Defense Science Board
Task Force

on

Future Need for VTOL/STOL Aircraft

July 2007

Office of the Under Secretary of Defense
For Acquisition, Technology, and Logistics
Washington, D.C. 20301-3140

This report is a product of the Defense Science Board (DSB).

The DSB is a Federal Advisory Committee established to provide independent advice to the Secretary of Defense. Statements, opinions, conclusions and recommendations in this report do not necessarily represent the official position of the Department of Defense.

The Defense Science Board Task Force on Future Need for VTOL/STOL Aircraft completed its information gathering in January 2007.

This report is unclassified and releasable to the public.

OFFICE OF THE SECRETARY OF DEFENSE
3140 DEFENSE PENTAGON
WASHINGTON, DC 20301-3140

DEFENSE SCIENCE
BOARD

July 18, 2007

MEMORANDUM FOR UNDER SECRETARY OF DEFENSE FOR ACQUISITION, TECHNOLOGY AND LOGISTICS

SUBJECT: Final Report of the Defense Science Board Task Force *on Future Need for VSTOL/STOL Aircraft*

I am pleased to forward the final report of the Defense Science Board Task Force on *Future Need for VTOL/STOL Aircraft*. This report offers important recommendations for the military services as they move forward in developing concepts for distributed ground combat operations.

As a basis for its analysis the task force evaluated airlift needs for mounted aerial maneuver, a fundamental component of the Army's family of future concepts for its force. To meet the requirements as this concept is currently envisioned, the resulting aircraft will be very expensive, technically risky, and require a lengthy developmental timeline. In the view of the task force, alternative concepts should be examined that would lead to the same results at lower risk and cost; the report makes recommendations toward this end.

Another critical area evaluated by the task force is that of rotary-wing safety, survivability, vulnerability, and reliability. The Department of Defense has made considerable investment in these areas for fixed-wing aircraft, with tremendous results. However, a similar investment has yet to be made for rotary-wing aircraft, but will be essential to any distributed combat concept using air assets for deployment or sustainment.

I endorse all of the study's recommendations and encourage you to forward the report to the Secretary of Defense.

William Schneider, Jr.
Chairman
Defense Science Board

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MEMORANDUM TO THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Final Report of the Defense Science Board Task Force on Future Need for VTOL/STOL Aircraft

Since the start of the global war on terrorism, many operations involving U.S. forces have been supported by helicopters, to include combat operations, counter-insurgency operations, security operations, disaster relief, and humanitarian assistance operations. But in many cases, rotary wing aircraft have not been well suited to the mission. In fact, helicopter-related losses are among the leading causes of fatalities in operations in Afghanistan and Iraq. In consideration of these facts, this task force was convened to address the features and capabilities that vertical take-off and landing (VTOL) and short take-off and landing (STOL) aircraft should have in order to contribute to the nation's security needs into the 21st century.

As a basis for its assessment, the task force evaluated the lift requirements to support the Army's current concept for distributed ground combat—mounted aerial maneuver—the centerpiece of which is the Future Combat System (FCS). The success of this concept depends on the ability to lift troops, equipment, and supplies from an intermediate staging base, located either on land or at sea, to battlefield enclaves that could be in unimproved, primitive locales.

The conclusion reached by the task force is that mounted aerial maneuver with current FCS forces strains airlift technology and operations. Suitable aircraft and supporting ships, while technically possible, will be costly, technically risky, and take a long time to field. The bottom line of this study is this: there are airlift solutions to distributed, long-distance combat. But the costs and benefits, according to the proposed operational requirements, should be carefully examined and alternative concepts explored to achieve the same results at lower risk and cost.

The recommendations of the task force focus on three major areas:

1. Rotary wing safety, survivability, vulnerability, and reliability improvements are essential to the success of mounted aerial maneuver or any other distributed combat concept using air assets for deployment or sustainment. Investments need to be made in flight/crash data recorders and improved aircrew and aircraft reliability upgrades.

2. The best single fit for a tactical ground combat support aircraft is one that combines elements of both rotary- and fixed-wing technology in a hybrid aircraft. But a single aircraft designed for such purposes is likely to be very expensive. Therefore the most cost-effective solution may be a mixed fleet of hybrid and fixed-wing aircraft. The Secretary of Defense should charter a special task force, similar to the group chartered in the early 1960s to examine alternatives for the early rotary wing aircraft, to determine the best mix of aircraft to meet future intra-theater airlift needs. Parallel development efforts should begin for a high-thrust, high thrust-to-weight ratio, fuel efficient, reliable engine suitable for use in a VTOL heavy lift hybrid aircraft.

3. The weight and size of the vehicles in today's Future Combat System are significantly heavier and larger than the original FCS vehicle requirements. Thus, the task force recommends incorporating into development of a VTOL airlift fleet, aerial-refueling capabilities to allow payloads heavier than the notional, fully-fueled payload, and the ability to fold rotors for sea-basing capability.

VTOL/STOL heavy-lift aircraft can be developed and built to support future distributed combat concepts such as mounted aerial maneuver and sea basing. But tradeoffs will have to be made between the requirements driven by current distributed combat concepts, technical risk, and cost.

William G. Howard Jr.

Dr. William G. Howard, Jr.
Co-Chair

Donald L Pilling

Admiral Donald L. Pilling, USN (Ret)
Co-Chair

Table of Contents

Executive Summary

Throughout the past fifteen years, the Defense Science Board and other groups have engaged in future ground combat studies. The aim of these efforts has been to revolutionize ground combat—to significantly lighten forces; employ massed, precision fires and agility in place of large units; increase maneuverability; heighten the element of surprise; and make the best use of modern sensor, computing, and communications technology as dramatic force multipliers. Thinking in the Army and Marine Corps has evolved in response to lessons learned in Somalia, Afghanistan, and Iraq as visionary force concepts have evolved from the Army's "Army 21" to "Army After Next" to Future Combat System (FCS) and their Marine counterparts.

The Future Combat System, as originally conceived, was to be a radical advance in soldier effectiveness and empowerment. The FCS network capability, allowing near-real-time decisions, could result in a revolutionary warfighting capability. FCS was to be the embodiment of the shift from linear battle to a networked force—distributed small units, readily deployed and sustained by air using existing airlift assets. These lightly armed units were to depend on tightly-coupled, quick-response support assets that gave platoon and squad-level personnel the ability to call upon superior firepower of far larger and heavier units in real time for offensive punch and force protection. The network was an integral element, directly coupling FCS forces to ground-, air-, and sea-based precision fires. FCS units were to be distributed throughout the fighting force, but would not be the entire force—they were to rely on other assets for their combat effectiveness.

The U.S. military has learned a great deal about the future of warfare through its experiences during the past two decades. In response to these lessons, FCS departed from its initial concept to become the mainstream force. Light, agile, small units grew into medium-weight armored battalion- or brigade-sized forces complete with organic artillery, air, logistics, medical, and staff support. The tight coupling of leading-edge units to close, real-time combat fire support has morphed into a more conventional command structure. FCS has become more evolutionary

than revolutionary, although it makes much better use of available technology than current, conventionally-equipped forces.

As the FCS concept has developed, it has become much heavier; and the appetite to reach further into enemy territory with forces able to act independently has grown. Vehicles originally intended to weigh 17 to 18 tons are now approaching 30 tons. Light, maneuverable scout vehicles are supplemented with tanks, some equipped with 155 mm howitzers and heavy mortars. Squads, platoons, and companies will have to operate within battalion- and brigade-sized "units of engagement." The FCS revolutionary concept has shifted to an evolutionary modernized conventional force.

The desire for an operational capability to reach far behind enemy lines persists. The Army concept has been named "mounted aerial maneuver," and it does offer many operational benefits. However, the heavier hardware of today's FCS places it well outside the ability of current aircraft to deliver to primitive sites. This capability can be deployed with existing C-130s, C-17s, and rotorcraft to certain parts of the world; however, limited available runways and/or rough terrain will not allow this deployment to other parts of the world. A new heavy lift aircraft will insure that potential enemies cannot use this weakness to their advantage.

FCS's future as a distributed combat capability rests on developing lift proficiency to quickly deliver the system to the right place, at the right time. Deploying current medium-weight FCS forces will require new aircraft; capable sea base ships; and air operations to deal with payload, range, survivability, and reliability well beyond what the United States can do today.

The terms of reference for this report identifies rotary wing safety and survivability and issues with heavy-lift vertical take-off and landing (VTOL) and short take-off and landing (STOL) aircraft. The former topic is covered in Chapter Seven. The remainder of the report is the conclusion of the task force's study to characterize the aircraft, sea bases, and support systems needed to make the current FCS force the distributed combat force of the future. The task force took on the challenge of conceptualizing the best airlift vehicles and supporting capabilities to achieve desired operational specifications. The members

have had a rich, wide-ranging dialog on aircraft, ships, safety, logistics, operations, and reliability. As the ensuing document shows, mounted aerial maneuver with current FCS forces strains airlift technology and operations; suitable aircraft and supporting ships, while technically possible, will be costly, technically risky, and take a long time to field. The task force took no position on the merits or shortcomings of the mounted aerial maneuver concept but addressed its capabilities and what needs to be done if the concept is pursued.

The bottom line of this study is that there are solutions to distributed, long-distance combat. The costs and benefits of doing so, according to the initial operational requirements, however, should be carefully examined and alternate concepts explored to achieve the same results at lower risk and cost, as recommended below.

The task force conclusions and recommendations focused on three major areas:

1. Rotary-wing safety, survivability, vulnerability, and reliability improvements are essential to the success of mounted aerial maneuver or any other distributed combat concept using air assets for deployment or sustainment. Today's rotary-wing aircraft safety, survivability, vulnerability, and reliability performance, regardless of service, fall well short of operational needs. The task force recommends that flight/crash data recorders, improved aircrew and aircraft protection systems, enhanced situational awareness capability, and aircraft reliability upgrades be installed in all DOD operational rotary-wing aircraft and that data produced by these recording systems become an integral part of tactical training, mission debrief, aircraft health monitoring, and post-mishap analysis.

2. The task force concluded that the best single fit for a tactical ground combat support aircraft is one that combines elements of both rotary- and fixed-wing technology in a hybrid aircraft. The task force examined several hybrid aircraft concepts and prototype designs, concluding that one of these options has the best chance of fitting future distributed combat needs. In addition to operational specifications, development, production, and operational costs are critical decision

criteria in selecting the final aircraft concept. More study is needed to select the best configuration choice. In any case, providing a best single fit for all mounted aerial maneuver needs will be expensive.

The task force observed that mounted aerial maneuver, or any similar operational concept, requires different lift considerations for deployment (such as vertical take-off and landing [VTOL]) than sustainment (such as the possibility of preparing an airfield after initial deployment). A single lifter, either rotary-wing or fixed-wing, will not meet all the critical specifications for deploying and sustaining a deeply distributed battalion or brigade-size force. Analyzing their potential, in light of the objectives, results in the conclusion that both pure rotary-wing and pure fixed-wing solutions have serious problems meeting defined future combat support needs.

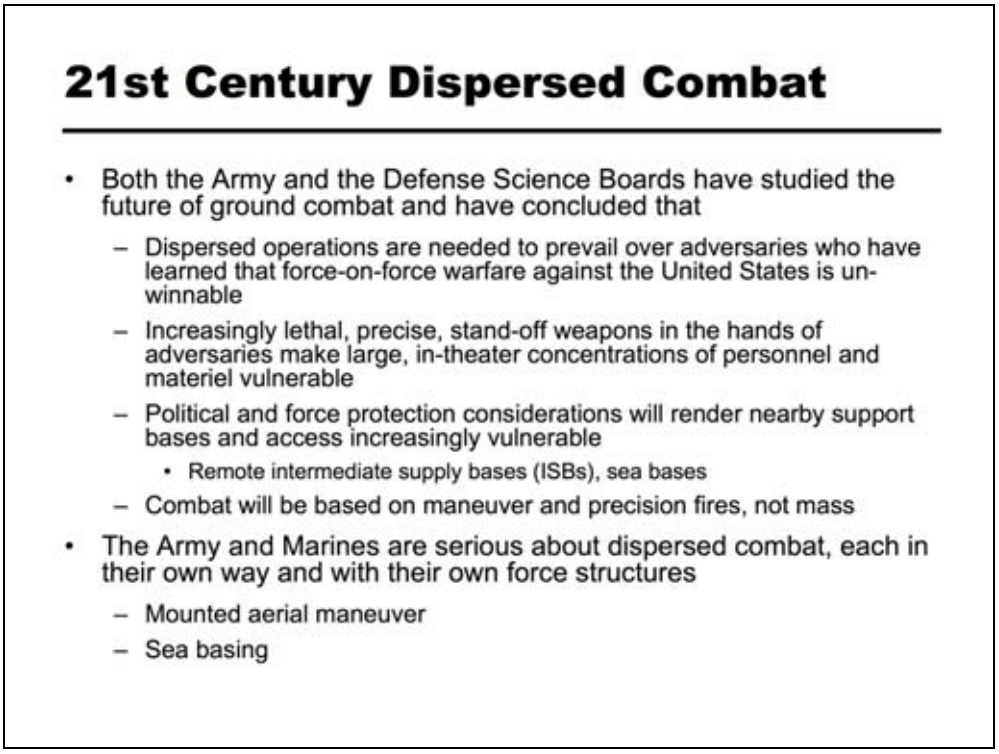
The task force therefore concluded that the most cost-effective solution to meet the spectrum of mounted aerial maneuver may be a mixed fleet of hybrid and fixed-wing aircraft. The Secretary of Defense should charter a special task force to determine the best mix of legacy, Advanced Mobility Concept (AMC-X), super short take-off and landing (SSTOL), and/or Joint Heavy Lift (JHL) aircraft to meet future intra-theater lift and mounted aerial maneuver needs of the Army. Parallel development efforts should begin for a high-thrust, high thrust-to-weight ratio, fuel efficient, reliable engine suitable for use in a VTOL heavy lift hybrid aircraft.

3. The weight and size of the vehicles in today's Future Combat System (FCS) are significantly heavier and larger than the original FCS vehicle requirements. Transporting a full FCS combat-ready battalion will require lifter payloads of 30 tons. After careful study, the task force concluded that developing a VTOL aircraft with a 30-ton payload and operational radius of 250–500 nautical miles, without a refueling capability, will be very costly and entails substantial technical risk in new engine and hybrid aircraft design.

The task force recommends that the Army consider mounted aerial maneuver operations that include the possibility of incorporating a VTOL deployment lifter fleet with aerial refueling capabilities, the ability to fold rotors for sea-basing capability,

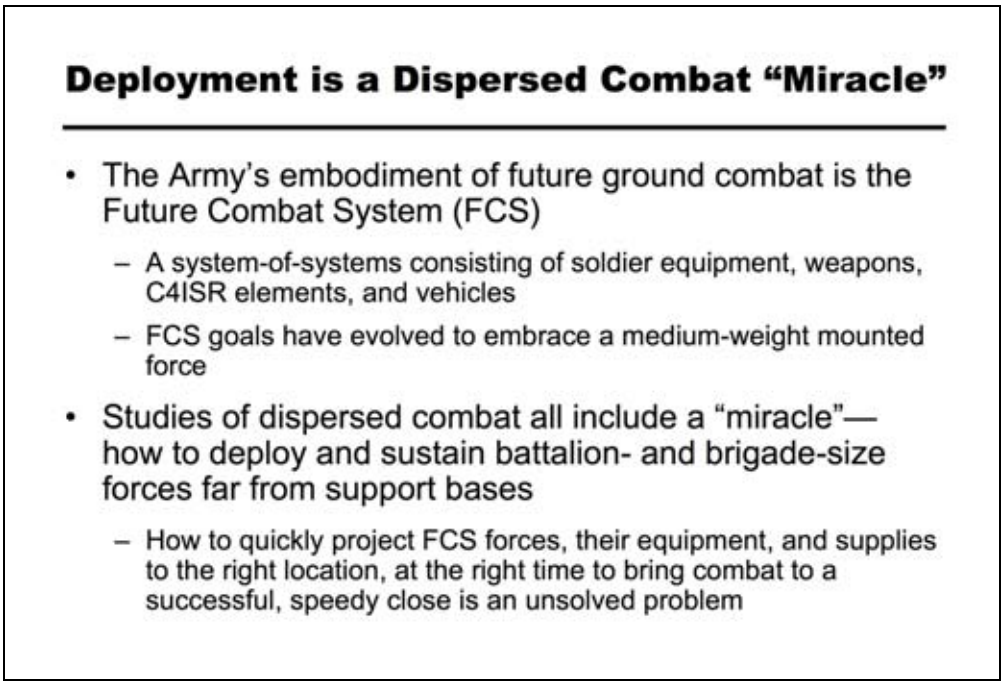
and payloads of less than 30 tons per aircraft. A reconfigured mounted aerial maneuver operational plan would emphasize (1) use of the lightest FCS vehicles; (2) aerial refueling after takeoff to maximize aircraft to lift a limited number of heavier loads; and (3) dependence on networked, non-organic air-defense close combat support.

Chapter 1. Introduction: Air Support for Distributed Ground Forces



U.S. military operations doctrine has been undergoing revision for the past two decades in response to major shifts in the global geopolitical environment. Cold War–era forces and doctrine are out of step in today's world of non-state adversaries, precision weaponry, asymmetric adversaries, distributed war, insurgency, and the global war on terrorism. The likelihood of future force-on-force combat has receded as potential adversaries have learned through experience that today's U.S. military forces are virtually unbeatable in conventional warfare. The continuous transformation process that started in the 1990s is resulting in dispersed combat concepts without forward lines of battle, emphasizing maneuver and precision instead of mass, closely coordinated and informed using ubiquitous information systems. Operation Enduring Freedom exemplified "new" combat thinking.

The Defense Science Board (DSB) and its sister service science advisory boards have studied 21st century land warfare in many contexts and concluded that while there is much to recommend, many new concepts are still evolving in each of the military services. Many individuals who served on these studies were impressed with new developments in combat systems; doctrine and training; C4ISR systems (command, control, communication, computer, intelligence, surveillance, and reconnaissance); medicine; unmanned vehicles; sensors; and many other areas. However these same advisors, from both civilian and military backgrounds, are struck with a few "miracle moments" that crop up in each scenario. Miracle moments occur when it becomes evident that some basic operational need has gone unmet by the conclusions of their study. Since the remainder of the study concepts are so compelling, it is often concluded that the unmet issue will somehow be met—an assumption that a "miracle" will somehow occur.



One persistent miracle in distributed combat, both for land- and sea-based operations, lies in how combatants on a distributed battlefield can be supported with the materiel and transportation services they need to do their job and stay safe. As far back as the DSB 1996 summer study on 21st century warfare and continuing through reports on logistics, aircraft carriers, sea bases, mobility, and future technology, the problem of satisfying the transportation demands of U.S. ground combatants remains unsolved.[1] The Army Science Board has independently observed similar force, materiel, weapons, and evacuation movement shortcomings in its future combat planning studies.

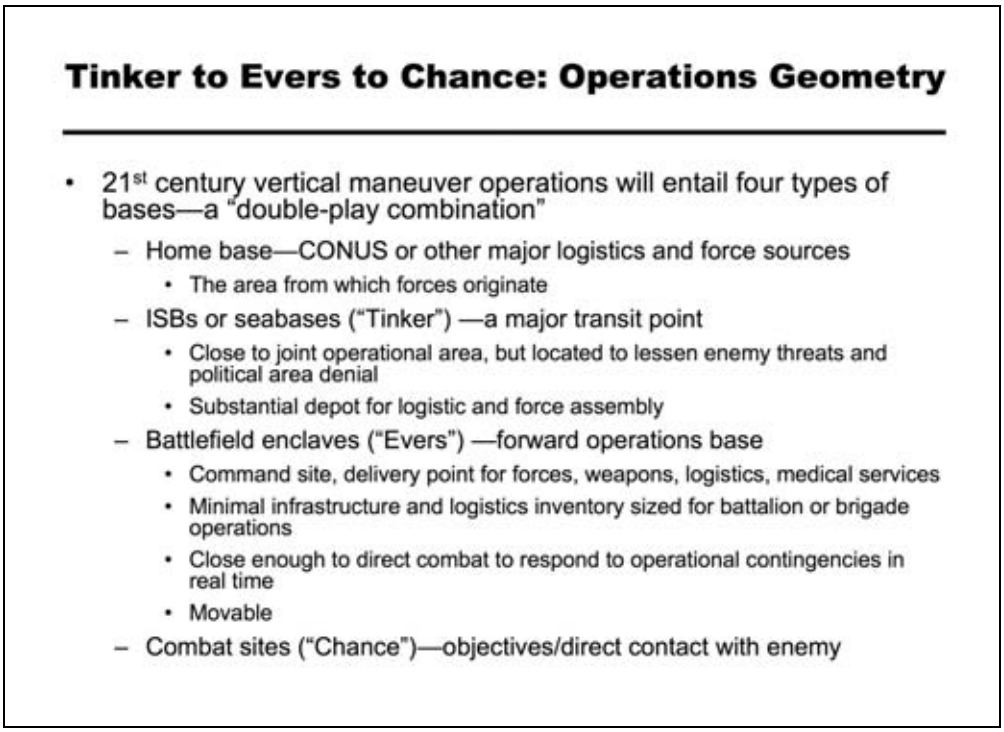
1. See *Defense Science Board 1996 Summer Study on Achieving an Innovative Support Structure for 21st Century Military Superiority, 1997*; *Defense Science Board Task Force on Logistics Modernization*, 1996; *Aircraft Carriers of the Future*, 2002; *Defense Science Board Task Force on Seabasing*, 2003; *Defense Science Board Task Force on Mobility*, 2005; and *Defense Science Board 2006 Summer Study on 21st Century Strategic Technology Vectors*, 2007.

The current Army Training and Doctrine Command (TRADOC) distributed ground combat model—unlike traditional combat models with definable front lines and rear areas or beachheads—envisions multiple isolated operational enclaves, separated from support bases by as much as 250–500 miles, each capable of supporting battalion or brigade-size forces. Logistics, force protection, weapons deployment and sustainment, force integration, and casualty evacuation each require the ability to transport substantial loads quickly to and from forward operational enclaves. Brigades have voracious appetites for fuel, water, ammunition, and a host of other commodities; they experience casualties that must be evacuated as fast as possible.

Distance, volume, weight, and speed requirements—as well as likely threat environments—rule out ground transportation in many instances. Deployed forces will require air bridges connecting enclaves to more developed intermediate supply bases (ISBs) or sea bases far from the scene of combat.[2] This task force was assembled to examine the air transportation needs of developing combat scenarios with emphasis on distributed combat far from established support bases, either on land or at sea. The task force considered many distributed combat models, from small special operations to brigade-scale force projection. It considered force-on-force, stabilization and reconstruction, counterinsurgency, operations other than war, as well as small unit operations.

The task force focused primarily on air vehicles capable of transporting an FCS battalion or brigade equipment significant distances, with the FCS vehicles manned and combat-ready upon insertion. TRADOC calls this capability "mounted vertical maneuver," but we have chosen to refer to it as "mounted aerial maneuver" in order not to exclude STOL or SSTOL options where feasible. (A further description of this concept is in Appendix D.)

2. According to Joint Publication 3-07.5, an intermediate staging base is a temporary location used to stage forces prior to inserting the forces into the host nation.



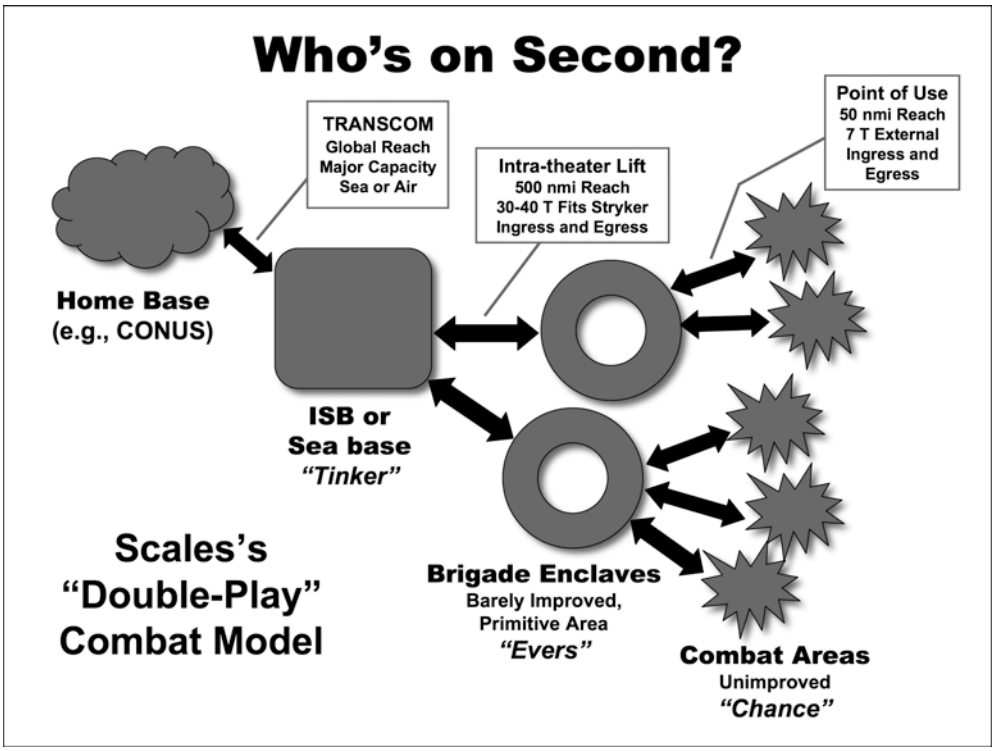
To focus discussions, the task force concentrated on a model developed in the early 1990s by MG Robert Scales, later discussed at length in his book, *Yellow Smoke*.[3] This scenario is a design point that stresses air bridge capability. Sea basing, an operational concept developed by the Marine Corps and the Navy, also under study by the Army, has the same air-bridge requirement and some additional requirements beyond those of pure land combat. Other distributed operations scenarios require, for the most part, less capability.

Scales's plan, nicknamed by the task force the "double-play model," involved projecting one or more brigade-size combat forces from the continental United States (CONUS) to a conflict area outside CONUS where nearby support bases are not feasible, either operationally or

3. MG Robert H. Scales, Jr., *Yellow Smoke: The Future of Land Warfare for America's Military*, New York: Rowman and Littlefield, 2003. See also, "U.S. Army Thinks 'Vertical Mounted Maneuver,'" *Defense News*, October 10, 2006.

politically. Transportation nodes in this model include CONUS, an ISB or sea base ("Tinker"), one or more brigade enclaves ("Evers") as far as 250–500 miles from the ISB, and the points of combat ("Chance").[4]

4. Chicago Cubs shortstop Joe Tinker, second baseman Johnny Evers, and first baseman Frank Chance formed the most memorable double-play combination in the history of baseball. Tinker, Evers, and Chance were all part of the Chicago Cubs' World Series–winning team in 1908.

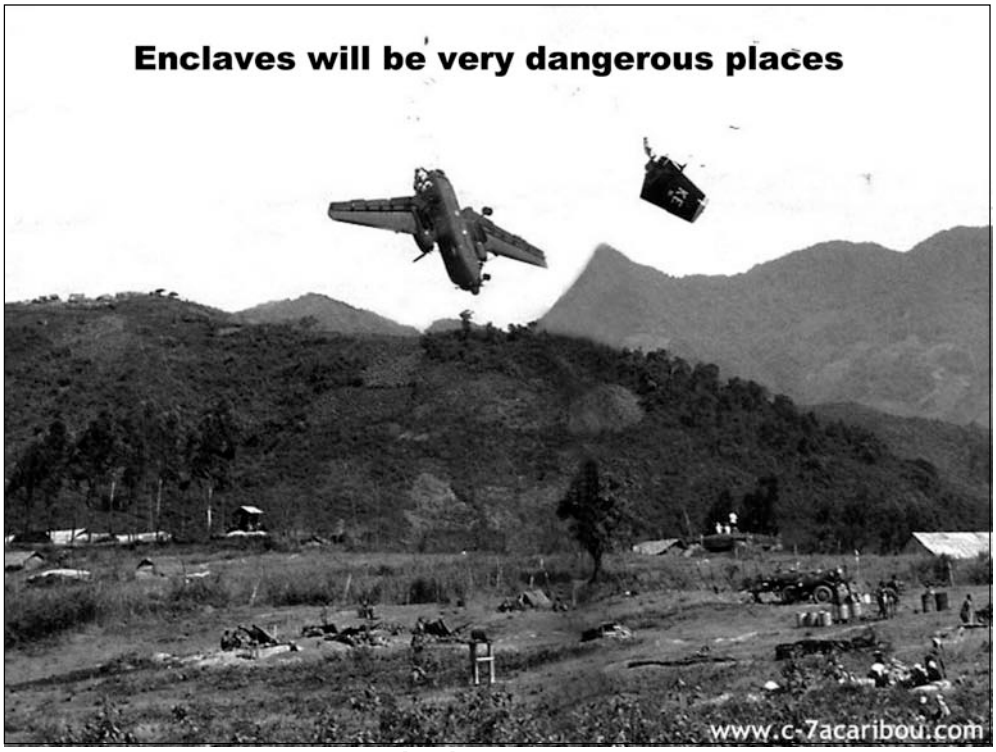


The task force concentrated on the link between the ISB and forward enclave. Capability for strategic lift from CONUS to Tinker is well established as the responsibility of the U.S. Transportation Command. Support of the combat teams (Evers to Chance) is provided by organic Army helicopter and ground capabilities. The subject of this study is the air link between Tinker and Evers—support for forward enclaves.

Enclaves Will be Primitive Locations

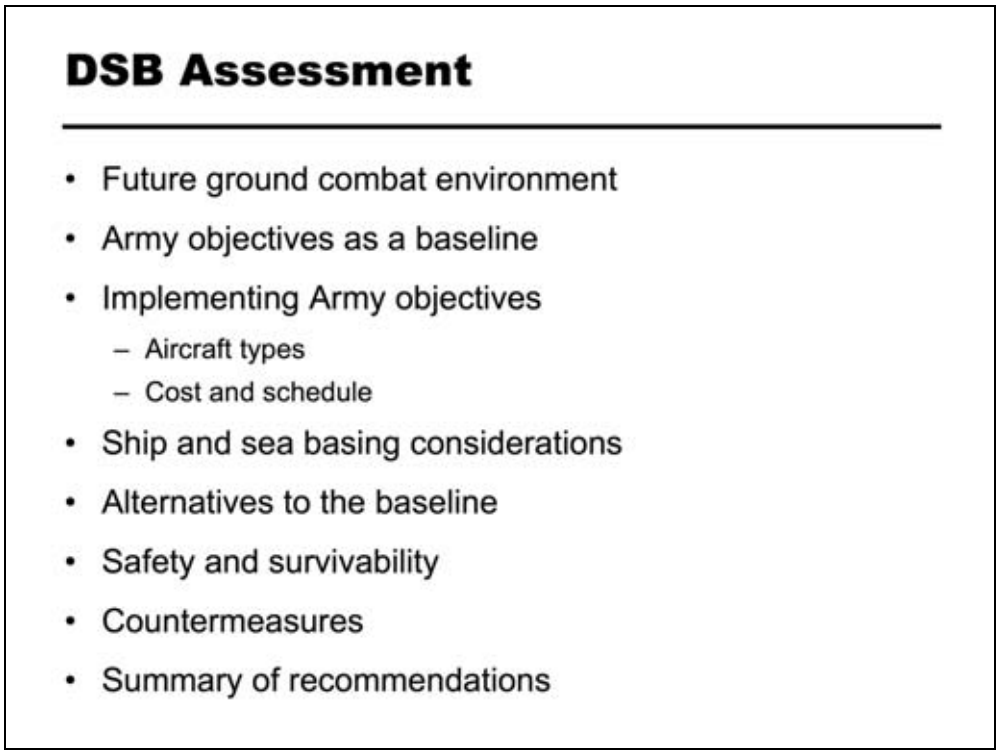
Unlike this Vietnam example, there will be no fuel available and probably no airstrip, at least not at the outset.

At best, maintenance at enclaves will be at best “seat of the pants”



Source: Bettmann/CORBIS; reprinted with permission.

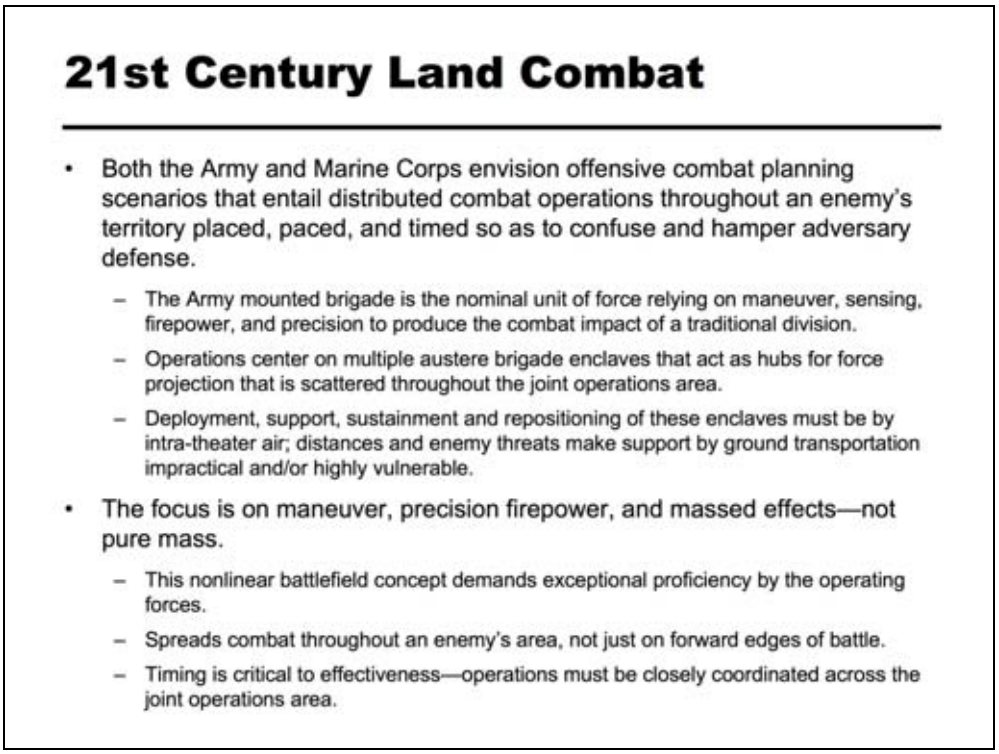
Forward enclaves are nodes for reception, assembly, and sustainment of combat forces and their weapons systems. Their transportation umbilicals must be capable of delivering forces and their weapons quickly and of sustaining the materiel needs of the forces. Since these enclaves are at best primitive sites and subject to enemy action, their transportation support assets must be robust and capable of using barely prepared landing areas.



This report begins with an examination, in Chapter 2, of the future ground combat environment, including operational models, threats, need for stealth, future unmanned aerial vehicle possibilities, and vulnerability. Chapter 3 presents objectives for airlift and supporting system capabilities based on the Army's current FCS requirements. Then the report turns, in Chapter 4, to an assessment of the Army's objectives—examining various airplane types in light of these objectives, including rotary wing, fixed wing, and compound aircraft options, as well as assessing cost and schedule. Lengthy consideration was given to advantages and limitations of available technologies, characteristics of operational and prototype vehicles, and projections of future possibilities. Ship and sea basing considerations are also addressed (Chapter 5).

Departing from the Army's baseline, Chapter 6 examines alternative airlift objectives and the resulting aircraft requirements to meet these alternatives. Chapters 7 and 8 examine safety and survivability and countermeasures—areas that require improvement in both the current and future fleet, regardless of the future fleet's design configuration. The report concludes with a summary of recommendations.

