# Minimum Cost Design
# for Space Operations

**Arthur Schnitt**

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# Foreword

General Astronautics is pleased to make available to the public a series of articles prepared by Arthur Schnitt, entitled "Minimum Cost Design".

Minimum cost design (MCD) is a criteria for the design of space hardware. The criteria minimizes total program costs by trading cost, weight and reliability. The criteria differs from the more commonly used design criteria that minimizes weight and maximizes performance.

The columns dated from 1997 January 26 to 1998 June 4 were initially hosted by New Space and later by Launchspace Publications on their Web sites.

Some of the articles are commentaries, but most deal with the derivation, analytic and design aspects of the MCD criteria. The criteria is demonstrated by describing its application to the design of the MCD Space Launch Vehicle (often referred to as the Big Dumb Booster) and the Semi-Mobile Intercontinental Ballistic Missile (SMICBM). The application of the criteria to the redesign of an existing satellite is also described.

Many columns are written in story format so that the trials and tribulations Mr. Schnitt experienced in conducting this work are described for the purpose of providing a better understanding of the criteria, and the antagonistic attitude toward its use taken by the established members of the aerospace community.

Mr. Schnitt conducted his work on MCD while employed by The Aerospace Corporation. Previous to joining Aerospace in 1958, he held the position of chief structures engineer at Bell Aircraft, and was known for his cutting-edge work and publications on the subject of structures operating at elevated temperatures.

Mr. Schnitt passed away in 2010 at age 94.

January 26, 1997

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# SSTO: A Path to Minimum Cost?

This column represents two of the virtues of the Internet. First, it allows me to present new work that was previously rejected for publication by our singular professional society. Second, it allows me to widely distribute this information to a special audience where it will hopefully spark relevant discussions. I wish to thank New Space for publishing this column which I trust will serve, not only my personal interests but those of the aerospace community and the general public.

This column will revolve about a central issue. As far back as 1959, while employed by Space Technology Laboratories (split in 1961 to form The Aerospace Corporation and the TRW Systems Group) I was astonished to discover that ballistic missiles, space launch vehicles and payloads (satellites) have been and are being incorrectly designed to airplane design criteria that calls for the minimization of weight and maximization of performance. The criteria is ingrained in all aeronautical engineers, and its use results in minimizing the cost of most winged aircraft. At that time, I introduced a more appropriate criteria for the design of space systems that I called design for minimum cost, or, minimum cost design (MCD). I crudely showed that the application of the new criteria has the potential for appreciably reducing the costs of space operations.

Intermittently from 1963 to 1968 the MCD criteria, under Air Force, NASA, and contractor sponsorship, was studied by applying it to a large number of system and subsystem designs. It was also used to fabricate and test critical space hardware components. This work was performed mainly in support of two systems configured at Aerospace: the semi-mobile intercontinental ballistic missile (SMICBM, 1963) and the MCD space launch vehicle (MCD/SLV, 1965). Most of the work supported the contention that the use of the MCD criteria could reduce costs by factors ranging as high as 10 or more.

In May 1968, the Air Force program office, established to research and develop the MCD/SLV, was closed down, and all new work relative to the use of the criteria was abruptly halted. To this day the industry, the Air Force, NASA, the Congress, and the White House (sometimes referred to as the aerospace community) refuse to recognize and accept the MCD criteria.

During the interim the aerospace community has worked on many new "low-cost" space launch vehicle programs, repeated studies of some of the same concepts, passed billions of taxpayer's dollars among themselves, and has come up with no firm solution. While this has been going on, the French, Russians, and Chinese have been forging ahead, developing their own SLVs. Their lower cost vehicles (that is, lower than ours) now launch most of the world's payloads including U.S. commercial satellites. By the end of the century and into the next century, with the introduction of the Japanese SLV and the Ukrainian rocket, these countries appear destined to increase their market share.

Currently, there are two, new low-cost launch vehicle programs under study, one sponsored by the Air Force, the other by NASA. Both are worthy of a little scrutiny to see whether our principal procurement agencies are treating a serious national problem in a timely and judicious manner.

The Air Force program is called the evolved expendable launch vehicle (EELV). The program uses updated components of current vehicles and some advancements in technology. Cost savings of up to 50% are projected. The heavier-lift Atlas, Delta, and Titan vehicles are to be replaced by a new family of SLVs that will have low-earth orbit payload capabilities of 2,500 to 45,000 pounds. Nonrecurring costs are estimated at $1.4 to $3 billion. Initial operational dates are 2001 and 2002 for the medium-lift version, and 2005 and 2006 for the heavy-lift version. Operational dates are years later when the vehicles demonstrate reliable operations. If the program isn't canceled and if its modest cost-reduction objectives are met, it seems that the EELVs will be years late and, consequently, may not capture much of the world's market.

There are two developments which may occur under the EELV program that are worth noting. Rocketdyne, as part of the McDonnell Douglas's effort, may develop a liquid hydrogen/oxygen, high-thrust engine that contains 93% fewer parts than the comparable main Shuttle engine. Aerojet and Pratt & Whitney are evaluating and testing engines based on Russian technology (known for their simplicity and ruggedness) for use on Lockheed Martin's proposed EELVs and Atlas IIAR, and on McDonnell Douglas's Delta 3 SLV. I would like to think that some of the guidelines which may have been derived from the MCD criteria have influenced these efforts. Moreover, I was aghast in reading in AvWeek, February 5, 1996, p.86, "But Orbital's [Orbital Sciences Corp.] apparent desire to redesign the X-34 [essentially a test vehicle for the X-33 (see below)] to cost rather than capability has again put the project in jeopardy."

The concept NASA is sponsoring has been studied in depth several times in the past. It is another crack at the life-long dream (the original concept of the Shuttle) of a recoverable, single-stage, winged vehicle that would operate like an airliner, and mimic its relatively low operational cost and turnaround time. It is hoped that further advancements in technology will permit a reduction in payload launch costs to about

$1,000/pound, a factor of 7 to 10 less than current Shuttle costs. Estimated research and development (nonrecurring) costs vary widely from $2 billion to $15 billion. I have yet to see a published initial operational date for the vehicle, nor can I find a projected estimate of the cost of each vehicle. With the X-33, the half-scale experimental vehicle first to fly in 1999, I can only assume that the initial operational date is so far away that it can be disregarded as a competitive vehicle in the first decade of the 21st century.

I find the pursuit of the above single-stage-to-orbit (SSTO) most perplexing. Why do some aeronautical engineers persist in believing that the best space configurations should look like airplanes? As I hope to show the reader in later columns, the MCD criteria, applied to this type of vehicle, not only calls for minimum weight/maximum performance design, it also calls for large expenditures in R&D to further minimize weight, maximize performance to achieve lower overall costs. Simple physics and simple cost analyses would show that the addition of a nonrecoverable first stage would reduce costs and development time and bypass the described design and cost dilemma. But this configuration would be reverting to the Shuttle configuration, probably a step at a time, further digressing from the dream of airline operation of a single stage.

I can only come to this conclusion: the SSTO program is meant to provide employment for the more highly-trained engineers and scientists, to advance the design of high temperature structures, and to develop a linear, plug-nozzle, rocket engine. Just about everyone has been lead to believe that advancing technology is great without questioning whether their application appears promising.

Are these programs the last attempt of the establishment to stave off the acceptance of the MCD criteria and the MCD/SLV type of vehicle? Are they worried that it will cause widespread unemployment in the aerospace industry and that some work will be done by commercial industries? Have they performed an analysis to substantiate these fears? Have they performed an analysis that might show the enormous expansion of space activities if launch costs and payloads (also designed to the DMC criteria) costs are appreciably reduced? Others apparently have. Quoting from the Commentary in the January 1997 issue of *AEROSPACE AMERICA*, prepared by the co-chairs of the Third AIAA International Space Cooperation Workshop: "Immediate reductions by at least a factor of 10 are needed if a significant expansion of space activity is to be realized."

**Q & A**
**Will SSTO rocket development lead to lower cost space operations?**

These days, it seems that everyone is talking about "order of magnitude" reductions

in launch costs. The phrase rolls off the tongue quite nicely doesn't it? But I wonder if this is really feasible using today's rocket technology? Heck, I would be happy with a cost reduction of 3 or 4 times. We could do a lot more low cost space missions if our cheapest orbital launcher had a $3M price tag instead of $12M. But instead people are enamored with achieving this "order of magnitude" improvement. As Mr. Schnitt points out, this sounds a lot like the propaganda that was used to sell the Space Shuttle, and we all know how that turned out. I do believe that SSTO programs can be useful as technology development efforts, but not as the magic solution to all of our launch needs.
- Joshua Cohen
- New Space

Mr. Schnitt is quite right that minimum weight does not equate to minimum cost and this is also generally true not only for space launch vehicles but also for transport and other aircraft. The common fallacy that he describes seems to have come about due to as a result of long periods of experience with aircraft built of materials of nearly the same basic cost and quite similar fabrication cost and powered by one type of engine. As the range of materials and- in the case of space launch vehicles- engine types- has expanded,the common fallacy leads the unwary further and further astray.But aircraft design has not gone down the wrong path in recent years. The obvious example of this fact is that major fractions of aircraft structure (other than on V/TOL's, for which the cost- performance- tradeoff functions are substantially different from those of conventional aircraft) are not made with high strength/ high stiffness fiber composites as they would be if weight minimization were the driving design criterion. Thus, if the rationale for minimum- weight design of launch vehicles is supposed to be found in aircraft experience, it no longer exists. Two other recurrent fallacies that beset advanced launch vehicle design. as Mr Schnitt indicates, are that single- stage- to- orbit and maximum recoverability are inherently lower- cost solutions for space launch systems. The reasons for these assumptions have never been clear and the experience with the Space Shuttle belies their validity in general. This is not hindsight on my part. I testified to the Proxmire Committee at the start of the Shuttle program that whatever other virtues the Shuttle might have, it would never lead to lower launch costs.
- Alexander H.Flax
- Consultant

With reference to the preceding comment by Joshua Cohen, I wish to clarify the term “order of magnitude” as it was used in defining the desired reduction in space launch costs. It was a slightly more definitive term than “drastic” or “major,” and that was

the intent. No one knew how much of reduction was possible; in fact, my limited design work has shown reductions of less and more than a factor of 10. Let's take what we get when using the more rational design criteria for space hardware. It was gratifying to gain the concurrence of Dr Flax. I am appreciative of the added arguments of support he presented. It would be gratifying as well to hear from individuals in industry who are cognizant of airplane transport design. Would they be kind enough to answer such questions as: Is the airplane life cycle cost minimized on a strict basis, or, because this would result in the airplane having too high a sales price for the market place, to what extent is the airplane minimum cost criteria modified? Is the value of a pound of weight used in the airplane design? Since this value is location sensitive, is a computer program used to achieve a balanced design?
- Arthur Schnitt

February 5,1997

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## Recommended Reading

In these columns I intend to supplement two, readily available reports that discuss the minimum cost design (MCD) criteria and its applicability. I highly recommend them.

One, published by NEWSWEEK, "Big Dumb Rockets" by Gregg Easterbrook, as the cover story of their August 17,1987 issue (subsequently summarized by READER's DIGEST in their December 1987 publication) discusses some of the design issues raised by the criteria. The article also explains the economical and political consequences of the criteria on the aerospace community and how the community reacted to its introduction.

The other publication, "Leo On The Cheap" by Lt Col John R. London III, Air University Press, Maxwell Air Force Base, Alabama, October 1994, discusses the engineering problems associated with placing payloads in low earth orbit (LEO) and the work performed by industry in applying the MCD criteria to system and subsystem design. The author also provides background information on existing and proposed launch systems and the reasons why the aerospace community should accept the MCD criteria.

Nevertheless, my effort will be quite extensive. I plan to provide a description, an understanding, and the analytical derivation of the MCD criteria. I also plan to provide the thinking that led to the design of the SM(Semi-Mobile)ICBM and the minimum cost design space launch vehicle (MCD/SLV) and the analytical techniques used in configuring minimum cost systems, subsystems and components. This work will be based mostly on material contained in The Aerospace Corporation report, "Proposed Minimum Cost Space Launch Vehicle System" by A. Schnitt and Col F.W. Kniss, July 1968, and on material contained in unpublished papers and briefings. Personal experiences that may add to the understanding of the problems associated with the use of the criteria will be described.

These are the salient points made by Gregg Easterbrook, albeit circa 1987. Most of these points will be expanded upon in subsequent columns.

- It was feared that the introduction of the MCD/SLV, dubbed the "Big Dumb Booster" (BDB) might undermine Shuttle funding.
- The Soviets apparently took a low-cost approach to space, a conclusion that one

may reach by noting the many similarities that appeared to exist between what was known of their hardware and the BDB design.

- The minimum weight/maximum performance criteria was first used, perhaps correctly, in the design of our ICBMs. If there were reasons for thinking that it was the proper design criteria for ICBMs, there were no logical reasons for carrying it over in the design of space vehicles.
- The MCD analysis showed that first stages, as part of a multi-stage expendable SLV, should be the least sophisticated; and that the optimum degree of hardware sophistication increases with each successive, upper stage.
- The Saturn V moon rocket "exemplified the maximum-technology approach."
- The auxiliary ground equipment, whose cost and complexity can be greatly influenced by the propellants used in the launch vehicle, is an important element in minimizing total system cost..
- Both procurement agencies (NASA and the Air Force) and Congress like expensive programs. There is no "political payoff" in programs "designed to save money."
- The industry turned away from the BDB because embracing it would undermine their relations with the procurement agencies and undercut high-cost programs currently under contract and on the horizon, like the aerospaceplane ((now known as the single stage-to-orbit (SSTO) launch vehicle)) and the space station.
- TRW fabricated a 250,000 pound thrust, short duration, test engine (later successfully tested at Edwards AFB) for an extremely low cost. The injector design was based on the (10,000 pound thrust) LEMDE rocket engine. The LEMDE engine was used in the descent module of the Apollo moon lander...... (I selected the main propulsion engines for the BDB to be larger versions of the LEMDE because of its design simplicity, reliability, low cost, throttlability, and likely scalability to multi-million pound thrust levels-in essence, because it appeared to be the "rubber" rocket engine that fit an overall design and development plan.)
- Boeing (fully appreciative of the MCD criteria and not under contract to develop or build SLVs) recognized the potential of the TRW engine and the MCD/SLV. Using in-house funds they fabricated a stage scaled to match a 250,000 pound thrust engine to which the TRW engine was attached for exhibition purposes. However, Boeing lost interest in the MCD/SLV when "NASA and the Air Force had agreed that all future payloads would use the shuttle."
- To maximize Shuttle use, NASA obtained a monopoly in launching commercial satellites (rescinded after the Challenger accident). Since 1972, NASA "lobbied against further rocket research." In addition, industry's interest in the MCD/SLV was stifled by NASA whose stated intent was to use the Shuttle to build and

service the space station.

Col London's excellent, most comprehensive work provides relevant information, circa 1994. Selected portions of his report are summarized below. You will notice his relatively benign approach to the subject, particularly in the beginning. However, high-impact passages can be found throughout the report when he describes the political and economical pressures that thwarted the use of the MCD criteria. Remember, he was writing from within the "high-cost" side of the fence. Judging from my experiences, I did not expect the Air Force to release the final report.

- A study of launch vehicle costs shows that if these costs could be drastically reduced, say, by an order of magnitude or more, many significant programs might be realized or sustained.
- Although the U.S. has adequate launch capability, we may lose out against lower-cost, foreign competition.
- There are a number of new launch vehicle concepts under study and development, but it is wondered whether any of them can appreciably reduce cost.
- Our heritage in designing to the minimum weight/maximum performance criteria may effectively hinder a drastic change in design philosophy.
- It is a myth that space vehicles must be complicated, delicate, and costly. Launch vehicle components built in a "foundry" may be practicable and the way to go.
- The right design choices, particularly the choice of the propulsion system-the system that has the most impact on the overall vehicle design-determines whether life-cycle cost of a new SLV can compete with the recurring costs of existing SLVs.
- Finally, in 1988, some of the terminology used in the MCD criteria became somewhat acceptable in the aerospace community. The Air Force, in announcing their Advanced Launch System project (later canceled) stated that one of its objectives is to reduce costs. More specifically they stated that weight may be traded for cost in the vehicle design; this may be regarded as an significant break with the minimum weight/maximum performance criteria. This was followed in a 1989 paper given by a Pakistani who featured his (national) vehicle as having been designed to the MCD criteria. A DoD/NASA paper published in 1991 concluded that the "pathway to low-cost, highly operable space transportation" essentially lies in adopting the MCD criteria.
- There is a strong link between the cost of an SLV and the complexity and cost of the payload it carries. As launch cost in \$/pound of payload decreases, so can the payload cost decrease and the reliability increase. (In later columns I plan to show

this relationship graphically and explain how a designer can approach the payload design problem analytically.)

- Nevertheless, there is not much enthusiasm for minimum-cost launch vehicles as exemplified by NASA's and the Air Force's sponsorship, respectively, of the SSTO and the EELV programs. (See Column dated January 26, 1997. NASA hopes to achieve low operating costs by advancing technology while the Air Force is relying mainly on existing technology except for a few components that are apparently designed to guidelines derived from the MCD criteria.)
- After reviewing the numerous SLV system studies currently being performed by major aerospace contractors and newly organized companies, all using the MCD criteria, Col London issues a clarion call, a plea, to those responsible for policy to fully and quickly accept the MCD criteria. He further calls for the design an MCD/SLV using current technology.

As indicated earlier, these columns will provide the analytical tools and the design methodology-although they were published in 1968 but perhaps in too much of an abbreviated form-that will better explain the MCD criteria, and hopefully, inspire its use.

**Q & A**

**Do government agencies such as NASA and DoD have a preference for high cost programs?**

Having read both the Easterbrook and London references that Mr. Schnitt cites, I have to agree that the U.S. government has failed to make any significant headway toward truly low cost space programs, especially in the realm of launchers. Rather than subscribing to some kind of conspiracy theory, I just think that a lot of inertia, built up in the previous 30 years of programs like Apollo, Shuttle, and Space Station, makes it difficult to adopt new design criteria overnight. It may be many years before NASA can say that its programs are, for the most part, designed to cost. In the interest of speedy progress, I would advocate a "spreading of the space dollar" to other agencies that could create space programs without 30 years of NASA baggage dictating design criteria. For example, suppose the Dept. of the Interior were funded to create an earth resource monitoring system. Results might be much quicker and more useful than what is going on with NASA's mission to planet earth.
- Joshua Cohen
- New Space

Looks great Arthur. Keep up the good work!!

