

FOREIGN TECHNOLOGY

An Overview of Japanese Space Technology

An assessment of Japan's current capabilities in the areas of space and transatmospheric propulsion is presented. The primary focus is upon Japan's programs in liquid rocket propulsion and in space plane and related transatmospheric areas. Brief reference is also made to their solid rocket programs, as well as to their supersonic airbreathing propulsion efforts that are just getting underway. The results are based upon the findings of a panel of engineers made up of individuals from academia, government and industry, and are derived from a review of a broad array of the open literature, combined with visits to the primary propulsion laboratories and development agencies in Japan. The opportunity to meet with many of the Japanese scientists, engineers and leaders, was the key that made the study possible. Not only did their courtesy and cooperation aid us while we were in Japan, but it also proved to be crucial in helping us establish an identity with research work reported in the literature.

Japan's long term plans for space activity as well as their generic paths for achieving these plans are outlined in the Fundamental Guidelines of Space Policy. This document was originally written in 1978, and has since been revised twice to reflect a rapidly broadening space vision; first in 1984, and most recently in 1989. As with any other such plan, the present version will require continued periodic updating to keep pace with anticipated advances in technology, and changing socio-economic factors. Even a cursory review of Japan's space program shows that it is a very aggressive and forward-looking program. Their on-going activities as well as their planned programs are broad, bold and far-reaching in perspective. Japan's future goals in space include virtually all aspects of space activity.

The current emphasis in Japan's space policy is on developing appropriate internal resources for a variety of space activities. Japan is particularly cognizant of a need to develop an infrastructure for space that will enable them to encourage well-coordinated, but diverse, domestic space development activities, while keeping pace with, and contributing to, international space development. Their motivation arises from a desire to advance basic science and technology, enable expanded participation in international space ventures and satisfy a growing interest in a broad range of domestic space activities. Domestic space interests encompass activities that exploit the unique environmental conditions of space, prepare for civil space development, and promote manned space activities. Japan's plans for international collaborations include cooperation in programs established by other countries, initiation of collaborative programs of their own, including

regional cooperative projects in the Asian Pacific, and assisting developing countries with space activities.

Japan's space program is founded upon two basic tenets which underscore all their activities. The first is that they wish to develop "assured access" to space, while the second is that their space activities are for "solely peaceful" purposes. Although they encourage international cooperation in space, concerns may sometimes arise in conjunction with potential collaborations with the US, because synergisms between NASA and Air Force programs may conflict with their guideline for purely peaceful uses of space. Further, their "assured access" policy dictates that they develop autonomous capabilities in space, which in many instances will duplicate capabilities in other countries. Japan's space aspirations, however, leave ample room for cooperative Japan-US space endeavors and it was clear from our visit that they are committed to establishing new joint ventures with the US as well as continuing existing ones. Future joint ventures between Japan and the US would appear to be mutually beneficial.

Japan's goals for the present decade include plans for continuing their already strong thrust in scientific space research, for bringing their satellite and launch technologies up to those of international standards, for creating the infrastructure for Space Station activities, and for developing the basic technologies required for their own manned space activities. These near-term goals include the promotion of advanced satellite technologies such as their Engineering Test Satellite (ETS) series and communication, broadcasting and navigation satellites, culminating in the development and manufacture of commercial satellites. Importance is also given to the development of scientific satellites with supporting efforts in space sciences, facilities, and tracking and control systems. These scientific areas are seen as being particularly appropriate for international cooperation. Japan's near-term plans also reaffirm their significant participation in the US Space Station through the Japan Experiment Module (JEM) and SSIP modules. These collaborative efforts will serve to develop basic domestic technologies. Eventually Japan's plans call for an independent manned spacecraft, built on current technology programs.

An area of primary emphasis in Japan's near-term space plans, and one that is also of central focus in this report, is the establishment of their own space transportation system. Self-assured access to space is envisioned as being indispensable to Japan's long-range space development activities. Primary near-term goals in space transportation are the development of an expendable launch system for transportation of materials to geostationary orbit, the establishment of a technology for unmanned space to ground

transportation and the promotion of fundamental research and development for long-term manned space transportation capabilities. Current transportation plans for expendable launch vehicles are focussed on developing and enhancing the H- and M-series of liquid and solid rocket systems. The H-series liquid rocket system, which will ultimately provide commercial launch capabilities for Japan, are addressed in the first half of the present report.