Chapter 2. The Future Ground Combat Environment



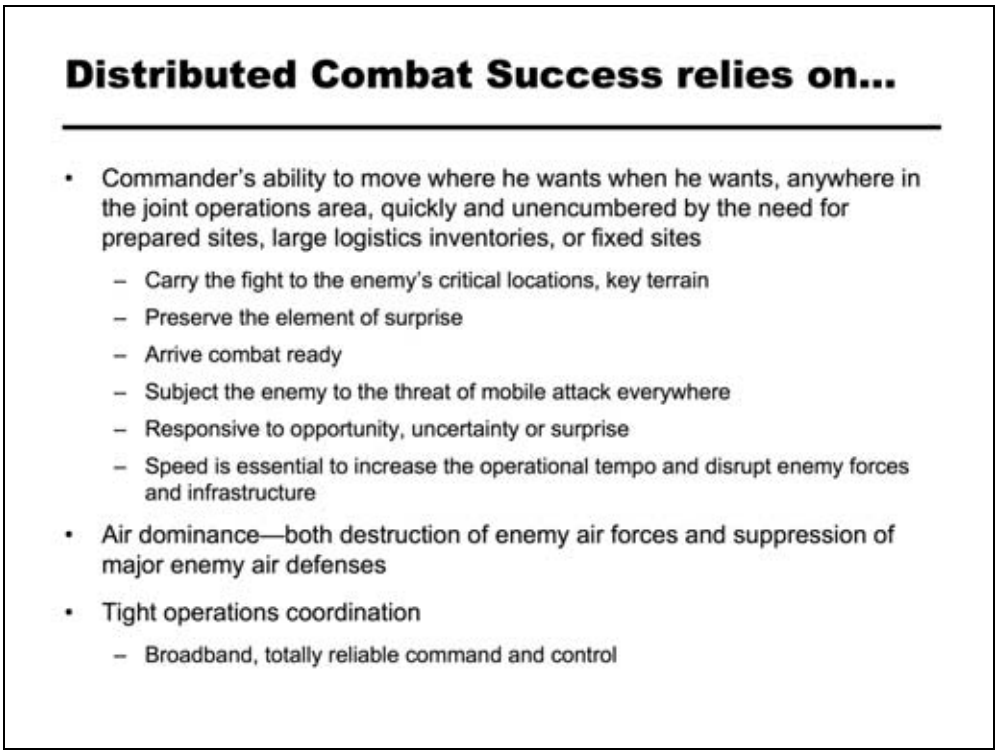
Future U.S. ground forces face adversaries who have carefully studied the American way of war. The primary lesson most opponents have learned is never to face U.S. forces in major force-on-force combat. Hence, future combat will be distributed, without front lines or rear areas. Opponents have shown in Somalia and Iraq that bogging down American forces in a distributed war neutralizes U.S. technology and the advantages of massed fires. Regular or irregular opposing forces, equipped with widely available weapons and spread throughout a large area, can counter a U.S. presence at fixed sites over time.

Further, U.S. enemies have access to defensive weapons that can make attacks against prepared critical sites, beaches, and transshipment points extremely difficult. Future American military success depends on

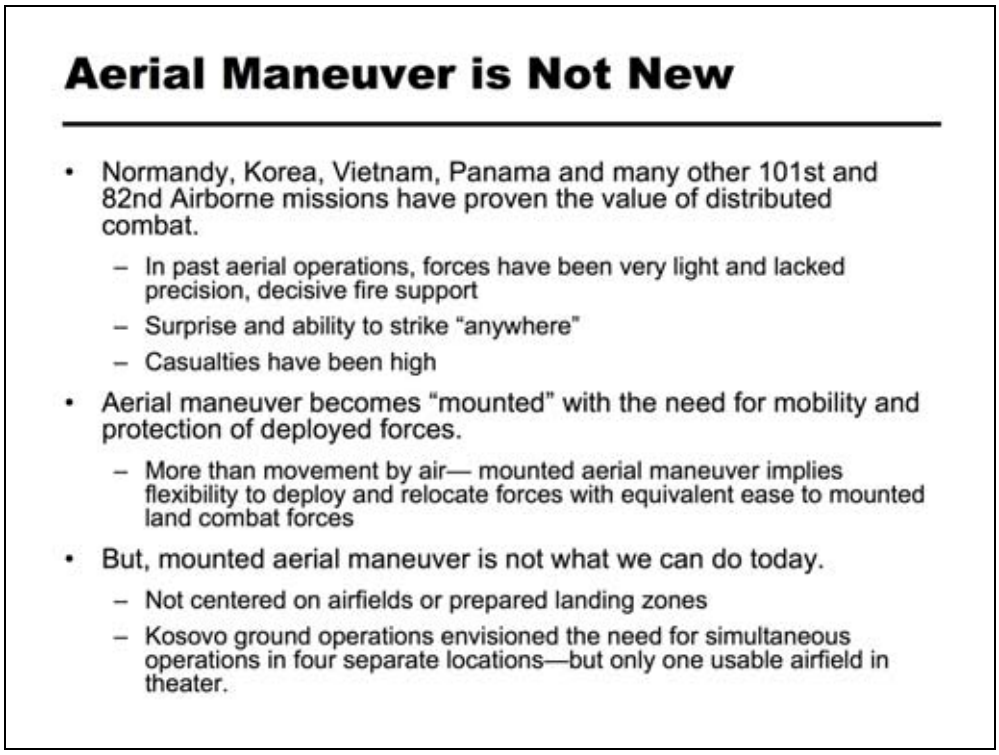
the ability to conduct a ground war anywhere within an enemy's area of control—leaping over the shore; reaching out to unprepared, critical sites; and moving around ports and established airfields. Offense in depth presents an insurmountable defense challenge to adversaries as opposed to defending borders, strong points and shores against conventional tactics.

Advanced U.S. military thinking, since the mid–20th century, has come to realize that major combat success hangs on agility, surprise, speed, and the ability to carry the fight to where the enemy least expects it, inside the enemy's time to react, and with overwhelming force. Synchronization of forces and effects implies critical timing and an ability to coordinate action in several separate locations simultaneously. To a potential adversary, along this line of reasoning, conflict with the United States becomes an intractable defense problem since the time and place of U.S. operations will no longer be tied to beaches, borders, airfields, or seaports.

The U.S. Army realization of this concept is called "mounted aerial maneuver;" others refer to this capability as sea basing. In other contexts, aerial maneuver competencies of agility, reach, speed, and flexibility improve U.S. forces' ability to conduct low-intensity combat, counter insurgency operations, raids, and other diverse tasks including disaster relief.



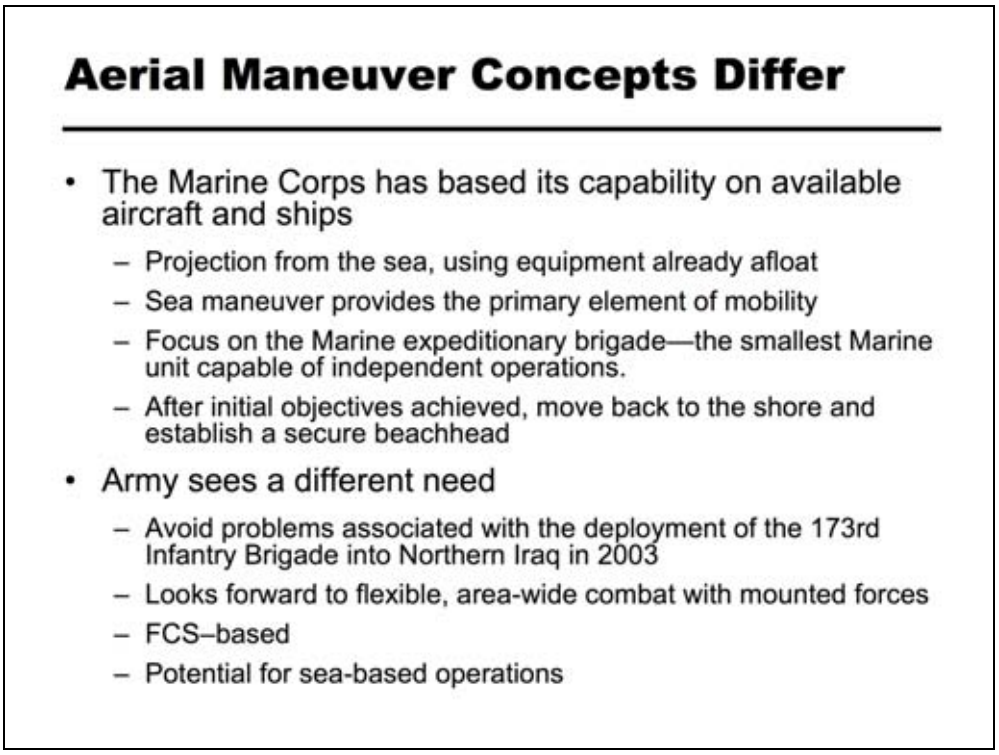
Successful mounted aerial maneuver entails close harmonization of many capabilities. Firepower, force protection, mobility, logistics, and a host of other capabilities must all combine to make a mounted aerial maneuver system-of-systems work. There must be a workable solution to problems in each dimension of a multidimensional effort.



Aerial maneuver is not new. The Army and Marines have deployed troops by parachute for many years (such as in the Normandy invasion, Panama, and a multitude of other operations by the 82nd and 101st Airborne Divisions). In the 21st century, however, with dissolution of conventional forward lines of battle and vulnerability of rear areas, combat success relies on an ability to hit the enemy when and where he least expects it from support bases well removed from the combat scene. As in the past, mounted aerial maneuver will require strong interdependence among all the military services.

Aerial maneuver becomes "mounted" with the need for dispersed forces to be mobile and to have sufficient protection and firepower to secure substantial objectives quickly. Mounted aerial maneuver can apply to the full range of forces up to brigades, depending on the circumstances.

But mounted aerial maneuver is not what U.S. forces can do today. This concept is not centered on airfields or prepared landing zones, but rather on the ability to operate in primitive sites under all types of conditions.



The Marines and Army have each pursued their own realization of distributed operations.

The Marine Corps, constrained by ships, equipment, and available aircraft has chosen, for the most part, to develop its operational model to fit within existing capabilities or those that can be achieved in the near-term. The Marine emphasis is on vaulting over the shoreline directly to inland military objectives and assaulting them quickly and decisively using sea-based forces. Today's Marine doctrine identifies the marine expeditionary brigade as the smallest force capable of independent action ashore, sustained by sea-based close air support. Because of its need for "at sea" presence and traditional role in armed conflicts, the Marines have focused on lighter forces and shorter aerial reach. Their aircraft of choice are the CH-53K and MV-22. Later in a conflict, the Marines anticipate clearing beachheads to land heavy equipment and supplies—M1A1s, bulk liquids, and equivalent.

The Army has come to mounted aerial maneuver via a different route. Distributing heavy, conventional combat forces solely by air is not possible in today's rapid environment of operational tempo, using current capabilities. In March–April 2003, as part of Operation Iraqi Freedom, the 173rd Infantry Brigade deployed to Bashur Airfield in Northern Iraq to establish a lodgment and demonstrate the threat of forces attacking Bagdad from the north. Over thirteen days, using 24 C-17 sorties and averaging two sorties per day, the brigade was able to transport five M1A2 Abrams tanks, five M2A3 Bradley fighting vehicles, twelve M113 armored personnel carriers, organic fire support, and elements of the forward support battalion.[5] The force deployed was far short of a dispersed force ready for major combat.

The Army has long concluded that it must lighten its combat formations. Army philosophy has evolved through a series of visions, starting with Army of the 1990s, to Army 21, to Army After Next, and culminating in today's Future Combat System. FCS is a giant leap—redefining weapons, vehicles, soldiers and their equipment, the networked battlefield, and C4ISR to empower much smaller forces to act with the impact of classical large, heavy units. The Army has invested heavily to develop equipment to make the FCS vision real.

The realities of 21st century warfare, as shown in Afghanistan and Iraq, are that the once bright line between Marine and Army operations has blurred and both may find each other with overlapping missions. Either may be called upon to operate from the sea. Both may find themselves entangled in long-term missions, including post-combat operations. The task force elected to concentrate on the Army's mounted aerial maneuver concept as the force driving dispersed combat and the need for heavy lift tactical support aircraft, realizing that its conclusions can apply to both the Army and Marine Corps.

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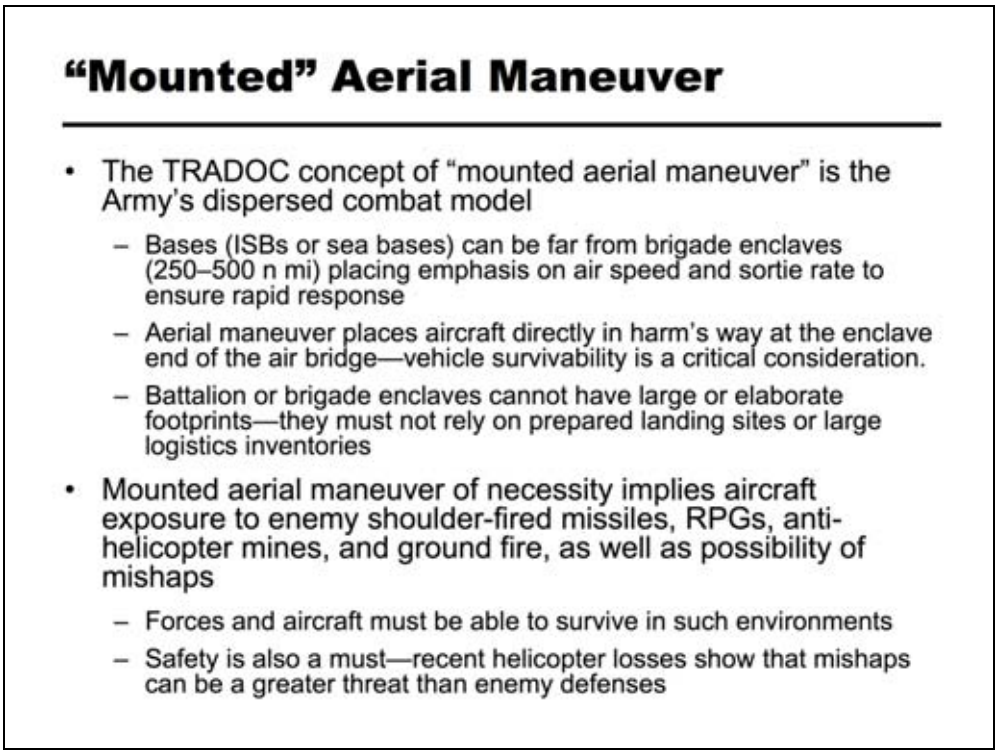
5. *Future Combat Systems (FCS) Operational Maneuver Analysis of 24 Ton Build-up Design Concept*, Final Report, TRADOC Analysis Center, Ft. Leavenworth, Kansas, 28 April 2005.



The United States has had preferential access to technologies that enable dynamic warfare operations with global reach by air and sea; precision weaponry; digital technology and sensing for C4ISR; materials for more lethal, lighter weapons; and superb training that allows today's professional military to adapt quickly to the unique aspects of individual campaigns. Many of the concepts of warfare, based on concentration of military mass, have fundamentally changed, altered by the speed and power of today's combined arms assault. To date the United States has pioneered and dominated high-technology warfare.

This recent period of U.S. dominance is being challenged. Potential adversaries in Kosovo, Iraq, Afghanistan, Iran, China, and elsewhere are hard at work studying U.S. military doctrine. They have successfully developed tactics and arms, mostly low tech, that can effectively counter American advantages. The time when the United States could telegraph its punches by assembling massive fixed logistics support bases before starting an assault is over. Effective ballistic and cruise missile threats, not to mention mobile anti-ship weapons and sophisticated mines, have rendered safe-haven rear and littoral areas vulnerable to enemy attack and denial.

Future adversaries will be incapable of matching American conventional military capabilities, thereby forcing them, whether national or non-state actors, to abandon force-on-force combat. They will adopt highly asymmetric modes of conflict to accomplish their aims and prepare for long-term insurgent operations. As operations in Desert Storm, Iraq, Afghanistan, and the Balkans have shown, U.S. forces must not only take down enemy forces in the force-on-force combat phase of conflict, they must also project lasting ground presence to follow up initial invasion successes. Post-combat ground forces must perfect U.S. combat objectives.[6]

It is during this perfection process that U.S. forces face their greatest future challenge as opportunities for asymmetric conflict abound after organized shooting stops. Insurgents strike at times and places difficult to anticipate. Agility and adaptability are just as necessary in post-conflict, stabilization operations as they are earlier in the fight. Insurgent fighters in Iraq are already practicing distributed warfare. Effective counterinsurgency operations must be similarly dispersed and have reaction times short enough to discourage insurgency leaders.

Dispersed combat in future conflicts cannot rely on nearby central support bases or on ground supply trains for deployment and sustainment. Transit times are too slow. Iraq and Afghanistan experience clearly illustrates the vulnerability of convoys for force projection and resupply. Massed supply and transshipment areas in theater will present unacceptable risks. In-theater bases may have to be light and mobile to be defendable. Distances from major support bases (based either on land or at sea) to major combat areas may have to be 250 nautical miles or more, another drawback to ground-based supply transit.[7]

According to the mounted aerial maneuver concept, operations areas in future wars will have to be independent enclaves that serve as maneuver centers allowing digitally connected, friendly forces based in

6. See *Defense Science Board 2004 Summer Study on Transition to and from Hostilities*, 2004.
7. Distances provided by U.S. Transportation Command.

several locations to continually maneuver to the disadvantage of the enemy. The commander's flexibility in placing areas of operations in locations and times that disadvantage the enemy will be a key factor in the success of such dispersed operations. Relying on major improved facilities, such as airfields and large supply dumps, in remote operational areas reduces a commander's freedom to use maneuver-based warfare to its best advantage.

Massed logistics are a constraint, not an advantage, to dispersed combat commanders. Future battlefields can contain no logistics mountains—logistics and support must become a stream flowing when and where the commander orders. There will be no room for motor pools and tank parks—combat and support vehicles must be available, fully fueled and armed, set to move out by air, as needed, throughout the area of operations.

Future areas of operations will still require medium-weight armored vehicles, personnel, fuel, water, munitions, and much more. The dynamic environment requires great agility as to when and where these requirements can be delivered. Operational support by air is the only option capable of meeting these needs.

The mounted aerial maneuver concept however, encompasses serious risks. Knowing when and where to establish enclaves requires prescient command decisions that rely on nearly perfect situational awareness. When and where to deploy a battalion or brigade size force, independent of ground ingress and egress routes without assured knowledge of the disposition of enemy forces and defenses is a risky decision, as the French discovered at Dien Bien Phu, the Allies at Arnhem, and Custer at Little Big Horn. Force protection will be a major consideration.

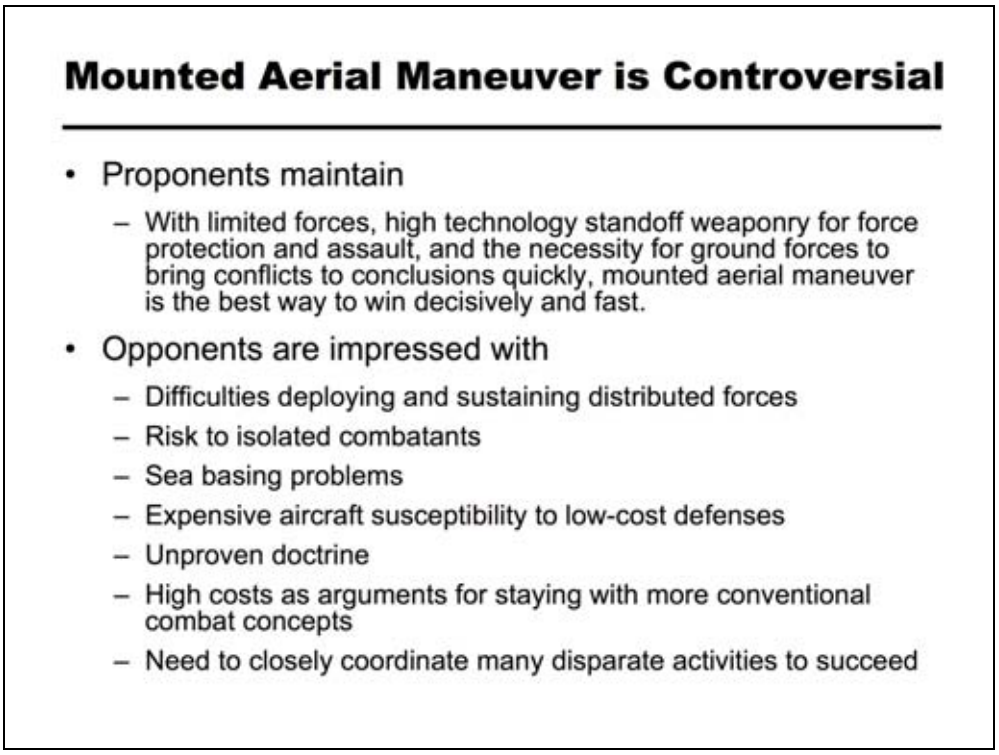
Today's enemies are already equipped with effective defensive weapons against low-flying aircraft. The risk to aircraft flying below 10,000 feet for prolonged missions over hostile territory (either in transit or landing at an enclave) from various inexpensive enemy air defense (EAD) systems (man-portable air defenses [MANPADs], antiaircraft guns, anti-helicopter mines, rocket propelled grenades [RPGs]) is high. The 11th Assault Helicopter Regiment discovered how

serious the EAD problem could be in its operations against Karbala in March 2003. Aerial deployment and sustainment vehicles must fly high and incorporate effective defense against both passive and active counter-air weapons to cover landings and takeoffs from enclaves.

Low observable characteristics (stealth) are a useful attribute for aircraft supporting special operations forces, but are less likely to be of crucial importance for other aerial maneuver operations since non-low-observable aircraft can operate at altitudes above shoulder-fired anti-aircraft weapons, and suppression of enemy air defenses is assumed for more sophisticated systems. Vulnerability of heavy lifters to enemy air defenses in the vicinity of the enclave air facility depends less on stealth than on anti-missile systems.

Sufficient situational awareness is yet another challenge. With the rise of irregular forces masked within civilian populations, enemy force identification and location is uncertain. Even in friendly environments, problems with situational awareness were evident in the deployment of a small helicopter force in Albania during the Kosovo campaign. Here problems of mud, pilot training, and lack of knowledge about the location of Serbian air defenses prevented this force from playing any combat role. Additionally, the effectiveness of camouflage and concealment used by the Serbs in Kosovo clearly demonstrated the limitations of today's ground intelligence systems.

For sea basing, the needs of many heavy lift aircraft capable of operating from shipboard demands new designs and new thinking about where to base aircraft and how to land, load, service, and takeoff waves of aircraft in minimum time.



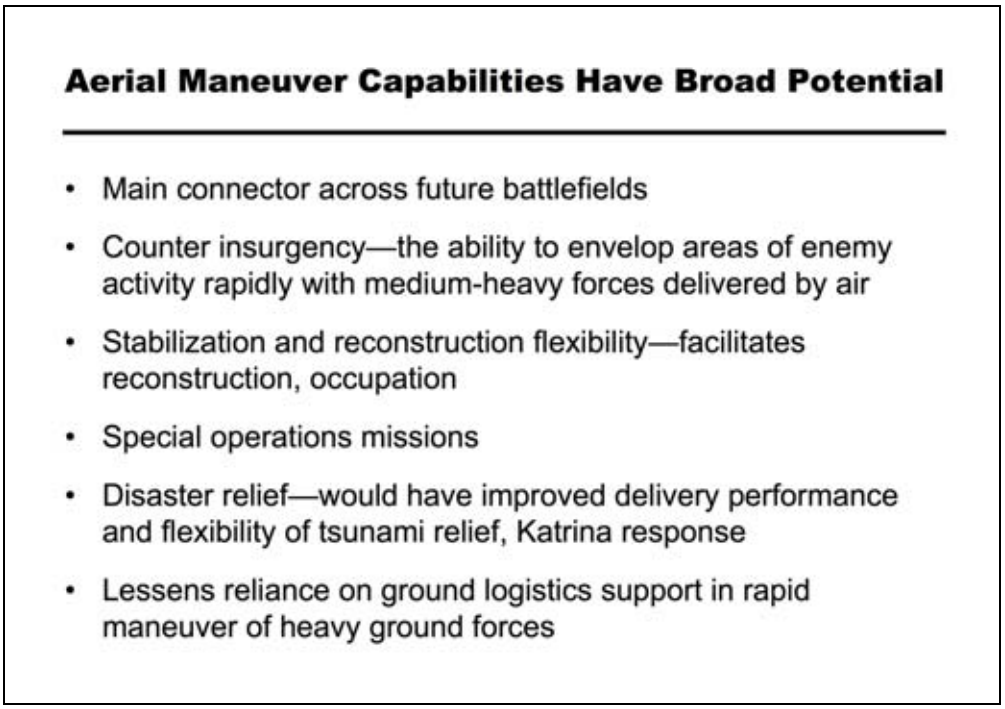
The mounted aerial maneuver concept is controversial. A formal debate over mounted aerial maneuver could be framed as follows:

- U.S. land forces cannot exploit their full technological advantages if they are tied down in a static confrontation with opponents. They must instead develop and exploit mobility systems that confer a modern-day leap-frog capability—decisive actions like Guderian's blitzkrieg or MacArthur's Inchon.
- Resolved: DOD should aggressively build and practice mounted aerial maneuver capability.

Proponents argue that, with limited forces, high technology standoff weaponry for force protection and assault, and the necessity for ground forces to bring conflicts to conclusions quickly, mounted

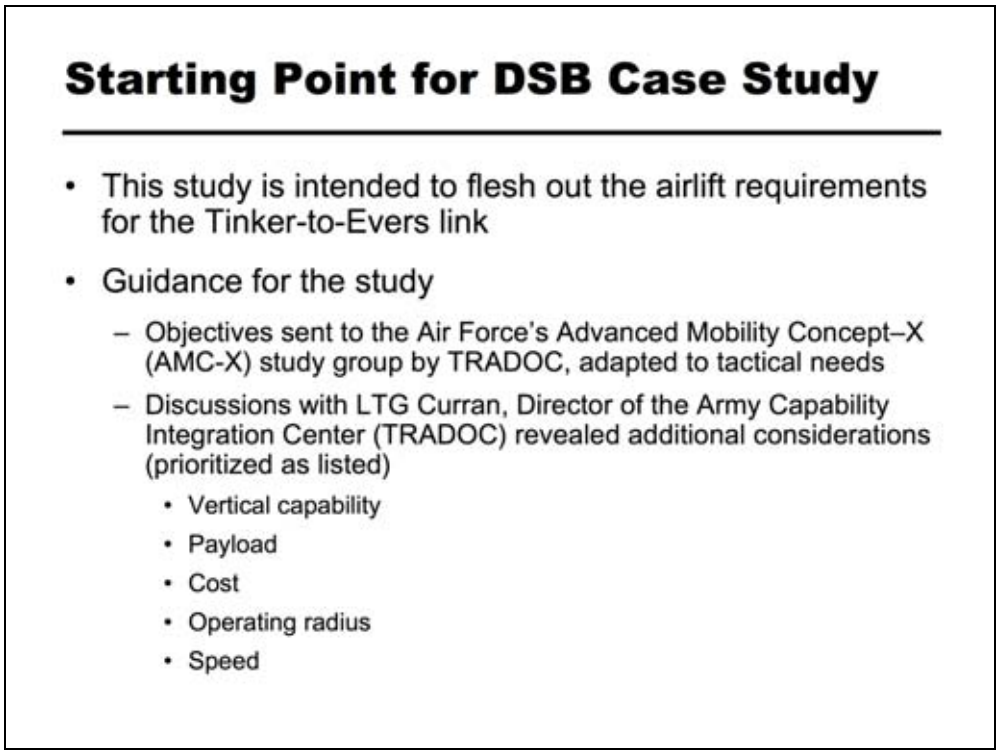
aerial maneuver is the best way to win decisively and fast.[8] Opponents cite difficulties deploying and sustaining distributed forces, risk to isolated combatants, sea-basing problems, expensive aircraft susceptible to low-cost defenses, unproven doctrine, and high costs as arguments for staying with more conventional combat concepts.[9]

8. Brigadier General Robin P. Swan and Scott R. McMichael. "The Transforming Power of Mounted Vertical Maneuver," draft article for publication in *Military Review*, December 2006.
9. John Gordon IV, David E. Johnson, and Peter Wilson. *Air Mechanization: An Expensive and Fragile Concept*. Santa Monica, Calif.: RAND, forthcoming.



Capabilities required for mounted aerial maneuver combat operations apply as well to other types of military activities. The speed, mobility, and payload of a VTOL heavy lifter enable swift reaction to insurgent assaults, facilitating containment and clean-up operations. The ability to lift and deliver heavy loads ease peacekeeping and reconstruction operations, as well as occupations. Special operations forces can use heavy lifter capability to deploy and extricate teams better equipped than now possible. Availability of a heavy lifter could have expanded U.S. tsunami relief efforts. Needless to say, VTOL heavy lift eases conventional ground forces' reliance on terrestrial logistic supply chains.

Chapter 3. Army Future Combat System Objectives as a Baseline

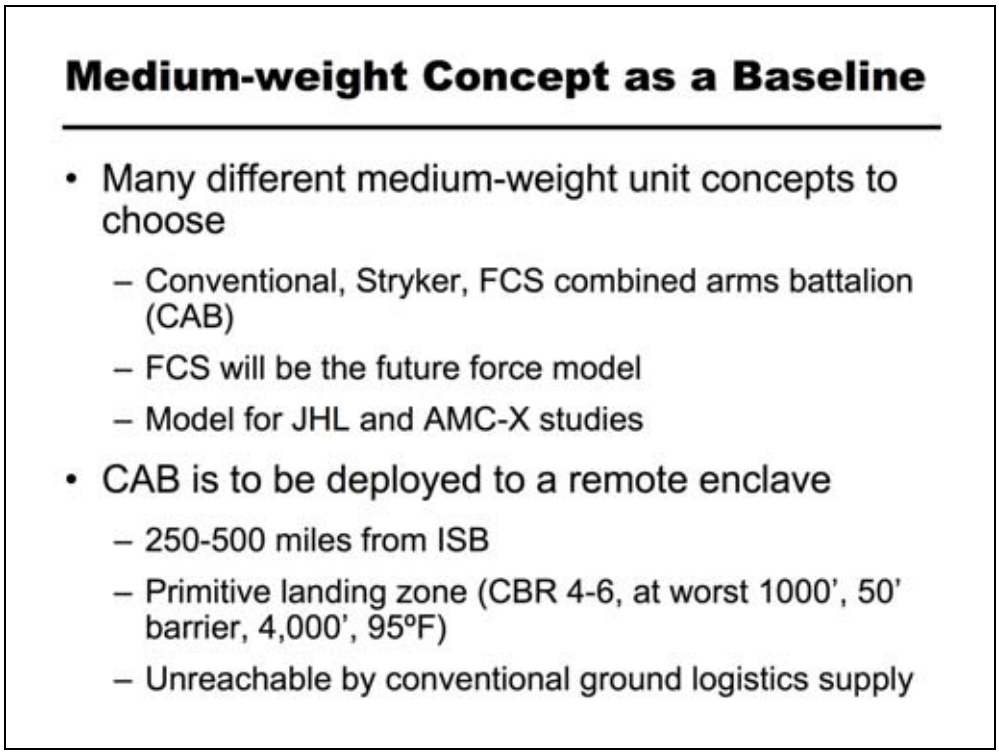


This study examines the airlift needed to deploy and sustain distributed ground combat forces: the Tinker-to-Evers link, as described in the previous chapter. Goals for this tactical heavy lifter study are driven by the Army's expressed tactical operations needs for FCS forces. The framework for these objectives derives from objectives sent to the Air Force's Advanced Mobility Concept–X (AMC–X) study group by TRADOC in an April 17, 2005, memorandum from Lt. Gen. John M. Curran, Director of the Army Capabilities Integration Center.[10]

10. Lieutenant General John M. Curran, Director, Army Capabilities Integration Center, Air Mobility Command/CV, "Advanced Mobility Concept-X," memorandum, April 17, 2006.

These goals, originally intended as guidance for the Air Force's AMC-X program, were adapted to focus on tactical heavy lift needs. The task force fully understands that a mix of conventional and dispersed operations is likely in any future conflict; and that some deployment and sustainment assets will be air-dropped. Further, sizable remote forces in place for long times will construct landing fields for conventional fixed-wing aircraft.

Additional considerations were provided during discussions between the task force and Lieutenant General John Curran, where he elaborated on the following: airlift using VTOL capability, as well as details on payload, cost, operating radius, and speed. He indicated that this list, as presented here, also reflects his prioritization of requirements.



Several models can describe the forces used in distributed ground combat operations: the original light concept; its evolved extension into a much heavier, mounted force; Stryker forces; FCS forces; and conventional forces. The task force elected the FCS combined arms battalion and the FCS brigade as its baseline models.

As originally conceived, the FCS force was to be light, mobile, intimately connected, and capable of bringing massive firepower to bear on its objectives—whether from light, organic weapons or from distant heavy weapons (artillery or precision air). FCS units were to be modest in size, specialized groups, backed by more conventional forces as needed. Speed, agility, firepower, and surprise were to be the hallmarks of the FCS style of combat. FCS units were to be readily deployable to remote locations, relying on inorganic backup as needed for logistics and firepower.

FCS has come a long way and developed a life of its own. FCS has now become the model for much of the Army's future combat units: vehicles and organic weapons have grown in size, weight, and power.

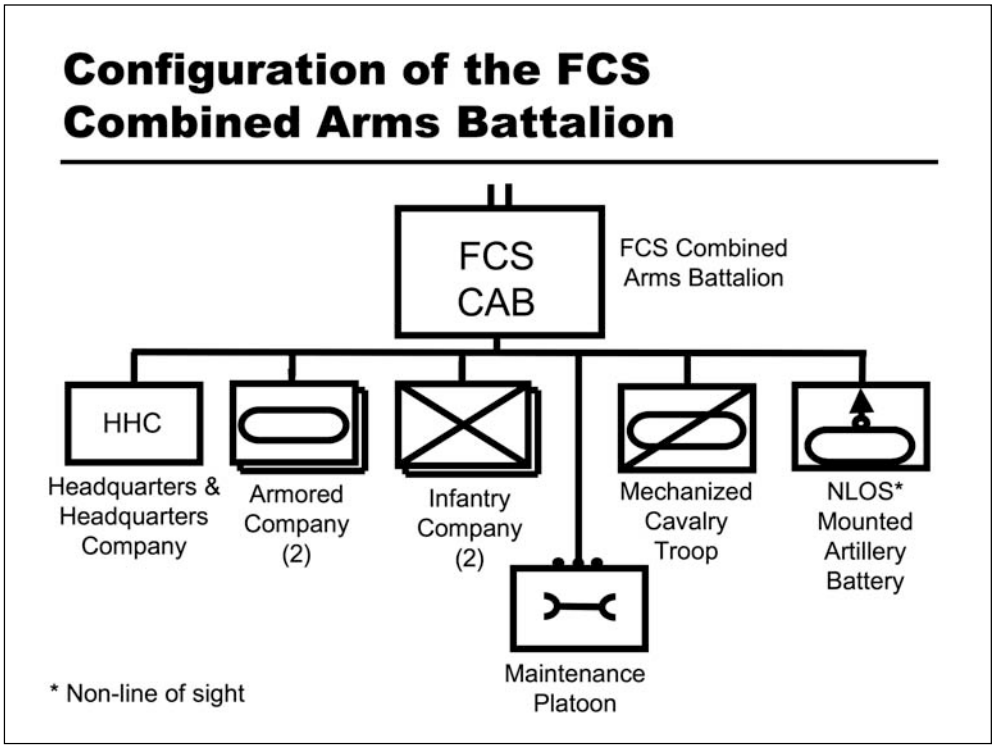
FCS units, originally conceived to be squads, platoons, or companies capable of operating in isolation, have become battalions and brigades with medium tanks, organic helicopter units, and heavy artillery operating from remote enclaves, possibly with airfields.

Simultaneously, in response to a shift to precision weaponry and maneuver, the Army has downsized its basic unit of combat force from the division to the brigade and, in some instances, the battalion.

The original FCS forces were to be easily transported in aircraft similar in payload and size to C-130s. As it has now evolved, mounted aerial maneuver requires wholly new aerial lift capability to move and sustain the force, its weapons, and vehicles. Growing requirements have outstripped the ability of existing transportation systems to support remote forces in primitive locations. The transportation dimension of the multidimensional mounted aerial maneuver problem has no solution at this time.

To address this problem, the Army initiated a Joint Heavy Lift program that is targeted at vertically lifting a *20-ton* payload for hundreds of miles. Since a 20-ton lifter cannot deploy a combat-ready FCS vehicle and a full aircraft fuel load, the Army has developed a concept for a 30-ton lifter. The 30-ton tilt rotor design (deemed the "best technical approach" tilt rotor) is what the task force considered in its baseline analysis.

This study evaluates one model of how to deploy and sustain an FCS battalion into combat by air. The battalion's remote operations emanate from an enclave where air, logistics, and support operations are based. The enclave is distant from the nearest intermediate support base, unreachable by conventional ground logistics means. The deployment includes all necessary personnel, combat vehicles, support systems, and material as well as evacuation capability for casualties—described further in the remainder of this chapter. The task force characterizes the enabling air transportation systems required to make FCS mounted aerial maneuver a reality in operations projected from both land and sea bases. It focuses on the technical decisions and issues associated with deployment and sustainment of major combat forces by air.