- Chris Largent
- CSUN

I see that Joshua Cohen objects to “subscribing to some kind of conspiracy theory” on the part of the aerospace industry in not reducing costs, but rather attributes it to “inertia” resulting from 30 years of experience that “makes it difficult to adopt new criteria overnight.” Well, Mr Cohen, let me disillusion you. As far back as the early sixties, when the aerospace industry was relatively minuscule, MCD was rejected because “too many programs were set in concrete.” As time went on, there were more programs but more concrete. Obviously, that was not the issue and is not the issue today. There are no agencies questioning the government trough worth billions of dollars from which the “iron triangle” (not my term) feeds. How knowledgeable has Congress been about the issue? Permit me give you one, documented example. On July 8, 1989, Sen John Glenn was interviewed by John McLaughlin on the “One on One” PBS (TV) Program. In answer to the question, “Isn’t this the age of the big dumb booster?” Sen Glenn replied, “No. We based our space launch vehicles on our ICBMs......which were based on high technology.......which the Soviets do not have....” In the subsequent discussions Sen Glenn promoted the Space Station. When John McLaughlin brought up the age of the big dumb booster again, Sen Glenn avoided discussing it further.
- Arthur Schnitt

Thanks Chris. Keep up with your studies.
- Arhur Schnitt

Just an update on the paper "Proposed Minimum Cost Space Launch Vehicle System" by A. Schnitt and Col F.W. Kniss, July 1968. This paper is not available from The Aerospace Corporation anymore. Instead they direct you to the Defence Technical Information Center (DTIC 1-800-CAL-DTIC; 225-3842). The ordering number is AD395911. The Cost is $6.00
- Scott Pearson

Conspiracy may be a strong word, but it probably fits the bill. There has been case after case all through the government and big business of this type thing going on. It comes down to this, If its not your money, you tend to spend it rather freely!!!! After being a consultant for a few years, I have been shocked at what companies will spend their money on, when they could have spent a fraction of the amount and done the job themselves... It appears that American Aerospace companies do not want routine access to space because routine leads to mass production, which leads to competion

and lower margins. R & D and limited production for a contractor means high margins and big profits. Since corporations tend to only look at Quarter to Quarter numbers 'routine' does not add to the bottom line, so they have very little interest.
- Scott Pearson

Scott Pearson: This pertains to your first comment. Before I listed the report in a Column, “Proposed Minimum Cost Space Launch Vehicle,” I checked with the Aerospace Library to learn of its availability. I was told that a written request for a copy would be directed to the Air Force for their approval. Approval time would take about 30 days. There would be no charge for the report. It seems that Aerospace decided not to supply free copies anymore. Sorry for the inconvenience. Other readers interested in obtaining copies will appreciate learning of your experience. Thanks. This pertains to your second comment. Gregg Easterbrook and Col London laid out the whole story, told of all the work performed by industry and NASA in checking my work, and talked about the political and economic forces involved, and nothing happened. I concur with all you say. I plan to tell of some of my own experiences with agencies of the government in the Fall. Although we are in dire need of SLV’s to launch the many commercial satellites that are being planned (and also could reduce the cost of the satellites as well) the return on the investment is so great that again there is little interest in saving money on a new breed of low-cost SLVs.
- Arthur Schnitt

Apparently I spoke to soon when I earlier wrote that the DTIC would provide a copy of the Mr. Schnitt's report....... Later in the day after I ordered it, I received a phone call informing me that since I was not a government employee or an employee of a government subcontractor, I could not have a copy. I even tried to use the phrase "Freedom of Information Act", but to no avail. I believe earlier we were speaking of conspiracy...Hum... - Scott Pearson

Scott Pearson: Am sorry to hear that you are unable to obtain a copy of my (Aerospace/Air Force) report. I do not have the fortitude to argue with the DTIC at this time. However, if you or others wish to do so, you might tell them that the first unclassified and unrestricted disclosure of the MCD criteria and the Aerospace/Air Force MCD/SLV design was made at the SYMPOSIUM OF INTERNATIONAL ACADEMY OF ASRONAUTICS DURING the XXIV INTERNATIONAL ASTRONAUTICAL CONGRESS held in Baku, the Soviet Union, on October 1973, by Gerry W. Elverum, Jr. of TRW, the inventor of the LEMDE engine that so completely meshed with the MCD criteria and the resulting design concepts. The title of the paper was “SCALE UP TO KEEP MISSION COSTS DOWN.” Remember:

TRW had complete access to my work, and they also conducted a study of the MCD criteria and an MCD/SLV design for NASA that was published in 1969. The Aerospace/Air Force report was not declassified until about 1980. Moreover, Col London's report is a complete synopsis of the MCD criteria and all of the applicable work performed by industry under Air Force, NASA, and in-house sponsorship—a most informative contribution. If you are particularly interested in applied Calculus you may find my report of value; otherwise, most everything is available in unclassified and unrestricted literature.
- Arthur Schnitt

Mr. Schnitt, I have gotten a copy of the NEWSWEEK article "Big Dumb Rockets". I must say OUTSTANDING!!! This should be required reading for anyone studing space policy. It's also nice to be able to put a face to someone I have read about and E-mailed... I have also gotten a copy of "Leo on the Cheap", also OUTSTANDING!!!... One item I noticed that was missing in the report was any mention of OTRAG. This is or was a German company formed in the 70's that had a rocket based on MCD. One difference that stands out was they had all 3 stages essentially of the same design and used small engines, which I would say would not make the most cost effective rocket but may allow a company to get in the business with the lowest up-front cost. The last I heard was the company had gotten into political problems since they were dealing with several 3rd world countries as well as some type of German cruise missle scandal. Mr. Schnitt, have you ever heard of this company and if so, what do you think of their design. If not, I would be happy to give you all of the information that I have... Looking forward to your September writings. Thanks.
- Scott Pearson

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# The Genesis

About August 1959, when I completed an assignment on the Minuteman ICBM program, I was asked to devise a means of reducing the cost of space operations by about an order of magnitude. I was cautioned that concepts that show a 20 to 30% cost savings, an amount statistically less than the usual overrun, would not be taken seriously. I was sympathetic with the project but not optimistic about its accomplishment.

Although this occurred at Bell Aircraft several years prior to this point in my employment at Space Technology Labs, I still carried the feelings of disappointment and frustration I experienced when I learned how expensive it would be to launch the boost-glide (BOMI) vehicle we had worked on for several or more years. Unless a better way was found, I too was convinced that space operations would be limited by excessively high costs.

I was given one idea to start: recover the Titan first stage by having a helicopter snatch it before it crashes into the sea. At that time helicopter snatching of jettisoned reconnaissance satellite capsules was a successful technique; and Sikorsky was developing a very high-load capacity crane, large enough to carry the spent Titan stage. I also asked several of the staff for ideas. Almost everyone suggested recovery of part or all the hardware as the most promising concept to pursue. At first glance it seemed that the goal might be met by successfully recovering all the hardware perhaps only 20 or 30 times. "Fly-backs," or winged recoverable stages, were considered to be the promising concept for total hardware recovery.

In studying the snatching of the Titan first stage, I found that adding minor-weighing frills to the stage in order to make it flat-spin in, would make the concept feasible. The stage would then be subjected to low dynamic pressures and negligible aerodynamic heating, and arrive at the snatchable altitude at a low-enough speed. A rough cost estimate, however, showed that the concept fell far short of the goal. Various concepts for retrieving the second stage, protected against the thermal and aerodynamic loadings of reentry, were briefly studied and found not at all promising on a cost basis.

I then examined recoverable, winged stages. Those were the days of the slide rule, and only rough calculations of the back-of-the-envelop variety were possible.

The concepts, of which there were many variations, turned out to be sure losers when total life-cycle costs were considered, that is, the sum of the nonrecurring and recurring costs for the life of the program.

I recall having only one concept left that warranted study. I can trace the origin of the concept to my training and experiences, particularly my experience on the Minuteman program. We often used the "exchange ratios" for the missile as design guidelines in minimizing weight and maximizing performance. These ratios related the burnout (essentially hardware) weight and the engine specific impulse of each stage to the weight and velocity (or, range) of the payload.

Since maximizing the weight of the payload and increasing its range were desired objectives, it had the effect of stimulating the need for decreasing weight and increasing engine efficiency almost regardless of the added cost. Although the burnout weight and the engine efficiency of the first stage had the least influence on the payload weight and its velocity, all stages were designed to have the same level of high sophistication. Every pound of structural weight removed and every point in specific impulse gained in any stage were considered rewarding.

I subscribed to this design approach. I seriously thought that perhaps we were spending too little funds advancing technology. More specifically, I felt that if we learned how to further minimize hardware weight and increase propulsion efficiency to some higher levels of sophistication, the sought after cost reduction might be achievable. I thought I might be able to devise an exploratory analysis that would show that advancements in technology are needed. The analysis I subsequently prepared gave surprising results; it lead to the minimum cost design criteria.

To conduct an exploratory analysis of this nature it was necessary to make rather sweeping, yet reasonable assumptions. The major assumption was a definition of the relationship between hardware cost and weight. In formulating this relationship I assumed that all weight was designed by pressure loads since the tanks and engine represent almost all of the inert weight. Additional, minor assumptions were made, and these may be found in The Aerospace Corporation report, "Proposed Minimum Cost Space Launch Vehicle System," by A. Schnitt and Col F.W. Kniss, July 1968.

I used only two points to define the cost-weight relationship that I intuitively felt was exponential-that pressure vessel cost increases exponentially with decreasing weight. I learned that the basic Atlas and Titan propellant tanks cost about $100/lb. I knew from my experience at Bell Aircraft, in deriving design and testing criteria for high-pressure airborne pressure vessels, that commercial tanks built to ASME codes have a factor of safety of 4.3, can be pressurized an infinite number of times, are fabricated from very ductile materials, operate at relatively low stress levels, and cost $1/lb in steel and $3/lb in aluminum.

A graphical presentation of the relationship is shown in the figure below.

Hardware cost on linear and log scales are related to the operating stress level given in thousands of pounds per square inch (ksi) in steel. Note that the operating or working stress level is the inverse of hardware weight. The expected optimum regime is shown to be somewhere beyond the current, minimum weight state-of-the-art.

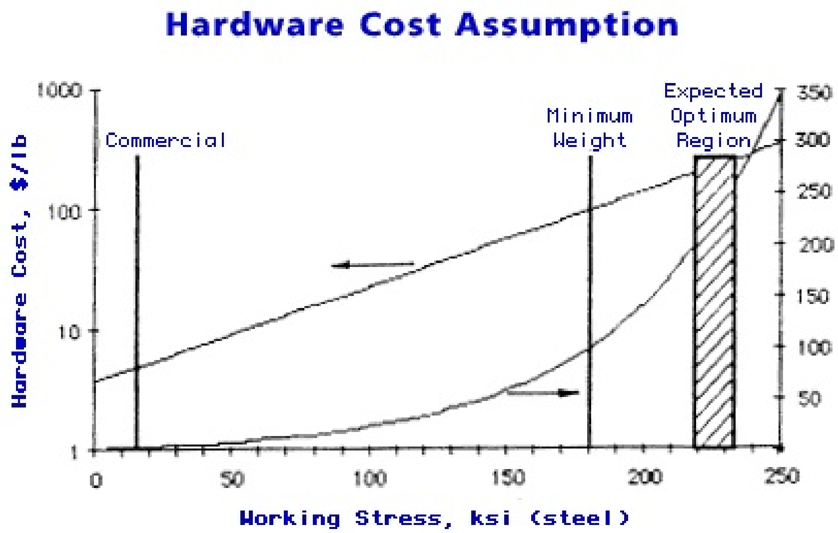


Figure 1. Hardware Cost-weight Relationship.

The hardware cost-weight relationship was introduced into the ideal rocket equation: $V = I_{sp}\, g \ln (W_i/W_{bo})$, where

$V$ = stage incremental final velocity, feet/sec.
$g$ = gravity constant, 32.17 feet/sec. squared
$I_{sp}$ = specific impulse, sec.
$W_i$ = initial vehicle weight, lbs
$W_{bo}$ = burnout weight, lbs

The hardware cost in the resulting equation was differentiated with respect to payload weight. The resulting expression was equated to zero, and the optimum hardware cost in \$/lb was calculated.

The inceptive analysis considered only a first stage. The initial vehicle weight was the takeoff weight of the total vehicle. The burnout weight was the weight of the stage before being jettisoned plus the weight above it, or, the takeoff weight less the weight of the fuels consumed by the first stage. In treating a first stage, the payload weight is the weight above the first stage.

The first stage of a typical three-stage, expendable, liquid-fueled vehicle designed to reach low earth orbit (LEO) was studied. Losses due to gravity and aerodynamic drag were accounted for in estimating the ideal velocity of the stage at burnout. An average $I_{sp}$ was assumed, as well as the hardware weight as a fraction of the stage weight. The optimum cost of the hardware was calculated at about $4/lb. Correspondingly, the reduction in stage cost was huge although it grew somewhat in size. This unexpected, incredulous answer led me to conduct a parametric analysis from which it might be possible to understand and rationalize the validity of the result. A range of values of each variable in the ideal rocket equation was considered.

I had the support of a team of people filling out table after table-work that now can be done in relatively little time by a programmable hand calculator. The thought that if the analysis is correct and we have indeed been designing space vehicles "to play in the wrong ballpark" was indeed stimulating. Had I hit the jackpot in finding the solution to the cost problem?

**Q & A**

**How much of total launch cost is dictated by hardware?**

I imagine that the launch operations and non-hardware is the largest portion of the total cost, but I am interested in what you assumed for the initial BDB studies, and what the actual statistics are. Your story is fascinating, and I am looking forward to future columns.
- Leon Bush
- Retired

I appreciate your comment, Mr Bush, but when the life cycle cost of the total system shows that the cost of the space launch vehicle does not dominate, the application of the MCD criteria will still result in very large savings. As explained in the March 4, 1997, Column, application of the MCD criteria to the vehicle and payload designs includes the cost and weight tradeoffs between the vehicle and payload and all other elements of the system. Reliability, which has not been addressed as yet in the Columns, would be included in the tradeoff analyses.
- Arthur Schnitt

March 4, 1997

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## Results of Parametric Analysis

The exploratory analysis discussed in the previous column, and its extension to upper stages and payloads, were described in three Aerospace Corporation reports. Besides estimating the optimum hardware costs of upper stages, these reports provided the results of the parametric analyses of the optimizing equations, the rationalization of the results, and some design implications.

Although the first two reports, each carried the title, "Cost Optimization of Large Booster Systems," dated November 1959 and July 1961, were not approved and released, the third report, "Proposed Minimum Cost Space Launch Vehicle System," July 1968, incorporated significant material discussed in the unreleased reports. The third report is available from The Aerospace Corporation and contains much of the work, some in greater detail, that will be discussed in these columns.

For those concerned with the political aspects of this work: since minimum-cost launch vehicles may continue to be unwanted by the aerospace community, the second report was reviewed for technical accuracy by three, outside consultants. In my mind this was a delaying action by management since the report had received the usual internal reviews. When the consultants submitted their reports in which they expressed whole-hearted agreement and I pressed for release of my report, I was told to drop the project.

I quit Aerospace in August 1962 and accepted employment as a consultant to the new NASA Associate Administrator for R&D; he was one of the consultants who reviewed my report and believed that NASA would greatly benefit from using the MCD criteria. My assignment was to brief personnel at Washington Headquarters and Wernher von Braun's team in Huntsville to gain their concurrence. (I plan to cover this experience in a later column.) After many months of waiting for a reaction, I was told that NASA programs are too far along to permit making a far-reaching change in design criteria. Not able to secure employment in my former discipline of structures with some of the local, prime aerospace contractors, I returned to Aerospace in May 1963. I was assigned to the ballistic missile division.

I was indeed surprised when, after several months, I was asked to design a survivable ballistic missile weapon system using the MCD criteria. Several years later I was given another assignment: apply the criteria to an MCD space launch vehicle, and after that, to a redesign of an existing payload. Between these programs I worked on the "high-priced line" in the Titan III program office where I gained valuable, relevant experience. It is noted that the released report also contains a description of the MCD/SLV design.

The parametric analysis, initiated in the first report, led to the following conclusions:

- The cost of typical, multi-stage, expendable space launch vehicles could be appreciably reduced.
- The optimum hardware cost, in \$/lb, increases with each upper stage; that is, the optimum sophistication of the second stage is higher than that of first stage, and so on with each, successive upper stage. However, the final stage that reaches LEO should have a lower sophistication level than current hardware.
- Lower values of specific impulse increases optimum hardware cost.
- Minimum-weight, expendable stages that have high structural factors do not lend themselves to much in cost savings when designed for minimum cost.
- The optimum sophistication of a single stage increases rapidly (more quickly with a flyback stage that has a higher structural factor) as its velocity approaches that required for LEO; therefore, in the interest of minimizing cost, at least two stages are called for in reaching LEO.
- Considerable R&D is required to devise new forms of hardware that range in cost, in \$/lb, from close to commercial to near the state-of-the-art of aerospace hardware. This calls for the development of an array of materials, forms of construction and fabrication techniques, together with appropriate manufacturing facilities and the methods of transportation to the launch site. Research and development may be required to increase the current level of hardware sophistication for very high-velocity missions.
- Kick stages, which impart small, incremental velocities to payloads, should use unsophisticated hardware because the increase in stage weight is negligible.
- It is not clear whether MCD pressure-fed or pump-fed propulsion systems would be less expensive. A design example of a simplified, higher-weight turbopump should answer this question.
- Payloads should have the same sophistication level as the final stage. It should be realized that in the boundary condition, when launch costs approach zero, payload costs could approach zero as well.
- It may be economical to recover a first stage if this can be done by simple means and if only minor refurbishment is necessary. If this could be devised, the cost-optimum velocity of the stage should increase as well as its sophistication level, particularly if propellant costs are significant as a result of reuse. If

recovery significantly lowers the stage cost, the sophistication levels of the upper stages and payloads should be somewhat less, thus providing additional cost savings.

- It would be uneconomical to retrieve and reuse stages that reach orbital velocity. Such stages, because they carry recovery gear and hardware to shield against the thermal and aerodynamic environments, must be designed for minimum weight. These hardware configurations would result in much high costs than achievable by simple, expendable stages.
- Most importantly, in designing a launch vehicle for minimum nonrecurring and recurring (life cycle) costs, all elements of the complete system including such items as facilities, operations, readiness, and reliability must be considered simultaneously. This is in contrast to the strict design of a minimum-weight launch vehicle that, by definition, need not be related to the rest of the system.

Several **design implications** have been derived from the parametric analysis:

- MCD launch vehicles, of the same basic design, should be manufactured in a variety of sizes. An easily scaleable propulsion subsystem could make this possible.
- Minimum cost payloads may be more efficiently designed if such a family of launch vehicles exists. It would provide assurance of the existence of a launch vehicle large enough to carry the final design that generally experiences weight growth.

The results of the parametric analysis were **rationalized** as follows:

- Consider a first stage. If one pound of weight is added to the stage to reduce its hardware cost in $/lb or to increase its reliability, the weight of the stage must increase by more than one pound in order for the stage to have the same performance. Say, the weight increases by a factor is five; this is known as the "growth factor." It is composed of the added pound of weight and four pounds of incremental tankage, propellant, and other subsystems. Since hardware cost is many times more than propellant cost in $/lb, it is reasonable to expect a minimum-cost stage to be slightly heavier but cost much less a minimum-weight stage.
- Consider a second stage. If the growth factor of the second stage is the same as the first stage, a pound of weight added to the second stage will increase the weight of both stages by a factor of 30. This explains why the optimum sophistication of a second stage is somewhat higher than that of a first stage.

- It follows that subsequent stages and payloads should be designed to higher levels of sophistication.

A graphical representation of the optimization procedure for upper stages and payloads will be presented in a subsequent column.

In 1962, while waiting for NASA's decision on whether they wished to pursue the MCD criteria, I prepared a paper in which I fully described the criteria and its application. The paper was submitted to the AIAA for publication and it was rejected.

**Q & A**

**Based on the criteria above, what do you think an ideal minimum cost vehicle would look like?**

Shooting for the lowest $/lb leads one to think about larger and larger vehicles. But when I think minimum cost, I think small. After all, a Big Dumb Booster that lifts 100,000 lbs to LEO is still going to cost a lot of money, even if it is super cheap per pound of payload. Given the rapid advances in microelectronics technology, I think it makes more sense to build the smallest possible vehicle. If my cost cap for a launcher is $1M, then maybe I can only figure out how to lift 10kg to LEO using minimum cost design principles and off the shelf technology. Fine. My laptop weighs less than 10kg and does a lot more than the average satellite.
- Joshua Cohen
- New Space

I plan to describe a minimum cost SLV in a later Column. If advantage is taken of the attributes of a rugged design in simplifying structure and in reducing weight, the SLV is not much larger than one designed for minimum weight. Today's method of estimating costs is to use CERs, or cost estimating relationships. These relationships essentially assign fixed costs that are multiplied by vehicle component weights. If you assume this approach to be valid, then smaller vehicles will cost less. These relationships are valid only when one designs essentially the same subsystems to the minimum weight criteria. Electronic components are the only hardware elements that get smaller, weigh less, and increase in reliabiliy with time. These characteristics do not apply to other hardware elements. Hence, a laptop computer cannot be compared with the major components of a payload.
- Arthur Schnitt

Excellent. BDB is one system. I would be rather keen on the good ole' SASSTO, with a potentially low structural cost and partial to complete re-usability. Read Niven

Pournelle & Flynn's 'Fallen Angels', and/or Gatland and Bono's 1974 book 'Frontiers of Space'. Almost anything is better than flying a bathroom to orbit, wasting fuel on a lot of wings. Maybe fine for military missions, but not to get the ordinary bloke into orbit. I bags the janitorial franchise on the first decent space-station.

- Richard Edkins
- Richard Wordsmith

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## The Minimum Cost Design Criteria: A Description

Design criteria are the values or limits given a set of parameters by which system hardware is selected and designed to best satisfy a given mission. In the design of most transport vehicles to specified performance, operational requirements and constraints, the basic irreducible parameters appear to be time, cost, and loss of human life. The ideal design would minimize all three parameters but it is apparent that they cannot be minimized at the same time. Constraints may specify the importance of one parameter over the others, or specify a limiting value to one of the parameters. Often other criteria parameters are used; such as factor of safety, reliability, readiness, testing requirements and (hardware) life, but they can always be reduced to these three parameters.

Factors of safety are used to account for unknowns in the loadings to which the vehicle will be subjected, for unknowns in the environment in which the vehicle will operate, and for variations in strength or performance of the vehicle and its components. The magnitude of factors of safety effect reliability which in turn can be related to cost and loss of human life. Analytical procedures for deriving factors of safety have been proposed, but it is believed that the practice of using traditional factors will continue as long as there are advanced missions and innovations in technology. Whenever feasible, derived relationships between factors of safety and cost, and factors of safety and reliability would represent powerful design tools.

Aircraft are designed essentially to the minimum weight criteria. Many design iterations have shown that its use results in a minimum cost vehicle. The criteria, however, may sometimes be constrained by such factors as sales price and modified by operational considerations such as ease of refueling. In certain designs, minimum weight, like reliability, is a convenient substitute criteria for cost. Very often it pays to spend large sums to advance the state-of-the-art in minimizing weight. Of course the least costly way of manufacturing minimum cost hardware is generally sought and employed. On rare occasions during detail design, weight is traded for cost, using an arbitrary or "calculated" value of a pound of weight. (Example: An unnecessary pound of weight can be removed from a fuselage bulkhead by more intricate machining at a cost of $300 per airplane. If this cost is less than the value of a pound of weight, the more intricate machining is approved.)

