The Space Congress® Proceedings

1969 (6th) Vol. 1 Space, Technology, and Society

Apr 1st, 8:00 AM

The Launch Cost Bottleneck

R. A. Lynch

General Dynamics Convair

Follow this and additional works at: http://commons.erau.edu/space-congress-proceedings

Scholarly Commons Citation

http://commons.erau.edu/space-congress-proceedings/proceedings-1969-6th-v1/session-6/1
"Space operations are very costly." This simple statement is widely accepted as true and is the major deterrent to the full utilization of space. This discussion concentrates on the major contributor to space operations cost: the launch system.

It will be shown, initially, how high current space operations costs are. The launch vehicle is a major element in the overall system operations cost. Extremely high launch costs are the major deterrent to increased space traffic. However, if space traffic is not maintained or increased, our entire space utilization potential may disappear. Low-cost launch systems are needed now to ensure growth. We may be at a turning point.

Next, several low-cost launch-system concepts are discussed, including the low-cost expendable, 1-1/2 stage or droptank concept and the Triamese reusable launch vehicle/spacecraft concept.

Progress toward a reusable launch system has always been hampered by the "anti-low-cost launch-system feedback loop." Each element of this loop is examined to indicate that we may currently have the ability to break this loop and move forward.

This discussion is not based on a rigorous technical analysis, although it contains some technical elements. The ability to break the launch-cost bottleneck and proceed with space utilization is based on many nontechnical, political, psychological factors. Some of these more intangible factors are included in this discussion.

Current Launch Systems

Figure 1 presents some current launch vehicles with their operational cost per flight and a dollars per pound of delivered payload measure of efficiency. Two-way transportation of payload is even more expensive because launch vehicle payload must be invested in an entry vehicle. These costs seem high, but when compared with other complex transportation systems they seem unexplainably high.

There have been many analogies made between modern commercial jet transports and space transportation systems. These analogies serve two main purposes. First, they tend to describe the space transportation problem in terms that all persons familiar with modern air travel might understand. Second, they supply a convenient target for the host of people that disagree with the manner in which they are done.

Figure 2 presents a picture of a Boeing 707 and a space logistic system using a Saturn IB launch vehicle and a semiballistic return capsule. The systems are comparable in size and complexity. The passenger safety requirements are of similar importance. If the systems are compared on an equal energy basis (foot-pounds), the 707 would have to fly a round trip between Los Angeles and Saigon to expend energy equal to an orbital flight (~ $10^{12}$ foot-pounds). A passenger on the 707 would pay ~ $940 while a passenger in the space logistic system would pay ~ $300,000 (assuming he was
not required to pay his share of development cost for the logistic system. It should be noted here that the return trip from orbit greatly increases the cost over what is normally quoted for one-way delivery only.

Why are the aircraft costs so much less? The following may be reasons:

1. The airliner is fully reusable.
2. The airliner is designed for economical and rapid turnaround.
3. High airline utilization (traffic) spreads facility costs and development costs.
4. Aircraft development costs are relatively lower than those for spacecraft and expendable launch vehicles.

This discussion would lead to the general conclusion that one promising method of reducing launch costs is to develop a reusable launch system having airplane charateristics. This was a general conclusion of the AIAA Launch Vehicle Committee in March 1967 (Ref. 1 quote from a comment by G.H. Stoner, vice president of Boeing, "I also can envision the eventual system as a single-stage-to-orbit vehicle similar in function and possibly appearance to the airplane of today"). These vehicles are now within our grasp, as will be discussed later.

The foregoing discussion presents a dilemma regarding reasons for the high cost of space transportation. Next, let’s examine the elements which make up the total cost (nonrecurring and recurring) of a space transportation system. Figure 3 presents a cost breakdown for the postulated NASA Advanced Logistic Support System (ALSS). This logistic system consists of a nine-man semiballistic crew module, a cargo-maneuvering module and an uprated Saturn IB launch vehicle. The costs shown are based on development of the logistic spacecraft and operation of the system for 133 flights to low earth orbit over a nine-year operational period. The useful payload of the system to a low earth orbit of 30 degrees inclination can be considered as 16,500 pounds per flight. If total program cost, including development, is used as a basis, the payload delivery cost is $4,050 per pound; (if development is excluded, this cost becomes $3,780 per pound). Comparing this cost with the costs of Figure 1 shows logistic resupply costs to be even higher than currently quoted basic launch vehicle costs.

