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Propulsion Technology Symposium

EXPENDABLE LAUNCH VEHICLE PROPULSION

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This presentation will review the current status of the U.S. ELV fleet, the international competition, and the propulsion technology of both domestic and foreign expendable launch vehicles. The ELV propulsion technology areas where research, development, and demonstration are most needed will be identified. These propulsion technology recommendations are based on the work performed by the Commercial Space Transportation Advisory Committee (COMSTAC), an industry panel established by the Department of Transportation.

Expendable Launch Vehicle Propulsion

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INTRODUCTION

There have been extensive changes in America's space launch architecture since the Challenger tragedy occurred in January 1986. The major impact has been the revival of the U.S. Expendable Launch Vehicle (ELV) fleet in response to changes in National Space Launch policy. The NASA and the Air Force have adoped use of a "Mixed Fleet" of space launchers, and have prohibited the Shuttle Space Transportation System (STS) from competing for launch of commercial payloads. The availability of this diverse stable of launch systems has helped to assure access to space for critical payloads.

The foundation for a commercial launch industry has been established in the United States for the Delta, Atlas, and Titan III launch systems. The NASA and Air Force have provided a base for a commercial launch industry by long-range procurements of ELV launch services, and access to government facilities. U.S. industry has responded to legislation and enabling regulations by investments of private resources and funds.

However, international competition from government-subsidized launchers in Europe and Japan, and state-owned launch organizations in the non-market economies of the People's Republic of China (PRC) and the Soviet Union (USSR) threaten the survival of the U.S. commercial launch industry. The foreign launch systems enjoy competitive advantages due to government support for applied research and continued product development that need not be recovered in their pricing.

Similar support from NASA is needed to enhance the future competitiveness of the U.S. ELV industry. Near-term applied technology research aimed at cost reduction and product improvements to the current ELV fleet should be included in the NASA Research and Technology plans. In addition, long-term basic research is also needed to maintain parity with the new generation of foreign ELVs that will enter the market for commercial launch services in the mid and late 1990s.

Expendable Launch Vehicle Propulsion

Introduction

- **U.S. ELV launch fleet revived following 1986 STS-51 tragedy**
  - Change to "Mixed Fleet" national space launch policy
  - Need for assured access to space for critical payloads
- **Commercial ELV launch industry established for Delta, Atlas, Titan III**
  - Private industry responded to enabling legislation & regulations
  - Business base provided by NASA and Air Force procurements
- **International competition threatens U.S. commercial launch services**
  - Government supported launch industries in Europe & Japan
  - State-owned launch systems from non-market economies in PRC & USSR
- **NASA basic and applied research funding needed for ELVs**
  - Near-term improvement of current ELV propulsion
  - Long-term basic propulsion research

COMMERCIAL SPACE TRANSPORTATION ADVISORY COMMITTEE

The Commercial Space Transportation Advisory Committee (COMSTAC) is an advisory group to the Office of Commercial Space Transportation (OCST) of the Department of Transportation (DoT). The OCST reports to the Secretary of Transportation, the Honorable Samuel K. Skinner, who is a member of the National Space Council (NSpC). The Director of OCST is Stephanie Lee-MIller.

The objective of the COMSTAC is to promote U.S. commercial space transportation by acting as an advocate for private industries involved in providing space transportation goods and services. COMSTAC provides, thru the OCST, industry views on space transportation policies, regulations, and procedures. The chairman of COMSTAC is Dr. Alan Lovelace of the General Dyanmics Corporation.

COMSTAC consists of a full committee of 23 appointed members from small, medium, and large corporations representing space transportation suppliers and users. The committee is organized into five (5) Working Groups:

- Technology & Innovation Working Group
- Infrastructure Working Group
- Insurance & Risk Management Working Group
- International Competition & Cooperation Working Group
- Procurement Working Group

Each working group, headed by a member of the full committee, is the focus of COMSTAC efforts on specific issues and areas relevant to space transportation.

The Technology & Innovation Working Group, chaired by Mr. Paul N. Fuller of Rocketdyne, is responsible for identifying and prioritizing technology needs (including propulsion technology) for commercial ELVs. The working group has been chartered to review and advise on the NASA Component Technology Plans, and to work on a long-range plan for industry-government cooperation to develop the next generation of U.S. commercial expendable launch vehicles.

