Spacelift 2025
The Supporting Pillar for Space Superiority

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by

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Executive Summary

The US spacelift system in 2025 focuses on routine operations. The research and development (R&D) mentality of past spacelift programs is replaced by the aircraft-like operations of a fully reusable spacelift system, operated by both commercial industry and a US spacelift wing. Though developed primarily as a practical and affordable alternative for orbital access, the multipurpose transatmospheric vehicle (MTV) is expanded into force-enhancing missions like intelligence, surveillance, and reconnaissance (ISR), global mobility, and strike. MTV becomes the strategic strike platform of 2025. It can be flown manned or unmanned, depending on mission requirements, but it is primarily used in the unmanned mode. With the capability to accomplish the earth-to-orbit (ETO) mission as well as these other earth-to-earth (ETE) missions efficiently, the MTV is a flexible platform which strengthens all air-and space-core competencies. MTV is complemented by the orbital transfer vehicle (OTV) for space orbital missions. After MTVs park satellites in low orbits, OTVs provide the additional thrust needed to push the payloads into higher energy orbits. OTVs also facilitate the maintenance of satellites in orbit by retrieving existing platforms for repair, refueling, or rearming. Finally, OTVs give the spacelift system a rapid orbital sortie capability for deterrence, space control, reconnaissance, counterspace, and force application.

This paper recommends Air Force support for NASA's X-33 transatmospheric reusability demonstration and investment in a follow-on military MTV and an initial OTV using today's technologies. Once routine operations are institutionalized with these first generation reusable systems, propulsion and material technology should be infused to provide a more capable system. This paper recommends avid support of R&D funding needed to provide these technological advances. The technology push should not end with the initial incorporation of advanced propulsion and lightweight materials into second generation systems, as third generation revolutionary concepts like fusion and antimatter promise even greater capability. Finally, the paper recommends development of innovative missions for the 2025 spacelift system which enable it to strengthen all air-and space-core competencies. The incremental approach outlined in this paper provides the best opportunity to field an operable system which supports all customers.

Chapter 1

Introduction

Space started in an R&D mode; it has difficulty moving to an operational mode.

— Gen Ronald Fogelman, CSAF

Spacelift is the key supporting pillar of the space superiority core competency. Without the support of spacelift, other platforms do not make it into orbit to execute space superiority operations. Space superiority, along with global mobility, information dominance, air superiority, and precision employment, are the US air-and space-core competencies.[1] Since losing spacelift capability would have a devastating effect on US ability to achieve space superiority, spacelift is the strategic center of gravity for all space operations. Moreover, spacelift in the year 2025 is more than just a critical supporting pillar for space superiority, because affordable, reusable spacelift also is an effective force enhancer for the other air-and space-core competencies.

The focal concept of spacelift in the year 2025 is routine operations to, through, and in space. The 1994 *Space Launch Modernization Plan* advocates a shift away from a "launch" mentality to an "operations" mentality.[2] This operations mentality is vital to building a 21st century space architecture, which the Air Force's *New World Vistas* study envisions as a survivable, on-demand, real-time, global presence that is affordable.[3] Without affordable access to space, the rest of the space missions are difficult to accomplish. There simply is not enough funding available to develop innovative space-based capabilities while continuing to employ brute force methods of getting to orbit. Routine operations are more affordable, because they eliminate the large standing armies required by the research and development (R&D) processing philosophy of current expendable systems. Affordability can be improved further through the infusion of revolutionary, evolutionary, and commercial advances in technology, particularly propulsion and materials. These advances lead to reusable, single stage to orbit (SSTO) spacelift vehicles, capable of satisfying all spacelift requirements. These vehicles allow aircraft-like routine operations to occur in spacelift.

In the year 2025, spacelift is the conduit to the “high ground” of civil, defense, and commercial space operations. To maximize the operational advantages of space, the US has established a composite spacelift wing composed of vertically launched, SSTO, fully reusable, and maintainable multipurpose transatmospheric vehicles (MTV). These MTVs responsively deliver light-to-medium payloads into and through low earth orbit (LEO). In addition, the Department of Defense (DOD) maintains a squadron of orbital transfer vehicles (OTV), attached to the international space station infrastructure. These are employed to move satellites between orbits, thus minimizing initial lift requirements for the MTVs. OTVs also add life to satellites by refueling, rearming, and resupplying them, as well as protecting the US space architecture. This MTV/OTV combination provides any theater with rapid response, all-weather surveillance and sortie capabilities in less than an hour.

Heavy lift is a joint government and private commercial venture for scientific and commercial purposes with military mission augmentation capabilities. To expand scientific knowledge and economic opportunity, NASA, DOD, and industry pursue intersolar system exploration as a joint international venture. DOD is the space traffic control manager. They also lead the international planetary defense system (IPDS) and operate a directorate on board the space station. In the commercial sector, spacelift ventures are based on average launches per day and safety records comparable to the airline industry of the 1990s.

Using a flattened organization with technician-level maintenance, spacelift operations are routine. Space launch corporations have transformed several closed Air Force bases into space ports. The remoteness of these bases provide added safety buffer zones. Advances in computer diagnostics provide real-time, on-the-pad systems checks with self-repair and automated rerouting of vital space vehicle functions. Seeking to protect and modernize their space architecture, some nations and multinational corporations pursue the space debris environmental cleanup, which is a multimillion dollar business. Space-based antisatellite weapons, antiballistic missile weapons, and precision guided munitions (PGM), including lasers, particle beams, kinetic weapons, and nonlethal weapons, are the DOD’s primary arsenal for space control and force application deployed from standardized modular packages. MTVs contribute to global mobility by inserting small, highly equipped, armed teams of the US Space Special Operations Forces or critical cargo anywhere on the globe through LEO. Air Force global reach is felt anywhere in the world in less than an hour[4] Intelligence, surveillance, and reconnaissance (ISR) and capable MTVs provide almost immediate situation awareness of any trouble spot, and strike-configured MTVs add force application capability. The US Spacelift Wing is the primary deterrent force of 2025.

The above spacelift concept in the year 2025 is derived using the horizon mission methodology, which channels creative thinking by envisioning missions and desired architecture in the future then projects them backward toward the present to provide the evolutionary and revolutionary progress needed to achieve that future.[5] Using this methodology, the key attributes of the 2025 spacelift system are routine operations with reusability, high-thrust/energy propulsion, modular mission packaging, lower mass fraction (a combination of structure materials and fuel), streamlined infrastructure, and operational simplicity. The combination of these attributes provide affordability. This paper addresses these solution characteristics, describes the spacelift system, details the concept of operations, and gives recommendations that expand the options presented in the *Space Launch Modernization Plan*, *SPACECAST 2020*, and *New World Vistas*. In the year 2025, routine spacelift operations into, through, and in space will strengthen air-and space-core competencies.

Notes

[1] Air Force Strategy Division;, *Air Force Executive Guidance,* Office of the Secretary of the Air Force (Washington D. C.: Government Printing Office [GPO], 1995), 2.

[2] Under Secretary of Defense for Acquisition and Technology, *Space Launch Modernization Plan*, Office of Science and Technology Policy (Washington D. C.: GPO, 1995), Executive Summary, 14–17.

[3] USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century*, summary volume (Washington, D.C.: USAF Scientific Advisory Board, 15 December 1995), i.

[4] Lt Col Jess Sponable, *Advanced Spacelift Technology* (U), Phillips Laboratory, PL/VT-X, briefing, Air University Library, 2025 Support area, 6 March 1996. (Secret) Information extracted is unclassified.

[5] John L. Anderson, “Leaps of the Imagination Using the Horizon Mission Methodology,” *Ad Astra*, January/February 1995, 37.

Chapter 2

Required Capabilities

The cost of spacecraft has come down an order of magnitude in dollars per band width during the last decade. The cost of launch is $10,000 a lb. We want $1,000 a lb.

—NASA Administrator Daniel S. Goldin

The 2025 spacelift system is a dedicated, responsive, reliable, and affordable operation that supports DOD space superiority missions. The *Air Force Executive Guidance*, December 1995 update, describes *space superiority* as a "core competency" for the future.[1] The 2025 spacelift system employs a combined concept of lift from earth-to-orbit (ETO), earth-to-earth (ETE), and space-to-space (STS) to support movement of US assets. The ETO spacelift is the routine operation of sending payloads into LEO. The ETE spacelift focuses on transferring cargo globally through space and executing global-presence missions using space as a transit medium. Finally, the STS spacelift is transferring, positioning, or maintaining payloads in orbits using a reusable orbital vehicle to operate within the space environment.

Commercial industry has driven the responsiveness of spacelift toward routine operations in 2025. Advances in computing, composite materials, and energy generation has lowered payload weight for most routine satellite requirements, spurring the proliferation of medium and light lift systems. With launch schedules measured in minutes instead of months, the commercial markets are dominated by the most capable systems and the most responsive providers. Deep space exploration, lunar economic expeditions, and space station support still require a small percentage of heavy lift capability, but this operation is performed by a combined corporate and government venture.

In 2025 power is defined by information. Information dominance is maintained through a combination of ground, air, and space sensors that feed an extensive data-fusion system. Responsive spacelift supports this system. With events transmitted at the speed of light, the response time to a global crisis is minutes. Spacelift system responsiveness is assured by assets already positioned in space and by ground-based space assets, which can be launched rapidly from several locations. The 2025 space forces are the global presence deterrent with rapid response launch capability to support a myriad of space missions, which includes space control, force application, space maintenance, counter space, command, control, communications, computers, and intelligence (C^4I), and research. These assets include planetary defense and intersolar system travel. In the ETE mode, any global point must be accessible from CONUS base in less than an hour.

The 2025 spacelift system is characterized by reusability, high-thrust/energy propulsion, modular mission packaging, economically designed mass fraction, streamlined infrastructure, and operational simplicity. The above solution characteristics, coupled with routine sortie operations, drive the affordability of placing a payload into orbit. With the resulting lower cost per pound to orbit, market demands for exploiting the medium increase. This in turn drives costs even lower. Once the system demonstrates affordable spacelift, innovative ETE missions are pursued. The following are expansions of the above solution characteristics, starting with some definitions.

Definitions

Specific Impulse (I_{SP}): the standard measure of propulsion efficiency. Simply defined, I_{sp} is the number of seconds a pound of propellant produces a pound of thrust[2]. **I_{SP}** is a measure of fuel efficiency for comparing propulsion systems, similar to octane measurements for automotive gasoline.

Mass Fraction: In this paper, mass fraction refers to that portion of the vehicle weight that is propellant (propellant mass fraction).

Cryogenics: Liquid hydrogen and liquid oxygen propulsion systems common to many current spacelift systems, including the space shuttle and the Centaur upper stage. Cryogenic propellants must be kept cold to remain in a liquid state. This complicates the storage and operations. However, cryogenics are much more environmentally friendly than other current chemical propellant alternatives.

Generations: A method used in this paper to identifying broadly system characteristics that relate to capabilities instead of time. The three generations of spacelift in this paper are:

- First Generation: initial operable system based on current technology;
- Second Generation: first generation modified and infused with propulsion and material technology currently in development; and
- Third Generation: second generation upgraded with revolutionary propulsion system.

Margin: the portion of systems performance that remains unused and is kept in reserve to ensure reliability. Current spacelift systems leave little margin. Propulsion systems are pushed to their maximum. This is analogous to driving a car at maximum revolutions per minute all the time. With the high cost of expendable spacelift, users want to use the largest possible payload, so only minimum safety margin is maintained. By running the propulsion system below its maximum and thus maintaining margin, maintenance is reduced, reliability is increased, and costs are decreased.

Reusability

Reusability in 2025 refers to routine aircraft-like operations. The system does not require standing armies of engineers to check and double check each system prior to a launch. Instead, MTVs and OTVs are flown and reflown with minimal maintenance between most missions.