Designing aircraft to a substitute criteria and subjugating costs has been quite convenient; however, it has had negative consequences. Designers have become better at estimating weight than cost. Although there has been a history of weight growth, cost growth has often been much larger. There are other hardware systems for which reliability or life is the substitute design criteria, and neither weight or cost is justifiably given much consideration.

There is another design criteria concept worth noting that may be useful in the design of small components of an aerospace system. It is impractical to proof or static test complete civil engineering structures such as buildings and bridges. (Some suspension bridges are now model tested in a wind tunnel as a consequence of the failure of the Tacoma bridge due to flutter.) Instead, large factors of safety are used to insure structural integrity.

At the time these observations were made (1960-62) there were no published analyses that proved that aircraft, ballistic missiles, space launch vehicles or space payloads should be designed to the minimum weight criteria. (No literature search on this design aspect has been conducted since then; however, it appears that only small deviations from the minimum weight design criteria have been proposed.) The apparent reasons for the universal adoption of the criteria have been somewhat different for each vehicle type, although the designers felt assured that they were designing minimum cost vehicles.

In the design of most aircraft the desire to attain maximum performance and payload for available propulsive power led to the minimization of hardware weight. In addition, since typical aircraft growth factors range from 10 to 20, each pound of weight saved represented a saving of 10 to 20 pounds of which a large fraction was hardware weight. Commercial transports had the added impetus to reduce fuel costs for the expected life of the airplane. Under the usual assumption that hardware costs in $/lb were essentially fixed, smaller aircraft meant lower fabrication costs.

In designing our first intercontinental ballistic missiles (about 1955 to 1960) more emphasis was placed on minimizing weight in order to maximize payload weight and range. In one instance, there was the added constraint of vehicle size to facilitate transportability. However, there is no evidence that the designers had the slightest suspicion that the minimum weight criteria may not apply for this vehicle type.

The early space launch vehicles were adaptations of ballistic missile stages. It did not take long before payload requirements became too ambitious; this resulted in extremes in payload weight minimization and sophistication of structure and components, and low reliability. Meaningful cost constraints were lacking.

During 1960, '61 and '62, there were six publications known to me that discussed deviations from the minimum weight design criteria. None of the papers disputed the minimum cost design criteria, but they did employ limited cost-weight tradeoffs.

They discussed the following:

- Breakeven cost-weight relationships for solid rocket motors.
- Selecting solid rocket motor materials and propellants on a cost basis.
- Reducing the cost of space operations within the limits of current technology.
- Whether our current approach to vehicle design leads to the optimum program.

The last discussion is contained in Wernher von Braun's paper, "What is an Optimum Program?" Astronautics, Vol. 5, No. 11 (1960). The paper is consistent with what I learned when I visited Huntsville while I was a consultant to NASA (please see Column dated March 4, 1997). More specifically I was told by his design team, headed by H.H.Koelle, that at some point after the start of the Apollo program, von Braun seriously doubted the appropriateness of the minimum weight criteria. He dropped pursuing an alternative because of the disruption it would cause. His attention was re-focused on hardware reliability.

There are several perceptions upon which the MCD criteria is based:

- Most hardware, having the same function and performance, can be designed to a wide range of weights as determined be the selection of materials, tolerances, factors of safety, fabrication and inspection procedures, etc. Generally, hardware cost increases rapidly with decreasing weight. Costs reflect total system and life cycle costs. In essence, cost may be traded with weight.
- Reliability can be increased by using larger factors of safety, designing simpler and/or more rugged components, introducing redundancies, engaging in environmental test programs, increasing quality control, conducting R&D programs on new components that potentially have greater reliability, prolonged prelaunch checkout, etc. Each item represents either an increase in hardware weight or cost or both. It is equally evident that reliability can approach unity as expenditures approach infinity. Furthermore, reliability can be appreciably increased by the addition of small weight increments.
- To design to minimum weight, maximum reliability and minimum cost simultaneously are incompatible requirements. Since cost is the basic parameter to be minimized, tradeoffs should be made between cost and reliability, and reliability and weight.

**Q & A**

**Do you have any experience trading Minimum Weight vs. Minimum Cost Design?**

Having been a structures designer and having asked management "do you want it cheap or light" I have found out many things about costs. An expensive machined part will often be cheaper than a built up sheet metal part when you take into account the assembly costs of the sheet metal parts. The flight structures are way cheaper than the systems (guidance, engines, pressurization). Absolute Minimun Costs carries at least a 100% weight increase. For a tank, you want to have minimal machining, which means no ribs and frames, which means fully monocoque structure and heavy structure. To further cut down on costs, no testing, which means a F.S. of 2 for limit vs a tested F.S. of 1.1 on limit. So as you well know, you have one curve for material cost (heavier vehicle means more material and with a fixed material cost per pound, any pound of weight as cost) including bigger engines, and another curve for machining and assembly and test costs vs weight and where they cross, you have your cheapest vehicle.
- David Pearce
- Lockheed Martin Astronautics

David Pearce: This is in reply to your comment... I appreciate learning what you think of Minimum Cost Design even though it is in disagreement... I believe that if you were to check with experienced designers they will tell you that in most instances machined parts cost much more than ones that can be fabricated from sheet metal. However, this is an inapplicable argument since the tradeoffs analyses between weight, cost and reliability should tell you whether a sheet metal or a machined part is cost-optimum for a particular application...The MCD criteria applies to all subsystems including those you mentioned. I tried to explain this in the “Design Examples” which follow...I don’t know what work you have done to support your contention that a minimum cost vehicle will weigh twice as much. In my experiences, I found the weight to be less than 25% more; please see the May 29th Column...I believe you are subscribing to the contention that the cost of hardware is a constant (as one might conclude from the CER relationships commonly used) and that increasing hardware weight increases cost. Of course the MCD criteria obviates the use of CER relationships.
- Arthur Schnitt

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## Methods of Design Analysis

Until the Big Dumb Booster was designed in 1965, the method of design analysis envisioned was exceedingly complex if not unworkable. To be sure it would have required many more manhours than a system designed to the minimum cost/maximum performance criteria, at least initially. Cost, weight and reliability relationships of each subsystem for a spread of sophistication levels, together with relationships to account for subsystem interactions, would be prepared. Life cycle costs consisting of R&D, Production and Operations would be estimated. Perhaps more than one basic design might be under consideration such as, pressure-fed and pump-fed, liquid propellant propulsion systems. An extensive computer program would perform the optimization process.

The computer program would have defined the minimum cost vehicle and its reliability as well as the weight, cost and reliability of each subsystem, and the system life cycle cost. This methodology made the critical assumption that the required relationships are continuous and could be prepared even for new forms of construction, materials, etc. Moreover, the procedure would have given designers little visibility. Computer solutions, checked by design layout, would require repeating the entire procedure. Defining a practical methodology was viewed as a perplexing, unresolved problem.

Faced with the task of designing a space launch vehicle to the minimum cost design criteria in a period of several months, a simplified method of design analysis was quickly devised. (A deadline is a superb stimulator!) It permitted stages and payloads to be treated as separate entities, thus breaking down the design problem into more manageable proportions. The basic procedure is explained in Figure 2 in a simplified manner by ignoring the many details involved.

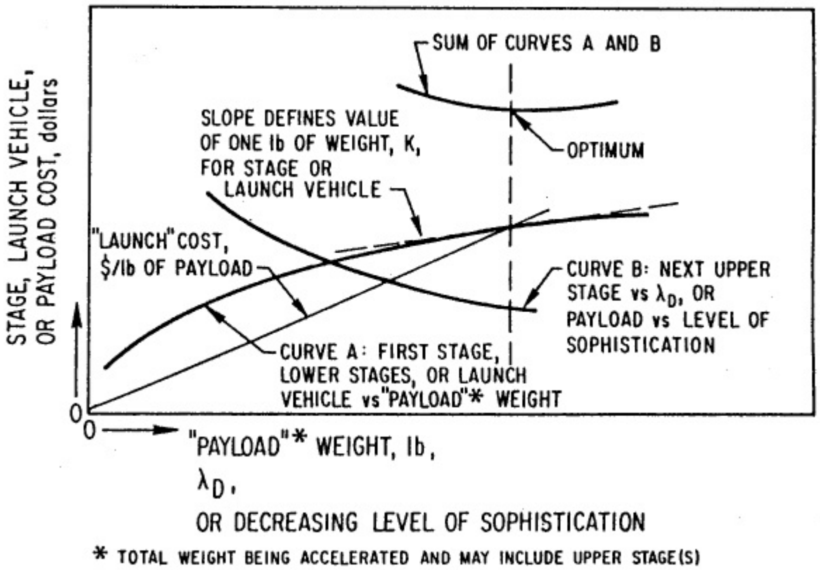


Figure 2. Stage, Launch Vehicle, Payload Optimization Procedure.

Consider Curve A to represent a family of cost-optimized first stages that achieve a given burnout velocity and reliability in terms of cost and the "payload" weight the stage carries, where "payload," in this instance, is defined as all weight above the first stage. The optimum size of the first stage is determined in conjunction with the optimum sophistication of the second stage. The second stage is depicted as Curve B. Curve B represents the cost of the second stage plotted against $\lambda_D$, where $\lambda_D$ is the ratio of stage burnout weight to used propellant weight.

The optimum size of the first stage and the optimum degree of sophistication of the second stage occur when the local slopes of Curves A and B at the same payload weight are equal and opposite or, in effect, when the sum of Curves A and B is minimum. The positive value of the slope is defined as K, and it is the value of a pound of weight in the second stage. As explained later, K is used to permit finalizing the second stage design in an iterative manner. The same procedure applies to all higher stages and payloads. Note that the value of K increases with each, successive stage.

Thereby Curve A can represent two or more stages for the purpose of designing the next, upper stage or the final stage and payloads. This infers that payloads are designed to the same sophistication level as the final stage. It is also noted that the value of a pound of payload weight for design purposes is always somewhat less than launch vehicle cost in $/lb of payload.

Parametric analysis, employing current values for weight, cost and reliability are generally used to identify the "ballpark" design. The design is then defined through iteration using the breakeven relationships between the various design parameters. Breakeven relationships are relatively simple to derive for a first stage, and are obtained by taking partial derivatives; however, the same procedure proved unmanageable in treating higher stages.

In treating higher stages only the breakeven relationships are between cost and weight, and specific impulse and propellant cost are considered, since the values for cost and weight should reflect tradeoffs with reliability previously conducted. Consider the cost-weight breakeven relationship that is universally applicable and is related to K. By inspection, when $w_B > w_I$:

$$c_B w_B = c_I w_I - K(w_B - w_I)$$

where,
$w_B$ = breakeven weight. lbs
$w_I$ = initial weight, lbs
$c_B$ = breakeven cost, \$/lb
$c_I$ = initial cost, \$/lb

In Figure 3 the above equation is plotted for a large range of $c_I$/ K values. The figure shows that when the ordinate parameter is about one, there is a good likelihood that it might pay to decrease weight of the ballpark design in order to decrease cost. Furthermore the figure shows that when the parameter is near 100, which generally corresponds to relatively costly and low-weight components, it would probably pay to increase weight almost indiscriminately to effect a cost reduction.

Thus a designer of a subsystem need only be given the value of K and the reliability goal in order to finalize a minimum cost design. In achieving the reliability goal he also may have to simultaneously refine the cost-reliability and cost-weight tradeoffs, perhaps with the help of specialists in the area of reliability.

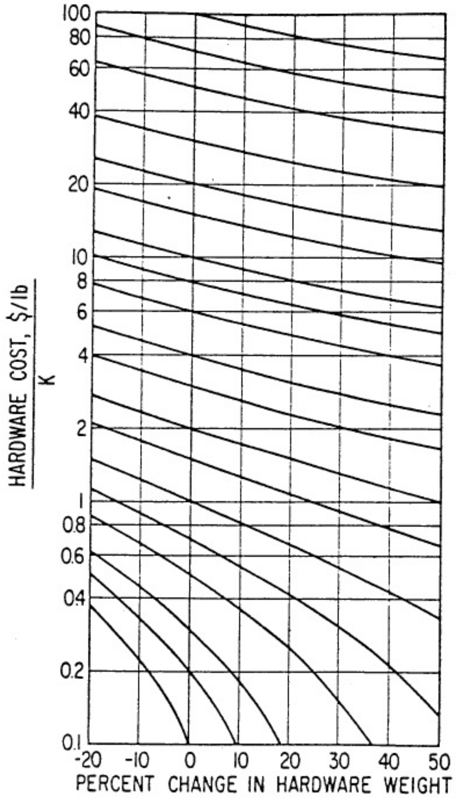

Figure 3. Hardware Cost-weight Breakeven Relationships.

Such analytical simplicity was not achieved with the specific impulse versus propellant cost breakeven relationship. The introduction of the K parameter, however, did reduce the complexity of the partial derivatives. The relationship, applicable to any stage, may be found in The Aerospace Corporation report, "Proposed Minimum Cost Space Launch Vehicle System," by A. Schnitt and Col F.W. Kniss, July 1968, p 2-17.

At times it may be more convenient to determine the optimum hardware in a manner described schematically in Figure 3, particularly in the design of payloads. Figure 4 displays an array of designs of a subsystem or component, each having the same performance and reliability.

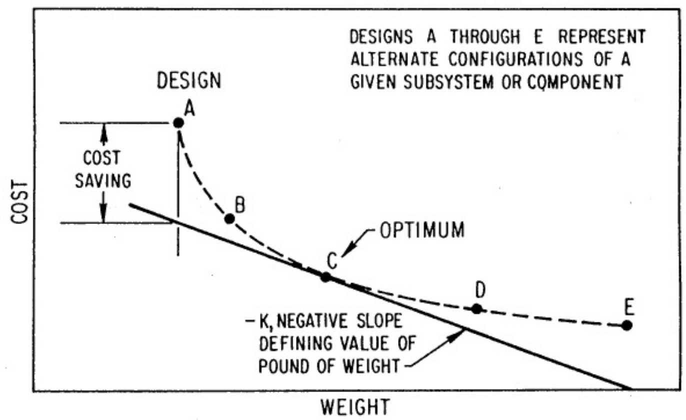


Figure 4. Technique for Selecting Cost-optimum Hardware Design.

Design A may represent the minimum weight, current aerospace industry type of hardware while Design E may be called the "cost-end-point" design since its main consideration is minimum cost though it may be heavy and large in volume. Generally, several intermediate designs are feasible and can be sketchily defined.

It is suggested that the designer display on the graph the negative value of K previously determined for the stage or payload under design iteration. (See Figure 3.) By so doing, the designer might be able to more closely estimate the location within the spectrum (Designs B, C and D) where further design efforts should be concentrated. This technique is a graphical presentation of the breakeven equation previously defined. The cost saving in comparison with the minimum weight design may be estimated as illustrated.

The previous approach to payload design infers that there is a close match with an available launch vehicle of the required weight capability. If this is not the case, and the singular launch vehicle has a larger or smaller payload capability by a significant amount, the optimization parameter K can be raised or lowered to fit the launch vehicle capability. By employing this technique it is evident that a more cost-balanced payload design would cost less.

Consider another payload/launch vehicle mismatch condition. In this case the singular launch vehicle can carry multiple payloads. The payload optimization procedure could employ the full value of K as determined by the launch cost per pound of payload without incurring a significant loss in being off-optimum.

In the case when there is a singular launch vehicle available to carry a singular payload, there is no apparent payload design cost-optimization procedure. It is suggested, however, that the major, more important components of the payload be designed first, using the full value of K as determined by the launch cost per pound of payload. Any payload weight still available would then accommodate the other payload requirements. Never, or hardly ever, should the cost of the main components be raised in cost and reduced in weight to make room for the lesser payload objectives. An easily prepared analysis would be able to prove this.

**Q & A**

**How do today's computer capabilities affect space launch vehicle design analysis?**

A most interesting site and a fascinating problem. Pure layman guesses :- (1) Capability now of inputting very large numbers of factors for virtual testing of designs without flight-testing. (2) Ruggedised screen displays can replace instrument panels, so enhancing displays and overviews of flight-profiles. May reduce launch control complications. (3) Programme and system updates can take place in the software environment, so extending the lifetime and mission-complexity of existing systems.

- Richard Edkins
- Richard Wordsmith

April 10, 1997

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# Design Example: The SMICBM

Picking up on my personal saga last described in the first few paragraphs of the March 4, 1997, Column, and recalling my experiences at Aerospace, it seems that my work assignments were programmed by some invisible and unknown Aerospace or Air Force authority until I retired on January 1, 1981.

When I returned to Aerospace in 1963, I was assigned to the Ballistic Missile Division located in San Bernardino, an entity separated from the main operations in El Segundo by about 80 miles. I was given the job of heading a department composed of several disciplines; I remember that two of them were reliability and reentry vehicles. I was on this assignment about three months, perhaps enough time to become familiar with the technologies associated with intercontinental ballistic missile systems, when I was asked to design a survivable intercontinental ballistic missile system in accordance with the MCD criteria.

I begged off from accepting the new assignment, explaining that the development of the MCD criteria had caused me no end of grief, and problems with top management if not with the entire aerospace industry. Several days later I was again asked to take on the assignment. This time the importance of this assignment was explained with the argument that "the Navy is walking away with Polaris." In addition, I was assured that I will be treated differently, that I would get a team of seasoned designers to work with me, and that I could confer with specialists throughout the company on an as need basis. It seemed that I had no choice but to accept the assignment. Besides, I sensed some inner voice telling me to go for the opportunity to apply the criteria, and I wondered what an MCD-designed system would look like since my analysis told me it would look differently.

I was given about three or four months to complete the assignment. Initially I examined R&D and operations (cradle-to-grave) costs of existing ICBM systems. I was much surprised to learn that the bulk of the system costs was in operations. This, coupled with the belief that a "bare-bones" solid rocket booster, unconstrained by weight and volume limitations, could be made very cheaply, led me to envision a "shell game" basing concept as most promising.

In this scenario, multiple ICBM housings, or "silos," would be built, and only one in many would contain a complete, higher cost missile. The high-cost missile component and other system elements that would comprise a functioning missile would be surreptitiously moved at intervals from one silo to another. Under perfect conditions, all silos would represent legitimate targets.

The following description of the system studied, the SMICBM, does not disclose details that do not contribute very much to the understanding of the application of the MCD criteria to the system design. Sensitive aspects such as why the system is survivable, the vital system command & control and the security measures proposed are not discussed.

Among the first tasks undertaken in formulating its design was an analysis of the viability of the basing concept. The analysis contained multiple parameters representing all the system elements. Assigning likely ranges of values to these parameters showed that the system was very viable. After the second or third progress report briefing was presented, an analytically inclined Air Force colonel confronted me with a recent, unpublished RAND Corp. report that showed that shell-game basing was much less cost-effective than other means of achieving survival, such as hardened silos, for instance. After some frantic effort, I showed that both analyses were identical, and that the RAND report reached its conclusions by only applying typical, minimum weight/maximum performance costs to the system elements, while I used much lower costs as a consequence of designing to the MCD criteria. This incident illustrated that expectations based on experience may be misleading when the MCD criteria are applied in designing a new system.

The ultimate design criterion was considered the maximization of the ratio of the destruction cost to the deployment cost of the system. Hence, the design objective was to minimize the denominator while accounting for the composition of the threat. This led to the conceptual design of the following system elements. As already indicated, all elements were optimized essentially in unison and subjected to tradeoffs, particularly design and cost interactions.

Silos, hardened to a low overpressure, had the configuration of partially buried Quonset huts. They were spaced about a mile apart so that the majority of single enemy warheads could destroy only one silo. Each silo contained a veritable "dumb" booster that incorporated only the ignition system for the solid rocket motors, and an air-conditioning system. The boosters had no size or weight constraints. Their only requirement was to propel a "payload" weight a given distance – with a comfortable margin – at minimum cost; hence, the rocket casings, propellant, nozzle design, and other components were at the discretion of the contractor. The booster might have had a simple suspension system to absorb ground motions, if one were found necessary. The top of the booster was approximately flush with the floor of the hut. The optimum spacing of the silos and their degree of hardening was determined by the system optimization analysis.

An upper stage, called the "integrated payload package" or IPP, composed essentially of a reentry package, vehicle guidance and thrust vector control systems, was installed only on a small fraction of boosters. A portable auxiliary ground equipment (AGE) unit that monitored the IPP and hut operating systems, and provided the command and control link, accompanied the IPP. The fraction of complete vehicles was determined by a cost analysis that found that about only one missile in ten should be "live". The missile got part of its name (Semi-Mobile) from the fact that only the IPP and AGE were moved from silo to silo on a random basis, probably not too often, and after they were sometimes processed through a depot-type facility. Only commercial-type, small-size trucks were used. Few depot facilities were necessary. The computer-based operation of the system and the efficiency of the depot-type facilities promoted low manpower requirements and low-cost operations.

The system was very well received by Air Force and Aerospace management, and study contracts were issued to industry. Hughes Aircraft was awarded the system study contract. Boeing studied the design of the IPP. Several propulsion contractors studied the booster design, and these studies included pressure-fed, liquid stages. This was the first time industry was exposed to the MCD criteria. I did not get a chance to witness their reactions.