Japan's long-term goals for the first decade of the new century and beyond include the implementation of their own manned space capabilities, the launch and operation of a geostationary platform, the development of an orbital servicing vehicle and an orbital transfer vehicle, and the ultimate development of their own space station. Japan also places much emphasis on the commercial uses of space with plans for manufacturing experiments, materials development and a space factory. The advanced transportation capabilities required for these activities are discussed in detail in the spaceplane and transatmospheric propulsion sections of the present report.

The space program in Japan is under the auspices of the Space Activities Commission (SAC), a cabinet level body that oversees the space activities of the entire country. The primary operative body under SAC is the Space Technology Agency (STA) which oversees and coordinates the efforts of all space programs in Japan. There are three primary agencies devoted to space initiatives. These are the Institute of Space and Astronautical Science (ISAS), the National Aerospace Laboratory (NAL) and the National Space Development Agency of Japan (NASDA). Each of these agencies has major responsibility for certain areas of space initiatives.

Current budget levels (FY 1989) for Japan's space program including satellites, launch vehicles and propulsion systems is about 176 billion yen (\$1.26B US) plus additional private funding. Detailed plans of the various agencies and laboratories as well as the expanded goals set forth in the 1989 update of the Foundations of Space Policy document, suggest that this amount will grow substantially in the future. Specific plans are in place to strengthen the Space Activities Commission, to increase the breadth and depth of technical staff in related research and development institutions and to add faculty and upgrade equipment in universities and encourage academic institutions to engage in space-related research and development activities. To keep pace with these plans, annual space program growth rates in excess of 10% are forecast for the foreseeable future. Guidelines for space budgets are targeted at a level commensurate with Japan's current 10% share of the world economy. Both government and the private sector will be called upon to share in funding this increased space activity. To

strengthen and encourage private sector participation, the government will promote financing strategies, tax incentives and other considerations including provisions for enabling the private sector to participate in various space activities at reduced costs.

There are several major space transportation efforts in Japan including three expendable rocket launch vehicle programs and three airbreathing hypersonic vehicle concepts. The rocket launch vehicles include both operational systems and ones under development, the N-series, the H-series and the M-series, while all the airbreathing hypersonic vehicles are in the concept definition phase. The N-series of launch vehicles was based upon US technology developed under license, while the currently operational H-I vehicle includes technology that is partly based on Japanese design and development and in part retains technology developed under license from the US. The H-II vehicle, which is currently under development and scheduled for first use in 1993, is completely Japanese in design and positions Japan as a full-fledged member of the world launch community. The M-series rockets are solid boosters that have long been based upon Japanese design.

Japan's launch facilities at Tanegashima are located at 30.4 N latitude, a location that is nearly the same as our launch facilities at Kennedy Space Center, which are at 28.5 N. The size of the launch site is much smaller than KSC, and the transportation facilities in the immediate area are somewhat limited, but they appear to be adequate for the H-II. A current agreement with local residents limits launch windows to a few weeks per year, but plans for a public education campaign to inform local residents and interest groups of the importance of launch functions to Japan's national needs are in progress. This nationwide campaign will seek to encourage understanding of Japan's space development activities and to foster an environment conducive to space development.

The propulsion sources for Japan's various transportation efforts encompass some eight major development programs which serve as the focal point for most of the present report. These programs are in various stages ranging from concept development to operational. They include four cryogenic hydrogen-oxygen rocket engines and four advanced airbreathing systems which are not as far along in development as the rocket engines.

In conjunction with current H-series expendable launch vehicle programs, propulsion development is on-going for the LE-5a, and the LE-7 cryogenic propulsion engines. The HIPEX, expander cycle engine, represents an additional new major liquid hydrogen-oxygen engine development that is

currently underway. The LACE liquid air cycle engine which is also in advanced development is a generic propulsion system oriented towards advanced airbreathing systems such as strap-on boosters for up-rated versions of the H-II or hypersonic propulsion applications. The sixth engine configuration is the ATREX engine, an air turboramjet system which is in a similar development stage. The remaining two propulsion systems are a SCRAMJET engine concept development program at NAL for eventual hypersonic applications, and the newly announced Mach 5 turbojet/turboramjet engine development which is being supported by MITI for high speed commercial transportation in the Pacific rim area.

