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UPPER STAGE: ECONOMIC ADVANTAGE AND
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SOLAR THERMAL UPPER STAGE: ECONOMIC ADVANTAGE AND DEVELOPMENT STATUS

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ABSTRACT

A solar thermal upper stage (STUS) is envisioned as a propulsive concept for the future. The STUS will be used for low-Earth orbit (LEO) to geostationary-Earth orbit (GEO) transfer and for planetary exploration missions. The STUS offers significant performance gains over conventional chemical propulsion systems. These performance gains translate into a more economical, more efficient method of placing useful payloads in space and maximizing the benefits derived from space activity. This paper will discuss the economical advantages of an STUS compared to conventional chemical propulsion systems, the potential market for an STUS, and the recent activity in the development of an STUS. The results of this assessment, combined with the performance gains, will provide a strong justification for the development of an STUS.

VEHICLE DESCRIPTION

The STUS vehicle described in this section was formulated as part of a feasibility study performed by the Marshall Space Flight Center (MSFC). The overall configuration for this vehicle is shown in Figure 1. The mission this vehicle was designed to perform includes the transfer of a 1,000-lb payload from LEO to GEO. The thrust level of this STUS is 2 lb with a specific impulse (Isp) of 860 seconds. The configuration of this STUS is designed to be flown on a Lockheed LLV3 with a large shroud. The total dry mass for the stage is approximately 1,600 lb. The reflector for this vehicle uses an inflatable structure which is a 16.5- by 23.25-ft elliptical shape.¹

MISSION MODEL

The most efficient use of this vehicle is for the transfer of payloads from LEO to GEO. To economically justify this type of

vehicle, a mission model that provides the projected market for payloads, which require LEO to GEO transfer, must be developed. Once this has been accomplished, the cost of transporting these payloads via an STUS versus chemical propulsion means must be compared. Additionally, the potential for capturing a portion of the total market and the development cost of an STUS must be considered.

In Figure 2, the projected global market for payloads requiring transfer from LEO to GEO or geosynchronous transfer orbit (GTO) is provided. The time range for this figure is from 1994 through the year 2020. It should be noted that typically U.S. launch services companies capture approximately 40 percent of the global market. Figure 2 provides the projected payloads for the Air Force, NASA, and commercial missions. As can be seen, many years show a substantial number of potential payloads. The number of payloads averages approximately 16 per year for the years 2000 through 2020. The average payload mass (excluding Intelsat payloads) from this model is approximately 4,300 lb.

LAUNCH VEHICLE COST

The current cost to place a payload in orbit is a critical consideration for a commercial entity. This cost, measured in dollars per pound, varies from launch vehicle to launch vehicle. The key variables that drive this launch cost are launch operations and payload integration. Figure 3 shows graphically the cost flight for the various existing launch vehicles. As can be seen, the commercial launch services industry is an increasingly competitive marketplace. The competition will continue to increase with the introduction of "cheap" Russian Proton and Chinese Long March launch vehicles into the marketplace.

A contributing factor in the noncompetitive nature of the U.S. launch vehicle fleet is that many of the vehicles are based upon 1960's vintage technology. Many of the vehicles designs are actually based upon ballistic missile mission requirements. This

facet inherently leads to vehicles which are inefficient and operationally labor intensive.

In order to increase performance, as well as competitiveness, many of the U.S. launch vehicle providers propose upgrades to the existing fleet. While this may indeed increase performance in the short term, the cost of the modifications is estimated to cost from hundreds of millions of dollars to the billion dollar cost range. Even if these modifications are implemented, the newer vehicles, principally from foreign manufacturers, will incorporate state-of-the-art technology into their designs which ultimately will outperform the U.S. upgraded fleet.

SOLAR THERMAL UPPER STAGE COSTS

The cost estimates provided are an output from an STUS feasibility study performed by the MSFC.² These cost estimates include the total development cost and the first flight unit cost. Additionally, the cost of the first 25 flight units is provided. The cost for the first 25 units was produced assuming a 90-percent learning curve effect. The underlying assumptions for these cost data are provided in Figure 4. The cost data are provided in Figure 5.

