for manned vehicle and to enhance operational flexibility such as quick turn around capability.

In achieving the above cited spaceplane objectives, the system design features include;

(i) to exclude the vehicle expendability (fully reusable)

(ii) to utilize aircraft-type operation ground facilities, and to exclude the complexity of vertical launch

(iii) to employ the system capabilities for the horizontal take off and landing and less thrust loading at take off (by wing lift) with multi-engine redundancies

(iv) to reduce the heavy liquid oxygen and to improve propulsion performance by integrating the advanced airbreathing propulsion system

To assess the concept feasibility and to define system configuration, the baseline mission requirement for spaceplane is tentatively set as summarized below, i. e.,

- *Space transportation to and from Low Earth Orbit (500Km destination orbit with inclination angles of 28.5deg.) of 10 crew and payload recovery of 2 ton.*
- *Short-term experimental laboratory orbit for earth observation, microgravity etc,*
- *Servicing to platforms and satellites with resupplies, maintenance and repair, and space passenger tour by orbital or sub-orbital flight (with orbital stay time of minimum 5 days).*

Spaceplane system studies are underway with the specific objectives by the above mentioned SSTO space plane concept by providing the relevant data bases in NAL. 6)-9)

–SSTO Concept–

In the concept and system configuration analysis, one of the key issues is to to evaluate the adaptability of the hypersonic airbreathing engines to SSTO concept and to identify the technology needs and to obtain propulsion performance data required for spaceplane system studies.

For the feasibility of the SSTO spaceplane system, the key technology issue is to develop the high performance and minimum weight hypersonic airbreathing propulsion system satisfying the required weight and sizing constraints and operating efficiently across the wide ΔV regime. Airbreathing propulsion must have required high thrust for acceleration against trasonic drag and higher effective specific impulse at hypersonic flight regions, which hence must be superior to those of conventional liquid rocket engines.

The airbreathing propulsion concepts were evaluated based upon the following design criteria;

- Wide ΔV *capability*
- *High thrust to weight ratio*
- *High effective specific impulse*
- *Propulsion system integrability*
  (From take off to orbital speed)
- *Account for Japan's technology bases*

It was understood that for higher hypersonic flight regime, the scramjet engine was the only promising option and the feasibility of SSTO system depended upon the maximum operation limit of scramjet engine.

Also acceleration to an orbital speed by the scramjet engine would be far beyond from our scramjet technology bases.

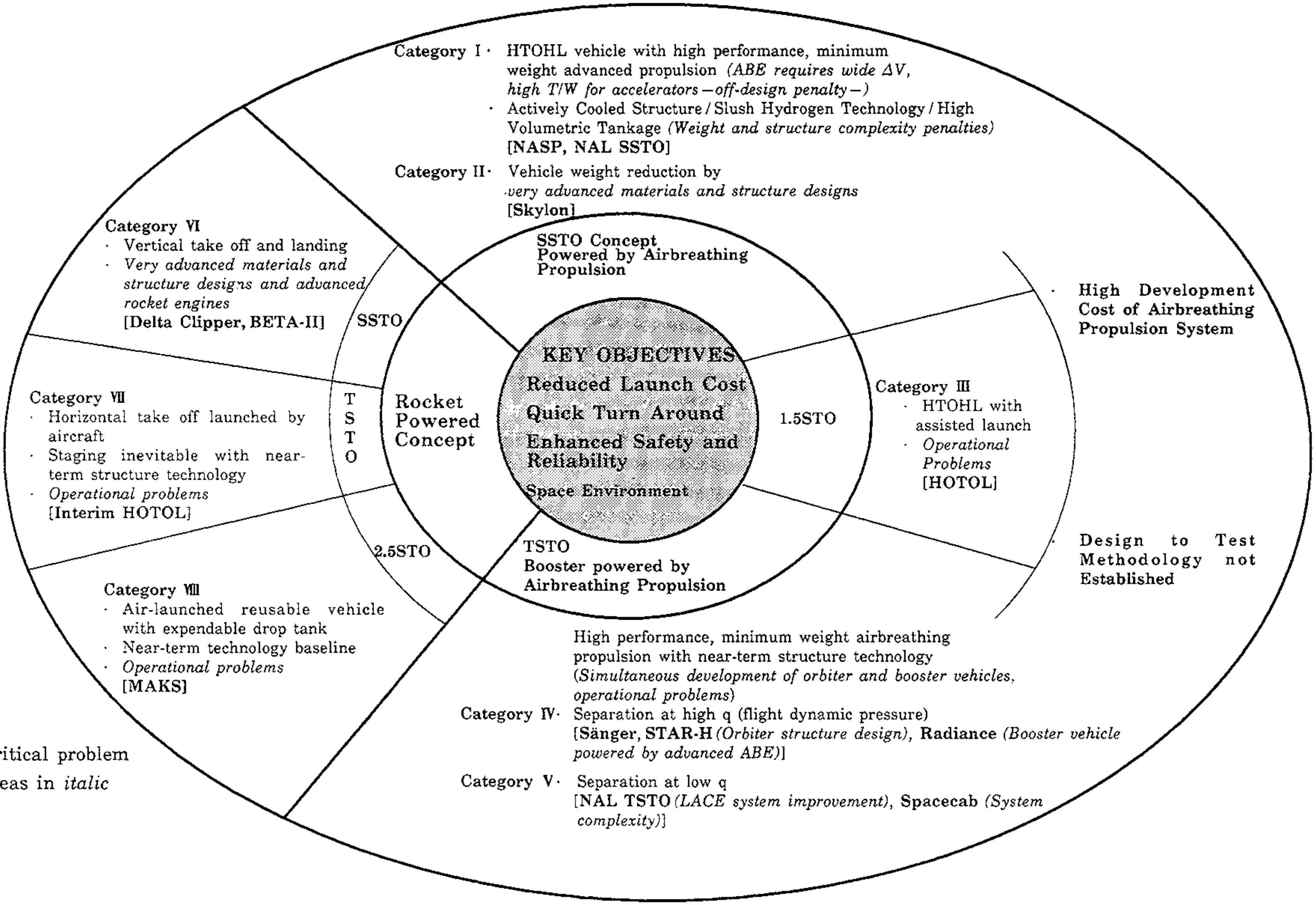
And if acceleration by the scramjet engine was achieved to $M=16 \sim 18$, which would correspond to roughly half of the energy required to orbit, the resulted fuel fraction would be approximately 75%.