The systems and performance of Japan's cryogenic liquid rocket engines are comparable to that of engines developed in the United States. In their designs, they have made extensive use of US data, procedures and technology and their engines have similar specific impulse and vacuum thrust to weight ratios. The new engines are; however, decidedly their designs, and show a number of significant differences from US systems. Their engine development programs, which are built upon a phased project management concept similar to that used by NASA and USAF, are composed of carefully planned steps involving low risk, well-characterized options, allow necessary adjustment of engine designs as the experimental results dictate. The general result is a conservative design that is heavily based upon experimental engine testing. The slightly more conservative design should facilitate reliability, and may be particularly beneficial when these engines and/or their derivatives are man-rated.

In most of Japan's space propulsion program, the emphasis is based upon building a launch capability to fill a need. The design requirements are set by the end product's use. Whereas, for example, the need for man-rated reliability, reusability and high performance has driven turbopump designs for the SSME, the Japanese have placed emphasis on expendable launch vehicles with low cost and limited life. They will undoubtedly delay man rating their engines until their engine developments have become more mature. Manned activities emphasize longer life, improved diagnostic measurements, and, in general, a well-perfected product, areas in which Japan has long demonstrated expertise. Certainly Japan's capabilities in fabrication and manufacturing as well as their broad based expertise in high technology in general, place them in a position to make very rapid advances in space capabilities and to contribute effectively to the world's space activities.

In the area of turbomachinery, the Japanese turbopumps and turbines again demonstrate performance levels that are similar to US capabilities. The

Japanese are behind the US in some areas of turbomachinery, but they are ahead in others. Their basic approach to design is to first ascertain the technology level, then apply an adequate margin to increase the probability of success, conduct component testing to verify and anchor the design, and then to proceed with the flight version. For example, in one instance, they have chosen a two stage over a three stage pump to avoid a technology development program. Their overall effort is a cooperative one that minimizes duplication of effort and maximizes the rate of advancement.

In the transatmospheric and hypersonic propulsion area, the Japanese are beginning a study of space plane concepts that emphasizes diverse topics such as aerodynamics, structures, slush hydrogen fuel, CFD, advanced propulsion and system development scenarios. The propulsion cycles under study are similar to those being considered in the US, and include the turbojet, the ramjet, the turboramjet or and the supersonic combustion ramjet (SCRAMJET). The propulsion systems of primary interest appear to be those for the Mach 3 to 6 range for the low Mach number portion of hypersonic cruise or SSTO vehicles, strap-on booster augmentation engines for launch systems, or airbreathing engines for a civilian SST. Their efforts in higher Mach number propulsion systems are directed more toward accumulating a data base.

In terms of engine development, there are two classes of engine that are presently in the prototype phase; the LACE engine at MHI, and the ATREX, air turboramjet, at IHI. There was also reference to the development of a turboramjet engine at KHI, but even though this is probably the least complex and risky cycle, it does not appear that engine components are presently available for this engine. Demonstration engines are currently available (or nearly so) for the LACE and ATREX engines, but the development programs have been put on temporary hold because all LH2 facilities are now dedicated to the LE-7 development effort.

The LACE demonstrator engine uses the LH2 pump and combustor from the LE-5 engine, along with new components for the air liquefier and the liquid air pump. This adaptation of components from existing rocket programs to new propulsion efforts is characteristic of Japanese space propulsion programs. They do a very effective job of using previously demonstrated components in advanced projects. In addition to the LACE engine, the HIPEX and the ATREX engines also contain heavy commonality with the liquid rocket engines. The ATREX engine relies upon IHI's existing turbojet-turbofan production and design experience as well as the expander cycle technology developed in the HIPEX engine. This interchangeable component technology appears to be providing very cost-effective progress

in Japan's new programs, while simultaneously enhancing the reliability of their liquid engines as well.

Although a considerable amount of technology development is directed toward SCRAMJET applications, the Japanese program in this area is only in the concept definition phase, and demonstration engine development does not appear imminent. Japan appears to have significant interest in the development of a hypersonic vehicle as a member of a consortium, instead of all alone. The general feeling is that the technology is now available for the LACE and ATREX engines, but that technology for the SCRAM engine is not yet accessible.