The figure above shows an exemplar battalion force structure, taken from the study, *Future Combat Systems (FCS) Operational Maneuver Analysis—A Comparison of FCS Forces and Heavy Forces Deployed With an Operational Mix of Aircraft*.[11]

An FCS combined arms battalion consists of two medium armor, two infantry, one mechanized cavalry, and one mounted artillery company, in addition to a headquarters company. A vehicle maintenance platoon completes the organization.

11. Annotated briefing: TRADOC Analysis Center, *Future Combat Systems (FCS) Operational Maneuver Analysis—A Comparison of FCS Forces and Heavy Forces Deployed With an Operational Mix of Aircraft*, 10 August 2005

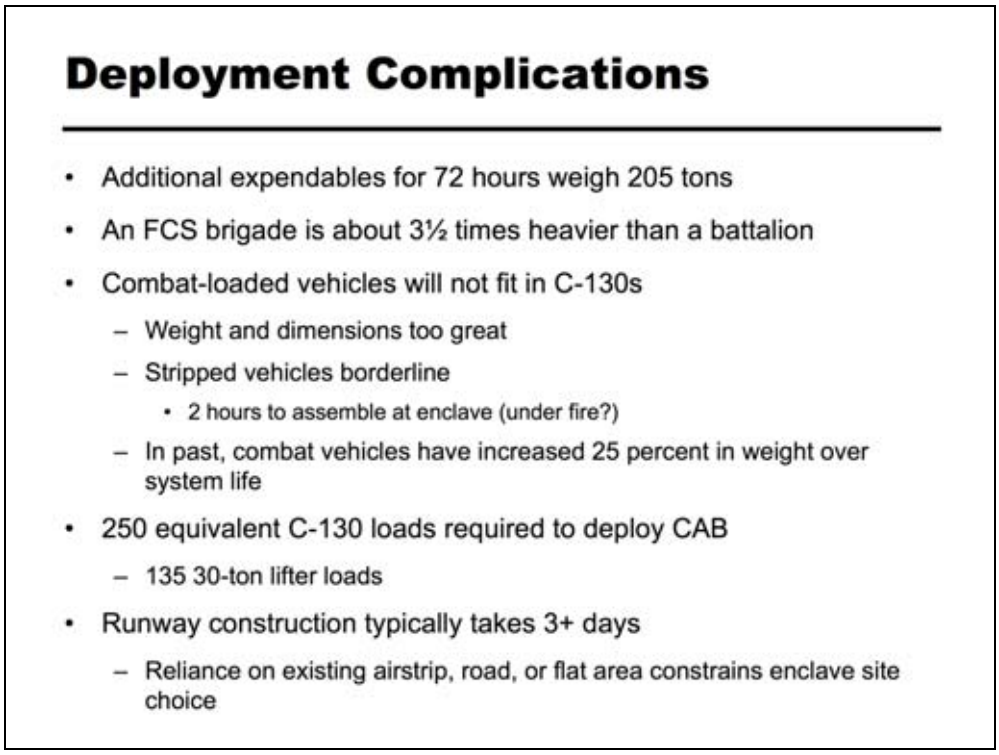
FCS CAB Deployment Load

		Combat Loaded				Stripped			
	Qty	Total Wt. (T)	Max Lngth (in.)	Max Wdth (in.)	Max Ht (in.)	Total Wt (T)	Max Lngth (in.)	Max Wdth (in.)	Max Ht (in.)
Personnel	683	171				171			
Vehicles: Manned	88	2376	328	144	127	1816	328	107	101
Unmanned Systems	82	270	213	99	97	270	213	99	97
Support Systems	89	1478	431	96	112	925	431	96	102
TOTAL		4295				3182			

Note: A Full-Combat-Capable FCS Manned Combat Vehicle Weighs 27 Tons

The deployment load breakdown for the FCS battalion in a Southwest Asia setting is depicted in the above table. This is a generic force—in many instances this force would be augmented or reconfigured to deal with specific threats or conditions.

An FCS unit of action, the equivalent of a brigade, consists of three FCS CABs in addition to a helicopter company, command, medical support, and engineering and other support units. The total brigade lift is more than three-and-a-half times that of a battalion.



The total combat loaded weight (4,295 tons in the case of the battalion) establishes lift required if vehicles and soldiers are to arrive ready-to-fight. The best condition combat-loaded FCS vehicle weight is 27.1 tons and its dimensions are 328 x 144 x 127 inches. The width, height, and weight of combat-loaded FCS vehicles all preclude using C-130 aircraft for deployment.[12] C-130 E/H/J maximum sea-level payload weight is 20.5 tons, and its cargo space is 480 x 119 x 108 inches, including safety aisles required by Air Force regulations. While multiple FCS vehicles can be carried in a C-17, enclave landing zone conditions preclude their use in most situations.

FCS vehicles can be lifted in stripped down configuration, in which case the FCS vehicle weight (21 tons) and dimensions border on C-130 E/H/J weight and load space capabilities. However vehicle assembly at the remote site, possibly under fire, is required along with equipment such as forklifts to move the armor plates from the air lifter to the

12. U.S. Air Force C-130 Hercules Factsheet, www.af.mil/factsheets/factsheet.asp?ID=92

vehicle. Time required to assemble armament and armor on an FCS vehicle can be as long as two hours.

Characteristically, combat vehicle weights increase throughout vehicle life cycle. According to the Army Transportation Engineering Agency, "developers and contractors should…plan for weight growth increases of 25% over the life of their system."[13] This consideration precludes use of C-130 aircraft for delivering FCS vehicles, even stripped down, in the long term. (Additionally, C-130 maximum payloads decrease substantially as the altitude of the landing zone increases.) DOD can expect that even the stripped down weight of FCS vehicles will reach nearly 25 tons by the end of their system lives. The driver for this growth is physics. As the threat environment worsens, vehicle armor weight increases, even with improvements in active armor.[14] As weapon discharge forces increase, so must vehicle weight to prevent upset.

The term "enclave," as used in this study, refers to the base location where the battalion or brigade is to be inserted. Based on TRADOC objectives, if fixed-wing aircraft are to be used, the enclave must at least have a 1,000-foot landing zone with no more than a 50-foot obstacle at the end; meet the 4,000 ft, 95º F criterion; have a California Bearing Ratio (CBR) of 4-6, and have no refueling or other support capability.[15] Its threat environment will require enhanced onboard protection against enemy ground fire. This airfield must have the durability to withstand heavy use—initial deployment of an FCS battalion would require nearly 250 equivalent C-130 landings (135 30-ton heavy lifter landings), all heavily loaded. The enclave may be as much as 500 nautical miles from the intermediate support base or sea base.

Long, heavy runways are expensive, take considerable time to build, and are vulnerable and rare, so enclave site choices are limited to

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13. Clapp, LTC Timothy P, Cassidy, Joseph F., Military Traffic Management Command, *Historic Weight Growth of U.S. Army Combat Vehicle Systems*, 27 August 2002.
14. Dion-Schwartz, Cynthia, et. al., *FCS Vehicle Transportability, Survivability, and Reliability Analysis*, IDA Document D-3100, Institute for Defense Analysis, April 2005, p. II-17 ff.
15. Curran, op. cit.

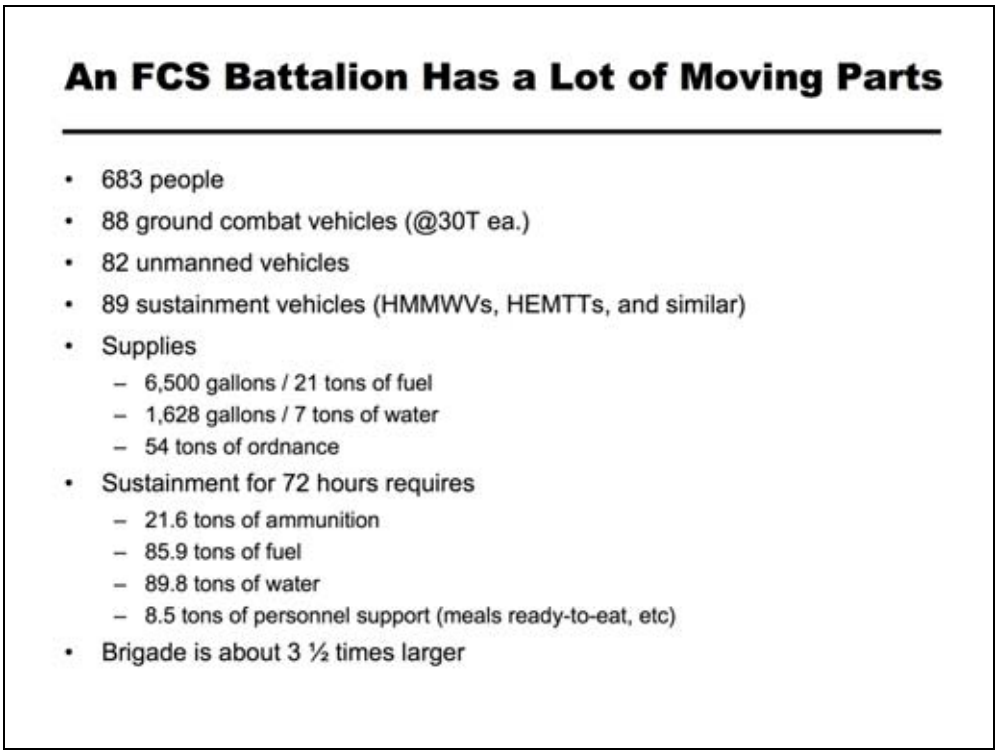
locations having pre-existing runways, major roads, or large, unusually durable, obstacle-free areas. Runway preparation for heavy use can take several days, depending on conditions; Marston Mats (pierced steel runway planks) or their equivalents, require significant lift to deploy, as does the heavy equipment required.

It is reasonable to presume that, when an enclave is used for more than a week, time can be taken to construct a suitable runway for conventional, fixed-wing aircraft.

Discussions with TRADOC personnel reveal serious concerns that insistence on an airfield at the outset as an enclave site requirement will unacceptably restrict the commander's choice of enclave locations to existing airfields, improved roads, or other prepared locations.[16] For forces to close on their objectives in a timely manner, preserving the element of surprise, and with the least enemy resistance, its commander must have as much flexibility as possible in enclave choice.

Other critical considerations in the choice of a mounted aerial maneuver aircraft include safety, survivability, and reliability. If VTOL heavy lifters do not have significantly improved safety and reliability over today's rotary-wing aircraft, the risk of VTOL lifter problems disrupting battalion and brigade remote operations is high; the risk of losing critical assets in the transportation phase is unacceptable. The threat environment over long stretches of enemy territory is severe. Experience in Afghanistan and Iraq indicates the need for significant improvements in both VTOL and fixed-wing operations, as will be discussed further in Chapter 7.

16. Private conversation with Lt. Gen. John Curran, June 1, 2006.



Logistics presents another challenge. The weight of vehicles and materiel required, even for a projected FCS combined arms battalion is impressive:

- 88 ground combat vehicles (at 30 tons each)
- 82 other vehicles
- 89 sustainment vehicles (high-mobility multipurpose wheeled vehicles [HMMWVs], heavy expanded mobility tactical truck [HEMTTs] and similar)
- 6,500 gallons/43,550 pounds of fuel
- 1,628 gallons/13,581 pounds of water
- 54 tons of ordnance
- 683 people.

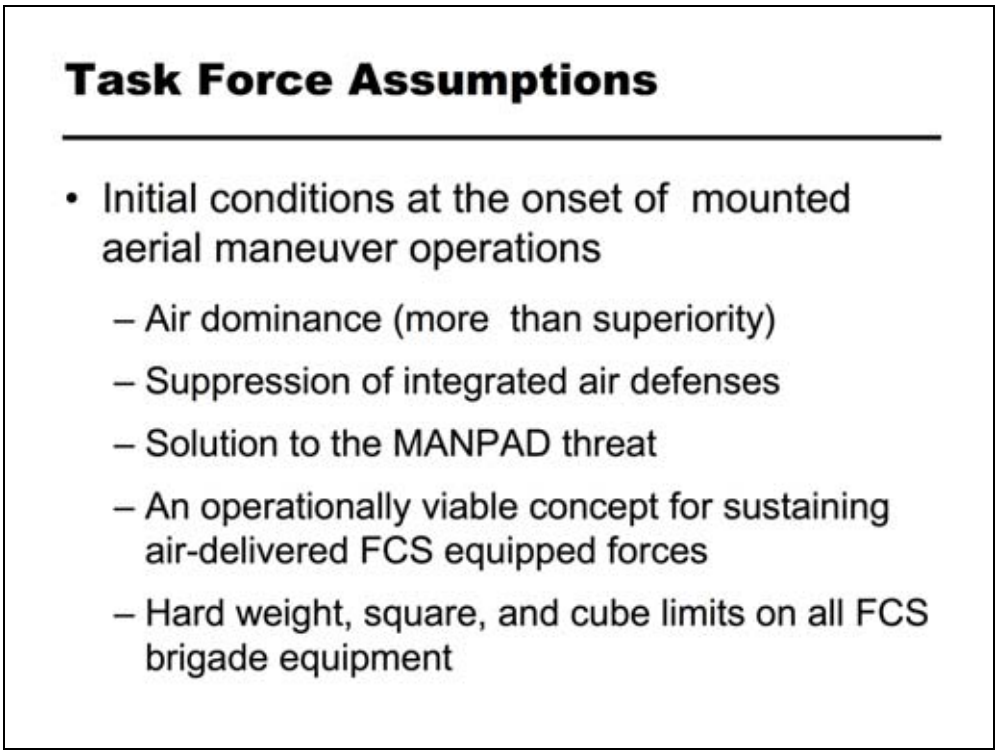
Together these vehicles and materiel total about 4,300 tons for the initial battalion deployment with enough consumables to last about 8 hours at high operational tempo. Sustainment requires a 72-hour supply of the following:

- 21.6 tons of ammunition
- 85.9 tons of fuel
- 89.8 tons of water
- 8.5 tons of personnel support (meals ready-to-eat, etc.)

These supplies total 205.8 tons every three days, not including medical and maintenance needs.

An FCS brigade requires about three-and-a-half times the battalion lift.

In addition to the lift required to move this volume and weight of materiel, staging, loading, fueling, and unloading it all within the constraints of remote enclaves or aboard ships present new challenges for airfield and shipboard operations.



In addition to the equipment, personnel, and sustainment items required by an FCS battalion, the task force assumed a set of initial conditions at the onset of mounted aerial maneuver operations:

- air dominance (more than superiority)
- suppression of integrated air defenses[17]
- solution to the MANPAD threat[18]
- an operationally viable concept for sustaining air-delivered FCS equipped forces
- hard weight, square, and cube limits on all FCS brigade equipment

17. Some would argue that these are the "miracles" described earlier for new operational concepts.

Best Case Time to Deploy FCS Forces (Hours)

	Air lifter Payload	Sorties Required	500 nmi Radius	250 nmi Radius
Battalion	20 T	186	18:15	10:25
	30 T	135	14:10	8:05
	40 T	100	10:05	5:45
Brigade	20 T	651	67.15	38.25
	30 T	440	42:45	24:25
	40 T	360	34:35	19:45

Assumptions: 40 Aircraft in Waves of 10; Speed – 300 kts; Support base / Sea base MOG – 10; Enclave MOG – 10; Turn around time (enclave) – 15 min; Turn around time (ISB) – 25 min; No slack time, no aborts

Note: Use of 20 T lifters necessitates vehicle assembly at the enclave (2 hrs ea.)

For study purposes, the task force characterized deployment of an FCS battalion and an FCS brigade from both 500 and 250 nautical miles from the intermediate support base to the enclave. Results of this simple analysis are shown in the table above. Considerations include the characteristics of the aircraft—such as size, speed, and payload—the maximum number of aircraft that can be on the ground at one time, the turn-around times at both the enclave and the intermediate support base, and the probability that a sortie might have to abort in flight. (Calculations and assumptions supporting these results are in appendix E.)

Using 30-ton lifters, one FCS battalion can be deployed 250 nautical miles in one 8-hour period of darkness, or 500 nautical miles in slightly more than 14 hours under the assumptions in the above table. A brigade would take over a day and nearly two days, respectively.

The Composite Lifter Objective is a Daunting Challenge

Payload	≥ 30 T	Landing zone: VTOL or 1,000', 50' barrier
Speed	≥ 300 kts	Safety, reliability, survivability ≥ .95
Operating Radius	250–500 nmi	Integral Air Defense System
Cargo Space	Per FCS vehicles	Turn around time at enclave and ISB ≤ 25 min
Transit Alt.	≥ 15,000 ft	Battalion set = 40 airlifters operational

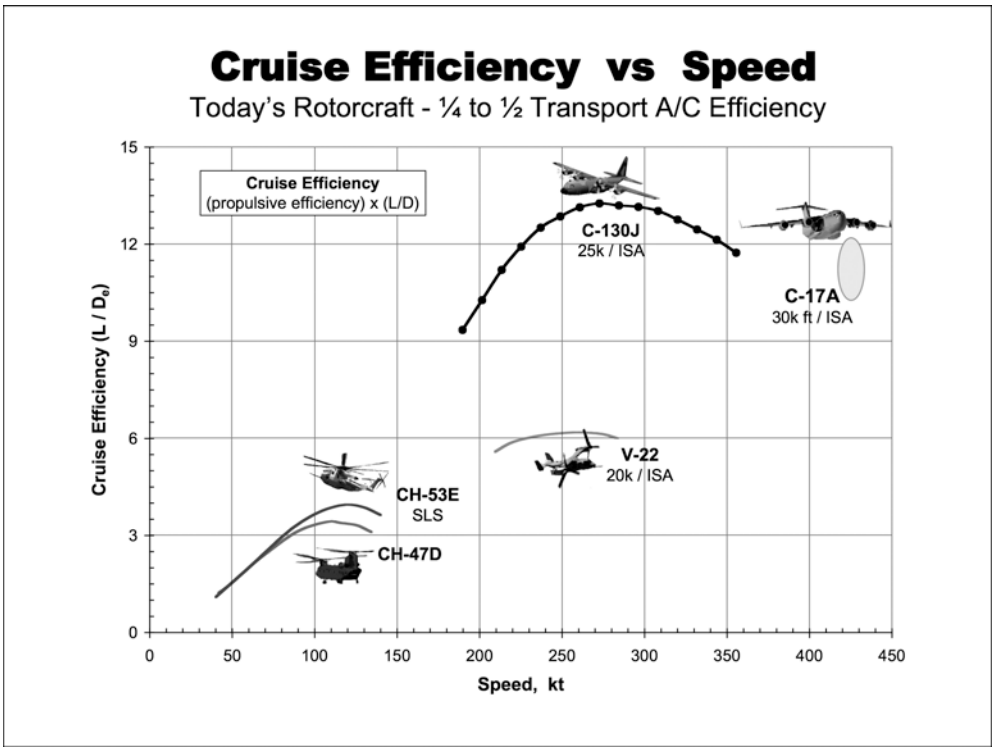
The composite specification for a tactical heavy lifter, based on the considerations in this objectives section is as follows:

- Payload: ≥ 30 tons
- Speed: ≥ 300 knots
- Operating radius: 250–500 nautical miles with no refueling at enclave
- Cargo space: consistent with FCS vehicles
- Transit altitude: ≥ 15,000 feet
- Battalion airlift vehicle complement: 40 operational
- Sea base compatible
- Capable of vertical takeoff and land or, failing that, able to use a 1,000 foot runway with 50 foot obstacle at the end
- Land and take off at 4,000 feet altitude, 95º F

- Significantly faster turn-around times—load/offload cargo—than currently realized in military practice
- Safety, reliability and survivability compatible with needs of battalion or brigade deployment operational risk management and assurance
- Integral, automated defense systems capable of protecting against infrared, radar-guided, and image-guided light air defense systems.
- Other specifics as set forth in Curran memo of 17 April, 2006.

These objectives are severely challenging. The following two chapters lay out considerations for fixed-wing and rotary-wing heavy lifters and ship- and sea-basing considerations associated with these objectives.

Chapter 4. Heavy-Lift Aircraft Suitable for Mounted Aerial Maneuver



Range and payload are the most critical factors in designing a heavy lifter for mounted aerial maneuver. Many major issues affecting the choice of candidate aircraft all hearken back to these two specifications. This chapter focuses on a number of factors that determine range and payload: aircraft type and engine fuel consumption and thrust. It also considers the development process for new heavy lifters to support mounted aerial maneuver.

Candidate Aircraft Types

The range of an aircraft is proportional to its lift-to-drag ratio, as determined by Breguet's equation.[18] The lift to drag ratio in turn depends on the aerodynamics of the aircraft. The figure above shows cruise efficiencies (proportional to lift-to-drag ratio) for various basic types of cargo aircraft.[19] These aircraft include fixed-wing aircraft such as the C-130J and the C-17A, located in the top right hand area of the graph. Rotary-wing aircraft, such as the CH-53E, V-22, and CH-47D, are located in the lower left quadrant.

The task force considered a broad range of aircraft concepts in its search for candidate aircraft to support the heavy lift requirements of the mounted aerial maneuver mission. The data in the above figure enables one to determine types of aircraft best suited to mounted aerial maneuver lift to a first order.

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18. Breguet's Range Equation:

$$RANGE = \left(\frac{\eta}{c}\right) \times \left(\frac{L}{D}\right) \times \ln\left(\frac{W_{takeoff}}{W_{takeoff} - W_{fuel}}\right)$$

where: $\left(\frac{L}{D}\right)$ is Lift-to Drag Ratio;

$W_{takeoff}$ is the takeoff weight of the airplane (airframe, engines, payload, fuel)

W_{fuel} is the weight of the fuel, and

$\left(\frac{\eta}{c}\right)$ is proportional to propulsion efficiency

19. Briefing to the task force by Michael Scully, March 21, 2006.

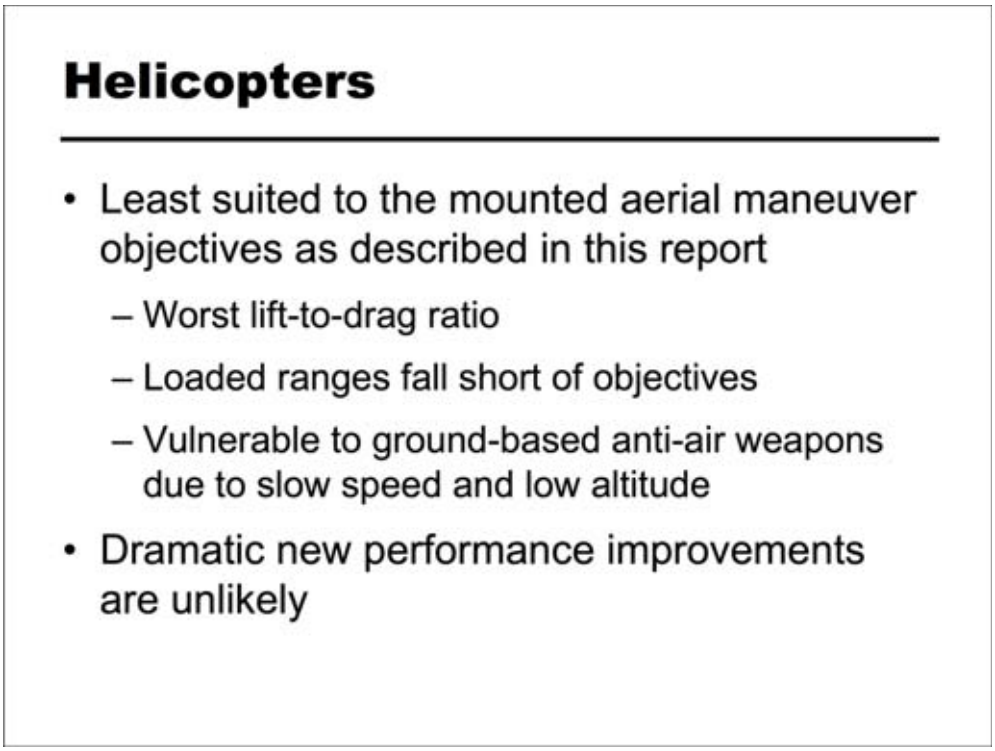
Summary Characteristics of Candidate Heavy-Lift Aircraft

Parameter	Units	CH-53K	C-14	AMC-X	Tilt Rotor
Length	feet	73	131	94–140	136
Width	feet	158	140	157–160	209
Height	feet	23	45.5	15–36	37
Max gross weight	tons	42	140	125–140	137
Efficient transit speed	knots	170	400	360–460	300
Efficient transit altitude	feet (000s)	3	35	0–40	25
Flyaway cost	dollars	43M	123M	TBD	190M
Operations and maintenance costs	$ per flight hour (000s)	20	13.7	TBD	20

The typical lift-to-drag ratio for helicopters, tilt-rotor, and fixed-wing aircraft are 4½, 9, and 18 respectively. These ratios drive the characteristics displayed in the above table for the candidate aircraft considered. These systems include: 1) CH-53K, the state of the art U.S. heavy helicopter in development; 2) C-14, a 1970s prototype fixed-wing, tactical lift aircraft based on Vietnam experience; 3) AMC-X, an Air Force concept successor for the C-130, and 4) tilt-rotor, an extension of the V-22 concept

Except for the CH-53K, none of these airplane concepts are programs of record for any of the military services. The data in this table represent the task force's best estimates, supported by discussions with seasoned aircraft designers in the Army and Air Force.[20]

20. The task force is deeply indebted to Dr. Mike Scully of the Army AMRDEC (RDECOM) and Mr. Barth Schenk of the Air Force Research Laboratory, Air Vehicles Directorate and their colleagues for their instructive briefings, patience with seemingly unending questions, and useful discussions on aircraft design considerations and processes.



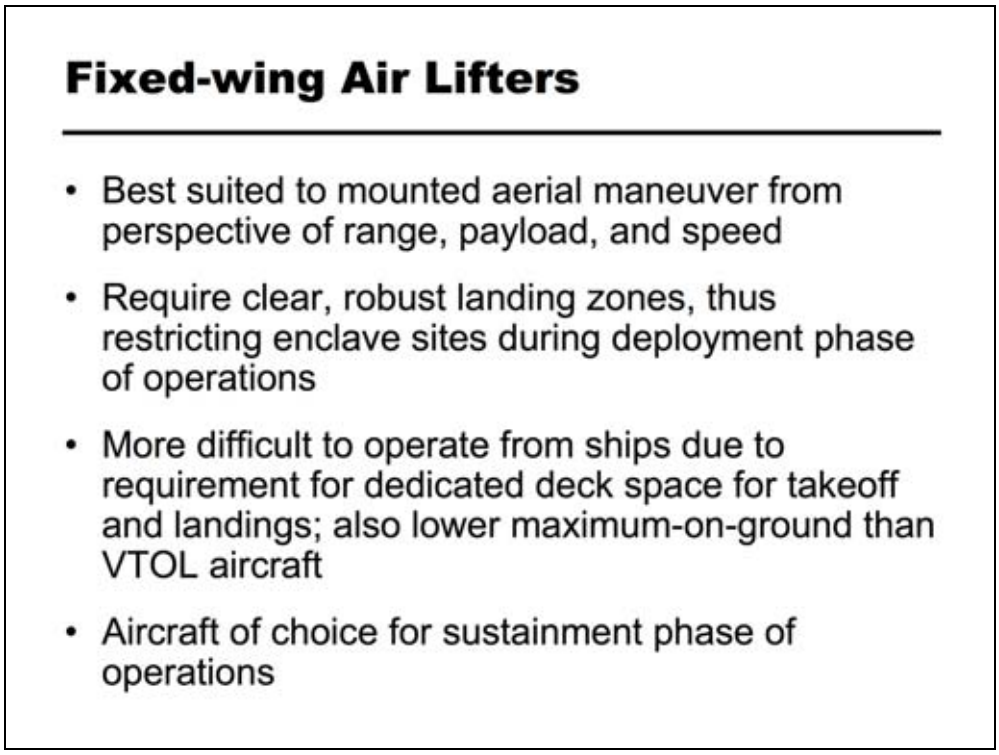
Helicopters

Helicopters are least suited to mounted aerial maneuver objectives as spelled out in the previous chapter of this report. Because of their long, narrow rotor-blades they have the worst lift-to-drag ratio of the type of aircraft considered by the task force in its baseline study, hence have the shortest ranges. The loaded ranges of existing helicopters are far short of the 250–500 nautical mile radius called for. Further, helicopter maximum speeds are slow (less than 190 knots). The fact that most power is spent lifting the aircraft and its payload further compromises helicopter cruise efficiency and greatly reduces the payload fraction of helicopter takeoff weight . Additionally, helicopters fly at low altitudes; this characteristic, coupled with their slow speed, makes them highly vulnerable to simple, inexpensive ground-based anti-air weapons.

The range and payload performance of the CH-53K (110 nautical mile range with 13.5 ton payload), the latest U.S. heavy lift helicopter,

and of the Russian MI-26 (300 nautical miles with 22 ton payload), the world's largest helicopter, both fall well short of the needs stated for mounted aerial maneuver. Although U.S. rotary-wing aircraft research has been moribund during the past several decades, dramatic new performance improvements are extremely unlikely. Considerations, based on first principles of physics, eliminate pure rotary-wing aircraft from this application.

The task force concludes that helicopters are not suitable for mounted aerial maneuver as defined in Chapter 3 of this report.



Fixed-Wing Aircraft

As indicated in the opening figure of this chapter, fixed-wing aircraft are best suited to mounted aerial maneuver missions from the perspective of range, payload, and speed. Further, their ability to routinely operate at high altitudes renders them less vulnerable to simple ground-based weapons. Since lift from these aircraft is provided by fixed wings as a consequence of the forward motion of the plane, fixed-wing aircraft are inherently able to lift heavier payloads at higher speeds than are pure rotary-wing aircraft.

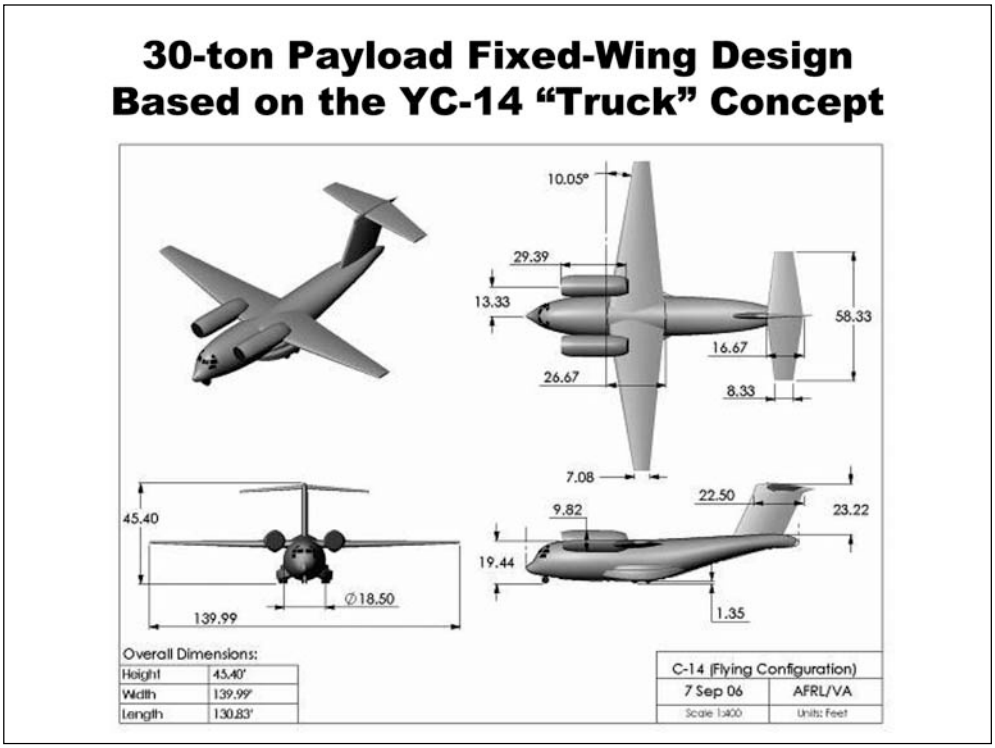
The problems with fixed-wing air lifters are at the ISB, ship, and enclave. Fixed-wing heavy-lift aircraft lack vertical takeoff capability. They require cleared, robust landing zones; are more difficult to operate from ships; and take up more ground space than VTOL aircraft. Long runways suitable for heavy aircraft are expensive, rare, and take several days to prepare. A commander's ability to choose the best enclave site for a specific operation is severely constrained if restricted to pre-existing landing zones suitable even for heavy-lift aircraft with short

take off and landing (STOL) capability. Super STOL, fixed-wing aircraft utilizing features that enhance lift (e.g., the Coanda effect) can reduce takeoff and landing distances.[21] But heavy STOL aircraft inflict substantial wear and tear on runway surfaces and would need novel under-carriages to survive repeated landings and takeoffs with heavy loads on primitive landing fields.

The fixed-wing enclave issues, described above, apply mainly to the deployment phase of mounted aerial maneuver. Following deployment, after sufficient time to prepare a suitable landing zone, fixed-wing heavy lifters are the aircraft of choice to support sustained operations from efficiency, cost, payload, and survivability standpoints.

Fixed-wing aircraft, operating from ships, require dedicated deck space for landings and takeoff. Since heavy-lift aircraft are generally too large to fit below decks, the maximum on ground of fixed-wing heavy lifters at sea is extremely small, severely restricting the sortie rate.

21. The Coanda effect entails the use of engine exhaust flowing over upper wing surfaces to enhance lift during aircraft takeoff (see .wikipedia.org/wiki/Coanda_effect).

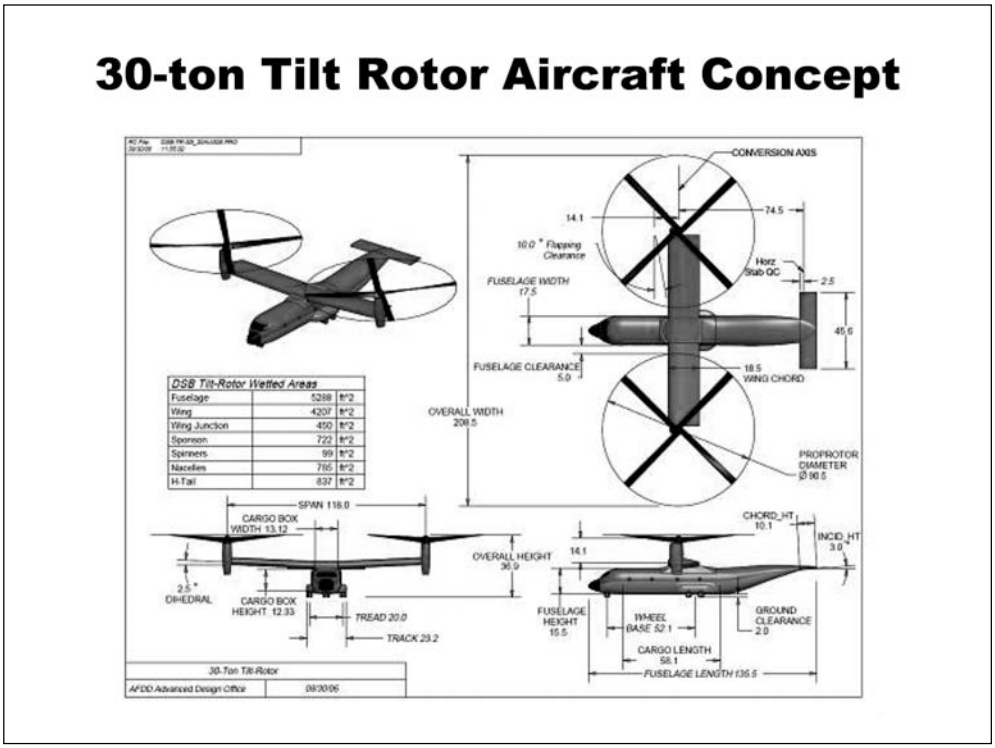


Summary characteristics of two fixed-wing aircraft, the C-14 and the AMC-X, were previously cited in this chapter. The C-14 data are based on experience with the 1970s Advanced Medium STOL Transport development program addressing Army tactical airlift needs learned "on the job" in Vietnam. Two prototypes were developed—the YC-14 and YC-15—but the tactical need collapsed at the end of the Vietnam War. The program then, with commendable agility, morphed into the C-17 strategic lifter development.

"AMC-X" data refer to an investigatory effort now underway to define a follow-on aircraft for the C-130. The AMC-X specifications are yet to be determined, accounting for the uncertainty in parameters previously cited. The specifications are flexible at this time, as the Air Force seeks to meet needs of special operations forces as well as that of tactical and inter-theater strategic airlift. Since the C-14 requirements are directed at performing tactical airlift functions—a straightforward "truck" that meets mounted aerial maneuver needs rather than a multi-use vehicle, the task force focused on it to typify fixed-wing heavy-lifter potential.

