2025 Aerospace Replenishment: The Insidious Force Multiplier

A Research Paper
Presented To

Air Force ***2025***

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Disclaimer

2025 is a study designed to comply with a directive from the chief of staff of the Air Force to examine the concepts, capabilities, and technologies the United States will require to remain the dominant air and space force in the future. Presented on 17 June 1996, this report was produced in the Department of Defense school environment of academic freedom and in the interest of advancing concepts related to national defense. The views expressed in this report are those of the authors and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the United States government.

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Preface

In the 1920s, the United States government and many others viewed the earliest attempts to replenish airborne aircraft as a barnstorming technique — an aerial circus act. Nevertheless, men like then Maj Henry "Hap" Arnold saw great potential in this possibility and endorsed a project to test the limits of flight endurance. In 1929, the "Question Mark" mission was announced, planned, and executed. That Fokker C-2, replenished by a modified Douglas C-1, remained airborne for seven days. The crew of the C-2 received 5,660 gallons of gasoline, 245 gallons of oil, 17 meals, water, batteries, and other supplies.[1]

It may be tempting to scoff at the new concepts and ideas as presented by this, or any of the other white papers in the ***2025*** project. The Aerospace Replenishment writing team wishes to honor the visionaries of the past and appreciates the kind attention of those of the future. Together, we can revolutionize warfare even more dramatically than that occurring at the beginning of this century.

In this conceptual work, artistic contributions are absolutely essential. This writing team owes much to Mr. Bill Walmsley, 42d Communications Squadron, Graphics Section, as well as Mr. Mike McKim and Mr. Nathan Smith, for the drawings in this report.

Notes

[1] "History of Aerial Refueling," (Videotape), Aerospace Audiovisual Service, Air University, Air Education and Training Command, Maxwell AFB Ala., (1990).

Executive Summary

Studies examining the future of airpower and space power (such as *New World Vistas* and *SPACECAST 2020*) generally have not revealed much in the area of replenishment. Indeed, there is a noticeable tendency to assume it away with the stated requirement or desire that aircraft should have longer range and loiter capabilities. Even if this were possible, replenishment should be better exploited to mitigate the effect of supporting all or most operations from the United States—a likely prospect in the not too distant future. In addition, some visionaries continue to insist that investment in satellite replenishment is unwise due to the constant need to modernize with new and revolutionary satellite systems. This argument fails to convince when one is open to the possibility that a replenishment platform may also modernize existing satellite systems, thus delaying obsolescence and replacement.

The objective of aerospace replenishment is to provide air and space vehicles with on-demand replenishment. To accomplish this, aerospace replenishment must have the ability to project itself both globally and beyond the earth's atmosphere. It must anticipate customer replenishment needs. Finally, it must have the innate operational responsiveness and flexibility to meet those needs. This paper identifies current vehicles, uninhabited aerial vehicles (UAV), transatmospheric vehicles (TAV), and satellites as potential customers in need of replenishment. Anticipated replenishment supplies will include energy, as well as numerous solids, liquids, and gases.

Clearly, the replenishment needs are vast. One platform cannot do all of the tasks well. Therefore, we have identified three types of platforms to meet the specialized needs of customers operating in different environments. A Mothership will meet the replenishment needs of UAVs. A Multirole Automated Replenishing System (MARS) will meet the replenishment needs of current vehicles and the TAV. A Space Support System (SSS), along with space tugs, will support satellites and other vehicles operating in space.

Aerospace replenishment in the year 2025 may be critical in supporting a future presence of US air and space power forces. This paper describes the continued applicability of aerospace replenishment and

identifies the plausible and credible systems and operational concepts required for the expanded role of aerospace replenishment in the aerospace operations of 2025.

Chapter 1

Introduction

The year is 2025. An economic dispute concerning mining rights between Hendi International, a Khan-based corporation, and Pavin Mining, a US-based multinational corporation, has escalated to the point where tensions now exist between the Khan and US governments. These tensions have increased rapidly and resulted in Khan's veiled threat to use weapons of mass destruction against the US. US intelligence has confirmed the mobilization of Khan personnel and equipment at a remote site capable of launching an attack against the US. The president of the United States has authorized a preemptive strike against this facility. His objective is to neutralize this site within 12 hours. Unfortunately, the president has a significant problem.

In 1996, popular thinking of the airpower theorists was centered on designing systems for autonomous global power projection thereby dismissing the need for replenishing systems. The fashionable image of fast and stealthy platforms captivated these theorists. Unfortunately, engineering and production limitations failed to produce systems capable of independent global power projection by the year 2025. Unable to respond to the crisis before escalation, the US military failed to meet the president's objectives. As a result, US military credibility has suffered a substantial blow.[1]

No one can precisely forecast what the future will hold for the United States and its air and space forces; clearly, however, air and space exploitation will remain important. Over the last 30 years, technological breakthroughs have been successfully exploited to build the strongest and most capable contingent of air and space power that humankind has ever known. Nevertheless, the future is not the time to rest on laurels. In the next 30 years, emerging technology must continually be exploited to build upon the vast capability that exists within air and space forces.

The geopolitical environment of the world requires that the United States continue an active leadership role in world affairs.[2] Although previously up to the task, the United States must hone and maintain its military instrument of power to continue to assert leadership throughout the world. Inherent in this task is the capability to project power globally. In planning for conflicts in 2025, one must assume a diminishing or nonexistent overseas US military presence. Some US military operations may be conducted from bases located within the US and require force projection over large distances.[3] With this type of situation on the horizon, the capability to provide aerospace replenishment to mobility and combat forces will become even more critical in supporting air and space power forces in the year 2025.

Military forces may operate in either the air or space, and only a few will regularly make the transition between the two. Thus, in 2025, the US may have separate air and space forces. The interactions between these forces may be substantial, with space-based surveillance and reconnaissance assets routinely fusing data to air forces. This paper will use the term "aerospace" to refer to the combination of air and space as well as their combined forces. In addition, "replenishment" refers to providing air and space forces with organic essentials such as energy, fuel, and weapons.

Operational doctrine indicates that aerospace replenishment's primary mission is to support other air and space forces. Aerospace replenishment will extend the performance of these assets; enabling airpower forces to perform longer missions and travel further through replenishment. In addition, aerospace replenishment can save time, money, material, and manpower. Replenishing a weapon system in the air can enable it to arrive over the target or reattack faster. Airborne replenishment can also reduce the ground infrastructure necessary to replenish these combat vehicles. By exploiting weapons replenishment technology, we may enhance performance of the complete weapon system. Space replenishment could extend the useful life cycle of satellites, thereby reducing launch costs and satellite replacement costs. There also is the added benefit of reducing space debris, which results from the growing collection of useless satellites. Eliminating some of the 3,000 tons of man-made debris will reduce the possibility of satellite damage from collisions.[4] Space presents numerous unique challenges; however, this paper will limit analysis to satellite replenishment possibilities.[5]

The organization of the paper nudges the reader through the world of 2025 and into the operational employment of aerospace replenishment forces in that future world. This journey begins with critical

assumptions to set the stage for the world of 2025. Following the assumptions, chapter two presents a case for aerospace replenishment; the required capability. This discussion describes the criteria for evaluating various transfer mechanisms and systems. Chapter three uses these criteria to evaluate the methods of transferring these organic essentials. After selecting the candidate mechanisms, the required platforms are described and evaluated. Chapter four presents a concept of operations for the three candidate platforms: the Multirole Replenishing System (MARS), the Mothership, and the Space Support System (SSS). Finally, chapter five provides recommendations on ideas that can lead the US from today towards the world of 2025.

Assumptions

The ***2025*** Alternative Futures study provides the backdrop for this paper.[6] These alternative futures cover a spectrum of possible scenarios and include various assumptions. The following assumptions, either synthesized from the alternative futures study, *New World Vistas,* or developed by this writing team, are the most relevant to this paper's thesis. For purposes of this study, the following assumptions apply:

- US reliance on space-based capabilities will continue to increase.[7]
- Supersonic travel is routine.[8]
- Transatmospheric dimension has been exploited for military application.[9]
- Requirement remains to refuel current aircraft.[10]
- The US must be capable of fighting at large distances from its shores.[11]
- Some operations may be staged directly from the US.[12]
- Bulk of US forces will be based in the US.[13]
- UAVs will be a key part of forces.[14]
- Foodstuff and fuel replenishment will extend manned space operations.

Aerospace replenishment in the year 2025 may be critical in supporting a future presence of US airpower and space power forces. This paper describes the continued applicability of aerospace replenishment and identifies the plausible and credible systems and operational concepts required for the expanded role of aerospace replenishment in the aerospace operations of 2025.

Notes

[1] Completely fictional scenario tied to ***2025*** Zaibatsu and King Khan Alternative Futures; developed during ***2025*** futures development phase.

Notes

[2] Joseph S. Nye, Jr., "The Case for Deep Engagement," *Foreign Affairs*, (July/August 1995), 90.
[3] Air Force Scientific Advisory Board, *New World Vistas*, Summary Volume, (15 December 1995), 5.
[4] Col Thomas J. Hall, *Space Debris: A Threat to National Security*, (Maxwell AFB, Ala.: Air University Press), 110.
[5]The "On-Orbit Support" ***2025*** study White Paper writing team provides a detailed investigation of other orbital support operations.
[6] The Alternative Futures White Paper team provides a detailed description.
[7] SAF/CSAF, *Air Force Executive Guidance (*Washington D.C.: Department of the Air Force, December 1995), 9.
[8] Bill Sweetman, "US Supersonic Transport Research Forges Ahead," *Interavia*, (January 1995), 20-22.
[9] "Space Lift," *SPACECAST 2020*, Volume 1, Air University, Air Education and Training Command, Maxwell AFB, Ala., (June 1994), H-1 — H-58.
[10] *Air Force Executive Guidance*, 7 ,8 ,11.
[11] *New World Vistas*, Summary Volume, (15 December 1995), 5.
[12] Ibid.
[13] Jeffrey Record, "The Air War," *Hallow Victory* (McLean, Va.: Brassey's [US], Inc., 1993), 148.
[14] *New World Vistas*, 8.