It has been shown that logistic costs to orbit are relatively high when compared to transportation systems of equal sophistication, such as commercial transport. The next question is, why do logistic systems cost so much to operate and which elements of the system operation cost the most? Figure 4 shows a relatively detailed cost breakout of the ALSS described above. The expendable portions of the cost bars are indicated by shading. Shading also indicates costs which are incurred because the recoverable system components are not basically designed for reuse. It can be seen that approximately 66% of the total operational cost is incurred because hardware components are expended and those that are recovered are not readily reusable.

In general, costs can be reduced appreciably by reusable systems or by major reductions in expendable costs. Both of these approaches will be explored later.
These high costs place space utilization in a very special management and political category. The reasons for a single space launch must be thoroughly justified, well in advance, through many tiers of management. Expendable hardware (launch vehicle) must be programmed well in advance. The launch vehicle must be completely loaded and possibly a group of relatively unrelated payloads must be assembled. The economic and political consequences of a failure (expenditure of launch vehicle and loss of payload) to achieve mission objectives are tremendous. This environment is not conducive to increased space utilization.

Mission Potential

One key to lower launch costs is mission justification and increased traffic. Space missions fall into three major categories: scientific, commercial, and military. None of these areas alone can probably justify a new launch system; but together they can. From a scientific point of view, the earth orbital space station seems a logical next step. The logistic support system is a major element in a space station program (Figure 5). Also, station flexibility is severely hampered by the extreme premium placed on reducing the number of logistic vehicle trips using expendable launch systems.

While the space station itself may be considered a scientific mission, the scientific/engineering task of providing a low-cost space transportation system may be a mission of equal or greater importance. There is considerable historical precedent for NACA and NASA providing basic aircraft research which was used by the military and commercial interests to create the air transportation system we have today.

Regarding commercial use of space, I think it is sufficient to state that real commercial use of space cannot take place until payload delivery costs are well below the current ~ $500 per pound.

A real justification for space utilization currently lies in the military area. There are a myriad of military orbital and suborbital uses of space. It is only possible to state in this unclassified paper that all of these potential uses depend primarily on an economical and flexible launch system.

There are currently missions being performed in space (Figure 6) which could be performed more economically using a low-cost launch system. The current trend seems to be one of "leveling off." We may be reaching a point in space activities where current high costs are stifling traffic growth. The new flexible, economic launch vehicle system must come first; and the missions will follow.

Figure 4. ALSS Cost Breakdown

Figure 5. Space Station System Cost

Figure 6. Space Traffic
Potential Launch Systems

As was shown in the ALSS example above, launch costs represented about 66% of the total logistic support program costs. Two approaches are currently being considered to reduce launch costs.

1. Low cost expendable systems.
2. Reusable systems.

Low-cost expendable approaches make use of "head-end steering," low-cost tank construction and "simple" pressure-fed engine systems. "Head-end steering" can be used as a generalized term to describe a concept which places all of the expensive components such as guidance in a reusable spacecraft on top of the low-cost booster. In some cases, the attitude control or steering during launch is provided by rocket motors mounted on the reusable spacecraft and the main boost engines are not required to gimbal.

Expendable launch vehicle costs arise from two considerations. First, the cost of the equipment and structure which is expended. Second, the cost of the testing and checkout to assure that the first and only flight the vehicle will make is successful. The low-cost expendable approach is not likely to be successful for three reasons:

1. Without a complete break with aerospace industry and government/customer practices, the development and production of a low-cost expendable launch vehicle is impossible. The current state of the art in aircraft and launch vehicles results in very sophisticated, high-performance, high-reliability hardware. It would require a major revision to direct this well established contractor/customer industry to an "ammunition" approach.

2. The desire for successful operation on the first and only flight may cause test and checkout costs to overshadow the low launch vehicle hardware cost.

3. A launch system having low-cost lower stages still requires a sophisticated reusable upper stage to carry the guidance system and provide mission functions.

It is not the objective of this discussion to pursue the low-cost expendable approach to any great degree, especially in view of the interesting and promising reusable systems which now exist.

The reusable launch vehicle approach is now about 10 years old. Myriads of vehicle concepts have been investigated, ranging from fixed wings attached to vertical takeoff rockets to the sophisticated air collection Spaceplane.

These reusable launch systems have not moved ahead for one or more of the following reasons.