The concept of a reusable vehicle is not new. The shuttle's original premise was complete reusability, but its ballooned infrastructure, zero-defect safety requirements, and R&D processing mentality prevented its use in the truly routine operational sense. One of the main tenets of the X-33 space plane is proving the operational reusability concept.[3] The *Space Launch Modernization Plan* states that solving current technology limitations are critical. These limitations excessive reliability/failure demands, large infrastructure costs, and the lack of institutionalized launch program oriented towards standardized requirements, metrics, and goals.[4] Further, the *President's National Space Transportation Policy* demonstrates the complementary nature of the reusability concept with military requirements. This includes vehicles maintained in "flight readiness-style," incorporated autonomous diagnostic design, flight vehicle support, ground support facilities, support logistics controlled by automatic interactive scheduling, and "airplane-like" operations. This pattern results in short turnaround with comparable safety requirements.[5]

Another advantage of reusability is increased responsiveness. The 2025 spacelift system is responsive in minutes with a fleet of MTVs continuously ready for launch missions. The MTV fleet is supported by a technician-based preventive maintenance system, with planned periodic overhauls for modernization. Advances in computer capabilities and artificial intelligence provide real-time and on-the-fly diagnostics and automated systems rerouting, while improvements in high temperature thermal conductors and fiber-optics integration reduce power requirements. Innovative thermal and radiation protection extend product life cycles, allowing reusable systems to last longer. Light-weight structural components are improved for longevity and resistance to cyclic failure. Overall, required system redundancies are minimized and a soft-abort capability is integrated to allow a return to launch site (RTLS) capability. Each of these advances contributes to MTV responsiveness.

Reusability is essential for routine operations, but some expendable systems still launch in 2025. A small portion of heavy lift is accomplished by the evolved expendable launch vehicle (EELV), but emerging third generation propulsion holds promise for NASA and commercial reusable heavy lift capability. The remaining heavy payloads are adapting to the standardized MTV requirements to avoid the excessive cost and environmental concerns associated with expendables. Eventually, all spacelift will be accomplished using reusable vehicles, but MTV performance increases are required to capture the entire spectrum of missions.

High Specific Impulse Propulsion

To satisfy all MTV performance requirements in 2025, high I_{SP} propulsion is a primary solution characteristic. The 2025 commercial industries dominate the conventional solid and cryogenic rocket launch market. These corporations and nonstate actors have developed reliable launch schedules with safety records similar to that of the airline industry, standardized chemical propulsion systems, decreased payload volumes and weights, and streamlined infrastructure costs. Foreign governments, unconstrained by environmental considerations and zero-defect requirements, use 1990s space technology for attracting commercial enterprises to satisfy their own national objectives. Though these systems optimize expendable technology, they cannot compete with a high I_{sp}, reusable MTV.

In 1994, Lt Gen Jay W. Kelley, chairman of the *SPACECAST 2020* study, tasked the faculty of the Air Force Institute of Technology (AFIT) to investigate unconventional approaches to solving national spacelift problems.[6] One of the identified problems was the current limitations of I_{sp}. Conventional chemical propulsion is reaching its maximum I_{SP} of 450 seconds. This conventional chemical limit, analogous to the sound barrier, suffices in propelling payloads to LEO, but does not give the propulsion margin to enable true mission operability in space. Unconventional approaches are necessary to break through the chemical propulsion limits and meet the flexible operational requirements of 2025 spacelift.

Propulsion, coupled with structural mass fraction improvements, continue to drive technology in 2025. Presently, the cost of placing mass in orbit is $20,000 per kilogram (approximately $10,000 per pound), and this cost is proportional to the dry-vehicle weight of the lift vehicle to payload, the supporting structure, and the energy of the fuel.[7] *New World Vistas* also advised research into the "computational design of energetic materials," lighter satellite payloads, and lighter lift vehicular materials coupled with lower mass-to-fuel ratios and compact computer diagnostic/control systems, which support the 2025 spacelift solution characteristics.[8] Lower mass fraction and streamlined infrastructure are discussed later in this chapter.

High- I_{SP} technology advances enable the 2025 spacelift system to consist of versatile, vertical launch and combined vertical or horizontal landing recovery operations. The 2025 MTV employs a second "transitioning to third" generation propulsion system, which generates both high I_{SP} and high-thrust. High-efficiency ion drive systems (solar and nuclear electric powered) are primary maneuvering systems on satellites and OTVs. These systems maximize I_{SP} without requiring the high-thrust needed to reach escape velocity in the ETO mission. The development of future unconventional fuels are a synergistic DOD, NASA, and commercial effort, which requires extensive sharing of information to spur the technology push required for reliable, high-energy, high-thrust propulsion.

Presently, the *Space Launch Modernization Plan* states that the current and projected funding is insufficient to support even a meaningful core space launch technology research program.[9] To create a core technology research base for furthering only current spacelift concepts (projected to 2013), which includes existing cryogenic and solid fueled upgraded launch vehicles, evolved expendable launch vehicles, and evolved reusable launch vehicles, the study recommended funding be increased from the current $45 million to $120 million.[10] The final plan lacks any revolutionary propulsion concepts and, therefore, does not provide the futuristic outlook needed for 2025. It recommends evolved expendable rocketry, increased cooperation with Russia for advanced engine technology and performance data, and pooling resources of the international community, rather than the strategic pursuit of unconventional propulsion alternatives. For achievement of routine spacelift operations, the US needs a strategic vision that drives propulsion technology towards unconventional solutions to achieve high I_{SP}. Revolutionary and evolutionary propulsion advances, which have the potential to achieve a third generation "on-demand" propulsion system, are required to provide the full spectrum of MTV capabilities.

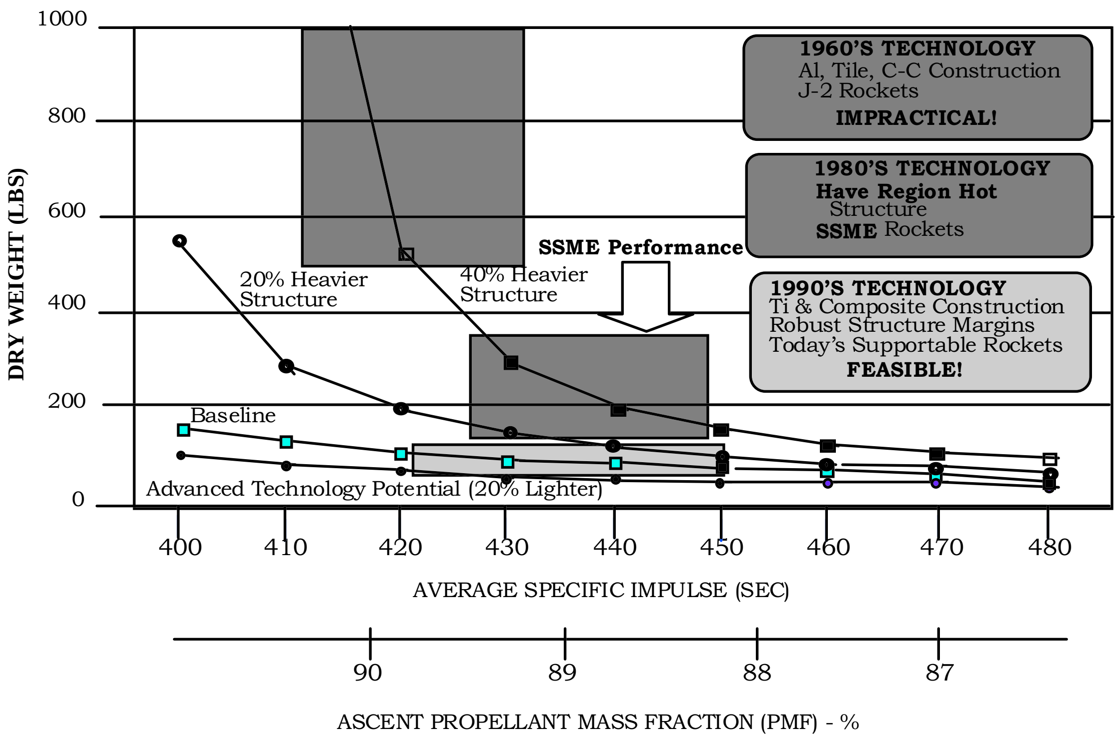
Modular Mission Packaging

Modular mission packaging is also not a new concept, but one derived from the X-33 concept of launching modularized payloads, which include satellite constellations, weapons deployment, logistics, and, even personnel.[11] Using encapsulated payloads with standard vehicle interfaces, mission flexibility, and responsiveness are enhanced, and ground operations are streamlined. The payloads are deployed from the payload bay singularly or in an integrated package. Moreover, the payload package is delivered and stored hours, days, or months in advance. The pilot of the vehicle can fly virtually from the ground, or fly in the manned mode if required for strike, surveillance, or mobility missions. The manned mission package has less residual capability, since the modular crew compartment uses some of the volume and performance normally dedicated to payload.

Economical Mass Fraction

Coupled with the decreased mass fraction due to propulsion technology pushes 2025 spacelift takes advantage of continued advances in light weight composites. Figure 2-1, disregarding the space shuttle main engine (SSME) performance, demonstrates the improving relationship between the dry vehicle weight, mass fraction, and specific impulse as technology advances over time. The upper lines demonstrate that the heavier structure increases propulsion design risk (e.g., a 20 second I_{SP} shortfall can double the vehicle dry weight requirements). Conversely, given the baseline shown in the graph, one sees the immediate benefit of even 20 percent lighter future structural composites. Even a large change in engine performance does not significantly add to the dry weight of the vehicle.

The applications of light weight composites to structural materials continue to be integrated into air-breathing systems as demonstrated by the B-2 and the MV-22 Tiltrotor aircraft projects.[12] These advances also reduce the size and weight of many payloads. Most satellite systems, deployed in distributed constellations, display trends toward weights in the 10s to 100s of pounds, driving most lift into the medium and light categories.



Source: Lt Col Jess Sponable, *Advanced Spacelift Technology* (U), Phillips Laboratory, PL/VT-X, briefing, Air University Library, 2025 Support area, 6 March 1996. (Secret) Figure is unclassified.

Figure 2-1. Mass Fraction Reduction Baseline

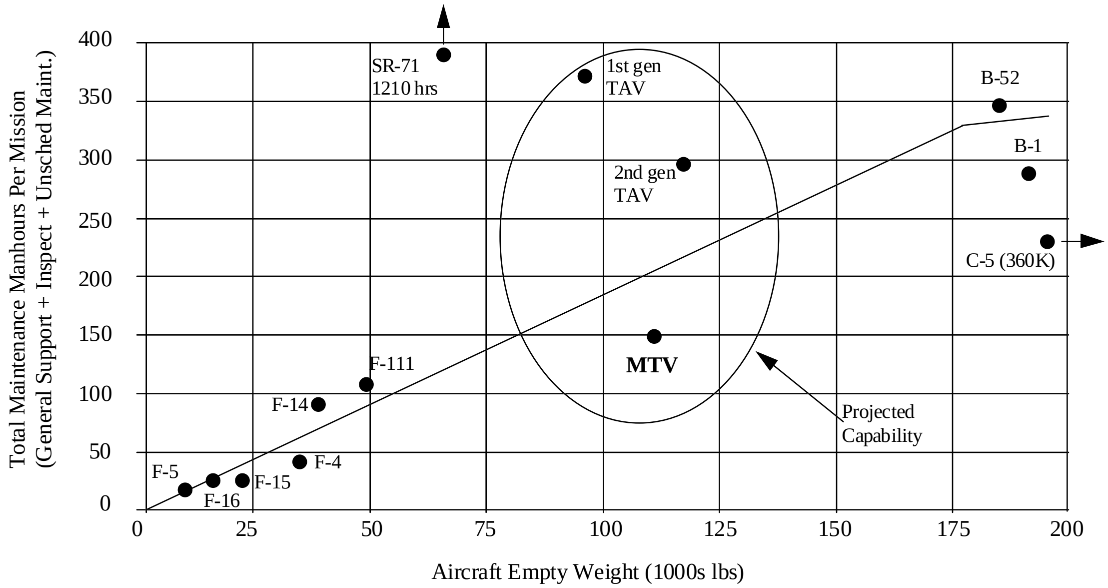
The 2025 spacelift uses ultralight composite materials, which include structural composites, high/low temperature resistant materials, and revolutionary manufacturing technologies (singular crystal structures, automatic winding, and thermopultrusion.

Light-weight electronic systems employ fiber-optic technologies with adaptive commercial electronics (such as guidance) and self-diagnostics with expert systems, automated self-repair and reroute, computer programming advances (autocoding, molecular storage), and artificial intelligence.[13] Moreover, advances in high-temperature superconductors reduce friction requirements, produce more efficient power generation and engine systems, and reduce the component size of equipment. The above technologies help to reduce the MTV's dry weight, which, in turn, improves mass fraction.

This technology push utilizes and develops lightweight structural components with a long-design life and resistance to failure within reasonable engineering criteria. The combination of high I_{sp} propulsion and light dry vehicle weight results in economical mass fraction. MTV's low-mass fraction and high-energy propulsion give it the performance needed to satisfy all customers.

