Modernizing Legacy Weapons Systems for the Future: The Case of the C-5 Galaxy

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Introduction

The nature of warfare has changed dramatically since the end of the Cold War. Today, the nation faces new threats that range from transnational terrorism, the proliferation of weapons of mass destruction, a growing cyber threat, growing regional instabilities and the rise of China as a possible peer competitor. Yet the military continues to rely on weapons systems that were built or developed during the Cold War. As one might expect, many of the systems that form the backbone of U.S. military capabilities are nearing the end of their anticipated service life.

The replacement of aging systems with new, state-of-the-art equipment was a priority of the Department of Defense (DOD), but the2008 economic recession and sequestration forced a reduction in military spending and changes to many of these plans. Emblematic of this era was the Army's Future Combat Systems (FCS), an ambitious, transformative initiative that included the development of new manned vehicles, unmanned air and ground systems, and joint radio communications that, together, would enable unprecedented battlefield awareness. FCS was cancelled in 2009, because vehicle designs did not reflect the lessons learned from operations in Iraq and Afghanistan, even as the costs increased significantly, to $87 billion (Gates 6 April 2009). The DOD has since moved to a decidedly less-ambitious strategy (referred to as "the 80% solution" by former Defense Secretary Robert Gates) that promotes the acquisition of affordable systems with more modest capabilities (Gates 16 April 2009). For example, in 2014 the Air Force called for "a shift away from big-ticket weapon systems that take decades to develop and a move toward high-technology armaments that can be quickly adapted to meet a range of emerging threats" (Cooper, 2014).

The DOD has come to realize, however tentatively, that leveraging existing technologies—as opposed to developing new ones—is critical to the affordable fielding of new systems. But as budgets continue to decline, the DOD may have to rely not only on existing technology, but on its existing weapons systems as well. However, there is reason for optimism in this regard. In the case of the C-5 Galaxy, industry has shown that legacy systems can be modernized to cope, and even excel, in today's operating environments, often at a fraction of the cost of new system development.

Current Environment

The DOD proposed a budget of $582.7 billion for FY2017, a $2.4 billion (<1 percent) increase from the FY2016 appropriated budget (FY2017 Budget Request). This represents approximately 14 percent of the $4.15 trillion proposed federal budget (The White House 2016). Of the $523.9 billion requested defense budget, 39.3 percent ($205.9 billion) is budgeted for Operations and Maintenance (O&M); FY2017 Budget Request). Figure 1 provides more details of the budget breakdown, comparing currently enacted funding to the FY2017 proposal. O&M is the only category that showed a somewhat significant increase in funding. As the DOD continues to prioritize the sustainment of its systems, this appropriations category will increase in importance.

By Appropriation Title	FY 2016 Enacted			FY 2017 Request		
	Base	OCO	Total	Base	OCO	Total
Military Personnel	135.3	3.2	138.6	135.3	3.6	138.8
Operation & Maintenance	197.5	47.0	244.4	205.9	45.0	250.9
Procurement	110.7	8.1	118.9	102.6	9.5	112.1
RDT&E	68.8	0.2	69.0	71.4	0.4	71.8
Military Construction	6.9	--	6.9	6.1	0.2	6.3
Family Housing	1.3	--	1.3	1.3	--	1.3
Other	1.2	0.1	1.3	1.4	0.1	1.5
TOTAL	**521.7**	**58.6**	**580.3**	**523.9**	**58.8**	**582.7**
Defense Bill	**513.5**	**58.6**	**572.1**	**516.5**	**58.6**	**575.1**
Military Construction Bill	**8.2**	**--**	**8.2**	**7.4**	**0.2**	**7.6**

Figure 1: FY2017 President's Budget by Appropriation Title (billions of 2016 dollars) (FY2017 Budget Request)

Between 2003 and 2014, defense spending was the largest component of total federal discretionary spending. This trend ended in 2015, when non-defense discretionary spending eclipsed defense spending for the first time in eleven years (CBO 2016). It is uncertain if that trend will change again in the near future.