Expendable Launch Vehicle Propulsion

Commercial Space Transportation Advisory Committee (COMSTAC)

- **Industry advisory committee to Office of Commercial Space Transportation (OCST) of Department of Transportation (DoT)**
- **Objective: Promote U.S. space transportation industry**
  - Industry views to Transportation Secretary and National Space Council
  - Review & recommendations on space policies & procedures
- **Organization: Committee of the whole and Working Groups**
  - Technology & Innovation • Procurement • Infrastructure
  - International Competition & Coop. • Insurance & Risk Management
- **Charter: Technology & Innovation Working Group**
  - Define technology needs for U.S. space transportation industry
  - Review & advise on NASA Component Technology Plan
  - Develop long-range plan for industry/government cooperation

COMSTAC TECHNOLOGY & INNOVATION WORKING GROUP
WORKING GROUP CHARTER

The Technology & Innovation Working Group, chaired by Mr. Paul N. Fuller of Rocketdyne, is responsible for identifying and prioritizing technology needs (including propulsion technology) for commercial ELVs. The working group has been chartered to review and advise on the NASA Component Technology Plans, and to work on a long-range plan for industry-government cooperation to develop the next generation of U.S. commercial expendable launch vehicles.

Expendable Launch Vehicle Propulsion

COMSTAC Technology & Innovation Working Group

Working Group Charter

- Offer advice on NASA's Component Technology Program by defining areas or programs which offer the greatest payoff in expenditure of Research & Technology funds toward assuring future world-wide competitiveness of the U.S. space transportation industry.

- Develop a long range plan for a joint industry/government cooperative project to develop next generation U.S. commercial ELVs. Include in the plan integration of NASA's Component Technology Program, ALS Technology Programs, and the President's Space Exploration Initiative.

COMSTAC TECHNOLOGY & INNOVATION WORKING GROUP
WORKING GROUP MEMBER ORGANIZATIONS

The FY90 members of the Technology & Innovation working group represent 12 U.S. corporations involved in supplying goods and services to the commercial space launch industry. The membership represents new and emerging industries as well as large, established organizations that have been involved in space launch systems for over 35 years.

Expendable Launch Vehicle Propulsion

COMSTAC Technology & Innovation Working Group

Working Group Member Organizations:

- **American Rocket Company (AMROC)**
- **American Telephone & Telegraph Corporation**
- **Boeing Helicopters**
- **GenCorp, Inc. - Aerojet TechSystems**
- **General Dynamics Corporation - Commercial Launch Services**
- **International Technology Underwriters (INTEC)**
- **Martin Marietta Corp. - Commercial Titan Inc.**
- **McDonnell Douglas Corp. - Space Systems Company**
- **Rockwell International - Rocketdyne Division**
- **Space Services, Inc. of America**
- **United Technologies Corporation - Pratt & Whitney Division**
- **United Technologies Corporation - United Space Boosters, Inc.**

DOMESTIC ELV LAUNCH FLEET

The domestic ELV launch fleet consists of the following launch systems:

SYSTEM	SUPPLIER	USERS
• Titan II	Martin Marietta Corporation	Military, NASA
• Delta II	McDonnell Douglas Space Systems	Military, NASA, Commercial
• Atlas I, II	General Dynamics Space Systems	Military, NASA, Commercial
• Titan III	Martin Marietta Corporation	NASA, Commercial
• Titan IV	Martin Marietta Corporation	Military, Government

With the exception of the Titan II, production has resumed for construction of all new ELV components and flight hardware. The Delta, Atlas, and Titan III launch systems are available for commercial payloads. Titan II and Titan IV are used for military and/or other government launches.

The domestic fleet of ELVs were derived from ballistic missiles and government launchers developed in the 1950's and 1960's. The current launch system configurations are the result of evolutionary, incremental uprates and improvements made to the propulsion systems, vehicle structures, avionics, manufacturing processes, and launch facilities. The systems used in the U.S. ELV fleet, including propulsion subsystems, are mature, flight-proven designs; however, commercial application and low cost were not initial design considerations.

The private sector has made significant investments in ELV launch systems on the assumption that commercial markets will develop. Firms such as General Dynamics have invested several hundred million dollars in facilities, start-up costs, and quantity orders based on assumed capture of targeted segments of the commercial launch services market. Total private industry cash flow commitment and capital investment is estimated to exceed $500M. Government contracts have benefited from these investments through lower unit costs for launches of government payloads.

However, private industry cannot affort the additional investment in the non-recurring costs needed to develop new launch systems to meet the competitive challenges of foreign launch vehicles in the mid-1990s.