For the SSTO spaceplane fueling with slush hydrogen, the design of cryogenic fuel tank of 75% fuel weight fraction is critical constraint because of high volumetric tank being required to design within the limited vehicle volumes.

Considering these design constraints, acceleration by the scramjet engine had to be achieved to the region beyond $M = 16$ as the optimized compromization.

Second problem is the low speed propulsion concept which accelerates the vehicle to scramjet operating region.

Hence the final acceleration to orbital speed being achieved by the liquid rocket engine, the low speed propulsion of rocket based concept had an advantage in view of the system integrability.



Category I · HTOHL vehicle with high performance, minimum weight advanced propulsion *(ABE requires wide ΔV, high T/W for accelerators — off-design penalty —)*
· Actively Cooled Structure / Slush Hydrogen Technology / High Volumetric Tankage *(Weight and structure complexity penalties)*
[NASP, NAL SSTO]

Category II · Vehicle weight reduction by *very advanced materials and structure designs*
[Skylon]

Category III
· HTOHL with assisted launch
· *Operational Problems*
[HOTOL]

· **High Development Cost of Airbreathing Propulsion System**

· **Design to Test Methodology not Established**

High performance, minimum weight airbreathing propulsion with near-term structure technology *(Simultaneous development of orbiter and booster vehicles, operational problems)*

Category IV · Separation at high q (flight dynamic pressure)
[**Sänger, STAR-H** *(Orbiter structure design)*, **Radiance** *(Booster vehicle powered by advanced ABE)*]

Category V · Separation at low q
[**NAL TSTO** *(LACE system improvement)*, **Spacecab** *(System complexity)*]

Category VI
· Vertical take off and landing
· *Very advanced materials and structure designs and advanced rocket engines*
[Delta Clipper, BETA-II]

Category VII
· Horizontal take off launched by aircraft
· Staging inevitable with near-term structure technology
· *Operational problems*
[Interim HOTOL]

Category VIII
· Air-launched reusable vehicle with expendable drop tank
· Near-term technology baseline
· *Operational problems*
[MAKS]

Note: Critical problem areas in *italic*

Table 2 **Spaceplane Reference Concepts Summary**

KEY REQUIREMENTS IN ACHIEVING
Space Plane OBJECT

OBJECT :

- Enhance Operational Flexibility, Safety / Reliability
- Reduce Operational Cost

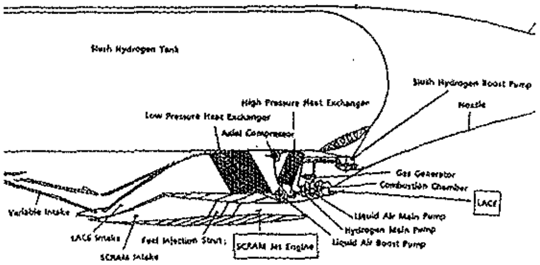
REQUIREMENTS :

- Totally Reusable
- Horizontal Take-Off and Landing
- Ability to Abort Safely at All Times following an Initial Failure
- Quick Turn Around
- Acceleration by Advanced Hypersonic Airbreathing Propulsion System

Table 3.