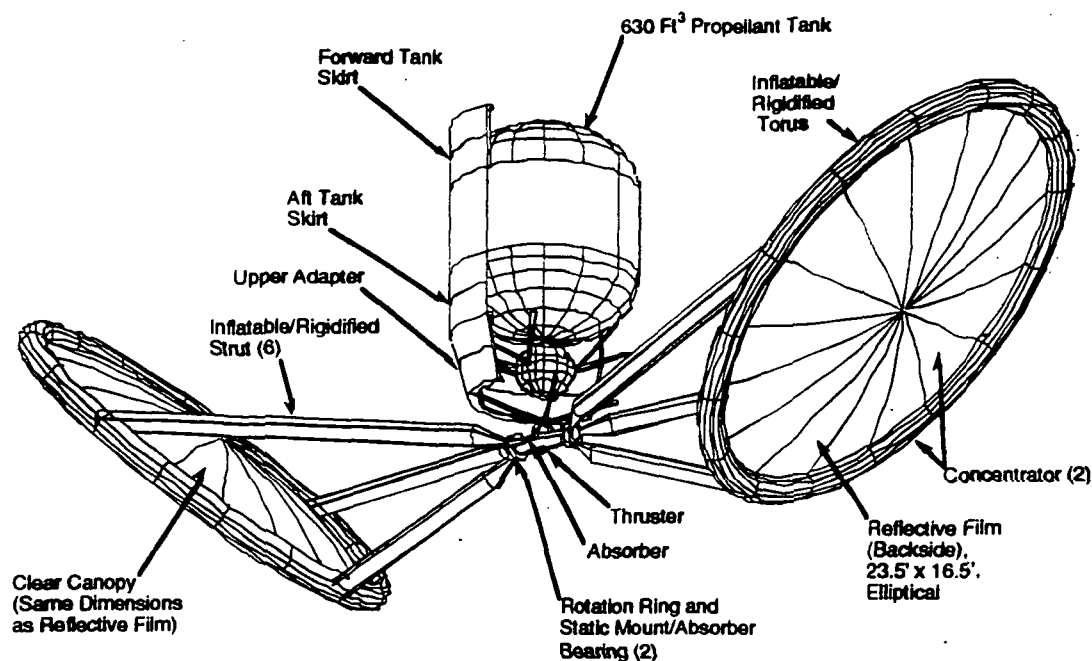
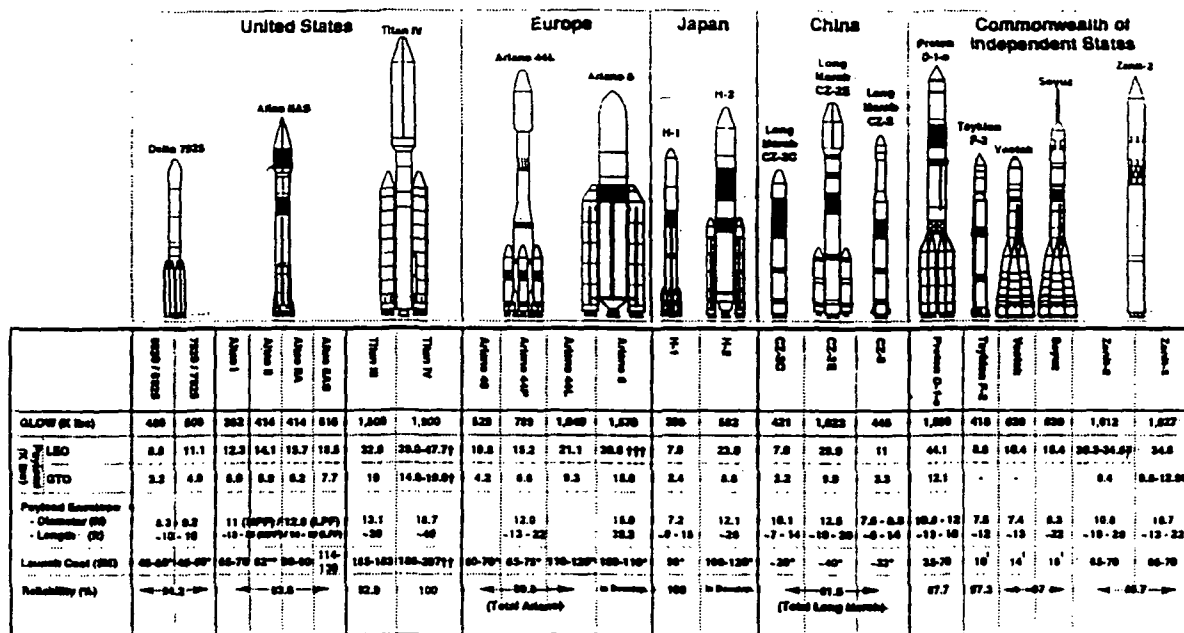


FIGURE 1. SOLAR THERMAL UPPER STAGE.