Expendable Launch Vehicle Propulsion

Domestic ELV Launch Fleet

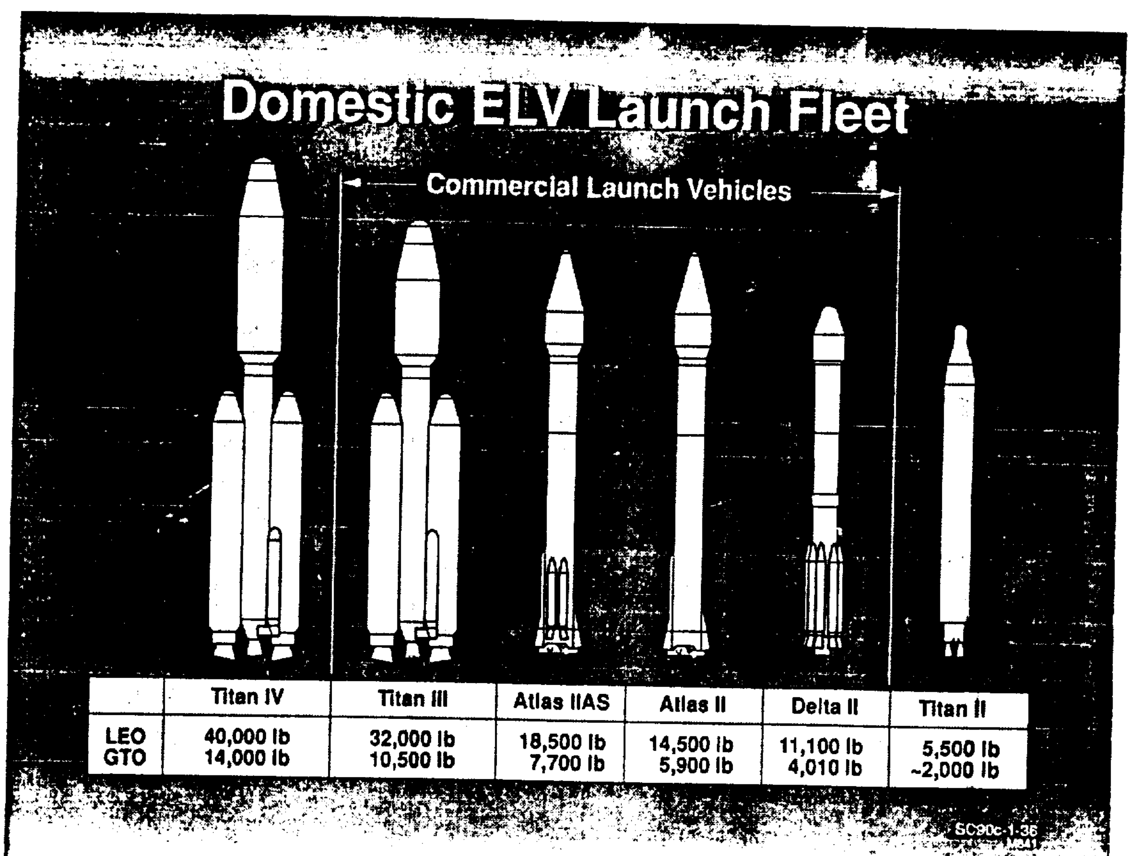
- **Production and launches resumed for U.S. ELV fleet**

• Titan II	Martin Marietta	Military
• Delta II	McDonnell Douglas	Military, NASA, Commercial
• Atlas II	General Dynamics	Military, NASA, Commercial
• Titan III	Martin Marietta	NASA, Commercial
• Titan IV	Martin Marietta	Military, NASA

- **Derived from ballistic missiles & government space launchers**
  - Propulsion systems are mature, flight proven designs
  - Current configurations - incremental uprates & improvements
  - Commercial application & low cost not initial design considerations
- **Private sector made significant investment in ELV launch systems**
  - Start-up costs and quantity orders of materials & systems
  - Cannot afford non-recurring development costs of new systems

DOMESTIC ELV LAUNCH FLEET

The U.S. Expendable Launch Vehicle (ELV) fleet is shown on the opposite page with their payload capabilities to Low-Earth Orbit (LEO) and Geosynchronous Transfer Orbit (GTO). The Delta II, Atlas II, and Titan III are competitors for commercial launch services. Some order has been established in the domestic launch service market. Each of the launch systems has its own market niche where it has a competitive advantage in either payload capability or launch price.