Streamlined Infrastructure

The 2025 spacelift infrastructure consists of small, modular general purpose facilities and a minimal processing/operating team. The 1995 NASA report of shuttle ground operational efficiencies noted that "the life cycle cost triangle of flight hardware, processing facilities/GSE, and headcount *must be dramatically and radically reduced*" to pursue an affordable operational tempo.[14] Additionally, the direct failure and opportunity costs experienced by the current space program must be eliminated.



Source: Phillips Laboratory, *Advanced Spacelift Technology* (U), 1996. Provided current airframe maintenance data only. (Secret) Figure is unclassified.

Figure 2-2. Reusable MTV Maintenance Requirements

The 2025 spacelift is a streamlined organization using the technician-level maintenance structure coupled with civilian technical advisors. The armies of technicians employed to launch rockets in the 1990s are no more. Figure 2-2 proposes first generation MTV maintenance requirements. Using the above solution characteristics, the 2025 Spacelift system pushes spacelift maintenance requirements toward today's fighter maintenance levels. Reliability is ensured through standardized operation programs augmented by real-time, continuous diagnostics and artificial intelligence (AI) driven self-repair and rerouting. Standowns due to failures are limited locally to specific MTV squadrons and do not necessarily ground the entire spacelift system. While investigations are conducted, operations are not normally impeded.

The 2025 spacelift system combines easy maintenance and engine access with interactive computer diagnostics and fault tracing. Ground operations use common equipment and modular component replacement with post-repair-two-level maintenance (2M) capability. Modular command and operations centers, coupled with vertical launch characteristics, enable a smaller physical infrastructure and basing requirements. Virtual pilot control operations lead to larger cargo payload deliveries without human life support concerns. Modular payloads generate generic loading operations and real-time mission flexibility.

The composite nature of the missions reduces pilot specialization requirements. To mitigate the risk of an enemy targeting MTVs, the modular organizational concept provides mobility for flexible orbital access from numerous launch facilities.

Current launch operations in the 1990s are concentrated at Cape Canaveral Air Force Station, Florida and Vandenberg Air Force Base (AFB), California. In 2025 physical spacelift infrastructure is more dispersed to include operations at higher altitude locations, closer to the equator for greater orbital access and more remote for increased public safety. Primary MTV locations include Peterson AFB Colorado, and Holloman AFB New Mexico. Clear launch pads, free of massive towers and other support facilities, provide simple ground operations and easy access maintenance. Encapsulated cargo reduces payload processing facility requirements. The resulting infrastructure is less expensive to maintain and facilitates routine operations.[15]

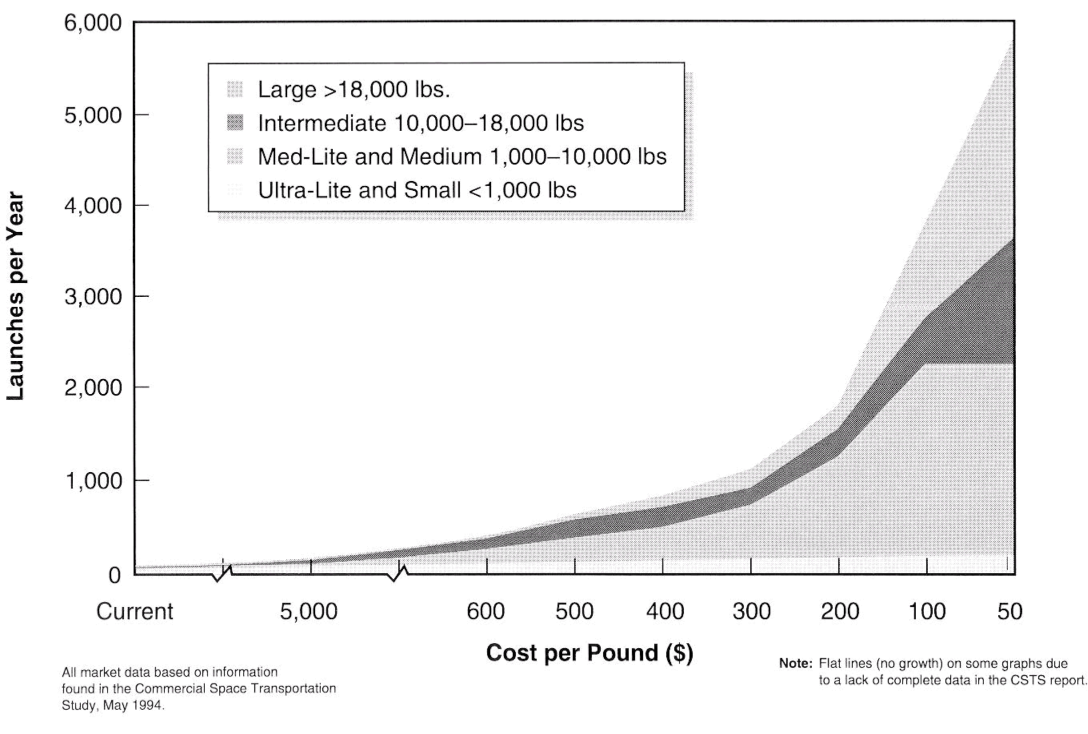
Operational Simplicity

The 2025 spacelift system exploits advances in reusability, propulsion, and materials to meet spacelift, ISR, strategic strike, and mobility requirements with a single platform. Complex operational solutions to such reusable vehicle performance as a mothership, refuelable craft, or magnetic rail accelerated vehicle proved too costly. Each of these operational solutions work around to the propulsion challenge required extensive additional infrastructure and industrial base support. The Black Horse refuelable spacecraft concept was touted in the *SPACECAST 2020* study.[16] With the added development, operations, and support costs of a mothership, an oxidizer transferring airframe, or a complex, inflexible rail launch site, these novel approaches to increasing performance could not compete with the low life-cycle cost of a SSTO MTV concept.

Affordability

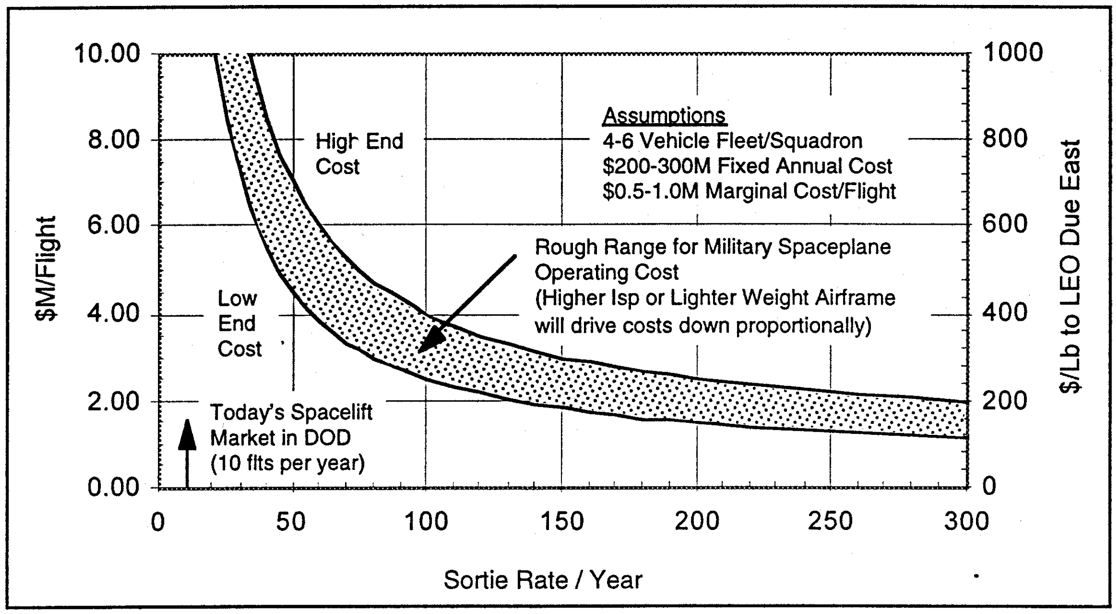
By employing the combination of these solution characteristics in an operational environment, spacelift becomes affordable. Figure 2-3 demonstrates the commercial flight-rate potential as MTV launches become operational and cost per pound is driven toward $200/lb. Further, history shows that the introduction of new operational transportation systems opens new markets, which, in 2025, include space exploration, space economic resource exploitation, hazardous waste disposal, rapid response commerce, and space settlement. For the military, the 2025 spacelift system results in rapid response supporting core competencies at an operationally affordable cost. The initial driver of cost reduction is reusability. Other drivers include decreased personnel overhead and improved reliability. The remaining solution characteristics described above contribute to further cost reductions.

Life-cycle costs for an MTV wing is comparable to current bomb wing requirements adjusting for inflation, but the utility of the vehicle makes it more affordable than maintaining separate mission platforms. AS figure 2-4 illustrates, the combination of the solution characteristics (assuming nominal operating costs) and operational sortie rate (150-200 sorties/year) has the real potential to achieve $200 per pound payload cost for a third generation MTV.



Source: National Aeronautics and Space Administration, *Space Propulsion Plan* (Draft), Marshall Space Flight Center, 22 January 1996, 8.

Figure 2-3. Commercial Launch Potential



Source: Lt Col Jess Sponable, *Advanced Spacelift Technology* (U), Phillips Laboratory, PL/VT-X, briefing, Air University Library, 2025 Support area, 6 March 1996. (Secret) Figure is unclassified.

Figure 2-4. Impact of Flight Rate on per Flight Cost of an MTV

Notes

[1] Air Force Strategy Division, *Air Force Executive Guidance,* Office of the Secretary of the Air Force (Washington D. C.: Government Printing Office [GPO], 1995), 2.

[2] Dr. Robert Zurbin, "A Question of Power," *Ad Astra*, November/December 1994, 40.

[3] Lt Col Jess Sponable, *Advanced Spacelift Technology* (U), Phillips Laboratory, PL/VT-X, briefing, Air University Library, 2025 Support area, 6 March 1996. (Secret) Information extracted is unclassified.

[4] Under Secretary of Defense for Acquisition and Technology, *Space Launch Modernization Plan*, Office of Science and Technology Policy (Washington D. C.: GPO, 1995), Executive Summary, 23-29.

[5] *The RLV Operations Concept 'Vision,'* Summary of the President's National Space Transportation Policy. on-line, Internet, 7 February 1996, available from file:///C/-2025/tav/rlvhtp1a.htm.

[6] Air Command and Staff College, *SPACECAST 2020 into the Future* (Maxwell AFB, Ala.: Air University Press, 1994), section 5, 1.

[7] USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century,* summary volume (Washington, D.C.: USAF Scientific Advisory Board, 15 December 1995), 44.

[8] Ibid., 44–45.

[9] Under Secretary of Defense for Acquisition and Technology, *Space Launch Modernization Plan*, Office of Science and Technology Policy (Washington D. C.: GPO, 1995), Executive Summary, 14.

[10] Ibid., 14-17.

[11] Sponable briefing.

[12] Ibid.

[13] Ibid.

Notes

[14] National Aeronautics Space Administration, *NASA, Shuttle Ground Operations Efficiencies/Technology Study* (Washington D. C.: GPO, 1995), volume 6, NAS 10-11344.

[15] Sponable briefing.

[16] Air Command and Staff College, *SPACECAST 2020 into the Future* (Maxwell AFB, Ala.: Air University Press, 1994).

Chapter 3

National Spacelift System Capabilities

> *No one can predict with certainty what the ultimate meaning will be of the mastery of space. (It may) hold the key to our future on earth.*
>
> —President John F. Kennedy

Using the horizons mission methodology, the 2025 spacelift architecture is an emerging third generation system that has take advantage of technology advances since the early 1990s. The systems characteristics and core competency missions are described in the 2025 environment, and notional progress is shown from first through second generation systems. Propulsion is described in detail in the appendix, because it is the pivotal technology push required for success of the system. The progress to 2025 occurs in three distinct steps: a first generation system exploiting current propulsion technologies, structural composite advances, and low-cost technology reusable demonstrators; a second generation system integrating evolutionary/revolutionary advances in conventional chemical propulsion, technological advances in structures and computers, and refinement of the first generation operational system; and, finally, an emerging third generation system performing all required lift and mission requirements with refinements in second generation propulsion, compact fuel storage, and vehicle dry-weight reductions.

2025 System Characteristics

The 2025 spacelift system is derived through incremental application of technology and operational enhancements. This system description analyzes the progress toward 2025 based on the characteristics outlined in tables 1 and 2. Table 1 compares the attributes of a notional X-33 demonstrator and first through third generation MTVs against today's systems. Table 2 compares the attributes of notional first through third generation OTVs.