Number of Payloads Per Year (Projected)

	Year																				
	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Air Force (4,000-6,000 Lb)	4	4	7	7	1	1	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Commercial (2,000->10,000 Lb)	5	8	10	13	28	24	15	14	9	5	10	16	10	11	15	12	14	11	17	13	13
Total	9	12	17	20	29	25	15	15	10	6	11	17	11	12	15	12	14	11	17	13	13
1. Data Provided By McDonnell Douglas 2. Data Represents International Market																					

FIGURE 2. PROJECT GLOBAL MARKET.



NOTE: Performance numbers for each launch vehicle based on launch from the respective current launch facilities.

Launch Costs From International Reference Guide To Space Launch Systems, International, 1991.
 Unless Otherwise Noted,
 *Costs in 1990 Dollars.
 **Launch Costs Provided By General Dynamics Space Systems, Huntsville Office, May 1992.
 † Estimated Launch Costs From International Reference Guide To Space Launch Systems, 1991.
 ‡ Estimated Launch Costs From International Reference Guide To Space Launch Systems, 1991.
 § Launch Costs For Titan IV or the Upper Stage of Titan IV Using Current Upper Stage.
 ¶ Launch Costs For Titan IV or the Upper Stage of Titan IV Using Current Upper Stage.
 †† Launch Costs For Titan IV or the Upper Stage of Titan IV Using Current Upper Stage.
 ‡‡ Launch Costs For Titan IV or the Upper Stage of Titan IV Using Current Upper Stage.

FIGURE 3. LAUNCH VEHICLE COST.

- STUS COSTS ARE IN FY 1994 \$ K.
- SEER-H COST MODEL (A COMMERCIALLY DEVELOPED COST MODEL) IS USED TO ESTIMATE THE STUS SUBSYSTEMS COST.
- THERE ARE TWO COST ESTIMATES OF STUS. ONE ESTIMATE ASSUMES THE TOTAL DEVELOPMENT OF THE STUS PROGRAM BY THE CONTRACTOR AND THE SECOND ESTIMATE ASSUMES A PARTIALLY IN-HOUSE DEVELOPMENT OF THE STUS PROGRAM. THE STUS ABSORBER AND THE SOLAR COLLECTOR DEVELOPMENT WILL BE DONE BY THE CONTRACTOR AND THE REMAINING WORK WILL BE DONE IN-HOUSE.
- THE IN-HOUSE COST ESTIMATE WAS DONE BY DIVIDING THE PORTION OF THE WORK THAT IS GOING TO BE DONE IN-HOUSE BETWEEN LABOR AND NON-LABOR AND CONVERTING THE LABOR COSTS TO MAN YEAR USING THE HISTORICAL MAN POWER DATA. THEN APPLY THE MSFC PROGRAM MISSION SUPPORT (PMS) RATE OF \$22K/MAN YEAR TO CALCULATE THE CIVIL SERVICE MAN POWER COST.
- THE ESTIMATES INCLUDE DDT&E AND FIRST UNIT COST FOR STUS SPACECRAFT. THE INTEGRATION OF STUS TO THE LAUNCH VEHICLE IS NOT INCLUDED. THE COST OF THE FIRST TWENTY FIVE UNITS ARE ALSO SHOWN GRAPHICALLY. THESE COSTS WERE CALCULATED USING A 90% LEARNING FACTOR.
- THE WEIGHTS USED FOR ESTIMATING THE COST OF THE STUS SUBSYSTEMS INCLUDE A 20% CONTINGENCY.
- THE ABSORBER, GIMBALL, PROPULSION FEED SYSTEM AND THE TANK COST INCLUDES 3 TEST ARTICLES. THE RCS THRUSTER DEVELOPMENT COST INCLUDES 16 TEST ARTICLES. THE SOLAR COLLECTOR AND THE PNEUMATIC SYSTEM COSTS INCLUDE 2 TEST ARTICLES. ALL OTHER SUBSYSTEMS COSTS INCLUDE ONE TEST ARTICLE.
- THE COST ESTIMATE REFLECTS THE SEER-H COST MODEL ESTIMATED SCHEDULE FOR EACH SUBSYSTEM.
- BOTH ESTIMATES INCLUDE 10% FEE, 15% PROGRAM SUPPORT AND 30% CONTINGENCY.
- THE SOFTWARE COST IS AN ESTIMATE BASED ON THE OMV SOFTWARE COST. IT INCLUDES BOTH GROUND AND FLIGHT SOFTWARE.
- THE DEVELOPMENT COST FOR ANY EXISTING HARDWARE REPRESENTS ONLY THE INTEGRATION COST OF THAT HARDWARE.