Eighty-three percent of the defense budget is split among three major categories (in 2016 dollars) — O&M ($244 billion), military personnel ($139 billion), and procurement ($119 billion). Sustainment costs are included in the O&M category (CBO 2016). Figure 2 illustrates the breakdown of total defense spending in major categories over time. If the current trends were to continue as illustrated, O&M spending would likely continue to increase.

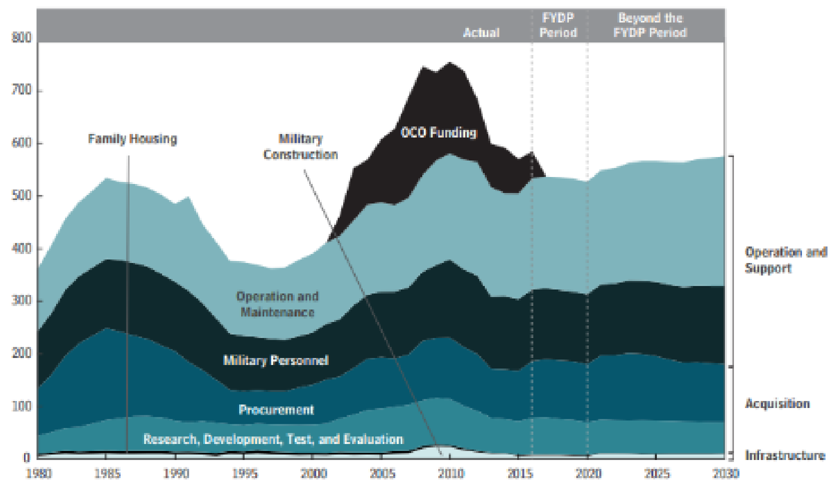

Figure 2: Costs of DOD's Plans, by Appropriation Category (Billions of 2016 dollars) (CBO Long-Term Implications, January 2016)

With the largely unpredictable nature of the current operating environment, the DOD must maintain its technological superiority while bridging the gaps between resources and operational requirements. If historical trends continue, then there is a distinct possibility that defense spending may continue to decrease in the coming years, despite this year's proposed increase. Even as the topline budgets have declined, O&M costs have increased, and unless legacy systems are modernized, the cost to maintain them will increase. The Air Force's inventory of aircraft is the oldest it has ever been, with planes averaging more than 27 years in the fleet (Versprille, 2016). Older systems not only break more often, but rely on parts which are often unavailable. In light of these budgetary constraints, the DOD must explore all approaches to force modernization, so operational requirements can continue to be met.

Framework for Modernization

When providing the required military operational capabilities, the DOD most commonly uses:

1) modernizing existing platforms with the latest technological innovations, or

2) building new platforms altogether.

Both strategies have advantages and disadvantages, and neither is applicable to all cases of force modernization. Some key considerations must be answered when determining whether or not to modernize a legacy system platform.

- **Operational Requirements** – Will modernization best serve the warfighter on the battlefield? Modernizing an aging platform can meet the operational need that is required of the weapons system, but the overall requirement that must be met may be better served by new acquisitions in certain cases.
- **Cost-benefit analysis** – Will system modernization be less costly than new acquisitions? In certain cases the overall program cost for platform modernization may come at a higher price than new acquisition replacement. This is determined mainly by system size, quantity, age, and complexity. Also, does modernization reduce upkeep cost? Logistical footprint, depot time, and overall maintenance costs are crucial to determining the value of the modernization strategy. This impacts both operational requirements (e.g. how long a weapons system must be in maintenance relative to time in use) and overall costs.
- **Service Life Extension** – Will modernization enable weapons system to remain operational for decades to come? The length that a weapons system can remain operational is crucial in deciding whether modernization is appropriate.

Other general considerations include both the speed at which program start and equipment fielding occurs, and how many or how long training requirements must be met for operators and maintainers. For all the considerations listed, there is no one-size-fits-all model. Different platforms, weapons systems, and operational requirements apply to every case of system modernizations. One strategy is not inherently better than the other.