Chapter 2

Required Capability

A revolutionary concept, within the ***2025*** study, would be to put aerospace replenishment out of business.[1] While most future weapon systems may attempt to maximize performance and capabilities, employment of these weapon systems for extended periods of time, at large distances from the US, may require replenishment operations to fully exploit the complete weapon system. As a minimum, replenishment capability within US aerospace forces will increase the effectiveness of military options for future commanders.

Planning for "worst-case" scenarios in ***2025*** dictates planning for unknown threats in unknown locations. This may entail sustained operations being "executed day and night in all weather."[2] In addition, the US military may be required to have the capability to rapidly project combat forces globally from the US, while employing these forces in synchronized aerospace operations. In the Gulf War, "The bulk of work came from much older systems and mundane technologies such as air refueling (which was required for three-fifths of all combat missions)."[3] Aerospace replenishment forces, as part of the global mobility forces, are required to project and sustain future operations.

Core Competencies

Aerospace replenishment must continue to provide on-demand support and global mobility to the warfighting commander. These competencies, derived from air refueling core competencies, are built on the

concepts of saving time, reducing cost and manpower, and increasing performance—thus providing enhanced flexibility and responsiveness.

The US Air Force demonstrated in Operation Restore Hope that eliminating land-based refueling would increase the on-time delivery rate of cargo to Somalia. Through air refueling, C-5s and C-141s were able to take off with more cargo, thus increasing their cargo carrying performance. Eliminating the en route staging requirements increased the aircraft's maintenance reliability and reduced the associated manpower costs. Additionally, eliminating en route ground time reduced the time required to arrive at the destination.[4]

The research questions are "how do current core competencies project into future requirements and how are they synthesized into ***2025*** aerospace operations?" Evolutionary projections of current air refueling capabilities may lead to the development of possible future aerospace replenishment missions. This chapter evaluates possible replenishment media and credible methods of transferring the media between platforms through operational analysis methods. This leads to five candidate transfer solutions, which that are refined in chapter three.

The aerospace replenishment mission statement for operations in 2025 is to provide on-demand support to air and space vehicles requiring replenishment. Global aerospace mobility and on-demand support are the aerospace replenishment core competencies required to support air and space operations in 2025.

Providing on-demand support to air and space vehicles requires global mobility. US air and space forces must be able to conduct and support aerospace operations throughout the world. Aerospace superiority, the ultimate "high ground," may remain a vital component of future operations. Aerospace replenishment will support aerospace superiority operations by extending the range and endurance of the combat vehicles carrying out this mission. In the year 2025, control of the air and space above the battlefield may remain a critical factor for our contingency planning efforts. With advances in information technology and information warfare, 2025 war fighters may need to control the "high ground."[5] Thus, space and space systems will become increasingly more essential for effective operations.[6] Much of the military benefit derived from space comes from satellites and the trend is for smaller, lighter, and cheaper designs. One ***2025*** lecturer indicated that some future satellites may be small and light enough to be handheld.[7] During Desert Storm, commanders needed satellites moved to strategic locations to obtain more critical data. Yet using fuel to move satellites shortened the usable life of these satellites.[8] Having the capability to replenish a

satellite with fuel will increase the useful life of space systems, thereby enhancing future campaigns. In addition to supporting operations around the world, global mobility involves the capability to reach into space and replenish satellites as well. The mission statement calls for on-demand replenishment. Part of "on-demand replenishment" dictates a global aerospace capability to provide this service. Thus, global aerospace mobility becomes a core competency.

The remaining part of "on-demand replenishment" dictates providing support to the platforms requiring services. On-demand support involves providing the customers what they need, when and where they need it. Global mobility will ensure the "where" part of this equation is attainable. The "what" part of the equation identifies specifically what the receiver platform requires from replenishment operations. By 2025, there may be an opportunity for a weapons replenishment capability in addition to the current fuel replenishment capability that exists today. The "when" part of the equation dictates a need for an integrated command and control system capable of coordinating required information to both the replenisher and the receiver. This information system will be capable of providing real time updates regarding timing and requirements between the various platforms.

On-demand support is comprised of responsiveness and flexibility. The Prussian strategist Count Helmuth von Moltke the elder once said, "No plan survives contact with the enemy."[9] Since aerospace replenishment forces support other aerospace forces, they need to be responsive and flexible. A well-integrated command and control system ensures exploitation of this flexibility. Thus, global aerospace mobility and on-demand support are core competencies in 2025 due to the criticality of aerospace replenishment support during aerospace operations.

Areas For Evaluation

Geopolitical uncertainty about the future dictates that the US must maintain a military force capable of projecting power globally, with the bulk of US forces based primarily in the US. The future warfare tempo may be so rapid that advanced technology weapon systems may be rendered less effective if they cannot deploy in sufficient time to counter global threats. In 2025, a credible aerospace replenishment capability enhances the global employment of US aerospace forces. Traditionally, weapons and propulsion fuel have

been the organic essentials required to conduct air operations. In 2025, an aerospace replenishment capability may exist for the following organic essentials:

1. Energy: Lasers, directed energy (DE), and kinetic energy (KE) weapons.
2. Solids: Bombs and bullets to KE particles and food stuffs.
3. Liquids: Jet fuel to hypergolic fuel or chemicals.
4. Gases: Air to plasma.
5. Information.[10]

The next areas to be evaluated are the methods to transfer these materials. A listing of various systems for transferring these materials follows:

1. Direct: Materials delivered through physical contact.
2. Beaming: Atmospheric energy transfer from source to recipient.[11]
3. Parachute: Lightweight containers that parachute between platforms.[12]
4. Glider: Pods with wings that fly or glide onto platforms.[13]
5. Robotic: Arms that install replenishment supplies onto platforms.[14]

To visualize the feasibility of transferring these materials by the various methods, see the matrix of these materials and methods in table 1. In addition, combinations of transfer methods and transfer materials are scored—on a scale of zero to ten—on the basis of the feasibility of accomplishing the task in 2025. For example, the direct transfer of electric energy rates a "10," the highest possible score, because it is very feasible that aerospace forces could accomplish this transfer. The vertical and horizontal score totals indicate where the overall research should be centered: in the areas of direct transfer of various materials and different methods of transferring electrical energy.

Table 1

Replenishment Materials and Transfer Methods

TRANSFER METHODS	**TRANSFER MATERIALS**				
	ELECTRIC	**SOLIDS**	**LIQUIDS**	**GASES**	**TOTALS**
DIRECT	10	5	10	10	**35**
BEAMING	8	0	0	0	**8**
PARACHUTE	0	4	2	2	**8**
GLIDER	0	3	3	3	**9**
ROBOTIC	7	8	5	5	**25**
TOTALS	**25**	**20**	**20**	**20**	

The five highest scoring combinations from this feasibility evaluation are the direct transfers of electrical energy, liquids, and gases, the beaming of electrical energy, and the robotic transfer of solids. The systems description section of the paper evaluates these five combinations. Although limited technology exists to transfer or replenish information, another ***2025*** writing team will address future information replenishment capabilities.[15] While the paper will further detail these five previously identified combinations, the evaluation must first validate the applicability of the aerospace replenishment of these materials.

To provide measures of merit, this paper identifies the criteria used to evaluate the effectiveness of the transfer and platform systems. Analysis identifies eight prioritized criteria for future transfer systems:

1. Operational benefit: The added capability for the user.
2. Transferability: Ability to accept various media from other platforms.
3. Maintainability: Ease of maintenance and reliability of the platform.
4. Safety: Designed to reduce accidents.
5. Cost effectiveness: Overall cost minimization from cradle to grave.
6. Automation: Reduced human interface during the process.
7. Reload capability: Ability to rapidly reattack or reengage the target.
8. Environment: Concern for the surroundings.

Analysis identifies 10 prioritized criteria for future transfer platforms:

1. Transfer capability: Ability to provide various media to other platforms.
2. Interoperability: Capability to replenish a variety of vehicles.
3. Operating envelope: Capability to operate at varied speeds and altitudes.
4. Survivability: Ability to prevent or avoid destruction.
5. Storage capability: Ability to store large and various energy media.
6. Automation: Reduced human interface during the process.
7. Cost effectiveness: Overall cost minimization from cradle to grave.
8. Mobility: Worldwide ease of movement.
9. Safety: Designed to reduce accidents.
10. Environment: Concern for the surroundings.

Currently, the only method of aerospace replenishment is the direct transfer of fuel through a boom or drogue. In order to fully evaluate the benefits of replenishment, this paper explores the complete spectrum of materials such as energy, solids, liquids, and gases. Directed energy (DE) power sources such as electrical, gases, and liquids can possibly be transferred; however, the scientific community needs to further explore storage technology to be able to justify the cost of DE power transfer. This stems from the fact that current electrical storage technology is not feasible or economical for DE weapons employment.[16] The development of storage devices should proceed much faster than DE weapons development due to the commercial use of

storage technologies. Therefore, by the time DE weapons become operational, storage devices should not be a restriction and the need to transfer energy will remain.

Inflight transfer of solids to include conventional type weapons (such as bullets and bombs) provides another opportunity to more rapidly employ firepower, thereby overwhelming the enemy's ability to react. Through the use of robotics, it may be feasible to rearm aerospace vehicles with conventional munitions inflight. A general officer indicated that there was much discussion during past conflicts on the obvious desirability of accomplishing conventional weapons replenishment.[17]

With advanced technology available for flight guidance computers, automated aerospace replenishment technology should be pursued. This feature facilitates a low-visibility aerospace replenishment capability, thereby increasing the effectiveness of our air and space power forces. In addition, automated uninhabited replenishment platforms eliminate the need for planning crew rest prior to long operations. These automated vehicles contribute to enhancing the replenishment capability of aerospace forces in 2025.