FOREIGN ELV LAUNCH FLEET

The international competition for commercial launch services is fierce. Arianespace is the industry leader, currently capturing about 50% of the market. Arianespace is the launch services marketing organization for the Ariane family of vehicles developed by the European Space Agency (ESA), a multi-national consortium. Arianespace enjoys a competitive advantage in the international launch services market. Its launch pricing is based only on recovery of recurring cost, and its large backlog of commercial and captive ESA payloads enables flexibility in manifesting. Furthermore, with ESA support, Arianespace has also demonstrated it is able to develop and market new launch vehicles in a short period of time. The Ariane 4 was recently introduced to replace the 5-year old Ariane 3 system. Continuing non-recurring development support from ESA for Ariane 4 is estimated to be $50M/year. An all-new Ariane 5 is being developed with ESA funds (~ $5B/year) for introduction in 1995.

State-owned launch systems from non-market economies are recent entrants into the market for commercial launch services. The People's Republic of China's (PRC's) Long March family of launch vehicles have captured launch contracts for the Asiasat, Aussat, and Arabsat spacecraft. The Soviet Union is also poised to enter the commercial launch services market with its Proton and Zenit launch vehicles.

The PRC and USSR enjoy a competitive advantage vis-a-vis private firms from Western market economies by being able to price launch services independently of costs. This ability to arbitrarily price is the major threat to the future survival and growth of the U.S. commercial space launch industry.

Expendable Launch Vehicle Propulsion

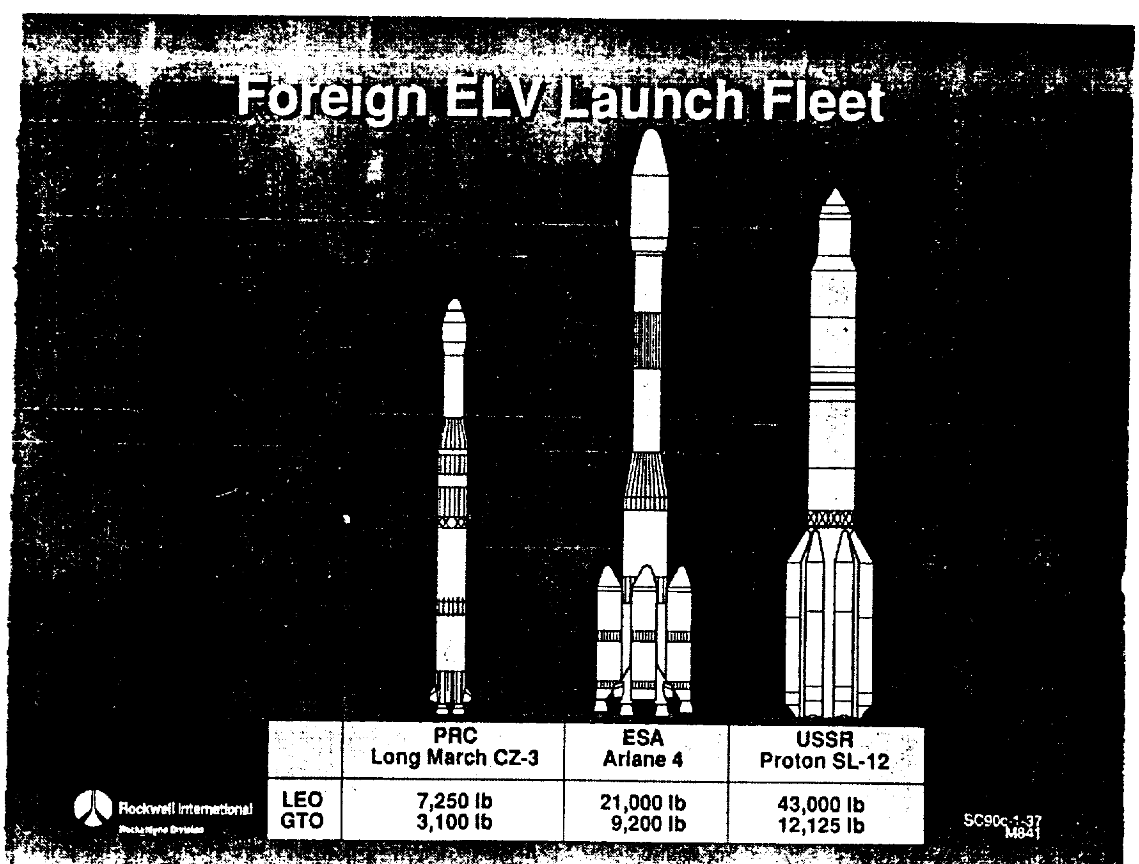
Foreign ELV Launch Fleet

- **Fierce international competition for launch service contracts**
- **Ariane is industry leader - 50% of commercial market**
  - European government consortium (ESA) supported development
  - Captive ESA payloads enables flexibility in manifesting
  - Converted from Ariane 3 (1983 - 1989) to Ariane 4 (1988 - present)
- **Arbitrary pricing competition from non-market economies**
  - Long March CZ-3 — People's Republic of China (PRC)
  - Proton SL-12 & Zenit SL-16 — Soviet Union (USSR)
- **Near-term threats from ELVs designed for commercial market**