The SCRAMJET technology programs include considerable emphasis on experimental studies of supersonic combustion including ignition and diffusion flame studies and shock tube studies of elementary reaction kinetics of hydrogen. In addition, high speed inlet tests are currently underway on a scale model. This work takes place in the national laboratories and at several universities. Two new university efforts that involve some 20 faculty at several schools and are oriented towards hypersonic reacting flows and component technology for advanced propulsion systems are also underway. To complement these experimental studies, CFD studies of SCRAMJET configurations are being conducted at NAL Chofu where they are using this experimental data to validate and anchor their CFD codes.

In terms of facilities, there are SCRAMJET facilities at NAL Chofu, NAL Kakuda and the University of Tokyo which all have capabilities for Mach 2. A new SCRAMJET facility is also being built at Kakuda. The Japanese also plan to construct an engine test facility at Kakuda for testing supersonic airbreathing engines. This will be a key facility in MITI's recently announced engine development program for a high speed civil transport.

Japan also is placing attention on advanced fuels development and on plant construction for hydrogen production. Japan has developed two high density hydrocarbon fuels for rocket applications, and is in the process of stepping up their hydrogen production capabilities to serve the H-II and advanced airbreathing propulsion systems. They are currently constructing a new hydrogen plant that makes hydrogen as the byproduct of ethylene production, and are building a pilot facility for the production of hydrogen from coal gasification.

In the area of advanced diagnostics, Japan is a user of the latest systems from the US and Europe, but are leaders in the development and manufacture of many of the basic lasers, optics and electrooptic components that go into these systems. Of particular interest to advanced diagnostics implementations are new tunable diode lasers that are being developed in Japan and a new surface emitting diode laser with reduced beam divergence that offers possibilities for higher spatial resolution.

The area of computational fluid dynamics (CFD), which is an important supporting area in all propulsion development, represents an area of strength in Japan. Their domestic supercomputers are among the best in the world, and they have major supercomputer installations at NAL and at the privately owned Institute for Computational Fluid Dynamics. The national universities also have excellent supercomputing capabilities. This abundance of supercomputer access has resulted in rapid progress in computational areas. The Japanese routinely include real gas effects and complex reaction kinetics in flowfield analyses, and their codes are based on the latest algorithms. Their visualization and postprocessing capabilities are also at the leading edge. Clearly they have appropriate CFD capabilities to enable them to move rapidly in this aspect of propulsion development.

Finally, we note that contractor selection in Japan is an area in which there are differences from that in the US. Although competition exists, particularly at the concept development level, the award of new propulsion contracts generally based on the technical capabilities which the contractors have demonstrated in previous projects. For example, MHI is generally the overall engine developer for liquid rocket engines, while IHI will generally emerge as the turbomachinery contractor. The project share generally appears to be set by historical factors, rather than by competitive procedures.

Their industry role is coordinated and strengthened through the Keidanren and the Society of Japanese Aerospace Companies (SJAC).

The LACE cycle is effective up to flight Mach numbers of 6 to 8. Both HIPEX and the LACE systems are in advanced development states with engine hardware currently available for near term test.

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A REVIEW OF LIQUID ROCKET PROPULSION PROGRAMS
IN JAPAN

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Penn State Propulsion Transportation Symposium
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The Pennsylvania State University

JAPAN'S SPACE PROGRAM: NATIONAL POLICY

- **FUNDAMENTAL GUIDELINES OF SPACE POLICY**
 - Long-Term Plans
 - Generic Paths for Achieving Plans
 - Issued 1978
 - Revised 1984, 1989
- **CURRENT EMPHASIS IN SPACE POLICY**
 - Developing Internal Resources for Far-Reaching Space Program
 - Diverse Domestic Space Activities
 - Contributors to International Space Development
- **BASIC TENETS**
 - "Assured Access"
 - "Solely Peaceful Purposes"

JAPAN'S SPACE PROGRAM: GOALS AND PLANS

- **DOMESTIC SPACE INTERESTS**
 - Prepare for Civil Space Development
 - Promote Manned Space Activities
 - Exploit Environmental Conditions of Space
- **INTERNATIONAL COLLABORATIONS**
 - Cooperate in Programs Established by Other Countries
 - Initiate Collaborative Programs of their Own
 - Regional Projects in Asian Pacific
 - Assisting Developing Countries