A C-14 class aircraft could use engines already developed for commercial applications that have high thrust, light weight, excellent specific fuel consumption, and high reliability.

The figure above illustrates the C-14 conceptual aircraft.



Hybrid Air Lifters

Hybrid aircraft—those having vertical takeoff and landing capability, but which fly like conventional aircraft when cruising, like the V-22 Osprey—offer compromises between helicopter and fixed-wing capabilities.[22] The task force considered a broad range of hybrid aircraft configurations (tilt-rotors, tilt-wings, and proprietary VTOL aircraft concepts; see Appendix F). It used the tilt-rotor configuration (similar in concept to the V-22) as its baseline study vehicle.

Tilt-rotor aircraft characteristics lie between those of helicopters and fixed-wing lifters. While not as efficient as the C-14 or AMC-X models, a 30-ton payload tilt-rotor aircraft can have sufficient payload and range capabilities to meet forecasted mounted aerial maneuver objectives.

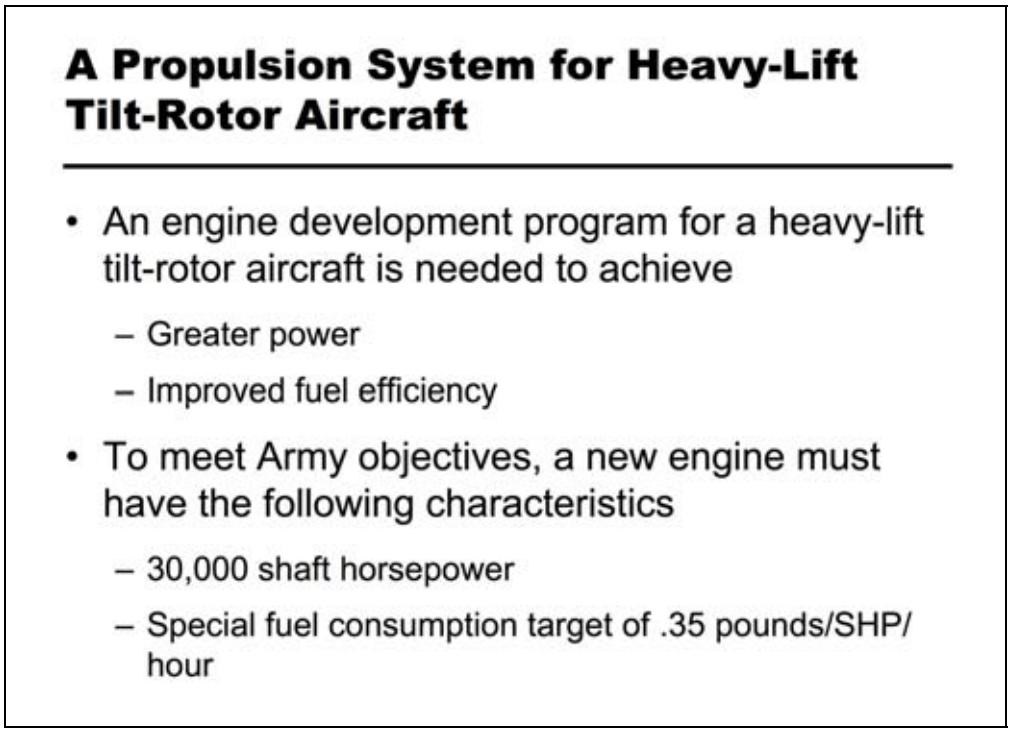
22. The term "hybrid," not an industry standard term, was adopted by the task force to denote aircraft designs that combine VTOL capabilities with fixed-wing lift in cruise. The task force chose not to use the alternate term "compound" because it applies to a subset of hybrid concept designs.

Additionally, tilt-rotor lifters can have VTOL or extremely short-field takeoff capability and do not damage landing zones to the same extent as fixed-wing vehicles will. While tilt-rotor heavy lifters are very large (hence have limited shipboard maximum on ground) and can develop strong downdrafts (a hazard at the enclave and onboard ship), they do not require the deck runway space needed by fixed-wing vehicles. Preliminary operational analyses indicate that ship-based heavy lift tilt-rotor aircraft can support the deployment needs of FCS battalions.

Development of a tilt-rotor heavy-lift aircraft suitable for mounted aerial maneuver requires substantial research, development, engineering, and testing. Such a vehicle will require a new engine capable of thrust beyond what is now available in rotary-wing aircraft configurations. (A discussion of tilt-rotor engines follows.) Additionally, the specific fuel consumption of this new engine will have to be impressive to achieve the 250–500 nautical miles operational radius without refueling.

A tilt-rotor hybrid aircraft concept is shown in the slide above.

Any decision to pursue a hybrid heavy lifter must incorporate a more detailed investigation to determine the configuration best suited to mounted aerial maneuver. Research and development support for rotary and hybrid aircraft has been largely ignored for several decades. Results of studies of aircraft configurations, flight characteristics, and power trains will be critical to engineer successful hybrid heavy-lift aircraft to meet mounted aerial maneuver needs.



A Propulsion System for Heavy-Lift Tilt-Rotor Aircraft

In the end, all new aircraft are designed around engines. The preliminary estimate for a twin-engine, tilt-rotor aircraft with a 30-ton payload and 250–500 nautical mile range, is that each engine must produce 30,000 shaft horsepower (SHP). By using advanced structures technology and achieving exceptional fuel efficiency, it may be possible to reduce the power requirement somewhat, but 30,000 SHP is a reasonable working objective.

Industry currently makes a broad range of turbo shaft engines, including those used in ships where the volume and horsepower per weight ratio is not an important constraint. These engines range from 5,000 to more than 45,000 shaft horsepower. Aircraft turbo shaft engines are specifically designed and optimized to attain aircraft performance, chiefly fuel efficiency and improved power-to-weight ratios. There is currently no modern, high-performance aviation turbo shaft above 12,000 SHP.

Turboprops (like those used on regional aircraft) are available up to 3,000–3,500 SHP. Military turbo shaft engines, like those used in military helicopters, run from around 1,000 SHP, through the 1,700 SHP range of the H-60 class, up to the 6,000 SHP range of the V-22. Commercial turbo shaft engines are available in the hundreds of horsepower ranges for small commercial helicopters.

Turbine engines develop raw power by increasing airflow (and fuel) and/or raising turbine temperature. Turbofan engines develop as much as 120,000+ pounds of thrust. Improved fuel usage and power/weight is related to the "pressure ratio" of the engine, whether turbofan or turbo shaft. Should a high performance 12,000+ SHP engine be required, a modern high-pressure ratio core development would be required.

The current state of the art for turbo shaft engines is around 7,000 SHP. V-22 engines produce about 6,000 SHP and GE has contracted to provide 7,500 SHP engines for the CH-53K. European efforts to build the A400 plan a 10,000 to 11,000 SHP engine, but it is still being developed.[23]

Sizing estimates for heavy lift indicate a need for an engine in the 15,000 to 18,000 SHP range for a 20-ton lifter and nearly 30,000 SHP for a 30-ton lifter.

The least-cost approach to producing a new turbo shaft engine is to blend an existing turbofan "core" (thereby avoiding new core design and qualification) with a gearbox/shaft making adjustments to optimize the match and performance. However, studies have shown that the resulting fuel load for this type of derivative engine results in a lower performing and more expensive aircraft system.

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23. For reference, the Russian MI-26 heavy lift helicopter is powered by two 11,000 SHP turbo shaft engines. It has been operational since 1980. The European A-400 transport aircraft, now in development, will be powered by four turbo shaft engines in the 11,000 SHP class. The new CH-53K helicopter now being developed for the Marines Corps will have three 7,500 SHP class engines.

Current turbo shaft pressure ratios are achieved using a core based on a combination of axial and centrifugal flow compressors. Larger turbofan engines are all-axial flow. To achieve goals such as the heavy lifter range, it is likely that an axi-centrifugal core would be needed. Developing a turbo shaft with excellent pressure ratios may require a new core design rather than adaptation of an existing turbofan core.

One estimate of the "breakpoint" between axi-centrifugal and axial flow engines is between 10,000 and 20,000 SHP, so it is possible that there is a technology breakpoint to be exploited for smaller heavy lifters.

To develop a high performance, large turbo shaft engine, technology maturation and demonstration will be needed via engine science and technology programs to develop the configuration that would provide projected improvements in fuel consumption, SHP/weight, and cost. A high performing, new-design VTOL aircraft for heavy-lift-sized payloads would achieve significant payoff from a new, advanced engine.

Propulsion systems figure into Breguet's range equation. Besides the ratio of lift-to-drag, range also depends on propulsion efficiency ( ) which is directly proportional to engine specific fuel consumption (SFC). The fuel efficiency of the turbo shaft engines in a tilt-rotor aircraft is the major factor in minimizing its takeoff gross weight and in minimizing operating costs. In designing an aircraft capable of transporting a 30-ton payload 250–500 nautical miles, engine fuel efficiency is the primary factor determining the vehicle weight and, therefore, the engine power required. Meeting a very aggressive fuel efficiency objective will require development of a new turbo shaft engine.

SFC is the metric by which engine fuel efficiency is measured and specified. SFC is defined as the number of pounds of fuel consumed per hour per pound of thrust. Lower SFC values mean higher engine fuel efficiency. Large improvements in engine SFC have been made over the past three decades, with the primary driver being improved fuel efficiency for commercial jet liners.

Making major improvements in SFC, as compared with that of current turbo shaft engines, must be a major objective of any engine development program for heavy-lift VTOL aircraft. Put simply, the higher the SFC, the more fuel required for a given mission at the expense of payload.

During a four-hour mission, a 30-ton lifter with engines with a .4 pound/SHP/hour could burn as much as 20 tons of fuel. At takeoff, this fuel weighs 66 percent of the maximum payload weight. One way to increase the payload fraction is to liftoff with tanks 25 percent full, allowing up to 15 tons additional payload weight, refuel in flight immediately following takeoff, and continue with the rest of the mission.

The task force estimated that an engine development program for a 30-ton tilt-rotor lifter should have as its objective an SFC of .35 pounds/SHP/hour. In any event, to be acceptable, the SFC should be no more than .40.[24]

24. By comparison, the Liberty AE10713 engine, the 6,000-SHP engine used in the V-22 Osprey, has an SFC of .42 lb/shp/hr.

Estimated Heavy Lifter Program Cost
(in billions of dollars)

Aircraft		Fixed Cost				Production Cost	
Concept	Payload	R&D	New Engine Dev.	Prototype (2)	Total	100th A/C	2 Bn Sets + Training
Fixed-Wing	30 T	$.5	0	$1.5	$2.0	$.123	$18.5 (150 A/C)
	40 T	$.6	0	$1.8	$2.4	$.160	$19.2
Rotary-Wing	20 T	$.5	$1	$2	$3.5	$.150	$36 (240 A/C)
	30 T	$.75	$1.5	$2.5	$4.75	$.190	$28.5 (150 A/C)

Cost Estimates

Estimating the cost of the tactical heavy lift aircraft to support the Army's mounted aerial maneuver plans is at best an approximate effort. Requirements for both fixed and rotary-wing concepts are, at this time, "flexible." The two existing studies (AMC-X and JHL) directed at meeting mounted aerial maneuver needs lack firm goals; needless to say, neither is a program of record for any service.

In the fixed-wing case, the AMC-X configuration is undecided, as well as the need for expensive features such as low-observability and high speed. The task force has had to base its back-of-the-envelope cost estimates on experience from the YC-14 prototype of the 1970s and the V-22 from the 1990s. Both fixed- and rotary-wing heavy-lift aircraft will require serious research and development investments.

For the fixed-wing concept, a deep technical base and major components, such as engines, already exist. Most of the research and development effort should be directed to STOL technology (basically a

new wing configuration) and development of a novel undercarriage on top of which a heavily loaded aircraft can land and take off from a short, primitive field. Cost to build two prototype fixed-wing lifters will be approximately $1.5 billion.

The rotary-wing heavy-lift concept will demand a much more serious effort. Since helicopters are not viable candidates, much effort is required to understand and characterize hybrid designs. Even a tilt-rotor heavy lifter, a scaled-up version of the V-22, requires substantial research to understand its stability and flight characteristics. For the rotary-wing lifter, the engine is the pacing element. A new engine must be developed for the rotary-wing airplane as no existing engines have sufficient power, power/weight, and fuel efficiency performance suitable for a 30-ton lifter. Its estimated development cost is $1 billion. The approximate cost for two prototype aircraft, using the new engine, is $2–2.5 billion.

Estimated program costs for options considered in this study are shown in the table above. Not included are costs to improve logistics flow and defensive systems.

Assuming the DOD elects to purchase two battalion sets of 30-ton lifters (50 each for operations and 15 each for downtime, such as for overhaul or upgrade) and one training squadron (20), the total aircraft acquired is 150. This fleet allows simultaneous deployment of two battalions. Following initial deployment, most aircraft can be redirected to additional movements.

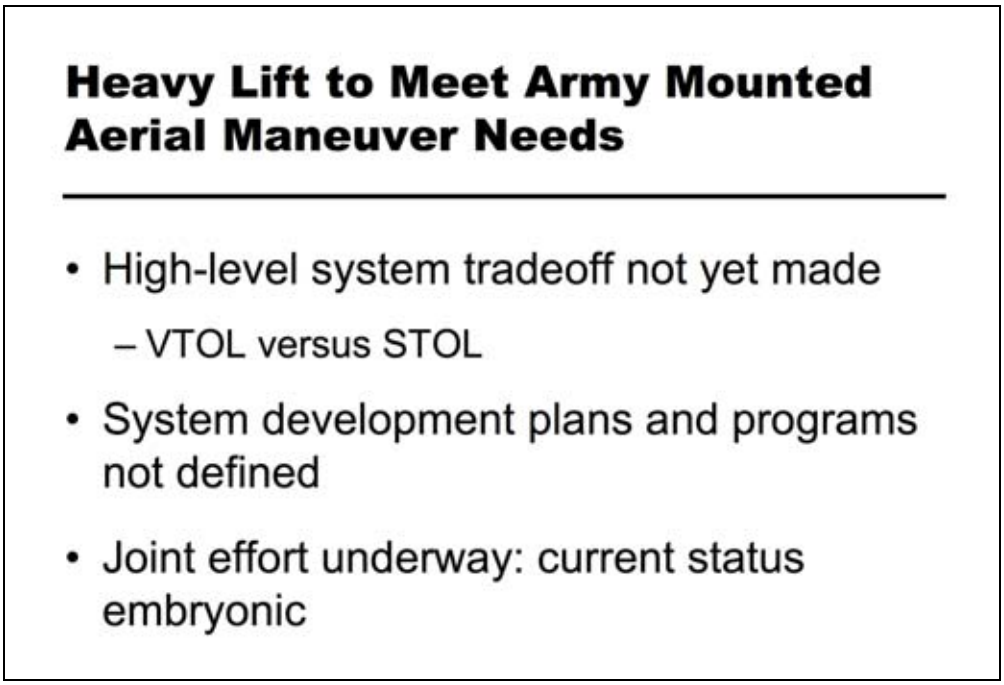
The Heavy Lift Aircraft Bottom Line

After completing its baseline analysis, the task force concluded that the cost, technical risk, and time required to research, develop, prototype, and build a 30-ton VTOL lifter (especially engines with long science and technology development time) is inconsistent with the Army's need to conduct mounted aerial maneuver in the near future. The combination of payload and range objectives poses a large technology leap. The task force then went back to the original specifications to determine alternative heavy lifter specifications consistent with the mounted aerial maneuver concept.

A more achievable, near-term goal for hybrid lifters, in terms of payload and range, is in the range of 20 tons and a mission radius of 250 nautical miles without refueling. An aircraft of this type would still require development of a new engine and extensive research into its flight and stability characteristics, but presents a far less daunting technical challenge.

The task force then revisited the usefulness of a 20-ton lifter in support of mounted aerial maneuver and observed that a VTOL aircraft with a nominal payload of 20 tons (that is a 20-ton payload takeoff capability) can ferry heavier loads if it takes off with reduced fuel, then immediately refuels en route. The aircraft can then complete its mission without further refueling.

This less costly, less risky alternative is discussed in Chapter 6.

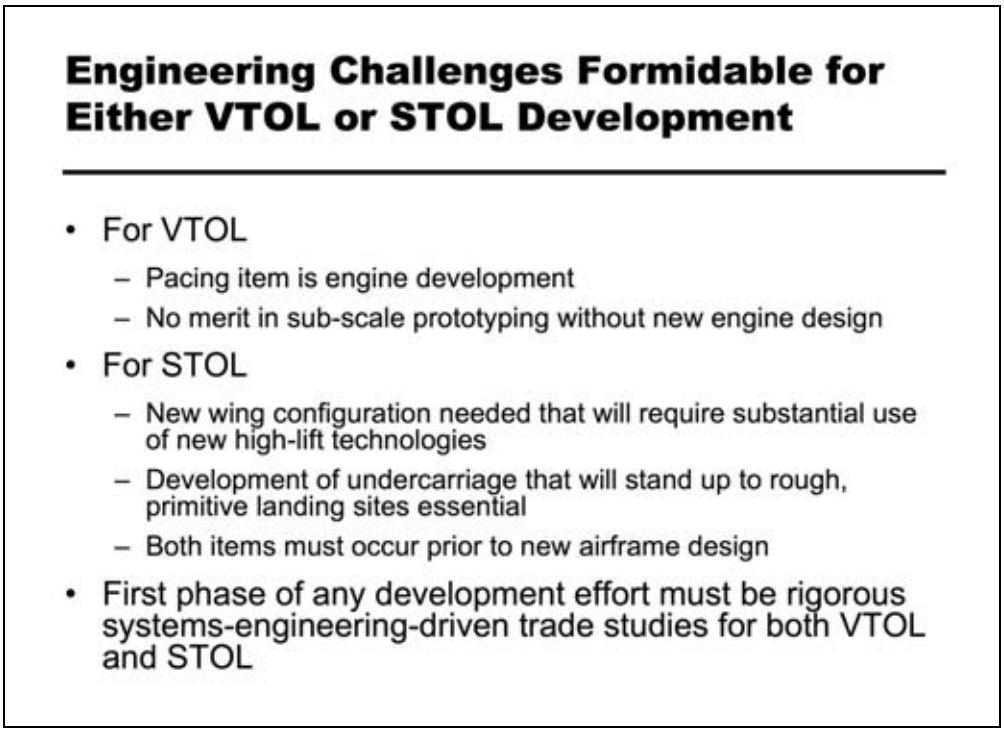


Developing Integrated Mounted Aerial Maneuver Enabling Systems

There are now no firm plans or defined system development programs for heavy lift VTOL or STOL aircraft to enable mounted aerial maneuver as defined by the Army. It is not clear whether VTOL or STOL aircraft is the best system to meet Army needs; essential high level trade studies have yet to be performed. It is clear, however, that if a VTOL aircraft is selected, a new turbo shaft engine must be developed, and if a STOL lifter is chosen, a radically different undercarriage must be devised to enable landings and takeoffs from very small, unimproved sites. Put simply, development of heavy-lift aircraft to meet the Army's stated requirements is but a vision.

Regardless of the lift and payload, the task force has identified some high level trade studies that must be performed during lifter development, and a set of system development options for both VTOL and STOL aircraft. In view of the lack of quantitative technical and cost data, and the tangible operational impact of needing suitable landing zones for fixed-wing aircraft, the task force was not able to make a sound

assessment as to whether even VTOL or STOL aircraft are the best choices to meet mounted aerial maneuver needs. A joint, rigorous front-end systems engineering effort is necessary to develop conclusive answers to the major questions. This task will be complex and difficult; performing it in the near future is of the utmost importance. Whatever decision is ultimately made, heavy lifter development will be challenging.



Developing a brand new VTOL heavy-lift aircraft will be a formidable task. The pacing item will be developing the required new turbo shaft engine. Since the performance of the aircraft depends so strongly on the engine's characteristics, there is no merit in designing and testing a sub-scale prototype VTOL aircraft.

Developing a STOL aircraft to meet mounted aerial maneuver needs will also entail very demanding engineering challenges. Landing and taking off from short, narrow, unimproved sites will be the most difficult requirement to meet. The task force anticipates that each competing prime contractor will be able to competitively select an existing jet engine. However the lifting surfaces of the STOL aircraft will require substantial use of new high-lift technologies. Devising, building, and ground-testing a full-scale, acceptably low-risk undercarriage for use on rough, primitive landing zones is also essential. Each of these developmental tasks must be completed up front; developing a new airframe prior to the completion of these preliminary steps would be unproductive.

The first phase of a realistic program, independent of acquisition strategy, is a rigorous systems-engineering-driven trade study for both VTOL and STOL aircraft efforts leading to two mutually consistent documents for each: a systems requirements document and a high-level system design specification.

This first phase will force a series of critical trade studies and important decisions that must be made to ensure development of an internally consistent set of system components. Near-term, high-level trade studies should include, among others:

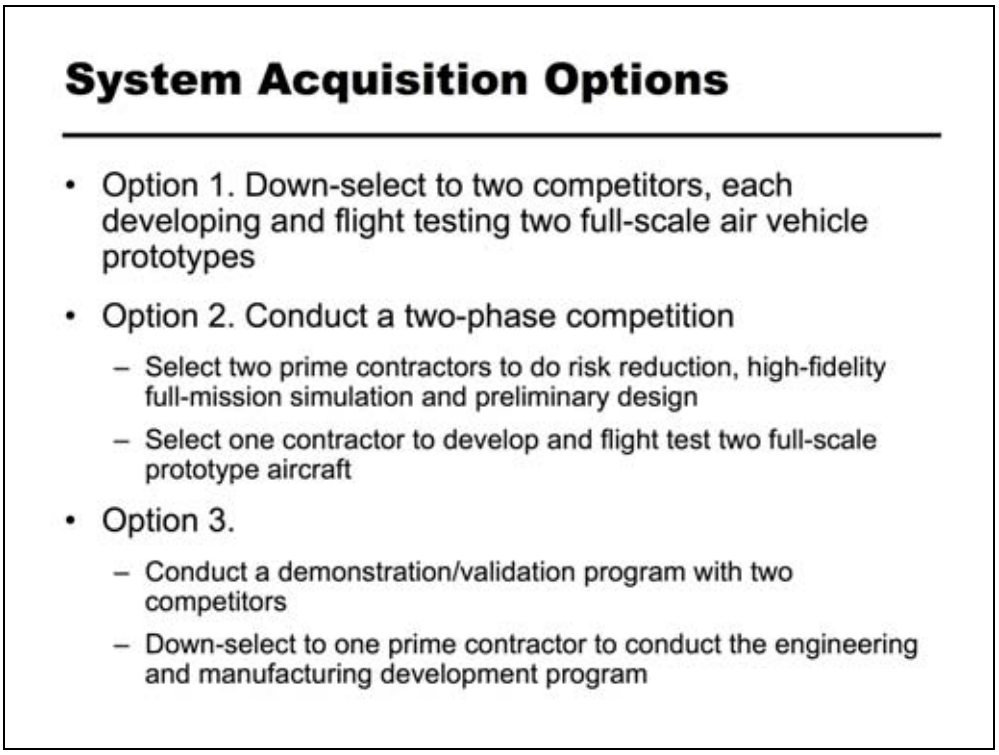
For a STOL heavy-lifter

- takeoff gross weight and cost, and landing and takeoff distances versus combat radius (800, 1000, and 1200 nautical miles)
- takeoff gross weight and cost, and landing and takeoff distances versus payload (20, 30, 40 tons)

For a VTOL heavy lifter

- takeoff gross weight versus operating radius (250, 350, and 500 nautical miles)
- mission fuel weight and takeoff gross weight versus engine special fuel consumption (0.30, 0.35, 0.40 pounds/SHP/hour)
- in-flight refueling versus takeoff gross weight and cost (both acquisition and operating costs)

The results of these high-level trade studies for the VTOL aircraft must be sufficient to allow specification of any new turbo shaft engine required for the tilt-rotor aircraft. The trade studies must be completed before the system acquisition options can be productively implemented and the VTOL engine prime contractor selected.



Once the trade studies are concluded, systems acquisition options can be considered. The task force considered three options.

Option 1: Down select to two competitors, each developing and flight testing two full-scale air vehicle prototypes. This option would conform to the acquisition approach used for the Advanced Tactical Fighter (ATF) and the Joint Strike Fighter programs. Such an approach would minimize government risk but would be costly, perhaps unaffordable, with program costs on the order of $4 to $5 billion.

Option 2: Conduct a two-phase competition. Down select to two prime contractors to do risk reduction, high-fidelity full-mission simulation, and preliminary design. Then select one contractor to develop and flight test two full-scale prototype aircraft.

This approach is more affordable (40 percent less expensive) than option 1, on the order of $2.4 to $3 billion. From a government perspective, risk would be somewhat greater than option 1, but still acceptable.

Option 3: Conduct a demonstration and validation program with two competitors doing system design, high-fidelity full-mission simulation, and risk reduction based primarily on extensive ground testing. Following demonstration and validation, select one of the two prime contractors to conduct the engineering and manufacturing development program.

The demonstration and validation program would be conducted concurrent with the development of the new turbo shaft engine. This option is the most affordable of the three, however from the government's perspective it would be substantially riskier than the other two options. Cost would be of the order of $1.5 to $2 billion.

Option 2 was the original acquisition approach planned for the ATF program in 1985. Following publication of the Packard Commission report, which strongly recommended prototyping, the Air Force ATF strategy shifted to option 1.

Nevertheless, if a mounted aerial maneuver aircraft is procured, the task force recommends Option 2 as the best strategy for heavy lifter development. It offers the best balance between cost and risk.

A final note on the heavy-lift vertical and SSTOL lifters is this: there does not appear to be a clear path for the DOD to evaluate the potential, cost, and utility of the two concepts relative to each other. The Department was faced with a similar situation in the early 1950s and 1960s when the Army chose to pursue organic air vehicles to enhance its air mobility capability. The helicopter industry was similarly awaiting direction from the military as to the requirements for the helicopters which would be used to flesh out the air mobility concepts. The Air Force was concerned with the Army's procurement of Mohawk aircraft because of their strike potential and the Caribou transporter which appeared to be a competitor to the Air Force's C-130 fleet.

These challenges led then Secretary of Defense McNamara to direct the Army in 1962 to re-examine its aviation requirements with a view to the potential changes in land warfare mobility. This examination led in turn to the establishment of the U.S. Army Tactical Mobility Requirements Board under the chairmanship of Lieutenant General

Hamilton Howze, commanding general of the Strategic Army Corps (often referred to as the "Howze Board"). This board and the 3,200 military personnel supporting it executed a series of war games and equipment and troop testing over several years that included Air Force participation. The results of these activities became the foundation of the Army's air mobility concept over the subsequent four decades. The DOD is now in a similar position to re-evaluate what heavy-lift vertical and SSTOL air vehicles offer to the joint warfighting commanders for the next several decades.

Chapter 5. Mounted Aerial Maneuver from the Sea

Sea basing replaces or augments the fixed, in-theater airports and seaports on which past military operations have focused and depended, with a maneuverable facility at sea—a mobile base of operations, command center, logistics node, and transportation hub. A commander can place a sea base where and when he chooses to exploit enemy weaknesses and employ the element of surprise, confusing enemy defensive preparations. A sea base can be a center for reconstitution and redeployment of forces in succeeding stages of complex operations.

This chapter discusses the pertinent characteristics of ship types that would be required to support mounted aerial maneuver with vertical lifters from the sea.

The task force examined the option of landing very large hybrid aircraft on Navy and converted commercial ships. The rotor span of 30-ton tilt rotor was greater than the width of the flight deck for all ship types considered. If the rotor blades could be folded, deck storage constraints would be considerably eased. However, providing this option would subtract four tons of cargo lift capability and add some additional complexity to an already very heavy and complex aircraft. Because these aircraft have a height of about 35 feet, they could not be stowed in a hanger deck on ships currently in inventory.

The number of ships needed depends on the concept of operations and the number of “spots” per ship (and therefore, indirectly, the size of the ship). Based on weight and number of vehicles to be lifted, the task force calculated that 40 aircraft would be required to meet the goal of lifting one battalion to an enclave 250 miles away within one period of darkness (nominally: 800–1000 troops and 4000 tons in an 8 hour interval). Twenty five percent of the aircraft would have to be at the ships, 25 percent at the enclave, 25 percent going toward the enclave, and 25 percent returning from the enclave at any one time. These assumptions establish the number of landing spots needed on ships as 10—a number that can only be achieved realistically on two or more ships.

While operations can be accommodated with two ships, carrying the aircraft to the sea base would require 40 landing spots if the aircraft cannot fold, thus greatly increasing the number of required ships.

The task force asked Naval Sea Systems Command (NAVSEA) to perform a quick feasibility analysis for a ship concept that could operate tilt rotors capable of lifting 30 tons. Size and weight of these aircraft were provided to the ship designers, based on aircraft feasibility analyses by the Army's Research, Development and Engineering Command (RDECOM).

NAVSEA's first concept design effort resulted in a very large ship that could operate up to eight 30-ton-capable tilt rotors of the provided specifications. The ship would be 1,330 feet long and have a beam of 130 feet (206 feet at the flight deck level) with a displacement of nearly 80,000 tons. A 50,000 horsepower plant would provide for a range of 3,000 miles at 20 knots (or 36,000 miles if it uses on-board aviation fuel).

There is only one graving dock in the United States that can accommodate construction and maintenance of a ship of that size. It is at Northrop Grumman's Newport News shipyard, and is already dedicated to aircraft carrier construction. Therefore, using it for this rotor craft carrier would interfere with its long-planned use. NAVSEA recommends considering two options:

- building the ship in two sections and joining them after launch (still leaving a maintenance deck conundrum)
- building more, but smaller ships

The first option is feasible, though novel for naval ships. Construction of the smaller ship is possible in several U.S. shipyards. Having more ships offers more tactical flexibility, but results in more cost ("overhead" of more hulls and equipment to accomplish the mission).

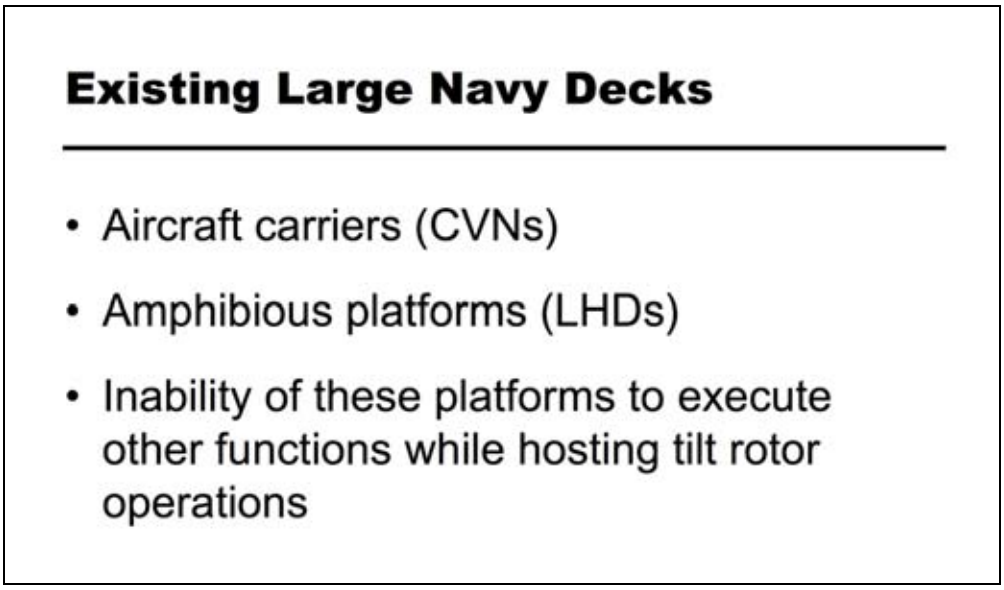
The NAVSEA ship would have no hangar facilities for the aircraft due to their height. Thus, large volume and (below the flight deck) deck area is available and could be put to good use for vehicle and container storage, and for arranging the many ramps and elevators required to support the operational load and offload scenarios. An additional risk is that the pace of operations would require a more than doubling of the aircraft fueling rate, as compared to current practice, from 250 to 540 gallons per minute.

Preliminary cost estimates indicate that the large ship (with eight spots) would cost about $4.5–5.5 billion. This ship would be built to Navy standards meeting all safety requirements and having all certifications for handling aircraft. Assuming 10 spots are required for the mission, at least two such ships would be required, resulting in a cost of about $10 billion, or roughly the entire recent historical Navy ship construction budget for any one year.

If a smaller version of the ship were to be built, with five spots per ship, two ships would be needed. But flexibility would be gained since the ships could be built at any one of several shipyards and the additional platforms yield greater tactical flexibility as well. However, it is unlikely that significant cost savings would be realized because the cost of "hanging steel" (and thus varying the size of the ship) is not a major cost driver. Rather, a key driver is the safety and certifications required; therefore, if the smaller ship were to meet the same standards as the big one, the cost differential might not be very great.

If the 30-ton tilt rotors can fold and the aft three spots on a five-spot ship were used for deck storage, each five-spot ship could support 13 folded aircraft and two spread tilt rotors for a total of 15 per ship.

Given three five-spot ships, a total of 45 30-ton capable tilt rotors could be carried. Some operational complexities arise with the transition from stowed decks to fully operational desks and vice-versa, but it is a potential way to transport enough 30-ton tilt rotors to move an FCS battalion in 8 hours.



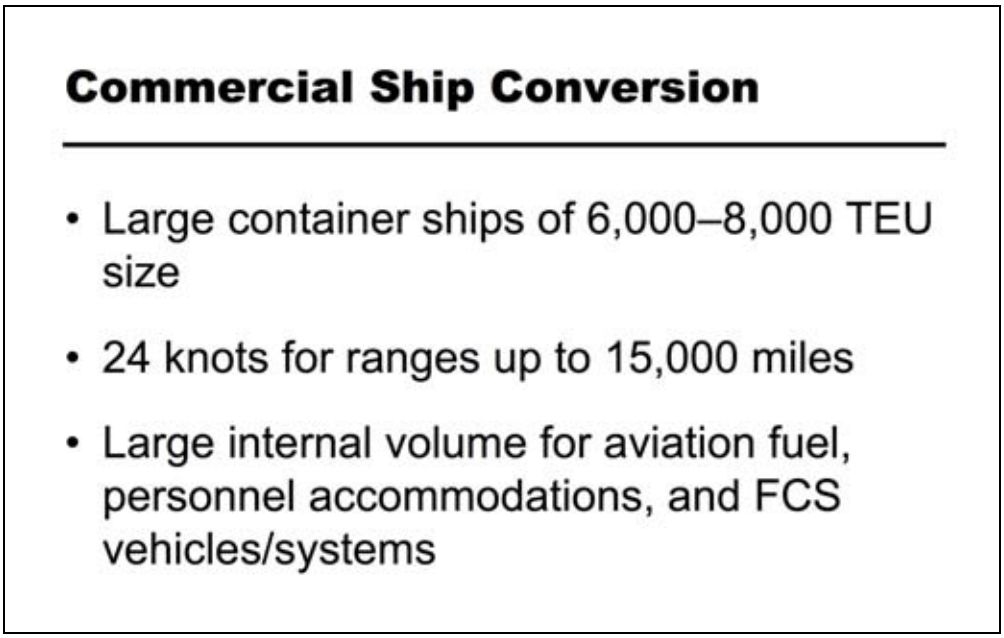
NAVSEA examined the option of supporting the rotor craft on existing carriers or amphibious platforms and concluded that, while possible, the solution is inefficient as a sole means of accomplishing the mission.

Considering only a static situation, a Nimitz-class carrier has enough deck space to accommodate six rotor craft and each LHD-class ship can accommodate three (if built or modified to the "reduced island" configuration). Clearances of 25 feet between aircraft (or between aircraft and structure) were assumed for these calculations and the task force noted that this maybe quite tight for operating such large aircraft at night.

To provide ten landing spots, as discussed above, two carriers or one carrier and two amphibious ships would be required for the duration of the mission, depriving the Navy of considerable war fighting capability, perhaps exactly when it is needed.

More important, as noted above, while landing the aircraft may be possible (deck strength will be discussed later), the aircraft carriers lack the ability to stow vehicles and cargo, transport soldiers, and load and offload the aircraft at a tempo commensurate with the concept of operations. The LHD-class ships can carry some vehicles and some personnel, but also lack the load and offload capabilities needed for the intense cargo flow scenario contemplated.

Modifications to these ships to meet the cargo transfer goals and operate as launching platforms for mounted aerial maneuver when needed, and still be able to perform their normal functions at all other times, will prove difficult technically. Major internal re-arrangements would be necessary—elevators and ramps to the decks would have to be installed and cargo handling equipment would have to be added.