These contracts were hardly underway when I was asked to return to the El Segundo facility and work on the preliminary design of the Titan III B. My job was turned over to a very hard-working individual who was assured that I would be available for consultation and visitations with him as necessary. In addition to telephone conversations, I did meet with him about every ten days. After about two months, my supervisor informed me that I would be "wasting my time" continuing to work on the SMICBM. I recognized that the project was doomed and would be canceled.

Many months later I received a urgent call from my replacement. He visited me and told me with great distress that the general officer in charge of the Ballistic Systems Division called him into his office and told him that he is canceling the project because it would not employ very many Air Force personnel that will be available to him. I confessed that I knew this would happen and assured him that it wasn't any fault of his.

About the time the SMICBM was first proposed to the Air Force, and for several years thereafter, there was a rash of contractor proposals on various shell-game systems and other survivable concepts. Every concept used a complete ICBM, of course designed to the minimum weight/maximum performance criteria. They were transported about on huge, special-purpose, multi-wheeled vehicles, sometimes on a continuous basis, sometimes between special garages where they were parked for a random period of time, or run around specially designed racetracks. Or the missiles were encapsulated and moved submerged within a gridwork of canals. The system that received the most study had missiles moving about on the existing railroad system. Some time along the line it became known as the MX Missile project. The final basing mode placed the missiles in hardened silos. It seems that after many years and many billions of dollars spent, the RAND Corp. survivable basing analysis prevailed. Thus deception-basing concepts were relegated to the junk heap.

Occasionally and for many years later, I would get together with several members of my SMICBM design team to discuss the various survivable basing concepts as money was lavished on industry to study them. We concluded that all concepts would have cost many times more than the SMICBM and would have taken much longer to R&D and install. Those concepts that used the shell game had to assume the ratio of live-to-dummy missiles since no back-up analysis for determining this ratio was ever made. We concurred that the most labor-intensive concept was railroad basing, and facetiously wondered why this was not accepted as the final system.

May 1, 1997

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## Design Example: The MCD/SLV

I spent a little more than a year working in the TITAN space launch vehicle program office, first on the preliminary design of the TITAN III B and then on more advanced concepts and subsystems when, about mid-1965, I was asked to design a minimum cost design space launch vehicle (MCD/SLV).

Working in the TITAN program office was excellent preparation for this new assignment. Among the very many aspects of the design and operation of SLVs, I learned of the detail design, history and developmental problems of solid, liquid, and hybrid rocket propulsion systems, particularly their efficiencies, propellant choices, development times, costs and reliabilities. When visiting contractor facilities - and this included manufacturers of other than TITAN SLVs - I was often successful in finding those individuals who were overall system designers from whom I was able to gain some of insight into their design thinking, and learn of the problems encountered in development and fabrication.

During this time period, I ran across several reports prepared by propulsion contractors who were under subcontract to Hughes on the SMICBM program (the subject of the April 10 column). It was my impression that there was a lack of interest in designing anything meaningful. Definitely there were no attempts made to originate engine designs that might appreciably reduce cost and increase simplicity, ruggedness and reliability. No follow-up work was conducted by the contractors; when the SMICBM program was terminated, contractor interest in minimum cost design ceased as well.

I do not plan to describe as much of the MCD/SLV as contained in The Aerospace Corporation report, "Proposed Minimum Cost Space Launch Vehicle System" by A. Schnitt and Col F.W. Kniss, July 1968, copies of which may be obtained by written request addressed to Aerospace. What I do plan to provide is how I applied the results of the parametric analysis, how I proceeded with its design, where I obtained much of my information and help, and my reasoning in reaching certain design decisions.

From rough-cut cost and stage weight analyses, I made an early decision to use two stages to LEO, thereby accepting a slightly higher gross weight than that of a 3-stage vehicle. Since the first stage would be rugged and the major cost segment of the SLV, I planned to recover it at sea. I knew I should pay about $6 a pound for the basic, Stage 1 hardware, such as, tankage, propellant ducting, and combustion chamber shell. The cost of Stage 2 basic hardware was about $30 a pound, but this value was considered flexible because multiple system interactions were influencing its optimum value.

My initial hardware decision was to choose liquid rocket propulsion. It was an easy choice over solids and hybrids. I considered propulsion to be the key subsystem because I felt that its design strongly influenced the selection of most other vehicle components and subsystems. In examining the weights of existing turbopump-fed liquid engine subsystems, I was surprised to learn that the advertised low weight-to-thrust ratios for minimum weight design liquid rocket engines did not exist in reality because of the relatively large amount of propellants trapped in the turbopump, in the propellant ducting, and in the piping, at stage burnout. This revelation prompted me to consider higher weight, simpler, pressure-fed systems as an initial choice.

I planned to use the same TITAN SLVs hypergolic propellants in both stages. It would certainly lower launch costs. Of more importance, the propellants are storable at ambient temperatures and are compatible with steel that I valued as a low-cost construction material. (Several years later, these propellants were classified as environmentally undesirable and became extremely expensive.)

The parametric analyses showed that, in order to realize minimum payload cost as well, a family of MCD/SLVs should be developed that has a wide range of payload weight capability. In order to minimize R&D costs, the vehicles should be scaleable to the fullest extent possible. This meant that the propulsion systems should be scaleable, but did not necessarily imply that upper stages of large vehicles would be used as first stages of small vehicles.

I had set aside the use of strap-on stages as being structurally inefficient and costly. This meant that the first stages of the larger vehicles would be too large to be manufactured in current aerospace industry production facilities. This restriction on production facilities was not considered detrimental because large first stages would have near-commercial construction.

I had learned that "shower-head" type of fuel injection engine configurations usually led to high development costs and time with each attempt at scaling to higher thrusts. The intricate, small, multiple fuel injection orifices were considered a "show-stopper" to designing for minimum cost. What was needed was an easily fabricated engine with large fuel injection orifices that is also scaleable, say, from several thousand to several million pounds of thrust. A small loss in efficiency might well be tolerated.

At the time I shared an office complex with the head of the liquid propulsion department in the TITAN office. I described my propulsion requirements to him. He identified the TRW LEMDE pressure-fed engine that was used in the Apollo program as the most likely candidate. He reasoned that it would probably lend itself to scaling to multi-million pound thrusts since the current 10,000 pound engine was capable of being throttled to 1,000 pounds. We contacted the designer of the LEMDE engine at TRW, and he concurred with our thinking. His extended cooperation and assistance was further stimulated by the fact that he was acquainted with the analytical work leading to MCD and was an ardent adherent. With the promise of a scaleable engine, I concluded that a single engine per stage would result in much simplification and weight savings.

Having established this keystone subsystem, I proceeded to define a conceptual design of the SLV. Because of the time constraint to produce a minimum, or a near-minimum cost design of appreciably lower cost than current vehicles, I did not attempt to conduct elaborate tradeoff analyses. Instead I selected what I judged might be the optimum subsystems, feeling that tradeoff analyses should best be performed as part of the R&D program.

A critical example of consequences of this design approach was the selection of a pressure-fed propellant subsystem. There was a small group of propulsion specialists at Aerospace who had performed sufficient work on the design of a much simplified turbopump (of slightly higher weight) to believe that a pressure-fed propellant system would be cost-optimum. From what I have read of developments under the current Air Force EELV program, a simplified turbopump of this description has been developed. The Aerospace group may have indeed been right 30+ years ago.

Another critical design decision was the propellant tank material. Steel was judged to be least costly provided it had sufficient tensile strength and the weld strength would not be less than that of the basic material. I called upon friends at the Battelle Memorial Institute to advise me. They suggested HY-140, a steel used by the Navy in the fabricating the hulls of advanced submarines. Indeed, abiding by the parametric analysis, a large first stage should more resemble a submarine than an aerospace-typical structure and be more compatible with sea recovery.

The tank thickness required to sustain the propellant pressurization was considered sufficient to permit simplifications that would result in major cost and weight savings. For instances, a common bulkhead was used between tanks, and the single engine was bolted directly to the bottom of a tank.

"Main Tank Injection" was selected as the subsystem for pressurizing the tanks. In this subsystem the fuel was injected into the oxidizer tank while the oxidizer was injected into the fuel tank. The hypergolic property of the propellants caused minor explosions that produced hot, pressurizing gases. Further developmental tests yielded inconsistent results, and was the project was dropped. In the work subsequently done by others in designing an MCD/SLV, other pressurization subsystems were proposed which were considered to be satisfactory, such as, a simplified hot gas generator.

With the contents of the Aerospace report, previously identified, available to industry and NASA during its preparation and certainly after its release, there was a flurry of activity by industry, the Air Force and NASA. Several industry activities were supported with internal funds. Other activities were supported by the Air Force and NASA. Many of these activities will be described in the next column.

May 15, 1997

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# Design Example: The MCD/SLV Continued

There was another reason for providing only a cursory description of the MCD/SLV design in the previous Column, and omitting discussions of many of the subsystems. A more comprehensive description did not seem warranted because the design was developed more than thirty years ago and much of it is considered obsolete. I am sure, by incorporating aerospace and commercial technology advancements, superior minimum cost vehicles can be designed today.

An example of new technology that may drastically reduce the size, cost, and weight of the MCD/SLV was suggested by a NASA representative at the "Workshop on Low Cost, Low Technology Space Transportation Options." (The workshop was held in 1987 and was sponsored by the Office of Technology Assessment (OTA), the technical arm of Congress.) He suggested changing the main structural material from moderately high-strength steel to filament wound S-Glass/Epoxy. I know of no follow-up work on his suggestion. Perhaps better choices of materials exist today. (I plan to discuss OTA's activities in connection with the MCD criteria and the MCD/SLV in one or more future Columns.)

In mid-1965, as the design of the MCD/SLV was coming together, the work in progress was briefed informally to the Air Force and industry. The local Air Force, the Space and Missile Systems Organization, supported by Aerospace under contract, were quite enthusiastic about the work as well as several industry companies, namely TRW and Boeing. NASA initially showed curiosity and later made a formal effort to learn more about the activity by contracting TRW to do an MCD study. Most of the remainder of industry offered or provided little support, and a few were outwardly hostile.

MCD and its potential for reducing the cost of space operations became a popular subject of papers and after-dinner speeches delivered by Air Force colonels and general officers. TRW and Boeing studied the derivation of the MCD criteria and the methods of design analysis. They also studied, fabricated, and tested the engine and propellant tanks. A small stage was fabricated for display purposes.

TRW, using in-house funds, built and successfully test-fired an engine rated at 250,000 pounds of thrust at their San Juan Capistrano rocket test facility. The engine was throttled to 50,000 pounds to stay within the structural limits of the test facility.

It was checked for combustion instability, the big bugaboo in liquid rocket engine development. C*, the symbol for combustion efficiency, was measured at 95%. The test also demonstrated a factor of 50 in the scalability of the LEMDE injector, corresponding to a thrust range from 1,000 to 50,000 pounds. TRW estimated the cost of the program at $60,000, an uncommonly low figure for an aerospace program of this content.

There was an amusing but instructive side to this program. TRW farmed-out the fabrication of the engine and its supporting structure, less the injector that they fabricated themselves, to a "job-shop," commercial steel fabricator located near their facility. The contract price was $8,000. Two TRW executives visited the facility to observe the fabrication process. They found only one individual working on the hardware, and when queried, he did not know nor care that he was building an aerospace rocket engine. This encounter was told and retold to emphasize the vast dissimilarity with typical aerospace attitudes and procedures.

TRW later received an Air Force contract to provide an engine for test at its rated thrust of 250,000 pounds. The test was successfully conducted at their rocket test facilities at Edwards AFB.

I had arrived late to witness the test, and only saw the firing. I was told by others who witnessed the entire test procedure that the engine was pulled out of outdoor storage where it lay unprotected against the elements. Before it was placed on the launch stand, the test crew dusted off the desert sand that had clung to it. This unplanned inclusion of a bit of an environmental test also demonstrated hardware ruggedness of the kind no other liquid rocket engine could approach.

Boeing most thoroughly reviewed the analytical work that led to the MCD criteria and the minimum cost methods of design analysis. They showed intense interest and agreement, and presented the work in a briefing to their management. It was given the (Boeing) name of "SCOT," for "System/Subsystem Cost Optimization Technique." Subsequently, they engaged in an extensive and significant role: they showed that propellant tanks and a stage can be produced at very low cost. The costs incurred by this effort were borne by Boeing.

In checking practice against theory, the initial step taken by Boeing was to have a commercial tank manufacturer (Dixie Steel) build a propellant tank of HY-140, the prescribed material, to tighter than commercial tolerances. The tank cost was on the order of several dollars per pound. Boeing production engineers witnessed the entire fabrication process, and made note of the tooling and fabrication techniques used. When the engineers returned to home base they designed their own tooling and fabricated the same tank for less money. To Boeing and all who knew of this sequence of events, the estimated cost and feasibility of the MCD/SLV gained much credibility. The tests demonstrated that even in small quantity, production costs could be quite low.

Following this, Boeing fabricated a stage of the unrecoverable configuration, sized for the 250,000 pound thrust TRW engine. The last time I saw the stage was at TRW's San Juan Capistrano test facility – more about this later.

Sometime in 1968, NASA awarded a study contract to TRW to design an MCD/SLV, including the design of all major subsystems; such as, the gas pressurization system, the thrust vector control system, the guidance system, and the launch facility including operations. The scuttlebutt was that NASA issued the contract to learn what the Air Force was up to and what the MCD criteria is about. My work as a consultant to NASA on DMC seemed to have made no lasting impression.

Early in 1968, the Air Force started to gear up to form an office to research and develop the MCD/SLV. I was completing the paper, "Proposed Minimum Cost Space Launch Vehicle System," when I became aware of political forces coming into play. My supervisor told me of Aerospace's hesitancy in releasing the report, and that I should make Col Floyd Kniss, the Air Force head of the MCD/SLV program, a co-author; this would permit the Air Force to release the report in case Aerospace failed to do so. Recalling my past experiences with the political/economic forces that arose when the customary way of doing business appeared threatened, I gladly added his name. It saved the paper but it did not save the program.

The Bidder's Conference to kick-off the R&D program was held in the auditorium at Aerospace on 24 May 1968. All of the usual aerospace contractors were invited. In addition, upon the suggestion of Col Kniss, I added several commercial fabricators to the invitation list who might, in this instance, become members of the aerospace industry. They were those who had assisted me with my work by supplying information and data; such as, American Bridge and Iron (a US Steel subsidiary) and Pittsburgh Des Moines Steel. The invitee list was made available to all attendees as part of the handout. I overheard several negative comments by representatives of aerospace companies about commercial companies attending the briefing.

The handout stressed the fact that the two cognizant offices at Air Force Headquarters in Washington had not yet given their approval of the program. It also asked the recipients of the handout, which contained a preliminary work statement, not to divulge its contents to outsiders, particularly the press.

I found the handout, which I did not see previous to the briefing, quite disturbing. My biggest disappointment came when I heard Col Kniss start the briefing by saying: "Gentlemen, the gravy train is over!" It produced a huge moan from the audience, then mutterings and a shuffling of bodies. From my past experiences with MCD, I feared the collective power of the industry. At that moment I felt that all may be lost.

My intent was to further the industry, not to diminish it. No one saw it that way. Unfortunately, very few see it that way even today.

About one week later, the program office was shut down. Col Kniss was given an immediate assignment in Paris, and I was banished to "Siberia" (from my perspective) within Aerospace. In fact, I was instructed to sever all communication on the subject of MCD with anyone within Aerospace, in the industry, and in any governmental agency. I was cut-off from the MCD studies that were currently underway and those that were planned to be conducted during the following several years. I was also told that after these studies run their course, MCD and the MCD/SLV will become mute subjects.

After the shutdown, one significant follow-on study was conducted by Aerospace, and many others were performed under Air Force contract or by industry using in-house funds. I plan to comment on these studies, relying upon information obtainable from the open literature. Also, I plan to report on the results of MCD studies of hardware elements other than the MCD/SLV; these studies were conducted during 1966, 1967, and part of 1968. I further plan to describe my experience in attempting to design an MCD payload and of TRW's successful effort.

**Q & A**

**Can anyone pinpoint the institution that killed MCD and the MCD/SLV? Should it be revived in the light of the large number of US commercial satellite programs and foreign competition in launch vehicles?**

I would like to say thank you Mr. Schnitt for this column. It is very informative and inspiring. It also unfortunately shows how the government and people can negatively react when someone starts "rocking the boat". How does Robert Truex's Sea Dragon concept fall into the history of MCD? Thank you,
- Scott Pearson

Scott Pearson: This is in reply to your comment and question...Your comment is gratifying and very much appreciated...With respect to your question, sometime in the 60s I learned of Robert Truax and that he was thinking along the the same lines as the MCD criteria. At that time he was head of advanced planning (if my memory serves me correctly) at Aerojet General. I invited myself to visit with him and learned what he had done experimentally and his views toward design. He was using some of the concepts upon which the MCD criteria is based. We had several subsequent visits. As I stated in the Aerospace report, “Proposed Minimum Cost Space Launch Vehicle System,” p. 3-17, I considered the first stage of an advanced version of the MCD/SLV to be sea recoverable, as “suggested by the ‘Sea Dragon’ study (Ref. (5).”

The reference describes some of Truax's work. I am still a proponent of the cost-effectiveness of this approach and I hope that some organization makes use of his knowledge and experience.
- Artthur Schnitt

May 29, 1997

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## Additional Studies of the Application of the MCD Criteria

As forewarned, MCD and the MCD/SLV slowly faded from the scene and became mute subjects about 1970 as far as Aerospace, the Air Force, NASA, and the major industry contractors were concerned, except in one, or perhaps two, instances. A singular Air Force sponsored study took place in 1980, and MCD appears to have influenced the design of a launch vehicle configuration that competed in the current EELV program; see Column dated January 26,1997 .

The Air Force program office for the development of the MCD/SLV ceased to exist on or about June 1, 1968, soon after it announced the start of the "MCD Feasibility and Study Phase." However, a portion of the office remained. Its duties were to conduct in-house studies of the MCD/SLV, coordinating with the Air Force Rocket Propulsion Laboratory at Edwards AFB, and manage existing and any further contracts with industry. The Aerospace personnel who assisted in these efforts were former members of my team.

Between 1966 and about 1970, Aerospace and nearly all major industry contractors studied the MCD/SLV and the MCD design of SLV components. The work was performed under in-house sponsorship and under contract to NASA and the Air Force. Many of these studies are briefly reviewed. These studies are in addition or supplement to the Aerospace, TRW, and Boeing work described in previous Columns. They show the scope and extent industry participated in the understanding and application of the MCD criteria. Those studies in which I played an active part are identified by a double asterisk (**). Since I was officially out of the loop as of June 1, 1968, the information that I am reporting on, conducted after that date, was obtained from not-to-many reports and briefings passed to me by sympathetic individuals, and from the excellent research performed by Lt Col London; see Column dated February 5, 1997 .

**Cost Effectiveness Studies of Solid Rocket Motor Stages.****

A simplified MCD analysis identified and redesigned those subsystems of the TITAN IIID, 5-segment motor strap-ons that would result in a more uniform degree of sophistication among components and a reduction in recurring costs.

The MCD analysis was used to calculate the dollar values of a pound of weight and a point of specific impulse of each stage. It showed that a new propellant of higher density, specific impulse and cost would not be cost effective if used in any of the Minuteman ICBM stages.

**Cost Effectiveness Study of the Structural Design of a "Large Diameter" TITAN Stage 1 Core.****

In the proposed configuration, the diameter of the Stage 1 core, enlarged from 10 to 15 feet, supported four, rather than two, Aerojet engines. The Martin-Marietta design followed the same construction, load paths, materials and fabrication processes as used in the TITAN III family. The Aerospace design replaced the high-strength aluminum alloy tank skins, heavily machined to provide integral longitudinal stringers and thickened weld edges, with a ring-stiffened, lower strength aluminum alloy sheeting of high weld strength. The airframe weight increased by 7.2% while the recurring costs decreased by more than 50%. The tank skins were no longer scratch sensitive. It was suggested that a small increase in burn time be used to compensate for the increased tank weight, although the decrease in payload weight would be negligible. The reduction in recurring costs in program management, engineering, inspection, etc., was identified.

**Cost Effectiveness Study of Pressure-Fed, Liquid Strap-ons.****

Pressure-fed, liquid propellant strap-ons, designed to match performance and abide by the vehicle and handling constraints of the proposed 156 inch, 3-segment solid rocket motors, were estimated to cost more than 50% less. The nonrecurring costs were not estimated but were obviously appreciably less. As recorded by Lt Col London, TRW extended this study in October 1968.

**Study of MCD Upper Stages for Synchronous Equatorial Missions.****

Procedures for designing MCD stages traveling from a low parking orbit to the synchronous equatorial orbit were defined. A design example showed that a pressure-fed, storable, bipropellant stage was far more cost effective than an advanced pump-fed, oxygen/hydrogen propellant stage, although the specific impulse of the latter propulsion system was approximately 50% higher. The study also showed that the stage should be relatively sophisticated even when launched by an MCD/SLV.