Japan's Space Program

- Expendable Launch Vehicles
- Communications and Broadcast Satellites
- Weather Satellites
- Earth Observation Satellites
- Robotics Systems
- Space Station Components
- Manned Vehicles

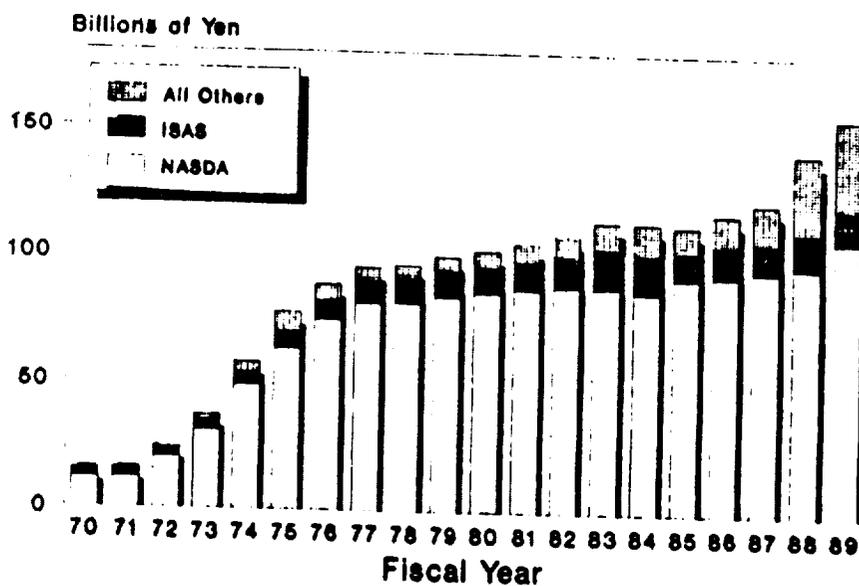
JAPAN'S SPACE PROGRAM: NATIONAL ORGANIZATION

- SPACE ACTIVITIES COMMISSION
 - Oversees All Space Activities
 - Cabinet Level
- SPACE TECHNOLOGY AGENCY
 - Primary Operative Body
 - Coordinates All Space Programs
 - Provides Major Funding
- ADDITIONAL EFFORTS
 - Ministry of Education (Mombusho)
 - Ministry of International Trade and Industry (MITI)
- THREE PRIMARY R&D AGENCIES
 - Institute of Space and Astronautical Science (ISAS)
 - National Aerospace Laboratory (NAL)
 - National Space Development Agency (NASDA)