FIGURE 4. COST ESTIMATE GROUND RULES/ASSUMPTIONS.

ECONOMIC FEASIBILITY

(FY 1994 DOLLARS)

STUS DEVELOPMENT COST	\$116M		
STUS FLIGHT UNIT COST	1ST	10TH	25TH
	<u>UNIT COST</u>	<u>UNIT COST</u>	<u>UNIT COST</u>
LLV3(INCLD INTEG)	\$28M	\$28M	\$28M
STUS	\$15M	\$11M	\$9M
SAVINGS OVER TODAY'S SYSTEM	\$7M	\$11M	\$13M
% SAVINGS	14%	22%	26%
CAPABILITY	1000 LBS	GEO	
CURRENT SYSTEMS			
DELTA II (7925)	\$50 - 60M		
STAR 48/AKM			
CAPABILITY	1000 - 2000 LBS	GEO	

FIGURE 5. SOLAR THERMAL UPPER STAGE COST.

The cost estimates were developed using the SEER-H cost model at MSFC.² The cost estimates reflect the assumption that the development of the STUS was done entirely by contracted effort. As can be seen from Figure 5, the development cost for an STUS would be approximately \$116 million. This development would produce a fully operational space-qualified upper stage. The first unit cost of such an upper stage vehicle would be approximately \$16 million dollars. A corresponding development schedule is shown in Figure 6. As can be seen from this schedule, an operational upper stage can be developed in approximately 7 years from Authority to Proceed (ATP).¹

As part of the NASA/MSFC feasibility study, an economic justification of an STUS was performed. As noted previously, the MSFC study utilized a Lockheed LLV3 launch vehicle. The estimated cost of the LLV3 launch vehicle is \$28M, including integration cost. The payload mass was 1,000 lb for this study. The launch vehicle used for comparison purposes was the Delta II (7925). The estimated cost of the Delta II launch vehicle is \$50 to \$60M.

Based upon this analysis, the system consisting of an LLV3/STUS would save in the range of \$7 to \$13M compared to the Delta II system. The savings value changed depending on which STUS production unit was flown. Using these cost savings estimates, an STUS will recover its development cost in 9 to 16 flights.

Even greater cost savings can be realized when considering the Atlas and Delta family of launch vehicles. For example, a payload that was manifested on the Atlas IAS could now be manifested on a Delta II launch vehicle that incorporates an STUS. This can be accomplished because by incorporating the STUS, the GTO payload capability of the Delta II launch vehicle can be increased from ~5,000 lb to ~8,000 to 10,000 lb. The cost saving associated with remanifesting this mission is ~\$55 to \$70M. With these cost

savings, the development cost of an STUS could be recouped in two flights.

If the Titan IV class of vehicles is considered, the cost savings are still greater. The Titan IV, however, is not a commercially available launch vehicle. Typically those Titan IV payloads are much higher in mass (>10,000 lb). The estimated cost range for the Titan IV vehicle range from a low of \$186M to a high of \$207M. Through the use of an STUS, the same payload could be manifested on a launch vehicle of lesser GTO throw capability. With an STUS, the 10,000 lb payload which was to fly on a Titan, could be remanifested to fly on an Atlas/STUS vehicle. This can be accomplished since the GTO payload capability of the Atlas IAS can be increased from 7,700 lb to ~12,000 to 15,000+ lb.

By flying on the Atlas/STUS system, the launch costs could be reduced to \$125M to \$145M. The resultant cost savings is on the order of \$60M to \$70M per flight. With these cost savings, the development cost of the STUS will be recouped in two flights.