**Methodology for Propellant Tank Material Selection Under the MCD Criteria.**

This study, conducted by the Materials Laboratory at Aerospace, provided a procedure for selecting minimum cost propellant tank materials. The parameters considered were the requirement for non-destructive testing, fracture toughness, weld efficiency, and material and fabrication costs. (Ref: "Designing Cost-Effective Pressure Vessels Based on Fracture Mechanics," L. Raymond, Proceedings of the Second International Conference on Space Engineering.)

**TRW Activities**

*NASA Sponsored Study of Low Cost Launch Vehicles (discussed in the May 15,1997 Column). Completed in June, 1969.*

This comprehensive and detailed study, defined by NASA as part of the National Space Booster Study, employed the MCD criteria in designing a family of low cost launch vehicles. The final configuration differed somewhat from Aerospace's design. The recurring cost was estimated at about one-fourth the cost of current launch vehicles. Special note was made of the following facts: payload costs far exceed launch vehicle costs, and payload costs may be appreciably reduced by designing to the MCD criteria and launching them on an MCD/SLV.

*Air Force Sponsored Study of MCD/SLV Configuration Equal to the Shuttle in Payload Weight Capacity. Completed in 1980.*

The vehicle configuration was an enlargement of the vehicle designed in the NASA study. The estimated recurring cost in production, having a payload weight of 65,600 pounds to LEO, was estimated at less than $1,000 per pound. It was reported that augmenting this study was opposed by NASA and certain members of Congress. The results of this study were reported publicly by D.E. Fritz and R.L. Sackheim at the AIAA/SAE/ASME Joint Propulsion Conference held in 1982.

**Aerospace Activities Subsequent to June, 1968.**

The major design activity was requested by the Air Force: configure a new baseline design of a family of MCD/SLVs, taking advantage of past and current industry studies. Parallel staging, using 2 and 4 strap-ons, were computed to be cost-optimum, obviously a configuration the aerospace industry could handle and whereby the commercial industry could be excluded.

**Boeing Activities.**

The initial, in-house, study evaluated the Aerospace MCD/SLV design. They called their slightly modified configuration COLV, for cost-optimized launch vehicle. This configuration was used in the display stage to which the 250,000 pound thrust TRW engine was attached.

**Air Force Sponsored "Minimum Cost Design Launch Vehicle Design/Costing Study," awarded in 1969, completed in 1970.**

Martin-Marietta, McDonnell Douglas, and North American Rockwell competed for this contract. Boeing's dominant design feature was to configure the propellant tanks as spheres rather than cylinders with dome ends, maintaining the Aerospace design feature of common bulkheads between the fuel and oxidizer. The configuration traded a small loss due to increased aerodynamic drag for an appreciable decrease in tank weight. The initial configuration did not include strap-ons; however, the final configuration used parallel staging as used in Aerospace's baseline design. Launch costs ranged between $700 and $1100 per pound of payload to LEO, depending upon the payload weight configuration. The Air Force program office applied the MCD criteria in devising the management plan for the development of the vehicle.

**Martin-Marietta Activities.**

From 1965 on, Martin-Marietta, the manufacturer of the TITAN series of SLVs and most affected by the procurement agencies acceptance of MCD, closely tracked Aerospace's MCD activities. They conducted parallel studies on nearly all items, particularly the MCD/SLV that compete with the TITAN series. They found the advanced version of the Aerospace MCD/SLV, in which sea recovery of the first stage further reduced recurring costs, particularly worrisome. There were instances where the study results did not agree, but the disagreements were always resolved.

**Other Major Contractor Activities.**

The following major, aerospace contractors studied the MCD/SLV in-house to various depths:

- Space Division of North American Rockwell Corporation
- Space Division of Chryster Corporation
- McDonnell Douglas

**Tour of TRW Capistrano Test Site on September 30, 1969.**

The Air Force invited me to attend a meeting that was billed as "Orientation Tour of Minimum Cost Design (MCD) Booster Hardware at the TRW Capistrano Test Site." I secured permission to attend. The meeting was attended by about 30 Air Force and 6 Aerospace personnel. The tour was actually a "wake" mourning the demise of MCD, and the closure of MCD and the myriad of studies it initiated. The display booster stage that Boeing built, to which TRW attached the 250,000 pound engine, was on display near the rocket test stand. I asked a TRW staff member what it was doing there and he related the following story.

For many months they had tried to get President Nixon to visit the facility and have him see the stage. Given the opportunity, they planned to brief the definition of

MCD, and inform him of the many millions of dollars industry has spent in corroborating the criteria and the large, potential reduction in space costs. The enticement for his visit was for him to play "astronaut" in the lunar module descent and landing simulator located at the test site. They were unsuccessful in persuading his scheduling secretary to include this visit as part of one of his west coast tours.

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# MCD Payload Studies

In the fall of 1967, when the conceptual design of the MCD/SLV was essentially complete, I was asked to drop the program management long enough to answer these questions:

- Could you provide an example of a payload designed to the MCD criteria?
- Would MCD payloads represent large cost savings?
- If payloads are designed to various levels of sophistication, how should discrete designs be matched with launch vehicles that have different payload weight capabilities?

The vice-president of the satellite division at Aerospace was alerted to my assignment. I briefed him and his staff on the MCD criteria and how I thought I might proceed in answering the questions asked of me. Their response was quite encouraging. They agreed with the MCD criteria and the value of the mission, and expressed their willingness to assist me in accomplishing it. It was suggested that I study a particular satellite whose design was nearing completion and, as a consequence, the analyses performed in selecting the subsystem designs were fresh in the minds of the program staff.

When I bunked in at the program office I was given a stack of reports to read that described the satellite in detail. It soon became apparent that I was dealing with a huge, complex, military satellite that contained a large optical and other sensors, and many electronic subsystems. In analyzing the satellite I learned that at least one-third of the satellite weight was in structure, and I felt that I could rely upon my discipline of structures in dealing with this component. However, I needed the staff to help me better understand the remaining subsystems so that I could work with them in designing alternative configurations of higher weights and reliabilities and lower costs.

Such help and cooperation were not forthcoming. When it became clear that I would not receive the support of the program office staff, I reported the impossible situation to my supervisor. Instead of demanding the program office to cooperate with me, which he could have done by virtue of his position, he took my suggestion that I ask TRW if they would be interested in working with me. I explained that TRW appreciated the value of the MCD criteria, and that we had developed a close relationship by working on the TRW LEMDE engine configuration as the main propulsion subsystem for the MCD/SLV. Besides I was familiar with many TRW personnel because we had once been part of the same organization; namely, Ramo Wooldridge and Space Technology Labs.

The satellite division at TRW was receptive to working with me. I briefed a group of about six senior designers and the assistant manager of the division. Afterwards, the group had a whispered bull session. Then one member of the staff spoke up and said that they believe they understand the MCD criteria as it applies to payload design, and that they anticipate its use would decrease payload cost by about 5%. Fortunately the assistant manager of the division was not in agreement with the evaluation. He instructed one member of the group to work with me.

When I later met with the designated individual, he suggested that he study a relatively simple, existing satellite, namely VELA, which TRW fabricated and was first launched in October 1963. The satellite had 12 X-ray and 18 neutron and gamma-ray detectors, and was powered by solar cells. He agreed to attempt to develop one or more designs of higher weight and lower cost and, hopefully, to the same or higher level of reliability.

When I met with him next I found that he had taken each subsystem and designed it to several levels of decreasing sophistication, with commercial and laboratory hardware representing the end points of highest weight and lowest cost. He presented the results of his work in graphical form in the manner shown in Fig. 4 of the March 27, 1997, column. Most striking about these curves, which arranged themselves in a vertical array, was that the initial slopes from point A to point B were greater than I had anticipated; in other words, initial increases in the weights of the minimum weight subsystems decreased costs appreciably. This was shown to be true for all subsystems.

Shortly after this meeting my supervisor advised me that the CEO of TRW had spoken with the president of Aerospace on the subject of this breakthrough in reducing the high cost of payloads. However, I became skeptical of the value of this news when I lost contact with the TRW designer. The situation revealed itself when I was officially told that TRW will not adopt the MCD criteria in the design of their payloads. In tapping the grapevine, I learned that TRW decided, after much high-level discussion, that it would be economically foolhardy to adopt the MCD criteria.

This ended my MCD payload design effort. This part of my assignment was accomplished, but obviously not with the documentation I had anticipated. However, the TRW study added to my confidence in saying that MCD payloads could cost appreciably less, and that their cost could be further reduced when they are designed to be launched by lower cost launch vehicles.

I answered the third question by presenting and discussing the following figure.

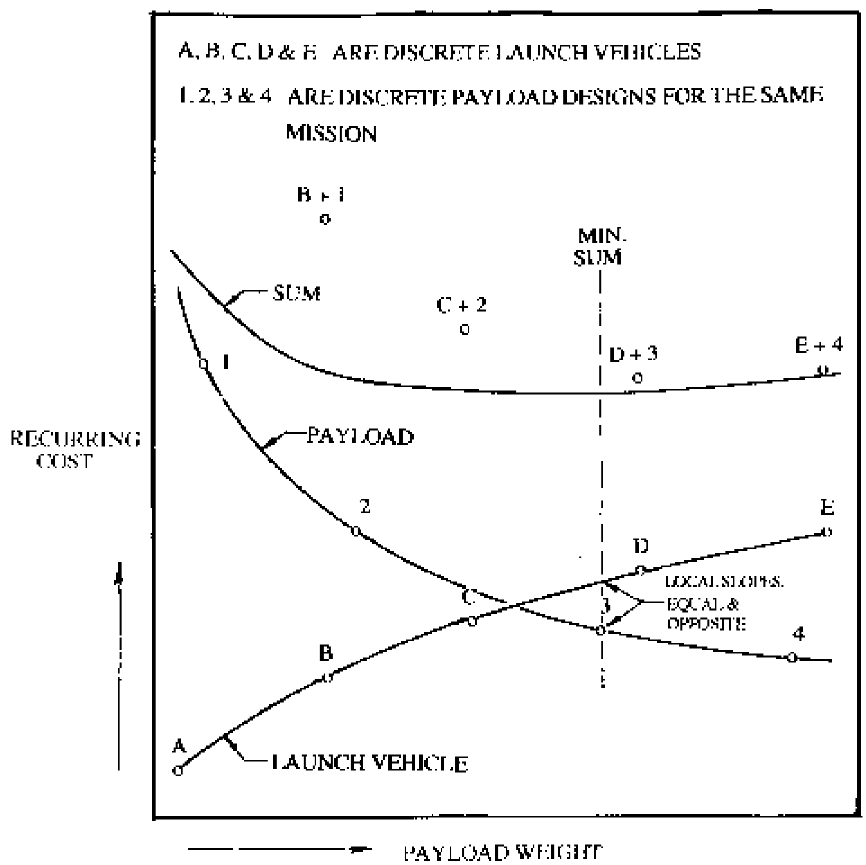


Figure 5. Methodology for Selecting Discrete Payload Designs and Launch Vehicles.

In previous descriptions of the MCD criteria, I assumed the cost-weight relationships of launch vehicles and payloads to be continuous, and that the optimum combination of payload weight and launch vehicle occurred when the local slopes of the cost-weight relationships for payloads and boosters are equal and opposite; that is, when the sum of the payload and launch vehicle costs are a minimum.

In practice, there may be a stable of launch vehicles of different capabilities, perhaps as shown by points A, B, C, D and E. The payload designer may have chosen to configure discrete MCD payload designs, and these are as shown as points 1, 2, 3, & 4, where Design 1 represents the minimum weight design.

The figure is designed to illustrate the following points:

- Because of the likely shapes of the continuous curves, a near-minimum cost combination can exist for a wide range of payload weight.
- The costs of combinations B + 1 and C + 2 happen to be much higher than the minimum cost combination under the assumptions of this hypothetical example.
- Combination D + 3 is closest to the minimum cost. However, E + 4 may prove to be optimum when nonrecurring costs are accounted for.
- If the payload were to be lofted to a higher orbit, requiring perhaps another stage, the launch vehicle cost curve would move up and the optimum launch vehicle-payload combination would approach Payload 1. This also may be viewed as a line, representing launch costs in dollars per pound of payload (or the value of K) increasing in slope such that it becomes tangent to the payload cost curve close to Payload 1.

The answer to the third question was presented to Aerospace management in a briefing. As I indicated earlier they were fully aware of the answers to the first two questions.

I know of no other MCD payload study that has been conducted, although several approaches have been used to lower the cost of payloads. A current popular approach is to limit the payload mission requirements.

**Q & A**

**Do you believe it is feasible to design minimum cost payloads?**

In a recent issue of LAUNCHSPACE Magazine, Rick Fleeter writes that there may be too many constraints to lowering the cost of space hardware. I wonder how others feel?
- Arthur Schnitt

Yes, at this time I feel the US aerospace industry is being asked to design to other constraints than cost. (I assume you were referring to the August 1996 issue of Launchspace.) I do not feel that Dr. Fleeter's point was simply that the industry labors under too many constraints to embrace minimum cost design but rather that it optimizes for other things (like minimum weigth, as you have stated). He stated examples of optimizing for political, mission and technology exploration reasons. He went on to state that MCD will happen when conditions favor it. I feel that true MCD of a space transport system will not occur until there are several transport suppliers out there selling by the pound (lots of customers would help too). The quickest way to do this would be to require the government to purchase transport rather than build it. This is, of course, unworkable for a large number of reasons. In the end view, I

feel that MCD is best seen as one tool in an engineers tool kit. After all I complain continuously about how large a percentage of my salary is devoted to personal transport (i.e. my car) but I bought a Corvette over an econocar. P.S. I've enjoyed reading your column and will continue to do so. Hopefully the "econiche" for MCD of space transport systems will be created soon.
- Jason Quinn

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## Start Up Companies

Since the Air Force's Space and Missile Systems Organization and The Aerospace Corp. (collocated in Los Angeles) were ordered to close the MCD/SLV development program in 1968, the aerospace community has not attempted to develop a new launch vehicle of greatly reduced recurring cost, comparable to the cost reduction potential of the MCD/SLV. As a consequence, and in recognition of the likely development of a large commercial space market, many start up companies emerged to manufacture low cost space launch vehicles.

Some of these companies are in business today while many have gone under, including companies that claimed to be designing to the minimum cost design criteria. It was regretful to see this latter group fail. As far as I was able to ascertain, no company in this group attempted to fully understand the MCD criteria and use the methods of design analysis contained in the report readily obtainable from Aerospace/Air Force. Instead they seemed to treat the criteria as a "philosophy" or a "concept," and to reduce it to a set of design guidelines; such as,

- make it simple,
- make it rugged,
- let it weigh more,
- use commonality,
- treat all stages equally in sophistication,
- use less than optimum hardware if it saves money, and,
- minimize nonrecurring (developmental, one-time) costs.

Expendable space launch vehicles, although less complex than recoverable vehicles of any configuration, are immensely complicated. SLVs designed to the MCD criteria are simpler, contain far fewer parts, are inherently more reliable, and, in most part, lend themselves to simpler fabrication techniques. Yet they must sustain the same environmental loadings and interface with payloads and launch facilities. Moreover, it should be remembered that the MCD criteria requires a new design approach that adds some complexity to the design optimization process, more so the first time it is used.

The additional complexity is incurred by the introduction of cost as an equal and the ultimate parameter. This means that the production cost of components and subsystems, including such items as the costs of acceptance testing and installation, must be estimated along with weight and reliability so that tradeoffs can be made to select the cost-optimum component or subsystem. Nonrecurring cost of each subsystem must also be estimated so that, ultimately, the total system configuration represents the minimum cradle-to-grave program costs.

Payload designers should be surveyed to determine the limits of acceptable payload environments, such as acceleration, vibration and noise, that may be imposed by the SLV. Trade-offs between the payload and SLV costs might be worthwhile since the MCD/SLV has the potential for providing a more benign environment at lower cost. The design and cost of launch facilities that provide one or more vehicle environments are determined from which the optimum is selected. Similar tradeoffs may be made between the vehicle and payload costs and the cost of the launch facilities.

The optimization procedures outlined are in sharp contrast with SLVs designed to the minimum weight/maximum performance criteria. The MCD/SLV is not treated as an inviolable entity isolated from the rest of the system. No longer are the interface systems designed to protect the fragile SLV, notably the launch facilities, including assembly and test of the SLV before launch. The costs incurred by launch delay and SLV failure are more easily negated as well as the costs due to launch delays due to winds aloft and inclement weather.

Hence, the MCD optimization procedure is similar to the more recent practice of airliner designers. No longer do they "throw the design drawings over a transom" to the production department and to designers of other elements of the system. Now the airliner engineering department interacts and conducts tradeoffs between the airliner design and other system elements, such as the airline operators. Tradeoffs are also conducted between recurring and nonrecurring costs to establish the number of vehicles at which profits absorb nonrecurring costs.

This description of the MCD design procedure has touched on a few of the many engineering disciplines that are involved concurrently in designing an SLV. Many of the disciplines might reside in single individuals only found in vast engineering organizations. These are disciplines, such as, expertise in combustion instability, and knowledge for avoiding the propellant flow problem incurred by the dynamic reaction of the propellant feed structure under flight conditions. Moreover, an adequately functioning library with research capability is an indispensible part of an engineering organization.

Start up companies have circumvented many of these requirements using some of the following schemes:

- Selected developed propellants and propulsion systems, or those that have been partially developed and have never been exploited, compromising on suitability: efficiency, weight, cost, and reliability.
- Devised configurations which avoided many of the disciplines that would be involved in "a clean sheet of paper" design.
- Devised unique, far-out schemes of launching, refueling or recovery.
- Purchased the required engineering disciplines under subcontract.
- Assumed unreasonable risks.

In spite of such shortcuts, I feel fairly safe in saying that almost all start up companies UNDERESTIMATED the complexities of designing, fabricating and testing an SLV, irrespective of the criteria or guidelines they chose to use. Consequently, these companies went UNDER because they were UNDERSTAFFED and UNDERFINANCED.

Although I had a very small team of designers working with me in conducting the preliminary design and early development of the MCD/SLV, I did have the Aerospace engineering staff of more than 3000 engineers, scientists and technical specialists from which I drew specialized information. I also had available industry reports, some of which were proprietary. I further had the attention of industry that gladly answered or performed experiments to answer my questions. TRW and Boeing made significant contributions in propulsion and propellant tank fabrication that greatly furthered my work; see Columns dated May 1 and 15, 1997. Moreover, the major aerospace contractors checked and validated the MCD criteria and all of its claims.

For start up companies to obtain adequate financing has indeed been the critical problem. American venture capitalists are not tuned to investing relatively large sums of money in projects that will not show profitability in five or more years. Of course advancing technology for the benefit of an industry is not one of their goals. Understandably they choose not to become involved with the aerospace industry that is known to experience mishaps, large financial losses and overruns.

The characteristics of large space programs are generally government sponsored throughout the world. On face value it appears that our government has been sponsoring the design of new launch vehicles for the past thirty years that will reduce launch costs. In most programs, the objective has been a modest reduction of up to 50%; see Column dated January 26,1997. Until the White House and Congress recognize foreign competition and believe that it might be best for all concerned to appreciably reduce launch costs, I believe we will not have an MCD/SLV. Perhaps a positive attitude toward appreciably reducing costs must await effective campaign finance reform, and I do not see this happening soon.

Within the last several years I have appealed, without success, to the FAA, the White House and NASA to start an MCD/SLV program. I may, in a future Column, describe these efforts and the replies I received.

Today, the organizations with the most to gain from an MCD approach are those that are planning communication satellite networks, estimated to cost ten billion dollars or more. I invite Teledesic, Celestri and Globalstar to examine the history and potential of the MCD criteria. I know you are troubled with the current and future lack of launch services. Might not it be worth investigating whether you can save billions of dollars by designing the optimum size or sizes of MCD/SLVs and matching them with minimum cost payloads? Optimizing the launch vehicle and payload in combination should result in additional savings in time and money. In addition you would have greater control over launch vehicle cost and availability. Moreover these vehicles would be a highly salable product by themselves; as a commercial enterprise not seeking government funding, you would have fewer political constraints in selling launch services. Although you may feel, at this time, that the projected, large economic return of your communication network may make the investment cost of the system inconsequential, the large profits may not last if companies that follow effectively compete with much lower cost systems.