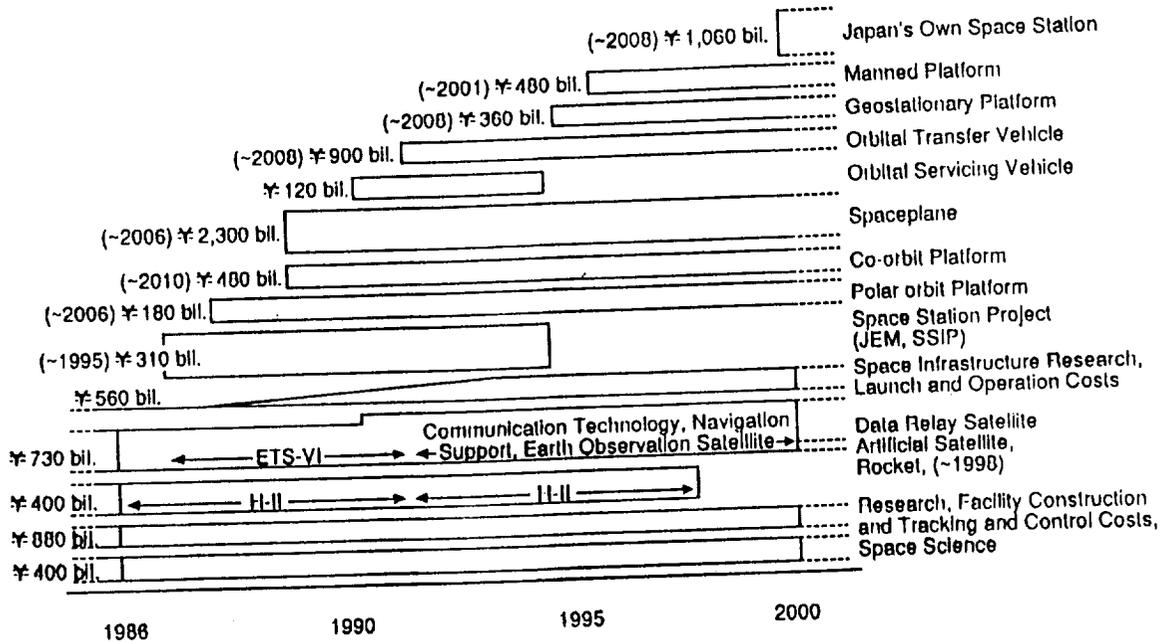
NATIONAL ORGANIZATION FOR SPACE

<u>ORGANIZATION</u>	<u>CHARTER</u>	<u>PERSONNEL</u>	<u>BUDGET</u>
NAL	Aeronautical and Space Technology	450	¥ 10,000 M \$ 70 M
NASDA	Applications Satellites and Launch Vehicles	950	¥ 110,000 M \$ 840 M
ISAS	Scientific Satellites and Launch Vehicles	291	¥ 21,000 M \$ 150 M
Others			¥ 27,000 M \$ 194 M
TOTAL			¥ 176,000 M \$ 1,254 M

JAPANESE SPACE BUDGETS (By Agency)



Lawrence Aronovitch, 1989



Major Projects

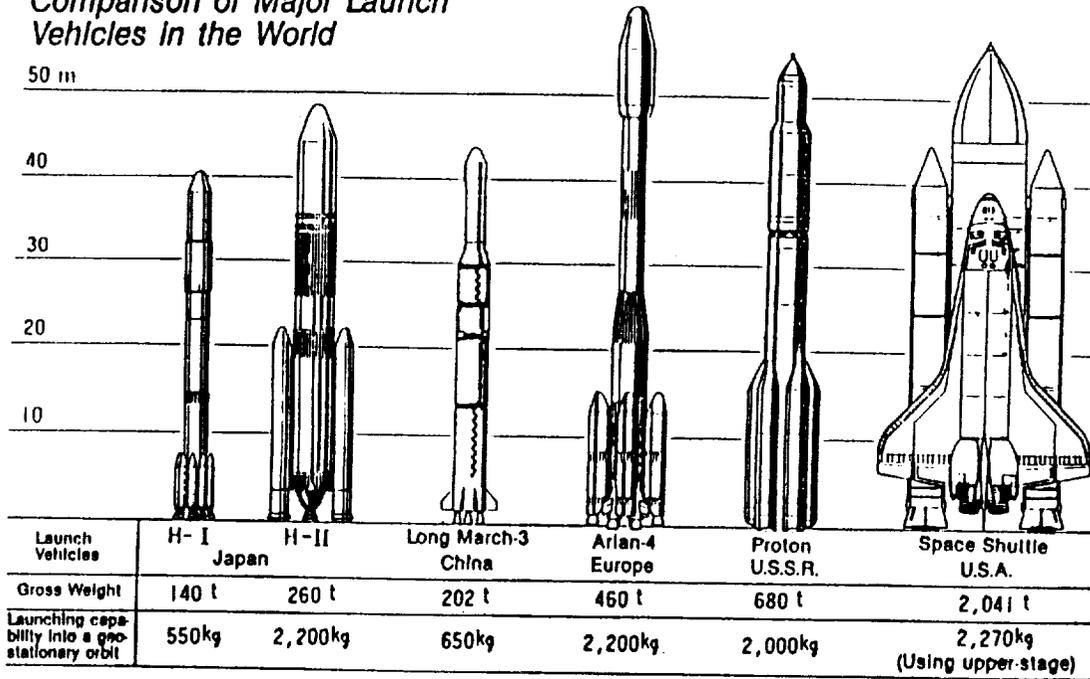
INSTITUTE OF SPACE AND ASTRONAUTICAL SCIENCE (ISAS)

- National Interuniversity Research Institute
 - Ministry of Education (MOMBUSHO)