Examples of Cold War Era weapons systems that have undergone significant upgrade and modernization efforts over the course of the last three to four decades include the AH-64 Apache attack helicopter, M1 Abrams Main Battle Tank (MBT), and F-15 fighter jet. Conceived in the early 1970s and first fielded in 1984, the AH-64 Apache has undergone extensive modernization(s) that have provided the most modern variant (AH-64E Guardian) with enhanced fire control radar, cockpit navigation systems, communication systems, engines, and transmissions. The Abrams MBT modernization program was initiated around the same time as the Apache. Increased armor protection, thermal sights for both driver and gunner, a more advanced main gun, advanced navigation systems, and increased protection for urban environments (among many other upgrades) have brought the Abrams out of the Cold War Era and enabled it to meet the requirements of the modern battlefield. The F-15 Eagle was developed in the 1970s as a primary fighter jet for the US Air Force. Incremental modernizations and upgrades were implemented to maintain the F-15's air superiority while addressing capability gaps and responding to evolving threats. The most modern derivative of the F-15, the F-15E Strike Eagle, is designed to maintain air superiority, as well as perform the Air Force's interdiction mission in all weather conditions. Further upgrades have improved the F-15's radar and electronic warfare system (Boeing 2015; DAMIR 2015; Feickert 2016; GAO 2012; Trybula 2012; US Army 2014).

While modernization is not the ideal strategy for all weapons systems, there are numerous potential benefits when it is appropriate. As commercial technology advances at a much faster rate than defense technology, upgrading existing systems, when appropriate, with commercial off the shelf (COTS) technologies allows for a more rapid integration of innovative technology into weapons system platforms. The use of commercial technology allows for the leveraging of global supply chains for spare parts, maintenance, and repairs that already exist to support their commercial companies. Maintenance supply chains, like GE Aviation's, allows for rapid maintenance and part replacement that is useful for aircrafts such as the C-5 which travel globally on a regular basis (General Electric Aviation 2007). This capability is a major benefit that comes along with modernizing systems, especially with commercial technologies. In most cases, modernization of legacy systems can be developed and fielded on a much faster timeline than acquiring new systems. Modernization may also help to bridge the gap between resources and requirements; upgrading existing platforms instead of developing and producing entirely new systems.

Overview of the C-5

Strategic airlift grants the United States military the exclusive ability to rapidly deploy forces worldwide. It can also provide logistics support for allied operations, as well as deliver aid to nations responding to natural disasters. America's strategic airlift capability is an unparalleled and indispensable capability that the US military must maintain to continue its strategic dominance.

The C-5M Super Galaxy is the crown jewel of American strategic airlift capability. It is also the largest military transport aircraft in the U.S. Air Force inventory. Produced by Lockheed Martin, and in operation since 1970, the C-5 has provided the U.S. military strategic airlift for every conflict since its initial deployment (DOD IG 2014). Thirty-six standard pallets alongside 73 troops can be carried in the rear upper deck pressurized cabin, and both loading and off-loading can be conducted simultaneously at the front and rear cargo openings. Both openings have full-width drive-on ramps, and the landing gear kneels to lower the aircraft when parked. The C-5M can carry 120,000 lbs. as far as 4,800 nautical miles without refueling. It has the ability to carry over 120,000 lbs. of outsized cargo such as tanks, mine-resistant, ambush-protected all-terrain vehicles (M-ATV), and Apache helicopters, over intercontinental distances. With aerial refueling the range of the C-5M is limited only by crew endurance (USAF 2014). The C-5M also has passenger seating enabling it to transport troops and their equipment worldwide (USAF 2014).

The C-5 continues to be a key element of the Air Force's strategic airlift capability. While older variants (C-5A) are retiring from service, newer models (C-5B/C) are receiving further upgrades to enhance performance and extend service life. By 2017, all C-5Bs will have received upgrades, and the aircraft will remain in service for at least the next two decades and possibly beyond. According to Lockheed Martin's former Vice President of Business Ventures, Larry McQuien, "[m]odernized C-5Ms can effectively serve the United States strategic airlift requirements well beyond 2040" (McQuien 2007). In keeping the C-5 fleet maintained and modern, the Air Force will continue to uphold its longstanding strategic superiority.

Strategic airlift is paramount to American and Allied success in meeting operational military requirements, providing peacekeeping forces, and delivering humanitarian relief to disasters worldwide. Not merely a matter of power projection on behalf of the United States' Armed Forces, strategic airlift is a crucial arm of American foreign policy. With the swift troop movement of American combat forces across continents and into theater, American strategic airlift capability enables the United States to conduct military operations worldwide, and do so rapidly. This unique American capability is unrivaled in scope by any other nation.