Total Length	94.0 m
Wing Span	29.0 m
Height	19.2 m
Body Length	90.0 m
Body Width	16.0 m
Body Height	13.7 m
Wing Delta Angle	70 deg
Wing Aspect Ratio	1.152
Wing Area	730 m^2
Take-off Wing Loading	480 kg/m^2
Landing Wing Loading	147.2 kg/m^2
Dry Weight	106.7 ton
Crew	10 persons
Propellants	
(i) SLH2	201.61 ton
(ii) LOX	28.3 ton
(iii) RCS & OME	12.7 ton
Vehicle Gross Weight	350.0 ton
Landing Weight	107.5 ton
(i) Body	*26.4*
(ii) Wing (Main & Tail)	*14.0*
(iii) Thermal Structure	*6.5*
(iv) Engine Thrust Structure	*4.4*
(v) Propulsion System	*43.0*
LACE	*(11.4)*
SCRAM	*(9.2)*
SLH$_2$ TANK	*(14.3)*
LOX TANK	*(0.4)*
RCS & OME SYSTEM	*(4.6)*
Suply System	*(3.0)*
(vi) Sub Systems	
G&C System	*0.7*
Thermal Management System	*1.5*
Electronics & Communication System	*2.5*
Landing Gear	*3.9*
Actuator System	*1.2*
Life-Support System	*2.8*
Main Engines	
(i) LACE (100ton thrust at S.L.S.,4 engines)	4 set
(ii) SCRAM (Intake Area,)	*6 modules* (18 m^2)

Table 4. SSTO Vehicle Characteristics



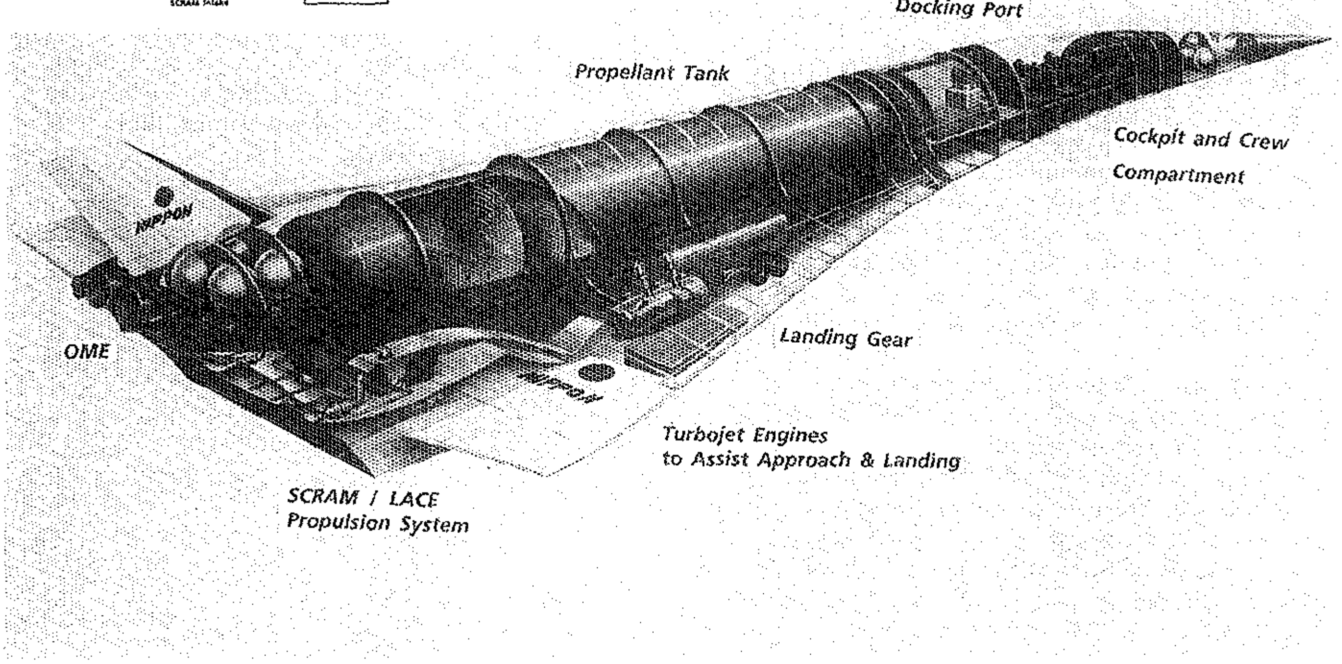


Figure 2. System Layout Of SSTO Spaceplane Concept

In the present SSTO concept studies, we have selected LACE (Liquid Air Cycle Engine) for low speed propulsion concept, accounting for performance capability and Japan's technology bases.

