The requirements of a Strategic Defense System (SDS) have levied many challenges on today's government and industrial space resources. Although most of the technical challenges and associated costs lie in the development and deployment of the space based weapon systems and sensors themselves, there also exists a challenge in developing a launch system architecture able to support a deployment decision, if and when it is made. This challenge is not so much in terms of technical risks, as the nation has proven it can build launch vehicle systems capable of lifting heavy payloads, but in terms of building a launch system which is able to sustain the necessary high launch rates in a cost effective and operable manner.

Although they constitute only ten to thirty percent of the total recurring costs of the national space program and are the least complex in terms of technical sophistication, today's launch systems are the limiting factor on any initiatives this country might wish to undertake in space. They are extremely limited in terms of their ability to lower the cost of access to space, accommodate substantial increases in total mass or mass/launch rate to orbit, provide the surge needed to recover from launch failure, or provide major improvements in the operational responsiveness of the launch process. This is due to several factors, including fabrication of the vehicles based on 1960's manufacturing techniques, operation within tight performance margins, vehicle processing that is based on pre-Apollo concepts of booster check-out, and payload-vehicle interfaces that are often optimized to specific payload requirements. In sum, today's launch vehicle systems can meet the current launch mass requirements of this nation through the next decade only if no new initiatives, such as the deployment of a Strategic Defense System, are undertaken. Today's vehicles cannot meet the cost and operability goals we now understand to be of equal importance to the mass requirement.

The purpose of this paper is to explain the fundamental requirement for cheaper and more reliable access to space which can only be accomplished through a new system, to describe the fundamental characteristics of such a new system, and then to compare the payback of such a system against existing systems.

**Current Launch System Capacity**

The payload capability of today's existing systems is extremely limited. Currently the Space Shuttle is the highest performing of the current systems with a payload capacity of 51,000 lb. of cargo to low earth orbit; however, the after effects of the Challenger accident investigation have limited its availability and will adversely affect its total payload capacity. The current expendable launch vehicle systems provide varying capabilities, ranging from Titan IV's 39,100 pounds to the Titan II 5,200 pounds performance to LEO. This payload weight limitation has caused cost growth for the spacecraft themselves as they strain to fit within the vehicle limits. To live within this constraint, the spacecraft are forced to trade cost for weight, to turn to the launch vehicle for necessary services, and to embark upon integration programs with the launch vehicles which have the effect of making the launch vehicles nothing less than extensions of the payloads themselves. This not only increases program costs but has the added effect of limiting the ability of the spacecraft to move from one launch vehicle to another.

Even if the problem of switching payloads from one launch system to another is resolved, the existing space launch infrastructure can only support a limited number of flights per year. The availability of launch systems -- the fraction of the time the system is operational -- is a function of its normal launch rate, its reliability, its surge rate capability (the ability to work off payload backlogs by going to a higher than normal launch rate), and the standdown times associated with system failures. This is depicted graphically in Figure 1.

![Figure 1. Operability of a typical launch system](image-url)
facilities will not improve capability so long as the system reliability is low and the system downtime for each failure is high. Translated into an annual capacity based on an 80% load factor (since a system does not always fly at full capacity), the nation as a whole is limited to approximately 700,000 lb. annually to LEO for any extended period of time.

The net effect of an investment to improve the Titan IV and develop the Shuttle-C would be to double our national space launch capacity to approximately 1.4 million lb. equivalent annually to LEO due east from the Eastern Space and Missile Center (ESMC). This would allow for several new DoD programs and provide sustained support for the space station. However, such a mission capability would not permit either the deployment of a Strategic Defense System (SDS) or such Civil Space Leadership Initiatives (CSLI) as lunar habitation or manned missions to Mars. Any one of these three projects would require a launch system capable of placing at least three million pounds per year into low earth orbit. Nor would those modified vehicles improve either the cost or operability performance of the fleet.

The Model

The Space Transportation Architecture Study (STAS), a two year effort involving four major aerospace contractors, looked at hundreds of architectures and identified the various vehicle and technology requirements necessary to support an expanded national space program. Typical SDS mission models studied showed requirements for more than doubling the current national payload to orbit requirements by the year 1998.