**Q & A**

**Is it possible for a start up company to produce an operational space launch vehicle?**

I think that it is possible providing they receive adequate funding. If they really apply MCD then a workable SLV should result. General Astronautics seem to be on the right track. I would like a startup to happen in Australia but funding is almost impossible to obtain here.
- Stephen Gloor

I believe that it is possible for a start-up to accomplish this goal. To succeed, the company must apply the principles of MCD criteria to provide a marketable product or service to its prospective customers. I believe the end line product could be a RLV for private commercialization as well as launch services. Additionally, the MCD criteria can be utilized as a marketing tool in the promotion of such services or products.
- Timothy Fasano
- Orbital Tech Unlimited

I truly hope that those who are serious about building Space Technology Firms for the purpose of engineering and deploying Satellite Networks, and MCD based

RLV/SLV systems - get a chance to review this. I saw the opinion written by Stephen Gloor, and I found it to be very true, however, only as it relates to CONVENTIONAL CAPTIAL SOURCES. Yes, it is difficult (if not down right impossible) to secure ADEQUATE funding from most of the traditional money pools, especially for severely "niched" players such as the "Space" industry, which today is both misunderstood by most conventional lending sources, as well as underestimated in it's potential investment return value. I personally, envision the so-called "Space" industry to ultimately become the largest and most dominant "Global Industry" in world history. Some industries that now dominate the macro-economic landscape, will eventually exist primarily for the sole purpose of "SUPPORTING" the new international giant. Predicting when this transference of technology, capital, mental as well as cultural focus will take the form such that the layman (someone with little to no technical background) could easily identify, that in fact, a new Global Industry has indeed arrived - is closer than we may all think. The problem for would be Start-Up's: Lack of Capital, and a Lack of Access to reliable Cashflow. The solution: Private Debt Equity Instrument Asset Conversion (tm). Actually, it is a very effective, somewhat complex in detail, yet simple to execute, Contract Financial Tool. This Financial Tool is really a hybird financial concept that dates all the way back to the Roman Empire. It has been used in its primitive form for many decades. The CSFN, with its Capital Resource Network (tm), dedicated to providing customized Financial Solutions, has brought to the forefront, a growth oriented concept that we call, Private Debt Equity Instrument Asset Conversion (tm). It is relatively new and it is definitely a more powerful variant than its' much older sibling. In essence, companies can use PDEIAC as a long-term strategic financial growth tool, WITHOUT THE USUAL HEADACHES NORMALLY ASSOCIATED WITH RAISING DEBT AND EQUITY CAPITAL! Since the CSFN's PDEIAC service is NOT A LOAN, users of the Financial Tool do not concern themselves with squeezing their financial statements to death, in search of creative ways to effectively service new debt. One of the major structural problems associated with certain types of Manufacturing and R&D companies, is the LACK OF CASHFLOW (yes, one word - Cashflow). When a company uses Private Debt Equity Instrument Asset Conversion - IT HAS NO CASHFLOW PROBLEMS. Therefore, the company can focus more of its resources, time, energy and effort into creative production and delivery of their products and services - on time, and with lower associated production costs, instead of having to spend 30% to 50% of valuable company time on raising capital that costs too much in real terms. PDEIAC provides a reliable, predictable and stable financial platform from which many Small to Middle market companies can flourish. If acquiring Production Contracts to build Satellite Systems and Launch Vehicles from customers and clients is not a problem for smaller start-up companies, THEN NEITHER IS SECURING ALL THE PRODUCTION CAPITAL YOU WILL EVER NEED! The CSFN represents the Capital Resource Network (tm) to the World. Through the Private Debt Equity Instrument Asset Conversion financial service, we have the ability to direct up to $3.5 billion per month into viable Production Contracts spanning every industry on the face of the planet, and eventually, on other celestial bodies as well. Getting into space can be capitalized and cost effective. The California Strategic Financial Network hopes to do its part in paving the way for real Space Firms to accomplish the impossible - boldly going where no one has ever gone bofore, is something well within our reach!

- Hosea Askew, President
- California Strategic Financial Network

September 18, 1997

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# OTA Experiences

My experiences with the Office of Technology Assessment, the technical/scientific arm of Congress, during 1987 and 1988, convinced me that Congress was more interested in maintaining the status quo desired by industry and the procurement agencies rather than in lowering the cost of space operations. In this and the next series of Columns, I will describe these experiences as carefully and completely as possible so that the reader can understand the circumstances that lead me to this conclusion.

A description of OTA's "assessment process" may be found on the Internet[1]. As further described by M. Granger Morgan of the Pittsburgh Post Gazette[2]: "Because of the political environment in which it has operated OTA reports rarely draw definitive conclusions. Rather... they summarized the technical facts, identified problems, laid out alternatives, and discussed their pros and cons." (OTA was legislated out of existence in 1995.)

On June 12, 1987, I received a call from a member of the OTA staff. After a brief explanation of the function of OTA, he outlined a task assigned to them by the House Committee on Science, Space, and Technology. They were to assess the Big Dumb Booster as part of a study by which lower cost space systems might be achieved. The assessment was to be made by having a one-day "workshop" attended by representatives of industry, the procurement agencies, others I chose to invite, and myself. The views expressed at the workshop would be used in preparing a report, planned to be issued the following Spring.

I vigorously objected to OTA's assessment approach and declined to partake in an effort in which I would be greatly outnumbered. Besides expressing this thought, I added:

- If they wished to comply with the request to study the feasibility of lowering space system costs, OTA would do better by evaluating the MCD criteria rather than the BDB since the BDB is only one application of the criteria.
- The applicability of the MCD criteria to payload design should be of considerable interest to Congress and should be addressed.
- OTA appears to be going over previously well tilled ground. Most major

aerospace contractors have studied the MCD criteria and found no flaws. Some contractors have designed their version of a BDB, while some have contributed to Aerospace's design by fabricating appropriate, MCD hardware, namely, TRW and Boeing, as described in previous Columns.

- Understandably, most of the industry as well as those at the policy-making levels of the procurement agencies made it known directly or indirectly that they were against the adoption of the MCD criteria.
- The workshop looks like a time-waster and a time-delayer at a time when the National Research Council and President Reagan were being asked to approve new, large space programs such as the ALS (Air Force/NASA Advanced Launch System) Program and the Space Station.
- I would appreciate receiving any documentation regarding Congress' request of OTA, and OTA's assessment plans in response.

I received the following documents in response from which the following statements are excerpted:

- Dated September 17, 1986. From the Senate Committee on Science and Transportation. "Identify and evaluate those key technologies which, if properly funded, might produce the greatest increase in launch vehicle capability, the most dramatic reductions in cost, and the greatest contribution to U.S. industrial competitiveness across a range of high-technology markets;..."
- Dated March 6, 1987. From the House Committee on Science, Space, and Technology. "The Congress will need credible information regarding...the feasibility of achieving critical technical and cost improvements in space transportation systems... Identify and evaluate those key technologies which, if developed in a timely manner, might produce significant increases in launch capability, substantial reductions in cost, and a major contribution to U.S. industrial competitiveness across a range of high-technology markets... Identify and evaluate a range of low-cost, low-technology space transportation options and examine the trade-offs that need to be made... Assess technologies in spacecraft design and operation which critically relate to launch vehicle performance..."
- Dated March 10, 1987. From the Chairman of the Senate Committee on Commerce, Science, and Transportation. He referred to the September 17, 1986, request and added, "I am still interested in OTA conducting this study as originally requested."
- Dated March 12, 1987 and Revised April 10, 1987. An OTA prepared study plan entitled, "Advanced Space Transportation Technologies," was to answer the

committees' requests. Of the eight tasks listed, the following three are of immediate interest. 1) "identify launch systems capable of serving the plausible range of demand for space transportation over the next twenty years;" 2) "identify and evaluate key technologies - including low-cost, low-technology systems - that might increase performance and reduce the cost of space transportation while contributing to U.S. industrial competitiveness;" 3) "determine how changes in spacecraft design and operations will influence launch technology."

I received the last document about August 15, 1987. After reviewing all the documents, I sent OTA the following letter, dated August 18, 1987:

"Thank you for sending me information that completely describes your study program... every few years, a broad study of space launch vehicles is undertaken by some agency, and 'low-cost, low-technology systems' are part of the study. Hardware based on the minimum cost concept are always shown to be losers... It seems that it is your turn to repeat the study which, as I indicated during our conversation, is [viewed as] just another bureaucratic boondoggle." In the closing paragraph, I implored OTA to review and evaluate all the work that has already been done on the MCD criteria and its applications by The Aerospace Corp. and by many industrial contractors, and to promptly reach a conclusion relative to its value.

I sought the advice of my politically astute friends. All advised that I would do better by accepting participation in the workshop, and that I should try to get as many of my supporters invited as possible. OTA was described as an organization of high integrity and that I would get a fair shake even if it comes later than I would like.

When the OTA representative called again to announce that the workshop will take place on December 1, 1987, I accepted the invitation to attend. I remember feeling buoyed by the Big Dumb Booster cover story that appeared in the August 17, 1987, issue of NEWSWEEK[3]. I identified five supporters who I wished to be placed on the invitation list. The representative assured me that the workshop results would be the subject of an extensive report that I would get to review prior to its release the following Spring.

Close to the end of November, I received an unexpected draft copy of a report that was prepared under contract to OTA, "A Technical Analysis of Low Cost, Low Technology Options for Space Transportation," by Dr. Russell C. Drew, principal investigator. The report was sent to all of the invited workshop participants, and they were asked to submit written reviews.

I found the report to be comprehensive and competently written with one major omission. It did not discuss the validity and the implications of the MCD criteria in the design of space hardware, both launch vehicles and payloads. The basis of his analysis was the NEWSWEEK story rather than the Aerospace report[4] that contained the derivation of the MCD criteria and its application to a space launch vehicle. The Aerospace report provided the material on which many of the preceding Columns were based. In my written review I emphasized that, although the optimum hardware derived from the MCD criteria, particularly for first stages, was more commercial- than aerospace-looking, the term "low technology" was inappropriate. The term carried a negative connotation for an industry that has made notable accomplishments through advancements in technology.

In spite of my efforts, the workshop subject was called, "Low Cost, Low Technology Space Transportation Options." Furthermore, I was never able to get OTA to drop "low technology" from any of their subsequently prepared material perhaps because it was the expression used in the House Committee letter.

Most unfortunately, of the five people I invited to the workshop, only one was able to make it, and another sent a substitute. Among the attendees, there were several representatives of agencies/organizations who had been MCD adherents in the past, but were now on the other side of the fence. Before the session started, two attendees whispered pleasant greetings to me from individuals in their organization before they quickly walked away.

The workshop was conducted in an informal manner. The attendees sat at tables arraigned in a large quadrangle. The proceedings were not recorded. There was an agenda that included two, short presentations: one on "Low technology Propulsion Concepts," by the TRW representative, and the other on "Structure and Materials Issues," by a NASA representative. We were asked to submit prepared statements to OTA and to all of the attendees. This was followed by verbal statements of more of the same. It did not take long before I became frustrated and demoralized. During one of the many recesses, I unsuccessfully pleaded with the OTA representatives to conduct an evaluation of the MCD criteria that I considered to be the primary and unresolved issue.

There was one positive outcome of the workshop. The NASA presentation, given by Dr. John Davis of Langley, showed how the redesign of the BDB, using advanced technology composite materials, could reduce the vehicle size to a fraction of its former self. Current costs of composite materials indicate that the previously estimated cost of the BDB could be reduced as well.

**References**

1. http://www.princeton.edu/~ota/html2/proces.html
2. http://www.princeton.edu/~ota/html2/ota95.html
3. Column dated February 5, 1997, "Recommended Reading."
4. A. Schnitt and Col F.W. Kniss, "Proposed Minimum Cost Space Launch Vehicle System," The Aerospace Corporation Report TOR-0158(3415-15)-1, July 1, 1968

October 10, 1997

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## OTA Experiences Continued

As noted in the preceding Column, the workshop took place on December 1, 1987. It was held in OTA's conference center, Washington, D.C. The meeting was chaired by Dr. M. Granger Morgan, Head of the Department of Engineering and Public Policy of Carnegie Mellon University. The OTA project director was Richard DalBello who I believe has been responsible for space policy in the White House for the past few years.

Twenty-two individuals participated in the workshop. Their names and affiliations are listed in the OTA report on the proceedings of the meeting.[1] Nine participants represented established aerospace companies, five were affiliated with NASA centers and three with the Air Force; the remaining five were composed of two consultants, two representatives of small companies, and one representative of The Aerospace Corp. I had added the Aerospace and TRW representatives to the invitation list.

Seating was provided for visitors off to one side of the workshop group. Most visitors did not stay for the entire proceedings. I recognized a group from NASA Headquarters and the Navy. The press was barred from the room.

Several weeks before the meeting, each invitee received copies of the workshop agenda and the recently published NEWSWEEK article.[2] The cover letter explained that the article was enclosed "in order to familiarize you with the concept of the low cost, low technology launch vehicle and some of the controversy surrounding it... " The article contained little in terms of an engineering discussion of the MCD criteria and its application to an SLV, but rather extensive criticisms of industry, NASA, and the Air Force, and why each participated in killing the concept. This was hardly suitable background information for workshop discussions of "the technical feasibility, advisability, and cost-effectiveness of developing simple or low technology space launch vehicles," as requested in the cover letter.

Not all the attendees submitted prepared material. I obtained copies of twelve submittals, but there might have been more. Since there were no verbatim records made of the proceedings, I made as many notes as possible. From what was said, I fully believe that, except for the TRW and Aerospace representatives and the Air Force manager of the Advanced Launch System (ALS) Program, no participant had an understanding of the MCD criteria. Following were some of the more pertinent comments – both negative and positive – as they reflect upon the MCD criteria.

**Negative Comments**

- Hardware assemblies composed of many, complex components are generally highly reliable; example: an aircraft turbojet engine. Simple structures are not inherently more reliable.
- There is no clear advantage in using the "Big Dumb Booster" (BDB) design approach.
- The path to lower costs is through high technology.
- Least costs can be achieved by making SLVs fully reusable.
- The BDB is a step backwards. Low costs can be achieved by building on existing technology.
- More than half of the recurring costs support a "standing army," and changing the SLV design will have little effect on the size of the army.[A]
- There is a "... perceived lack of technology base... " in designing for minimum cost.
- Larger tank sizes may require the abandonment of existing manufacturing facilities and the development of new capabilities.
- Solid rocket strap-ons have a better technical base than minimum cost liquid rockets.
- Low cost launch vehicles are inordinately large.

**Positive Comments**

- The Air Force manager of the ALS Program stated that the MCD criteria is being used in their design studies.[B]
- It was revealed that past industry studies that showed higher costs for MCD hardware used cost estimating relationships (CERs) that were based on historical costs of hardware designed to the minimum weight/maximum performance criteria. Because MCD hardware usually weighed more, and the CERs were weight-based, its costs were estimated to be higher. Consequently hardware designed to the MCD criteria was always shown to be a loser.[C]
- The 1969 TRW study of a low cost, expendable SLV resulted in recurring costs of one-fourth to one-fifth the cost of comparable SLVs of that era.
- Lowering launch costs provided the potential for reducing payload costs as well.
- As mentioned in the preceding Column, the size of the BDB can be reduced by using advanced composites in lieu of steel, and the cost can be further reduced

as well.

After the close of the meeting, the OTA representative with whom I had been in contact advised me that the report summing up the findings of the workshop was planned to be released early the following year, and that I would be given the opportunity to comment on its contents prior to publication.

At the end of March 1988, when I still did not receive a draft copy of the report on the workshop, I called OTA. I was told that Congress had put the BDB "on a back burner." I was further told that OTA is preparing a "buyer's guide" on SLVs in compliance with the requests of the Congressional committees. (This report was released in July and will be discussed in the next Column.)

I called OTA again at the end of June to learn the status of the workshop report. This time I was told that it is scheduled for completion at the end of July. However, its distribution will be limited to internal use only.

The delay and these comments raised my frustration level to the point that I felt compelled to impose upon some of my friends to try to learn what is going on at OTA, friends who had previously been in government service. I received a call from someone I trusted very much, a personal "deep throat." He advised me that the MCD criteria will not gain acceptance, and that I cannot buck the aerospace industry, the procurement agencies, and the government - known as the "iron triangle[D]."

**References**


1. "BIG DUMB BOOSTERS A Low-Cost Space Transportation Option? An OTA Background Paper," February 1989. (Available for reading/downloading at http://www.princeton.edu/~ota/html2/caty89.html.)
2. Gregg Easterbrook, "Big Dumb Rockets," NEWSWEEK, August 17, 1987. (Column dated February 5, 1997, lists some of the significant statements made in this article.)
3. William C. Strobl, "Cutting space launch costs with simulation," AEROSPACE AMERICA, September 1997, pp 23, 24.


**Notes**

A. The standing army is composed of all operations personnel who monitor the SLV and payload prior to launch and during flight, and personnel who must be kept at hand to inspect the hardware and to quickly perform repairs as necessary. I contend that the size of the standing army is directly related to the SLV and payload designs. Simpler, more rugged SLV's and payloads require a smaller army. In fact, by fully adhering to the MCD criteria, the SLV and payload designs are optimized in conjunction with the cost of operations, including the costs incurred by unreliability; such as, downtime, failure and failure analysis.

I had not come across any article on the technical aspects of the ALS program until last month.[3] Although Strobl does not spell out that the ALS program used the MCD criteria, it is quite apparent from his description of the design process that, not only was the criteria used, but an extensive computer program was developed to facilitate minimum cost design, a program I had proposed in a 1962 paper. As explained in Column dated March 27, 1997, "Methods of Design Analysis," I abandoned the development of the computer program at the time I was asked to design the MCD/SLV in several months. Reference 3 also described some specific design results of the ALS Program; viz.:

B. "... a small relief in weight constraints significantly reduced the cost of engines and structure... For example, the cost of a new ALS engine could be reduced significantly if the weight constraint were relieved by only 3% of the total system weight."

C. "For about a 25% weight increase [of a new turbopump volute] the cost for the new design is only about 8% of the cost of the traditional design."

According to Strobl[3], the same brand of CERs were NOT used in defining the nonrecurring and recurring costs for the SLV designed under the ALS Program. The ALS Program used a costing methodology that was commensurate with the hardware sophistication. (This point will be expanded upon in the next Column.)

D. Several years later I heard the term iron triangle used in a discussion of the political aspects of the aerospace community. Hedrick Smith, the author/reporter, explained the operation of the triangle in a PBS TV program.

November 10, 1997

15

# OTA's Draft Report on "Big Dumb Boosters"

As reported in the preceding Column, Congress set aside the preparation of the report on the outcome of the workshop on "Low Cost, Low Technology Space Transportation Options." Apparently Congress opted to receive a report[1] in which combinations of existing and proposed launch systems were identified that would support an array of possible mission models, together with projected costs.

The existing systems considered were the Shuttle, Titan IV, Delta II, the Atlas Centaur II. The proposed systems considered were the Shuttle-C (a cargo-carrier Shuttle derivative) the Titan V, and the Advanced Launch System (ALS). OTA considered other proposed systems although they were not actively worked on; such as, the Shuttle II (an all-recoverable Shuttle) and the Transition Vehicle (a partially reusable vehicle based on existing technology.)

The report is well prepared and is typical of OTA's high standards. It is comprehensive, well organized and tuned to the audience for whom it was written. It contains several interesting statements relative to the MCD criteria that are worth noting:

- By public law, the ALS was to seek a reduction in recurring costs by a factor of ten[A] less than costs current at that time (about $3000/pound of payload) for a payload weight of 110,000 pounds to LEO[2].
- The Air Force had asked the ALS contractors "to emphasize cost efficiency rather than performance as the primary goal[3]." I view this as a well-defined break with the use of the minimum cost/maximum performance design criteria.
- The Big Dumb Booster[4], described as a "concept" that uses "simple technologies," was not included in the studies because "no thorough analysis has yet been carried out on the life-cycle costs of using such a booster[B]." It is noted, in this and in other OTA reports discussed later in this Column, that OTA omitted the fact that the BDB was designed in accordance with the minimum cost design criteria. The term "minimum cost design" was not in the OTA's report-writing lexicon.

In his article on the method of design analysis used in the ALS program[5], William

Strobl[C] followed OTA's "party line" by not using the term minimum cost design. He did not even acknowledging the fact that a new design criteria was involved, although his description of the analysis clearly pointed to the use of the minimum cost design criteria. He described the cost-weight tradeoff, the most significant analysis conducted under the MCD criteria, by explaining that cost-weight relationships were developed "for every element of the launch system." He further explained that these relationships were used in a computer program that derived the optimum hardware and the minimum cost design.

In the same article, Strobl noted that historical cost estimating relationships (CERs)[D] were inappropriately used in determining ALS vehicle nonrecurring cost. By using these CERs, the nonrecurring cost was estimated to be about twice the cost computed by the design analysis; vehicle recurring cost was not discussed. However OTA[2], in a comparative vehicle analysis, assumed that the ALS would reach its recurring cost goal, and noted that the program was still underway and final vehicle configuration has not been selected.

In September 1988, OTA issued a second report dealing with existing launch vehicle systems[6]. This report was extensive and also very well prepared. Discussed in great depth was the feasibility of significantly reducing launch, operations, and management costs. They concluded that such costs could be decreased by some small amount. However, I found the report of great interest because it related to the MCD criteria.

MCD criteria, as described in the previous Columns, achieves minimum program life-cycle cost by considering all elements of a space system simultaneously in the design process. Specifically, launch vehicles and payloads are designed by trading cost, weight and reliability while the configurations and costs of all other system elements (such as, R & D, manufacturing, operations, launch facilities, and management) are also determined. Employing this criteria assures that the space hardware is not designed in isolation, and that the sum of the cost of all system elements are minimized. For instance, flight hardware may be off-optimum in weight in order to minimize program life-cycle costs.

With this definition in mind, here are some of the findings in the OTA report that I felt were in consort with and supportive of the MCD criteria:

- "... launch system designers have traditionally focused greater attention on achieving high performance than on operational simplicity or low cost[7]."
- "... designing to cost rather than for performance would lead to significant reductions in the costs of launch operations[8]."
- "... vehicle design significantly affects launch and mission operations and plays a crucial part in the ability to reduce costs[9]."