(We have liquid engine technology bases through the development of LE-5 and LE-7 rocket engines and LACE technology research is underway by MHI/NASDA in Japan.[10])

Based upon the previous concept analysis, the concept characteristics of the SSTO Spaceplane are summarized as follows;

- *Integrating the Scram / LACE hypersonic airbreathing propulsion system with an acceleration of the scramjet engine to Mach number over 16.*
- *Fueling with slush hydrogen with fuel weight fraction less than 70%*
- *Total gross weight of 350ton with the structural weight reduction by approximately 20% vs current technology potential*[11]

On SCRAM / LACE propulsion system and the extension of hypersonic operating range is briefly cited as follows.

For scramjet propulsion, the fraction of its propulsive energy achieved by hydrogen fuel combustion became less as the hypersonic flight Mach number increases.

For the higher hypersonic flight regimes beyond $M \simeq 10$ where energy losses due to internal drag and / or skin frictions and severe heat problems, heat recovery operation would be effective for the extension of the scramjet engine acceleration limit and improving its performance.

By using excess hydrogen fuel compared with the stoichiometric equivalence ratio of fuel to the air, active cooling can recover the heats generated by not only in the scramjet engine but also aerothermodynamic heating on the outer surfaces of airframe. The recovered heats by hydrogen would play a positive role, if they are optimally injected parallel to the engine internal flow, on producing thrust. If this mechanism is well designed, we could expect the effective operation of the scramjet engine beyond Mach 16.

Based upon the heat recovery concept, the scramjet engine performance was estimated [9,12] using the thermodynamic energy theories as defined by Czysz[13-15] and Builder.[16] ,

Of the LACE cycles as the low speed propulsion concept, accelerating to the region of $M \simeq 5$, the air compressor cycle with tank circulation LACE was selected based upon the performance analysis. A LACE utilizes an air liquefaction system by air intake and heat exchanger and a liquefied air is used as an oxidizer. A rocket mood operation for the final acceleration to orbit, after the cutoff of the scramjet engine, is achieved by changing the oxidizer from liquefied air to liquid oxgen (LOX) that is contained in the LOX tank. The slush hydrogen of 50% liquid / solid weight fraction, having high cryogenic source capability for active cooling, could also be utilized as a coolant to enhance an air liquefaction efficiency, as defind by an air-to-fuel mass flow ratio, while the LACE also needs a gas generator (GG) cycle to avoid excessive raising of fuel temperature with a booster pump. A part of slush hydrogen flow returns to a fuel tank as liquid hydrogen after passing through heat exchangers. The liquid hydrogen, therefore, is burned as a fuel in both the scram and LACE modes. The heat exchanger consists of two separate liquefication sections at low pressure and high pressure. In the high pressure liquefication process, the saturated air, which can not be liquefied in the low pressure section, is fully liquefied by increasing its pressure with an air compressor, that is, by decreasing the latent heat level.

Figure 2 illustrates the system layout of SSTO Spaceplane Conpect powered by SCRAM / LACE airbreathing propulsion system.

SSTO vehicle configurations and operational aspects were refined and updated using the relevant technology bases obtained by the on-going disciplinary research works.

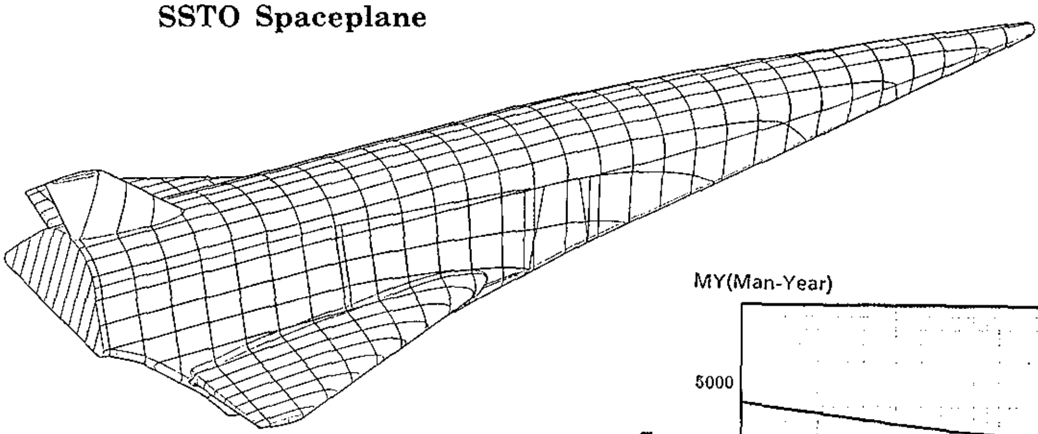
Main vehicle characteristics and general views of the present SSTO spaceplane are presented in Table 4 and Figure 3 respectively.