These performance/cost relationships are shown graphically in Figure 7.³ As also can be seen from this figure, that by incorporating an STUS into the current launch vehicle, namely the Atlas and Delta vehicles, the U.S. launch services industry can become competitive with the foreign competition, namely the Ariane launch vehicles. As shown in the figure, the Ariane goal is to achieve a cost efficiency, measured in dollars per pound of payload, of \$8,000/lb. The current Atlas IAS cost efficiency is ~\$14,800 to \$16,800/lb. The current Delta II cost efficiency is ~\$11,250 to \$12,500/lb. By contrast, the current cost efficiency of the Ariane IV family of launch vehicles is in the range of ~\$9,800 to \$14,300/lb. The planned Ariane V launch vehicle, which will have a GTO capability of 15,000 lb (multiple manifests), will have a cost efficiency of ~\$6,600/lb.

Through the use of an STUS, the cost efficiency of an Atlas IAS vehicle could be reduced to ~\$7,100 to \$8,700/lb. The cost efficiency of the Delta II vehicle could be reduced to ~\$6,600 to

\$8,000/lb. These cost efficiencies essentially double the current efficiencies of the Atlas and Delta launch vehicles.

An additional benefit of an STUS is that it will increase or provide a GEO/GTO capability for the small launch vehicles who either have very little or no current GEO/GTO capability. This augmentation of the small launch vehicle capability will allow greater access to space for small commercial enterprises and universities. This benefit may also have a potential application to the single stage to orbit (SSTO) launch vehicles which are currently being studied. The STUS would have the potential of greatly increasing the payload capability of an SSTO and further enhancing its cost effectiveness.

STUS CURRENT ACTIVITY

In order to continue to stimulate interest in solar thermal propulsion (STP), a Solar Thermal Alliance (STA) has been formed consisting of major industry, university, and government entities who are interested in STP. Many of the participants in the STA have many years of experience in the development of STP and its components. Recent feasibility studies, such as the one completed by NASA/MSFC, have also served as catalysts in the formation of the STA. The STA offers the opportunity to bring together the years of research experience, the renewed interest in less expensive access to space, and the latest studies into a comprehensive plan for the development of an STUS flight system.

To this end, the STA is pursuing several different programs designed to lay the groundwork for the full scale development of an STUS. One such program is the University Space Research

Association's (USRA) Announcement of Opportunity (AO) for university-led space research and development activity. Pursuant to the USRA AO, the STA submitted a proposal in August 1994. The USRA proposal was for a flight experiment to demonstrate the feasibility of an STUS in a space environment. The launch vehicle for this mission was a Minuteman or Pegasus class vehicle. The nominal mission per the AO is a 300 nmi polar orbit with a 300-lb payload. The configuration of the proposed flight experiment is shown in Figure 8. As can be seen from the figure, the experiment consists of a 12-ft diameter deployable concentrator which is in line with the absorber/thruster assembly. The thrust level of the vehicle is 0.4 lbf. For safety and mission simplicity reasons, the propellant for this flight experiment will be gaseous hydrogen.³

The basic objectives of the proposed mission are:

- To demonstrate the interaction between the concentrator and absorber/thruster assembly
- Performance mapping of the absorber/thruster
- Demonstrate the deployment of a thin film concentrator.

Should this proposal be selected, this mission will offer the first opportunity for in-space demonstration of STP. The selection by the USRA is expected in the September/October 1994 time-frame.

Another avenue being pursued to advance the level of development of STP is the Aerospace Industry Technology Program (AITP). The AITP is a NASA-sponsored research and development program. In the September 1994 timeframe, a proposal