Existing container ships carry up to 8,000 twenty-foot equivalent units (TEUs) at about 24 knots for distances as large as crossing the Pacific Ocean—a design point dictated by today's commercial needs. Newer designs reflect an increase in size to 12,000 TEUs while maintaining speed and range.

Converting commercial ships for various sea basing functions has been considered in previous studies by the DSB and the Army Science Board. One commercial operator of container shipping provided a briefing that outlined the option of converting a container ship to an "air-capable" ship for sea basing purposes.

The ship is a conversion of a 6,600 TEU commercial vessel. Its length is 1,138 feet; it has a beam of 140 feet; and, at a speed of 24 knots, has a range of 15,000 miles. This ship could provide up to 5 landing spots for the large rotorcraft under consideration. The main characteristic of the ship would be the new, specially designed deck, which would permit aircraft operations. Preliminary estimates indicate that the ship can carry up to 1,000,000 gallons of fuel, can house 1,000 troops, and can provide enough space for the vehicles and container cargo of a battalion. (Mission needs are estimated at 400,000 gallons for 40 aircraft operating 8 hours; 885 troops per FCS battalion; 4,000 tons

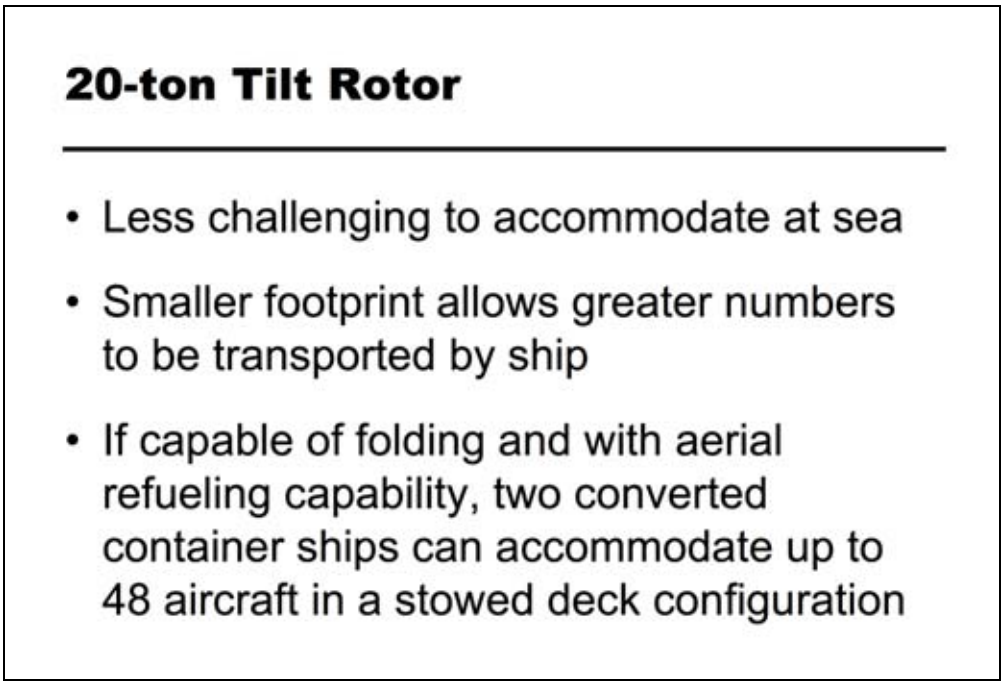
of materiel for initial deployment; and about 100–150 tons per day for sustainment). Cargo-handling and loading and offloading requirements were not explored in detail, but there appears to be enough space to accommodate ramps and cargo-handling gear.

That ship conversion was estimated to take about one to one and a half years and cost about $500–600 million. It is a tempting option because, for its apparent modest cost, it provides an immediate capability and a test bed for innovative new operational ideas.

Additional considerations include the following:

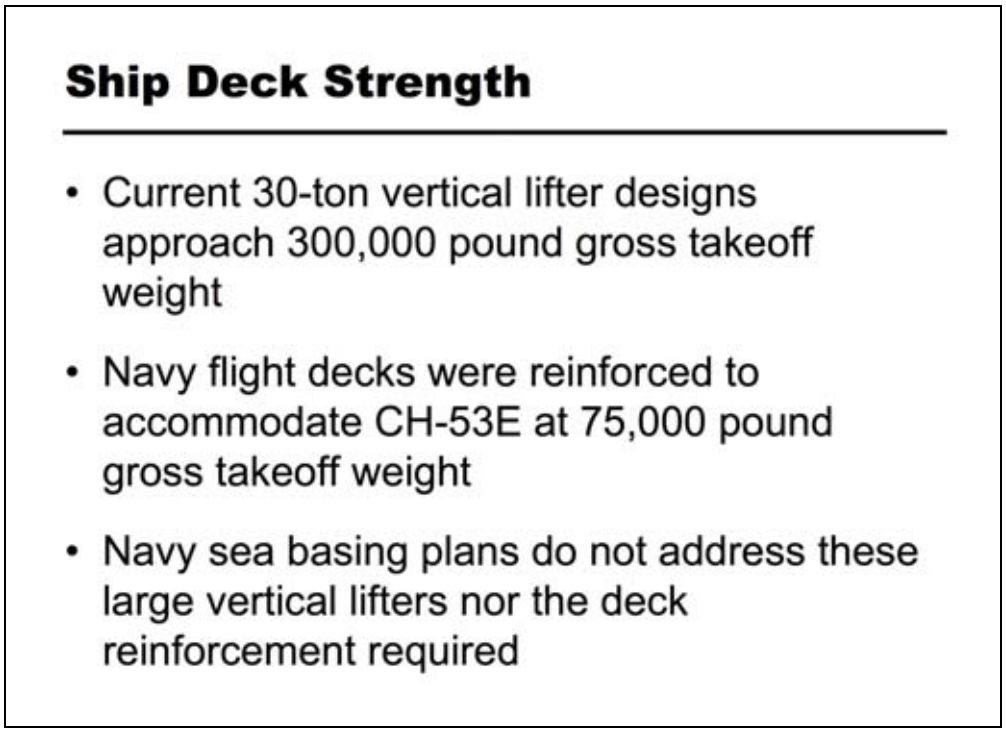
- The ship, as described by the company, has no self-protection, which implies that some sort of escort would be needed or that the ship's operating environment would be benign.
- In addition to available cargo handling options, some alterations will have to be made to accommodate the high throughput of cargo to meet the desired timelines. These alterations would include ramps or elevators to all landing spots, easy container flow paths, and rapid refueling rates.
- The question of whether the ship should meet Navy safety standards and certifications or simply maintain commercial standards was not addressed. This issue could have major cost implications as it did for the NAVSEA–designed ship..

With folding 30-ton tilt rotors and an open operational deck spot forward and aft, each ship conversion could accommodate two spread tilt rotors and 17 folded aircraft on deck, for a total of 19 tilt rotors. Two such ships would carry 38 tilt rotors, slightly short of the 40 needed to move an FCS battalion. To adopt this solution, however, the operational complexities of transitioning from stowed decks to fully operational decks would need to be solved.



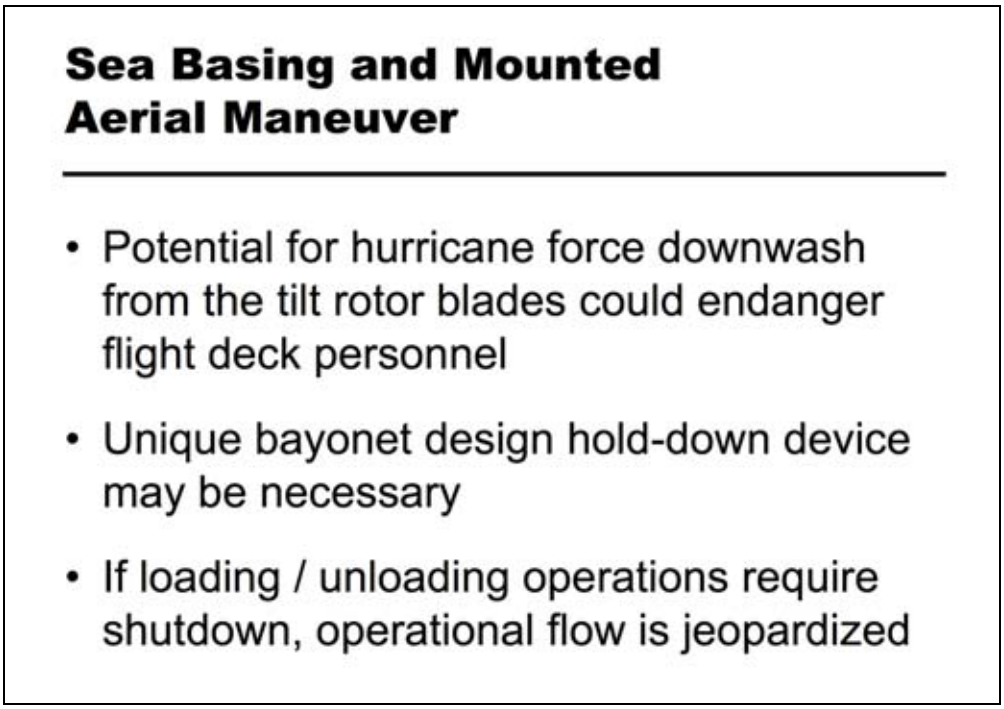
The notional Army tilt rotor design that lifts 20 tons appears more amenable to sea basing. With a fuselage length of 98 feet and a spread width of 168 feet, it has a gross takeoff weight of 170 thousand pounds versus the 280–300 thousand pounds of the 30-ton lifter. Its smaller size would allow the converted container ship discussed earlier to carry onboard 30 folded, plus two spread 20-ton tilt rotors, for a total of 32 aircraft.

While the Army doesn't provide a weight for a 20-ton tilt rotor folding kit, a figure of 2.5 tons was used as a sizing function. Because the notional Army design for a 20-ton tilt rotor carries 20 tons of fuel, if the aircraft were to launch with only 10 tons of fuel, it could lift 27.5 ton vehicles. Aerial refueling demands increase operational complexity, but if utilized, allow considerably more flexibility. For example, a converted container ship, with two spots operational both forward and aft (for a total of four operational spots), can carry a total of 24 tilt rotors. A two-ship configuration with 20-ton tilt rotors that fold and use aerial refueling capability could lift an FCS battalion in about 10 hours to 250 nautical miles.



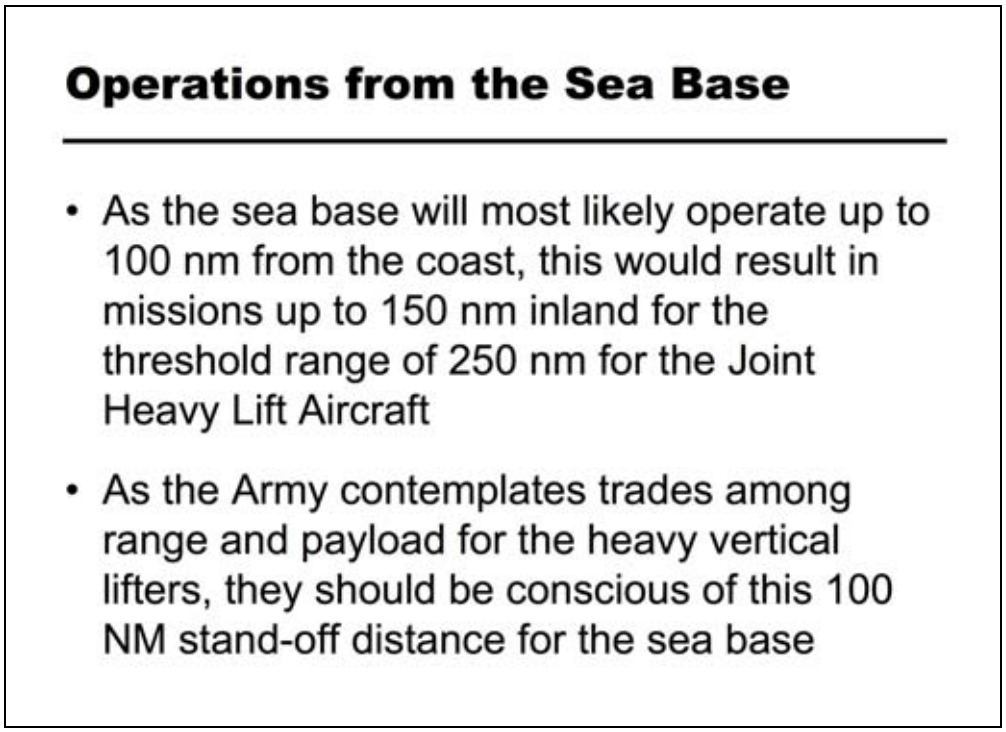
There are no flight decks on U.S. Navy ships that could accommodate a 30-ton vertical lifter. Navy LHA and LHD decks were reinforced when the CH-53E was introduced. These decks can accommodate nine CH-53Es, which is the equivalent topside weight of two of the 30-ton vertical lifter designs. NAVSEA naval architects believe that there will not be a stability problem for the LHAs and LHDs with three of these heavy lifters on the flight deck.

The task force found no evidence that current Navy sea basing plans envision accommodating these large aircraft on any future maritime prepositioning force platform.



Standard flight deck operations will be tenuous with these large vertical lifters. The downwash from a tilt rotor at relatively flat rotor pitch will be a critical item to evaluate with prototypes. Alternatives may have to be found to allow flight deck operations without personnel on deck or in the vicinity of these aircraft turning up. On helicopter flight decks for small ships, the Navy has developed and installed recovery, securing, and traversing systems—bayonet type hold-downs to secure the helicopters on the flight deck in rough seas. This approach might work for these large vertical lifters.

If shutdown during loading/unloading is required, any failure to restart will result in a reduction, by one, of the limited maximum on ground on the sea base ship or at the offload point. Members of the task force with extensive helicopter experience argued that most mission-capable failures occur during shutdown and restart.

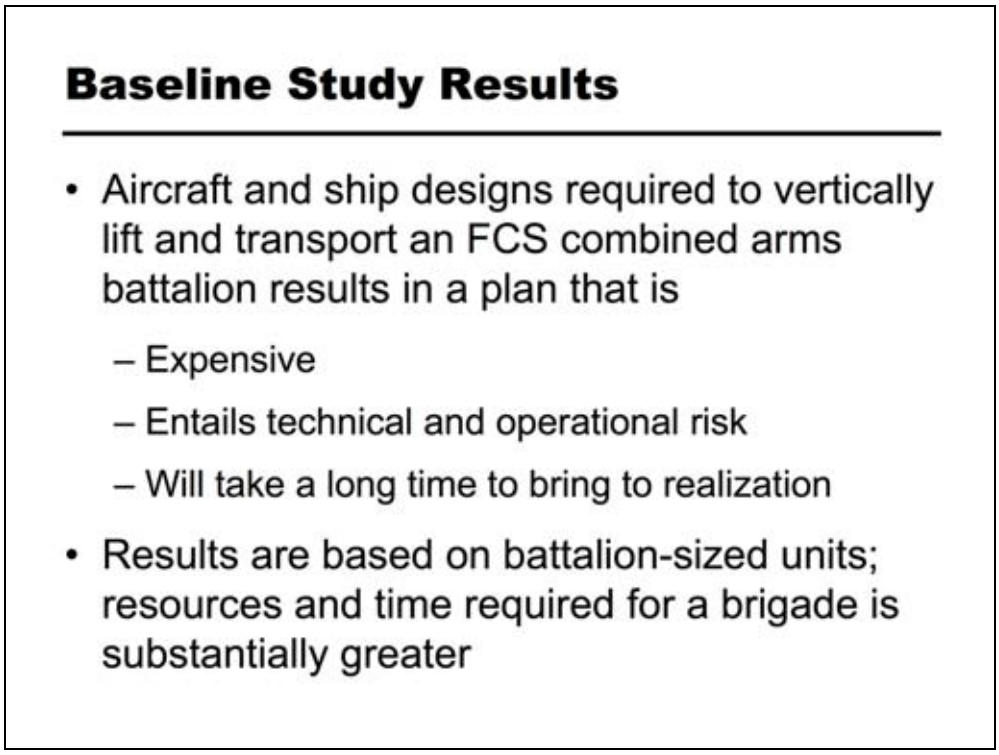


The threshold range for the heavy vertical lifters is 250 nautical miles, with an objective range of 500 nautical miles. If tradeoffs are made between range and payload to reduce the air vehicle size and footprint, the 100 nautical mile sea base standoff distance should be considered.

Sea Basing Recommendations

- Sea basing can enable mounted aerial maneuver with appropriate ship designs and procedural changes
- 20-ton tilt rotors with refueling capability and folding kits are more amenable to sea basing than 30-ton tilt rotors
- If heavy vertical lifters are prototyped, shipboard compatibility should be part of the demonstration phase
- Range/payload trades for candidate aircraft should be made within the context of the 100 NM stand-off range for the sea base
- Army and Navy should fully investigate commercial ship conversions as a potential enabler for mounted aerial maneuver

Chapter 6. Alternatives to the Baseline

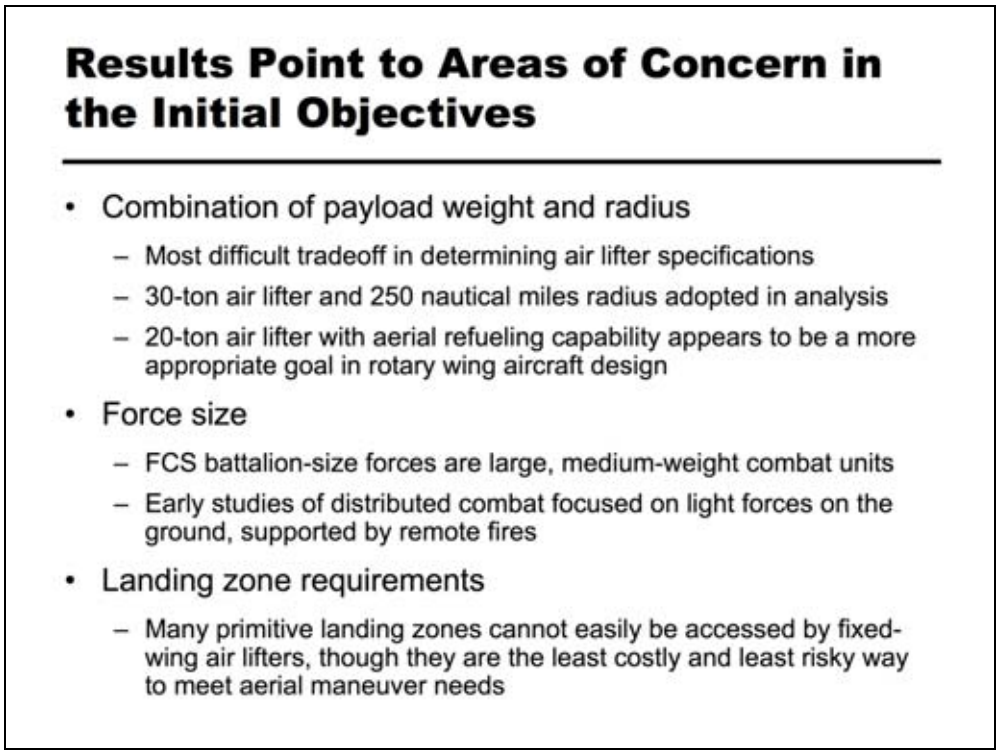


As described in the preceding chapter, goals for aircraft and ship design, to support mounted aerial maneuver operations, are driven by tactical needs to deploy and sustain a distributed force in the field, which in turn are a strong function of the size of the force, its equipment, and the distances to be covered.

The Army has made major investments in FCS systems and equipment and has fielded conventional and Stryker units that could have lift needs even greater than those stated for FCS units. In analyzing its case study, the task force determined the general nature of aircraft and ships required by an FCS combined arms battalion. It further identified gaps in today's technology and development processes that must be addressed for both fixed-wing and rotary-wing air lifters and ships capable of meeting the objectives of the case study.

The result is a plan that will be expensive, entail both technical and operational risk, and take a long time to bring to realization. These results are based on battalion-sized units; the resources and time required to deploy a brigade is substantially greater than that required for a battalion.

The choice of lifters to support deployment of mounted aerial maneuver operations is not constrained by technical limitations. The issue is much more a matter of time, cost, and risk for the operational capability enabled. The task force assembled a list of tradeoff investment versus capability questions to be examined before requirements are set.



Based on its analysis of the Army FCS case study, the task force identified several areas of concern in the objectives as originally stated.

Payload Weight and Radius. The combination of payload and range is the most difficult specifications for an air lifter design to meet. In its analysis, the task force adopted 30 tons as the payload goal for the air lifter, which is less than the 40 tons desired for the AMC-X, but workable for vehicles and loads that currently make up the FCS combined arms battalion.[25] Additionally, it focused on a 250 nautical mile radius, reasoning that 500 nautical miles can be achieved with additional aircraft and time.

Physical dimensions are much less of a problem than weight.

For rotary-wing aircraft, a payload of about 20 tons and 250 mile radius represents a combination of characteristics that meet

25. Lieutenant General John Curran, "Advanced Mobility Concept-X."

achievable technology and reasonable cost constraints. Falling back to a 20-ton payload limit demands a re-examination of the tradeoffs in FCS vehicle characteristics—in particular, tradeoffs between deployability, armor, and weapon weight. Can close air support substitute for heavy weapons, such as howitzers and heavy mortars in the deployment phase of an operation? Is mobility an alternative to heavy armor? These are the type of questions that need to be reexamined.

Force Size. The task force study used a battalion-sized force as the objective force in its case study analysis. The results of the study indicate a major, risky investment in developing and producing airlift for such a large force. A brigade presents even more deployment difficulty. The forces envisioned in the mounted aerial maneuver concept are evolutionary modernizations of today's conventional forces—they are large, medium-weight combat units.

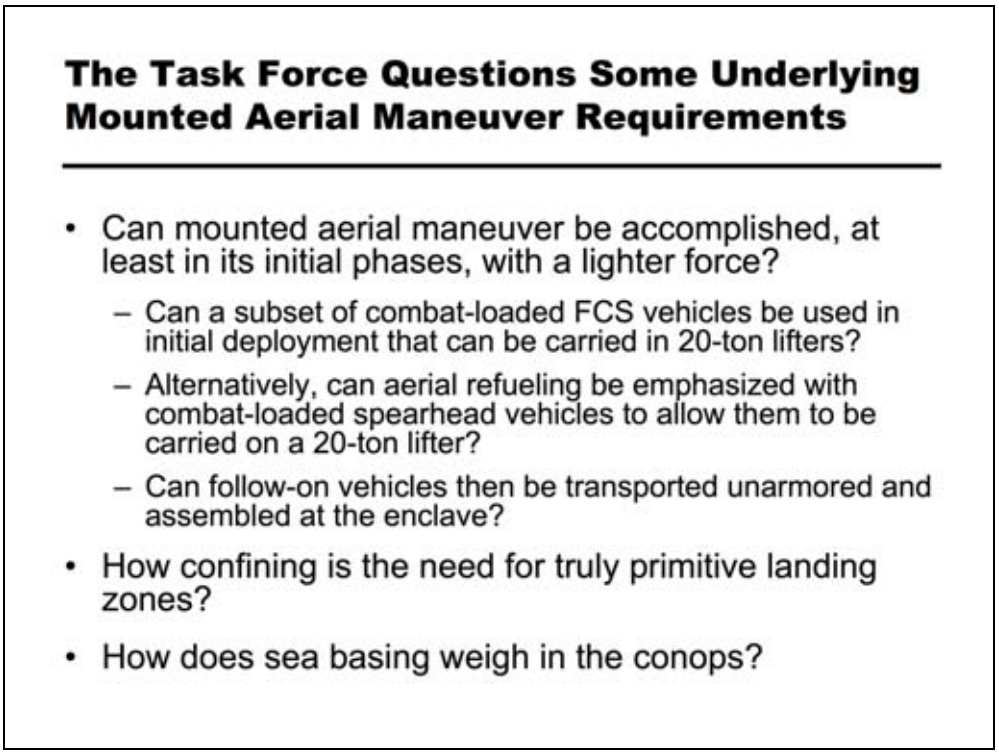
Early studies of distributed combat seized on a more revolutionary force concept—light forces on the ground supported by remote fires (air artillery or ship-based heavy weapons). These forces had no concentrated enclaves, no heavy vehicles, and light logistics requirements. These light company- or platoon-sized forces were to be closely connected to other units; remote fires; intelligence, surveillance, and reconnaissance; and logistics support by a ubiquitous, wideband communications network. Such forces could be deployed and sustained by much lighter VTOL lifters.

Should the mounted aerial maneuver concepts be retargeted to a much smaller, lighter, more maneuverable concept?

Landing zone requirements. As discussed in the previous chapter, fixed-wing air lifters are the least costly, least risky way to meet aerial maneuver needs. Their major failing is inability to land in and take off from primitive landing zones in the deployment phases of operations. The assertion that reliance on existing airstrips, highways, or other level, hard surfaces severely restricts a commander's choice of enclave sites is a cost versus benefit consideration. **How confining is the need for a landing zone capable of handling fixed-wing lifters?** Are there ways to prepare a surface for runway use by heavy, fixed-wing lifters in significantly less time than the three or more days

now deemed necessary to construct an airstrip? How much should answers to these questions drive the solution for a heavy lift aircraft?

Sea basing. Sea basing can enable mounted aerial maneuver with appropriate ship designs and procedural changes. However, no existing ships can accommodate the requirements for a 30-ton air lifter. Size, weight, and operational requirements call for a ship that is not currently in the fleet, nor planned by the Navy. A smaller, 20-ton air lifter, with a tilt rotor design, refueling capability, and folding kit is more amenable to sea basing than a 30-ton vehicle. The smaller footprint allows greater numbers to be transported by ship. **How important is sea basing in the overall concept of operations for the FCS combined arms battalion?** Ship board compatibility considerations must be part of any development effort for a new heavy vertical lift aircraft.



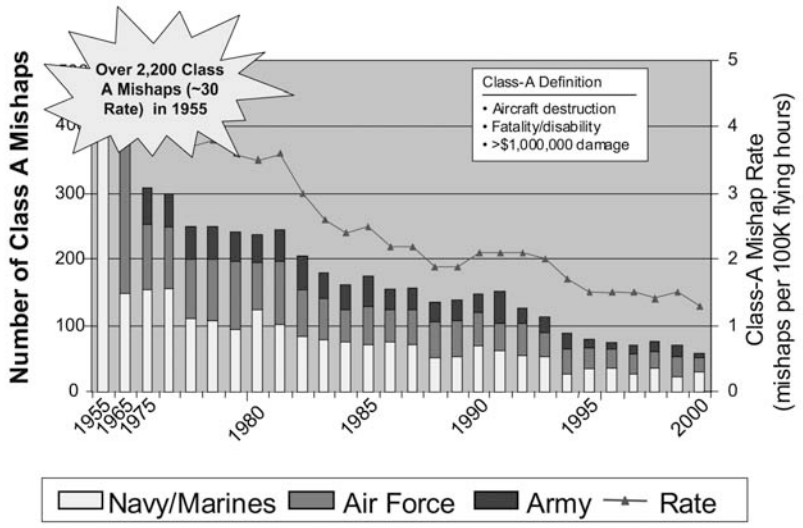
From its analysis of the mounted aerial maneuver baseline, the task force notes stresses between the FCS vehicle weights, the characteristics of the baseline heavy lifter, and the operational model.

The task force concludes that a less aggressive VTOL lifter design, combined with modified operational precepts (such as aerial refueling; use of lighter FCS vehicles; and greater reliance on networked, non-organic fires for offense and force protection) offer an effective model for mounted aerial maneuver operations. The task force recommends that the Army reconsider its operational model and adopt such modifications.

Chapter 7. Safety and Survivability

Class A Mishaps, FY1955–2000

- DOD fixed- and rotary-wing Class A mishaps (fatality, permanent disability, $1M damage, loss of aircraft) declined from FY 1955–2000
  - From 2400 Class A mishaps to 60
  - From 30.0 Class A mishap rate/100K flight hours to 1.3
- The 1998 DSB on Aviation Safety recognized
  - Class A mishaps still cost over $1B and 100 fatalities
  - Mishap rate was no longer declining and had "plateaued"



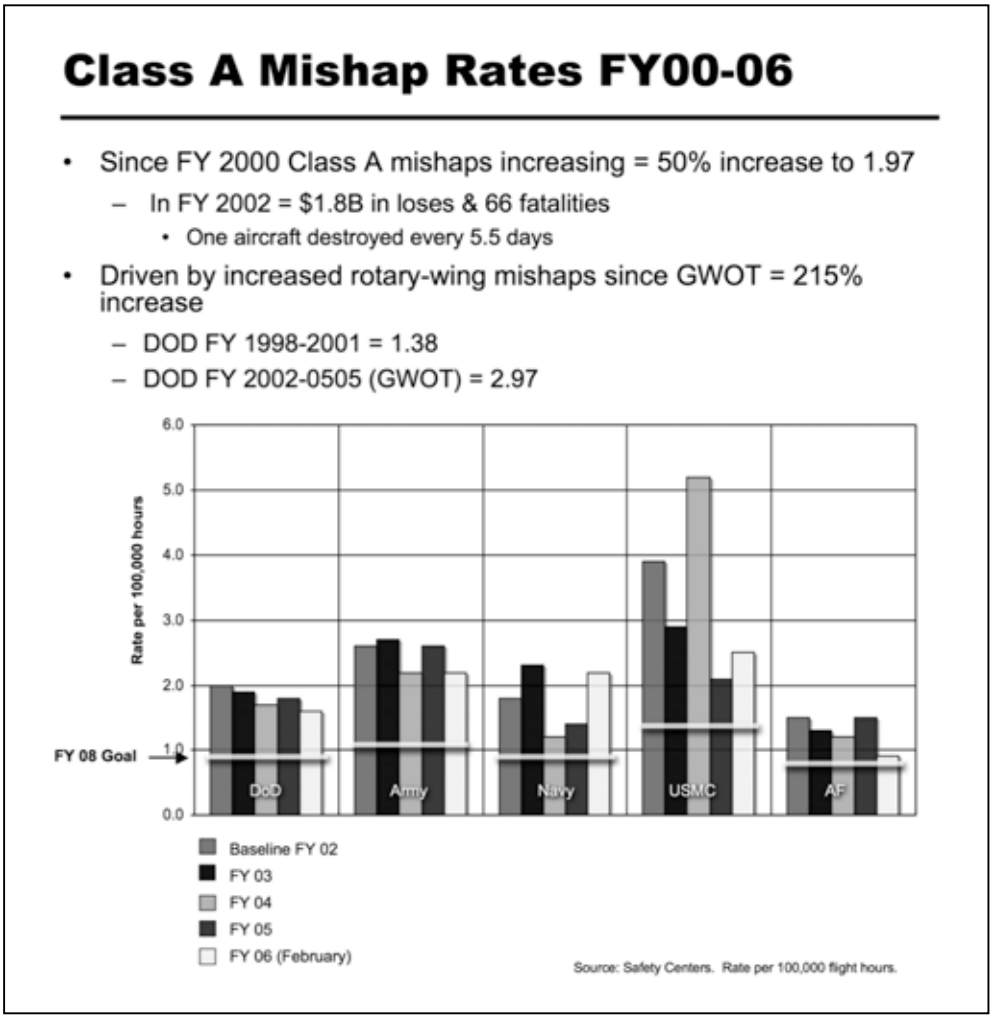
The Department of Defense started to measure aircraft mishap rates in 1955. DOD defines the most serious mishap as Class A, which includes any fatality, permanent disability, $1 million or more in damage, or the loss of an aircraft.

DOD fixed- and rotary-wing Class A mishaps per year have steadily declined from 2,200 in 1955 to approximately 60 in fiscal year 2000. The rate of mishap per 100,000 flight hours has declined from 30.0 to 1.3 over the same period.

These substantive reductions were the result of many factors and changes to better manage the inherent risk in aviation operations, including improved aircraft design and technology, enhanced crew training, and improved levels of maintenance training.[26]

Despite the improved mishap rates, the Defense Science Board noted in 1998 that DOD aviation mishap rates still cost over $1 billion and 100 lives per year. Also, the DSB noted that the number of military aviation mishaps and rate no longer seemed to be declining. The Congressional Research Service in September 2002 stated that "after 50 years of declining rates, improvements seemed to have stagnated."

26. Institute for Defense Analyses, Paper P-3671, p. ES-1.



DOD Class A aviation mishap rates significantly increased, by 50 percent, in fiscal year 2002, and the numbers and rates have continued to exceed goals and expectations. In fiscal year 2002, one aircraft was destroyed every 5 and a half days.[27]

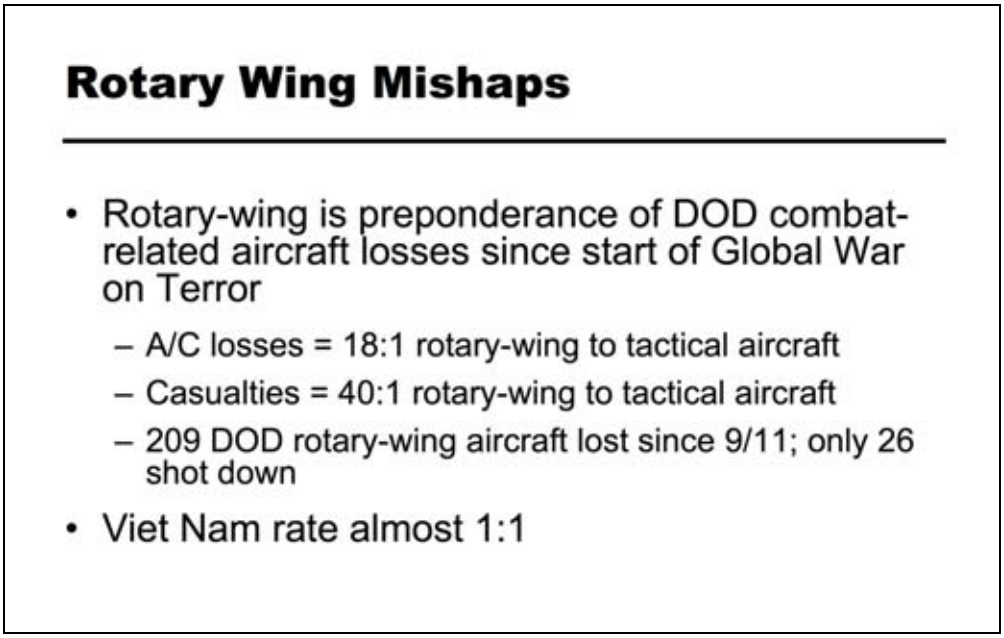
The Secretary of Defense's Mishap Reduction Initiative sets the fiscal year 2008 Class A aviation mishap rate goal at 0.5. Recent mishaps

27. Briefing to the Defense Science Board on Future Need for VTOL/STOL Aircraft on the Secretary of Defense's mishap reduction initiative, p. 4.

rates are not declining. The fiscal year 2005 rate was 1.8 and the fiscal year 2006 rate through February is 1.6.[28]

Rotary wing mishaps have increased 215 percent since the beginning of the global war on terror (GWOT). There are a disproportionate number of rotary-wing aircraft losses and casualties. Rotary-wing mishaps have become the driver for increased DOD aviation mishaps.