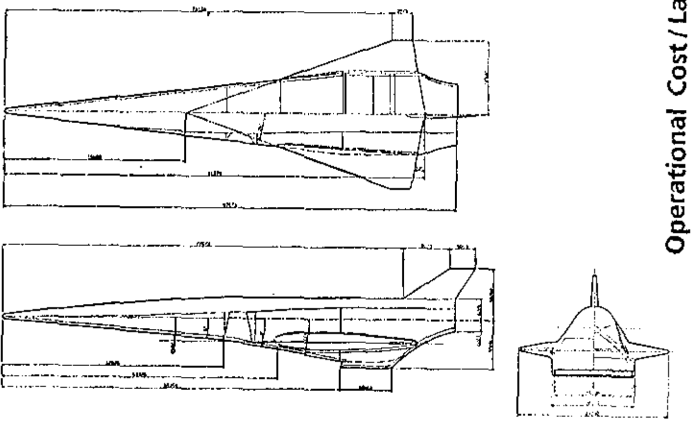
In Figure 4, launch cost of the present SSTO spaceplane are compared with the current STS (Space Shuttle at the initial design stage)[17].

Figures 5 shows the reference ascent flight trajectories for the present SSTO Spaceplane in terms of flight Mach number versus time from the take off respectively.

The LACE engines being started at ground accelerate the vehicle to scramjet operating region of $M=5$ at the altitude of 25.5 km, followed by the scramjet engines acceleration to $M=19.7$.For the final acceleration to the mission orbit, LACE engines are restarted and operated under LOX / LH_2rocket mode.

Figure 3. General View Of Present SSTO Spaceplane





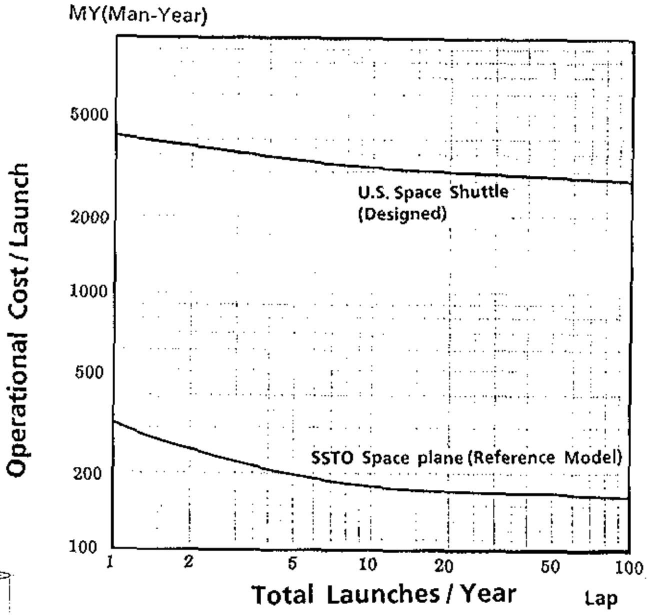
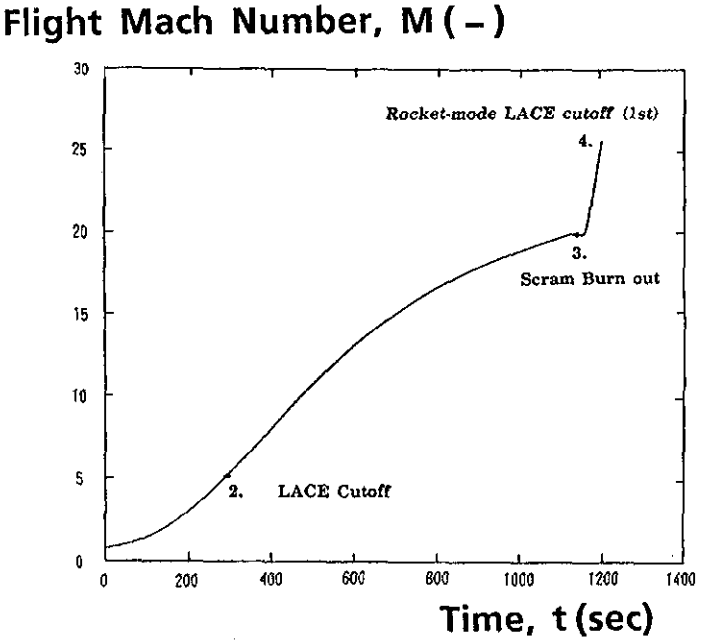