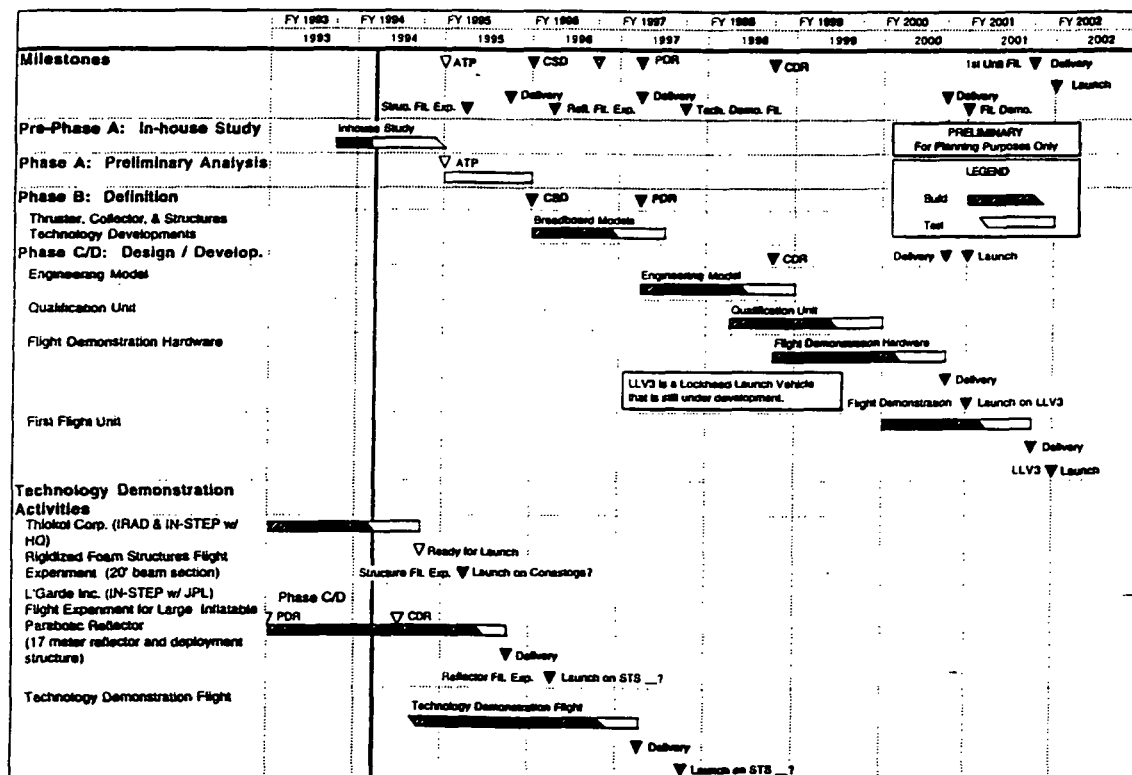


FIGURE 6. STUS DEVELOPMENT SCHEDULE.