• Long March CZ-2E & CZ-3A	PRC	1991
• H-II	Japan	1993
• Ariane 5	ESA	1995

FOREIGN ELV LAUNCH FLEET

Foreign Expendable Launch Vehicles (ELV) competing against U.S. ELVs for commercial launch services are shown on the opposite page. Note that their LEO and GTO payload capabilities are equivalent to U.S. launchers. Since technical capability are equivalent, price and market access are the key competitive issues. Launch system reliability (as indicated by insurability) has not yet been a discriminating competitive feature.

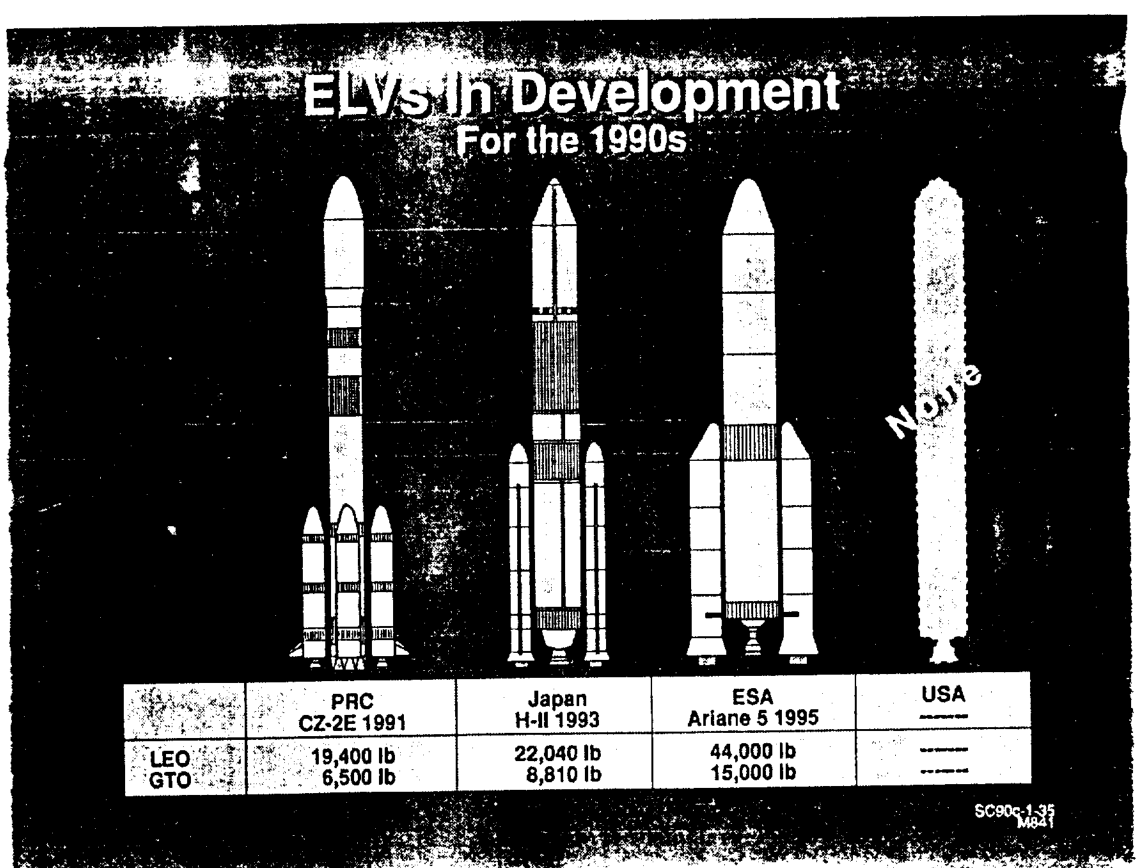


ELV's IN DEVELOPMENT FOR THE 1990's

The current competitive environment will become even more difficult for the U.S. commercial space launch industry in the mid-1990's when new launch systems from the PRC, Japan, and ESA become operational. The PRC is currently developing the CZ-2E (shown) an uprated version of CZ-2 launch system. The National Aeronautics and Space Development Agency (NASDA) of Japan is funding development of the H-II launch system that utilizes all LOX/H2 propulsion systems. Similarly , ESA is funding development of the LOX/H2 Ariane 5 launch system.