Based on these required aerospace replenishment capabilities, a multipurpose replenishment system can possibly accomplish the transfer of energy, solids, liquids, and gases. However, multiple platforms are needed to satisfy energy transfer needs within the aerospace environment.

Notes

[1] Dr. Dennis M. Bushnell, Chief Scientist, NASA Langley Research Center, ***2025*** Assessor Comment on ***2025*** First Draft White Paper, February 1996, (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

[2] *New World Vistas*, Summary Volume, (15 December 1995), 5.

[3] Eliot A. Cohen, "The Mystique of U.S. Airpower", *Foreign Affairs*, No. 1, Vol. 73, January/February 1994): 112.

[4] Lt Col Yoshio Smith deployed to Moron Air Base, Spain as the KC-135 Operations Group Commander to coordinate air refueling along the Portuguese Coast, Mediterranean, and Azores.

[5] While the North Vietnamese were able to "hide" against the might of the US air strikes, the future space-based battlefield dominant information system could pin point those in hiding against a less technologically endowed opponent. Of course, an opponent with less technology in their warfare could possibly counter the technologically superior opponent, perhaps the tempo of warfare may belong to the information dominant warriors.

[6] *New World Vistas*, Summary Volume, 11.

[7] Guest lecturer, lecture to ***2025*** participants, Air War College, Jones Auditorium, December 1995.

[8] Mr. Christopher Whitlock, Operations Support Office, National Reconnaissance Office, interview with Lt Col Yoshio Smith, Maxwell AFB Ala., 26 February 1996.

Notes

[9] Edward S. Miller, *War Plan Orange,* (United States Naval Institute, Annapolis, Md: Naval Institute Press, 1991), 333.

[10] John A. Kennedy, Delta airline pilot, during interview with Lt Col Yoshio Smith, stated that Delta aircraft can receive air traffic control clearances on a computer display within their cockpit without voice radio transmissions, 22 March 1996. Other ***2025*** teams are addressing information operations in the aerospace environment.

[11] Lt Col Brian L. Jones, Chief, ***2025*** Technology Team, interview with Lt Col Yoshio Smith, Maxwell AFB, Ala. 7 February 1996.

[12] Dr. Wade Adams, ***2025*** Assessor's comment on First White Paper Draft, February 1996, (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

[13] Ibid.

[14] Jones, interview with Smith, 7 February 1996.

[15] Other white papers in ***2025*** study address information operations.

[16] Verbal feedback on the Aerospace Replenishment Team's Briefing to the Air Force Scientific Advisory Board, Air University Library, 7 February 1996.

[17] Lt Gen Charles T. Robertson, Vice Commander, Air Mobility Command, comments to Aerospace Replenishment Writing Team, Air Mobility Command video teleconference, 28 February 1996.

Chapter 3

System Description

The previous chapter presented the aerospace replenishment core competencies and identified transfer media and platform characteristics. This chapter will analyze the replenishment mission and explore plausible technologies of 2025. It will also marry the scientific capabilities with the mission requirements in order to offer several credible systems for further analysis.

In order to fulfill the required mission capabilities, revolutionary systems are needed. The overall systems include the transfer mechanisms as well as the platforms that are needed to support those mechanisms. The transfer systems are those mechanisms employed to transfer the organic essentials: energy, solids, liquids, and gases.

Transfer Systems

A variety of methods to transfer the energy, solids, liquids, and gases are available. Previously described were four groups of materials and the feasibility of their transfer via individual transfer methods. Individual transfer systems would be inefficient; therefore, an integrated system that can transfer everything may be necessary (e.g., an integrated replenishment boom system).

A key component of the transfer system is a replenishment boom that can accommodate vehicles operating in 2025. In addition to transferring liquid carbon-based fuels, this system can transfer liquids such as hypergolic fuels. Transfer of solids, particles, or gases can be accomplished by modifying the boom to a pressure system where the replenisher selects the amount of pressure required to transfer the different media. Electrical transfer will utilize the same integrated replenishment boom. The insulated conductive material

located through the center of the boom facilitates electrical transfer while liquid, gas, or solid transfer occurs outside the conductive core. Therefore, a need exists for a single integrated boom transfer system that can transfer all four media. In the following sections we will explore such a system's feasibility.

Transferring Energy

The capability of directed energy and kinetic energy weapons in 2025 will extend beyond the capabilities of today's precision weapons. Already, laser technology has demonstrated the ability to destroy aerospace vehicles.[1] Easily envisioned are UAVs used extensively in the high-threat environment with DE and KE weapons as the standard armament. Will they need an external energy source to sustain operations? UAVs may be powered by small engines and may not have the generator capacity to energize the large capacitors or batteries needed for high-tempo operations.[2] Likewise, the limited carrying capacity will prohibit extensive internal storage devices for the electrical energy or chemicals. Therefore, the energy will need to be transferred from either a ground-, air-, or space-based system, each of which has advantages and disadvantages that must be evaluated (table 2).

Table 2

Energy Transfer Criteria Ratings

WEIGHTED CRITERIA	**GROUND BASED**	**AIR BASED**	**SPACE BASED**	**JOINT AIR & GROUND**
OPS BENEFIT (20)	16	17	14	19
TRANSFERABILITY (19)	16	15	14	18
MAINTAINABILITY (16)	15	13	8	14
SAFETY (14)	12	10	8	11
COST EFFECTIVENESS (10)	9	8	6	8
AUTOMATION (9)	7	7	8	7
RELOADABILITY (7)	7	6	5	7
ENVIRONMENT (5)	3	3	4	3
TOTAL (100)	**85**	**79**	**67**	**87**

The advantages and disadvantage of each system is further analyzed. For example, in a ground-based system, size is relatively uncritical and generating capability is maximized. Safety, generating capability, and cost advantages can be maximized; however, these are countered with mobility disadvantages. Air-based systems can be placed in numerous vehicles; however, the mobility and flexibility of air assets are offset by higher risk, higher operating cost, and lower generation capability. Space-based systems to reenergize UAVs have the advantage of constant availability and tremendous "multimission capability."[3] Unfortunately, the disadvantages of using a space-based replenishment system seem overwhelming; high cost, complicated maintenance, and limited generation capability. More important, if space systems had the capability to energize the UAV capacitors, they might independently destroy the targets. The final area for analysis is a joint ground and air system. In this joint system, the generating capacity of the ground system could be used to direct energy to an energy relay system located in-theater. The in-theater air asset could then transfer the energy to a low-altitude UAV (fig 3-1).[4]

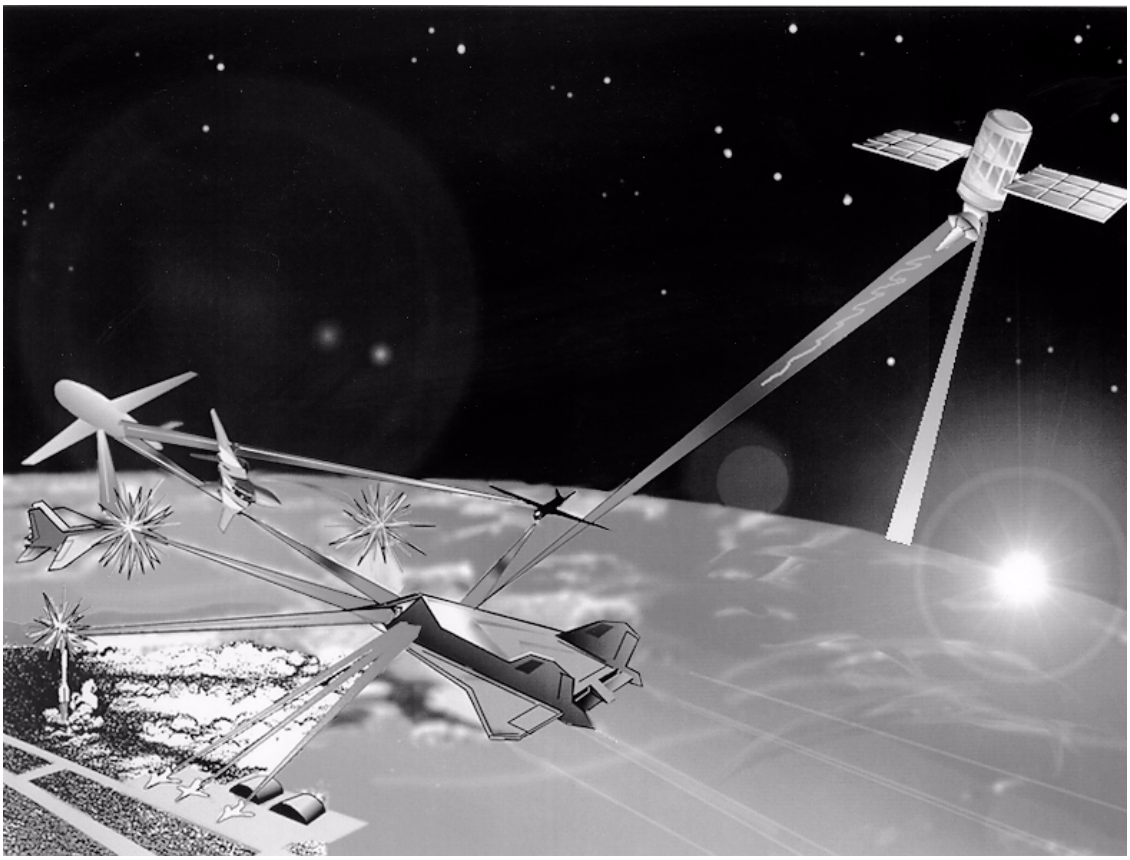

Figure 3-1. Energy Transfer Operations

Synthesis of the ground and air systems will be vital in 2025. If operations occur near friendly territory, the ground-based system could be deployed with the UAV support system to fulfill energy transfer requirements. During long-range operations and over extended hostile territory, the ground-based system could directly reinforce the generating capability of an aerospace vehicle, which could then replenish the UAV. This energy transfer is necessary if we are to meet the energy requirements of KE or DE weapons.