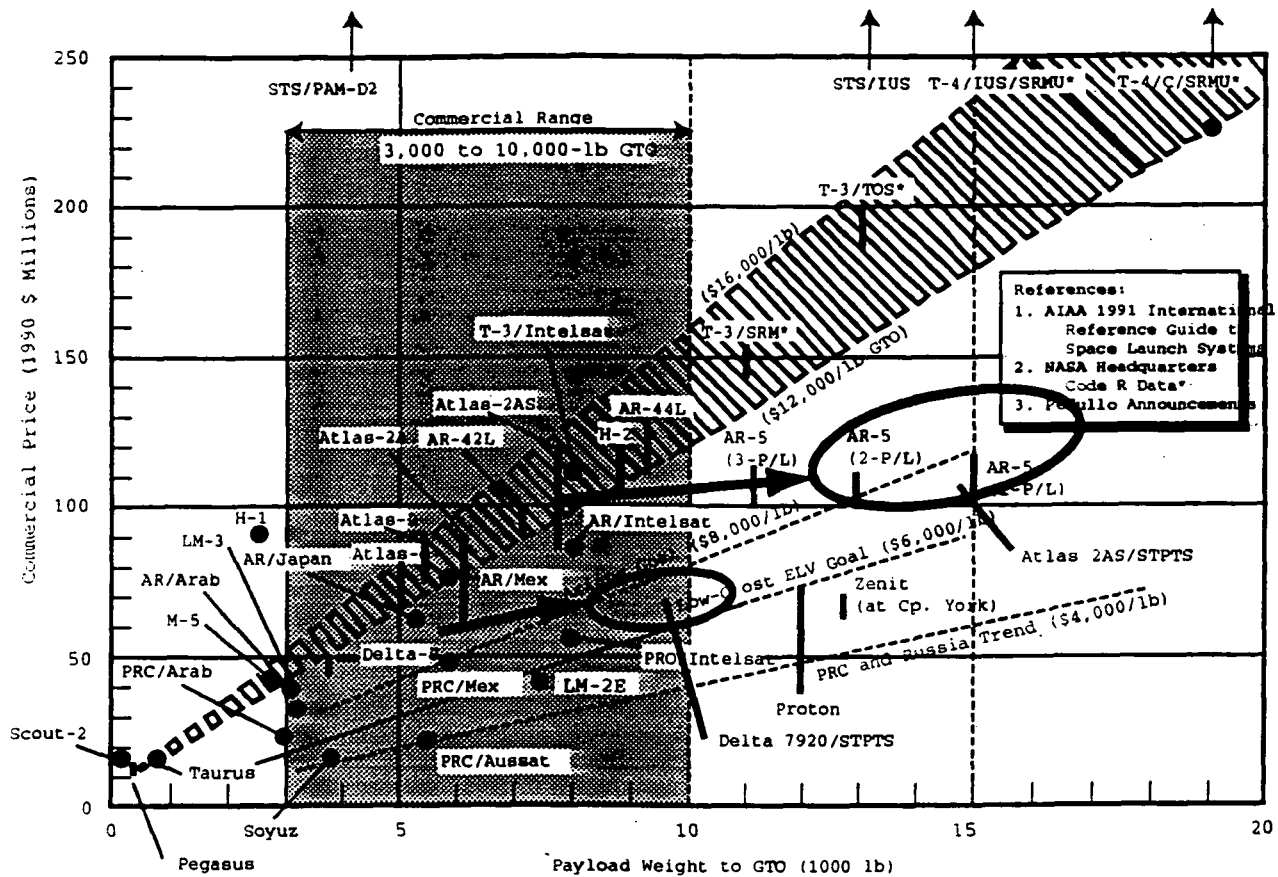


FIGURE 7. STUS PERFORMANCE COST BENEFITS.

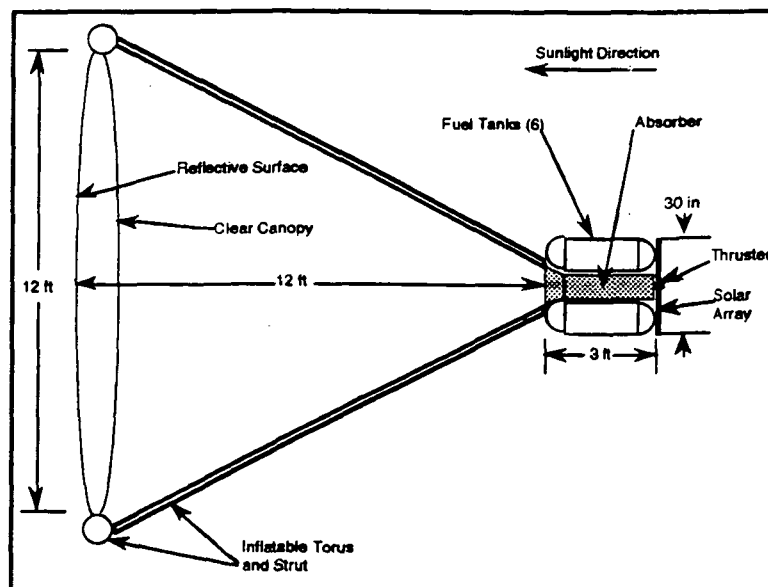


FIGURE 8. USRA STUS FLIGHT EXPERIMENT CONFIGURATION.

will be submitted to the AITP for the ground test development of STP key technologies and components.

Additionally, discussions are underway within the STA on how or if to pursue submitting a proposal to the Advanced Research Projects Agency Technology Reinvestment Project (TRP). The USRA and AITP proposals, along with the potential TRP proposal, will provide significant progress in the development of STP.

CONCLUSIONS

Of the advanced propulsion concepts which have been investigated over the last few years, STP offers the most benign, least complex, and least costly concept. These positive attributes, combined with the performance capability, make STP an extremely attractive option. STP effectively doubles the specific impulse of conventional chemical engines and can be developed at a modest cost. Estimated cost savings show that the development cost of an STUS can be recouped in as little as two flights.

STP provides a means by which the current U.S. launch vehicle fleet can become competitive with the increasingly efficient Ariane family of launch vehicles. STP may be essential for the U.S. launch industry to recapture some of its lost market share in the launch services industry. STP effectively reduces the cost per pound of placing payloads in GTO by 50 percent.

STP can greatly reduce the cost of placing payloads in GEO or GTO. By reducing the cost, the access to space is increased for small commercial entities and universities, and by allowing a greater number of payloads for given budgeted dollars. Access to space is further enhanced by providing or increasing the GEO/GTO capability of small launch vehicle suppliers.

Through the formation of an STA, the development of STP is poised for great progress. The initial flight demonstrations and extensive ground test program have been proposed. Much more work needs to be done to fully develop an STUS, and through the STA this work will continue. STP offers a great opportunity to enhance the capability of the nation's launch vehicle fleet.

REFERENCES

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