- "Include all segments of the launch operations team (including logistics personnel) in the design of any new launch system[9]."
- "... new launch systems, especially designed for low-cost operations, appear to offer the potential for significant savings[10]."

In October 1988, I received a draft copy of the report on the workshop. The cover letter explained that the preparation of the reports discussed above prevented them from completing this draft sooner. The letter also contained the following paragraph:"The issue of Big Dumb Booster continues to be of interest to Congress, especially in light of NASA studies on liquid rocket boosters and the Air Force/NASA ALS Program. Both efforts are exploring technologies that bear on Big Dumb Booster concepts."

I was happy to learn of the recognition the MCD criteria was getting. I answered their request for comments with a 9-page, single-spaced letter. I started by suggesting a different title to the report. Besides listing specific comments, I provided relevant background information. I also analyzed the issues, as I saw them, that might explain why it has been so difficult for the MCD criteria to be accepted by the aerospace community.

I received the final report[11] in February 1989, but found that very few of my comments were incorporated.

**References**


1. "Launch Options for the Future: A Buyer's Guide," OTA Special Report OTA-ISC-383, July 1988[E].
2. Ibid., p 71.
3. Ibid., p 12.
4. Ibid., p 10.
5. William C. Strobl, "Cutting space launch costs with simulation," AEROSPACE AMERICA, September 1997, pp 23, 24.
6. "Reducing Launch Operation Costs: New Technologies and Practices," OTA Technical Memorandum OTA-TM-ISC-28, September 1988[E].
7. Ibid., p 4.
8. Ibid., p 16.
9. Ibid., p 59.
10. Ibid., p 75.
11. "BIG DUMB BOOSTERS A Low-Cost Space Transportation Option? An OTA Background Paper," February 1989[E].

**Notes**

A. Where and when did I hear that before? See Column dated Feb. 5, 1997.

B. In the first place, Minimum Cost Design has not been presented as a concept but as a design criteria that is more appropriate for the design of most space hardware. Moreover, the life-cycle costs of an MCD/SLV will remain unknown so long as the attitude of the government remains the same as at the time the Air Force program office established for its development was closed down. See Column date May 15, 1997 .

C. As a representative of General Dynamics, he assisted and supported OTA in the preparation of several of their reports on space vehicle design.

D. Available CERs are based on accumulated cost data for hardware designed to the minimum weight/maximum performance criteria, and generally would not represent the cost of cost-optimized hardware.

E. OTA reports may be accessed for reading/downloading at a single URL: http://www.princeton.edu/~ota/ns20/year_f.html.

January 5, 1998

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## OTA's Final Report on "Big Dumb Boosters" Part 1

I was very disappointed in the brevity, content and format of the final report[1] which was appropriately labeled "An OTA Background Paper." It bore no resemblance to the quality of the other reports in the series prepared by OTA that preceded and followed it. I took this as indicative of how Congress and OTA ranked the subject. This was the third of five reports that were prepared as answers to the congressional committees' request for an "assessment of space transportation technologies."

Although I was forewarned[2] that MCD was unacceptable to the aerospace community[A], I could not resist sending them the 9-page commentary on the draft report mentioned in the previous Column. I guess I could not restrain myself from taking the opportunity to clarify the MCD criteria; I have always hoped that attitudes might have changed in the interim. As I mentioned previously, none of my counter-arguments was incorporated in the final report.

I have chosen to express my views and counter-arguments to OTA's final report by reviewing it section by section. Most sections cannot be summarized easily; besides, I do not want to possibly misinterpret or misrepresent statements made. I am forced, therefore, to beg the reader to download the report[1,B]. The page numbers and paragraph titles refer to the final report.

**Page 2. Origins of Today's Launch Vehicles**

As I explained in a preceding Column[3], to the best of my knowledge everyone, including myself, who worked on the early ballistic missiles and space launch vehicles, accepted without question the applicability of the minimum weight/maximum performance criteria. Although cost was not a prime consideration at the time, it was understood by most designers that using the customary aircraft design criteria would result in minimum cost systems. Except for the singular case when the weight of the vehicle was limited by a transportation constraint, the "stringent performance specifications" could have been met by the MCD criteria. Unfortunately we had no inkling of it at the time.

I have seen no analytical evidence to support the statement that the Shuttle's recurring cost would have been less if no limitations were placed on its development cost. Moreover I too believe that the Shuttle was "sold" on imaginative, exceedingly low estimates of recurring costs, as a technological challenge requiring a large program effort, and as a program that would place men in space which would have public appeal and support.

**Page 3. A New Design Criterion**

Actually the development of the MCD/LSV (or the Big Dumb Booster) was canceled one week after the local Air Force presented the first briefing to industry on the program[4]. Industry realized that the MCD criteria was being seriously considered by the Air Force and obviously did something about it – fast. True, the Shuttle program blocked the further development of a "real low-cost robotic launch system[5]," but this policy was formally established by the White House six years later, in 1972.

**Page 4. Continued Controversy**

OTA described MCD as a "philosophy" which it is not. It is a design criteria based upon physical facts and mathematical analysis. The Big Dumb Booster was an analytically- derived application of the criteria and was not a "concept." A concept implies an "idea." Other designers, employing the MCD criteria, would probably have derived different configurations that might have been slightly better or slightly worse. The designs would change with time with advancements in materials, fabrication processes, etc.

True, there was overwhelming evidence that the Soviets did not design to a minimum cost criteria. However, I learned from people whose job it was to know that the Soviets saved considerable amounts of time and money by not striving for the ultimate in weight savings. By stressing design simplicity, which incurred only minor weight penalties, they also compensated for a shortage of appropriately trained engineers and shop personnel, and for limited sophisticated fabrication processes, limited materials availability, and other limited resources.

**Page 5. Payloads**

The arguments OTA presented against applying the MCD criteria to payload design, which would permit lower cost and less weight-constrained payloads, were clearly naive. The arguments were made by a workshop participant who claimed that payload designers probably would not take advantage of the opportunities the MCD criteria would provide. To counter this possibility OTA felt that adherence to the MCD criteria would require "considerable management discipline," an observation that I fully agreed with.

I was pleased to see that OTA agreed with the design decisions that the Big Dumb Booster provide only a standard payload interface, thus eliminating mission-special interfaces, and not provide such services to the payload as power and air-conditioning prior to launch. The same design decisions were made in the Advanced Launch Vehicle (ALS) program which were probably supported by extensive cost analyses.

**Page 6. Conclusions**

It should be noted that OTA made no "assessment" or evaluation of the MCD criteria and the Big Dumb Booster, nor explain their potentials. However, OTA appeared to accept the rationale of the MCD criteria as applied to space launch vehicles. By limiting their effort to reporting only the positive and negative arguments presented at the workshop, it appears that Congress was not interested in OTA's assessment of the MCD criteria or the Big Dumb Booster.

I was pleased by OTA's suggestion that Congress fund either the Air Force or NASA to conduct a thorough systems study that would include "launch facilities, logistics and support" although I felt that the likelihood of this ever happening was negligible. I based this view on the abrupt cancellation of the Air Force development program for an MCD/SLV in 1968[6] soon after it was officially started. I believed that the same, negative forces that existed then existed in 1989, the time OTA prepared their report. Congress did not fund the Air Force or NASA to conduct the in-depth study OTA suggested.

**Page 7. Alternative Approaches**

To the best of my knowledge, Congress also did not fund any of the alternate studies suggested by OTA. These studies are identified and commented upon as follows:

- Fund NASA to apply the MCD criteria to the Liquid Rocket Booster Study current at the time.
- Task the Air Force and NASA, who are designing a minimum cost space launch vehicle system under the ALS program, to also design a vehicle that resembles the Big Dumb Booster. (I did not view this as a valid suggestion because I felt that a design team should be permitted to derive their own design as long as it is based upon a rigorous minimum cost design analysis. It appears that the ALS program did design to the MCD criteria[6].)
- Fund the Air Force and NASA to investigate technologies related to the Big Dumb Booster; such as, the gas pressurization system of a pressure-fed propulsion system, and high-thrust, low-pressure engines. OTA noted that one of these recommendations was already underway under the Shuttle LRB program.
- Fund an industry competition between an SLV designed in accordance with the MCD criteria and one designed for minimum weight/maximum performance.
- Do not hamper the development of commercial, minimum cost SLV's,

particularly by startup companies. (I saw no evidence of congressional involvement in startup companies striving to design minimum cost launch vehicles.)

- Assume that the Air Force and NASA will make the correct design decisions since they are under pressure to reduce launch costs. (It seems that the Air Force more than NASA has been making progress toward this end by downplaying the minimum weight/maximum performance criteria.)

The remainder of the OTA final report will be discussed in the next Column.

With the writing of these Columns, I have sought to present a comprehensive understanding of the MCD criteria[7]. I have defined and rationalized the criteria, illustrated its use by describing several applications[8], noted particularly recent instances where it has been accepted and applied[9], and spotlighted the critical institutions that have been keeping it at bay as I have personally experienced[10]. I hope this critique of the OTA report has added to the understanding of the various aspects of the subject.

**References**

1. "BIG DUMB BOOSTERS A Low-Cost Space Transportation Option? An OTA Background Paper," February 1989. (Available for reading/downloading via the OTA Publications Web Page, or, more directly at http://www.princeton.edu/~ota/disk1/1989/8904.html.)
2. Column dated October 10, 1997 .
3. Column dated March 15, 1997 .
4. Column dated May 15, 1997 .
5. Los Angeles Times, October 2, 1988, p 18-19, quoting Thomas O. Paine, NASA administrator (1968-9).
6. Column dated November 10, 1997 .
7. Columns dated February 15 , March 4 & 15 , and May 15, 1997 .
8. Columns dated April 10 , and May 1 & 15 , 1997.
9. Columns dated May 29 and June 26, 1997 .
10. Columns dated September 18 , October 10 and November 10, 1997 .

**Notes**

A. Namely; Congress, the procurement agencies (primarily the Air Force and NASA), and the aerospace industry.

B. All OTA reports can be downloaded free of charge. However, they are PDF files and are read by Adobe Acrobat Reader. The reader can also be downloaded free of charge, see http://www.adobe.com/prodindex/acrobat/readstep.html.

**Q & A**

**What questions has the OTA report and the critique raised in your mind?**

I believe OTA is merely a report-generating organization, whereas Congress makes its decisions on political and economic faxctors which may or may not be related to the OTA analyses. It therefore does not surprise me that the Big Dumb Booster never got off the ground!
- Leon Bush
- Retired

OTA was a well-regarded organization. In their day they produced very superior reports in a wide range of technical subjects. Because of the way they treated minimum cost design and the Big Dumb Booster, I felt it imperative that I discuss in detail my relationship with OTA, and with OTA's relationship with Congress. I hope that many more readers have recognized that Congress, for economic and political reasons, saw to it that this work would be downplayed, if not maligned, as much as possible. I wish more readers would care to express their thoughts in these Columns. Their thoughts need not coincide with mine. I am sure there are viewpoints I have been blind to or have omitted and should be aired.
- Art Schnitt

I just got through reading the report. It was very interesting, and raised many questions in my mind. I was particularly interested in the fact that graphite-epoxy tanks could be that efficient while still being relatively cheap. Also, you could really "cook with gas" if you got some RTM and fillament winding setups with the capability of making an "all composite" MCD ELV. Lighter than most, cheaper than almost all of them....Still like the idea of using an ablative phenolic insert in place of active cooling. Heck, make the thing even lighter and easier to build -- use shperical tanks. The DC-X proved that you can build an egg shaped rocket, so why not just make an ELV version. Maybe as you suggest see if the first stage is realistic to recover. All in all, it looks fascinating. They did sound rather pessimistic, but oh well.
- Jonathan Goff
- Brigham Young University

January 28, 1998

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## OTA's Final Report on "Big Dumb Boosters" Part 2

This is a continuation of the previous Column in which the final report prepared by OTA on the Big Dumb Booster is discussed. Again the page numbers and paragraph titles refer to the final report[A].

**Page 11. Engines**

With respect to the scalability of pressure-fed engines, I should like to point out that the configuration of TRW's Lunar Excursion Module Descent Engine (LEMDE) that was proposed for all stages of the Big Dumb Booster had exhibited a scaling factor of 250. The operational 10,000 pound thrust LEMDE engine was throttlable to 1000 pounds of thrust while the same engine configuration was satisfactorily tested at Edwards AFB at a 250,000 pound thrust level. Therefore a further scale-up by a factor of 5 to 10 to the multi-million pound thrust levels appeared quite reasonable. Thus the further development of pressure-fed engines of the thrusts required by a large Big Dumb Booster does not appear to be a "major uncertainty" as expressed in the OTA report.

The question of whether to use single or multiple engines in each stage should be resolved by conducting a cost-weight-reliability tradeoff analysis. The major inputs would be:

- The anticipated production quantity of SLV's.
- Engine development costs (Costs increase exponentially with thrust.)
- Recurring costs of small to large thrust engines.
- Recurring costs and weights of a single engine and multiple engine installations. (Recurring costs and weights of multiple engine installations are likely to be higher because of the added thrust structure, propellant lines, and trapped propellants.)
- Engine and vehicle reliabilities. (Small changes in reliability convert to very large values of cost. If all engines have the same reliability, a single engine would show a higher vehicle reliability, and may likely obviate the need for engine-out capability.)
- Limited development funds. (Although the analysis may point to single engine

configurations in each stage, a start-up company, for instance, with limited funds for development may be forced to choose multiple engine configurations.)

Insufficient information on pressurization systems was available at the time the Big Dumb Booster was designed. "Main Tank Injection," that was under development at the time, was chosen because of its simplicity, and low cost and weight. Since then I have become aware of many other promising-looking systems. I feel confidant that a satisfactory system would be available for an MCD/SLV.

**Page 13. Propellant Tanks**

Contrary to OTA's belief that inspection costs of weldments of moderate strength steel propellant tanks would be inescapably high, Boeing had demonstrated total tank fabrication costs, including inspection costs, of only several dollars per pound[1].

Since the time the NASA-Langley representative at the OTA sponsored workshop[2] showed that propellant tanks fabricated from composite materials had the potential for reducing the size, weight and cost of the Big Dumb Booster, extensive development of composite tanks has taken place. Consequently, discussion of moderate strength steel tanks has become superfluous. Although composite tanks have higher costs than steel in dollars per pound, their use results in SLV's of lower cost in dollars per pound of payload. OTA recognized, in this example, that the MCD criteria calls for using "appropriate technology" rather than commercial or lowest cost technology.

**Page 14. Propellants**

The Big Dumb Booster proposed using the same propellants, Nitrogen Tetroxide and Unsymmetrical Dimethyl Hydrazine, that were being used by the Titan III launch vehicle. At that time the propellants were inexpensive and their deleterious affects on the environment were overlooked. They also were storable at ambient (rather than cryogenic) temperatures, making them compatible with low-cost steels. Besides, these propellants made use of the existing propellant-handling ground facilities.

Use of large quantities of these propellants has been banned. The selection of propellants for a current MCD/SLV involves a rather extensive survey and a cost-weight-reliability analysis. Composite tanks appear usable even at cryogenic temperatures; however, some composite tanks may require liners that are compatible with the propellant or are part of the fabrication process. Several companies who are currently applying the MCD criteria and are using composite tanks appear to have made satisfactory propellant selections.

**Page 15. Avionics**
These are the only subsystems that have a history of decreasing weight and cost and increasing reliability with time.

**Page 15. Launcher Reliability**
The reliability argument here revolved about a single issue. I claimed that an MCD/SLV, having fewer parts and generally less sophistication, was inherently more reliable. Moreover, in many cases, critical components did not require redundancies, or it was less costly to add weight to a single component to attain its desired reliability. This is in contrast to employing redundancy to minimum weight components that are designed close to the edge of failure.

Certainly very complex, minimum weight systems and components can be made exceedingly reliable. It is just a matter of spending the necessary amounts of time and money.

**Page 17. Favorable Studies**
I did not have the opportunity to review the reports of the studies cited. It was reported that by applying the MCD criteria, the cost of placing payloads in orbit was reduced by a factor of 4 and 5. However, there were monstrous increases in vehicle gross weights. My past designs showed weight increases of 15 to 20 %. I suspected that their designs did not take advantage of cost and weight savings made possible by using easily fabricated materials. Boeing's "Double-Bubble" design of an MVD/SLV[B]was a good example of a radical vehicle configuration that took advantage of the design possibilities the MCD criteria could provide.

**Page 18. Unfavorable Studies**
Nor did I review these reports. Both studies cited reported increased SLV cost. As noted previously[3], these may be the studies where hardware costs were based on historical minimum weight hardware data rather than estimated costs of minimum cost hardware.

**Page 19. Critique**
The preceding comment also applies here. I cannot comment on the NASA Liquid Rocket Booster study because I have not been exposed to the details of this work.

**Page 22. Institutional Obstacles**
Here OTA did justice to the Big Dumb Booster by indicating that:

- The Aerospace Corporation management was not enthusiastic about pursuing the Big Dumb Booster because its development would not make full use of their capabilities.
- Vested interests preferred the high costs associated with advancing technology and with the traditional approach to booster design. These interests often pointed to the spin-off benefits of advancements in technology even though several investigators have shown that it would have been cheaper to develop the spin-offs directly.

Detractors failed or refused to recognize the potential for payload cost reduction by employing the MCD criteria and an MCD/SLV, as explained in detail in a previous Column[4].

I wholeheartedly agree with the comment that "It is sometimes difficult to dislodge an incumbent." It has been particularly true in this case. No compelling force wanted to "rock the boat." Hopefully with the onset of the global economy and the widespread intent on keeping our national budget balanced, the aerospace community may be forced to adopt the MCD criteria.

OTA never looked back on "Big Dumb Boosters" in the three subsequent reports they prepared in answer to the Congressional Committees' request for an "assessment of space transportation technologies."[5,6,7]The storm created by Gregg Eaterbrook's cover story in NEWSWEEK[8]was skillfully handled until it blew over.

In late February 1989, I was asked by the project director of the OTA studies and reports discussed in these Columns if I would work with the OTA personnel currently investigating low-cost payloads. I said I would. This work culminated in the preparation of "Affordable Spacecraft[6]." The next Column will discuss this report and some of the information exchanged with the principal analyst with the hope that this will add to the understanding of the application of the MCD criteria to payload design.

**References**

1. Column dated May 15, 1997 .
2. Column dated September 18, 1997 .
3. Column dated October 10, 1997 .
4. Column dated June 12, 1997 .
5. OTA Report, (http://www.princeton.edu/~ota/disk1/1989/8927_n.html) "ROUND TRIP TO ORBIT Human Spaceflight Alternatives Special Report", dated August 1989.
6. OTA Report, (http://www.princeton.edu/~ota/disk2/1990/9003_n.html) "AFFORDABLE SPACECRAFT Design and Launch Alternatives Background Paper", dated January 1990.
7. OTA Report, (http://www.princeton.edu/~ota/disk2/1990/9002_n.html) "ACCESS TO SPACE The Future of U.S. Space Transportation Systems", dated April 1990.
8. Columns dated February 5 and September 18, 1997 .

**Notes**

A. Reference 1, Column dated January 5,1998 .
B. Circa 1970, reference unavailable.

May 4, 1998

18

## OTA's Report on "Affordable Spacecraft"

I gladly responded to the request to work with OTA on their study of the feasibility of lowering the cost of payloads. I was impressed with the capabilities and openness of Dr. Michael Callaham who was designated principal analyst of the study. Since I had last worked on low-cost payloads in 1967, I believed applicable work, which could further these studies, had been done in the interim by the aerospace community and could be obtained by OTA. I also hoped to convince Dr. Callaham of the validity of the MCD criteria.

The interface with Dr. Callaham lasted several months. He had no hang-ups with the applicability of the MCD criteria to payload design. We agreed that the initial and most important task was to acquire data and analyses of payloads that have been designed to the minimum weight/maximum performance criteria; that is, designed to decreasing levels of sophistication that weigh more and cost less.

I advised Dr. Callaham of the work of TRW in which an operating satellite had been redesigned to progressively lower levels of sophistication,[1] and that I was not given the unexpected results beyond a verbal description and a casual look at the summary curves. Dr. Callaham contacted the person who did this work but he too was unable to get a copy of it. I found this to be most regrettable because I had worked with the TRW individual and knew that he fully understood the MCD criteria and the methods of design. However he did obtain two interesting reports, one prepared by Rand and the other by Boeing, copies of which he sent to me for comment. He further obtained some study results from Lockheed and personally performed a singular point analysis, all of which is discussed in OTA's final report.[2]

OTA labeled lower cost, higher weight payloads "Fatsats." In their report, OTA examined three other cost-cutting techniques, two of which did not directly involve the application of the MCD criteria and are not discussed further. The third, called "Lightsats," should respond to the application of the MCD criteria to the same degree as Fatsats.

The following discussion includes the information I sent to OTA as comments to the Rand and Boeing reports and to the draft of OTA's final report. I have enlarged and revised the comments I submitted, improvements I hope, as a result of experience gained in the intervening years and increased time available to me now.