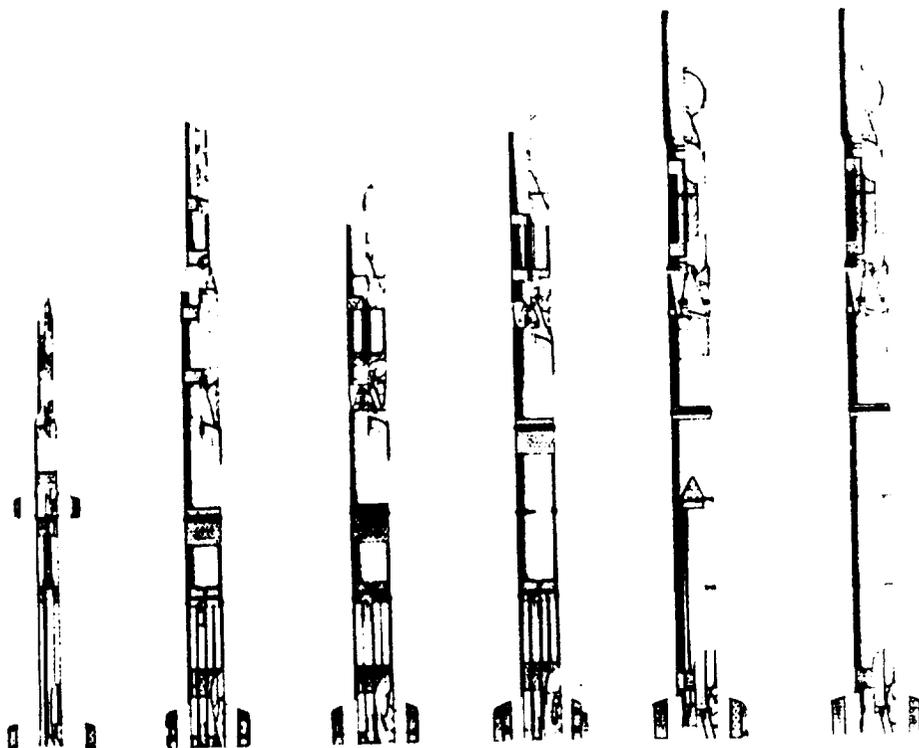
- Objectives: Research In Space Science
 - Scientific Satellites
 - Launch Vehicles
 - Sounding rockets
 - Balloons

- Launch Vehicles - M Family

Comparison of Major Launch Vehicles In the World



ISAS Launch Vehicles



	L-4S	M-4S	M-3C	M-3S(M-3H)	M-3SII	Improved M-3SII
Number of Stages	4	4	3	3	3	3
Total Length	16.5 m	23.6 m	20.2 m	1.41 m	27.8 m	30 m
Diameter	0.735 m Ø	1.41 m Ø	1.41 m Ø	0.735 m Ø	1.41 m Ø	2.5 m Ø
Total Weight	9.4 ton	43.6 ton	41.6 ton	48.7 ton	61 ton	120 ton
Payload*	Approx 26kg	Approx 180kg	Approx 195kg	Approx 290kg	Approx 770kg	Approx 2000kg

*Orbiting capability onto the circular orbit of 250km height with 31° inclination.

H-II LAUNCH VEHICLE

- Two-Stage Rocket with Two Strap-on Solid Boosters
- Booster Engines
 - 14% HTPB / 18% Al / 68% AP
 - 4 Segments/Booster
- First Stage -- LE-7
 - LOX/LH₂
 - Staged Combustion
- Second Stage -- LE-5A
 - LOX-LH₂
 - Expander Bleed Cycle

NATIONAL AEROSPACE LABORATORY (NAL) OVERVIEW

OBJECTIVES: Aeronautical and Space Technology

- Budget: \$70 M

{	Personnel	\$20 M
	Research	\$30 M
	Facilities	\$20 M
- Budget Flat Since 1982
 - Near-term Growth Expected
 - Major Increase in Facilities Budget Since 1982
- Personnel: 450

{	325 Research
	125 Other.