Figure 4. Launch Cost Comparison

Figure 5. Ascent Flight Trajectory (SSTO Concept)



Ascend Flight Trajectory

1.	Initial Gross Weight		350 ton
2.	LACE Cutoff		
	(i)	Altitude	25.5 Km
	(ii)	Relative Velocity	1494.0 m/s
	(iii)	Mach Number	5.0
	(iv)	Flight Path Angle	1.1 deg
	(v)	Vehicle Weight	300.0 ton
3.	Scram Burn out		
	(i)	Altitude	50.0 Km
	(ii)	Relative Velocity	6399.9 m/s
	(iii)	Mach Number	19.7
	(iv)	Flight Path Angle	3.9 deg
	(v)	Vehicle Weight	127.7 ton
4.	Rocket-mode LACE cutoff (1st)		
	(i)	Altitude	74.7 Km
	(ii)	Relative Velocity	7789.5 m/s
	(iii)	Apogee Altitude	500.0 Km
	(iv)	Perigee Altitude	-574.5 Km
	(v)	Vehicle Weight	102.0 ton
5.	Rocket-mode LACE cutoff (2nd)		
	(i)	Altitude	500 Km
	(ii)	Relative Velocity	7612 6m/s
	(iii)	Apogee Altitude	500.0 Km
	(iv)	Perigee Altitude	500.0 Km
	(v)	Vehicle Weight	94.7 ton

–TSTO Concept–

In spaceplane system studies, we have also studied a TSTO vehicle as the alternate reference concept to SSTO, to understand its operational features and to assess the technology feasibility. In general, the vehicle concept characteristics is dominated by the selection of the propulsion system to be integraeted. Although the SSTO concept would have better performance capabilities than TSTO in terms of the operational aspects, the basic design philosophy for TSTO was to accept the penalties of vehicle staging in orders to avoid the following technology problems of SSTO:

(i) Scramjet propulsion as a critical enabling technology for SSTO concept is not yet mature.

(ii) Airbreathing propulsion may not be suitable for accelerators such as spaceplane because of off-design penalties over wide ΔV *regimes, and low thrust to weight ratio capability.*

(iii) Development cost of airbreathing propulsion is very high and design to test methodology is not yet established.

(iv) Actively coold structure technology is not yet mature.

TSTO vehicle concept was designed by using near-term structure technology as far as possible and is powered by a rocket based propulsion system with partially airbreatherized cycle concept in order to improve propulsion performance, and achieve orbiter separation in a low flight dynamic pressure regime.

The general view of the present TSTO concept is shown in Figure 6 and TSTO Booster and Orbiter vehicle charateristics are presented in Tables 5 and 6 respectively. The initial GTOW (total gross weight) of 350 as a baseline reference was changed to 450ton due to the sizing optimization. The booster vehicle was powered by 5 LACE engines.

Table 7 shows the specifications of selected LACE engine cycle concept with air compressor(LACE-C). Number of LACE-C engines to be integrated and air intake area ($4.5m^2 \times 5$) are optimized or compromized for the maximum effective Isp. to be achieved within the permittable design constraints of based liquid rocket engine of LE-7 and booster vehicle sizing.

Also in the present TSTO concept, two turbojet engines of 12 ton S.L.S. thrust class are integrated on the booster vehicle for enabling the powered landing capability.

The Figure 7 presents the corresponding flight trajectory of the present TSTO concept.

The TSTO vehicle is to be accelarated to Mach number of 9.4, altitude of approximately 50km with low flight dymanic pressure of q=5KPa, where the orbiter is to be separated.

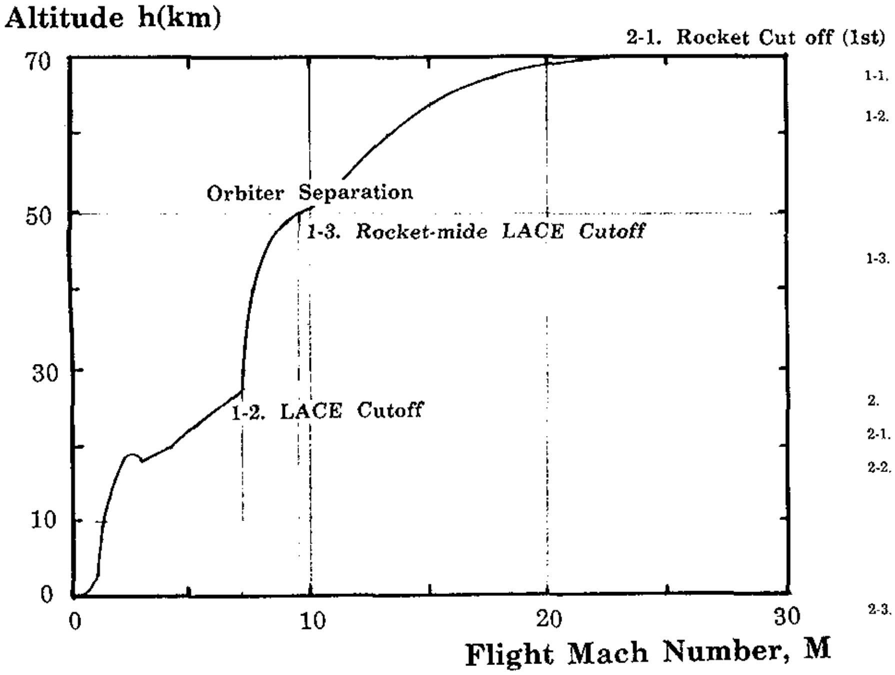
During the vehicle accelarations to Mach 9.4 by LACE engines, an accelerations from Mach 7 through Mach 9.4 was achieved by LACE with rocket-mode cycle engine by feeding liquid oxygen to the combustion chamber.