Table 1
MTV Systems Attributes

	Current Systems	X-33	1st Generation MTV	2 Generation MTV	3 Generation MTV
Cost/pound	$10,000	Develop-mental	$5000-$8000	$1000	$200
I_{sp} (seconds)	450	450	450	450 - 800	>1000
Reusable	No	Yes	Yes	Yes	Yes
Scale	not applicable	2/3 MTV	X-33 + 20%	Full	Full
Weight (lbs)	150,000-250,000	50,000-80,000	~100,000	95,000	90,000
Capability (lbs to LEO)	up to 50,000	Suborbital Mach 15 (can pop-up small payloads)	<10,000 (up to 28,000 with pop-up & refly)	20,000 SSTO	up to 30,000 SSTO
Response Time	Months	Days (Demo Hrs)	Hrs to a Day	Hrs	Minutes

Table 2
OTV Systems Attributes

	1st Generation OTV	2 Generation OTV	3 Generation OTV
I_{sp}	High	High	High
Thrust	Low	Medium	High
Reusable	Yes	Yes	Yes
Weight (lbs)	30,000 - 40,000	30,000-40,000	<30,000
Response Time	weeks	hours	hours
Propulsion	Solar-ion	Nuclear-ion	Fusion or Antimatter
Primary User	Commercial	Military	All

Primary Systems

The primary spacelift systems are divided into medium/light lift and heavy lift. The third generation MTV supplies 100 percent of all medium/light lift missions up to 30,000 pounds in the ETE and the ETO environments. The small market of heavy lift is accomplished by EELV, but the second generation commercial MTV and emerging third generation systems are rapidly consuming the market. As MTV proves its economic viability, more large payloads downsize. In the US, the advanced MTV spacelift wing strengthens air-and space-core competencies through a standardized modular command structure, modular and interchangeable payloads and weapons bays, technician-level maintenance, and on-demand responsiveness. In the STS environments, the OTV operates in conjunction with the international space station and/or the cislunar space defense station. Commercial OTVs perform satellite placement from LEO, satellite and station repair, research, and space debris removal. The DOD maintains a squadron of armed military OTVs for counterspace, force application, deterrence, and space-denial missions. Additionally, the military OTVs perform routine satellite maintenance, defense satellite positioning, and satellite repair on the national space architecture. They are attached to the space station defense directorate, which also performs the international space traffic control mission.

Multipurpose Transatmospheric Vehicles

The 2025 emerging third generation MTV is a high I_{sp} (greater than 1,000 seconds), medium-lift vehicle that integrates composite materials, advanced computer diagnostics, fiber-optic and superconductor technology for compact energy generation systems. It also integrates a modularized infrastructure for maximum responsiveness and flexibility. The propulsion system is an "accelerator class" engine combining laser pulse detonation (LPD) and magnetohydrodynamics (MHD) fan-jet principles, as outlined in the appendix. The emerging fusion and antimatter technologies hold promise for a strategic application of the MTV with unlimited range enabling Space Command (CINCSPACE) to finally possess a planetary area of responsibility (AOR). The following data describes the vehicle design advances required through first generation and second generation vehicles.

First Generation MTVs

The X-33 program generated the first reusable demonstrator, which proved the potential for routine operations. The first generation follow-on military MTV is 20 percent larger than the X-33 demonstrator. The MTV space system retains 20 percent propulsion capability margin to enhance operational reliability. The MTV, a vertically launched, single stage ETO and ETE system, capitalizes on current technologies. The vehicle uses cryogenic fuels in the X-33-developed integrated powerhead rocket engine (see appendix) to achieve orbit. For lift missions greater than 10,000 pounds, the MTV uses the X-33 demonstrated satellite "pop-up" and refly capabilities. In the pop-up mode, the payload is deployed in the upper atmosphere and uses an expendable upperstage to place it in LEO. For the refly mode, MTV deploys small reusable aerodynamic platforms for both ETE and ETO missions. These small winged vehicles are capable of making drastic orbital plane changes in the upper atmosphere by using aerodynamic forces on their wing surfaces. The MTV performs space superiority missions through tailored, standardized, modular mission payloads and satellite refly. Additionally, in the transatmospheric ETE mode, the MTV demonstrates force application and a rapid response ISR capability.

Structural Materials

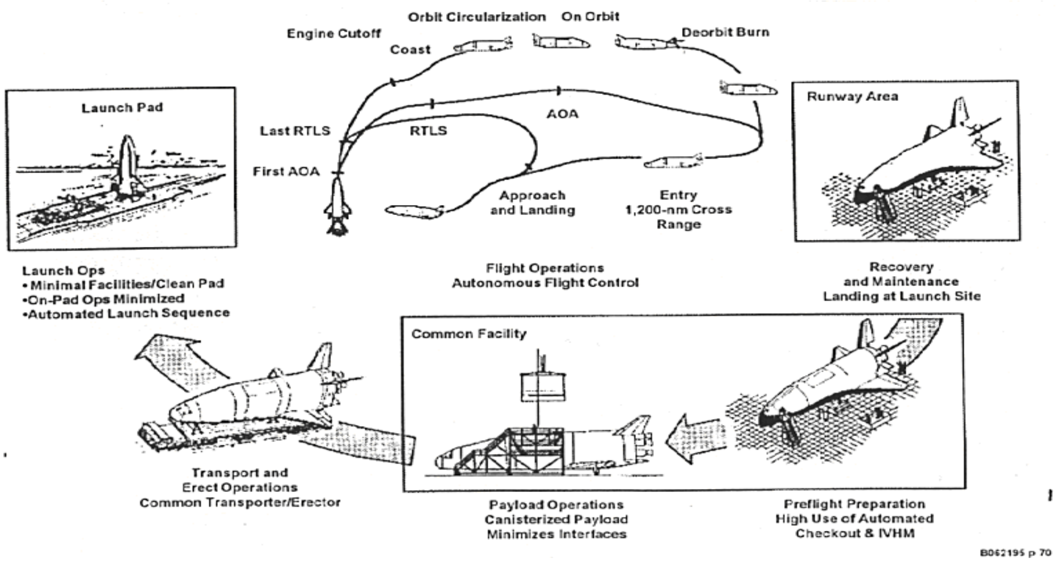
The current advances in composite technologies and thermal protection systems (TPS) are incorporated into a structure that is 20 percent larger than the X-33 but only 10 percent heavier, which should allow significant operational cost reductions. The TPS uses advances in current carbon-carbon (C-C) and carbon-silicon (C-Si) systems and thermoplastic pultrusion technologies derived from enhanced computer modeling of structural fluid dynamic solutions.[1] These thermoplastic pultrusion manufacturing techniques produce tougher mechanical properties with longer life cycles. Additionally, the process requires no chemical curing, so production rates increase lower lengthy production costs. Cryogenic fuel storage builds on current aluminum-lithium (Al-Li) technologies. Electrical components and computers take advantage of advances in high-temperature superconductors and first generation AI, and the vehicle uses fiber-optics for all control systems. Superconductors are manufactured to operate at 250 degrees Kelvin (-23 degrees Celsius), which currently seem viable by 2002.[2] This enables order of magnitude smaller control and pump motors using current refrigeration systems allowing either more payload or fuel to be carried. Third order of magnitude increases in computing power and advances in AI enabled the vehicle to incorporate a real-time, self-diagnostic system with automatic self-repair and reroute capability.[3] The system contains an interactive interface for technician fault isolation, rapid identification, and component replacement and enables a much smaller operational launch team.

Modular System Packaging

The MTV can be a manned or unmanned vehicle, depending on the mission. The vehicle in the manned mode uses a two-person crew: a pilot and a mission specialist, which can be a counterspace specialist, weapons officer, logistics specialist, or a satellite-deployment specialist. The integration of fiber-optics, superconductors, and advances in space life support science produces a smaller modular crew life support system, which is removed to increase payload size in the unmanned mode. Virtual piloting is conducted from a modular command center and is accomplished by way of integrated satellite link using current computer technology advances and the improved global navigation capability. Payloads are encapsulated for both ETO missions and ETE. Modular payload and weapons deployment is successfully tested by the X-33 demonstrator.[4] Human life support for special operations forces (SOF) deployable modules are in the test phase for the second generation vehicle.

Operational Infrastructure

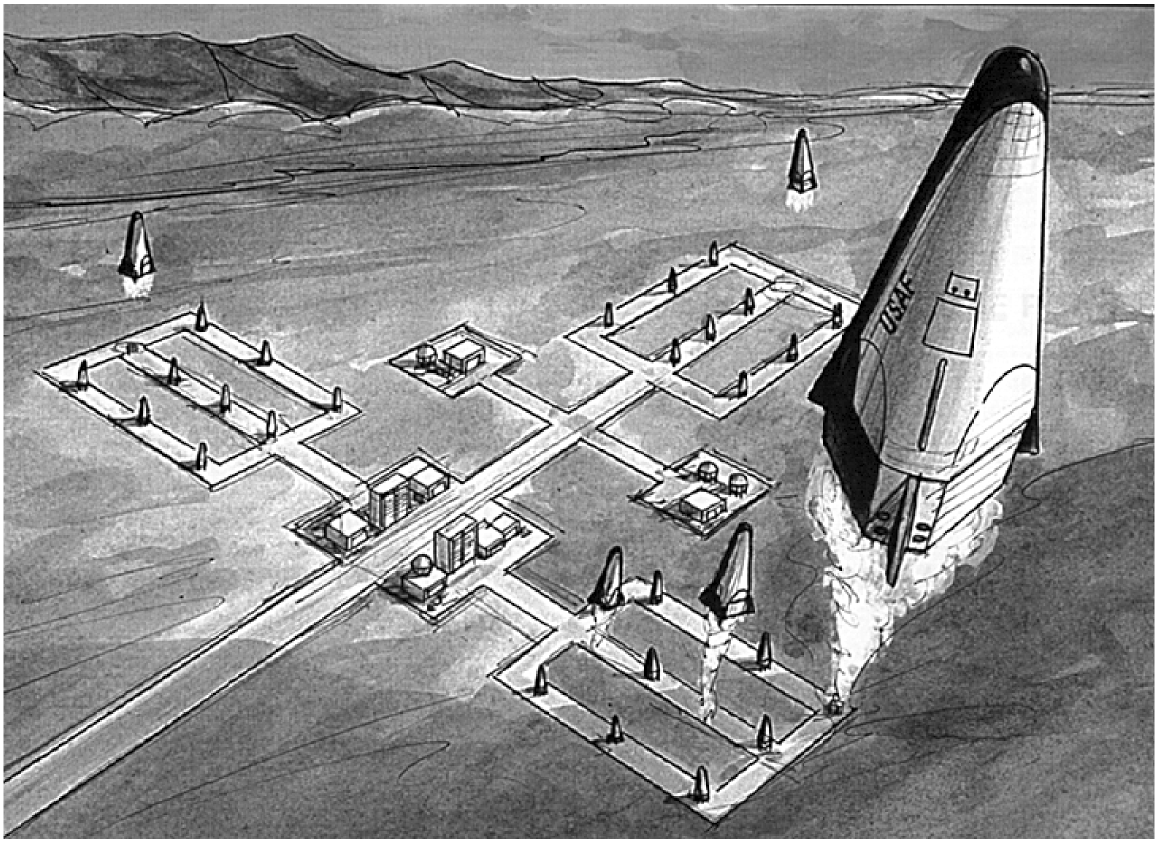
The US Spacelift Wing uses an organization analogous to the 1995 Air Force wing structure plus a commercial technical assistance division. The military MTV takes advantage of commercially driven material technologies with investments in propulsion advances to deploy space-based weapons, lasers, counterspace technologies, and logistics. The spacelift wing is located in two main operating aerospace bases, but the command structure is modularized for rapid deployment to any US Air Force base. Figure 3-1 shows a conceptualized operational turn around for a potential MTV-type design. Relying heavily on vehicle self-contained diagnostics, a common facility is used for automated preflight and payload operations.[5]



Source: Lt Col Jess Sponable, *Advanced Spacelift Technology* (U), Phillips Laboratory, PL/VT-X, briefing, Air University Library, 2025 Support area, 6 March 1996. (Secret) Figure is unclassified. (Secret) Figure is unclassified.

Figure 3-1. Conceptualized operations for the MTV

Preventive maintenance and preflight are standardized procedures for technicians employing a “blue-suit” concept. The civilian technical assistance group handles major technical problems. Components are line replacement units (LRU) with separate two-level maintenance system outside of the preflight facility. Average turnaround time is less than six hours, including refueling, but a priority aerospace mission sortie turn around of less than three hours is possible. Prior to launch approval, on-pad alert MTVs perform a 15-minute diagnostic check, yielding a global response time of less than one hour.