Directed energy (DE) weapons have great destructive capabilities because a large quantity of energy is transmitted in an extremely short time. A laser system does this by wavelength absorption. For example, a laser system can destroy a target by using thermal methods (infrared) to heat the enemy vehicle's surface in an extremely short period of time. DE weapons can also destroy objects by impulse methods—like a microwave—to blow material off the surface. This damage can be accomplished within a fraction of a second with 200 to 400 joules per square centimeter of energy transferred.[5] If the infrared or impulse wavelengths are extended, then nondestructive power transfer is possible.

Electrical energy may be rapidly transferred using lasers or microwave methods. Alternatively, another method of electrical energy transfer is through the collection and transfer of solar energy. For example, a satellite away from atmospheric disturbances can collect solar energy at approximately 140 milliwatts per square centimeter. Converting the sun's destructive rays into visible light makes it possible to beam energy to a lower orbiting satellite's photo-voltaic cells. This process can increase the solar energy collection significantly above the 15 to 18 percent efficiency possible from direct collection by the same low orbiting satellite. Another solar method is to convert the sun's energy into laser energy. The laser would transmit the energy for absorption to a chemical-type receiver unit that may then turn a hot turbine for propulsion. Well into the future, exotic methods such as the plasma ball concept may become possible. This method projects a space-generated plasma cell (like St. Elmo's fire) onto a receiving unit.[6] The transfer of energy is critical to aerospace replenishment of DE and KE weapons; however, the efficiency of the collection, transfer, and storage of electrical energy requires significant development.

Transferring Solids

Future aerospace campaigns may continue to require massing decisive force in an area and employment of this force on intended targets. If today's trend towards a knowledge-based society continues, the US may develop and procure a highly advanced or "Third Wave" military force. However, the requirement will remain to fight those forces that counter with an extensive industrial or "Second Wave" military. In this scenario, inflight conventional weapons replenishment contributes to an increased operations tempo. This capability may be necessary for future operations against "First or Second Wave" adversaries. The use of robotics could provide this physical transfer of conventional munitions. Robotics provides a substantial toolbox, including low-cost electronics, servomechanisms, controllers, sensors and communications equipment.[7] While the transfer of conventional weapons appears possible, it is a small niche in the aerospace replenishment environment. Unfortunately, this small requirement entails large expenditures. Therefore, the use of robotics for inflight conventional munitions replenishment offers limited force enhancement capability (fig. 3-2).

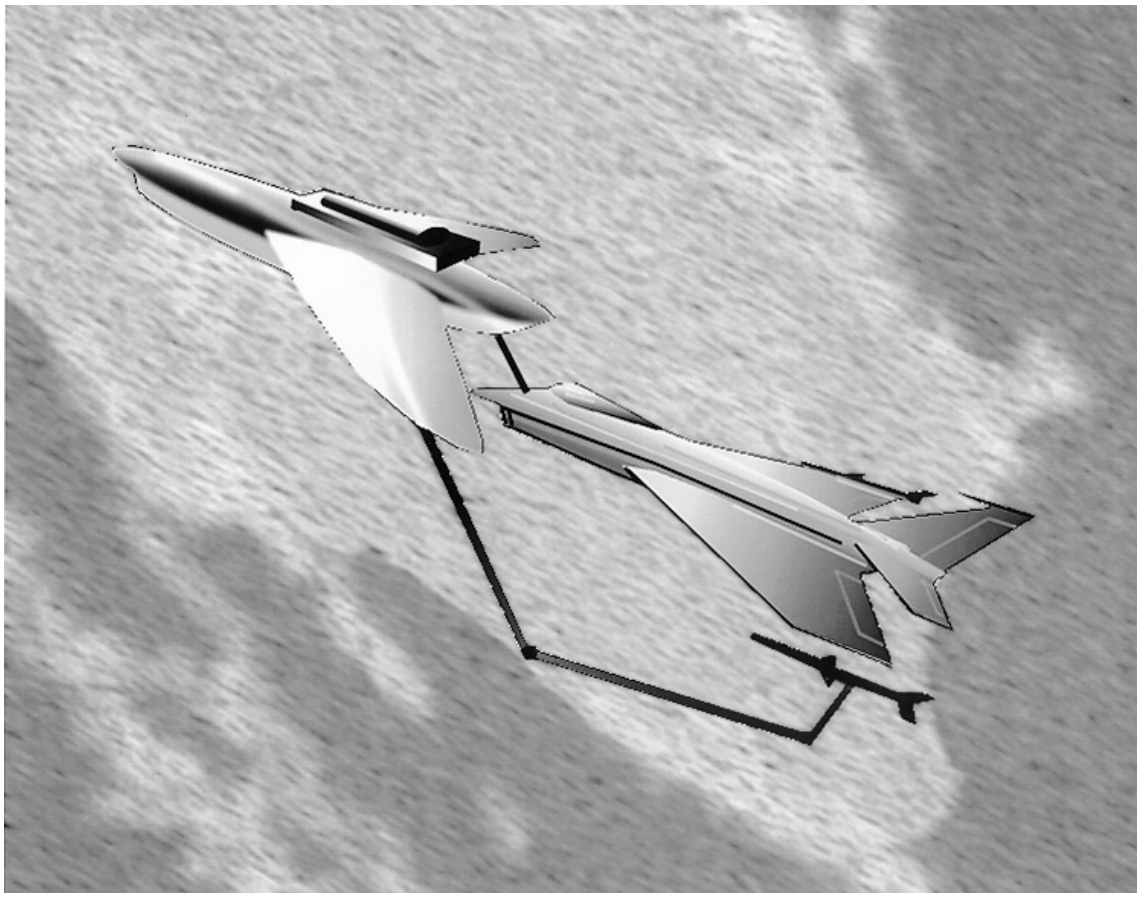

Figure 3-2. Conventional Weapons Transfer Operations

Kinetic energy and particle gun weapons replenishment can be accomplished through compressed gas or suspension of the particles. Particle transfer systems can employ a mechanism much like that of a BB gun, but with much lower pressure. If the particles are small, then suspension of the kinetic material in a liquid medium like water, oil, or jet fuel will be feasible. Once the transfer of the particles to the receiver is complete, they can be filtered for use in a weapon system. The suspension medium can be dumped overboard, used as an energy source, or simply extracted from the receiver vehicle upon landing.

More radical methods of transferring solids would include the use of parachute or glider operations between the platforms. Despite the fact that C-130s have used parachute recovery methods in the past, parachute operations appear to provide little benefit except to similarly configured cargo aircraft.[8] Powered glider operations may prove possible for transfer of large external munitions. In this concept, gliders would depart from the ground or another vehicle and maneuver to the receiver vehicle. Once in position, the

robotic mechanisms could complete the transfer. Some may consider this a dream but many considered transferring liquids impossible before the "Question Mark."[9]

Transferring Liquids

Future replenishment systems may require the ability to transfer noncarbon-based fuels to propulsion or laser systems. Hydrogen and chlorine-based compounds can be used as light and heat sources. In the propulsion system, the heat energy generated from chemical reactions is converted into thrust.[10] In the laser system, the excited molecules provide the light energy needed for laser weapons.[11] Therefore, a system that can replenish a vehicle with chemicals for propulsion can also replenish the laser system. Political and environmental benefits result from reduced dependence on petroleum. A UAV with the chemicals for a laser system can use the same chemicals for the propulsion system. There will be an employment tradeoff between using the chemicals to remain airborne verses availability of laser-kill shots.[12]

The replenishment systems need to separate liquids for internal use from those designated for transfer. The transfer of these liquids should not present physical problems; however, storage and safety solutions may prove difficult. Advanced liquids may have volatility, corrosion, or other problems. These concerns may force the development of additional systems that are incompatible with the integrated replenishment boom. Safety may also provide a reason for transferring gases.

Transferring Gases

While most gases liquefy for storage and transfer, some may remain gaseous for safety or material purposes. The transfer of these gaseous materials would use the same integrated replenishment boom used for liquid transfers. The chemical processes of these gases may be needed for power, light, or heat. The transfer entails irrigating or purifying the boom with an inert gas and then begin the transfer. The system could use a positive pressure transfer as previously described in the solids transfer sections. Currently, fuel pumps provide the pressure to transfer fuel. On the future transfer system, pumps will pressurize gaseous transfers.

Table 1 (page 11) provides feasibility values for each transfer combination. To facilitate systematic evaluation of the five highest-rated transfer combinations, an expanded matrix of the desired characteristics of the various transfer mechanisms is provided in table 3. The numbers following the individual criteria are the maximum scores for that event weighted so that a maximum total score is 100. Weighting these scores emphasizes the customer requirements that lead to operational capability.

Table 3

Transfer Systems Criteria Ratings

WEIGHTED CRITERIA	**DIRECT ENERGY**	**DIRECT LIQUID**	**DIRECT GASES**	**BEAMING ENERGY**	**ROBOTIC SOLIDS**
OPS BENEFIT (20)	17	19	15	18	13
TRANSFERABILITY (19)	16	18	18	18	10
MAINTAINABILITY (16)	14	12	12	13	9
SAFETY (14)	10	12	12	9	7
COST EFFECTIVENESS (10)	8	10	9	8	4
AUTOMATION (9)	8	8	8	9	9
RELOAD (7)	7	7	6	6	5
ENVIRONMENT (5)	4	3	3	3	4
TOTAL (100)	**84**	**89**	**83**	**84**	**61**

These eight characteristics are those deemed vital for aerospace operations in 2025. The highest-rated transfers systems are the direct transfer of electrical energy and liquids. That current systems are capable of transferring liquids and scoring 89 points indicates that this will continue to be a vital need in 2025. The direct transfer of electrical energy scored an 84, despite having rated average in the heavily weighted categories. The beaming of electrical energy is environmentally risky and relatively unsafe due to the flow of energy through the atmosphere. In addition, this system appears to be costly to both develop and field in the operational world. However, the beaming of energy is vital to the complete direct transfer system. The ability to beam energy from a ground or space station is the enabling technology for high-tempo directed-energy transfer operations. The direct transfer of gases would have scored much better, except for its limited operational benefit. If the need for inflight transfer of gases becomes necessary, the multipurpose

replenishment boom establishes this capability. The robotic transfer of solids scored lowest overall. The dangers of damaging the other vehicle or inadvertently releasing a weapon reduce the operational safety factor. This system appears to be expensive—from development through testing to operational employment. Robotic operations also requires the most extensive interface with the platform.