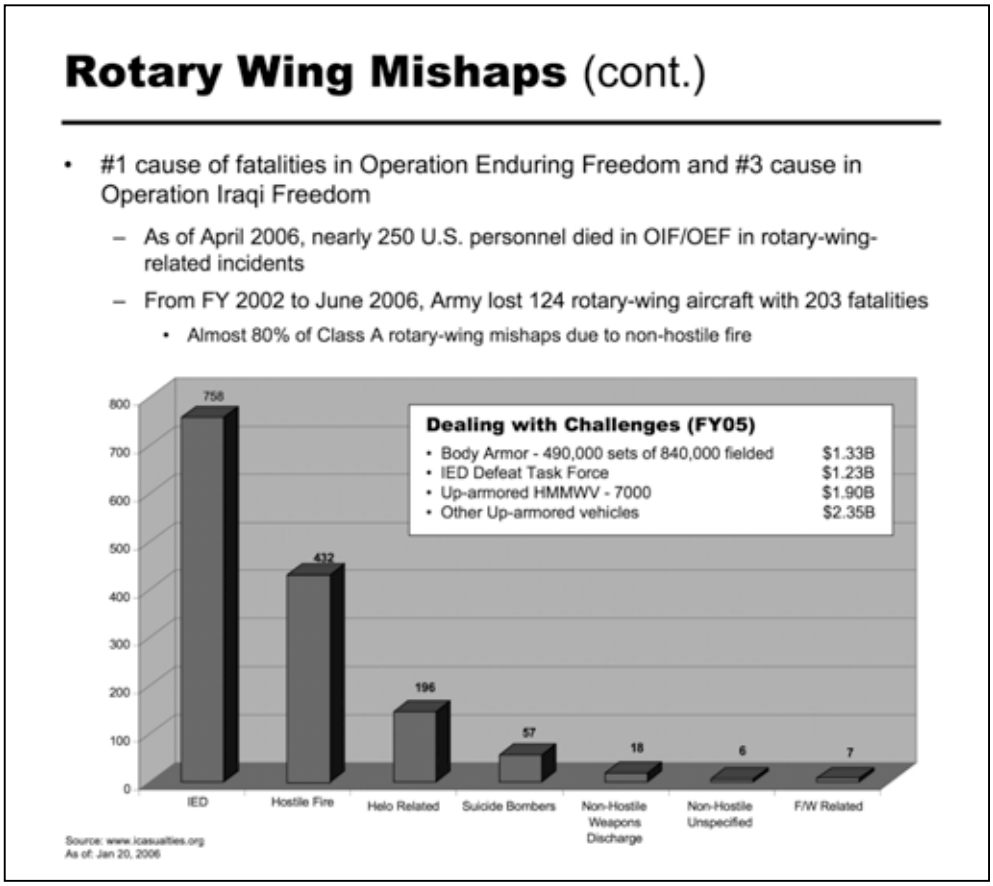
28. Ibid. p. 8.



Since 2001, the preponderance of aircraft and personnel losses have been rotary wing. For every tactical aircraft lost, there are 18 rotary-wing aircraft lost. For every tactical aircraft casualty, there are 40 rotary-wing casualties. This compares very unfavorably to Vietnam where the tactical air to rotary-wing aircraft loss ratio was 1.0 to 0.9.

Of the 209 DOD rotary-wing aircraft lost in mishaps since September 11, 2001, only 33 were from hostile fire.[29]

29. Briefings to the Defense Science Board Task Force on Future Need for VTOL/STOL from Col. Fred Wenger III, Director, Commandant of the Marine Corps Safety Division (Navy/Marine Safety), April 2006 and BG Joseph A. Smith, Director of Army Safety and Commanding General, U.S. Army Combat Readiness Center, Army Safety, "On the Edge: Composite Risk Management," June 2006.



Rotary-wing mishaps are the driving cause of fatalities in recent operations. As of April 2006, in Operation Enduring Freedom (OEF), rotary-wing-related mishaps were the number one cause of fatalities (91), far exceeding fatalities related to improvised explosive devices (IEDs) (45). In Operation Iraqi Freedom (OIF), rotary-wing-related mishaps accounted for the third largest number of lives lost (153), after IEDs (904) and hostile fire (294).[30] Through April 2006, nearly 250 U.S. personnel died in rotary wing related mishaps in Operations Enduring Freedom and Iraqi Freedom.[31] The Army has the vast majority of rotary wing assets. From

30. Briefing to the Defense Science Board Task Force on Future Needs for VTOL/STOL Aircraft on Investing in Improving Rotary Wing Systems, pp.3–6.
31. Briefing to the Defense Science Board Task Force on Future Need for VTOL/STOL, "Helicopter Attrition Update," June 21, 2006.

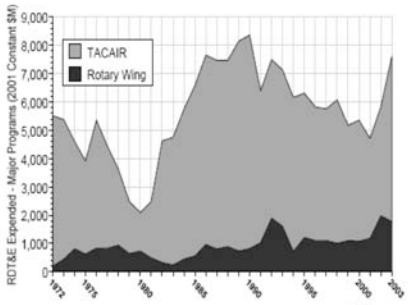
fiscal year 2002 through June 2006, Army rotary wing losses totaled 124 aircraft (26 hostile fire) and 203 fatalities (80 hostile fires).[32]

In fiscal year 2005, almost $6 billion was invested in personal and vehicle armor and other technology insertion efforts to deal with the IED challenge.[33] Investments in safety and survivability for rotary-wing aircraft and crews have come nowhere near this level.

32. BG Smith, Army Safety Briefing, June 2006.
33. Ibid. p. 3.

Why Disproportionate Number of Rotary-Wing Losses

- What changed between Vietnam and now?
  - DOD invested in tactical air, but very little in rotary wing
    - FY05/06 budget continued trend
    - Focused on survivability and lethality
  - Non-linear/asymmetric battlefield
    - No safe rear area
    - Rotary wing more exposed to all threats
  - Change in role of heliborne forces
    - Small scale maneuver, utility role
    - Limited SEAD due to urban battlefield
  - TacAir combined new technology, tactics, training to reduce threat & mishap potential
- Results of investment in tactical air
  - Tactical air Class A mishap rate in FY 2005 was 1.3 vs. 3.3 for rotary wing
  - Limited change in rotary-wing technology & tactics with increasingly demanding flight environment resulting in
    - Increased mission risk
    - Increased mishap rate



ARGUES FOR FOCUSED DOD INVESTMENT IN ROTARY WING SAFETY AND SURVIVAVBILITY

What changed to increase the rotary-wing-to-tactical aircraft mishap rate ratio from 1:1 in Vietnam to the current ration of 1:18? There are several contributing factors: investment in tactical aircraft; changes in battlefield employment; changes in the role of heliborne forces; and an infusion of new technology, tactics, and training for tactical air forces.

DOD has invested heavily in safety, survivability, and lethality for tactical aircraft. The 30-year trend of tactical air-to-rotary wing investment in research, development, test, and evaluation (RDT&E) shows an almost 9:1 investment ratio for tactical air. In particular, the fiscal year 2005 DOD budget programmed $7.5 billion for tactical air while rotary wing was $0.8 billion—a 10:1 ratio. The projected RDT&E trend to 2020 remains substantially skewed toward tactical aircraft.

The battlefield has also changed. In today's battlefield rotary-wing aircraft face a preponderance of asymmetric threats. There are no safe areas for low-speed, low-altitude aircraft. Rotary-wing aircraft are constantly exposed to all threats throughout the mission profile. Also, tactical aircraft missions often employ high altitude operations.

The role of rotary-wing aircraft and heliborne forces has changed as well. Large-scale assaults with accompanying escort protection have been replaced by small-scale maneuver and utility missions with reduced protective escort. In addition, due to a significant mission profile in urban areas and low technology threats, the use of suppression of enemy air defenses (SEAD) is greatly reduced.[34]

Focused RDT&E investments, plus new tactics, training, mission planning and risk management techniques were the key in decreasing the tactical air combat loss rate from 10.3 during World War II to .18 during Operations Enduring Freedom and Iraqi Freedom.[35]

The fiscal year 2005 tactical air Class A mishap rate was 1.3, while rotary wing was 3.3. Limited technology investments, coupled with a changing and increased threat, resulted in a significant increase in mission risk and mishap rate. The recent increase in rotary-wing mishaps, Class A mishap rate, and fatalities argues for a focused DOD investment in rotary-wing safety and survivability similar to the tactical air investments made during the last 20–30 years.

34. Investing in Improving, op cit, p.9.
35. Ibid., p.12.

Rotary-Wing Mishap Causal Factors

- Human factors are the leading cause of all DOD aviation mishaps = 80%
  - Judgment/decision-making
  - Cognitive factors
  - Supervision
  - Organizational influences
- Major mishap categories continue to be
  - Controlled flight into terrain
  - Powerplant underpowered
  - Loss of control in flight
  - Mid-air collision

Still flying into wires
Still crashing in brownouts
Still underpowered

A review of specific causal factors is essential to determine where to focus investments in order to get the greatest return in terms of mitigating flight risk and reducing mishaps. Human factors continue to be the leading cause of all DOD aviation mishaps. Approximately 80 percent of aviation mishaps result from human error, which include aircrew judgment and decision-making, cognitive factors, supervisory error, and organizational influences.[36] Excessive crew workload, degraded situational awareness, and ineffective risk management drive the human error chain in aviation mishaps.

Most aviation mishaps can be sorted into the following categories: controlled flight into terrain (includes brownout), underpowered power plant, loss of controlled flight, and mid-air collision.[37] In three of these four categories, degraded situational awareness plays a primary role. Rotary-wing aviation has not progressed beyond the Vietnam era

36. Mishap Reduction Initiative, op cit, .11.
37. Ibid., p. 11.

threats. Crews are still flying into wires; crashing in brownouts; and flying underpowered aircraft, especially when often tasked to operate in heavy load and/or high density altitude environments.

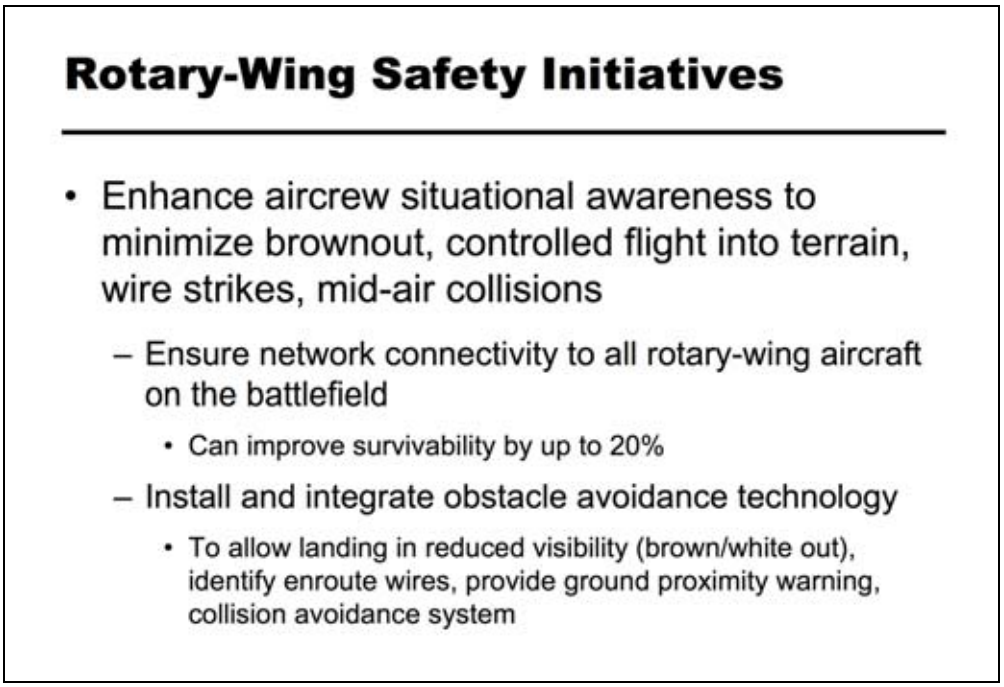
Rotary-Wing Safety and Survivability Focus

- Definitions
  - Safety initiatives = Prevent mishaps
  - Survivability initiatives = Reduce/mitigate damage & injury
- Mishap root causes
  - Aircrew situational awareness
  - Aircrew and proficiency/readiness
  - Supervisory/organizational knowledge
  - Aircraft systems
- Critical to focus technology insertion & aircrew safety initiatives on root causes
- Build a rotary-wing Safety & Survivability Roadmap to reduce mishaps and improve operational performance
  - Art of the possible NOW
  - Long term integrated approach for future development

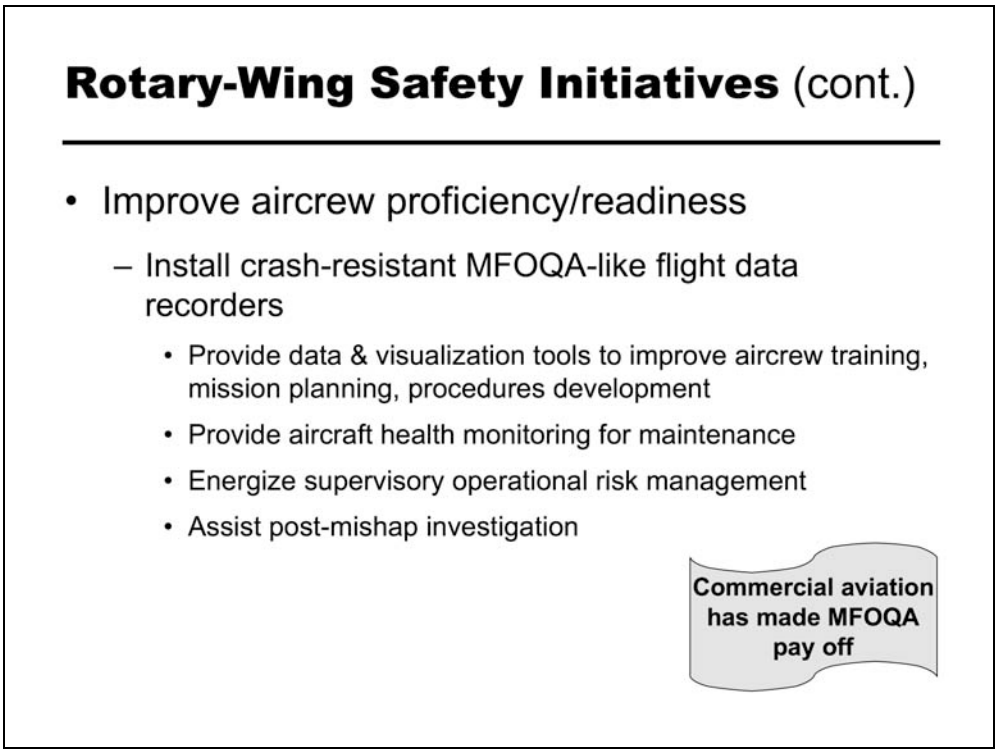
Safety initiatives are defined as those actions taken to prevent mishaps, while survivability initiatives are actions that reduce or mitigate aircraft damage and personnel injury. In reviewing presentations from the Office of the Secretary of Defense, Army, Navy, Marine Corps, and Air Force, the root causes of the increased number of Class A mishaps since fiscal year 2002 are aircrew situational awareness (brownouts, wire strikes, mid-air collision, controlled flight into terrain), aircrew proficiency and readiness (training levels, mission preparation), supervisory and organizational knowledge, and aircraft systems.

A safety and survivability investment plan must focus on solving the root causes of mishaps via technology insertion, aircrew training, and supervisory improvement initiatives. It is time to recognize that building a Rotary-Wing Safety and Survivability Roadmap will reduce mishaps and improve operational performance, just as it did for the tactical air community. Commercial off-the-shelf technology (such as flight data recorders and in-the-field mission simulators) to address some of the causal factors is within the art of the possible and can be made available now for current rotary wing aircraft. There also remains

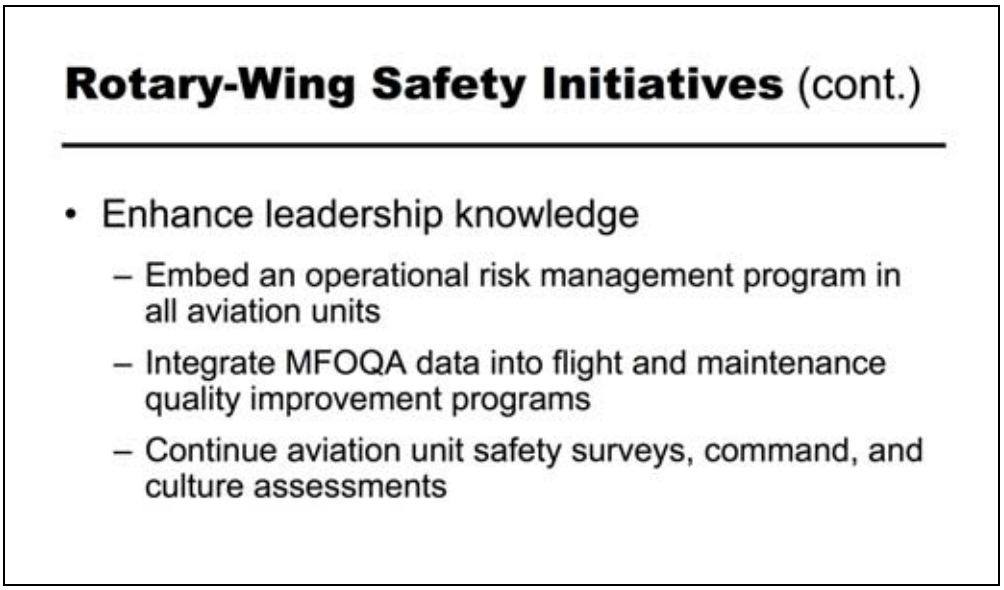
a critical need for a long-term integrated approach to develop rotary-wing-focused technology for the new battlefield (such as wire avoidance technology and advanced engines).



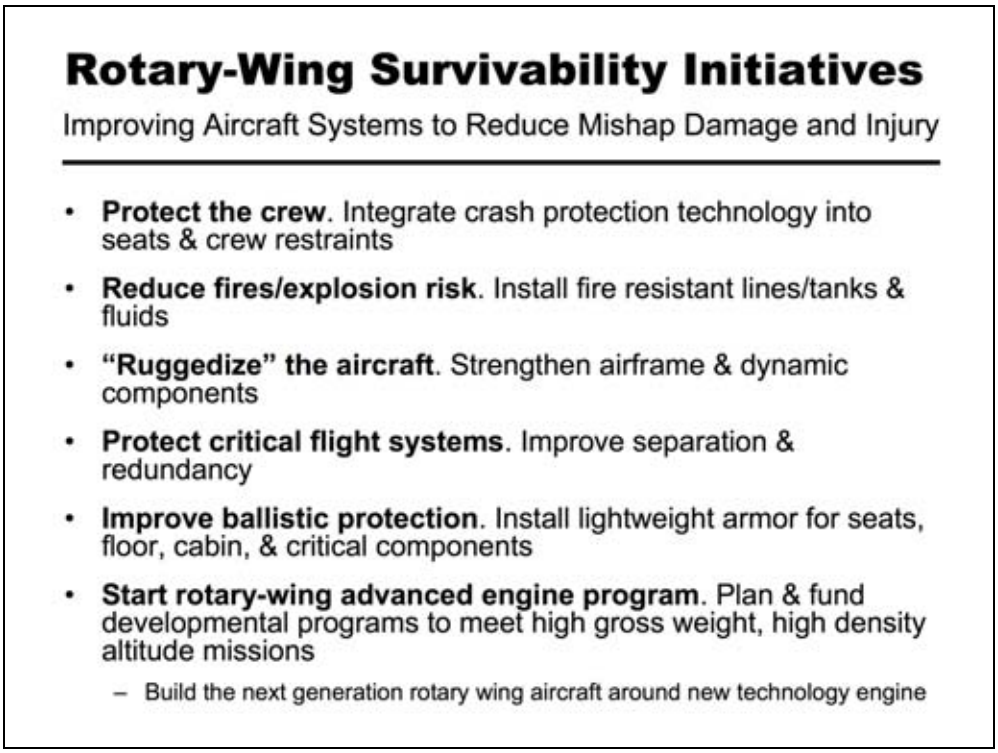
Both the near- and long-term rotary-wing investment should focus on improving aircrew situational awareness to minimize brownout, controlled flight into terrain, wire strikes, and mid-air collisions. An obstacle avoidance suite integrated into the aircraft display system is essential to allow aircrews to land in reduced visibility, to identify and avoid wires in flight, and to provide ground proximity warning and mid-air collision avoidance. Networking the rotary-wing aircraft across the battlefield could result in a 20 percent improvement in survivability.



Crew proficiency and training, and maintenance readiness systems must be improved to meet the new demands of combat and peacetime disaster response. Installing a military flight operations quality assurance (MFOQA)-like flight data recorder is an essential first step in reducing human error mishaps. MFOQA can provide data and visualization tools to train aircrew in the pre- and post-flight briefs. It allows aircrews to focus on in-flight excursions, mistakes, critical-mission risks, and mission planning. It also provides aircraft health monitoring for maintenance personnel to predict failure modes and replacement intervals using real-time data. The data recorders can be used by supervisory personnel to monitor aircrew trends and error modes in order to improve training, operational risk management, and mission planning. In addition, these recorders can be used effectively to determine mishap causal factors.



A final area in which safety investments can focus is on enhancing leadership knowledge. One step is to embed operational risk management programs in all aviation units. Another is to integrate MFOQA data into flight and maintenance quality improvements programs. Finally, the services should continue service-centered unit surveys, culture, and command assessments to improve the leadership's view of their unit and its people.

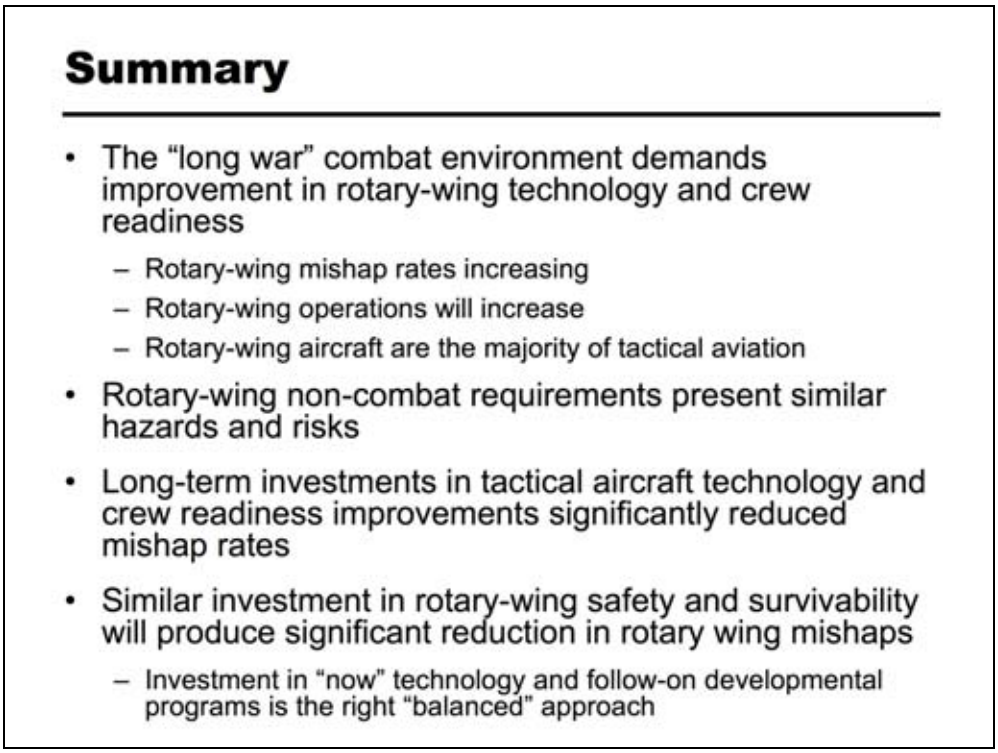


A number of survivability initiatives are needed to improve aircraft systems in order to reduce damage and injury. Protecting the aircrew is a primary imperative. To improve aircrew safety, focus is needed on integrating crash-protection technology into aircrew seats and restraint systems. Much of this technology is available off-the-shelf. Second, reducing the risk of fire and explosions is also essential to reducing injury and fatality rates. Installing fire-resistant fuel lines, tanks, and the use of fire-retardant fluids can substantively reduce this cause of mishaps.

The department also needs to initiate a developmental program to make rotary-wing aircraft more rugged for the current operational environments to include airframe, critical dynamic components, and separated critical flight systems. Lightweight ballistic protection for aircrew (seats, cabin, floor) and critical components should also be installed.

Finally, DOD must initiate and fund a robust rotary-wing advanced engine development program, specifically designed for present and

future “long war” missions. Emphasis must be placed on excess power available at high gross weight/high density altitude, reliability, and specific fuel consumption. Slight improvements in performance from existing engines are not the answer. What is needed is to build the right engine and develop the aircraft around it, as was done in tactical aircraft engine development.



The "long war" will drive combat aviation for the foreseeable future. Today's non-linear battlefield and asymmetric threats are more demanding for rotary-wing aviation than ever before. The requirement for rotary-wing capabilities on and off the battlefield is increasing. DOD's rotary-wing force is the majority of tactical aviation today. It is not difficult to understand that operational risk for rotary-wing aircraft is significantly increased and, not surprising, rotary-wing mishaps are increasing as well.

Non-combat requirements for DOD rotary-wing aviation, such as natural disaster relief, search and rescue, and utility and logistics support, possess similar risk factors to combat operations to include ground obstacles, reduced visibility, degradation of situational awareness, and high and heavy operations.

Long-term focused investments in tactical air safety and survivability—in areas such as aircraft technology, engines, simulators, and mission planning—significantly reduced mishaps over the past 20–30 years. A similar "balanced" investment strategy in rotary-wing safety

and survivability will produce similar long-term results. Commercial off-the-shelf technology is available now to initially start the program, but follow-on technology development programs in situational awareness, force networking, data visualization, mission planning and review, more rugged airframe and flight systems, and advanced engine technology are also needed.

Chapter 8. Threats and Countermeasures

Distributed combat deep inside enemy territory means aircraft will have to overcome many kinds of ground-based anti-air threats. Air lifters must have organic defenses to contend with several types of these menaces. Additionally, air operations must be executed to minimize air lifter exposure to autonomous ground weapons.

Ground-based Threats

Ground-based threats to the air bridge fall into two categories:

- integrated air defense systems
- decentralized air defense weapons

Integrated Air Defense Systems

Integrated air defense systems (IADS) are the most sophisticated air defense systems. Surface-to-air missiles incorporated in these systems are capable of destroying aircraft at all operational altitudes and at long range. Generally they are integrated into an area defense with distributed detection and targeting sensors (principally radar). Extensive command, control, and communication networks connect coordination centers, sensors, and launch sites.

Destruction and elimination of IADS by combat air and ground forces prior to the start of distributed ground force deployment is one of the preconditions listed in Chapter 3 for airlift studied by the task force. IADS countermeasures are not covered in this report.

Decentralized Air Defense Weapons

Decentralized air defense weapons either require motorized transporters or are carried by individual combatants. This category of anti-air weapons is highly asymmetric in that shoulder-fired projectiles emitted from launchers or guns costing $100s to $1,000s can destroy an aircraft costing in the range of $100 million. These weapons are the anti-air weapon of choice for insurgents and terrorists.

Decentralized anti-air devices requiring motorized transporters (surface-to-air missiles such as the SA-8 or heavy guns, generally 35 mm up to 100 mm) require open fields of fire. They typically have easily detectable signatures (i.e., transporters, guns, or launchers), making them relatively easy to spot and eliminate from the air when they are deployed. The task force assumes that air defense weapons requiring transporters will be eliminated by other tactical air forces.

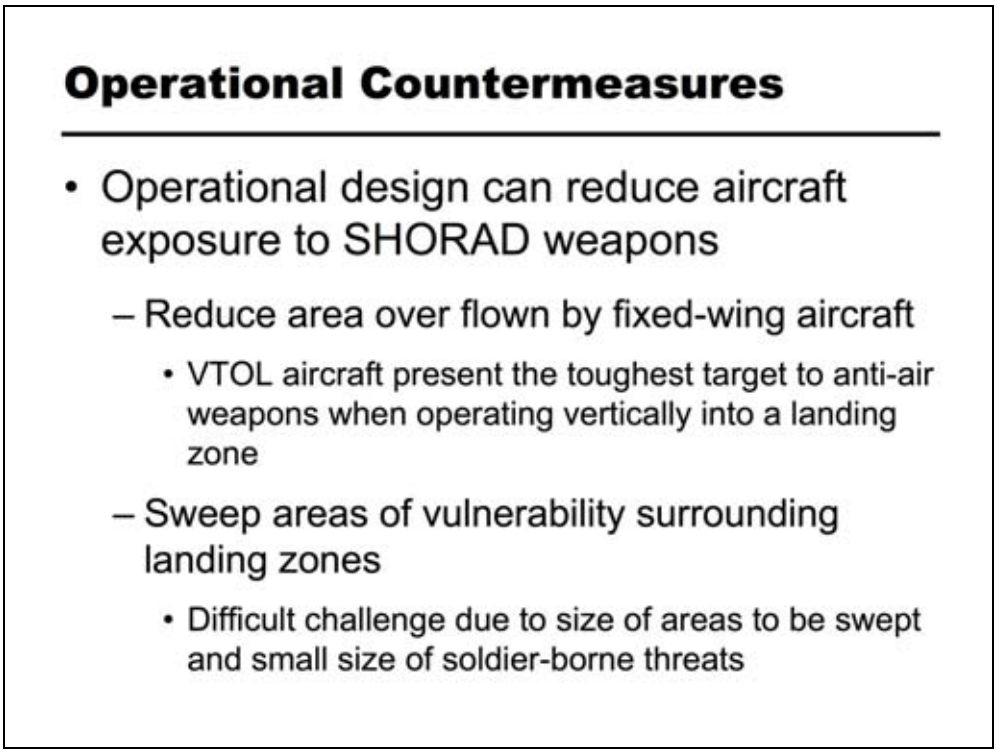
Soldier-carried weapons (such as rifles, RPGs, MANPADS, and machine guns) present a different challenge. They are not detectable until fired. Small arms are ubiquitous on the battlefield; there are hundreds of thousands of MANPADS in the field, both old and new, including old systems such as Red-Eye and SA-7, and newer weapons such as Stinger.

Guided short-range air defense systems (SHORADS) are infrared or visually guided and are susceptible to airborne countermeasures. The United States has expended a great deal of development on these countermeasure systems as a result of experience in Afghanistan and Iraq and is achieving significant success against existing SHORAD threats. Many new systems automatically activate in response to sensor detection of light missile launch, reducing the chance that aircrews may overlook incoming threats. However, SHORAD capabilities are certain to improve as adversaries seek to overcome aircraft defenses. Of particular concern are image tracking systems.

Continuing efforts to develop and deploy more effective countermeasure suites that detect and eliminate threats from new SHORADS will be critical to distributed combat force deployment and sustainment.

Ballistic man-carried weapons (AK-47s and machine guns) and RPGs are widely distributed on any battlefield. They are difficult to detect when fired and even more difficult to counter. The primary defense against these soldier-borne small arms has to be the survivability of the aircraft itself. As graphic pictures of aircraft returning with extensive battle damage show (such as A-10s returning from Kosovo), it is possible to design and construct aircraft that can take major damage, protect the pilot, and still complete a mission.

Survivability of air lifters, both through integrated SHORAD countermeasures and through inherent survivability, must be a prime objective for the aircraft design.



Operations can be designed to reduce aircraft exposure to SHORAD weapons. Flight paths can be configured to reduce the area over flown by landing fixed-wing aircraft by circling the landing zone and using the steepest possible glide-path and takeoff trajectories. VTOL aircraft present the toughest target to anti-air weapons as they can drop vertically into a landing zone and lift off similarly.

Areas of vulnerability surrounding landing zones must be swept by ground troops to cleanse them of ground-based anti-air weapons. The high altitude of approaching aircraft, however, makes the size of areas to be swept large and the small size of soldier-borne threats make thorough sweeps unlikely.

Appendix H (contained in a classified version of this report) offers a more thorough discussion of threats and countermeasures.

Chapter 9. Summary of Findings and Recommendations

Mounted aerial maneuver may become a critical capability for U.S. ground warfare to prevail against future enemies quickly and with minimum casualties. Substantial time and money are already committed to develop Future Combat System vehicles, weapons, C4ISR, and solider equipment enabling mounted aerial maneuver. Implicit in the task force findings and recommendations is the expectation that mounted aerial maneuver and its potential for sea-based operations will become mainstream future combat practices in DOD. Regardless of the options pursued, the safety and survivability improvements recommended here are necessary for both current and future rotary wing aircraft

Safety, Survivability, and Reliability

Safety, survivability, and reliability of rotary-wing aircraft are essential to U.S. military operations and are likely to play an important role in mounted aerial maneuver. VTOL operations as large and complex as mounted aerial maneuver in distant and unimproved enclaves demand a much higher level of operational reliability than is achievable today. Recent experience in Iraq and Afghanistan has highlighted concerns over rotary-wing operational safety, vulnerability, and reliability. DOD's support of rotary-wing aviation is well below what can be achieved using even today's technology. DOD has the ability to achieve a much better record than it has to date. The Secretary of Defense has ordered DOD to improve in all areas of safety. Flight data recorders, modern flight management systems, and effective pilot situational awareness systems are tools that can be far more effectively and systematically employed. Additionally, advanced threat detection and aircraft/crew protection is critical for ongoing and projected rotary wing operations. The task force recommends DOD take two steps to improve assurance of rotary-wing aircraft and operations.

Recommendation: **Give investments in integrated flight safety and survivability systems for rotary-wing aircraft, the same priority as those for fixed-wing military aircraft.** Operations are the best opportunity to observe and learn from rotary-wing aircraft mishaps. There is a critical need to iterate self-defense systems, flight management, and flight data recorder systems for improved detection, engagement, damage avoidance, after operations debriefing, and aircrew continuous improvement. **Second these integrated systems should also become an integral element in development of any future VTOL/STOL heavy-lift vehicle**.

Program Initiation and Funding

The task force found no apparent plans, schedules, or funding profiles for new heavy-lift VTOL or STOL aircraft to meet the Army's objectives for mounted aerial maneuver. Legacy aircraft cannot do the job. Both AMC-X and JHL are conceptual studies. There is a compelling need to identify and experiment with new air mobility concepts. Furthermore, industry rotary-wing engineering competence is eroding, and rotary-wing technology lags that which is needed to build a rotary-wing lifter. Moreover, there are no studies to develop concepts for ships to serve as sea bases for mounted aerial maneuver.

While the task force understands the constraints imposed on heavy-lift aircraft development to support mounted aerial maneuver imposed by operational, technological, time, and cost considerations, **DOD and the services must act quickly to clear away the underbrush that confounds decision-making on tactical heavy-lift aircraft.**

Forty-five years ago, U.S. land forces were faced with similar issues on how to incorporate the opportunities offered by rotary-wing aircraft. The Army established the Howse Board in the early 1960s to evaluate concepts and oversee experiments that leveraged the mobility, logistics, and assault capabilities possible in the newly available vertical dimension.

***Recommendation*: Secretary of Defense charter a DOD Special Task Force to determine the best mix of legacy, AMC-X, SSTOL and/or JHL aircraft to meet future intra-theater lift and mounted aerial maneuver needs of the Joint Task Force Commander.** This concept definition and exploration is envisioned to be the 21st century equivalent to the Howse Board and 11th Air Assault experiments of the early 1960s. Instead of large experiments with actual surrogate aircraft, it is recommended that distributed interactive live, virtual, and constructive simulation be leveraged.

Realistic Requirements

The mounted aerial maneuver lift objectives, as established by the Army, are extremely challenging. Developing and producing aircraft and ship designs to deploy and sustain even battalion-sized FCS forces with primitive enclaves is a massive undertaking. The parameters that pose the greatest challenges are payload weight (30 tons), mission range (250 nautical mile threshold; 500 nautical mile objective) and enclave aircraft handling capability.

***Recommendation*: Aerial refueling, shortly after takeoff, should be evaluated as a procedure for long-range, VTOL, heavy-lift missions.** Aerial refueling after liftoff from a land or sea base, as a routine operational procedure, would ease vertical lift requirements for long-range or heavy-load missions but with additional operating cost and complexity. It also can be frustrated by bad weather and/or limited tanker availability. Refueling allows an aircraft to takeoff without lifting the additional burdens of a full fuel load—weight that reduces the payload. Once in efficient flight configuration, the aircraft can assume the additional fuel weight. Aerial refueling is one way to operate 20-ton vertical lifters required to lift those FCS loads in excess of 20 tons.

Heavy Lift Aircraft Fleet

The task force concluded that while it is technically possible to design and build heavy-lift aircraft that will meet the Army's stated requirements for vertical mounted aerial maneuver, there are important cost, time, and performance qualifications. Substantial research and

development, selection among alternative concepts, design, and development could take 15 to 20 years and could be extremely costly for a full-up 30-ton VTOL airlifter.

- Slow helicopter speeds, limited range, low operating altitudes and shipboard compatibility make helicopters unable to fill the role of a heavy lift vehicle for mounted aerial maneuver penetration of enemy territory.
- A fixed wing STOL aircraft is the lowest-cost, lowest-risk approach to the Army's sustainment needs. Fixed-wing aircraft can be easily designed to meet the payload and range requirements of mounted aerial maneuver. But, the fixed-wing requirement for landing zones that are relatively flat, obstacle-free, have sufficient load-bearing strength, and ability to withstand the braking stress of heavy aircraft is a serious impediment to their use in the deployment phase of operations. Precision air drop of some loads can alleviate some of these problems.
- Hybrid aircraft (with a combination of rotary- and fixed-wing characteristics) can be designed to meet the payload and range requirements of mounted aerial maneuver. They can have VTOL capability, but will be extremely expensive and entail substantial technical risk. Further, some of these aircraft will present major problems both at takeoff and landing because of strong down wash.