Each of these systems are being designed specifically for the commercial segment of the space launch market. Further, the H-II and Ariane 5 are based on current state-of-art in propulsion, avionics, materials, structures, manufacturing, and launch operations. The Ariane 5 is designed to reduce the price of payload weight to orbit by 40% compared to the Ariane 4.

The U.S. has no comparible launch system under development at the current time.



U.S. ELV PROPULSION SYSTEMS

The propulsion systems in the current fleet of U.S. expendable launch vehicles were designed for ballistic missiles and government space launchers in the mid-1950's and early 1960's. The liquid rocket engines for the Thor, Atlas, and Titan launch vehicles were developed specifically for their intermediate and intercontinental range ballistic missile missions under Air Force contracts awarded beginning in 1954. The Delta launch vehicle utilizes engine hardware designed for the H-1 engine used in the NASA's Apollo program.

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These engine are mature designs, and have an outstanding records of flight success. Extensive production and launch history databases exists for these engine systems:

Engine System	Propellant	Systems Delivered	Launches
• Thor/Delta Engines	LOX/RP	>610	>550
• Atlas Engines	LOX/RP	>640	>490
• Titan Stage I Engines	NTO/UDMH	>310	>240

The current ELV propulsion system configurations are a result of continuous evolutionary performance improvements made to the original engine designs:

	Original	Current
• Delta Main propulsion thrust:	135,000 lb	207,000 lb
• Atlas Booster propulsion thrust:	270,000 lb	423,500 lb
• Titan Stage I propulsion thrust:	430,000 lb	546,000 lb

Propulsion system modifications were made over the years to satisfy specific mission requirements, and were funded incrementally to minimize cost and expedite schedule.

Although the propulsion systems for the current ELV fleet have outstanding heritages of flight reliability, the designs are based on requirements and techniques reflecting the state of the art of the 1950's and 1960's. Certain engine components had been out of production for over 20 years. In the recent production resumption, modern manufacturing processes and procedures have been applied to reduce cost and improve quality. However, since the systems were not originally designed specifically for low cost nor commercial applications, the benefits of this approach have been limited. Furthermore, the designs are operating near their inherent design limits due to the numerous upratings performed in the past.

Expendable Launch Vehicle Propulsion

U.S. ELV Propulsion Systems

- **Designed for ballistic missiles & government space launchers**
  - Thor/Atlas/Titan engines: Initial production 1955 - 1960
  - Delta (H-1) engines: Initial production 1960 - 1964
- **Mature designs with outstanding flight success histories**

	Engines delivered	Launches
• Thor/Delta engines:	610+	550+
• Atlas engines:	640+	490+
• Titan* Stage I engines:	310+	240+

- **Continuous evolutionary performance improvements made; but hardware near design limits**

	Original	Current
• Delta main propulsion thrust:	135,000 lb	207,000 lb
• Atlas booster propulsion thrust:	270,000 lb	423,500 lb
• Titan* Stage I propulsion thrust:	430,000 lb	546,000 lb

* Titan II to Titan IV storable propellant engine systems

FOREIGN COMMERCIAL ELV PROPULSION SYSTEMS

A formidable array of propulsion systems are utilized in foreign launch vehicles. The Ariane 4 uses the Viking storable propellant engines as main propulsion in the core vehicle, as well as a combination of liquid and solid propellant strap-on boosters. These engines were designed and developed in the 1970's. An efficient LOX/H2 upper stage engine, developed in the early 1980's, is utilized for transfer orbit insertion. Commercial launches are conducted from modern vehicle assembly and launch facilities located near the equator in French Guyana. Development costs of all Ariane launch facilities, launch vehicles, and propulsion systems are funded by the ESA consortium.

Storable propellant booster and LOX/H2 upper stage engines are also used in the PRC's Long March vehicles offered for commercial spacecraft launches. The Long March vehicles are based on military launch systems, and the entire launch service (propulsion system and vehicle production, payload integration, and launch operations) is conducted as a state-owned industry.