1. High development cost.

In addition to all of these specific reasons, the timing relative to national requirements has not been optimal. Many of these problems have been overcome, and current launch systems are extremely promising and timely. Numerous studies have shown that reusable spacecraft, particularly lifting types, provide operational flexibility and economy as far as spacecraft reuse is concerned. However, when a current expendable launch vehicle is used to launch these spacecraft, system costs become prohibitive. The stage-and-one-half (1-1/2 stage) or drop tank concept shown in Figure 7 was the first concept which really attacked this problem. Here, a single reusable spacecraft, incorporating rocket propulsion, is used to perform both launch and spacecraft function. The drop tanks used to supply propellants to the engines during the initial launch are relatively simple and low cost. Of course, the success of this concept depends to a large degree on the ability to produce large, light-weight, cryogenic drop tanks at low cost. Tank structure costs represent about 66% of the total logistic support program costs. Two approaches are currently under consideration to reduce tank costs. One element (or stage) is designated the orbiter and two are used as boosters. All rocket engines are burning at vertical liftoff, and the orbiter engines are using propellant being cross-fed from the boosters. The stage elements are staged off when empty, and the orbiter element continues to orbit on its own internal propellant. The boost elements perform an aerodynamic lifting body recovery downrange, extend their stowed wings and engines subsonically, and cruise back to the launch site to make a normal aircraft horizontal landing. When the orbiter has completed its mission, it performs a lifting body entry and returns to the launch site in a manner similar to the two boost elements. In this operation there are no items expended, and the entire mission is performed by a single vehicle design. In concept, the Triamese is developed and performs like the ideal "single-stage-to-orbit" system without the serious technology problems. The fact that three identical vehicles are attached in parallel during the initial boost has a relatively minor influence on system operation or economy.
The Triamese system technology is a direct outgrowth of the well established expendable launch vehicle. Figure 9 shows that the Triamese element consists of an expendable launch vehicle structural core around which are wrapped lightly loaded fairings that thermally protect the structure and equipment and provide a hypersonic lifting body shape.

The variable geometry, or stowable wing concept, has been shown to provide efficient subsonic performance while being lighter than competing approaches. Stowable wings are used on the Triamese element to serve several essential functions. The wings permit efficient subsonic performance without the necessity of a delta planform on the basic body. The essentially cylindrical elements are easy to stack in parallel for launch. Subsonic cruiseback of the boost elements to the launch site is efficiently performed.

The internal arrangement of a Triamese orbital element is shown in Figure 10. The only major difference between an orbital element and a boost element is that, in the boost element, the cylindrical sections of the propellant tanks are extended into the central cargo/equipment bay.

Figure 7. 1-1/2 Stage System

Figure 8. Triamese System

Figure 9. Triamese Configuration Evolution
PERSONNEL CAPSULE
250K HIGH-PRESSURE ENGINES (2)
HYDROGEN TANK
OXYGEN TANK
CARGO EQUIPMENT BAY
TURBO-FAN ENGINE
LENGTH 118 FT.
LAUNCH WT. 358,000 LB.
PAYLOAD 18,500 LB.
ENTRY WT. 67,500 - 86,000 LB.

Figure 10. Triamese Orbital Element

In addition to economy, the Triamese concept offers other operational flexibility. As shown in Figure 11, after the system is fully proven, it may be launched at any azimuth since expended hardware is not jettisoned, and the hazard to people and property should be no greater than for overflight of aircraft.

The Triamese system has good growth capability for a completely reusable system. Increased payload can be provided by adding plugs in the constant body section as shown in Figure 12. This type of growth would be dependent upon normally expected rocket engine thrust growth. Triamese elements can also be assembled in parallel in various numbers for special missions and provide growth as shown in Figure 13.

The Triamese can be developed economically by combining rocket and aircraft techniques. Initial flights would be made using the turbofan engines for horizontal takeoff with no propellant aboard. Single-element vertical takeoff flights would be made to gradually higher velocities, reaching about 18,000 feet per second. The element thus could be gradually exposed to more severe heating and loads. Finally, launch economy permits testing a Triamese for a number of flights approaching its required life within a short development program to verify structural and subsystem life.

A Triamese system shows cost reduction potential when compared with the ALSS system discussed earlier, as shown in Figure 14. In this comparison, expendable launch vehicle practices have been retained to some extent for the Triamese system. Triamese system costs may be further reduced (~50%) if full aircraft development techniques are used.

Figure 11. Triamese Unrestricted Launch Azimuth Capability

Figure 12. Growth by Body Stretch

Figure 13. Growth by Multiple Elements
§ 6

feedback loop. " Only semitechnical reasons are ized in Figure 15 as the "anti-low-cost launch-system important political factors also prevail (e.g., com­petition with concurrent expendable systems). in sufficient variety, development costs have been paid, and operating costs are closely related to traffic. Each expendable launch must be very highly justified to warrant the large expenditure. Low traffic means minimum providing also that no vehicles were built. low program cost. In the ridiculous extreme, if no expendable vehicles were flown, the cost would be pendable launch systems through low traffic right back to expendable systems.