Source: Dr. Dick Mueller, Washington Strategic Analysis Team, “Global Response Aerospace Sortie,” briefing, 6 March 1996.

Figure 3-2. Artist’s Rendering of 1st Generation Spacelift Wing

The base additionally contains hydrogen/oxygen generation and storage facilities. The command structure consists of a communications building, which performs administration and is tele-linked to the space traffic control center in the space station’s defense directorate, and the virtual command center, which holds the pilot control system and mission briefing areas (secure video-teleconference capable). Figure 3-2 is a conceptualized picture of an operating spacelift wing employing one possible vehicle configuration.

Second Generation MTVs

The second generation MTV integrates revolutionary propulsion into an improved first generation MTV aerospace frame. Dry-vehicle weight is reduced another 5 percent. The propulsion system is a first generation laser pulse detonation and magnetohydrodynamic “accelerator class” engine with laser air spike technology (see appendix). This propulsion system is designed to operate each engine variant in its most efficient mach regime. To increase engine thrust efficiency in the laser detonation cycle, the cyrogenic propulsion system uses a boron additive.[6] The increase in I_{sp} to greater than 600 seconds has rendered the satellite pop-up maneuver obsolete, since most payloads can be directly inserted into orbit. Propulsion margin of 20 percent is easily maintained. A commercial heavy lift MTV demonstrator is being tested, and a commercial passenger MTV is on the drawing board. The second generation MTV is the joint bomber/logistics transport capable of contributing to air-and space-core competencies. Advances in artificial intelligence and superconductors are incorporated into a fully self-contained preflight and diagnostic system with real-time self-repair and reroute. Additionally, these advances have reduced required personnel for refueling and maintenance support.

Structural Advances

Thermoplastic protrusion technologies are commercially adopted, and thermosets are past history. Research at Sandia National laboratories has developed powder metallurgy with high-gas atomization, which is now in production.[7] The MTV is an all-composite design with Al-Li cryogenic storage tanks. Composites continue advances in C-C and C-Si with titanium derived alloys to lower structure weights 20 percent below baseline.[8] These manufacturing technologies are commercially derived and provide an economical space frame with 20 percent lighter materials, long life cycle, and high strength, to further reducing life cycle costs. Additionally, the structure is supported by a commercial as opposed to military industrial base. This arrangement should spread spare and replacement costs across a larger group. It also should provide larger basing opportunities. To reduce control system weight, the system employs buckytubes (molecular-level electrical materials with AI) which are the electrical information carriers for the self-diagnostic system.[9] They also manipulate micromechanical devices in the MTV's control systems.[10] The MTV's surface is monitored by first generation shape memory alloys, which use piezoelectric actuators and fiber-optic sensors to transmit MTV control surface information to the real-time diagnostics that allowed personnel reductions.[11] Superconducting quantum interference devices (SQUIDS) detect and measure the earth's magnetic field and are integrated into the MHD (an engine which uses the earth's magnetic field to generate energy) control portion of the "accelerator class" engine.[12] A zero-degree Celsius superconductor has revolutionized the pump and motor industry, leading to a four-fold reduction in weight and size and again improving payload or fuel capability. These realistic electrical advances reduce heat dissipation requirements, lower both structural and volumetric weight requirements, and enable the development of real-time diagnostics and control systems, which improve reliability and operability.

Modular Payloads

The improvements in propulsion negate the pop-up requirement for satellite movement to LEO, but modular payloads remain important. The SOF deployment system is tested successfully and scheduled for production. Space special operations forces are being trained for future transatmospheric insertion. The MTV has assumed all strategic bombing missions.

Infrastructure

Continued advances in materials, computing, and propulsion, lengthen mean time between overhauls. Commercial advances continue to be exploited by the military, and the volume of spacelift guarantees a robust industrial base. The self-diagnostic capability has reduced technician support. Pilot specialization is not required, because the same crew performs all missions. Turnaround time is less than three hours, with a potential to drop to 90 minutes for a priority sortie. Real-time diagnostics enable five minute alert status on the pad. Deployment of the US Spacelift Wing to anywhere in the US is less than 24 hours for a limited time depending on mission and orbital access required.

Orbital Transfer Vehicles

The emerging third generation military OTV is powered by a revolutionary engine supplemented by emergency high-density hydrogen fuel cells. While this system is in the demonstration mode, OTV requirements are met with first and second generation OTVs. The OTV squadron is supported by the international space station defense directorate, which incorporates the space traffic control system, or is part of either a cislunar or a orbital space defense station. The OTV carries out the routine operational missions of satellite deployment, repair, refueling, rearming, and reconnaissance. Further, the OTV is armed for counterspace, space denial, and space force application missions. The advantages of this system are economical space architecture maintenance, rapid response positioning of assets and global reach missions for space superiority. The vehicle is a single piloted vehicle (F-16 sized), unmanned and controlled virtually in the defense directorate control center. Structure advances and diagnostic computer advances are identical to the MTV systems. The following are the advances required from first through second generation vehicles.

First Generation OTV

The OTV system capitalizes on the satellite capture demonstrations from the shuttle program. Research into magnetic satellite capture is on-going. The OTV is considered an integral part of the IPDS. The propulsion system is solar-electric ion drive; the low thrust is supplemented by emergency fuel cells during national contingencies. For ion drive, solar energy is used to ionize an inert gas and extract it through a nozzle to produce thrust (see appendix). The infrastructure is attached to the defense directorate and, in national emergencies, is operationally chopped to the US Spacelift Wing. The OTV demonstrates the first space laser satellite destruction. Composite technologies and unknown orbital trajectories make the vehicle stealthy. Maintenance of the OTVs is accomplished by modular repair coupled with MTV similar built-in diagnostics, automatic preflight, and technician-level maintenance. The first generation OTVs are attached to the international space station infrastructure or capitalize on a dedicated cislunar or orbital defense space station, and financial investment recapitalization occurs within seven years (similar to emerging industries). Overhauls of the OTVs are conducted on Earth every two years.

Second Generation OTV

Nuclear-electric ion drive propulsion is incorporated with higher thrust. The nuclear energy generates a higher degree of ionization generating more thrust and range. These attributes enable the military OTV to meet the mission flexibility and responsiveness requirements. Satellite capture using magnetic fields is a demonstrated capability. The spacelift infrastructure has expanded to include OTV overhaul in space. Structure composites and computer advances are identical to MTV development. Communication advances enable OTVs to be permanently part of the US Spacelift Wing with the defense directorate as the on-scene headquarters. The MTV missions and the OTV missions enable space superiority and global force application. Fusion and anti-matter propulsion technologies hold promise for the third generation OTV in a strategic role. CINCSPACE finally possesses a planetary AOR defined by the earth-moon system, which is a sphere inscribed by the moon's orbit.

Countermeasures

The stealth characteristics of the MTV are its high speed (>Mach 25), large portion of composite structure, and unpredictable orbital position. Counterspace devices on satellites, ground-based laser devices, and direct attack on launch facilities are the greatest threats. The long range of weapons deployment and rapid sortie ability cause unpredictability and standoff capability. Rapid deployment of the launch infrastructure prevents effective strategic targeting. The OTV is stealthy by nature, but it is susceptible to international sabotage at the space station and counterspace satellite defense weapons. The OTV's orbital unpredictability and speed are its greatest assets. Internal defense on the station is a requirement. More powerful lasers, kinetic weapons, and particle beams give extended standoff for force application roles. The OTV also is capable of nonlethal satellite blinding and deception.

Table 3
Qualitative System Comparison

System Attribute	Refuelable Black Horse	Single Stage MTV	2-Stage with Mothership	Magnetic Rail launched TAV	EELV
Capability (lbs to orbit)	Good-Excellent	Good-Excellent	Good-Excellent	Good-Excellent	Excellent
Reusable	Yes	Yes	Yes	Yes	No
Respon-siveness	Good	Excellent	Good	Good	Fair
Flexibility	Good	Excellent	Good	Fair	Fair
Soft abort	Good	Good	Good	Good	None
Logistics	Good	Excellent	Good	Good	Fair
Operational Simplicity	Good	Excellent	Good	Good	Fair
Cost ($/lb to LEO)	Good	Excellent	Good	Good	Fair
Development Risk	High	Medium	Medium	Medium-High	Low

The MTV/OTV system performs two basic space deployment tasks: lifting payloads to orbit and transferring payloads between orbits. The utility of systems performing these functions is measured in terms of weight to orbit, volume to orbit, civilian surge capability, system responsiveness, and reusability for MTVs. OTV utility is measured in terms of timeliness and reusability. In addition to the spacelift tasks, the MTV is used for airlift, strike, and ISR tasks. The MTV reaches anywhere on the globe in less than an hour, so it can perform vital missions rapidly. For example, airlift systems are employed to move a brigade of troops to a theater, but MTV can provide rapid SOF insertion for squad-sized units. These Air Force Institute of Technology derived utility measures are used to determine which weapons systems in the *Air Force 2025* study hold the most promise. The following is a more detailed qualitative comparison using required system attributes.

The MTV/OTV system was selected from a variety of systems that addressed the spacelift mission (table 3). Each of these systems provided enough capability to meet the bulk of mission requirements, but the EELV was chosen initially by other studies, because it was the only system with low-development risk and because it captured the entire current mission model. While EELV provided a needed initial cost reduction, it was the only expendable system; so, it did not offer the promise of routine operations. A reusable system was destined to take center stage. Two stage systems and the single stage MTV had medium risk while the magnetic rail and oxidizer refueling systems presented some unique new technical challenges. A magnetic rail similar to the EELV was tied to extensive infrastructure, which reduced its flexibility as a multipurpose system. The major discriminator between MTV, Black Horse, and two stage to orbit vehicle was operational simplicity. The Black Horse concept required added development and maintenance of a tanker capable of refueling oxidizer at high speed in addition to the basic vehicle. This additional infrastructure increased logistics requirements, reduced flexibility of deploying the system, and complicated responsiveness. Similar concerns existed with the mothership in the two stage to orbit concept. This state left the MTV as the best choice to provide simple routine operations capable of satisfying all existing and potential customers.

The first-generation MTV system acquisition cost was $1.7 billion, and the prototype vehicles were scheduled for fielding in 2003. The first functional vehicle was declared operational for 2010. With routine operations already proven, second-generation costs were held to under $1 billion, and the system was declared operational in 2020. Third-generation systems are still in development.

Notes

[1] Basil Hassan et al., "Thermophysics," *Aerospace America,* December 1995, 19.

[2] Paul C. W. Chu, "High Temperature Superconductors," *Scientific American,* September 1995, 128–131.

[3] Douglas B. Lenat, "Artificial Intelligence," *Scientific American,* September 1995, 62-64. Lenat describes current ability for computer systems to reason and projects near future abilities to incorporate into commercial applications.

[4] Lt Col Jess Sponable, *Advanced Spacelift Technology* (U), Phillips Laboratory, PL/VT-X, briefing, Air University Library, 2025 Support area, 6 March 1996, (SECRET). Information extracted is unclassified.

[5] Ibid.

[6] Bryan Palaszewski, "Propellants and Combustion; *Aerospace America*, December 1995, 46.

[7] Hassan, 19.

[8] Sponable.

[9] George M. Whitesides, "Self-Assembling Materials," *Scientific American,* September 1995, 116.

[10] Kaigham J. Gabriel, "Engineering Microscopic Machines," *Scientific American,* September 1995, 120.

[11] Craig A. Rogers, "Intelligent Materials," *Scientific American,* September 1995, 123–124.

[12] Chu, 130-131.

Chapter 4

Concept of Operations

Our destiny in space has always been inextricably linked to our launch vehicles.

—Astronaut Buzz Aldrin

Spacelift operations in 2025 will be primarily commercial. The market began transforming from one of reliance on national space programs and international consortiums to one driven by private industry in the 1990s.[1] As commercial markets continued to expand, the cost of launch decreased, as more and more commercial innovations capitalized on inexpensive access to space. Many commercial spacelift providers specialize in operations leaving manufacturing to someone else, much the way airlines have run commercial air operations for decades. Large corporations capable of building, launching, and operating space-based systems sell such services as communications and imagery instead of selling hardware and launches. A spacelift reserve fleet (SRF) of commercial MTVs, analogous to the commercial reserve aircraft fleet handles wartime spacelift surge requirements.

