N90-28636

OPERATIONAL COST DRIVERS

Arthur L. Scholz
Boeing Aerospace
Kennedy Space Center, Florida 32899
and
William J. Dickinson
National Aeronautics and Space Administration
Kennedy Space Center, Florida 32899

ABSTRACT

To be economically viable, the operations cost of new launch vehicles must be reduced by an order-of-magnitude as compared to STS.

This paper presents a summary of propulsion-related operations cost drivers derived from a two-year study of Shuttle Ground Operations.

Examples are given of the inordinate time and cost of launch operations caused by propulsion system designs that did not adequately consider impacts on prelaunch processing.

Typical of these cost drivers are those caused by central hydraulic systems, storable propellants, gimballed engines, multiple propellants, He and N2 systems and purges, hard starts, high maintenance turbopumps, accessibility problems, and most significantly, the use of multiple, non-integrated RCS, OMS, and main propulsion systems. Recovery and refurbishment of SRB's have resulted in expensive "crash and salvage" operations.

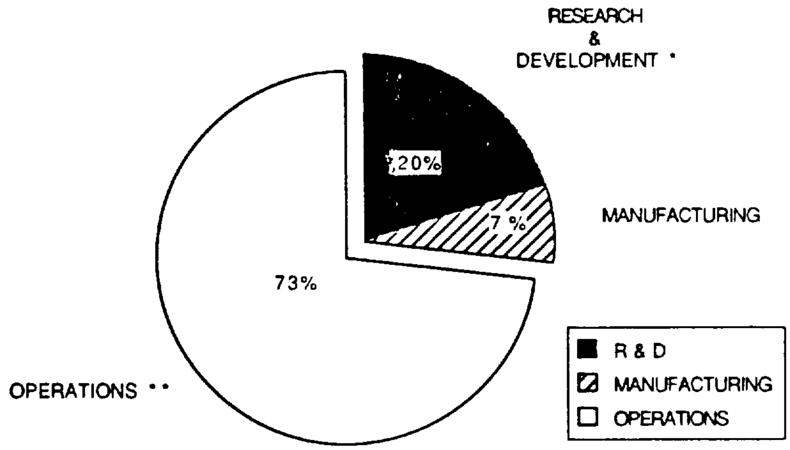
Vehicle system designers are encouraged to be acutely aware of these cost drivers and to incorporate solutions -- beginning with the design concepts -- to avoid "business as usual" and "costs as usual".

DISCUSSION

OPERATIONAL COST DRIVERS

For several decades, the Free World launch vehicles have been designed for performance, with very little attention given to considerations for supportability and/or maintainability. As a result, recurring cost of operations over the life of a program has been an inordinately large contibutor to Life Cycle Costs (LCC) - see Figure 1.

Life Cycle Costs
Figure 1



* 1.65 B$ (1965) escalated using NASA Headquarters factor of 4.199 for 1965 - 1985

** 2189.4 M$ (1985) - Data supplied by NASA to the Congressional Budget Office

Extrapolation of current operational costs (using actuals from the 8 FY85 Space Shuttle Program launches) indicates that total Operations Costs exceeded 73% of the LCC, whereas Design and Manufacturing were approximately 27%. This exorbitant Operations cost drives the LCC for one 100-flight Orbiter to $33.9 billion (in '85 dollars). Our best performance for the fleet of four orbiters to date is the 8 launches in FY 85. The cost per pound to LEO exceeded $5,000! Obviously, in future worldwide price competition, the "business as usual" approach for our Space Program will be suicidal and must be changed.