History of the C-5 Galaxy

With increasing engagement in overseas conflicts in the late 1950's and 1960's it became evident that the US was in need of something that could quickly transport troops, weapons, and combat equipment overseas to any place in the world (Lockheed Martin 2012). Military officials envisioned a large transport aircraft that would replace the C-133 Cargomaster and was capable of carrying heavy and bulky cargo, such as tanks and helicopters, over long distances (Griffin 2005). On June 20, 1963 the Air Force released the requirements document for the Cargo Experimental-Heavy Logistics Systems (CX-HLS) that stated that the aircraft would need to be designed to carry a 125,000 lb. payload over a distance of 8000 miles, or twice that load over a shorter distance (Kaminski 2015).

On September 30, 1965 it was publically announced that Lockheed had won the CX-HLS contract to develop what is now known as the C-5A (Knaack 1998). Since then two other variants have been produced, the C-5B and C-5Cs (two C-5As modified to carry oversized NASA cargos such as satellites). In total 131 airplanes were produced. Of that total, 81 C-5A models were produced and delivered to the Air Force between 1969 and 1973. These were later modified with stronger wings and improved turbofans. The remaining were the C-5B models that were produced and delivered between 1986 and 1989. Since the beginning of the 21st Century, C-5As have been gradually retired, with the total C-5 fleet falling to 102 total aircraft in January 2012, then to 72 in February 2013, and only 57 aircraft in 2016. Five remaining C-5As are to be retired in 2017, bringing the final fleet inventory to 52 C-5Ms, consisting of 49 upgraded C-5Bs, two upgraded C-5Cs, and one upgraded C-5A (Balle 2016).

Modernizing the C-5

The modernization of the C-5 was prompted by the fact that "[t]he C-5 [had] been plagued with reliability problems. FY2005-FY2007 data show C-5 mission capable rates of only 48% for C-5A/C and 65% for the C-5B" (Bolkcom 2008). The Air Force conducted a study concluding that despite the C-5's performance problems, 80% of the C-5 airframe service life remained (DOD IG 2014). To address the reliability issues, the Air Force proposed two major modification programs designed to bring the C-5 mission capable rates up to a goal of 75% while extending the C-5s service-life and maintaining its strategic edge (Bolkcom 2008). The first, the Avionics Modernization Program (AMP), was an upgrade to the C-5s communication, navigation, and air traffic control surveillance components (USAF 2014). The second, the Reliability Enhancement Re-engining Program (RERP), is a compilation of more than 70 improvements to the C-5s availability, reliability, and maintainability. The main component of this program is the replacement of the original C-5 engine with the commercial General Electric CF6 engines. The RERP process converts C-5Bs to the C-5M Super Galaxy. Both programs originated from contracts awarded to Lockheed Martin, with the first (AMP) being awarded in 1999 and the second (RERP) awarded in 2007 (DOD SAR 2016; Bolkcom 2008; DOD IG 2014). The C-5 had one of the highest operating costs of any Air Force weapons system and AMP and RERP were designed to address its cost and reliability problems (Defense Industry Daily 2014).

The C-5M has demonstrated its reliability and reaffirmed its standing as a world-class provider of airlift capabilities. The RERP upgrade requires the C-5M to have a wartime Mission Capability Rate (MCR) of 75 percent. Since the start of RERP production in 2010, the C-5M successfully demonstrates that capability. While supporting a real-world airlift operation, transporting helicopters and cargo from Portugal to Afghanistan in December 2015 and early January 2016, the C-5Ms on that mission achieved an impressive 90.5 percent MCR. This aircraft has also managed to set a number of world records. In the time to climb category, the Air Force has noted that with a payload of approximately 264,000 lbs. (gross takeoff weight of 735,222 lbs.) the C-5 set 46 records. These were recorded by the National Aeronautics Association and the Fédération Aéronautique International. According to the Department of Defense, the C-5M "is now the top aviation record holder with a total of 89 world records"

(DOD SAR 2016). Although adapted from an older system, the C-5M Super Galaxy has demonstrated its ability to remain a contender among heavy lift aircraft well into the 21st Century.