The DOD operates a wing of dedicated MTV vehicles to ensure spacelift responsiveness, global presence (ISR), and global power (strategic attack). These vehicles give commanders a flexible spacelift option and facilitate other ETO missions, like ISR, a small unit or troops, and/or equipment deployment, rapidly to a remote part of the world. The MTVs fly from a main operating base, such as Peterson AFB, Colorado and Holloman AFB, New Mexico, but are capable of operating from sites.[2] Operating bases are selected according to public safety, elevation, and proximity to the equator, but the system is capable of operating at any airfield to maximize flexibility.

The operating base consists of minimal facilities. A central operations center houses the virtual cockpits employed to fly the preponderance of unmanned missions. Fuel storage, maintenance, and a cargo-ready area are also sited with the vehicles. The crew for a mission consists of a pilot and a mission specialist, plus a ground-based crew chief and technician support.

The system requires minimum support in terms of a maintenance crew. It is capable of flying 100 missions without a major overhaul. The routine turnaround time is measured in minutes instead of days and is performed by technicians instead of engineers. Tech data is developed using AI and approved prior to operations to facilitate this capability. The MTV's expendable rocket predecessors were operated in accordance with a set of procedures developed or revised before each mission by an army of engineers. This R&D mentality led to many of the inefficiencies of spacelift in the last century. Built-in-test and fault tolerance streamline both operations and maintenance. Extensive use of the AI tech data and LRUs all but eliminates the need for a depot. The manufacturer serves in what little depot role is left.

The 2025 MTV incorporates standard interfaces for its modular payload packages. Though primarily an unmanned system, the MTV packages can contain crew compartments, satellites, weapons bays, or refly modules. MTVs are used in both the ETO and the ETE mission areas. The same crews are capable of space support missions, force enhancement and force application. The standard interfaces provide a baseline for the development of tech data and facilitate the mission rates required to realize economies of scale. The large number of missions using the same multipurpose vehicle reduces the cost per pound to orbit by allowing development costs to be amortized over a greater number of flights.

While most satellites have evolved into smaller networks of distributed satellites, some heavy-lift requirements remain. Space station resupply and some reconnaissance satellites still need heavy lift, since some of them could not be shrunk while maintaining the quality of products.[3] Given the long-development timelines, the big satellites have not yet capitalized on the small reconnaissance technology now available. As a result, operational EELV heavy lifters still operate out of Vandenberg AFB and Cape Canaveral.

In the STS area, OTVs have commercial, civil, national, and defense missions as well. Operating like harbor tugs, commercial OTVs fall under the same SRF arrangement as MTVs with the military owning several dedicated units. OTVs dock at the international space station or the DOD defense station as a base of operations. From there, they push new satellites into higher energy orbits and retrieve satellites needing fuel, maintenance, or retrofit. Replenished satellites are then returned to their operational orbits. While the civil/commercial OTV is powered by solar-electric propulsion, the military version uses a nuclear-ion drive to give it a more rapid response time. The following is a notional scenario employing the operational aspects of the US spacelift system for illustration purposes.

A Plausible 2025 Scenario

> The high-demand 2025 space lift system is incorporated into second generation fleets of MTVs transitioning to third generation. With a spacelift wing consisting of more than 40 operational MTVs and a squadron consisting of 10 OTVs, all US aerospace missions are obtainable. The US Spacelift Wing is the deterrent force with rapid response to anywhere in the world in less than an hour.
>
> EELVs are being phased out in favor of the NASA/commercial cooperative heavy-lift MTV incorporating the "accelerator class" engine. The medium lift MTV operates with excess performance margin with a reliability record greater than 0.99.
>
> *Mission 45*. The 45th mission of MTV #3 is scheduled for launch. This mission is preceded by systems check in the preflight facility, which checks structural integrity and interfaces with the vehicle's self diagnostics. A satisfactory check at the 45 sortie point historically indicates that 100 launch criteria will be met prior to overhaul. Finally, the modular payload is inserted into the cargo bay. The vehicle is delivered to the erection and launch area and refueled. Time elapsed is two hours. Previously, MTV #3 has boosted two medium-lift payloads to LEO for repositioning by the standby OTV to GEO in the last 36 hours. The unmanned, virtually piloted, MTV #3 has enabled the accommodation of increased payload.
>
> MTV #6 is sending a human payload of six space technicians to the space station for the first phase expansion to an OTV overhaul facility. MTVs #7 and #8 have recently positioned modular components for the space station in LEO.
>
> In the past 60 days, 39 missions have been flown including a record 11 launches in two days by three MTVs. Spacelift wing projects four missions per day average by 2026. The MTV success has generated funding for 22 third generation MTVs and two, third generation propulsion demonstrators using a Penning trap in a microfusion/antimatter propulsion system. Estimated cost per pound to orbit is $200/lb with projections to $100/lb in the next 10 years.
>
> Perhaps the most remarkable aspect of the MTV/OTV system is that, with a wing of 100 vehicles and two squadrons of OTVs, if just 30 percent of the wing is mobilized at a sortie rate of two launches per MTV per day, a four day launch schedule would yield 10.8 million pounds of lift for $ 4.3 billion. This is equivalent to the entire US spacelift in the 20th Century. During one year, it is possible to sortie each vehicle 70 times including maintenance periods. A wing of 100 MTVs would put 315 million pounds into orbit at a cost of $ 126 billion. The weight is equivalent to putting three aircraft carriers in space! If the space shuttle were used, it would take 20 times as long at a cost of $ 4 trillion.
>
> With the miniaturization of PGM weapons and reusable carrying capacity, space control enthusiasts once again claim that space superiority can by itself win wars and that space is

the truly joint environment. The costs of conducting a seven day hyperwar with MTVs and OTVs would run about $ 10 billion excluding payload weapon costs. Decisive force is brought to bear within 40 minutes of the NCA decision. OTVs conduct routine refueling of the satellite constellation and rearming of the ABM defenses. Next week is a combined joint exercise in counterspace force application against a fictitious enemy's satellite system.

Notes

[1] Marco Antonio Caceres, "Space Market Shifts to Private Sector," *Aviation Week*, 8 January 1996, 111.

[2] Lt Col Jess Sponable, *Advanced Spacelift Technology* (U), Phillips Laboratory, PL/VT-X, briefing, Air University Library, 2025 Support area, 6 March 1996. (SECRET). Information extracted is unclassified.

[3] Joseph C. Anselmo, "Shrinking Satellites," *Aviation Week*, 26 February 1996, 64.

Chapter 5

Recommendations

> *A hundred years from now people will look back and wonder how we ever managed our affairs on this planet without the tools provided by the space program . . . a world without spacecraft is as hard to imagine a world without telephones and airplanes.*
>
> —Wernher von Braun

Spacelift's center of gravity is *ROUTINE OPERATIONS*. A paradigm shift in strategic thinking from the specialized R&D space focus to mission accomplishment in national security and national economic growth must be accomplished. The following passages summarize the requirements to develop an operational system based on incremental long-range technological and operational art advances.

As US spacelift transitions into an environment dominated by commercial providers, it is unlikely that the DOD will continue to support its own separate industrial base. At the October 1995 Air Force Association convention in Los Angeles, Secretary Sheila Widnall stated, "It is clear this nation can only afford a defense industrial base in those areas where there is no commercial activity."[1]

A key aspect to reducing the cost of spacelift is enlisting industry support in the commercial sector for the development of new systems. NASA administrator Dan Goldin is attempting to build such a partnership with the private sector to reusable launch vehicles. After experiencing an order of magnitude reduction in satellite cost per bandwidth over the last decade, NASA is teaming with industry to realize a $10,000 per pound to $1,000 per pound reduction in the cost of launch.[2] Looking a generation beyond the $1,000-per-pound barrier, the $200-per-pound mark further enables commercial uses of space into such areas as entertainment and space tourism.[3]

Given the magnitude of spacelift challenge, no magic solution can resolve all of the issues instantaneously. Instead, the problem must be attacked incrementally. The first step is to address the crippling cost issue. The *Space Launch Modernization Plan* outlines how the country will change one of the current expendable launch vehicles into a family of vehicles capable of satisfying the myriad of lift requirements facing the country, from medium payloads to heavy payloads. The resulting EELV system requires sustainment of one system infrastructure versus the three systems currently maintained for Titan, Atlas, and Delta. But this "right-sized" infrastructure, combined with more reasonable processing timelines, is only the first step in controlling the cost of launch. Concurrent with the DOD expendable effort, NASA is pursuing a truly reusable spacelift system, the X-33. Capitalizing on the advances of the X-33, the first generation, reusable MTV must provide responsive operations with airline-style operations.

This first generation space MTV's primary focus will be routine operations with an expanding mission base. It will provide aircraft-like operations, improved reliability, technician-level maintenance, and simplified infrastructure. The system will remain cryogenically powered and will demonstrate operable spacelift operations without requiring revolutionary technology.

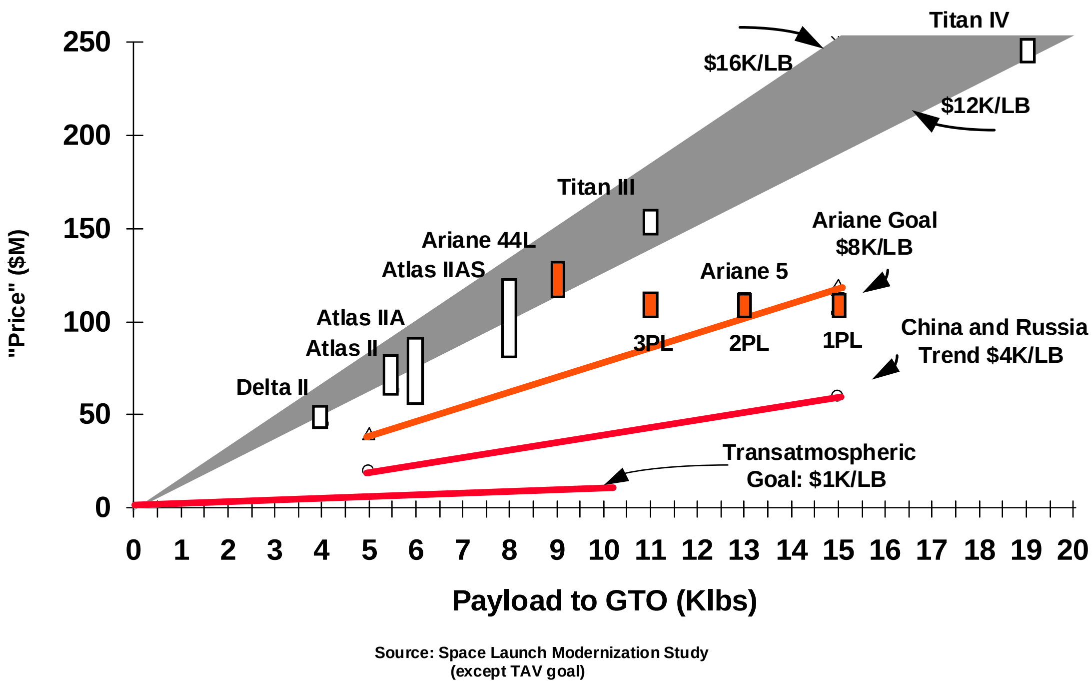
The next step will expand on the lessons learned with the initial MTV by pushing propulsion and material technologies toward leading edge evolutionary technologies, including combined-cycle engines using laser pulse detonation, magnetohydrodynamics, and higher energy propellants. Combined with advances in reduced vehicle dry weight due to advances in materials and lighter weight fiber-optic avionics, the second generation MTV will see large improvements in performance. Finally, the third generation MTV will incorporate a high-energy propulsion system capable of producing an I_{sp} of greater than 900 seconds. Combined with further structural advances in materials, which decrease the dry weight of the vehicles, and increased sortie rates, this resulting generation of MTVs will possess a lower mass fraction and will provide an order magnitude improvement in cost per pound to orbit.

The key to realizing these leaps in spacelift performance is to protect the seed money for a variety of technologies while the initial steps take place. Propulsion and material technologies drive the development of MTV systems. Early reductions in the cost of launch from EELV and first generation MTVs are gained by directing investment in these key technologies. The DOD must form partnerships with NASA and the commercial sector to provide synergy in achieving this goal. Stovepipe efforts create stovepipe systems which can no longer be afforded. National Space Strategy must be examined and revised every couple of years to ensure the efforts of all sectors are properly orchestrated with the DOD as lead agent to ensure that it is in concert with the National Security Strategy.