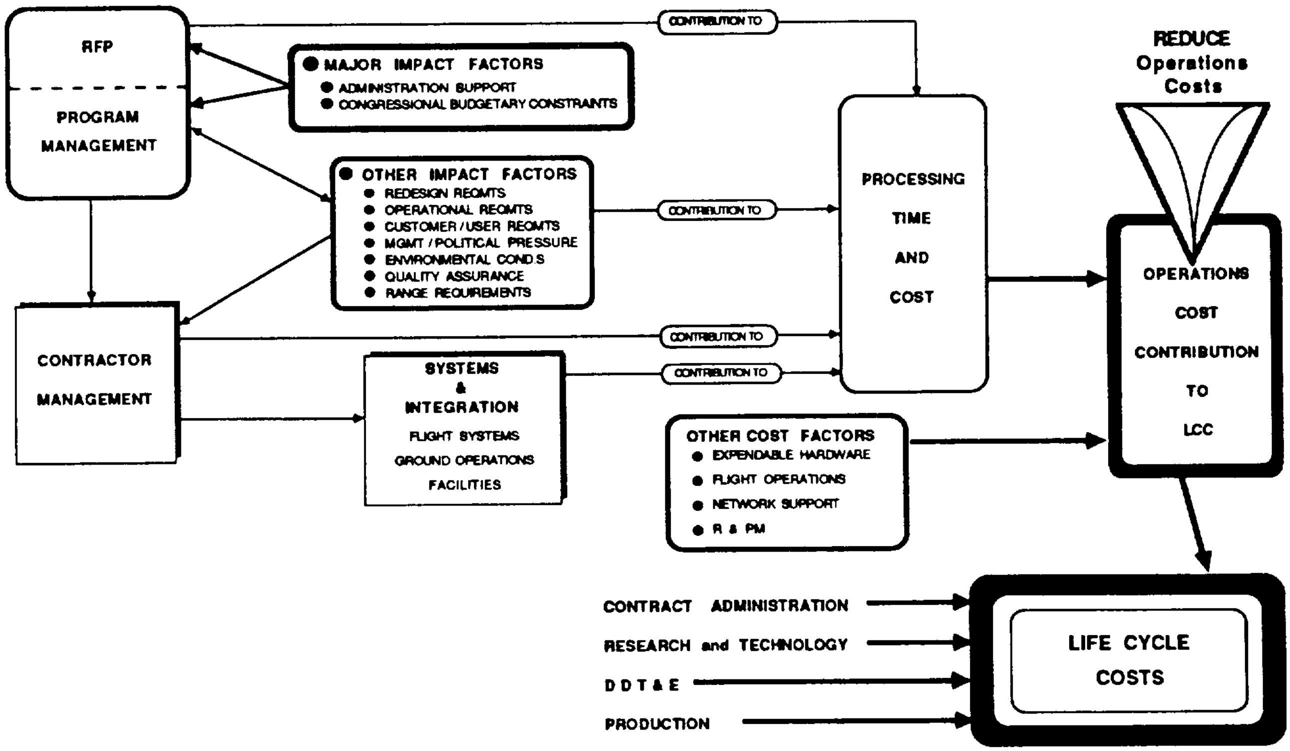
Figure 2 describes the elements that contribute to LCC, and here we see that the process starts with development of the Request for Proposal (RFP). Traditionally, the RFP is overburdened with minute specifications. Many of these are necessary -- but are they looked at in light of what <u>costs</u> they impose on the program vs the <u>benefits</u> they provide? The RFP usually describes, in great detail, "how to do it"; whereas the RFP should be primarily devoted to a generic description of the product. Between the RFP and the delivered product, there are many contributors to Operations costs. This discussion will address various "engine system" contributions to those operational costs.

Fortunately, opportunity exists today to significantly improve the process of considering system supportability requirements while designing a system that meets performance criteria. To make the most of these opportunities requires two major changes in our way of doing business:

(1) Change the "mind set" of all of us in the space program to make (or accept) compromises in performance if they contribute to a reduction in LCC.

(2) Provide more effort (dollars) upfront in the early design phase to provide for operational efficiencies -- <u>supportable and maintainable</u>, robust systems.