In terms of payload size and weight, a typical SDI Kinetic Energy Weapon (KEW) mission model consisted of five payload types. Though large in number, the payloads described in this mission model were small enough in size and weight to be able use current launch vehicles and upper stages for deployment. The vast majority of these payloads required a West Coast launch capability to high inclination, low earth orbits. The mission areas covered by these payload types included surveillance, battle management/command, communication and control, and target acquisition, tracking, and elimination.

The large scale payload deployment rate began in 1997 and ramped up to approximately 320 Titan/Shuttle sized payloads per year over the following nine years. Spacecraft replacement and continued spacecraft servicing accounted for the relatively constant deployment rate from the years 2009 through 2020. Once the deployment rate had stabilized, it was assumed, in this study, that the payload mass launched per year leveled off at approximately 1.8 million pounds.

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The Study Results

This scenario, although used for study purposes, showed the inherent challenges associated with increasing the launch requirements in terms of both payload size and rate compared to today's space launch architectures. The study showed that to support such a deployment using the Shuttle alone, because of the volume limited nature of the Shuttle and the fact that only three KEM spacecraft could be deployed per flight, approximately 2000 Shuttle flights would be required. Alternatively, using the Titan IV system would require over 2600 flights due to its even lesser capabilities.

Given the current reliabilities, extensive downtimes associated with launch system failures, limited flexibility to switch payloads among launch vehicles, and launch limitations due to external factors such as weather or other environmental conditions, analysis has demonstrated that the current fleet of launch vehicles in the inventory are incapable of even approaching the launch rates depicted above. A new vehicle, a heavy lift cargo vehicle, is required.

In contrast to the United States, the Soviet Union has developed a large number of different vehicles that can support launches of a number of different payload configurations. This provides the Soviet Union with not only the "lesson learned" benefits from repetitive operations but also the protection from prolonged groundings which the United States is presently experiencing. These groundings have associated with them a tremendous monetary cost and loss of apparent world status in space flight leadership.

Characteristics of the Advanced Launch System

Given that a new system is required to meet national objectives, what would it look like and how much will it cost? Given that is must be designed for both high reliability and high flight rates, is it possible to build such a system at an affordable cost? These are some of the basic questions that the Advanced Launch System Program Office and its contractors looked at as they built upon the results of the STAS report and applied a creative approach to both the vehicle and the operations system that would support it.

The driving feature of the Advanced Launch System is that it is being designed as a transportation system. It will rely on high reliability and short post-failure standdowns to insure high availability. It will achieve the required throughput and on-time operations rate through ground systems and facilities compatible with high launch rates. It will employ simple, standardized procedures, including no physical access to the payload after mating, and will be designed with broad operating margins and envelopes. It will also allow cargo-launch vehicle independence and interchangeability through simple, standardized interfaces and minimized payload services. The ALS will use an In-Transit-Launch approach to minimize on-pad time and will not even have a gantry tower for access on the pad. All on-pad services will be provided at the base of the vehicle to negate the need for gantry towers and its associated "standing army" of technicians. In short, the ALS operations approach looks more like that of the C-141 or C-5 than that of the current launch fleet.

One of the primary goals of the ALS program is to reduce the recurring costs associated with our launch operations. Congress has legislated a $300 per pound to LEO cost goal (b) to the program which agencies believe is achievable if one designs a highly operable system based on simplicity and robustness. Current estimates indicate that less than $500 per pound can be achieved by 2005 with an all-expendable vehicle system. While variations that include some degree of reusability would provide even greater savings given high mission models. The key technological features of such a system include a low-cost liquid oxygen/liquid hydrogen (LO2/LH2) engine, and the integration of numerous available or soon to be available subsystem technologies such as automated manufacturing, "paperless" management, and the use of expert systems for health monitoring and flight operations. The on-going ALS focused technology program is in place to: (a) provide the basis for the program, (b) allow the implementing agencies to demonstrate mastery of the technologies to prove the cost goals, and (c) provide a source of improved technologies that can be spun off to existing launch systems in the near term.