Avionics Modernization Program

The AMP was the first phase of the C-5 modernization effort, and was designed to ensure C-5 compatibility with the evolving air traffic management requirements. This upgrade enabled C-5s to operate in global airspace without restrictions (Bolkcom 2008). The program installed Global Air Traffic Management (GATM), Terrain Awareness Warning System (TAWS), and Traffic Alert and Collision Avoidance System. New safety equipment and a new autopilot were also included in the upgrade (DOD IG 2014). Additionally, new engine instruments, flight instruments, and flight system components replaced obsolete variants that had become unsupportable (Griffin 2005). The initial $120.5 million contract was awarded to Lockheed Martin in 1999, for the eventual upgrade of all 126 then active C-5A/B aircraft. This was later cut to 111, then cut again to 80, as C-5As were gradually retired. The initial production began in 2002, with the first AMP modified C-5 aircraft delivered to the Air Force in 2004. The first operational testing was completed in 2006 (Bolkcom 2008). The final AMP C-5 was delivered in 2012, bringing the total to 79 AMP modified planes (although 80 was the final number of AMP modified C-5s, one aircraft crashed in 2006). (DOD 1999; Petrescu 2012; Moyers 2007; Lockheed Martin 2012; Mouton et. al. 2013.) According to the Air Force:

AMP implements communication, navigation, surveillance/air traffic management (CNS/ATM), navigation/safety capability and the all-weather flight control system (AWFCS). It installs directed navigation/safety equipment: terrain awareness and warning system (TAWS) and traffic alert and collision avoidance system (TCAS), reducing the threat of controlled flight into terrain and mid-air collisions. CNS/ATM capability requirements are incorporated in the aircraft to meet current and future International Civil Aviation Organization (ICAO)/Federal Aviation Administration (FAA) requirements and better align with the planned next generation air transportation system[1]. The AWFCS replaces low reliability line replaceable units (LRUs) in the automatic flight control system and updates aging, non-supportable mechanical instruments in the engine and flight systems. Connectivity to mobility command and control capabilities is also incorporated in the AMP design. The portion of avionics capability required for modernization that does not complete at the end of AMP development will be captured and funded in [follow-on] development programs. AMP requirements have been expanded to incorporate updates to the new avionics architecture, to include security enhancements to the global positioning system. Equipment diminishing manufacturing source (DMS) issues will be resolved to support continued operations through studies, development, and redesign efforts." (USAF 2012). The upgraded avionics included 7 flat panel liquid crystal displays (LCD) installed in the cockpit, providing the C-5 with a modern "glass cockpit" (DOTE 2009). Figure 1 displays the C-5 avionics before and after AMP.