Cost Contributors
Figure 2

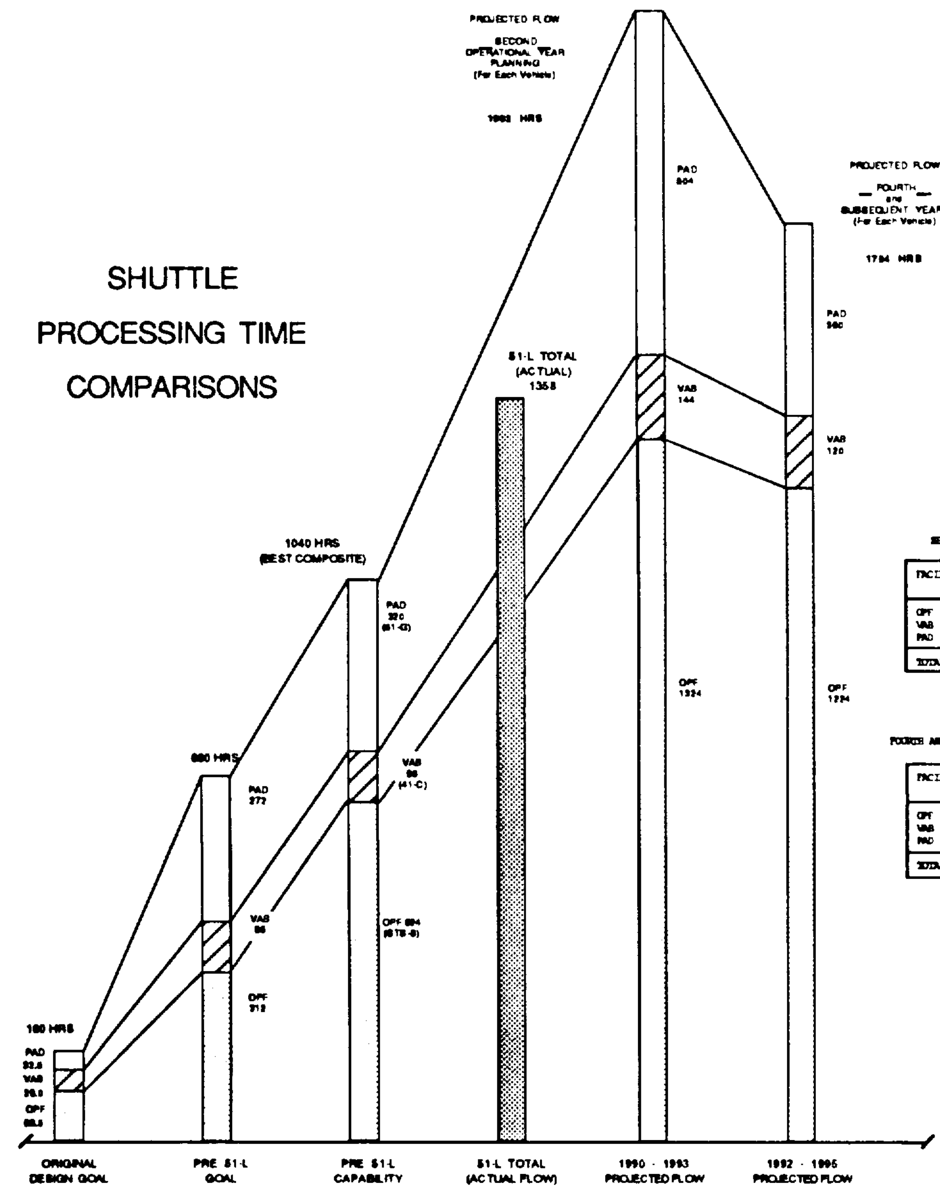


As noted earlier, operations costs constitute 73% of LCC, (see Figure 3).

The original goal for shuttle turnaround was 160 hours. However, it soon became apparent that 160 hours was not achievable with the hardware designed and built within Congressional budget and Management schedule constraints. Prior to 51-L, the goal of 680 hours had been established by KSC as the "shortest processing time that KSC could achieve". While this was much greater than the original "spec value", it was a justifiable goal considering the best composite processing time achieved (1040 hours) consisted of 624 hours in the OPF by STS 8, 96 hours in the VAB by 41-C, and 320 hours on the Pad by 51-G! This "best composite" considers the 25 vehicle processing/launch operations of the Shuttle Program to date.

Due to the very significant changes as a result of 51-L, processing time at the end of the second operational year (in the 1990-93 time period) is projected to be1992 hours for each of the four Shuttle vehicles. Subsequently, the flow is projected to decrease to 1704 hours after the end of the fourth operational year and is then expected to level off at that figure. Obviously, the Shuttle, not designed for supportability and maintainability, will require a very significant amount of additional processing activities for the forseeable future.

Shuttle Ground Operations Processing
Life Cycle Costs (Pre / Post 51-L)
Figure 3



SECOND OPERATIONAL YEAR PLANNING

FACIL	WORK DAYS	DAYS/SHIFTS	HOURS
OPF	56 DAYS	7/3	1344
VAB	6 DAYS	7/3	144
PAD	21 DAYS	6/3	504
TOTAL	83 DAYS	249 SHIFTS	1992

FOURTH AND SUBSEQUENT OPERATIONAL YEAR PLANNING

FACIL	WORK DAYS	DAYS/SHIFTS	HOURS
OPF	51 DAYS	7/3	1224
VAB	5 DAYS	7/3	120
PAD	15 DAYS	6/3	360
TOTAL	71 DAYS	213 SHIFTS	1704

ORIGINAL PAGE IS
OF POOR QUALITY

What can be done? Each of the design disciplines, including propulsion, can develop many cost effective solutions which will contribute to the required reduction in LCC.

The following are some criteria for the propulsion system (engines, propellants, propellant supply, tankage, pressurization, TVC, etc.) that can provide a significant reduction to the propulsion contribution to operational costs of a Program. The basic objective is to consolidate, simplify, and/or eliminate functions or components. While a system may be very complex internally, the interfaces that it presents for launch servicing and support should be as simple as possible. The less care, handling, and support required at the launch site, the smaller the number of support people, equipment (GSE), and/or facilities will be required. Only in this fashion can over-all launch costs be reduced. Not just the vehicle must be simplified, the total infrastructure, and the requirements for vehicle processing operation, must be evaluated and minimized as well.

SIMPLIFIED LAUNCH SYSTEM OPERATIONAL CRITERIA

Propulsion

INTEGRATED PROPULSION SYSTEM

Simplified robust propulsion system

- Fully throttleable engines (multi-phase)
- Soft engine start
- TVC by delta thrust and/ or RCS / or aero
- One oxidizer / one fuel

ELIMINATE

- Separate OMS and RCS
- High maintenance turbopumps
- Hydraulics
- Hypergols
- GN_2 / He on-board purges
- GN_2 / He pressure systems
- Gimballed engines
- Extensive recovery & refurbishment

Selected topics from the above list will be addressed in the following discussions.