MAJOR PROJECTS:

- ASKA STOL Aircraft 1977-88
 - Design, Manufacture, Flight Test
- Innovative Aerospace Technologies, 1987 -
- LE-7 LOX Turbopump Initial Development

NATIONAL SPACE DEVELOPMENT AGENCY (NASDA) OVERVIEW

- Objectives: Applications Satellites and Launch Vehicles
- Budget: \$840 M
 - Approximately Flat Since 1982
 - Near-term Growth Expected
- Personnel: 950
- Major Projects:
 - Launch Vehicles
 - Satellites
 - First Material Processing Test (Shuttle/Spacelab)
 - Japanese Experiment Module (JEM)

LE-5A Engine for H-2 Second Stage

**Expander Bleed Cycle
Propellant - LOX/LH₂**

Thrust = 26,460 Lbf

Mixture Ratio = 5.0

Specific Impulse = 452 sec

Chamber Pressure = 570 PSIA

Nozzle Area Ratio = 130

Burn Time = 525 sec

Weight = 540 Lb

Status - Qualification

LE-7 Engine For H-2 First Stage

Staged Combustion Cycle

Propellant - LOX/LH₂

Thrust = 265,000 lbf, vac

Mixture Ratio = 6.0

Specific Impulse = 451 sec

Chamber Pressure = 2133 psia

Nozzle Area Ratio = 60

Burn Time = 315 sec

Weight = 3439 lb

Status - Development

UPPER STAGE ENGINE TURBOMACHINERY

LE-5 vs RL10

	<u>Hydrogen</u>		<u>Oxygen</u>	
	<u>LE-5</u>	<u>RL10A-3-3A</u>	<u>LE-5</u>	<u>RL10A-3-3A</u>
Number of stages	1	2	1	1
Mass flow rate lb/sec	7.8	6.2	42.7	30.8
Speed, RPM	50,000	32,800	16,500	13,100
Pump discharge pressure, psia	825	1120	740	670
Impeller tip speed ft/sec	1250	1010	315	250
Shroud impeller	Yes	No	Yes	Yes
Efficiency, %	59	57	66	63

BOOSTER STAGE ENGINE TURBOMACHINERY

LE-7 Vs SSME - Hydrogen

	<u>LE-7</u>	<u>SSME</u>
<u>Pump</u>		
Number of stages	2	3
Mass flow rate, lb/sec	87	149
Speed, RPM	46,100	34,100
Pressure rise, psi	4,700	5,800
Efficiency, %	71	77
<u>Turbine</u>		
Number of stages	1	2
Inlet pressure, psia	3,520	4,920
Inlet temperature, °R	1,770	1,780
Pressure ratio	1.43	1.45
Efficiency, %	72	82

BOOSTER STAGE TURBOMACHINERY

LE-7 Vs SSME - Oxygen

<u>Main Pump</u>	<u>LE-7</u>	<u>SSME</u>
Number of stages	1	1
Mass flow rate, lb/sec	505	1,070
Speed, RPM	20,000	27,200
Pressure rise, psi	3,030	3,730
Efficiency, %	75	67
<u>Preburner Pump</u>		
Mass flow rate, lb/sec	96	100
Pressure rise, psi	1,650	3,029
Efficiency, %	65	80
<u>Turbine</u>		
Inlet pressure, psia	3,410	4,984
Inlet temperature °R	1,750	1,455
Pressure % ratio	1.43	1.51
Efficiency	49	79

UPDATED H-II VEHICLES

- Concepts Currently Under Study
 - Increase Number of Solid Boosters
 - Replace SRB's with Liquid Propellant Boosters
 - LOX/CH₄
 - LOX/RP
 - LOX/LH₂
- Payload Increase from 2.2 to 5.5 tons

SUMMARY

- o Agressive Space Policy**
 - **Broad-Ranging Focus**
 - **Self-Assured Access to Space**
 - **Plan Major Role in Space Development/Exploration**

- o Emphasis to Date on Expendable Launch Vehicles**
 - **Current Efforts on Airbreathing Propulsion**
 - **Future Plans for Manned Flights**

- o Government Organizations Significantly Smaller than U.S.**
 - **NASDA 1000 people**
 - **NAL 500**
 - **ISAS 300**

SUMMARY (CONT'D)

- o Basic Launch Vehicles:**
 - **H-I operational**
 - **H-II 1993**
 - **Upgraded H-II versions planned**

- o Current Rocket Engine Focus**
 - **LE-5 LE-5A**
 - **LE-7 HYPEX**

 - **Have Demonstrated Thrust Levels from 2000 to 260,000 lbs.**
 - **Engine Performance Generally on Par with U.S. Engines**

PRESENTATION 1.5.2

RUSSIAN TECHNOLOGY