Once the ETO problem is mitigated, the funds required to assure access to space can begin to address the problems of assured access through space (ETE) and assured access in space (STS). These ETE frontier spacelift missions enable spacelift as a true force enhancer. The ETE mission is a natural outgrowth of an affordable and efficient, high-energy MTV. Once the system becomes plausible, the military is just one of many customers in line to take advantage of the leap in capability. The military MTV must be developed as the future strategic war fighting vehicle.

STS missions will benefit from some of the same technological advances that facilitated the high-energy reusable vehicle. High-efficiency, low-thrust solar ion propulsion systems will provide inexpensive orbital transfer for those customers able to wait weeks for their satellite to reach programmed orbit. Military customers requiring a quicker route to orbit will use a nuclear ion propulsion system on a similar vehicle bus. To best utilize the expanded spacelift mission area of 2025, the DOD will need to refine the concepts and define the entire spectrum of missions now!

The overriding factor to the spacelift problem is routine operations, which ultimately leads to affordability. Combining solution characteristics described in this paper, affordability become the outgrowth of increased sortie capability and reusability. Given the increasing pressures of lower cost foreign goods (fig. 5-1), the motivation to lower costs is common to all sectors of the US space launch community. Commercial providers cannot regain market share at $10,000 per pound while facing a European trend of $8,000 per pound and Russian and Chinese trends towards $4,000 per pound. While a $1,000 per pound MTV does not capture all of today’s market, it does provide the motivation to lower the weight of any cargo to the point where such reduction is physically possible.



Source: Under Secretary of Defense for Acquisition and Technology, *Space Launch Modernization Plan*, Office of Science and Technology Policy, 1995.

Figure 5-1. Launch Costs

Implementing the incremental approach outlined above provides a safe, realistic path from space launch to spacelift operations. It lowers the cost of the current system while providing a spacelift capability to meet the national defense requirements at any time during the incremental development. The ETO mission remains the cornerstone of spacelift operations. Once cost improvements are realized in the ETO area, expansion into ETE and STS missions becomes a reality.

To reach this 2025 spacelift vision, the initial effort must begin now. First, true reusability must be demonstrated in a first generation MTV. While NASA has the lead in the reusability track, DOD must stay engaged by supporting technology, ensuring the system meets military as well as civil/commercial requirements, and developing operational mission uses for the initial system, including pop-up and refly satellite options. Second, investment in propulsion technology must be pursued aggressively. The total DOD launch technology investment has atrophied at about $45 million per year.[4] A portion of investment dollars must be used to pursue such revolutionary propulsion systems as laser pulse detonation, magnetohydrodynamics, the "accelerator class" propulsion concept, high density fuels, and ion propulsion.[5]

This propulsion development must take advantage of commercially derived advances in composite technology and manufacture (including thermopultrusion), metallurgy, and computers. The propulsion system must be able to power the MTV through all conceived mission profiles. Finally, development of innovative missions for a future MTV/OTV system must be studied relative to air-and space-core competencies. To become a viable foundation for global presence, planning for information dominance, precision employment, and space superiority, *must begin now!*

Notes

[1] John A. Tirpak, "The Air Force Today and Tomorrow," *Air Force Magazine*, January 96, 22.

[2] Daniel S. Goldin, "Viewpoint," *Aviation Week*, 26 February 1996, 74.

[3] National Aeronautics and Space Administration, *Space Propulsion Plan* (Draft), Marshall Space Flight Center, 22 January 1996, 8.

[4] Under Secretary of Defense for Acquisition and Technology, *Space Launch Modernization Plan*, Office of Science and Technology Policy (Washington D. C.: Government Printing Office, 1995) Executive Summary, 1995, 14–17.

[5] USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century*, summary volume (Washington, D.C.: USAF Scientific Advisory Board, 15 December 1995), 45.

Appendix A

Propulsion Advances

A Pivotal Technology

In 2025 spacelift sees second generation propulsion employment advances toward third generation propulsion systems. The MTV is a combination of revolutionary and evolutionary technology. The vehicle incorporates a vertically launched, single stage-to-orbit, "accelerator class" propulsion system. This propulsion system produces greater than 300 times the thrust (at less than Mach 6) of current systems with a specific impulse greater than 800 seconds. The fuel storage is dense, contained, or compact and contributes to lowering mass fraction. This propulsion system is derived from the evolutionary second generation, reusable launch vehicle, which incorporates evolved combined rocket/air breathing engine cycles employing an accelerator class laser pulse detonation and magnetohydrodynamic propulsion system for atmospheric transport to orbit. Each engine cycle is optimized for a specific portion of the ascent profile. The second generation vehicle is derived from current propulsion systems based on the first generation military and commercial/NASA version of the space plane. The following are the notional advances required from first through second generation propulsion systems.

First Generation Propulsion Alternatives

Technical Considerations. Physics dominates spacelift, and Newton's third Law, stacked heads true time which purports that for every action there is an equal and opposite reaction, holds. To achieve orbital velocity, sufficient momentum (mass x velocity) must be generated to counteract the earth's gravitational pull. Launch vehicles expel expended fuel mass with velocity to propel itself through the atmosphere in the opposite vector. Translated, the thrust (the rate of change of momentum) required for propulsion is the mass flow rate times the velocity of the fuel. The primary measure of thrust-producing efficiency is the I_{SP}, which is measured in seconds as the impulse provided per unit weight of fuel expended.

X-33 Demonstrated Performance. Using the lower mass fraction available due to composite development and the additional payload capability made possible by the pop-up maneuver and refly options, the use of current cryogenic propulsion systems of low I_{SP} (less than 400 seconds) continue to execute heavier medium-lift missions from the upper atmosphere.[1] Employing an X-33-developed integrated powerhead rocket engine, a cryogenic propulsion system provides 250,000 pounds of thrust, yielding a 28-second improvement in I_{SP} and a thrust-to-weight ratio greater than 75:1.[2] The X-33 primarily provides the proof of concept for reusability and operational tempo. Further advances in cryogenic fuels are spurred through international pooling of information, including Russian engine and fuel pump technologies. The second generation systems take advantage of evolutionary advances in propulsion technology.

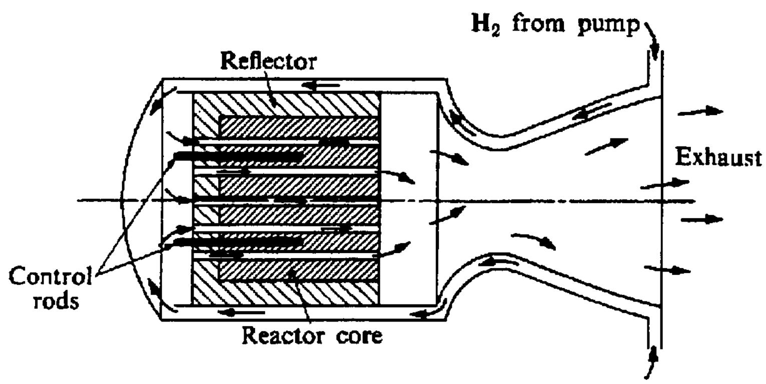
Other Current Propulsion Options. The Blackhorse (as outlined in *SPACECAST 2020*) propulsion technology spin-off is hydrogen peroxide propulsion with the combined monopropellant storage. Low I_{SP} of hydrogen peroxide inhibits extensive development of this fuel source for a rapid response ground-to-orbit vehicle. Lockheed Martin reusable launch vehicle research is working toward to a linear airspike engine, which would improve I_{sp} through atmospheric flight using cryogenic propulsion.[3]

Second Generation Propulsion Options

Laser Pulse Detonation and Magnetohydrodynamic Fan-jet. Pulse detonation is laser induced, high frequency, sequenced detonations of fuel in a closed tube with a nozzle on one end in lieu of conventional combustion. High efficiency, greater thrust is produced through the use of rapid energy release of detonation as compared to controlled burning of current cryogenic systems. Pulse detonation provides the best option for a revolutionary technology push in conventional rocketry using unconventional physics. The system produces 15 percent higher I_{SP} than conventional cryogenic systems with 40 times the decrease in feed pump pressure, which contributes to weight reduction and increased operational efficiency.[4] This system also provides an alternative to chemical propulsion by using air-breathing technology where feasible as the vehicle transitions to orbit. These accelerator class engines transition the subsonic, supersonic, and hypersonic regimes to mach 25 with each engine variant operating within its most efficient regime.[5] Using laser technology, the LPD engine can transition to the electric MHD fan-jet engine in the final push to orbit.[6] This propulsion system uses the earth's magnetic field to produce energy for ionization of gases in the upper atmosphere or in an onboard propellant and accelerates these gases through a hypersonic fan jet for thrust generation. The MHD engine theoretically produces 6,000-18,000 seconds of I_{SP} for acceleration to velocity greater than March 25. Technology pushes in high-temperature superconductors, laser wave detonation, and compact, light-weight, high-energy generation devices are required.

High-Density Fuels. This program, currently titled the "High-Energy Density Materials Program" (HEDM), is a concept to increase the energy content in conventional chemical bonds of non-nuclear fuels.[7] For example, a 5 percent boron additive to solid hydrogen is projected to produce a 107-second I_{sp} improvement in efficiency, and other additives such as titanium and boron/titanium composites show promising results.[8] This trend results from the continuation of study suggested by *New World Vistas*. This program possesses high potential in the search for metastable fuels, which are reasonably stable and practical. Future environmental considerations must be factored into their feasibility. This increase in $I_{sp,}$ due to higher chemical release over the chemical maximum of 450 seconds, could result in a payload increase of 22 percent. Currently, the most promising research is in metallic hydrogen/oxygen propellants. The synthesis of these highly energetic propellants is the technological challenge, but the rapid increase in computational modeling could drive the concept toward reality without large capital investment in research and development.

Nuclear Fission. This concept has been developed extensively through the 1960's and 1970s. It has the advantages of I_{sp} greater than 1,500 seconds, and the fuel mass fraction is much smaller with an associated compact fuel geometry due to high-fuel density. Moreover, it works easily in space, because the reaction requires no atmosphere. In nuclear thermal propulsion, a propellant gas is heated as it flows through the core of a reactor and is then expanded and expelled through a nozzle (fig. A-1). The reactor core can be solid, liquid, gas, or plasma. The last two approaches can produce high temperatures and greater efficiency but are limited to space orbital applications due to the expulsion of radioactive gases. Project Rover directed by Los Alamos National Laboratory produced a solid core engine that produced 200,000 pounds of thrust with 9,500 kilogram reactor mass and an I_{SP} of 845 seconds.[9] Therefore, the concept has been proven in theory and practice. Further, dual-use designs can be developed which provide electrical generation and ion drive maneuvering power after the propulsion phase is complete. Finally, the technician-driven infrastructure is proven since Naval Reactors has trained personnel to operate reactors with automatic controls at the "blue-suit" level safely for years with a well-established training and maintenance record. Recent NASA research on the lunar-augmented nuclear thermal rocket combines a scramjet with near-term nuclear thermal rocketry and demonstrates the utility of this concept.[10]



Source: Air Command and Staff College, *"High Leverage Space Technologies for National Security in the 21st Century"* (Maxwell AFB, Ala.: Air University Press, 1995).

Figure A-1. A Basic Nuclear Thermal Rocket

The largest obstacles to nuclear rocketry are both political and environmental. Radiation shielding is required for human and payloads and adds significantly to the vehicle mass fraction. There is some inherent fuel erosion due to the velocity and hot temperature of the propellant, which ejection of fission products into the exhaust. Improvements in metallurgy since 1973 could correct this problem by using improved cladding, different propellant gases, or more efficient fluid regimes (detected through computer-aided design). Finally, uncontrolled reentries or launch failures result in nuclear material entering the environment either intact, in pieces, or dispersed as fine particles. Offsetting this problem is the fact that the reactor mass is small by comparison and would result in little or negligible environmental impact, and remote launch sites could further reduce the risks.

For reusable vehicles, disposal of spent fuel adds to the commercial problem. Current commercial reactor designs have significant safety features built into them; nuclear reactors do not exchange by-products with the environment, and the integral fast breeder reactor technology, demonstrated by Argonne Laboratory, is inherently safe and utilizes plutonium and by-products as fuel.[11] The spent fuel is the largest storage problem due to long-lived radiation products. Recent technological advances could make this problem a non-issue. These include permanent subterranean/seabed storage in stable geological formations in glass-encapsulated canisters, Argonne Lab's nuclear transmutation, which reduces long-lived radioactive isotopes to less radioactive ones through high-intensity nuclear bombardment, and shooting the waste into the sun, the moon, or deep space, which could expand the launch market.[12]

With over 200 years in Uranium resources and as the world's largest consumer of energy, the US may intensify its commercial nuclear industry by 2025 and educate Americans regarding benefits. Realistically, this scenario is remote currently or in the future. Moreover, public disposition would not allow the development of a nuclear fission space propulsion system which is used within the earth's atmosphere. Conversely, satellite history has demonstrated the application of nuclear power in space-based vehicles.