Table 5. TSTO Vehicle Characteristics (Orbiter)

Total Length	38.7 m
Wing Span	16.7 m
Height	10.0 m
Body Length	35.7 m
Body Width	4.4 m
Body Height	5.0 m
Wing Forward Swept Angle	70 deg
Wing Aspect Ratio	1.18
Wing Area	222.4 m^2
Landing Wing Loading	155.2 kg/m^2
Dry Weight	33.7 ton
Crew	10 persons
Propellants	
(i) SLH2	13.4 ton
(ii) LOX	80.6 ton
(iii) RCS & OME	4.1 ton
Vehicle Gross Weight	132.6 ton
Landing Weight	34.5 ton
(i) Body	*6.0*
(ii) Wing (Main & Tail)	*4.8*
(iii) Thermal Structure	*4.6*
(iv) Engine Thrust Structure	*0.3*
(v) Propulsion System	*6.75*
ROCKET	*(1.8)*
SLH_2 TANK	*(1.38)*
LOX TANK	*(1.36)*
RCS & OME SYSTEM	*(1.75)*
Supply System	*(0.45)*
(vi) Sub Systems	*11*
Main Engines	
(i)ROCKET (100ton thrust at S.L.S,)	1 set

Table 6. TSTO Vehicle Characteristics (Booster)

Total Length	77.8 m
Wing Span	27.8 m
Height	9.7 m
Body Length	75.8 m
Body Width	6.4 m
Body Height	7.4 m
Wing Delta Angle	60.0 deg
Wing Aspect Ratio	1.416
Wing Area	470.0 m^2
Take-off Wing Loading	957.4 kg/m^2
Landing Wing Loading	186.2 kg/m^2
Dry Weight	87.5 ton
Crew	10 persons
Propellants	
(i) SLH2	122.6 ton
(ii) LOX	85.4 ton
(iii) Jet Fuel	18.2 ton
Vehicle Gross Weight	450.0 ton
Landing Weight	91.8 ton
(i) Body	*22.8*
(ii) Wing (Main & Tail)	*15.8*
(iii) Thermal Structure	*0.3*
(iv) Engine Thrust Structure	*1.3*
(v) Propulsion System	*39.9*
LACE	*(16.7)*
SLH_2 TANK	*(13.8)*
LOX TANK	*(2.3)*
JET FUEL TANK	*(0.9)*
Supply System	*(3.6)*
(vi) Sub Systems	*6.5*
Main Engines	
(i) LACE (100ton thrust at S.L.S.,5 engines)	5 set
(ii) Jet Engine (12ton S.L.S,)	2set



1-1.	**Initial Gross Weight**	450 ton
1-2.	**LACE Cutoff**	
	(i) Altitude	27.2 km
	(ii) Relative Velocity	2098.8 m/sec
	(iii) Mach Number	7.0
	(iv) Flight Path Angle	0.6 deg
	(v) Vehicle Weight	342.3 ton
1-3.	**Rocket-mode LACE Cutoff**	
	(i) Altitude	49.8 km
	(ii) Relative Velocity	3095.7 m/sec
	(iii) Mach Number	9.4
	(iv) Flight Path Angle	1.1 deg
	(v) Vehicle Weight	242.6 ton
2.	**Orbit Flight Trajectory**	450 ton
2-1.	**Initial Gross Weight**	132.6 ton
2-2.	**Rocket Cutoff (1st)**	
	(i) Altitude	70.0 km
	(ii) Inertial Velocity	7987.6 m/sec
	(iii) Apogee Altitude	500.0 km
	(iv) Perigee Altitude	70.0 km
	(v) Vehicle Weight	39.6 ton
2-3.	**Rocket Cutoff (2nd)**	
	(i) Altitude	500 km
	(ii) Relative Velocity	7612.6 m/sec
	(iii) Apogee Altitude	500.0 km
	(iv) Perigee Altitude	500.0 km
	(v)Vehicle Weight	38.5 ton