The Soviet Union's Proton launch vehicle is powered by storable propellant booster engines, and a LOX/RP upper stage engine. The storable propellant engines are of advanced design, and operate at higher chamber pressures than comparable ELV systems in the U.S. or Europe. The Proton is only one of 9 military ELV launch systems available in the Soviet space launch fleet. Indications are that other Soviet launch systems will be offered on the commercial launch market in the near future.

The Japanese are in the final development stages of their H-II expendable launch vehicle. The Japanese NASDA funds all propulsion, vehicle, and launch facility development activities. The LOX/H2 LE-5 upper stage engine has flow successfully in 3 missions on the current H-I launch vehicle. The LOX/H2 LE-7 main propulsion system is currently undergoing development testing. The H-II is specificially designed for non-military applications, and is scheduled for initial launch in 1993.

Expendable Launch Vehicle Propulsion

Foreign Commercial ELV Propulsion Systems

- **ESA Ariane 4 (present) and Ariane 5 (1995)**
  - Ariane 4: Storable propellant booster & LOX/H2 upper stage engines
  - Ariane 5: LOX/H2 booster & upper stage engines
  - Propulsion developed by ESA for low-cost space applications
- **PRC Long-March CZ-3 (present), CZ-2E (1991), & CZ-3A (?)**
  - Storable propellant boosters & LOX/H2 upper stage engines
  - State-sponsored commercial launchers based on military systems
- **USSR Proton SL-12 (present) and Zenit SL-16 (?)**
  - Storable propellant booster & LOX/RP upper stage engines (Proton)
  - LOX/RP booster and upper stage engines (Zenit)
  - Advanced technology, high chamber pressure engines
  - One of 9 ELV military space launch systems
- **Japan H-II (1993)**
  - LOX/H2 booster and upper stage engines
  - Cryogenic engine technology equivalent to U.S. SSME & RL-10
  - Propulsion developed by NASDA for non-military applications

ELV PROPULSION TECHNOLOGY NEEDS

Public Law 100-657 "Commercial Space Launch Act Admendments of 1988" directed that NASA, in consultation with the U.S. space launch industry, design a research and technology program for launch system components aimed at the development of higher performance and lower cost launch vehicles for commercial and government payloads to ensure development of a competitive domestic ELV industry."

The COMSTAC Technology & Innovation Working Group has been tasked to identify and prioritize technologies needed to enhance ELV competitiveness, and to advise on the NASA Component Technology Plan.

Beginning in 1989, COMSTAC has provided inputs to the NASA Component Technology Plan. The Working Group is currently completing its report on ELV technology needs in the areas of propulsion, avionics, structures (& materials), production processes, and launch operations.

The list of technologies needed in the area of ELV Propulsion was compiled by the Working Group independently of the NASA plan. A preliminary version of the list is shown in the following charts, and is divided into the technologies needed to support:

- Liquid Propulsion
- Solid Propulsion
- Hybrid Propulsion.

The areas identified have been prioritized based on a consensus of the Working Group members. The final report of the Working Group will be submitted to the full COMSTAC committee before the end of the fiscal year.

Expendable Launch Vehicle Propulsion

ELV Propulsion Technology Needs

- **COMSTAC Technology & Innovation Working Group**
  - Identify technologies needed to enhance ELV competitiveness
  - Advise on NASA Technology Plans as mandated by 100th Congress
  - Propulsion, Avionics, Structures, Production, Launch Operations
- **Specific ELV Propulsion technologies identified and prioritized**
  - Liquid Propulsion
  - Solid Propulsion
  - Hybrid Propulsion
- **NASA/OAET Component Technology Plan reviewed**
  - Generally in agreement with ELV Plan - Propulsion
  - Needs more near & mid-term focus for commercial launch industry
  - Develop & demonstrate technologies to enhance current ELVs
  - Support development of new family of ELVs

NASA COMPONENT TECHNOLOGY PLAN

The COMSTAC Technology & Innovation Working Group reviewed the NASA Component Technology Plan submitted to the OMB in March 1990. In general, the Working Group agreed with the NASA Plan in the area of Propulsion. However, we felt that the NASA Plan needed to focus more on near-term (1 - 5 years) and mid-term (5 - 7 years) technology development activities. The Working Group believes that applications from these technology programs are going to be required in the mid to late 1990's to remain competitive with the foreign ELV competition.

The Working Group also felt that the NASA Plan should include tasks that involve the development and demonstration of technologies to enhance the *current* fleet of ELVs. These near-term activities could be the development of prototypes of cost reduction product improvements, demonstrations of significant performance enhancements concepts, and/or applied technology demonstrations of propulsion system components and subsystems.