Platforms

Three generic platforms are required to transfer the various energy, solid, liquid, and gaseous mediums. These systems are provided to enable a more coherent concept of operations. These platforms are the MARS, the Mothership, and the SSS.

MARS

The MARS supports mobility, combat, and spacelift requirements in the year 2025. The critical concerns for the MARS (fig. 3-3) are the platform and the transfer system.

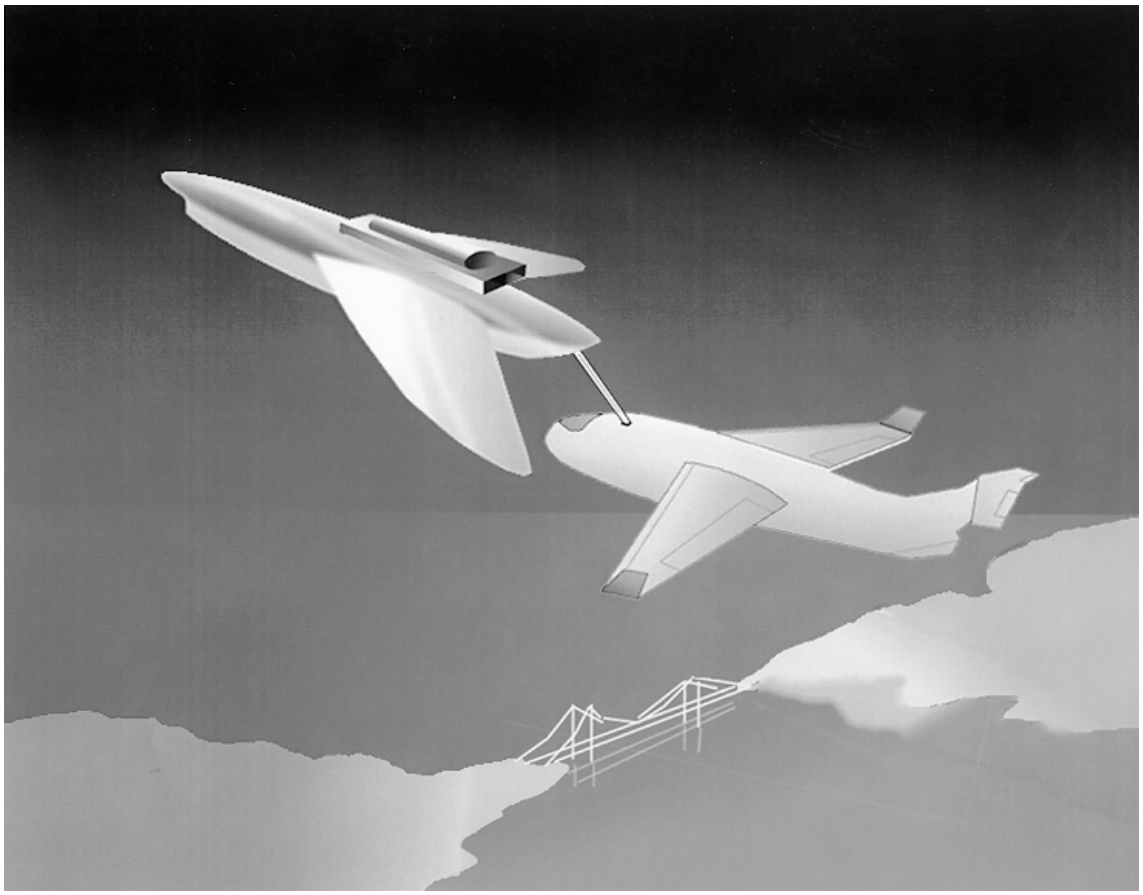

Figure 3-3. MARS Replenishing Transport Aircraft

The MARS must be able to carry palletized cargo and fuel, oxidizer tanks, and electrical energy generation and storage devices. In order to meet these challenges, a composite material must be developed that can be light and strong enough to allow a high payload to structure ratio. This vehicle must be able to take off and land in an austere environment, perhaps on unprepared surfaces and using advanced vertical short takeoff or landing technology.[13] Both replenisher and receiver aircraft will be equipped with all computerized equipment necessary to conduct automatic rendezvous and replenishment operations. The computerized uninhabited MARS uses advanced guidance technology throughout all aspects of the replenishment operations.

Automated precision air refueling technology is capable of exploitation. This capability can evolve from current navigation, formation station keeping equipment or SKE, and auto-land systems found on large military and commercial aircraft. Synthesizing this technology into a system capable of accomplishing the

mission is the next step. The MARS must have the ability to replenish current vehicles with fuel. In addition, with an integrated replenishment boom, the replenishment of various medium is possible.

Mothership

The Mothership (fig. 3-4) is designed to provide direct combat support to UAVs engaged in delivering precision guided munitions (PGM) or providing combat air patrol.

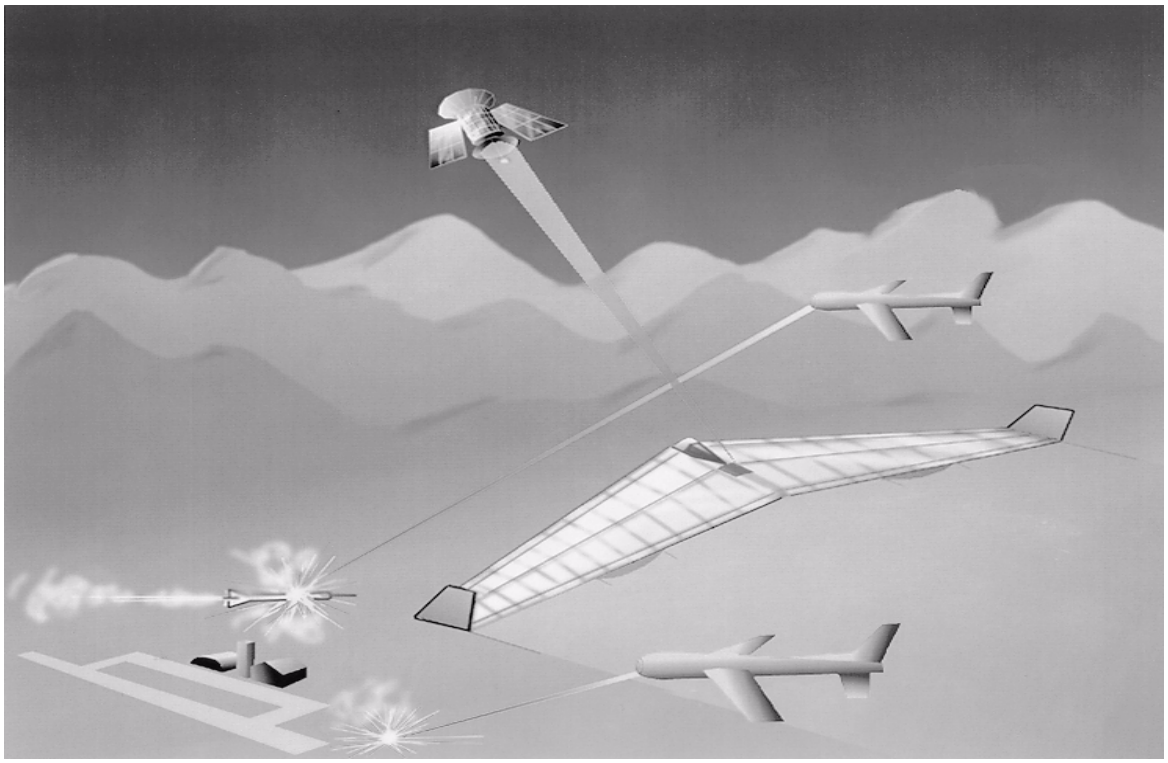

Figure 3-4. Mothership Operations

The Mothership is a large wing-type platform used to replenish numerous UAVs with weapons and propulsion power. Kinetic particle and directed energy replenishment occurs through the docking pods located on the lower surface of the Mothership. The Mothership has the ability to collect beamed energy, gather solar energy, convert and store solar energy, and transfer the energy through physical means or via beaming. The beamed energy collection antennae is located on the lower surface in order to collect energy transferred from a ground-based system and on the upper surface for aerospace collections. The Mothership could possibly serve as the "rearming platform" for the "Fotofighter" described in *New World Vistas*.[14]

The photo-voltaic collection and conversion process requires a revolutionary development to provide the efficiency needed to support high-tempo operations. The photo-voltaic capability of the Mothership is adequate during low levels of conflict; however, the need to assist the Mothership becomes vital in a high-threat operation. A combination of a ground-based and space-based directed energy replenishment system satisfies this need. Storage devices require significant development to reduce the size and weight of the package. We need to develop the ability to target and destroy vehicles with directed energy. At the same time, we need the ability to collect and transfer this energy.

Directed energy transfer from one platform to another requires accurate tracking. Some developing UAVs operate in the 250- to 350-knot range.[15] While 300-knots is slow relative to the speed of light, it is still fast enough to cause tracking and aerodynamic problems. The UAV's collection panel either deploys from the surface or is an integral part of the UAV skin. If the panel deploys, there is less body interference; however, the mechanics and aerodynamic problems are more challenging. Therefore, a panel that is an integral part of the fuselage may be required.