Analysis indicates that the investment cost of a 150,000 lb. payload ALS would be paid back in lowered operating cost by the year 2003 at a 2 million pound per year mission model as compared to a Shuttle-C and 2001 compared to a Titan IV, assuming those systems could even be flown at such a launch rate. Of course, higher mission models would result in an earlier amortization and even a low model of 1 million pounds per year would be amortized by the year 2008 compared to the Shuttle-C and 2007 for the Titan IV. A SDS deployment similar to the mission model described above would be amortized prior to 2002 compared to the Shuttle-C, even if you assume that Shuttle-C is as reliable as the ALS, can fly as often, and can carry the same 150,000 lb. payload.

While the operability and cost requirements of the ALS are well known, the capability requirements have not yet been fully defined. While it is clear that any new vehicle should provide a vast increase in actual payload size and weight capability, the specific requirements have not yet been clearly defined. In addition, the actual launch rate requirement has not been determined as it is dependent on the mission requirements of the systems to be deployed. Given this uncertainty, it is likely that a decision to proceed with the ALS development effort will include direction to retain...
flexibility in the operational capability
arena while the community sorts out the exact
payload requirements for a future launch
system. It appears that there is sufficient
time in the program to allow these
requirements to be determined before
significant cost and schedule impacts would
occur.

The Challenge

Thus, as the Air Force looks to the
future, it must determine whether the current
vehicles, or their derivatives, will continue
to meet the nation's needs. The issue is not
projected payload sizes, orbital geometries
and launch rates; it is the Air Force's
ability to meet the obligations of the
Executive Agent for space launch for the
national security needs of a space faring
country.

In meeting this obligation a commitment
is needed to a new generation of launch
systems capable of meeting requirements after
the turn of the century. This commitment
must acknowledge that major changes will be
needed in production and manufacturing,
payload interface, pre-launch processing and
launch and flight operations. While the
price of such a commitment will be high, the
rewards will be substantial -- a family of
vehicles that meets the operational
requirements for availability, reliability,
flexibility and assured access to space while
lowering the total cost of space operations.

This high price and its associated
benefits, however are highly dependent on the
costing criteria and the mission model that
is assumed. Factors such as vehicle
capacity, total system capability, and
operability have to be examined to fairly
evaluate alternatives associated with
satisfying any mission model.

To be successful, this commitment must
be more than a commitment to a new launch
system development; it must include a
fundamental change in attitudes about space
operations. Traditional tradeoffs between
operational characteristics and performance
must be decided as much on military need as
on technical imperatives. This system must
be more than a system to provide economical
high mass/high launch rate capacity. It must
have diversity to satisfy operational
requirements across the spectrum of payloads
from today's Scout class to the 100,000 Kg
class of a Strategic Defense System. The
family of vehicles that will satisfy those
requirements may result from modularity in
design of one or more new systems, from
evolutionary application of technology to
existing systems, or from a combination of
approaches. Most importantly, the commitment
must be sustained over a period of decades to
meet the long term national needs for a
robust, economical, operational launch
capability.
Simulation and testing, the infant offspring of new capabilities in computerized systems analysis, is taking large strides toward maturity as the Strategic Defense Initiative's (SDI) National Test Bed (NTB) begins to come on line. When fully operational in 1990, NTB will provide the nation a unique resource whose potential impact reaches beyond SDI into nonmilitary government and commercial efforts.

The NTB is a primary element of the five-year, tri-service SDI effort. Its purpose is to study concepts and technologies of ballistic missile defense through the use of computer simulations built from very large databases.

In its technical challenges, the NTB will explore the capabilities of supercomputer parallel processing, distributed simulation modeling, and Global Wide Area Networks operating at high data rates. More specific to the SDI program and joint military applications, the NTB will help develop SDI software and hardware architectures, study battle management/C3-cubed, and evaluate the human role in rapid-paced nuclear conflict scenarios.

The development of these simulated scenarios will provide a system-level framework into which key defense technologies are plugged to observe how they perform. This will permit the testing and identification technologies showing significant promise from those needing further basic research so that the National Command Authorities can make informed decisions on SDI.

Perhaps the most bipartisan justification for the NTB is that it will supply a factual and rational basis for assessing if the concept of a ballistic missile defense system is both technically feasible and economically viable.