I evaluated the Rand report[3] as misleading except for the fact that the author permitted payload weight to increase, and assumed cost to vary inversely and exponentially with weight, thereby acknowledging one of the precepts of the MCD criteria. He correctly identified the optimum payload to occur when payload plus launch vehicle costs are at a minimum. The analysis, however, was purely parametric. Values were not assigned to the exponents in both the launch and payload cost equations. Under many assumptions, which I found difficult to evaluate in terms of reality, he concluded that lower cost launch vehicles would not provide significant savings in the cost of space operations.

OTA extended the Rand analysis by providing values to the exponents that define launch and payload costs as a function of payload weight. The costs of the Delta, Titan and Space Shuttle were used to determine the value of the exponent in the launch cost equation. However, the negative exponent in the equation for payload cost as a function of payload weight was arbitrarily assumed close to one. The latter assumption assured that only small cost savings would result in applying the MCD criteria to payload design; moreover, the optimum payload weight was shown to be about three times heavier than the minimum weight design.[4]

The Boeing report[5] was based on weights and costs estimated from preliminary designs of a "typical" payload. The payload included a small propulsion or "kick" stage.[6]The results of Eder's study is shown in Figure 1. The estimated cost was reduced 30% at a 15% weight increase. The author prudently did not carry the analysis much beyond a payload weight increase of 100%.

FIGURE 1. ESTIMATES OF PAYLOAD COST VS WEIGHT

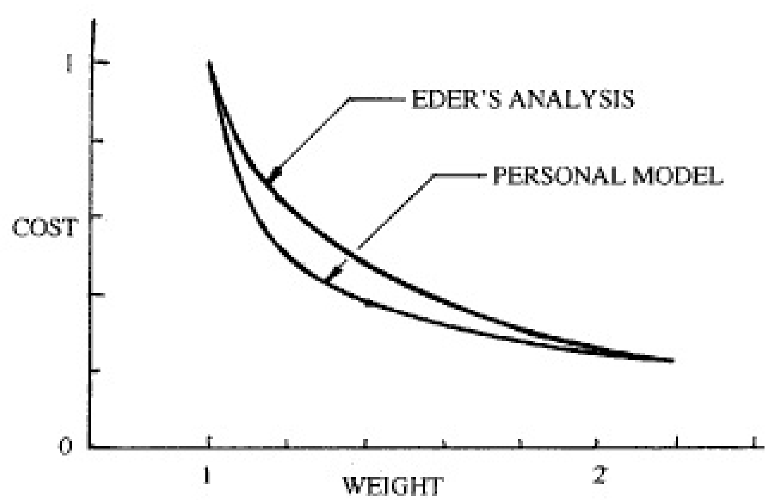


Figure 6. Payload and Weight from Boeing Report.

Neither OTA nor I concurred with Eder in his calling the study payload "typical." We felt that each of the vast number of payload types and missions would have a different cost-weight relationship, and that some of the relationships may differ sharply from that shown in Figure 1. Nevertheless, from personal experience with the design of space structures of lesser sophistication, I felt that the general shape of the curve was correct for most payloads. Specifically, I felt there would be an important, initial large drop in payload cost for a small increase in weight. This contention is supported by relevant data presented in the initial pages of the OTA report that refer to TRW's payload design experience.

Also plotted in Figure 1 is the personal model that is used in the studies that follow. It differs slightly from Eder's analytically derived curve by the assumption that payload costs are cut in half at a 20% increase in weight. The studies are intended to illustrate some of the overall cost consequences of the application of the MCD criteria to payload design. Specifically, the work answers the question: Under what conditions is the optimum cost of the payload related to the cost of the launch vehicle? In other words, when can payload costs be further reduced by lower launch costs?... Certainly in the boundary case when launch costs approach zero, the payload could consist of "unpackaged" laboratory-type components adequately protected against launch and space environments.

Insight to the answer to this question is contained in Figures 2 and 3. Two classes of payloads are considered: payloads that are few in number such that the nonrecurring costs are significant, and payloads that are fabricated in the hundreds, typical of direct-access satellite systems. It is assumed that all minimum weight/maximum performance payload designs weigh 10,000 pounds. OTA launch costs versus payload weight, current at the time the report was prepared (1990) are shown as a continuous function (Curve A).[7] Lower cost launch costs are assumed at one-third of "current" launch costs (Curve B).

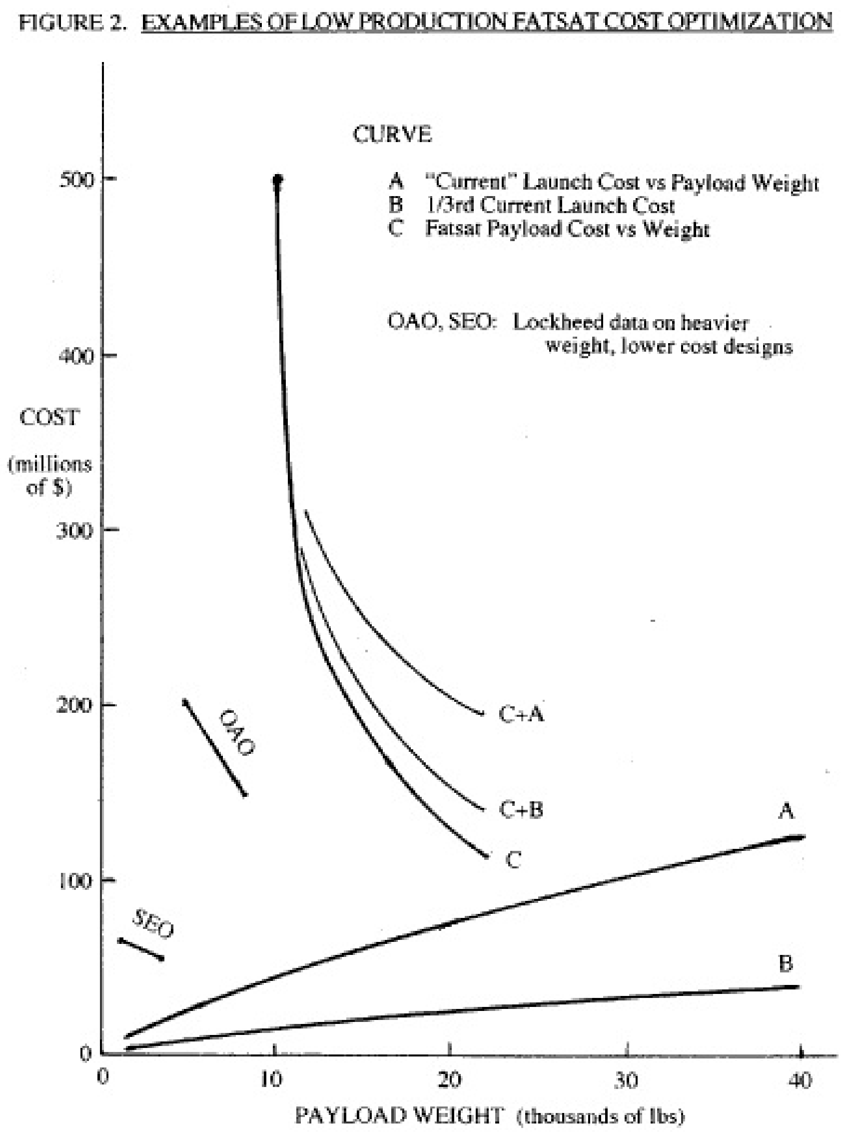


Figure 7. Cost Estimate from Boeing Report.

Figure 2 shows what the optimization of low production payloads might look like. The minimum weight cost of the payload, which includes a small propulsion stage that places the satellite in orbit, is assumed at $50,000 per pound, fully fueled.[8] Curve C represents the Fatsat payload cost-weight relationship under the assumption made in Figure 1. In this example no additional saving in payload cost is incurred by the lower launch costs. The optimal payload weight is the same at 22,000 pounds for both launch costs.

Some of the data provided by Lockheed are also plotted in Figure 2. These are estimates of the weight growths and cost reductions of redesigned versions of the Orbiting Astronomical Observatory (OAO) and the Synchronous Equatorial Orbiter (SEO).[9] Because of the ambiguous conditions under which these estimates were made, the data are considered to serve only to show that both satellites responded to approximately the same Fatsat cost-weight relationship: the more expensive satellite experienced a larger decrease in cost.

FIGURE 3. EXAMPLES OF HIGH PRODUCTION FATSAT COST OPTIMIZATION

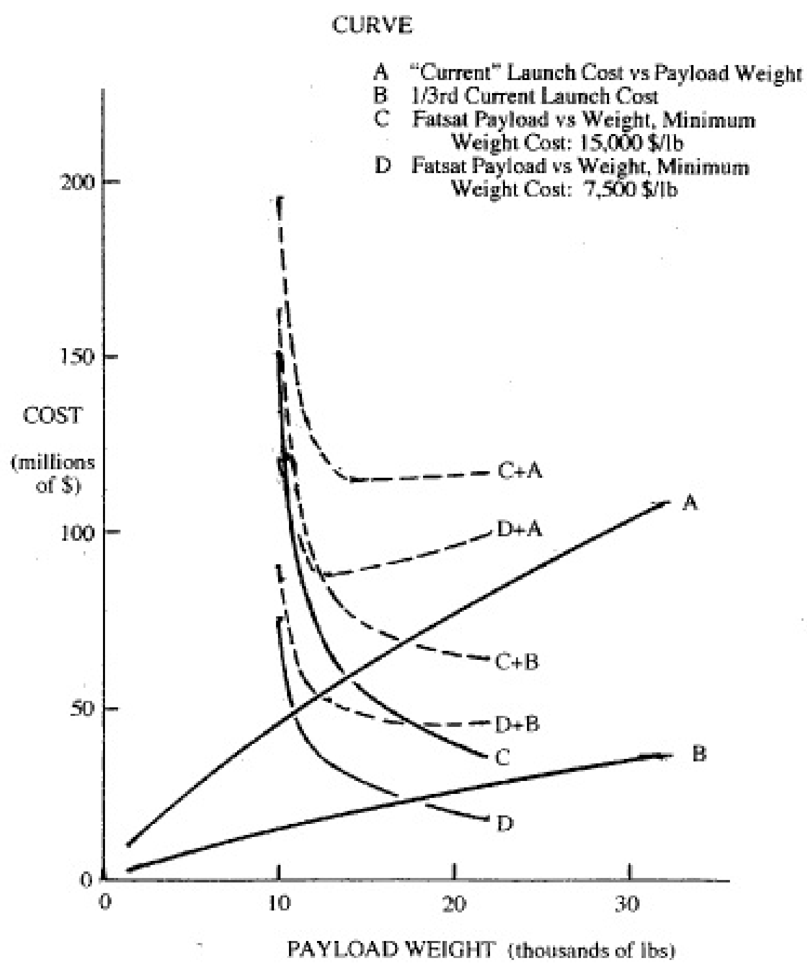


Figure 8. Cost by Production Rate from Boeing Report.

Figure 3 depicts what the optimization of high production payloads might look like. Two minimum weight payload costs are considered: one at $15,000 per pound (Curve C) and the other at $7,500 per pound (Curve D). The immediate observation that may be made from viewing the payload plus launch costs is that optimal (saddle) points appear when the payload cost approaches launch costs. This means that optimal cost payloads may not require large increases in payload weight.

Of additional significance is that in both cases, reducing launch costs decrease total (payload and launch vehicle) costs above that gained by the reduction of launch costs. This point is exhibited in the following table. All costs are in millions of dollars, and payload weights are in thousands of pounds. Scaled, not computed values are given.

| Curve | Payload Weight | Launch Cost | Payload Cost | Total Cost |
|---|---|---|---|---|
| C+A | 14,500 | 59 | 55 | 114 |
| C+B | 14,500 | 20 | 55 | 75 |
| C+B | 22,000 | 27.5 | 34.5 | 62 |
| **Maximum Savings Among Fatsats:** | | 31.5 | 20.5 | 52 |
| | | | | |
| D+A | 13,200 | 54 | 33 | 87 |
| D+B | 13,200 | 18 | 33 | 51 |
| D+B | 20,000 | 25.5 | 19.5 | 45 |
| **Maximum Savings Among Fatsats:** | | 28.5 | 13.5 | 42 |

Figure 9. Cost Savings.

The reductions in total cost from $75 million to $62 million (Curve C) and from $51 million to $45 million (Curve D) are the additional reductions that are realized by lower launch costs.

Of course, launch costs are not continuous, and the method of treating discrete launch vehicles is discussed in the Column previously referenced. Note that the application of the MCD criteria results in larger payloads and launch vehicles. Further note that for a small cost penalty, optimal payloads and launch vehicles may be appreciably less in size.

It is hoped that these examples, although future payloads will have somewhat different cost-weight characteristics, will spur the development of a family of MCD/SLVs[10] as well as assist in the design of low-cost payloads.

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3. Carl H. Builder, "Are Launch Vehicle Costs a Bottleneck to Economical Space Operations?" Rand working document D-19482-PR, December 1969.
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June 4, 1998

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## A Relevant Happening

I was quite taken by the possible misdeeds by the White House and several aerospace contractors relative to China launching American satellites. It has been a sizable, long-lasting political flap[1,2,3]. Many questions have been raised by members of Congress and the media. All questions have dealt with the possible transfer of technology to the Chinese, and the probable reasons behind the contributions made to the Democratic Party by the Chinese and a satellite contractor. I found that an obvious question relevant to my interests – promoting low-cost space launch vehicles – was not asked.

One of the stated, alarming consequences of this interface with the Chinese was that they might now be able to improve the accuracy of their ballistic missiles. The politically charged situation has embroiled many branches of government. Most alarming to me was that no one asked why the Chinese were launching our satellites in the first place although I do recall reading one article, which explained without elaboration, that Chinese rockets were available and were less costly than ours. No one chose to explore why the Chinese have been launching our satellites during the years of the Bush and Clinton Administrations while at the same time no suitable American launch vehicle was under development or in the initial stages of production. I felt that a review of the many failed and current NASA and Air Force programs to develop low-cost launch vehicles would be of interest, although I have partially covered this subject in previous Columns.

In gathering references, I came across an article by Gregg Easterbrook[4]on the "OP-ED" page of the June 2, 1998, New York Times in which he discusses the question I have chosen to ask and answer. In his enviable style he writes: "... the root-cause question of the scandal has gone unasked – why are American satellites sitting atop Chinese launches at all, rather than arcing skyward from the space installations American taxpayers have spent billions to construct?"

Easterbrook discusses the principal reasons for this situation. He also discusses current launch vehicle development programs that are meant to reduce costs. I plan to add to his discussion and explain personal beliefs, some from an insider's point of view. I will also state my views of current NASA and Air Force launch vehicle programs which, by the way, differ from those of Easterbrook's.

Easterbrook makes the following poignant points:

- "... NASA and Pentagon officials" have been "reluctant to build low-cost rockets... for fear of losing the golden goose of high launching costs." Moreover: "To justify manned space flight and the space shuttle, NASA has for three decades shunned research into the type of relatively inexpensive rockets China and other nations have featured."
- "Other American satellites have flown on French or Russian rockets, which also charge appreciably less than their American counterparts [5]."
- American launch vehicles, on a dollar per pound of satellite basis, cost more than twice that of the Chinese. For a Loral size satellite, this represents a difference of about "$50 million or more."
- Preceded by several extremely hi-tech and costly programs that were canceled, current programs designed to reduce launch costs are the Pentagon sponsored [family of] Evolved Expendable Launch Vehicle[s] and NASA's recoverable, single stage (X-33) vehicle. "... full-scale operation of either design is years away."
- "Several start-up companies... are now designing what may become the first generation of entirely private space vehicles."
- "... American space policy not only created the conditions that led to the satellite deals with China, but it also has jeopardized its own hopes for the future."

In 1968 when the Air Force program office was established to develop The Aerospace Corporation's Minimum Cost Design/Space Launch Vehicle (MCD/SLV)[6]and was abruptly closed down by the Pentagon, I drew the conclusion that the aerospace industry convinced members of Congress that low-cost launch vehicles "would spoil the party" and that the idea should be suppressed in the future since I, as innovator and project manager of the MCD/SLV, was not permitted to work on any Air Force program for the rest of the (12) years spent at Aerospace.

Then I heard that NASA was behind the cancellation because they did not want a launch vehicle to compete on a cost basis with the Shuttle. Besides, the Shuttle needed as many payloads to launch as possible in order to justify its development and to amortize the large research and development costs. Many years later I heard that launch vehicle policy emanates from the White House. Lt Col London, [7] who researched the subject of MCD meticulously and in fine detail, identified the agency that blocked the MCD criteria and the SLV as "the government." I currently believe that all of these agencies were and are still involved in formulating and maintaining this policy.

During the past several decades DoD and NASA have spent billions of dollars upgrading the Space Shuttle and the expendable launch vehicles. New vehicle programs were also worked on and they all carried the requirement to reduce cost appreciably. The gap in the low payload weight range was filled by the development of the Pegasus, and its larger derivative, the Taurus. A considerable sum of money was spent on the National AeroSpace Plane (NASP) program, an unrealistic launch vehicle concept. The concept required an unreasonable amount of advanced technology and development and was eventually canceled. The "NASP aimed to develop a new type of supersonic combustion ramjet (scramjet) engine that could propel an aircraft to near-orbital speeds [8]." The gap in the high payload weight range was filled by the development of the Titan IV vehicles, extensions of the Titan family.

A serious attempt at reducing costs was made in the design of the Advanced Launch System, an expendable rocket configuration. The MCD criteria was reputed to have been used, at least partly, in the design [9]. However its projected nonrecurring and recurring costs were erroneously raised. This may have contributed to its cancellation, although the official reason given was that it was no longer needed because of the demise of the SDI program.

In recent years, the Air Force has been supporting the development of the Evolved Expendable Launch Vehicle (EELV) program. These vehicles are scheduled to become operational in the early part of the next decade. They are modified existing expendables. One of the expressed purpose of the program is to reduce recurring costs "by a minimum of 25%, with an objective of 50% [10,11]." This range of cost reduction will approximately meet foreign competition. In the future, however, the cost of foreign launchers may be less.

NASA is not contributing realistically to a reduction in launch costs with their current program. Their effort is to develop a single-stage-to-orbit, fully recoverable launch vehicle. My views of this program are extremely negative [12].

I concur with Easterbrook, in his OP-ED article, that a start-up company may now be developing the first of a new breed of very low-cost vehicles. I know of at least one, and perhaps two companies whose designs much resemble the MCD/SLV. In the past, private companies have stumbled along the way, primarily due to lack of funds[12].

It appears, therefore, that the new "China Syndrome" will not end in the near future. The only ray of hope rests with the start-up companies.

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1. TIME Magazine, June 1, 1998, p 46
2. AVIATION WEEK & SPACE TECHNOLOGY, April 13, 1998, p 23; April 20, 1998, p 25; May 11, 1998, p 55; May 25, 1998, p 19; June 1, 1998, p 22.
3. INTERNATIONAL SPACE INDUSTRY REPORT, April 9, 1998, p 2.
4. Gregg Easterbrook, "Big Dumb Rockets," NEWSWEEK; see summary of article in Column dated February 5, 1997.
5. Further discussion of this point may be found in Column dated January 26, 1997.
6. See Columns dated May 1 & 15 , 1997.
7. For a discussion of Lt Col London's report see Column dated February 5, 1997
8. FAS, MILITARY SPACE PROGRAMS, LAUNCH SUPPORT , Federation of American Scientists, http://www.fas.org/spp/military/program/launch/overview.htm
9. Column dated October 10, 1997 .
10. "DoD Reverses Strategy on Evolved Expendable Launcher," LAUNCHSPACE, April/May 1998, http://www.launchspace.com/mag/0302/eelv.html.
11. One notable example of cost reduction is the development of the RS-68 oxygen/hydrogen engine for the EELV Delta 4. In this instance, the application of the MCD criteria is apparent. Compared with the Shuttle SSME engine, the RS-68 has 80% fewer parts. The nozzle appears to be made of laminate rather than fuel-cooled tubing. (See AVIATION WEEK & SPACE TECHNOLOGY, MAY 4, 1998, p 53.) Quoting from this page: "A major shift in management philosophy is leading the RS-68 development. Cost, not performance, is the focus - with performance viewed more in the context of what can be traded off for the sake of lowering cost or simplifying the design."
12. Column dated June 26, 1997 .

SCHNITT, Arthur

Dec. 2, 1915 to Jan. 3, 2010

Arthur Schnitt, 94, passed away peacefully at his home in LA on January 3rd. Dearly loved father of David and Susan, his four grandchildren and extended family. A native of NY, he was a nationally recognized aeronautical engineer. He earned his bachelor and masters engineering degrees from New York University, worked on aircraft design at Curtiss-Wright during the war and became a leading expert on structures. He then worked for Bell Aircraft and Ramo-Wooldridge on the Minuteman Program where he developed the Minimum Cost Design concept and the "Big Dumb Booster"; his story was a cover story in Newsweek and Reader's Digest magazines. He finally worked at the Aerospace Corporation until his retirement.