Technology for the Mothership concept will require a minimum of 10 years of serious development.[16] Moreover, synthesis of several technologies will be required to realize this concept. The precision guided rendezvous capability is at least one generation above the current navigation and formation technology. This system will need integration with future navigation equipment to improve the accuracy of the current precision guided tools. The means for energy collection and the transfer of directed energy weapons warrants research. In the command and control environment, limited data fusion technology is available today. With a Mothership supporting numerous platforms, data fusion and coordination between these weapons systems becomes critical for successful mission accomplishment.

Analysis of MARS and Mothership

Table 4 presents an objective analysis for comparing the current replenishment systems, the MARS, and the Mothership against ten weighted criteria. This table addresses the most important criteria for an aerospace replenishment platform in 2025. A grading scale is provided for each criteria, with the key terms for the high and low ratings provided in the "scale" column. A "0" is always the low value and the number in parenthesis in the "weighted criteria" column is the weighted high value. The scale provides a weighting,

based on customer requirements, for each of the criteria. For example, a perfect transfer capability system rates a “16”; a minimally capable system rates a “0.” The ideal system would score a total of 100 points. That system is virtually unrealistic, however, due to the contradictory nature of the various criteria. For example, a large storage capability dictates a large platform—which degrades the survivability of that platform. Objective analysis of the data reveals that the Mothership appears to provide the most utility for operations in 2025. However, because of the various receiver aircraft or platforms, both the MARS and the Mothership are required to fulfill all replenishment needs in 2025.

Table 4

MARS and Mothership Criteria Ratings

WEIGHTED CRITERIA	SCALE		CURRENT SYSTEM	MARS	MOTHERSHIP
TRANSFER CAPABILITY (17)	MULTIPLE	SINGLE	5	12	16
INTEROPERABILITY (14)	HIGH	LOW	5	10	8
OPERATING ENVELOPE (13)	WIDE	SMALL	6	9	7
SURVIVABILITY (12)	HIGH	LOW	3	10	9
STORAGE CAPABILITY (10)	LARGE	SMALL	4	7	9
AUTOMATION (8)	FULLY	MINIMAL	3	8	8
COST EFFECTIVENESS (8)	HIGH	LOW	8	3	5
MOBILITY (7)	HIGH	LOW	7	9	7
SAFETY (6)	SAFE	UNSAFE	6	5	5
ENVIRONMENT (5)	GREEN	BROWN	4	4	5
TOTALS (100)			**51**	**77**	**79**

Space Support System

The need to replenish in space is the basis for development of the SSS. The SSS is a large orbiting platform that can replenish multiple vehicles. The platform’s design enables energy collectors to gather solar energy, beamed energy from Earth, or beamed energy from other satellites. The SSS is designed to provide

space replenishment to orbital vehicles (fig. 3-5). The multilayered platform increases the "ramp" space used to replenish, modify, and refurbish the vehicles.

Figure 3-5. Space Support Operations

The SSS needs to replenish the same media as the MARS and Mothership. However, even with the ability to replenish energy, solids, liquids, or gases, the key is to provide fuel to satellites. Propulsion fuel is a limiting factor for space systems because the fuel is used to maintain proper spacecraft orbit or to reposition the spacecraft for mission purposes. Future commanders will have more flexibility to obtain needed data if there is a capability to replenish the satellites.

Two critical issues are the affordability and the purpose of the replenishing system. With dwindling defense dollars, there is a need to keep the satellites in orbit longer. However, cost of launch (currently about $8,000 to $10,000 per pound of payload) must be such that spacecraft replenishment is more cost-effective than launching a new satellite.[17] Historically, satellites are lasting longer than projected. If a fuel replenishing capability existed, satellites could remain in orbit even longer. On the other hand, many satellites become "outdated" soon after they are placed into orbit because of rapid technological advances

and ground station enhancements. Costs aside, if satellite design incorporates modular components that are accessible in orbit, then the possibility exists to replenish satellites and upgrade the systems at the same time. Trade-off studies analyzing modular designs for future upgrades versus a new system are continually required.

The SSS is similar to the Mothership in that it is a main operating base and other vehicles will provide support.[18] One of these vehicles is the "TUGSAT," a conceptual orbital maneuvering vehicle capable of acting as a space tugboat while repositioning satellites into alternate orbits. The "TUGSAT" can also be used as a replenisher platform by transferring fuel or energy from the tug to the satellite.[19] Another method of accomplishing this mission could be through refueling satellites.[20] These systems are capable of carrying satellite fuel such as hydrazine and "Shell Oil 405."[21] Physical contact can be accomplished through a docking device and transfer system similar to the integrated replenishment boom. Robotic arms and hands can then replenish the fuel and install upgrades as necessary, reducing the reluctance to move satellites due to fuel limitations. Satellite-to-satellite refueling will prevent expensive satellites from becoming virtually worthless after their original fuel is depleted.[22]

Another method of satellite energy replenishment is "beaming"—the transfer of energy from the ground to a satellite. The energy beam can provide propulsion for maneuvering the satellite or be used to recharge the electrical systems.[23] This may prove difficult, however, because atmospheric effects make beaming into space much more difficult than from space to earth.[24]

The replenishing satellites and TUGSATs could be permanently stationed in space. The Department of Defense may have difficulty in funding this expensive program on its own, but industry and international communities may be interested in making this a joint global venture. It would seem to be in everyone's best interest to increase the life cycle of all satellites via a transfer from a space replenishment platform.

Supporting space superiority will require the assurance that our satellite force will have the flexibility to contribute to an aerospace campaign no matter where the conflict occurs. In 2025, satellites and space-based weapons could very well be the primary means of force employment during campaigns. The use of an SSS to support space superiority may become critical to assure support for our space-based assets.

Countermeasures

Aerospace replenishment is increasingly viewed by possible adversaries as a "critical soft target."[25] Indeed, aerospace replenishment forces are considered a valuable center of gravity that is an insidious force multiplier. With this in mind, the replenishment platforms need to identify threats at as great a distance as possible—and defend themselves accordingly.

Countermeasures for the replenishing systems evolve from those existing today. Antiaircraft (including DE and KE) weapons are primary threats; secondary threats entail interference and jamming of the onboard systems and data links. In addition, the systems must withstand electromagnetic pulse (EMP) and other possible disturbances.

These countermeasures can be passively mitigated by deploying the systems outside the effective range of enemy threats, deploying computer security measures, encrypting data signals, EMP hardening, and employing stealth technology. Active counter-countermeasures include the use of onboard or escort DE or KE weapons to destroy the threats, since protection against DE or KE weapons appears to be cost-prohibitive. To prevent the destruction of the MARS or Mothership, the air forces must be capable of destroying the enemy KE and DE weapons prior to their firing. Due to the high value of the replenishment assets, employment of all passive counter-countermeasures and escorts should be included in the Mothership mission package.

The *New Worlds Vista* study recommended a directed energy self-defense system for air mobility aircraft.[26] The key component of this system will be a laser (or high-powered microwave) system that can be fired to defend the air mobility vehicle. This will provide the vehicles the ability to defeat advanced surface-to-air and air-launched missiles. There must also be included in the system a means to provide missile warning, a dedicated high-performance computer to predict the incoming missile's trajectory, and to establish fire control data for the directed energy device. Such a small, energy-frugal system is estimated to weigh less than 500 pounds, be packaged in a 3' × 2' × 2' space, and be deployable internally or in a pod. Prime power requirements for the very short-duration laser firing should be less than 150-kilowatts.[27]

With the future trend leaning towards uninhabited combat operations, survivability and safety of employed platforms becomes an economic issue, rather than a human issue. Combat planners have greater

flexibility when using uninhabited platforms—and combat operations are enhanced when replenishment platforms are employed closer to the battlefield.

Notes

[1] Steven Watkins, "Service Closes in on an Airborne Laser," *Air Force Times*, 21 August 1995, 102.

[2] Mr. Darrell Spreen, Director ABL Technology Office, Lasers & Imaging Directorate, Phillips Laboratory, telephone interview with Lt Col Yoshio Smith, 21 February 1996.

[3] Spreen, ***2025*** Assessor comment on first White Paper draft, (Maxwell AFB, Ala.: Air War College/***2025***, February 1996).

[4] *New World Vistas*, Summary Volume (15 December 1995) 41. Modified photo to reflect beamed energy from a ground source.

[5] Spreen, 20 March 1996.

[6] Ibid. Spreen provided the information on solar energy collection, laser transfer, and the plasma ball concept. St. Elmo's fire is a static electricity discharge that can take the form of a "fire" ball.

[7] Joseph F. Engleberger, "Robotics in the 21st Century," *SCIENTIFIC AMERICAN*, (September 1995), 132.

[8] Lt Col William P. Stewart, Jr., Air War College student with extensive C-130 pilot operational experience, interview with Lt Col Yoshio Smith, 7 April 1996. He stated that recovering satellites using parachute has not been done since the mid-1980s out of Hawaii.

[9] Office of the Historian, *Seventy Years of Strategic Air Refueling, 1918-1988, A Chronology*, (Headquarters Strategic Air Command: Offutt AFB, Neb), 2-3.

[10] Spreen, 21 February 1996.

[11] Ibid. The equation for the chemical reaction is $H_2O_2 + Cl_2 \rightarrow HCl + O_2^*$. The excited form of oxygen, O_2^*, provides the light and by-products in the form of common salts and heat exhaust in the form of water and oxygen. Only 25 percent of the energy is mustered in the form of light; the remaining 75 percent is in the form of heat exhaust.

[12] Ibid.

[13] Stanley W. Kandebo, "Lockheed, Pratt Test ASTOVOL Concept," *Aviation Week & Space Technology*, (6 March, 1995), 48.

[14] *New World Vistas*, Summary Volume, 15 December, 1995.