Simplified Robust Propulsion System

Operations Solution:

Simplified, integrated, robust propulsion system that, using the same oxidizer and fuel, provides the essential elements of:

Main Propulsion

Orbit Insertion / deorbit

Attitude / Rendezvous Control

Rationale:

Current propulsion systems started with an engine design , with the MPS and vehicle built around it.

There is a necessity to simplify and integrate all propulsion systems to radically minimize the ground operations and maintenance.

One Oxidizer / One Fuel

Operations Solution:

Design vehicles using only one oxidizer and one fuel; simplifying propellant procurement, transport, storage, pumping, safety equipment and procedures, and headcount.

Rationale:

Each individual propellant ground system requires expensive, hazardous facilities / GSE, and its own little army of engineers, technicians, and safety.

STS has five propellant components, each of which require separate procurement, transport, storage, pumping, GSE, safety, operational procedures, engineers, technicians, etc.

Eliminate Separate OMS and RCS

Operations Solution:

Delete OMS and RCS as separate systems from MPS.

Rationale:

If MPS can be utilized as the hot gas source for OMS and RCS, it may significantly lighten vehicle and will simplify ground support operations.

Eliminate High-Maintenance Turbopumps

Operations Solution:

The ideal solution is to eliminate high maintenance turbopumps. If turbopumps remain in the system, they must be made more robust to reduce refurbishment and maintenance requirements for recoverable stages.

Rationale:

Turbopumps are costly to develop and manufacture, heavy, run at very high RPM and pressures, and are cavitation-sensitive.

Rocket engine cost, refurbishment frequency, refurbishment cost, and test & checkout time are largely driven by turbopump sensitivity.

Pressure-fed engines with plug nozzles are a viable prospect as specific impulse is relatively insensitive to chamber pressure per se. Chamber pressures on the order of 200 psia should be investigated to lighten the tank structure and pressurization system. Multiple clustered stages may be necessary to achieve the required base/nozzle exit area.

No Hydraulics

Operations Solution:

Provide high thrust actuators for vehicle systems using some system other than hydraulic.

Rationale:

Hydraulic systems are heavy, complex, and plagued with O&M and GSE activities. They require extensive facility hydraulic systems to provide a source of hydraulic power for ground checkout of flight systems, and a separate little army of engineer-specialists, technicians, etc.

No Hypergols

Operations Solution:

Avoid use of hypergols for launch, orbital propulsion, or APU systems.

Rationale:

A very significant quantity of non-productive manhours occurs during each flow for the "area clear" required during hazardous "opening", entry, or operation of orbiter OMS and RCS systems. There is a snowballing effect in facilities and O&M requirements for special ventilation, scrubbers and a multitude of safety equipment, including a small army specially trained to do their job in SCAPE (self-contained atmospheric protective ensemble) suits. Further, a pound of hypergol costs about \$8, whereas, a LOX/H_2 mix costs less than \$0.22/lb; a LOX/CH_4 mix costs less than \$0.15/lb; and a LOX/C_3H_8 costs less than \$0.08/lb.

No GN2/He On-board Purges

Operations Solution:

Delete launch vehicle on-board GN_2 and He purge systems.

Rationale:

Subject systems add weight to vehicle and the associated electro / mechanical / pneumatic subsystems require special small O&M army and much time for ground processing and launch.

Elimination of GN2 and HE storage bottles, supply valves, manifolds, plumbing, and multiple test and checkout, will significantly lighten the vehicle, and simplify and speed-up ground support operations.

No Gimballed Engines

Operations Solution:

Devise thrust vector or vehicle attitude control systems which eliminate need for gimballed engines and associated hydraulics, seals, pivots, bellows, etc.

Rationale:

Gimballed systems are expensive, heavy, and add a severe burden of O&M, and test and checkout to ground support operations.

CONCLUSIONS

A direct frontal attack on Life Cycle Cost reduction is of prime importance to realize the potential of any conceptual future launch system.

The propulsion community is faced with a major challenge in reducing Life Cycle Costs. As engineers and managers, we are prone to look for the "elegant solution". For instance, a turbopump designer is always looking for that additional few feet of head rise while reducing the weight.

It will require a major change in "mind set" by everyone to back-off on performance requirements, thereby seeking the goal of significantly reduced ground support operations. Compromising with the "elegant solution" holds the promise of acquiring a launch system that can do the required job, is relatively cheap to operate, requires very little inspection / test, and provides a robust long useful life.

If we are to be successful in the future, the battle cry must be :

DESIGN THE SUPPORT

not

Support the Design !!