Figure 15 shows the current feedback loop from ex­usable launch system alternate has been pursued for many years. Excessive development risk, development reasons not to follow this approach. Turnaround cost (i.e., refurbishment) has been cited as the reason for high operating cost. Development and operating costs must be evaluated relative to the anticipated traffic. If traffic maintains its current level or increases, a reusable launch system having sufficient mission flexi­bility becomes a logical choice. In summary, expend­able launch systems are associated with declining space activity, and reusable launch systems should be identified with a continuing or growing space program.

The major reasons for not proceeding with a new system have been mentioned above and are summarized in Figure 15 as the "anti-low-cost launch-system feedback loop." Only semitechnical reasons are discussed here, and it must be remembered that many important political factors also prevail (e.g., competition with concurrent expendable systems).

Expendable launch vehicles are currently available in sufficient variety, development costs have been paid, and operating costs are closely related to traffic. Each expendable launch must be very highly justified to warrant the large expenditure. Low traffic means low program cost. In the ridiculous extreme, if no expendable vehicles were flown, the cost would be minimum providing also that no vehicles were built. Figure 15 shows the current feedback loop from expendable launch systems through low traffic right back to expendable systems.

Exploring the other main leg in Figure 15, the reusable launch system alternate has been pursued for many years. Excessive development risk, development cost, and operating cost have been used as the chief reasons not to follow this approach. Turnaround cost (i.e., refurbishment) has been cited as the reason for high operating cost. Development and operating costs must be evaluated relative to the anticipated traffic. If traffic maintains its current level or increases, a reusable launch system having sufficient mission flexi­bility becomes a logical choice. In summary, expend­able launch systems are associated with declining space activity, and reusable launch systems should be identified with a continuing or growing space program.

With the loop described above firmly established in the technical/political community, what will permit a promising concept such as Triamese to move forward to realization? Three elements in the loop are chang­ing. First, we have reached the point where we have strong desires to go on more missions than our budget can afford in terms of expendable launch vehicles (the National Space Station, MOL support, and advanced military systems). Second, technology has slowly progressed to the point where a concept such as Triamese is definitely approaching state of the art. Third, we almost admit that a new spacecraft concept is needed (low g lifting entry, horizontal landing, on dry land, in a reusable condition), and if we can combine the spacecraft function with a reusable launch vehicle function in a single reasonable cost program, we are interested.

The following paragraphs present seven of the major reasons given in the past for delaying reusable launch vehicle development. Each statement is accompanied by current reasons why a system such as Triamese should proceed.

1. Statement: Reusable launch vehicle development costs are high.

Status: Spacecraft users (NASA, Air Force) have developed a strong desire to have a new spacecraft with increased mission flexibility and improved reusability. These users are talking routinely about development programs approaching $1 billion spread over five or six years (ALSS development cost is estimated to be $700 million over four years). A reusable launch vehicle such as Triamese can be developed with a similar budget and timing because technology requirements are similar although physical sizes are different.

2. Statement: Reusable launch vehicle development risk is high because an inadequate technology base exists.

Status: Past reusable launch vehicle concepts have been dependent on a wide range of technologies. Many concepts required exotic airbreathing propulsion schemes and sustained hypersonic flight in the atmosphere. The Triamese concept is derived chiefly from a combination of current expendable liquid propellant launch vehicle technology with subsonic aircraft technology. Lightweight thermal protection systems to provide protection during entry is perhaps the most critical technology remaining. However, the ability to use uncoated superalloy heat shields because of low entry platform loading is an important relieving factor.

3. Statement: There are insufficient predicted future missions to warrant the development cost of a reusable launch vehicle.

Status: Figure 16 presents the classic cost-versus-traffic plots for an expendable and a reusable system. Certain conservative assumptions have been used in this figure. The expendable system requires no further development and the Apollo spacecraft and other investment costs are ignored. The initial Triamese development and investment costs are high ($2.5 billion) by a factor of 2 if true aircraft development procedures are used. Triamese turnaround cost of $3 million per launch is high for true aircraft-like operation. Even with these conservative assumptions the Triamese system begins to show savings after 50 launches. Referring to Figure 6, it is seen that 60 launches per year is approximately our current rate. We currently have sufficient traffic potential to war-
Figure 15. Anti-Low-Cost Launch-System Feedback Loop

Figure 16. Program Cost Comparisons

1. Statement: Justification of new missions is too difficult considering the sizeable cost of each additional flight. The best way to reduce the cost of an expendable launch vehicle is not to use it. An even more economical approach is not to build any more expendable vehicles. This logic quickly results in the death of a space program. Our immediate future approach may not be this decisive, but it certainly may retard the growth of space utilization.