[15] David A. Fulghum, "International Market Eyes Endurance UAVs," *Aviation Week & Space Technology*, (10 July, 1995), 43.

[16] Anonymous Assessor Comment on ***2025*** first white paper draft, (February 1996), (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

[17] Dr Dennis M. Bushnell, ***2025*** Assessor comment on second draft White paper, (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

[18] Primary concern from a technological point of view is the affordability of space station technologies. A detailed investigation of orbital and long-term space exploration technologies is also required; however, as an alternative to the more expensive spacelift operations, the SSS may become attractive. The energy collection and transfer technologies available in space should be explored to exploit this concept. The ability to extend operations in the atmosphere is even more important in space due to the high launch costs. Exploiting this enhancement is the primary purpose of the SSS.

[19] ***2025*** Concept No. 200150, "TUGSAT," ***2025*** Concepts Database, (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

[20] Concept submission number 200209, "Refueling Satellite," ***2025*** Concepts Database, (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

[21] Lt Col Phillip B. Fitzjarrell, AWC student with extensive missile operations experience, interview with Lt Col Yoshio Smith, 27 February 1996.

[22] Concept submission number 200123, "Satellite to Satellite Refueling," ***2025*** Concepts Database, (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

[23] Spreen, ***2025*** Assessor Comment on first white paper draft, (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

[24] Lt Col Jess Sponable, PL/VT-X, Phillips Labs, interview with the Aerospace Replenishment Writing Team (Maxwell AFB, Ala.), 6 March 1996.

[25] Tony Mason, *The Era of Differential Air Power*, (Brassy's Inc., 1994), 242.

[26] *New World Vistas*, Summary Volume, 33.

[27] Ibid.

Chapter 4

Concept Of Operations

Today, laser weapons demonstrations have been carried out on the airborne laser system aboard a Boeing 747 where over 200 kill shots can be fired.[1] In 2025 these operations will be carried out by much smaller and less vulnerable platforms. Determining how to employ these weapon systems is vital.

General Operations

The aerospace replenishment platforms of the year 2025 will have the capability to replenish nearly all propulsion and weapons systems. All US aerospace platforms capable of receiver replenishment will have standard replenishment systems. This receiver replenishment system will have an integrated receptacle for simultaneous fuel, energy, and weapons replenishment. Each platform will maximize its value to future aerospace operations through multirole capabilities.

MARS Operations

In the year 2025 aerospace replenishment operations will still require a platform-to-platform physical transfer of energy and weapons. An improvement in operations will be the capability to conduct these operations simultaneously and automatically. The MARS provides a flexible platform that is capable of operating in a variety of environments. The MARS provides rapid replenishment support to combat, mobility, and spacelift forces. In addition, the MARS will have the capability to replenish itself from other

replenishing platforms. The uninhabited MARS is controlled by a UAV controller operating in a control room located at the main operating base or in a control pallet aboard a C-17 or future airlifter.

The MARS will be US-based, with a lean logistical structure supporting global deployments and operational missions. Integrated unit deployment of the MARS logistical structure will support autonomous operations on a global scale. If we are required to conduct operations at great distance from the actual battlefield, we must obtain forward operating bases to support MARS operations. With forward operating bases, the MARS will be capable of off-loading a large amount of weapons and fuel. Operations from the US provide unique challenges for replenishment operations, but the MARS platform must be designed to operate effectively in this "worst case" situation.

Most of the airlift fleet will require replenishment at the same geographic point when undertaking a large mobility operation. If this point is outside the support range of US replenishment assets, it will be necessary to obtain a forward operating base for MARS operations. The MARS will have the capability to replenish various mobility platforms. Once a MARS has expended the fuel set aside for replenishment, it will return to base and a fully replenished MARS will take its place.

Ideally, aerospace replenishment anchor areas will be set as close to the battle as possible. This will require replenishment platforms to be equipped with package assets for defense. Each replenishment platform will be assigned to an anchor area for a specified period of time. When a combat platform requires replenishment, it will set a predetermined channel into the auto replenishing mode of the flight data computer. This will enable the receiver aircraft to automatically identify its replenisher, proceed to it, conduct the closure, and commence replenishment operations.

Strict preflight coordination will be necessary for future mobility replenishment operations. The strategic airlift mission must let the replenisher know precisely where and when they need replenishment and how much transfer they require. This is possible through secure command and control channels during the mission-planning phase. This information will be fused into the replenishment platform's internal flight computer. The internal flight computer will be connected to the global command and control system, which will provide the capability for flight planning based on real time and forecast weather conditions.

If diplomatic conditions are positive, a main operating base should be established as close to the replenishment control point as possible. This will enable use of the "air bridge" concept to support the

mobility operations. Once a tasking has been received, required information is put into the flight data computer. Based on input data and weather conditions, a flight plan will be produced. This will provide required transfer information and takeoff time. The flight plan, codes for the auto rendezvous and auto air refueling, and transfer data will be transmitted to the aerospace replenisher during preflight operations. After takeoff, the platform proceeds on its planned route while the controller flight follows the aircraft. Rendezvous, rejoin, hookup, and transfer will be automatically conducted.

MARS spacelift replenishment operations allow a TAV to take off with less fuel and oxidizer thereby enabling added lift capability.[2] The MARS provides TAVs with a fuel or oxidizer top-off subsequent to their entering into orbit (fig. 4-1).[3] Preflight coordination is necessary to provide the required on-demand support. Each TAV will be assigned a dedicated MARS for each mission. Once a TAV is replenished, the MARS will return to base or replenish from another MARS and await a follow-on mission.

A primary communication factor in the development of the MARS is its interface with the TAV. The MARS operations must be highly coordinated efforts, much like the Cold War SR-71 operations. It will lose a significant mission capability if rendezvous and replenishment are not timely. Thus, a single agency must coordinate the command and control efforts.

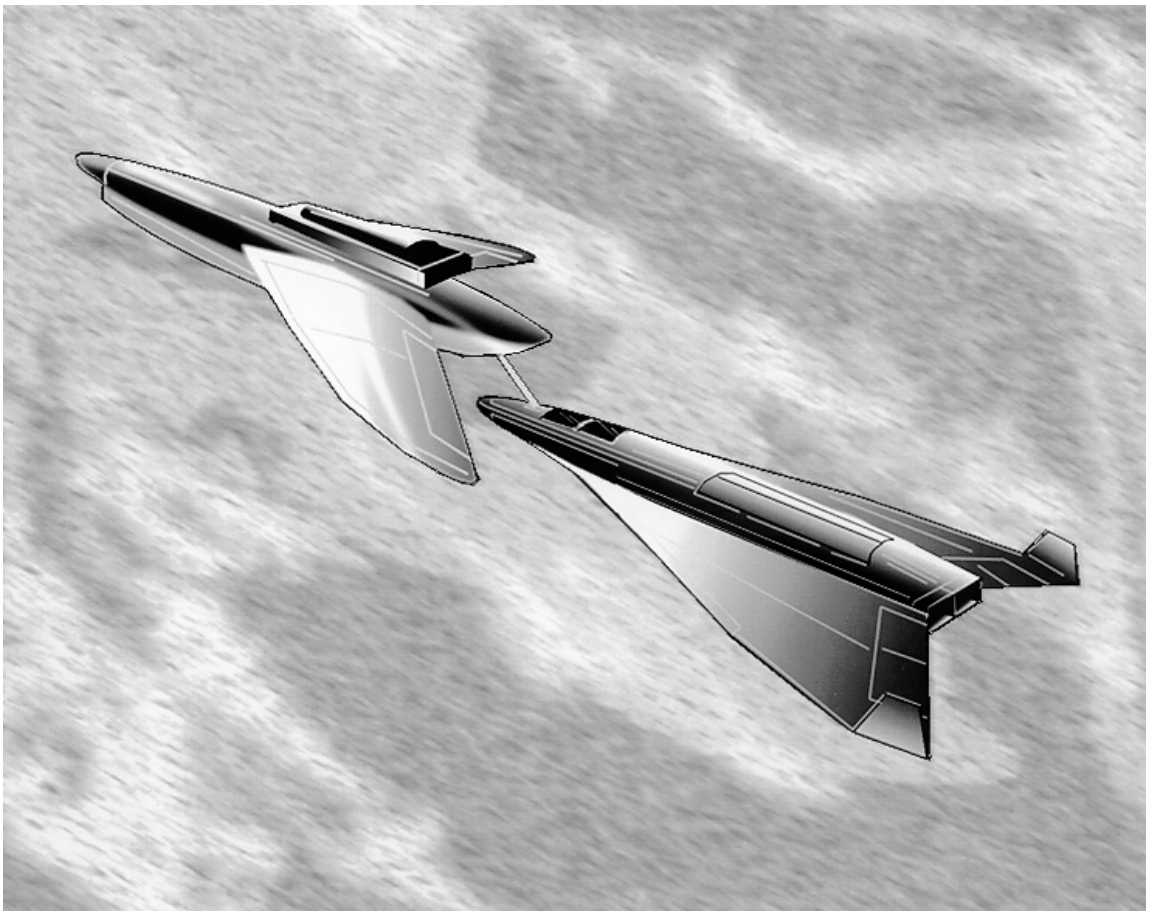

Figure 4-1. MARS Replenishing TAV

The MARS will enhance the capabilities of current aircraft that remain operational in 2025. In addition, it will be the only platform capable of replenishing all future vehicles. Replenishment transfer will satisfy the energy, solid, liquid, and gas requirements of tomorrow's vehicles. As the United States expands into space, the MARS allows each TAV to carry a larger payload. The benefits to space travel will be as great as the Mothership's benefits to UAVs.

Mothership Operations

The Mothership provides a unique opportunity to project lethal power globally, while operating from the Continental United States (CONUS). The Mothership requires support from a ground- or aerospace-based system capable of supplying energy replenishment to recharge the Mothership's batteries or capacitors.