Finally, the consensus of the Working Group is that the overall NASA Plan should recognize the need for government support to develop a new family of ELVs that have commercial applicability. Current NASA and Air Force plans focus on manned or advanced launch systems that provide heavy lift capability. Heavy lift systems have little commercial applicability in the foreseeable future, and the family of advanced launch vehicles should include configuations that can down-sized for commercial payloads.

Expendable Launch Vehicle Propulsion

NASA Component Technology Plan

- **Background:**

  Section 10 of Public Law 100-657 "Commercial Space Launch Act Amendments of 1988" directed that NASA:

  "In consultation with representatives of the Space Launch Industry, design a program for the support of research into launch systems component technologies, for the purpose of developing higher performance and lower cost U.S. launch vehicle technologies and systems available for the launch of commercial and government spacecraft into orbit.."

- **Purpose:**

  "To ensure the successful development of a competitive domestic expendable launch vehicle (ELV) industry.."

Expendable Launch Vehicle Propulsion

Liquid Propulsion Technology Needs

ITEM	PRIORITY
• **Low cost liquid booster engines**	
A. New LOX/H2 engine	1
B. Evolutionary LOX/RP engine	1
• **Advanced low cost LOX/H2 upper stage engine**	
A. 30-50K lb thrust	1
B. 100-200K lb thrust	2
• **Improved hydrocarbon propellant derivative engines & components**	2
• **Leak-free engine propulsion & pressurization subsystems** (joints, tubing, ducts)	2

Priority 1: Highest payoff - must do. Priority 2: Should do.
Priority 3: Good to do.

Expendable Launch Vehicle Propulsion

Liquid Propulsion Technology Needs
(continued)

ITEM	PRIORITY
• **Automated fluid, mechanical, and propulsion subsystem checkout**	2
• **Liquid air cycle engine (LACE)**	2
• **Pressure-fed propulsion subsystem technologies** (cryo helium storage, autogen. pressurization systems)	2
• **Booster recovery and reuse technologies**	2
• **Electronic pressure controllers**	2
• **Low-cost pressure fed engine**	3
• **LOX/H2 reaction control system (RCS) and ΔV system**	3

Priority 1: Highest payoff - must do. Priority 2: Should do.
Priority 3: Good to do.

Expendable Launch Vehicle Propulsion

Solid Propulsion & Hybrid Propulsion Technology Needs

ITEM	PRIORITY
• **Low cost filament wound motorcases**	**2**
• **Castable ablative nozzles**	**2**
• **Hybrid propulsion strap-on booster**	**2**
• **Clean burning solid motors**	**3**

Priority 1: Highest payoff - must do. Priority 2: Should do.
Priority 3: Good to do.

CONCLUSIONS

The U.S. no longer leads in ELV propulsion system technology nor in operational launch systems. The fleet of domestic ELVs are powered by propulsion systems that are reliable, but of aging design. Private industry cannot afford the investment in non-recurring development costs for new low-cost commercial launch systems that will be needed in the mid-1990s to compete against the modernized, low-cost foreign systems that will become operational.

NASA technology support is needed to regain leadership in space transportation. This includes near-term development and demonstration activities of propulsion technologies and applications that reduce cost or enhance the capabilities of the current fleet of domestic ELVs. It is also needed in basic propulsion technologies and vehicle development for a new family of low-cost ELVs with commercial applicability.

The COMSTAC industry advisory group has identified the propulsion technologies needed to enhance the future competitiveness of the domestic space launch industry. It stands ready and willing to support NASA and its plans for propulsion technology development.

A strong commercial launch industry will benefit the future of the U.S. It will reduce launch costs to the government, provide assured access to space for critical payloads, and contribute to economic growth and international trade in the 21st Century.

Expendable Launch Vehicle Propulsion

Conclusions

- **U.S. no longer leads in ELV propulsion systems**
  - Reliable but aging U.S. designs
  - Competing against modern low-cost foreign systems
- **NASA technology support needed to regain leadership**
  - Near-term development & demonstration of ELV supporting technologies
  - Basic research & technologies for new family of low-cost ELVs
- **COMSTAC ready to support NASA**
  - Identify ELV Industry needs and priorities
  - Promote NASA's budget and programs
- **A strong commercial launch industry benefits U.S.**
  - Reduces launch costs to government
  - Assured access to space for critical payloads
  - Economic growth & trade balance considerations

PRESENTATION 1.2.2

SHUTTLE PROPULSION SYSTEMS