4. Statement: The expendable launch systems we have are quite expensive to operate, but they are adequate to support our current programs requiring limited flights.

Status: The lunar program, based on a national goal, is reaching a peak and may be tapering off in activity. Both NASA with the National Space Station, and the Air Force with MOL and its possible successors, are in need of a logistic support system. Government budgets are not capable of handling the desired frequency of logistic support using current expendable launch vehicles. We cannot expand our space activities based on the costs of current expendable launch vehicles.

5. Statement: We are heavily committed in terms of personnel, facilities, funds, etc., to our current Saturn and Titan expendable launch vehicles.

Status: It is becoming apparent that the current expendable launch vehicles are too expensive to use. Justification of new missions is too difficult considering the sizeable cost of each additional flight. The best way to reduce the cost of an expendable launch vehicle is not to use it. An even more economical approach is not to build any more expendable vehicles. This logic quickly results in the death of a space program. Our immediate future approach may not be this decisive, but it certainly may retard the growth of space utilization.

6. Statement: Your reusable launch vehicle concept does not have the mission and payload flexibility obtainable with an expendable launch vehicle and a reusable spacecraft/service module concept.

Status: Some early reusable launch systems, particularly airbreathing types, could not readily handle varying size and volume payloads. As discussed above and shown in Figure 13, the parallel-staged, modular concept of the Triamese permits growth to cover a wide range of payloads. Also, although it is much larger, the Triamese element has all the mission capability of a reusable spacecraft plus added features such as suborbital and aero-cruise capability and large available internal volume. However, it must be admitted that a large orbiting element is not as efficient as a smaller spacecraft with an expendable propulsion module, if extensive propulsive maneuvers in orbit are required. However, the Triamese system acting as a tanker for a space shuttle is attractive.

7. Statement: Reusable launch vehicles are not really fully reusable without extensive and very expensive refurbishing.

Status: Reusable launch vehicles can be designed and developed to require minimum turnaround servicing if an aircraft philosophy is adopted. The only real difference between the turnaround of a large jet aircraft and a reusable launch vehicle is that the environment experienced by each is slightly different. Complexity, safety requirements, etc., are very similar. The reusable launch vehicle can be designed for its
more severe environment and then can be economi-
cally tested on a number of flights approach-
ing its anticipated service life (maybe 50 flights).
An aircraft does not have the luxury of a full life
test during its development.

It is important when discussing reusable launch
vehicles that the classic term "refurbishment" not be
used and the terms "servicing, maintenance, etc.," be
substituted. The term refurbishment implies that
the vehicle is damaged to some extent and must be
disassembled and partially rebuilt. This is the wrong
philosophy for a reusable launch vehicle.

General Observations

1. It is becoming increasingly evident that full utiliza-
tion of space cannot proceed until recurring pay-
load delivery costs can be decreased from $500
per pound.

2. The expendable launch vehicle portion of a typical
space program represents 66% of the total pro-
gram cost. Therefore, the creation of an economi-
cal reusable launch vehicle provides the potential
of significant program cost reduction.

3. Current and immediate future space traffic is suf-
ficient to justify a new reusable launch system.
Space mission traffic may be currently reaching a
maximum unless economical launch is available
to encourage further mission expansion.

4. The Triamese reusable launch vehicle/spacecraft
concept is representative of a new breed of vehicles
which are available using mostly current technology.
The major attraction of the Triamese concept is
that it provides a completely reusable system with
the development of a single vehicle.

5. The "anti-low-cost launch-system feedback loop"
is still in operation. However, many of the ele-
ments of the loop have weakened, and the possibility
of breaking the loop is close at hand. Potential
space traffic is a key element in the loop and unless
we move soon, the relatively modest space traffic
we now can predict may begin to decrease, and full
space utilization and the reusable launch system
may die together.

References

1. "The Next Generation of Launch Vehicles — Evolution
or Bold Step?" AIAA Launch Vehicle Committee
Position Paper, Astronautics and Aeronautics,
March 1967.

2. R. A. Lynch, "The First Manned Lifting Entry
Vehicle Configuration," AIAA Paper No. 66-959,
29 November 1966.