The Mothership, with numerous UAVs attached, deploys from a CONUS base and, through the use of beamed energy replenishment, proceeds to any point on the globe (fig. 4-2).

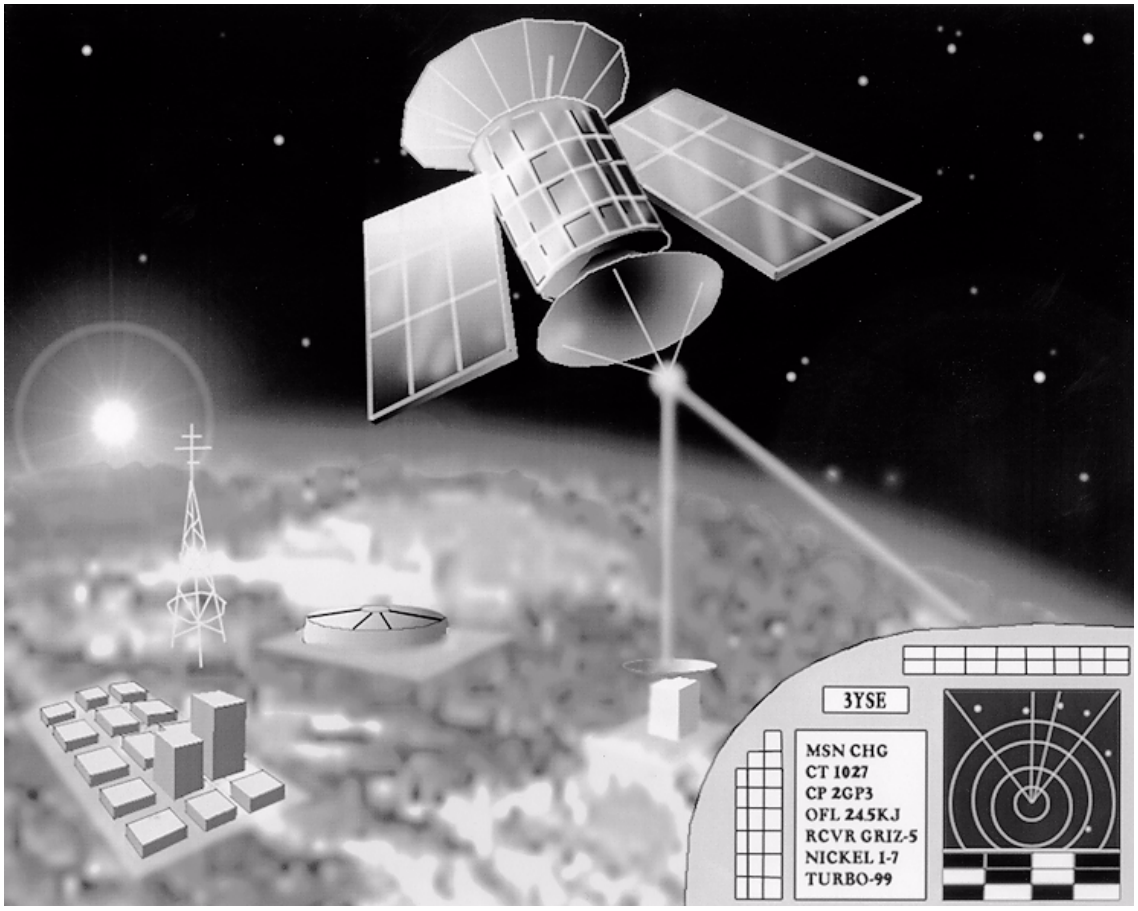

Figure 4-2. Energy Beaming Operations

As the Mothership proceeds on its mission, energy beaming occurs from a ground station or satellite to the Mothership, recharging its batteries and capacitors. This beamed energy will be used for propulsion and to replenish the UAVs. The Mothership has the capacity required for extended endurance because it is uninhabited and can obtain an abundant supply of beamed energy. In a combat scenario, the Mothership will proceed to a specific geographic point and begin loiter operations.

The UAVs will deploy from the Mothership and proceed to their preprogrammed targets. Once the UAVs have expended their weapons, they will proceed back to the Mothership. Upon return, the UAVs will dock with the Mothership and begin replenishment operations. The Mothership will provide UAVs with energy and weapons replenishment. When replenishment operations are complete, the UAVs can be

reprogrammed for a follow-on mission or remain in the replenishment dock awaiting further instructions. Once force employment operations are complete, the Mothership will return to its home base. The capability to globally project this type of sustained lethal power globally, offers future commanders a wide array of force application options and add a credible psychological threat to any future adversaries.

The Mothership will be controlled in a manner similar to that of MARS. It will be fully programmable and will be controlled by a UAV controller in a control room. The control room will integrate all UAVs involved in air operations, thus ensuring centralized control. The Mothership will be an integral part of any planned offensive UAV operation; its employment should be centrally controlled and integrated into the operations plan.

Although the Mothership is a replenisher, there will be times when it receives of replenishment. During energy transfer operations, a ground- or aerospace-based generation device could generate significant amounts of energy. This energy could then be transferred to the Mothership for storage and later transferred to a combat platform. The ground portion of the system should be mobile so that the system is not subject to a fixed object attack.

Mothership operations can greatly enhance the capability of UAV operations, but future commanders must have operational control of the Mothership and the UAVs if they are to be used effectively. A key element in extended duration Mothership operations is the use of space-based energy replenishment. This replenishment is gained through the integration of the Mothership and the Space Support System.

Space Support System Operations

The SSS mainly supports space power projection. Employment of this system will take many years, and close coordination with NASA experts will be required. The SSS will allow for replenishment of reconnaissance, power projection, and space superiority satellites. Key to this operational concept is that the SSS uses other vehicles to conduct the individual replenishments. These replenishment stations will allow the space-based assets to fully utilize their potential while diminishing the need for spacelift support.

The SSS can be placed both in low and high earth orbits to support space-based operations. Enough systems must be deployed in orbit to ensure adequate and timely coverage of most satellites. The

"TUGSATs" will be used to either reposition satellites or replenish satellites with maneuvering fuel. Once a requirement is identified, a "TUGSAT" will depart the SSS, proceed to the identified satellite, and facilitate repositioning or replenishment operations. In addition, energy beaming operations, similar to the Mothership operation, can be employed.

The complete replenishment system (consisting of the MARS, Mothership, and SSS) has a variety of development options, from transfer system to platform. Direct transfer of liquids and energy appears to be the most valuable. A single platform to replenish everything would be ideal. Unfortunately, due to numerous concerns, from cost to safety, this is not practical. Therefore, a system comprised of MARS, Mothership, and SSS will be required for expanded replenishment in the aerospace operations of 2025.

Notes

[1] Steven Watkins, "Service Closes in on an Airborne Laser," *Air Force Times*, 21 August 1995, 102.
[2] "Space Lift," *SPACECAST 2020*, Volume 1, H-1.
[3] Ibid. TAV operations detailed replenishment support at approximately 40,000 feet and 0.9 Mach.

Chapter 5

Investigative Recommendations

Probably to a greater extent than any other future concept, aerospace replenishment planning must be accomplished in concert with receiver platforms. Any system developed to enhance future replenishment operations must be synthesized with the needs and physical capabilities of the receiver platforms and their concept of operations. Developing the MARS and Mothership will be of little value unless other platforms have the physical capability to accept the specific replenishment medium. The following prioritized list of required improvements needs integration into a future concept of operations.

1. One standard military system for replenishment operations. Presently, US naval aircraft use a probe and drogue for refueling operations while US air forces use a boom. In 2025 a standardized replenishment system will be required for all joint forces.
2. To increase the effectiveness of combat platforms, research in energy transfer technology is needed. While the future shows many attractive alternatives, systems costs and funding levels will dictate the aggressiveness of development programs.
3. Replenish energy and weapons as well as fuel. If replenishment operations are expanded to include energy and weapons, the tempo and intensity of air campaigns can be greatly accelerated.
4. Capability to support global operations from the US. Present operations require forward staging bases to support operations far from the US. The battlefield of the future may be dynamic, and it may require the massing of decisive airpower over any point on the globe. These operations may be short in duration and may require replenishment to enhance combat operations. Replenishment platforms with extended range and loiter time demand investigation.
5. Computerized rendezvous and replenishment system to enhance operations, especially under inclement weather conditions. Low-visibility replenishment operations will be required to support aerospace operations in 2025.
6. Capability to employ replenishers with defensive capability in hostile airspace. Presently, air refueling platforms have no defensive capability. To enhance combat operations, replenishment vehicles will be deployed in hostile airspace. Some type of self-defense capability will increase the survivability of the replenishment platforms.
7. Increase the operational replenishment envelope. Ideally, replenishment forces should meet and service customers anywhere, and at any speed, throughout the aerospace regime. Unfortunately, the propulsion systems required to lift and support operations at high altitudes and high speeds are extremely expensive.

8. Replenish multiple receivers at the same time and at a faster rate. A limiting factor for planning purposes is cycle time on the boom or drogue. If the capability to quickly replenish receivers is pursued, a synergistic effect can be felt throughout the air campaign.

With the implementation of these recommendations, a fully integrated aerospace system will enable the expanded role of aerospace replenishment for aerospace operations of 2025. The thesis of this paper was to (1) describe the continued applicability of aerospace replenishment and (2) identify the plausible and credible systems and operational concepts required for the expanded role of replenishment in the aerospace operations of 2025. The capability required to conduct operations throughout the world is the starting point in proving the continued applicability of aerospace replenishment. Numerous transfer methods were presented; however, the research emphasis should hinge on the direct transfer of liquids and energy and on the beaming of energy. These transfer methods are valid throughout the entire replenishment spectrum. Unfortunately, a single vehicle is incapable of fulfilling the replenishment mission. Therefore, the development of MARS, Mothership, and SSS is warranted. With these advancements, aerospace replenishment can be the insidious force multiplier of 2025 and beyond.

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