The NTB is actually a concept of facility utilization, rather than only a nationwide network of research facilities. It coordinates, diverts, and previously isolated computer research centers to act as one immense system. The hub of this network is the National Test Facility (NTF) under construction at Falcon Air Force Base, located on the plains east of Colorado Spring, Colorado. The "spokes" are existing research sites around the United States, linked through the NTF by high speed satellite communications. Each site is capable of providing specialized toolsets and scientific expertise to be applied to SDI simulations. Thus the best minds and facilities of the nation can be linked in to work on specific problems as needed.

The NTB computers will be able to model the full end-to-end scenario of a conflict involving thousands of launchers, warheads and decoys; remote sensors and antisatellite weapons; ground-, air- and space-based defenses of different types; nuclear effects, countermeasures and other conditions. The resulting baseline environment will be a key research and development tool for evaluating individual technologies.

Because of its R&D status, required by international agreement and Congressional constraints, the NTB network is not part of any operational defense system, however, it could draw data from such systems for use in simulation experiments. Furthermore, command and control algorithms and man-in-the-loop interfaces used in the simulations are intended to model how algorithms or men interact and affect the system, not to formalize any specific solutions.

Indeed, stringent regard for compliance with national and international law is an essential part of the SDI research program. Every proposed test must pass close legal scrutiny to avoid jeopardizing the system's existence. One advantage of a National Test Bed, is that it can simulate portions of an experiment that would violate a treaty if it "physically" existed in the experiment.

At present, the NTF occupies 100,000 square feet of leased space in the Consolidated Space Operations Center (CSOC) building at Falcon AFB. Its "early" configuration, now in operation, consists of a Cray supercomputer, an IBM 3090, and two ELXSI super minicomputers connected in a local area network that can support 120 terminals for simulation and Experiment design, development, management and analysis. Narrow Band communications support the SDIO, Los Alamos National Lab, and the Army's Strategic Defense Command, Advanced Research Center. The system already can run "course fidelity" end-to-end simulations at approximately real time. Also up and running is an interactive gaming center which has been performing man-in-the-loop runs of simulations.

By early 1990, the growth to the final, or "core", configuration will be completed. This growth will include three more IBM 3090s and four VAX 8810 or 8820's. Also, the Cray's communications link will be reconfigured for a "hyper-channel" wide-band, high-speed data rate.

The Wide Band Telecommunications links to the various sites of the national network will have been completed by this time as well. These sites, as presently planned, are: SDC at Huntsville, AL; SDIO and the Naval Research Lab in Washington, D.C.; Los Alamos National Laboratories in New Mexico; General Electric's Valley Forge, PA center; the USAF Electronic Systems Division near Boston, MA; Rome Air Development Center in New York; the Foreign Technology Center at Wright Patterson AFB near Dayton, OH; the USAF Satellite Test Center at Sunnyvale, CA; and the USAF Space Division in Los Angeles, CA. Additionally, there will be two relocatable uplinks that can be "shipped in" and support other laboratories, academic research centers and technology contractor facilities.
During the summer of 1990, the computers will be added. The full-up core system will support 300 workstations to be used by 100 permanent military staff and additional non-military research teams whose numbers will vary with the overlapping experiment schedule of the NTB.

Part of the system will be located in a highly secure, TEMPEST-qualified area where the simulations can utilize the very latest intelligence data. This sensitive information will be critical as the SDIO approaches major "build or not to build" decisions.

The computing capacity of the fully operational NTB will be astounding. As an indicator, while the EOC configuration's early simulations were able to operate at near realtime using roughly 7 MIPS (million instructions per second), the current simulation support requirements are expanding across 10 processors at 7 MIPS each. By the end of this year, the toolset will be moved onto the CRAY, and the NTB will have conducted a major experiment, two major game exercises and 400 architectural simulations.

The demands placed on the NTB is expected to grow almost geometrically in the coming years as shown by Table 1 used for hardware sizing. In addition each of the Experiments, Exercises, and Simulations, becomes geometrically more complex as research data results from across SDI is incorporated into the National Test Bed Toolset.