The ultimate heavy lift needs of mounted aerial maneuver may be best met by a composite fleet of fixed and hybrid aircraft. The benefits of heavy-lift, vertical takeoff and landing at remote enclaves will not disappear. Speed, striking power, mobility, medical evacuation, and extraction contingency in the initial phases of a sizeable remote operation, as well as flexibility in choosing enclaves, will make vertical lift very desirable. On the other hand, the lower cost, greater payload capability, greater availability, higher speed and altitude, and the possibility of direct delivery from the continental United States argue for participation of fixed-wing lifters as much as possible. Actions need to be taken now to ensure that options considered by the DoD Special Task Force recommended above are not foreclosed due to lack of research and development investment.

Recommendation: Because of the increased operational capability, agility, and survivability due to the potential greater speed, range and lift of 20–30 ton useful payload SSTOL and advanced tilt-rotor configurations, **initiate immediately science and technology programs to address the technology gaps,** including:

- SSTOL undercarriage
- advanced turboshaft engine and drive train
- advanced aircraft survivability equipment
- design and analysis of a 20–30 ton useful load advanced tilt rotor prototype

Engine Development

A new engine is essential to power a VTOL heavy lifter. The exact specifications for this engine depend on the VTOL aircraft concept, range, and payload. However, the thrust, weight-to-thrust ratio, and specific fuel consumption are beyond today's engine technology in any case.

Recommendation: **Initiate, immediately, a program to develop technology for a high-thrust, high-thrust-to-weight ratio, fuel efficient, reliable engine suitable for use in a VTOL heavy lift hybrid aircraft.** This is the pacing technology enabler for a VTOL heavy lifter.

Ship Considerations

Sea basing can enable mounted aerial maneuver with appropriate ship designs and procedural changes. But the same increases in complexity, technical risk, and cost that attend the development and use of heavy lift aircraft are also reflected in cost, operational complexity, and technical risk in ships capable of supporting aerial maneuver from the sea. As payload capacity increases, aircraft spot size grows substantially and reinforced landing decks add topside weight. Ships capable of supporting more than five or six 30-ton hybrid lifters will be larger than today's aircraft carriers. The one U.S. graving dock large enough for construction and maintenance of these ships is already reserved to support aircraft carriers. The task force finds that multiple vessels sized for five to six

hybrid lifter spots provide flexibility at a lower cost than larger ships. In any case, concepts of operations, lifters, ships and logistics requirements for mounted aerial maneuver must be optimized for the entire mission—they must be determined concurrently.

Recommendations:

- **Vertical heavy lifters that have aerial refueling capability and the ability to fold are more amenable to sea basing and will be capable of heavier vertical lifts than the notional design payload.**
- **If heavy vertical lifters are prototyped, shipboard compatibility should be part of the demonstration phase.**
- **Range and payload tradeoffs for candidate aircraft should be made within the context of the 100 nautical mile stand-off range for the sea base.**
- **The Department of Defense should fully investigate commercial ship conversions as a potential enabler for mounted aerial maneuver. The DoD Special Task Force recommended earlier could be a suitable organization for this investigation.**

Program Management

Technical, operational, and cost issues entailed in designing and producing a usable heavy-lift vehicle for mounted aerial maneuver will require careful tradeoffs. Some of the types of questions that need to be addressed are as follows:

- Are the range and payload necessary as specified?
- Can mounted aerial maneuver forces fight with light- and medium-weight FCS vehicles until an airfield can be prepared to handle fixed-wing aircraft capable of lifting heavier FCS vehicles?
- Can heavier vehicles be transported without ordnance, fuel, and armor and be reassembled at the enclave under protection of a lighter FCS force?

- Is the 500 nautical mile mission radius realistic?
- Where can sea-based heavy lifters reside in theater?

These and many other tradeoffs will have to be made by one person or a small group of people steeped in operational, technical, and cost knowledge for each of the services.

***Recommendation*: Based on the outcome of the DoD Special Task Force, establish a single decision-maker, in a joint-service organization, with capability and responsibility for producing the best overall capability.** Once multi-service requirements are harmonized, developing such a complex system-of-systems requires a single decision-maker. Development of a heavy-lift vehicle must be a joint service effort. The scale of the effort will require participation and resources from all the services, as its utility will apply to operations in each service.

Program Development

This study addresses both fixed-wing and rotary-wing heavy lifter options. Development of STOL fixed-wing heavy lifter candidate concepts is well within today's commercial and military aircraft development process. Development of rotary-wing options, however, will require a more complex science and technology program, and substantial research, development, and testing.

Hybrid heavy air lifters (such as tilt rotor vehicles) can only be thoroughly evaluated by testing full-scale prototypes. As with any new aircraft, prototypes facilitate cost evaluation, production scale-up, and test validation of flight characteristics. Experimentation is also especially important. Evaluating complex aerodynamic interactions of the sort encountered in these vehicles is beyond today's computational fluid dynamics modeling techniques. Scaling problems can only be reliably found by full-scale testing.

The services should anticipate and work toward a competition resulting in, at a minimum, the preliminary design of two aircraft to determine the best overall choice for a heavy-lift aircraft. The

development program of the winning design should incorporate two flight demonstrators. Technology and engine availability are the pacing items determining when such a competition can usefully be held.

Recommendation. **Because of the technical risks of developing an unconventional VTOL heavy lifter, select two contractors to compete in risk reduction, mission simulation, and preliminary design. Then select one to construct and test two prototype aircraft.**

In Summary

The task force concluded that VTOL/STOL heavy-lift aircraft can be developed and built to support future distributed combat concepts such as mounted aerial maneuver and sea basing. The military services must pay careful attention to assuming that the combat scenarios match the state-of-the-art of VTOL/STOL technology. Based on its analysis of the baseline case for the Army's mounted aerial maneuver concept, as well as its evaluation of the safety, survivability, vulnerability, and reliability of current rotary-wing aircraft, the task force recommends the following:

- **Safety, survivability, vulnerability, and reliability for rotary-wing aircraft should be vigorously pursued.** Regardless of any future distributed combat needs, this is a **must do** for today's operations.
- **Evaluate the appropriate mix of a VTOL/STOL heavy-lift aircraft fleet**—a small number of VTOL aircraft for force deployment, and STOL fleet for sustainment.
- **Consider planning operations around a VTOL heavy lifter**, capable of takeoff with greater than 20-ton loads with a reduced fuel load and subsequent aerial refueling.
- **If vertical heavy lifters are pursued, the Navy** should plan for future sea base platforms accommodating these aircraft.

Appendix A. Terms of Reference

THE UNDER SECRETARY OF DEFENSE
3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

ACQUISITION,
TECHNOLOGY
AND LOGISTICS

JUN 23 2005

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference – Defense Science Board Task Force on Future Need for VTOL/STOL Aircraft

You are requested to establish a Defense Science Board (DSB) Task Force to assess the features and capabilities VTOL/STOL aircraft should have in order to support the nation's defense needs through at least the first half of the 21st century.

Combat operations since the start of the Global War on Terrorism have included a wide variety of operations supported by helicopters: combat operations, counter-insurgency operations, security operations, as well as disaster relief and humanitarian assistance operations. Throughout this period and across the wide spectrum of operations conducted, Department of Defense (DoD) rotary wing aircraft have shown themselves to be poorly suited to many of the demands placed on them. As an example, helicopter related losses (for all causes) in Operation Iraqi Freedom are one of the leading causes of U.S. fatalities; in Operation Enduring Freedom, they are the leading cause of U.S. fatalities.

Aviation investment trends since the end of the Vietnam War have focused DoD efforts on improving the tactical air fleet. Those investments have paid handsome rewards. Conversely, the lack of investment in the DoD rotary wing fleet may have produced a fleet that is poorly suited for the current and future fights. The traditional assumption of a linear battlefield with a safe rear area has been rendered moot by the current operational realities. Rotary wing aircraft acquired based upon that assumption may not be properly designed or equipped to be survivable on the non-linear battlefield. Further, rotary wing aircraft that are demonstrating a lack of safety and survivability may fare even more poorly in the future.

An additional issue for the future is tactical heavy lift capability. This issue has been raised in a number of venues, including the DSB Task Force on Seabasing and the Army Science Board study on heavy lift rotary wing aircraft. Improving the safety and survivability of current and future rotary wing aircraft could be of great value if fully integrated with a heavy lift development capability.

In exploring these issues, the Task Force should examine the broadest range of alternatives and be guided by the following questions:

- What is the operational environment expected to be for the next 20-50 years?
- How will distributed logistics and other supporting functions be accomplished on a distributed battlefield?
- What is the role of vertical lift aircraft (helicopter and other technologies) in supporting joint forces across the spectrum of conflict?
- What capabilities must a tactical vertical lift or STOL aircraft possess in order to provide that role?
- How best do we improve and enhance the current fleet of aircraft to that level of capability?
- What future capabilities should the Department focus development efforts on in order to ensure the Combatant Commanders are provided the necessary capabilities in the future?
- What are the synergies that are possible from heavy lift aircraft development that could enhance the safety and survivability of current and future rotary wing aircraft?
- What technologies are needed to enable future capabilities?

The study will be sponsored by me as the Under Secretary of Defense (Acquisition, Technology and Logistics), and by the Director, Defense Systems. Dr. William Howard and ADM Donald Pilling, USN (Ret), will serve as the Task Force Co-Chairmen. Mr. Michael Walsh, OUSD(AT&L), will serve as the Executive Secretary and LCDR Clifton Phillips, USN, will serve as the Defense Science Board Military Assistant.

The Task Force will be operated in accordance with the provisions of P.L. 92-463, the "Federal Advisory Committee Act," and DoD Directive 5105.4, the "DoD Federal Advisory Committee Management Program." It is not anticipated that this Task Force will need to go into any "particular matters" within the meaning of Section 208 of Title 18, U.S. Code, nor will it cause any members to be placed in the position of acting as a procurement official.

Kenneth J. Krieg

Appendix B. Task Force Membership

CHAIRS

Name	Affiliation
Dr. William Howard	Private Consultant
ADM Donald Pilling, USN (Ret.)	LMI

TASK FORCE MEMBERS

Dr. Joseph Braddock	Private Consultant
RADM Skip Dirren, USN (Ret.)	Battelle
Mr. Alan Ellinthorpe	Private Consultant
Dr. Paris Genalis	Private Consultant
Mr. Sherman Mullin	Private Consultant
Dr. George Schneiter	Private Consultant
Mr. George Singley, III	SAIC
Mr. David Swain	Private Consultant
Dr. David Underhill	Johns Hopkins Applied Physics Laboratory
Gen Mike Williams, USMC (Ret.)	LMI

EXECUTIVE SECRETARY

Mr. Michael Walsh	Office of the Under Secretary of Defense for Acquisition, Technology and Logistics

DSB REPRESENTATIVE

CDR Clifton Phillips, USN	Defense Science Board Office

GOVERNMENT ADVISORS

BG Stephen Mundt, USA	HQDA G-3/5/7 DAMO-AV
Brig Gen Scott Wuesthoff,USAF	HQ, AMC/A5

RDML John Bowling, USN	N75B
Col Frank Boynton	Headquarters U.S. Marine Corps

LtCol Dave Dowling, USMC	Headquarters U.S. Marine Corps, Department of Aviation
Maj. Rick Fuerst, USMC	Headquarters U.S. Marine Corps, Department of Aviation
Mr. Edmund Hubard	HQDA DCS G-3
LCDR Craig Huffnagle, USN	OPNAV-N753G
Dr. Spiro Lekoudis	ATL/DDR&E/DUSD (S&T)
Mr. Nick Linkowitz	Headquarters, U.S. Marine Corps
BGen Martin Post, USMC	Assistant Deputy Commandant for Aviation
BGen (Sel) Robert Walsh	Headquarters U.S. Marine Corps
Mr. Mike Watts	NASA Langley Research Center

STAFF

Ms. Barbara Bicksler	Strategic Analysis, Inc.
Ms. Stacy Zelenski O'Mara	Strategic Analysis, Inc.
Ms. Grace Johnson	Strategic Analysis, Inc.
Ms. Wilma Simms	Strategic Analysis, Inc.

Appendix C. Presentations to the Task Force

Name	Topic
JANUARY 30 – 31, 2006	
Colonel Frank Boynton, USMC Deputy Director of the Joint Vertical Lift Task Force	Investing in Improving Rotary-Wing Systems: What's the DOD Imperative?
Dr. John Gordon Senior Analyst, RAND	2005 RAND Study: Navy Heavy Lift Aircraft Study
Dave Manley Manager, Advanced Airlift Systems Boeing Technology	STOL Capabilities for Tactical Heavy Lift
Mr. Chris Martin Research Staff, Science & Technology Division, IDA	Rotorcraft Physics and Science and Technology Needs
Hal Rosenstein Manager, Developmental Engineering for Advanced Rotorcraft, Boeing Technology	Boeing Perspective on Future Needs for VTOL Aircraft – Emphasis on Heavy Lift
General Jack Woodmansee (Ret.) Chair, ASB Study on Future Force Aerial Systems Capabilities	Army Science Board Study on Future Force Aerial Systems Capabilities
FEBRUARY 22, 2006	
Mr. Scott McMichael System Studies and Simulation, Inc.	Army Force Projection Overview: Strategic Responsiveness and Operational Agility and Future Requirements for Advanced Airlift SSTOL and HLVTOL
Mr. Michael Coulman and Mr. Tomm Wood Bell Helicopter / Textron	Future Capabilities for VTOL/STOL Operational Level Heavy Lift
Mr. Thomas Sudbeck, USMC (Ret) Concepts Branch, Marine Corps Warfighting Laboratory	U.S. Marine Corps Operating Concepts For a Changed Security Environment
Mr. Terry Pudas Acting Director, Office of Force Transformation	Transforming National Security: The Logic, the Dynamic, the Opportunity
Dr. Tony Tether Director, Defense Advanced Research Projects Agency	Early Entry Systems Study

Mr. Chris Norden Assessment Group Leader, Turbine Engine Division, Air Force Research Laboratory	VSTOL/STOL Turbine Propulsion Technology

MARCH 21–22, 2006

Colonel Tracy Goetz, AFSOC	AFSOC Perspectives on the Future Security and Operating Environment
MG Robert Scales, USA (Ret), Colgen	Operational Vision
Dr. Mike Scully U.S. Army AMRDEC (RDECOM)	Systems Concepts Trades
Dr. Barnes W. McCormick Penn State University	VTOL/STOL Fundamentals
Col. Peter DeFluri, OSD PA&E	Mobility Capability Study
Chris Van Buiten, Teresa Carleton, and Mac McClaren Sikorsky Aircraft Corporation	Sikorsky Perspectives on the Future of Vertical Flight

APRIL 10–11, 2006

Col Fred Wenger, USMC Marine Corps Safety Division	Marine Corp Safety
LT James Mason, USN, Navy Safety Center	Navy Safety
Mr. Joe Angello OUSD (Personnel and Readiness)	The Secretary's Mishap Reduction Initiative
Mr. Kurt Garbow Office of the Deputy Assistant Secretary of the Navy (Safety)	Military Flight Operations Quality Assurance
LtCol Stephen Waugh, USMC USMC Operations for Air ASW, Assault, & Special Mission Programs	Naval Aviation Enterprise/Rotorcraft/Vertical Lift Technology Workshop & Prioritized Results
Maj Bill Spangenthal, USAF, HQ Air Mobility Command	Next Generation Intra-Theater Mobility Capability
Mr. Don Woodbury, DARPA Mr. Jay Groen, GBA	Heliplane
Ms. Darlene Costello	OSD Naval Warfare – Sea Basing and MPF (F)
Mr. Sam Powel, GE Aviation	Propulsion Technology for VTOL/STOL

MAY 24–25, 2006

Mr. Mike Watts, NASA	Fundamental Aeronautics Subsonic Rotary Wing
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CDR William Lawler EW Programs, DOT&E, USN	DOT&E Discussion
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Mr. John Gossett, LAIRCM Squadron, USAF Mr. William Taylor, AFRL/SNJW	Countermeasures Systems
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JUNE 21–22, 2006

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Mr. Abe Karem President, Karem Aircraft, Inc	Optimum Speed Tilt Rotor Technology
Mr. Barth Shenk AFRL/VAOT, Air Vehicles Directorate	Air Mobility Studies and Technologies Overview
Dr. Michael P. Scully U.S. Army AMRDEC (RDECOM)	Long Range VTOL Heavy Lift

Appendix D. Mounted Vertical Maneuver

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POINT:

Mounted Vertical Maneuver: A Giant Leap Forward in Maneuver and Sustainment

Brigadier General Robin P. Swan, U.S. Army, and
Lieutenant Colonel Scott R. McMichael, U.S. Army, Retired

FOR ALMOST 70 YEARS, the U.S. military has possessed and employed a capability to conduct strategic, operational, and tactical maneuver by air with light forces through airborne operations. Nearly 50 years ago, the Army expanded that capability by developing the means to conduct air assault operations with dismounted units. Readers of *Military Review* can easily visualize these kinds of operations and recognize the advantages they provide to joint and ground commanders. However, their limitations are also well known. Once positioned by air, dismounted forces are limited in tactical reach, lethality, and survivability. In most situations, commanders must quickly reinforce air-delivered light forces with other capabilities to fully exploit the positions of advantage achieved and to generate meaningful operational momentum. This effort often requires considerable time and is dependent as well on the availability of strategic airlift and the improved airfields needed for their employment.

In contrast, imagine having the ability to move mounted forces by air directly to positions close to objective areas, then having that mounted force seize critical objectives without extensive pauses or the need for immediate reinforcement. For roughly the past 10 years, the Army has devoted significant efforts to investigating the near-revolutionary effects it might achieve with such intra-theater operational maneuver and tactical vertical maneuver.

Mounted vertical maneuver (MVM) is the Army's concept of a future capability to move mounted, protected forces by air across extended distances, from positions either outside or inside the boundaries of the joint operations area (JOA), to strike directly against critical enemy objectives throughout the depth and breadth of the battlespace. If realized, MVM will provide extraordinarily versatile new options that will extend the reach and power of future joint force commanders (JFCs). It will enable JFCs to respond more effectively to opportunity or uncertainty, to conduct forcible entry, to isolate portions of the battlefield, to exploit success, and to expose the enemy's entire force to direct attack by mobile ground forces at any point. Furthermore, MVM could be one of the key means future JFCs use to accelerate the defeat of the enemy by combining the defeat mechanisms of *dislocation* and *disintegration*, as described in both joint and Army futures concepts. The operational benefits that this kind of capability affords are so great that the Army thinks MVM should be pursued as a national program.

Mounted vertical maneuver is a fundamental component of the Army's family of future concepts for the future Modular Force. It provides a means

Brigadier General Robin P. Swan is Director, Concept Development and Experimentation Directorate, Army Capabilities Integration Center, Training and Doctrine Command (TRADOC). He is a graduate of Indiana University of Pennsylvania, the U.S. Army Command and General Staff College, the School for Advanced Military Studies, and the Armed Forces Staff College. He has also been a National Security Program Fellow at the John F. Kennedy School of Government, Harvard University. BG Swan has served in numerous command and staff positions in the United States, Germany, Hungary, and Bosnia.

Lieutenant Colonel Scott R. McMichael, U.S. Army, Retired, is a director and regional manager for System Studies & Simulation, Inc. He has supported U.S. Army TRADOC as the senior concept developer for the past six years and is the primary author of the Army's future capstone concept, TRADOC PAM 525-3-0, The Army in Joint Operations. *A former artillery officer and Soviet foreign area officer, LTC McMichael is the author of* Stumbling Bear: Soviet Military Performance in Afghanistan *(Brasseys' UK, 1991) and was a major contributor to* Slaughterhouse: The Encyclopedia of the Eastern Front *(The Military Book Club, Garden City, NY, 2002). He publishes widely in defense journals.*

Artist's rendering of a mounted vertical maneuver operation.

to fully exploit the advanced capabilities of the Army's medium-weight forces, including existing Stryker Brigade Combat Teams (BCTs) and BCTs that will be equipped with the Future Combat Systems (FCSs) in the next two decades. The concept is equally applicable to the maneuver and air-based sustainment of any light, motorized, or medium-weight mechanized forces that may be mission-tailored into future combined and joint task forces. As this article will demonstrate, MVM is relevant across the full range of military operations, including homeland security. Moreover, it is not merely an Army idea, but has substantial support from other elements in the U.S. defense community.

Historical Background

How new is the idea of MVM? One hesitates to mention the imaginative "mobile infantry drops" of Robert Heinlein's *Starship Troopers* (1959) simply because critics of the MVM concept often dismiss the book's ideas, quite wrongly, as pure science fiction. Brigadier General Richard Simkin's highly admired book *Race to the Swift: Thoughts on 21st Century Warfare*, published in 1985, is probably the best known early work that addresses the capability.[1] In it, one finds a scholarly treatment, well grounded in military theory, of the need for a mounted vertical maneuver capability. To quote Simkin: "The rotor is to track as track is to boot." Simkin clearly viewed the development of an MVM capability as both feasible and necessary to maintain a maneuver and mobility advantage in future conflict.

The former Soviet Union actually developed a capability for mounted vertical maneuver within its airborne forces. Soviet airborne divisions included three airborne regiments, each containing three airborne battalions equipped with light armored assault vehicles (BMDs). In the Soviet-Afghan War (1979-1989), the Soviets used these forces most often in direct action against the *mujahideen*, almost always deploying them into action by helicopter. Soviet air assault brigades were similarly structured, with two parachute-trained and two heliborne battalions, the latter equipped with BMDs and employed in the same manner. A variety of authoritative sources note the extraordinary mobility and agility of these forces during that war and uniformly confirm their effectiveness, characterizing them as the units feared most by the Afghan resistance.[2] Soviet doctrine at that time also envisioned using these formations for deep operational maneuver in theater war (a feature the U.S. Army touts as fundamental to the MVM concept).

The German Army, too, experimented with the concept of mounted vertical maneuver during the cold war. Viewing the Soviet capability for deep penetrations by armored formations as a major threat, the Germans examined the utility of moving battalions and brigades equipped with light armor and anti-tank guns rapidly by helicopter, to block any deep penetrations by mobile Soviet forces.

Serious U.S. Army investigation of what was then called air-mechanization began in the mid-90s under the auspices of the U.S. Army Training and Doctrine Command (TRADOC). With the initiation of the Army After Next (AAN) program under Chief of Staff of the Army Dennis Reimer, TRADOC began a series of annual war games, supported by pre- and post-analytical excursions, that featured a variety of air platforms and organizational structures employed in MVM over operational and strategic distances. Concept exploration was pursued through the Army Transformation War Game series from 2000-2003 and subsequently continued through the Unified Quest series of annual war games in support of Future Force (and future Modular Force) development.

Since 2001, TRADOC has imported the MVM concept into war-gaming venues with the Marine Corps, Navy, Air Force, Joint Forces Command, and Office of the Secretary of Defense. The concept has

also informed three Defense Science Board (DSB) panels (2004-2006) and been identified as one of 10 critical future capabilities recommended for development by the DSB Sea-basing Task Force.

During the course of this eight-year period, TRADOC examined a variety of rotary, tilt-rotor, and fixed-wing platforms with Vertical and Super Short Take-Off and Landing (VTOL and SSTOL) profiles, as well as various organizational structures and equipment complements.[3] The command projected an assortment of other joint enablers, such as airborne lasers, persistent and pervasive ISR (Intelligence, Surveillance, Reconnaissance), networked joint fires, and advanced escort aircraft, that would support large-scale vertical maneuver. Concept planners also examined vertical maneuver within the context of joint sea-basing and produced a maturing parallel concept for the temporary basing of advanced vertical-lift capabilities on board a variety of sea platforms, such as converted container ships and aircraft carriers. This supporting concept, known as the Afloat Forward Staging Base, was explicitly incorporated into the Sea-basing Joint Integrating Concept (JIC). It is currently influencing several naval research and design efforts.[4]

In short, the MVM concept is founded on a comprehensive body of work carried out over a long period of time and exposed to a wide variety of experimental conditions, within a broad spectrum of service, joint, and defense forums.

Conceptual Foundations

Lessons learned from active operations around the globe comprise one of the primary foundations of the MVM concept because they reveal known operational shortfalls that MVM capabilities can address beneficially. Among the more important known shortfalls are—

- Absence of an agile heavy-airlift capability that can deliver forces and stocks to the point of need.
- Runway-dependent fixed wing airlift, leading to excessive dependence on improved airfields.
- Unsuitability of fixed-wing aircraft to conduct air-based sustainment into forward operating areas.
- Virtually non-existent capability to conduct forcible entry operations by air with mounted forces (except in a follow-on, airlanding framework).
- Tactical vertical maneuver and operational maneuver by air limited exclusively to light, dismounted forces because of the non-existence of suitable aircraft.
- Limited capability for ground force self-deployment over operational distances directly to the fight.
- Absence of capability to conduct vertical maneuver or sustainment by air from sea-based platforms except by dismounted forces, limited to tactical depths.
- Shortfalls in air refueling capability that could extend the depths to which non-strategic airlift can operate.

These deficiencies have serious operational consequences. Overall, they severely curtail the options available to joint force commanders to exploit the vertical dimension with ground forces. In addition, they reduce the operational agility of the joint force and limit simultaneity, while increasing the predictability and vulnerability of operations to enemy interdiction. Finally, they exacerbate the need for operational pauses and simplify the operational challenges facing any future adversary.

Assured access challenge. The emerging Joint Operational Environment (JOE) also drives the MVM concept.[5] For several years, the JOE strongly emphasized that future U.S. forces will likely face an increasingly complex challenge to regional access. The significance of this challenge was explicitly recognized by the 2001 National Defense Panel and the 2002 and 2006 Quadrennial Defense Reviews. Several components of this challenge were clearly apparent in recent operations.

The first component is political in nature. The United States can no longer take for granted that it will have the political access to theater staging bases, ports, or overflight rights that it has enjoyed in the past. Adversaries will, in fact, take overt action to limit U.S. regional access through a variety of means, including diplomatic action, threats, and coercion. Even erstwhile allies may deny the United States political access, as Turkey did during the force build-up for Operation Iraqi Freedom. In the future, responsible joint planners must avoid overly optimistic assumptions about regional access. They must prepare for the likelihood that U.S. forces will have to conduct deployment, forcible entry operations, and sustaining operations from more distant intermediate staging and forward operating bases than has been the case in the past.

Mere geography can also pose access challenges. Although it is reasonable to expect that U.S. forces will continue to operate largely within the littoral regions of continental land masses, that may not always be the case. Operation Enduring Freedom (OEF), for example, represents a notable exception to that rule. Had the United States not been able to secure basing rights in Pakistan and Central Asia, its ability to carry out OEF objectives would have been gravely compromised.

Complex terrain and immature infrastructure within operational theaters further complicate assured access. A long-range vertical maneuver and sustainment capability could be one of the most important means of overcoming these kinds of access limitations.[6] (See figure 1.)

Figure 1. Operational Example of MVM, Task Force 58, Afghanistan. From a sea base in the Indian Ocean, armored forces could have been introduced at night and sustained without forward operating base or airfield requirements.

Third, future adversaries will challenge U.S. access at the strategic, operational, and tactical levels. *Strategic preclusion* may rely primarily on diplomatic action, coercion of U.S. regional allies, or direct use of force against strategic deployment capabilities. *Operational exclusion* involves enemy use of physical means to deny, degrade, and delay the entry of U.S. forces into the theater. Adversaries will likely also conduct *tactical denial* to prevent U.S. use of air and sea entry points anywhere within the joint operations area.

Physical methods and capabilities to deny access will range from high- to low-tech and be applied, potentially, at any point in the U.S. land-sea-air power projection chain of operation from home base to tactical assembly areas. At the high end, the most capable enemies will employ theater ballistic missiles (TBMs), air- and ground-launched cruise missiles, advanced integrated air defense systems, sea mines, submarines, space and undersea denial operations, and NBC munitions. Farther down the scale, anti-access measures could include intentional contamination, wide-spread employment of landmines and complex obstacles, direct action by special operations forces, terror strikes, use of human shields to deter attack of key anti-access capabilities, and information warfare to degrade automated elements of the U.S./coalition deployment command, control, and planning process.

All of these challenges—political, geographic, and enemy anti-access action—will be exacerbated by the existing shortfalls enumerated earlier. Thus, it is imperative that the defense community empower future JFCs with capabilities that enable U.S. forces to adjust to and overcome such challenges. Mounted vertical maneuver that is not dependent on easily targeted airfields is one of the best means of meeting those challenges.[7]

Joint concepts. Although the MVM concept is most closely associated with the Army, many foundational joint concepts identify capability gaps in this area and point to the future need for vertical maneuver and sustainment. The Capstone Concept for Joint Operations and a number of other approved joint operating and joint integrating concepts all

identify future operational requirements for MVM capability.[8] These joint concepts recognize that future joint operations must account for the assured-access challenge. In addition, virtually all of them project that U.S. joint forces will conduct simultaneous, non-contiguous operations distributed broadly throughout the JOA. The joint concept of distributed operations is predicated on JFCs having the ability to dispose forces and focus operations against those enemy forces and capabilities whose defeat will lead most quickly and effectively to overall victory. This approach is in contrast to the highly sequential and highly phased campaigns of the past. It enables the JFC to combine the traditional defeat mechanism of destruction with those of dislocation and disintegration.[9]

Figure 3 below describes how JFCs will likely want to conduct campaigns in the future. Clearly, the ability to conduct non-contiguous, distributed operations within the land domain represents transformational change that will present significant operational benefits to the future joint force. Mounted vertical maneuver and sustainment are critical to enabling this kind of transformational change.

The MVM and Sustainment Concept

The centerpiece of the MVM concept is the ability, by means of advanced theater airlift platforms, to maneuver and sustain operationally significant, combat-configured, medium-weight mounted forces to tactical and operational depths for immediate employment against objectives of particular significance. The future Modular Force will execute joint-enabled operational maneuver by air to extend the reach of the JFC, to enable him to respond to opportunity or uncertainty, to isolate or dominate specific portions of the battlefield, and to exploit success. (See figure 2.) Operational *movement* positions or repositions forces to secured positions of advantage to dislocate enemy forces or place them at a disadvantage for subsequent operations. In contrast, operational *maneuver* repositions forces in proximity to objective areas for immediate operations, potentially exposing the entire enemy area of operations to direct attack.[10]

Originating from either land- or sea-based staging areas and terminating in a vastly expanded number of entry points, vertical maneuver manifestly enables

Strike with fires and maneuver throughout enemy's entire dispositions ★★★
- Lift combined arms formations with integrated sustainment throughout the JOA
- Conduct operational maneuver with mounted and dismounted forces ★★★
- Conduct air mobile strike operations against high value, high payoff targets
- Deny the enemy key terrain and facilities
- Strike from bases outside the theater

These are the ways and means to achieve dislocation and disintegration

Maintain continuous, high-tempo operational pressure ★★★
- Fully exploit the third dimension and the non-contiguous battlespace
- Mass effects without massing forces
- Rapidly move and shift forces and fires against critical objectives by air and sea
- Conduct forcible entry at any point, in any phase of the campaign
- Exploit a ground-air mobility advantage over a ground-bound opponent

Sustain high-tempo, distributed operations within non-contiguous framework
- Augment ground LOCs with air lines of communications
- Sustain by air from sea-based stocks and supplies
- Distribution sustainment directly to units in forward areas
- Significantly reduce sustainment demand ★★★

★★★
Transformational Change

Figure 2. How will the future joint force commander want to fight?

distributed operations within a non-continuous battlespace and permits direct attack against enemy centers of gravity with maneuver and fires. It can also be used to seize key terrain and decisive points. Because it compels the enemy to defend in all directions, it constrains enemy efforts to mass, reinforce, sustain, and resynchronize forces and operations. In all cases, it is intended to have a definitive impact on the course and outcome of major operations, often accelerating decision or setting conditions for subsequent phases of the campaign.

Operational maneuver by air depends on the suppression or destruction of enemy air defenses and security of the landing area. It will normally be most effective when it is supported by the rapid advance of ground-mobile forces to reduce risk, reinforce, and exploit the results of the air-based maneuver. At the tactical level, vertical maneuver will often lead to rapid tactical decision, shortening the duration of battles and enabling forces to move quickly from one engagement to the next without a significant operational pause. In all cases, forces must be capable of reorientation against follow-on objectives with minimum delay. Subsequent to force insertion, the same airlift assets will then be employed to sustain those forces until ground lines of communication are established. In this manner, vertical maneuver changes the geometry of the battlespace and mitigates the assured-access challenge at the operational and tactical levels. (See figure 3.)

Planners envision that the future Modular Force structure will conduct operational-level vertical maneuver and sustainment by multiple battalions, either mounted, dismounted, or mixed. Joint allocation of advanced heavy-lift VTOL and fixed-wing (SSTOL and current aircraft) assets will be required to generate and sustain operational maneuver by one or more brigades in close sequence.

Relevant to All Operations

The discussion above necessarily focuses on major combat operations as the best means of describing the benefits of the MVM concept. However, the broader relevance of MVM across the range of military operations is evident. Capabilities that enable MVM will also materially improve counter-WMD (Weapons of Mass Destruction) and other special operations due to extended range, higher payloads, improved terrain negotiation, greater simultaneity, expanded operational access, and increased options for force employment. Similarly, the inherent requirement of large-scale stability operations for widely distributed sustainment and maneuver of rapid, mobile response forces over extended distances will be better satisfied by MVM

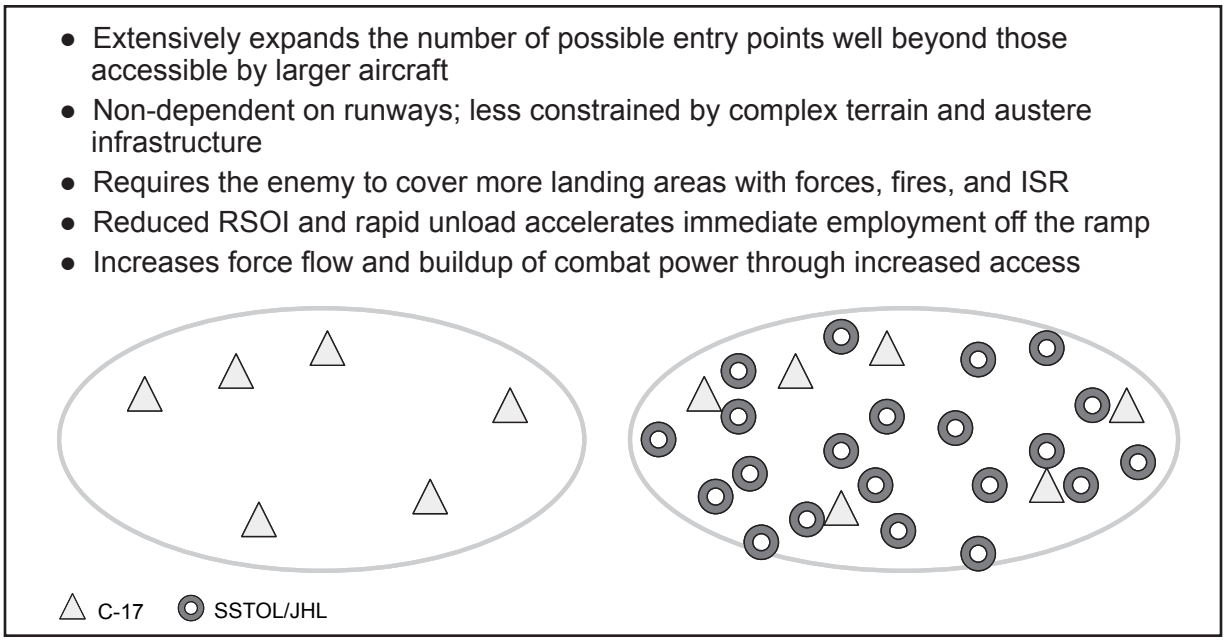


Figure 3. Vertical maneuver addresses the assured access challenge.

capabilities. Their applicability to border-security operations against hostile neighbors or to the isolation of enemy sanctuaries is also clear.[11] Furthermore, vertical maneuver would improve the U.S.'s ability to strike terrorists with mobile ground forces when remote, long-range fires won't suffice.

Vertical maneuver capabilities will also improve U.S. responsiveness to natural disasters and humanitarian crises. These crises often occur in remote regions or in regions hampered by austere transportation infrastructure (or infrastructure damaged in the course of the disaster). Recent contingency operations highlight the efficacy of MVM capabilities, particularly VTOL with extended range and payload. Since MVM capabilities can also be employed to move, maneuver, or sustain allies who may be hindered by the lack of even rudimentary airlift capabilities, they may also be an important factor in strengthening coalitions.

Keys to a Concept of Operations for MVM

In today's environment, an operation to move mounted forces by air is highly constrained, first by the number of C-17 aircraft allocated from the force pool, and secondly by the number of improved airfields and the maximum-on-ground capacity (MOG) of those airfields at both ends. Generally, these operations are highly sequential, relatively predictable (because of their dependence on airfields), displaced a considerable distance from objective areas, and long in duration.