Fusion. In the realm of plasma physics, nothing dominates it as the quest for commercial-fusion power. For propulsion, the laser-fusion concept, which is compressing a deuterium-tritium fuel pellet with symmetrically positioned lasers for a few billionths of a second until the nuclei fuse gives off the heat, is the most promising. In magnetic fusion, the fuel plasma is suspended in a magnetic field and heated until temperature and densities are achieved for the nuclei to fuse. Sustained reactions of one second have been demonstrated, but nuclei reactions with contaminants, lack of plasma-heating technology, and beam constraints have prohibited commercial application. If the technological difficulty of being able to vector the energy can be achieved or the energy can be harnessed in a working fluid, a propulsion engine without the long-lived radiation of fission could be designed for space applications. Recent research at the University of Michigan conceived a simple magnetic mirror confinement system to create a high-plasma density, which theoretically could produce a propulsion system with an I_{sp} of 100,000 seconds.[13] Continued advances in computer technology for plasma modeling, high-temperature superconductors, and charged particle beams could provide the technology leap to produce a self-sustaining fusion reaction by 2025. Current projections place commercial fusion applications at the year 2045.[14] This application of fusion to a propulsion system is a third generation system, which opens the solar system to an operationally strategic area.

Third Generation Propulsion Possibilities

Antimatter Drive. Early in the HEDM program, matter-antimatter annihilation was considered a possible propulsion fuel source. The theory is simply that antiprotons and positrons would be slowed, trapped, and recombined to form a charged anti-hydrogen cluster. This cluster forms one part of the bipropellant fuel and the other ordinary hydrogen. The antimatter cluster is reacted with the ordinary hydrogen and is almost completely converted to energy. Similar to nuclear reactions, the antimatter reactions swap rest mass energies, releasing energies 1,000 times greater than nuclear reactions.[15] The concept is simple, but practical implementation is beyond current technologies, since any fuel must be able to be produced in quantity, stored, reacted in a controlled manner, and energy vectored in a useful form. While small quantities of antimatter have been produced, the current capability is 12 orders of magnitude below required production. Recent research at Pennsylvania State University demonstrates a promising propulsion system based on antiproton catalyzed microfission/fusion, with their recent completion of a portable Penning Trap, which captures antimatter particles for storage them. This propulsion system uses the energy release from the antimatter reaction as the catalyst for a controlled microfission detonation (small vectored nuclear explosions) to produce thrust. The Penning Trap is being transferred to Phillips Lab at Kirkland AFB New Mexico for use in demonstrating microfission in late 1997.[16] The radiation and environmental considerations are less than nuclear fission propulsion, but the high temperature would require sophisticated magnetic containment (similar to fusion) to avoid a meltdown catastrophe. A technology leap in particle physics and magnetic containment is required to implement this technology.

Quantum Fluctuations/Space Drive. Recent theorists have proposed a particle theory for inertia and gravity.[17] This theory proposes that space is not empty but a "cauldron of seething energies," known technically as quantum fluctuations or Zero Point Energy, which have been detected but not tapped. Arthur C. Clarke points out that the potential impact on civilization would be incalculable, because the fuel source would be available to all infinitely and all fuel technologies and concerns over environmental impact would be obsolete.[18] Harnessing this technology requires the same technology leap in particle physics as antimatter and is considered remote by 2025.

Orbital Transfer Vehicle Propulsion

The 2025 military OTV employs second generation combined propulsion systems. A nuclear-electric ion drive combined cycle enables high maneuverability with maximum time to refueling. Commercial OTVs use solar-electric ion drive for economical maneuvering and thrust, augmented by improved fuel cell technology for minimum high-thrust requirements.

Combined Cycle OTVs

Nuclear/Solar Electric Ion Drive. Solar energy is infinitely available in space, but its energy density is small compared to other earth-born sources. It dissipates exponentially as one travels outward from the solar system. Consequently, its required space and mass fraction is large even for electrical generation. Nuclear thermal reactors have large-generating potential, but carry radiation, environmental, shielding, and public support problems. The space-based application of nuclear power has the history to overcome these difficulties. The use of nuclear or solar power for electrical generation enables a propulsion system that ionizes a nonreactive gas, in which the positively charged ions are pulled out of the engine, forming a jet that impels the craft forward. This way, unlike chemical propulsion, the energy generation and momentum are separated. It has the advantages of speed, efficiency, and economy as the current laws of physics allow. Refuelable fuel cells and thermionic reactors augment the power source requirements during high demand. Current research on Russian Express spacecraft with stationary space thrusters and on the Hughes Galaxy III-R communications satellite are the first tests of ion drive principles.[19] Moreover, NASA's millennium program for interplanetary exploration is proposing use of solar-electric ion drive.[20] Nuclear ion drive enables responsive orbital maneuvering (with adequate thrust-to-weight ratio not available from solar energy) required for space mission accomplishment.

Third Generation OTV Propulsion Systems

Magnetohydrodynamic and Laser Propulsion. Magnetohydrodynamics has the immense potential of I_{sp} in the range of 10,000 seconds. It derives its energy by using space magnetic field energy and converting it to electricity to drive a laser-propulsion system on the vehicle. Current research tested a magnetoplasmadynamic thruster on the Japanese Space Flyer Unit, and it should promise.[21] The major disadvantage is the large mass fraction of the vehicle to provide power for thrust requirements of major propulsion. A technology leap in superconductors and plasma physics are required before this technology is practically feasible. Laser propulsion is similar to ion drive, but a ground-based laser imparts energy to a working fluid (hydrogen) at a high I_{sp} (1,500 sec). A technology leap in laser physics with regard to atmospheric compensation is required. Further, the system requires a large ground-based infrastructure for vehicle tracking, a complicated design, and a large power generation requirement.[22]

Notes

[1] Lt Col Jess Sponable, *Advanced Spacelift Technology* (U), Phillips Laboratory, PL/VT-X, briefing, Air University Library, 2025 Support area, 6 March 1996. (Secret) Information extracted is unclassified.

[2] Ibid.

[3] Ibid.

[4] Notes, Dr Dave Bushnell, NASA, subject: 2025 Assessor Comments on Pulse Detonation Propulsion Systems, 29 February 1996.

[5] L. N. Myrabo, L. N. and T. D. Strayer, *Analysis of Laser-Supported Detonation Waves for Application to Airbreathing Pulsejet Engines* (New York.: American Institute of Aeronautics and Astronautics, 1995), 1–2.

[6] L. N. Myrabo et al., *Hypersonic MHD Propulsion System Integration for a Manned Laser-Boosted Transatmospheric Aerospacecraft* (New York.: American Institute of Aeronautics and Astronautics, 1995), 1–15.

[7] Air Command and Staff College "High Leverage Space Technologies for National Security in the 21st Century," *SPACECAST 2020: Into the Future*, (Maxwell AFB, Ala.: Air University Press, 1995), section 5, 3-5. A general discussion of HEDM attributes.

[8] Bryan Palaszewski, "Propellants and Combustion;" *Aerospace America,* December 1995, 46.

[9] Mohamed S. El-Genk, *A Critical Review of Space Nuclear Power and Propulsion 1984-1993* (New York: American Institute of Physics, 1994), 269–288.

[10] S. K. Borowski and B. N. Cassenti, "Nuclear Thermal Propulsion," *Aerospace America,* December 1995, 49.

[11] *Invention*, Discovery Channel, 27 February 1995. Program was a special on the Argonne Laboratory nuclear programs. Focused on the radiation storage problem, the radiation transmutation program

Notes

to reduce have lives of long lived radioactive products, and the extraction the integral fast breeder reactor inherently physics designed safety feature preventing meltdown.

[12] "Disposing of Nuclear Waste," *Scientific American*, September 1995, 143.

[13] G. Emanuel and D. A. Guidice, "Plasma Dynamics and Lasers," *Aerospace America*, December 1995, 15.

[14] Harold P. Furth, "Fusion," Scientific American, September 1995, 140–142.

[15] "High Leverage Space Technologies, section 5, 5–7.

[16] S. K. Borowski and B. N. Cassenti, "Nuclear Thermal Propulsion," *Aerospace America* December 1995, 49.

[17] Arthur C. Clarke, "Space Drive: A Fantasy that Could Become Reality," *Ad Astra*, November/December 1994, 38. Derived from Doctors Haisch and Putoff published theories in *Physics Review* in 1994.

[18] Ibid.

[19] Andy Hoskins, "Electric Propulsion," *Aerospace America*, December 1995, 47.

[20] Ibid.

[21] G. Emanuel and D. A. Guidice, "Plasma Dynamics and Lasers," *Aerospace America*, December 1995, 15.

[22] Lt Col T. S. Kelso et al., "Unconventional Spaclift," *SPACECAST 2020*, briefing, Air University, 25 March 1994.

Bibliography

Articles/Books/Magazines/Published Reports

Air Force Strategy Division, Air Force Executive Guidance, Office of the Secretary of the Air Force Washington D. C.: Government Printing Office, December 1995.

Anderson, John L. "Leaps of the Imagination Using the Horizon Mission." *Ad Astra.* January/February 1995.

Anselmo, Joseph C. "Shrinking Satellites." *Aviation Week*. 26 February 1996.

Caceres, Marco Antonio "Space Market Shifts to Private Sector." *Aviation Week*, 8 January 1996.

Clarke, Arthur C. "Space Drive: A Fantasy that Could Become Reality." *Ad Astra*. November/December 1994.

El-Genk, Mohamed S. *A Critical Review of Space Nuclear Power and Propulsion 1984-1993.* New York, New York.: American Institute of Physics, 1994.

Emanuel, G., and Guidice D. A. "Plasma Dynamics and Lasers." *Aerospace America.* December 1995.

Goldin, Daniel S. "Viewpoint." *Aviation Week and Space Review*. 26 February 1996.

Hassen, Basil, et al. "Thermophysics." *Aerospace America.* December 1995.

Myrabo, L. N., and Strayer, T. D. *Analysis of Laser-Supported Detonation Waves for Application to Airbreathing Pulsejet Engines*. New York, New York.: American Institute of Aeronautics and Astronautics, 1995.

National Aeronautics and Space Administration, NASA. Shuttle Ground Operations Efficiencies/Technology Study. Washington D. C.: Government Printing Office, 1995, vol. 6, NAS 10-11344.

National Aeronautics and Space Administration. *Space Propulsion Plan* (Draft). Huntsville, Ala.: Marshall Space Flight Center, 22 January 1996.

"Technologies For The 21st Century." *Scientific American.* September 1995.

Tirpak, John A. "The Air Force Today and Tomorrow." *Air Force Magazine.* January 1996.

Under Secretary of Defense for Acquisition and Technology, Space Launch Modernization Plan, Office of Science and Technology Policy. Washington D. C.: Government Printing Office, 1995, Executive Summary.

USAF Scientific Advisory Board. *New World Vistas: Air and Space Power for the 21st Century,* Summary Volume. Washington, D.C.: USAF Scientific Advisory Board, 15 December 1995.

Zurbin, Robert. "A Question of Power." *Ad Astra.* November/December 1994.

Assessors/Advisor Comments And Feedback

Bushnell, Dave, subject: assessor comments on ***2025*** Spacelift and pulse detonation technologies. Maxwell AFB, Ala.: Air War College/***2025,*** 29 February 1996.

Lectures/Speeches/Videos/Internet Sources

Inventions. Discovery Channel, subject: special on the Argonne Laboratory nuclear programs. Aired 27 February 1995.

Kelso, T. S., Lt Col USAF, et al.. "Unconventional Spacelift." *SPACECAST 2020*, briefing. Maxwell AFB, Ala.: Air Command and Staff College, 25 March 1994.

Mueller, Dick. Washington Strategic Analysis Team. *Global Response Aerospace Sortie,* briefing. Maxwell AFB, Ala.: Air War College/*2025*, 6 March 1996.

The RLV Operations Concept 'Vision.' Summary of the President's National Space Transportation Policy. On-line internet, February 1996, available from file:///C/-2025/TAV/RLVHP1A.HTM.

Sponable, Lt Col Jess. Phillips Laboratory, PL/VT-X, *Advanced Spacelift Technology* (U), briefing. Maxwell AFB, Ala.: Air University Library/***2025*** Support area, 6 March 1996. (Secret) Information extracted is unclassified.