The actual number of runs for initial architecture simulations is 6 to 12 times greater, since each simulation must be repeated for calibration and validation. As simulations increase in complexity, so will the number of validation and calibration runs. Already the amount of data generated by simulations has been such that every hour of simulation has required an hour of output data processing afterward.

High fidelity simulation enables testing hardware without the usual "build it and see how it works" approach. It also allows for test of design or operational concepts in a realistically complicated environment which cannot be established for a physical experiment (Nuclear War).

When testing a specific technology -- such as a space-based radar -- the simulations will have extremely fine detail and inject data from physical experiments, and collect measures of effectiveness where the simulation interacts directly with the test subject. Further simulation layers away, the interfaces will require only enough fidelity to provide the "realism" of a full environment to the detailed layers below. This allows the maximum application of Computational Power on the subject under study.

The data and algorithms from these hi-fi runs will upgrade the accuracy of the full, end-to-end simulations without slowing the run time. Question arising from this data and algorithm importation approach are the methodologies and reliability of scaling. What steps and validations are needed for a factored portion to represent the whole environment, or how much of the entire environment be recreated to be credible?

The National Test Bed, therefore is a technology research program, in and of itself. Can such a facility provide the necessary data to the National Command Authorities, with the confidence needed to support their decision processes?

Assuring that NTB's simulations of reality are valid will require a degree of trust, margins, and constant reassessment. We will utilize the Technology Validation Experiments to learn how much we can trust computer models as ground truth and perform predictions are reconciled, and modeling logic is improved. Margins of error in an NTB model's accuracy are evaluated for sensitivity by changing the simulation's parameters -- such as reducing the successful kill percentage of an interceptor system, allowing a key sensor to be knocked out, or programming a failure in a system. Those parameters show to be the most sensitive, indicate areas for higher confidence, either through more detailed algorithms or validation through experiments.

Reassessment of NTB accuracy will be a product of many evaluations from different perspectives. Not only is SDI a tri-service operation, with their particular views of the world, but it also involves academics from several educational institutions; and it interfaces with defense contractors across the nation. These various interest groups are working on a variety of technologies, many or most of which will never reach the procurement stage. Rest assured that any National Test Bed supported simulation and test that shows promise for an SDI system will come under critical scrutiny by those involved with competing systems.

Eventually real-life, full-scale system tests will also provide reassessment of large specific areas of the NTB databases. For example, the planned Sensing, Acquisition, Tracking and Kill Assessment (SATKA) integrated experiment will use

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a Vandenberg to Kwajalein test launch to test the NTB's computing ability. Data from test sensors will be compared with "truth" data from existing systems long used to track such test flights. The NTB will replicate the data to make one launch look like ten to twenty, then study how well the computers can pick the warheads out of the data flow.

Another proposed major experiment, STELLAR, will use the NTB to observe how human command and control works in a strategic defense situation. The test involves simulated command centers for both space and ground systems. It is actually a combining of two similar experiments, but had been scheduled to run independently. By using the NTB to coordinate and combine the tests, each will be more comprehensive than it would have been.

In the future, as the NTB database of the results data and algorithms expands the military services will be able to avoid unnecessary duplications of computer simulation and test activities. Instead, they can concentrate on questions being evaluated rather than the method of evaluation, and draw upon the NTB's vastly greater combined resources. This should provide long-range improvements in both the cost efficiency of testing and the interoperability of military branches.

Finally, in the "what if" category is the question of the NTB's future as the critical questions of SDI are evaluated and decisions made. It would be illogical to suppose this resource would "wind down" in activity or go to waste.

In our shrinking world, a great many of our national policies are effected by large "system of systems". The NTB has potential service in areas such as commercial air traffic control, telecommunications, space exploration, and commerce. In recent years, for example, we have learned that the interaction of the national airspace, commercial, and military aircraft may be made more manageable through high speed manipulation of networked databases for simulation, prediction, and conflict resolution.

We can only imagine what is possible in the non-military realm as we aggressively move forward and discover what can be done in the SDI arena. The next few years will provide the experience and tools and knowledge of what can be learned through the application of this new and exciting national resource, the NTB.