In contrast, the airlift platforms envisioned for MVM will maximize the simultaneity of an air operation by using multiple departure points and landing areas—not just improved airstrips, but also clearings, roads, agricultural fields, playing fields, large parking lots, golf courses, dirt strips, and other unimproved sites. Moreover, the use of multiple flight paths will enable the simultaneous delivery of formations in volume rather than sequentially, thereby reducing exposure time to enemy detection and complicating hostile engagement.

Planners will select landing sites based on their tactical proximity to the objective area (roughly 20-100 km, depending on the enemy's ability to detect and oppose) and to each other in order to enable rapid assembly and forward movement for immediate attack. Aircraft will move mounted platforms internally loaded, fueled, and armed with crews on board. Although larger insertions will normally be desirable, landing sites will be sized no lower than platoon level and arranged in time and space to permit rapid assembly to battalion strength. Aircraft characteristics will permit rapid egress to reduce exposure on the ground for both air and ground elements. If suitable airfields are available, current airlift may also be used to move selected elements of the committed force that are not immediately required for assault. Naturally, planners will consider a variety of factors in building the operation, to include the types and numbers of aircraft available and the need to sustain committed forces by air lines of communications through and beyond the operation's initial stages.

As noted earlier, vertical maneuver will be supported by a suite of dedicated joint capabilities to ensure protection from enemy detection and engagement during flight and landing, to enhance situational awareness, and to establish favorable conditions in the objective area. En route updates will keep leaders abreast of changing conditions and permit adjustments to flight paths and landing areas, if required.

Operationalizing the Concept

The first new capability required to operationalize MVM is advanced theater airlift. *Marginal improvement over current theater airlift will not be sufficient to enable vertical maneuver*. Fundamental requirements for new airlift include:

- VTOL or SSTOL capability to avoid reliance on improved airfields and to increase the number of entry points that can be employed simultaneously.
- Payload weight and volume sufficient to move one or more medium-weight armored vehicles with crews, fuel, and ammunition (26-30 tons, sized to Stryker and FCS).
- Extended unrefueled range (500 nautical miles) with maximum payload and improved speed (250-300 knots/hour).
- Ability to fly at altitude to reduce exposure to short-range surface-to-air missiles.
- Suitability for use in air-based sustainment.

VTOL and fixed-wing SSTOL have advantages and disadvantages when compared to each other in operational scenarios. Generally, fixed-wing SSTOL will fly faster, further, higher, and with larger payloads. On the other hand, VTOL aircraft

provide substantially more access, permit more simultaneity, have a higher degree of agility, may be more night-capable, and enable insertions closer to objective areas. Survivability considerations appear to be comparatively equal.

Currently, the Army places highest value on the qualities of access and operational agility, favoring VTOL over SSTOL (or STOL) capability for those reasons, although the combination of the two capabilities is the most desirable approach. Certainly, the cost to research, develop, and acquire VTOL or SSTOL airlift will be substantial, as it is for any new, non-incrementally developed major system, but numerous credible studies have demonstrated reliably that heavy-lift VTOL development is technically feasible.

Survivability. Ensuring aircraft survivability throughout the course of an MVM operation is a significant challenge that the Army fully recognizes. The proliferation of man-portable air defense missiles (MANPADS) and projected improvements in enemy capabilities to detect and oppose vertical maneuver are major threats. The complexity of the challenge demands a holistic solution set with the following components:

- Aircraft equipped with passive and electronic protection systems that deny, degrade, or deceive enemy detection and acquisition, coupled with active protection systems that effectively neutralize enemy fires in flight.
- Ability to fly at altitude for the majority of transit, with terrain-masking flight profiles nearing terminal points.
- Improved capability for joint suppression of enemy air defenses and the networks supporting them.
- Persistent surveillance of landing areas, tied to active means for suppression of enemy capabilities to oppose insertions.
- Neutralization of the MANPADS threat.[12]
- Deception operations.
- En route updates that enable commanders to adjust operations in flight.

Naturally, the development of effective tactics, techniques, and procedures (TTP) will also be important. TTP will address the use of escort aircraft, pathfinders, and special operations forces to monitor and assist in setting appropriately secure conditions and to enhance situational awareness of landing areas.

Joint fires. As a joint-enabled operation, MVM will require support by long-range and air-delivered joint fires characterized by high levels of synchronization, timeliness, positive control, and accurate targeting of enemy capabilities positioned to oppose the operation. Research suggests that both lethal and nonlethal (e.g., electronic suppression) munitions will be especially relevant for MVM. The quality and diversity of joint fire support must also be sustained during the ground assault phase of the operation.

Situational awareness. Vertical maneuver operations demand a high level of situational awareness because of their vulnerability, complexity, and simultaneity. Conditions in objective areas and enemy capabilities to oppose the operation must be identified with a high degree of fidelity. Again, improvement in capabilities for persistent surveillance and en route updates to situational awareness are imperative. Although the complete elimination of uncertainty is neither likely nor necessary, it is reasonable to expect that future advances will enable an appropriately high quality of situational awareness to support MVM operations.

Recent Analytical Efforts

While it is true that the Army has taken the lead in developing the MVM concept, joint and multi-service organizations have recently undertaken several significant analytical efforts. The most important of these is the Joint Vertical Airlift Task Force (JVATF). Directed by the Assistant Secretary of Defense for Acquisition, Technology, and Logistics (ASD/AT&L) in 2004, the JVATF was based on OSD's assessment that the lack of a heavy-lift VTOL capability is the military's most critical rotary-wing capability gap. After several months of preliminary study, the JVATF evolved to pursue two parallel joint research efforts focused on what is now called Joint Heavy Lift (JHL). Those two efforts—concept refinement and requirements analysis—are cosponsored by OSD and the Army, with joint participation in integrated product teams enriched by industry participation. The eventual goal is to complete an Initial Capabilities Document for approval by the Joint Requirements Oversight Council.

The concept refinement effort comprises modeling and simulation-based evaluation of five different technical approaches to JHL in a variety of

scenarios, missions, and environmental settings.[13] In parallel, a 30-person joint government team of scientists and engineers is conducting cost and technical feasibility analysis for the five technical approaches. Overall, these efforts represent the most authoritative operational and technical analysis to date in the area of heavy-lift VTOL.

Joint sea-basing is another area in which the MVM concept has been vetted with some degree of joint rigor. This article previously cited the incorporation of the Afloat Forward Staging Base concept for sea-based vertical maneuver within the Sea-basing Joint Integrating Concept. In 2005, the Army also partnered with the Marine Corps in a bilateral analysis of sea-basing capability gaps that has informed the refinement of the Joint Integrating Concept and been endorsed by the Joint Staff. That analysis explicitly cites MVM as an existing capability gap.

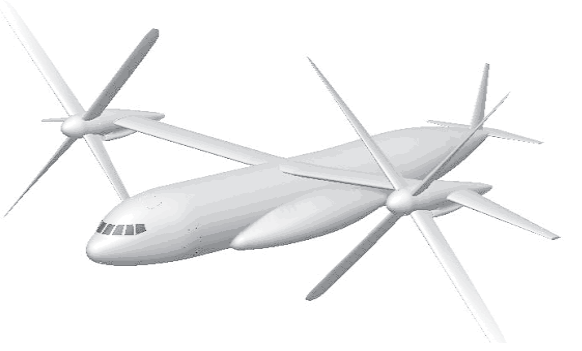
Third, the Defense Science Board HLVTOL/SSTOL Task Force is nearing completion of its 18-month study and is expected to release its draft report in early 2007. The MVM concept constitutes an important component of that study. The Army eagerly awaits its release.

Finally, the commander of the U.S. Transportation Command directed the initiation of the Joint Future Theater Airlift Assessment (JFTACA) in October 2006. Its stated purpose is to analyze potential joint-force theater airlift implications facing the future joint warfighter. JFTACA will examine non-materiel and materiel solutions such as Joint Heavy Airlift, the Advanced Joint Air Combat System, the Joint Precision Airdrop System, and other emerging technologies that may be available during the 2015-2025 time period. Targeted for completion in late 2007, the JFTACA concept-based analysis study may culminate with prioritized recommendations for both materiel and non-materiel solutions to theater airlift shortfalls. TRADOC is leading the Army's participation in the study. The MVM concept and the body of analytical work supporting it, including the Joint Heavy Lift project cited above, will inform the study comprehensively.

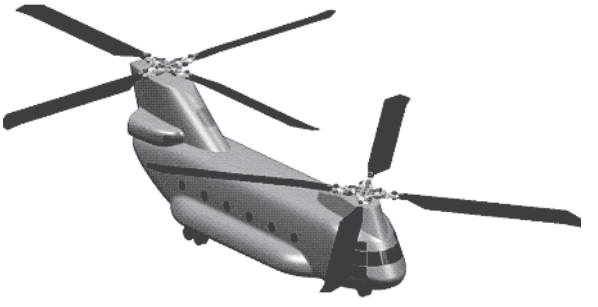
The Critics

The MVM concept is not without its critics. It must be stated forthrightly that some of the objections emerge from less than a full understanding of the concept and often result in its mischaracterization or oversimplification. For example, one recent evaluation of the concept characterized it largely as being a means of rapid strategic deployment, whereas the Army clearly views MVM primarily for employment at the operational and tactical levels. Critics also tend to focus on the significant challenges to MVM's realization without examining the ways and means by which these challenges can be overcome. Overall, the primary objections to the concept are—

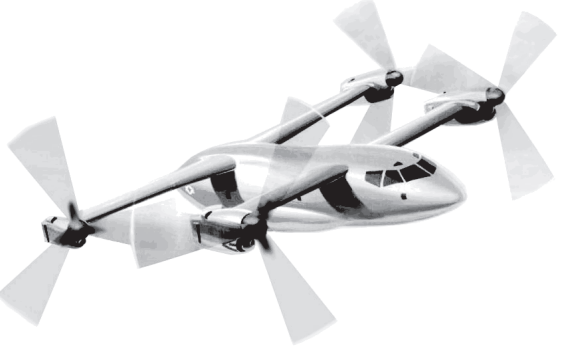
Slowed rotor tilt rotor



Advanced tandem rotor



Quad-tilt rotor aircraft



- *The risks are too great*. This argument rests largely on assertions that MVM will be too vulnerable to enemies employing inexpensive off-the-shelf capabilities, such as MANPADS, and that sufficient levels of situational awareness to support MVM will never be achieved. The Army perspective is that there is risk in every operation, but it can be dealt with effectively by using a holistic systems-of-systems approach with redundant capabilities.[14] One might also observe that the "too risky" argument is an old one that often accompanies debate over new programs. With respect to situational awareness, it would be difficult to identify any capability that is receiving more attention today for improvement across the joint force. The Army clearly recognizes the importance of situational awareness and understands its challenges. Given the ongoing work in this area it is possible to be confident about continuing advances despite the complex requirements of vertical maneuver.
- *MVM is unnecessary*. The Army considers that the need for MVM has been sufficiently established by the uniform concern within the defense community about future assured-access challenges; the emergence of a non-contiguous battlefield framework characterized by widely distributed operations; the operational demands of the war on terrorism; the rising importance of counter-WMD operations; the frequent involvement of U.S. forces in disaster relief and humanitarian crises; the lessons of recent operations; and strong support within joint concepts for maneuver and sustainment throughout the depths of a theater in conflict.
- *History says it cannot be done today; ergo, it cannot be done in the future*. This is another old argument that has accompanied the development of almost every major new advance in military capability, from the tank to the aircraft carrier. History is usually a good teacher, but it does not define the future. It can be a bad teacher if used selectively or if historical examples are mischaracterized.[15] Fortunately, the American military experience in modern times is to find a way to develop and employ new capabilities once they have been determined to be desirable and feasible.
- *U.S. industry will be challenged to develop and build the airlift.* While there is no question that the U.S. technical base regarding VTOL has atrophied over the past 20 years, a national commitment to develop new airlift will lead to revitalization.
- *HLVTOL and SSTOL capability are technically infeasible*. Critics charge that any aircraft built to carry heavy payloads into austere landing areas will fly too slow or too low to be survivable. This conclusion is disputed by a number of objective analyses that are readily available, including the work of the JHL government technical team cited above. In addition, none of the three DSB studies that have examined vertical maneuver requirements has reached this conclusion. Although there is technical risk, it falls within an acceptable range and no major technical breakthroughs are required.
- *Costs will be too high*. Some critics tend to exaggerate the cost of developing advanced HLVTOL or SSTOL airlift. One recent article cites a unit cost of $250 million per VTOL aircraft, which is roughly double the price tag cited in the two-year-long JHL study effort. More importantly, this argument is premature. The question is best left to a later date, after the joint requirements process has had full opportunity to determine the need. Ultimately, the question of how much cost is too much is a direct function of need and desirability.

A Final Word

The Army acknowledges the objections to MVM and accepts the need to evaluate them all as it continues to explore the concept. At the same time, it is desirable to encourage all interested parties to fully examine the large body of research and analysis that underpins the MVM concept. Three other concluding points are noteworthy:

- First, all should realize that MVM is a maturing concept, not a program. However, the concept has broad support that extends beyond the Army and appears to be growing. MVM is rooted in a mindset that looks 15 to 20 years into the future to consider what will be feasible and desirable in that timeframe; thus, it is focused far more on future opportunities than on current challenges.
- The MVM concept is not just about the Army; it is about enabling future joint force commanders to fight differently and more effectively.
- The capabilities MVM promotes are highly relevant not just to major combat operations, but across the entire spectrum of conflict.

Given this perspective, one can assert confidently that the defense community as a whole will benefit broadly from further exploration of the MVM

concept. Its ongoing development is particularly timely given the near-term requirement to replace the C-130 fleet. If continuing investigations confirm the operational significance of MVM and its ability to meet the diverse challenges of the future joint operating environment, the potential benefits to the future joint force could legitimately be characterized as near-revolutionary in quality. ***MR***

NOTES

1. Richard E. Simkin, *Race to the Swift: Thoughts on Twenty-First Century Warfare* (London: Brassey's Defence, 1985).

2. The most authoritative sources are those from Soviet military journals such as *Military Herald*, *Red Star*, and *Military History Journal*. For English-language sources, see Scott R. McMichael, *Stumbling Bear: Soviet Military Performance in Afghanistan* (London: Brassey's UK, 1991) or Mark Urban, *War in Afghanistan* (London: Macmillan Press, 1988).

3. Short Take Off and Landing (STOL) is defined by DOD as the ability to take off and land an aircraft within 1,500 feet over a 50-foot obstacle. Super STOL reduces the distance to 1,000 feet.

4. Department of Defense, Sea-basing Joint Integrating Concept, August 2005.

5. U.S. Joint Forces Command, *The Joint Operational Environment: The World Through 2030 and Beyond*, November 2006.

6. U.S. relief operations in Indonesia following the 2004 tsunami were particularly hampered by austere infrastructure made worse by the tsunami's destruction. Those operations relied heavily on vertical airlift to go where fixed-wing aircraft could not.

7. U.S. forces will likely face all aspects of the access challenges described here in any significant contingency involving operations against Iran.

8. Major Combat Operations, Joint Forcible Entry Operations, Sea-basing, and Joint Logistics (distribution) concepts also support the key ideas of mounted vertical maneuver.

9. Defeat by dislocation emphasizes using the maneuver of combined arms forces to obtain significant positional advantage over the enemy in a manner that renders the enemy's dispositions less valuable, perhaps even irrelevant. Disintegration focuses on integrating dislocating and destructive effects to shatter the coherence of the enemy's operational integrity through direct attack of his most critical capabilities.

10. The distinction between operational movement and maneuver is significant with respect to the immediate impact achieved against the enemy and the time available for the enemy to respond. The mobility capabilities required for operational maneuver and the level of joint support it will require will normally be considerably more demanding than for movement.

11. U.S. operations in Afghanistan and Iraq, as well as recent Israeli operations in Lebanon, were all hindered by the difficulty of securing borders with hostile states.

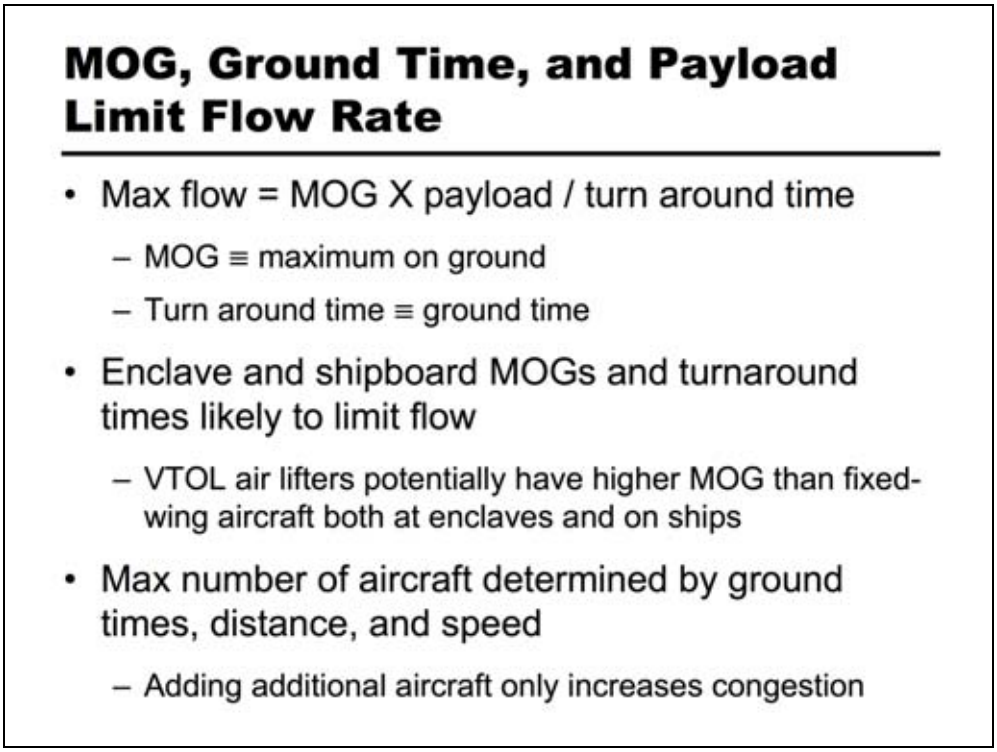
12. Although many of them are classified, significant programs explicitly focused on neutralizing the MANPADS threat have long been underway.

13. The Joint Heavy Lift (JHL) organization has completed two of the three functional analyses required by the joint requirements process, as well as a draft initial capabilities document. The performance parameters for JHL have been derived from this work.

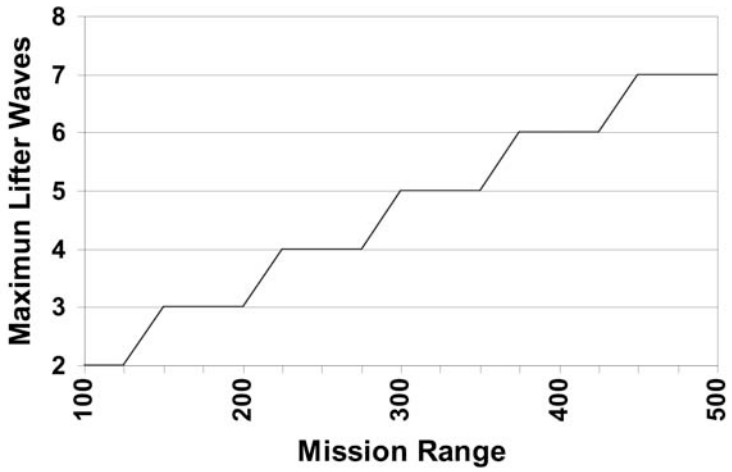
14. Every offensive system that exists today is vulnerable to cheaper defensive means if other means are not routinely incorporated through complementary and reinforcing action to reduce the risks. [For example, infantry to accompany armor]

15. History can be a malleable tool for parochial interests. For example, because Serb authorities eventually acceded to NATO demands, the 1999 Kosovo campaign is often cited by air-power proponents as an operational example of the effectiveness of remote precision strikes. However, those proponents fail to mention that the Serbs continued their ethnic-cleansing program during the NATO bombing campaign and made no concessions until their goals were largely achieved. One senior NATO official, Secretary General Lord Carrington, subsequently observed that NATO strikes actually caused rather than prevented ethnic cleansing. Many observers at the time asserted that ground forces were the best way to prevent ethnic cleansing and vertical assault was the best means of doing so quickly. Air-power proponents have challenged that perspective as being infeasible, ineffective, and excessively risky. Their assessment might have been true at the time, but it asks and answers the wrong question. A better approach to this bit of history would be to examine how ground forces could have been introduced, given different capabilities, and then assess their operational impact on that kind of military problem in the future.

Appendix E. Analysis of Time Required to Deploy FCS Forces



Aircraft characteristics alone do not establish the time needed to deploy a force. Maximum on ground (MOG) denotes the maximum number of vehicles on the ground at any given location—the intermediate support base, aboard ship, or at the enclave. Turn around time is the time required to land, refuel (if appropriate), load, and takeoff, at both the enclave and ISB (or sea platforms). Maximum on ground and turn around time are limiting criteria for short missions. Since enclave MOG must be kept low for operational and vulnerability reasons, and the MOG of existing and planned ships is modest (five or six); turnaround time becomes the limiting factor for rate of deployment for short missions.

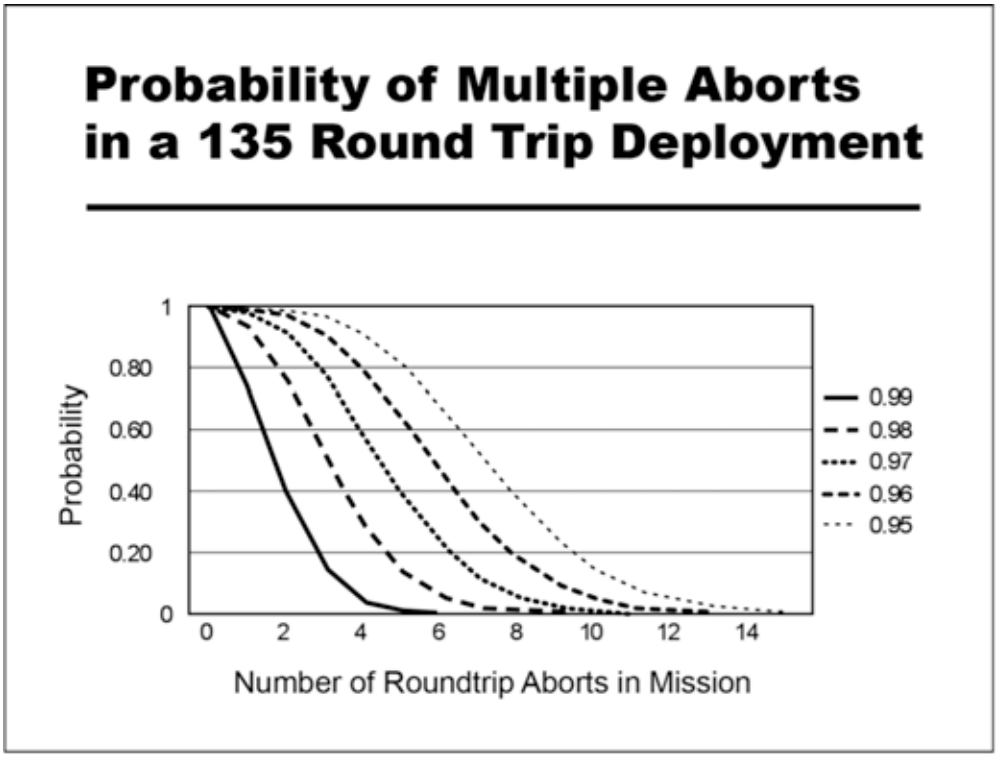


The above figure shows the effect of mission range on the maximum number of air lifter waves that can be accommodated at an enclave.

Based on a nominal mission of 250 nautical miles, this analysis assumes that the maximum number of waves the enclave can handle is four. If the enclave MOG is 10, that sets the number of lifters required to deploy a battalion at 40. Adding additional aircraft will not increase the deployment rate unless the MOG and/or the aircraft speed are increased and aircraft ground time reduced.

The maximum deployment throughput is limited by the number of aircraft per wave (determined by enclave and ISB MOGs), their payload capacity, and turn around time.

Typical turn around times for existing military air lifters are in the range of 30 minutes. Significant improvements must result from a combination of aircraft design, materiel packaging, and movement and operations organization. In the commercial world, FedEx routinely turns its DC-10 aircraft at terminals in 30 minutes, and can do it in 20 minutes in a surge.



The foregoing estimates contain very little room for error, which points to the importance of aircraft and operations reliability. If the probability of a single sortie going without an abort problem is .98, the chance of a battalion deployment proceeding without hitch (135 roundtrips) is slightly more than 1 in 16. The chance of multiple aborts, which could have a major impact on the overall operation, increases significantly as the probability of a single sortie abort decreases as shown in the figure above. This figure depicts a mission requiring 135 sorties—an FCS battalion deployed using 30-ton lifters.

The same curves for a brigade deployment are significantly worse because of the large number of sorties required.

Sortie operations, and the aircraft that fly them, must be highly reliable—like FedEx. Sorties must arrive every time, all the time.

Further, since perfection is unlikely, the air bridge deployment system must have spare capacity (e.g., extra MOG at the ISB or on ships, reserve aircraft, high aircraft survivability, and schedule slack to handle unforeseen sortie problems).

Appendix F. Mounted Aerial Maneuver Air Vehicle Designs

Although the task force used Army-provided "best technical approach" models of 20-ton and 30-ton tilt rotors for its analysis, the members did look at a number of other proposals for heavy vertical lifters.

In particular, the task force was briefed by the designers of the five designs being analyzed by the Joint Heavy Lift concept design and analysis team. All five designs have a design payload of 40,000 pounds. The two pure helicopters (the Technology Crane and the Advanced Tandem Rotor Helicopter) have design cruise speeds comparable to current helicopters, whereas the three hybrid, or compound lifters, have design speeds of around 250 knots or higher. The actual design specifications are restricted, proprietary data.

X2 Technology™ Crane (X2C)

165-kt Design Cruise Speed

Sikorsky Aircraft Company,
Stratford, CT

The Sikorsky's Technology Crane is a coaxial configuration and does not need a tail rotor. All heavy loads would be external and the only internal payload would be in a 14-seat cabin with sliding doors.

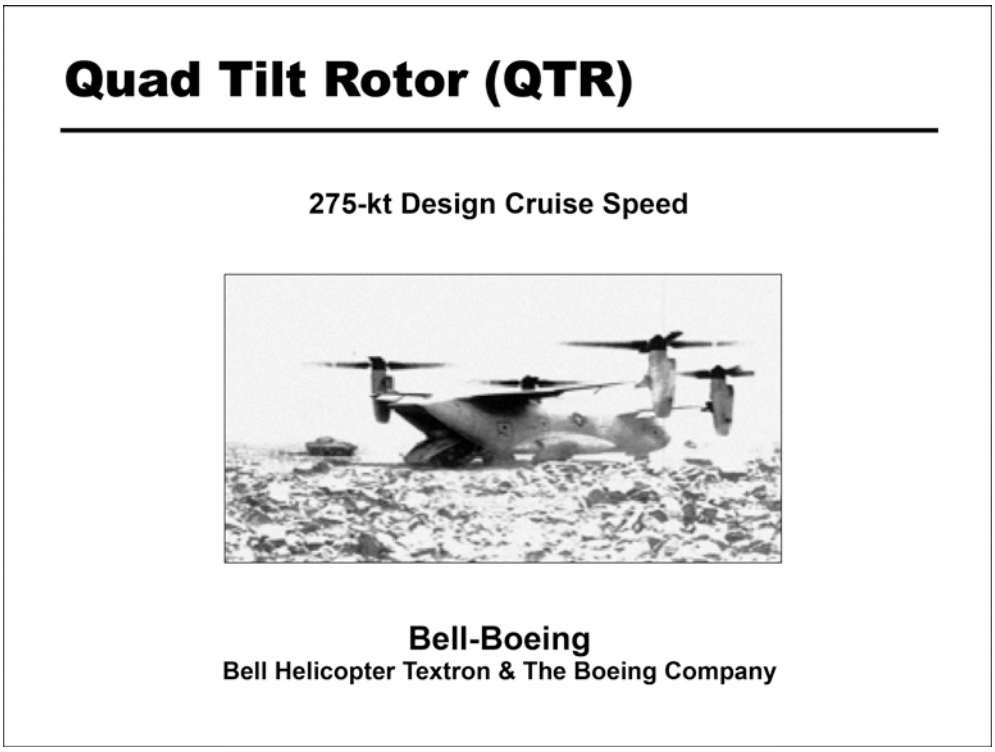
The Advanced Tandem Rotor Helicopter is based on proven Boeing concepts in the CH-46 and CH-47 designs for the Navy and the Army, respectively. The tandem rotor configuration obviates the need for a tail rotor. In incorporates an internal carriage with a split ramp door.

X2™ High Speed Lifter (X2HSL)

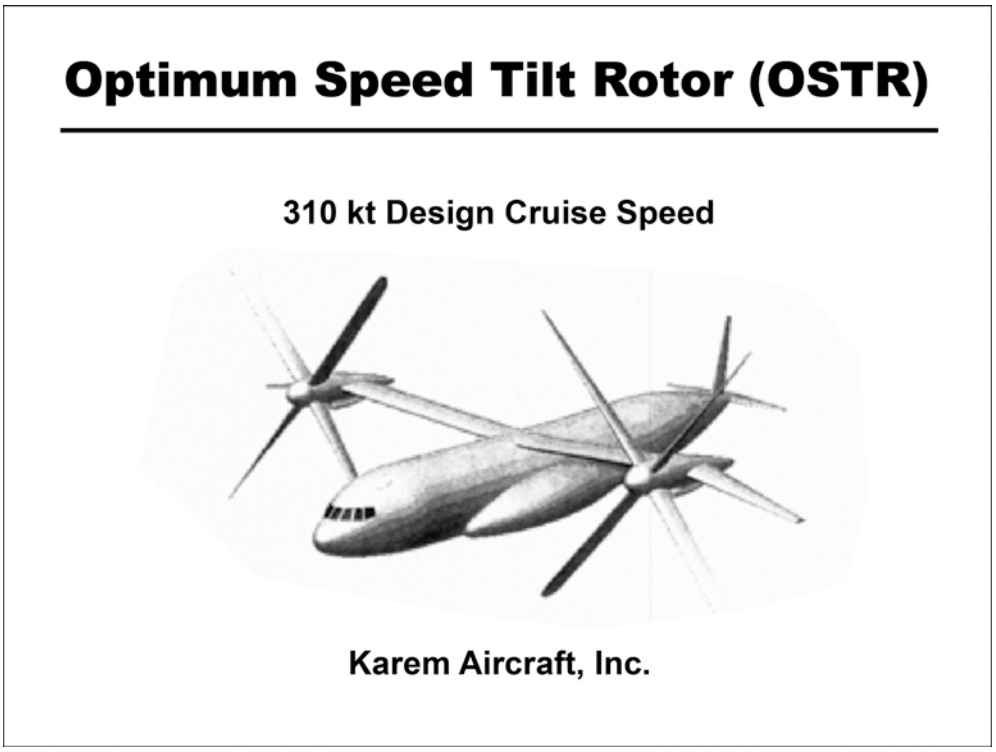
245-kt Design Cruise Speed

**Sikorsky Aircraft Company,
Stratford, CT**

The Sikorsky High Speed Lifter design is a coaxial rotor configuration with hingeless rotors and auxiliary propulsion for forward flight. No wing is required. The aircraft is capable of “straight in” loading for internal carriage.

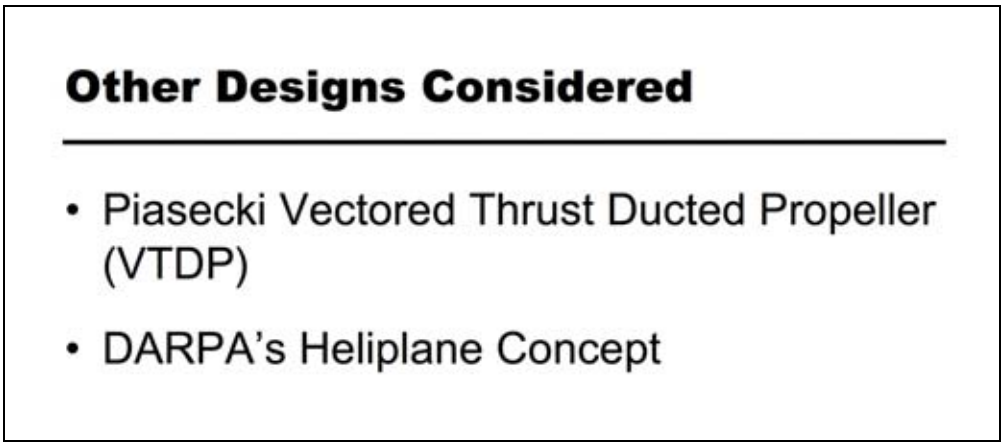


The Bell-Boeing Quad Tilt Rotor is a four-rotor configuration that would leverage Bell-Boeing's experience with the V-22, a dual engine tilt-rotor. Both front and rear wings provide lift in forward flight. There is uncertainty about the aerodynamic interaction of the four rotors.



Karem Aircraft's Optimum Speed Tilt Rotor would "tune" rotor speed for efficient aerodynamics and low fuel consumption. It also would carry loads internally. The design has an aggressive empty weight fraction.

Although not addressed in the JHL deliberations to date, the task force believes that an engine development program would be needed for any of these designs. The maximum shift horsepower of current helicopter engines is insufficient, and an emphasis would be needed on greatly improved SFC to achieve the ranges being discussed for these heavy vertical lifters.



The Piasecki compound helicopter uses a vectored thrust propeller instead of a tail rotor. It also has short wings at the bottom of the fuselage for lift in forward flight. The propeller provides vectored thrust when the aircraft is in hover and acts as a rear propeller in forward flight. The vectored thrust in forward flight allows a much more horizontal level of attack for the aircraft. There did not appear to be any new technology here, but the concept is being evaluated by the Army. A bailed H-60 has been converted by Piasecki to this configuration and will be flight tested if Army funding is provided. Piasecki believes the concept will allow increased speed and range and will reduce fatigue loads and resultant operation and support costs. Piasecki believes this concept is easily scalable and has significant growth potential.

DARPA is working on a different compound aircraft, with a three-bladed rotor powered by tip jets, and a highly efficient wing that is the most effective lifting surface at 400 mph+. The rotor would be slowed and would auto-rotate for high speed cruise. The major propulsive force would be fuselage-mounted twin turbofans. This design would be an upgrade of the concept employed by the British Fairey Rotodyne aircraft in the 1950s, which was a large 200-mph aircraft capable of carrying commercial passengers. The tip jet propulsion during VTOL mode would eliminate the need for an anti-torque tail rotor. DARPA is considering building a demonstrator to achieve 400 mph cruise speed, 1,000 pound payload, and a 1,000 nautical mile unrefueled range. The concept is in phase 1, rotor component risk reduction, at present. Flight test would be in fiscal year 2009.

Appendix G. Glossary

AMC-X	Advanced Mobility Concept
AMRDEC	[U.S. Army] Aviation & Missile Research, Development, & Engineering Center
ATF	Advanced Tactical Fighter
C4ISR	command, control, communication, computer, intelligence, surveillance, and reconnaissance
CAB	combined arms battalion
CBR	California Bearing Ratio
CONUS	Continental United States
CVN	aircraft carrier
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
DSB	Defense Science Board
EAD	enemy air defense
FCS	Future Combat System
GWOT	global war on terrorism
HEMTT	heavy expanded mobility tactical truck
HMMWV	high-mobility multipurpose wheeled vehicle
IADS	integrated air defense systems
IDA	Institute for Defense Analyses
IED	improvised explosive device
ISBs	intermediate supply bases
JHL	Joint Heavy Lift
LHD	amphibious assault ship
MANPADs	man-portable air defenses
MFOQA	military flight operations quality assurance
MOG	maximum on ground
NAVSEA	Naval Sea Systems Command

nm	nautical mile
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
RDECOM	Research, Development and Engineering Command
RDT&E	research, development, test, and evaluation
RPGs	rocket propelled grenades
SEAD	suppression of enemy air defenses
SFC	specific fuel consumption
SHORADS	short-range air defense systems
SHP	shaft horsepower
STOL	short take-off and landing
SSTOL	super short take-off and landing
TRADOC	U.S. Army Training and Doctrine Command
TRANSCOM	U.S. Transportation Command
VTOL	vertical take-off and landing
TEU	twenty-foot equivalent units