Figure 7. Ascent Flight Trajectory (TSTO Concept)

(Rocket mode)

Engine Cycle	gas generator cycle
Thrust (vacuum)	125ton
Combustion Chamber Pressure	100Kgf/cm^2
Specific Impulse (vacuum)	450seconds
Mixure Ratio	6:1
Propellants	LOX / LH$_2$

(LACE mode)

Engine Cycle	air liquefied with compressor
Thrust(S.L.S)	100ton
Combustion Chamber Pressure	100Kgf cm^2
Specifie Impulse	1280seconds
Turbine Drive	gas generator
Compressor	axial and centrifugal max. com. ratio 12.5
Fuel	50% slush hydrogen
Combustion Chamber	radiation cooled (columbium alloy)
Nozzle Skirt	2 stage extension radiation cooled (carbon / carbon)

Table 7. Specifications of LACE-C

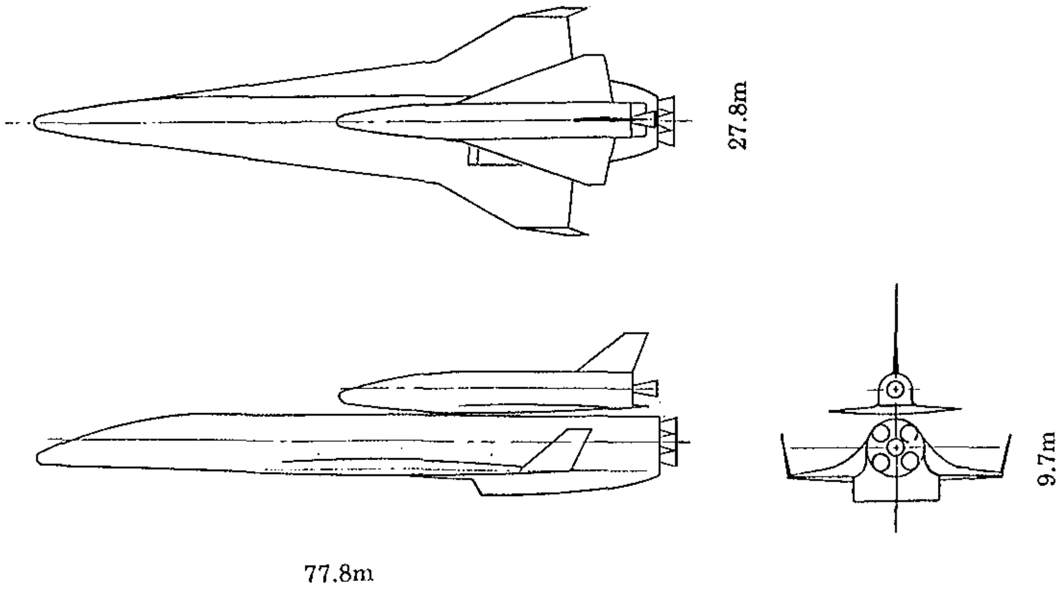


Figure 6. General View of Present TSTO Spaceplane

V Concluding Remarks

Japan's Spaceplane Program was overviewd, which primarily initiated by National Aerospace Laboratory in Japan, with an emphasis on the vehicle system concept powered by hypersonic airbreathing propulsion system.

The present spaceplane concept feasibility primarily depends upon airbreathing propulsion *performances to be achieved by technology* breakthroughs of the current program.

From 1993, the sub-scale model of scramjet engines will be tested by newly developed Ram / Scramjet Engine Test Facility at NAL Kakuda ground facility $_{18)}$. And LACE ground system test is expected after the successfully 1st launch of H-II Rocket, scheduled in February 1994.

The present SSTO and TSTO concepts are hence to be refined and updated using these on-going disciplinary research works.

Having considered a number of possible future space activities and analysing their implications for future launch vehicle requirements in terms of economics, *technological and policy aspects and overcoming* the disadvantages of the current system, the development of the low cost new space transportation system to and from lower earth orbit, as driven by the clear need for affordability and operational flexibility, would be key issue.

R&D efforts for such future space transportation systems are being conducted by U.S., Europe and other countries as their respective national programs.

However, with the consideration of the recent rapid changes or progress in international as well as national situations surrounding space activities, especially after the cold war era, R&D *in this field could benefit greatly from closer* international collaboration. Because the development cost would be high, and markets are currently small, it would be necessary for such a reusable vehicle to serve as the global market.

To this end we need to decide what vehicle it would be most appropriate to develop initially.

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