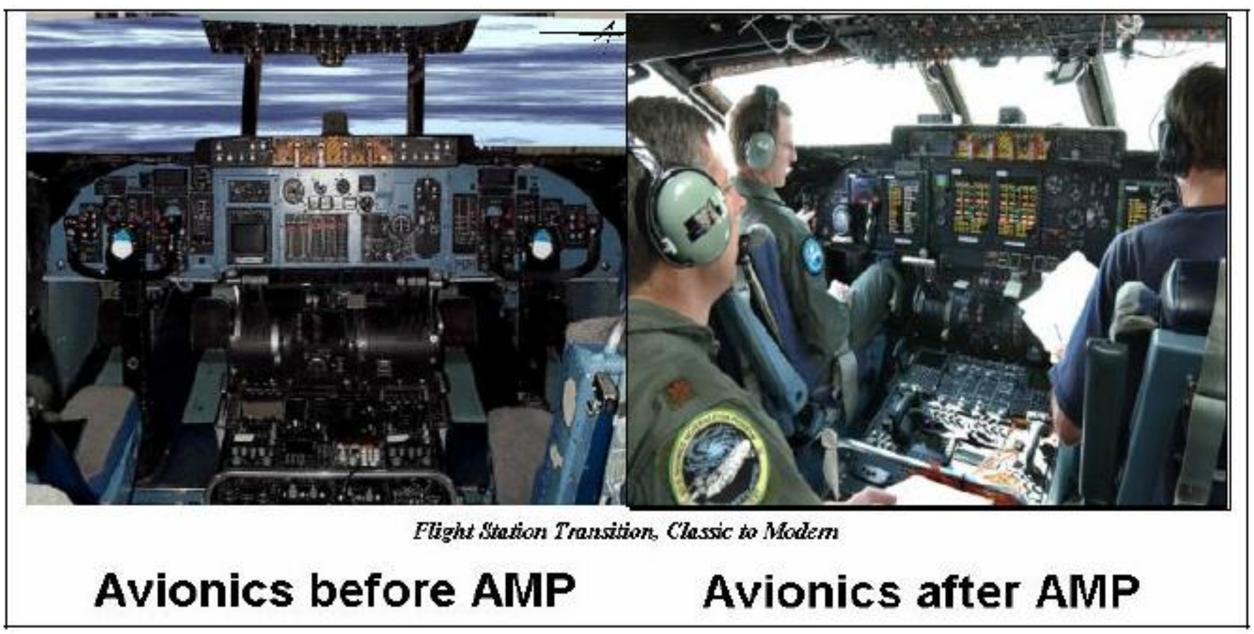

Figure 3. Cockpit from the original program compared to AMP (Griffin, J).

[1] The Next Generation Air Transportation System (NextGen) is a new National Airspace System due for implementation across the United States in stages between 2012 and 2025. NextGen proposes to transform America's air traffic control system from a radar-based system with radio communication to a satellite-based one.

The TAWS modification provides alerts for reduced terrain clearance, imminent terrain impact, premature descent, excessive rates of descent, negative climb rate or loss after takeoff and descent of the aircraft to 500 feet above terrain during a non-precision approach (FAA 2000). A navigational display incorporates a world map alongside information on airports worldwide. The AWFCS system features autopilot, an advanced GPS, and data link communications. These improvements provided the C-5 crew with the capability for vastly improved situational awareness. Improved displays and information systems also provide more timely, more detailed, and more accurate information. Fuel calculations and throttle control are now automated, enabling increased fuel efficiency while simultaneously decrease pilot workload (Lockheed Martin, "C-5 Modernization Program"). The last AMP C-5 was delivered to the Air Force in April 2012 (Lockheed Martin April 2012). Altogether, the AMP modifications brought a Cold War era aircraft into the digital age of the 21st Century.

Reliability Enhancement and Re-engining Program

RERP was the second phase of the C-5 modernization effort; aircraft that receive both the AMP and RERP upgrades are designated the C-5M Super Galaxy. According to the Center for System Engineering at the Air Force Institute of Technology "RERP improves reliability, maintainability, and availability; increases the Mission Capable rate to 75 percent; and is projected to reduce total ownership cost by $8.1 billion" (Lockheed Martin April 2012). Fifty-twoC-5s will have received RERP modifications by FY2017 (USAF 2014). The RERP program began in 2004, with the first C-5M flight occurring in 2006. Actual production began in 2009, with only C-5Bs and C-5Cs to undergo production. The last C-5As were retired in 2015. As of February 2016, a total of 34 C-5Ms have been completed, and 18 remaining C-5s will complete RERP modernization by the end of FY2017 (Griffin 2005; USAF 2014; Airforce-technology.com).

Figure 4. Overview of RERP modifications (DOD IG)

Under RERP, the engine is replaced with the General Electric CF6-80C2L1F commercial engine. This new engine increases takeoff thrust, increases aircraft climb rate, increases engine out climb gradient for takeoff, improves transportation system throughput, and decreases engine removals (DOD 2016). It is being used in various commercial aircraft like the Airbus Industrie A300, A300, A310, as well as the Boeing 767, 747, and MD-11 (General Electric Aviation, 2015). It makes the C-5 more environmentally friendly by reducing carbon emissions. Operational improvements enable the C-5M to have a 30 percent shorter takeoff distance, and also to reach cruise altitude 58% faster than all previous C-5 variants (Bolkcom 2008). The Air Force has stipulated that RERP modifications make the C-5 quieter than previous variants, and increase operations capability well into the 21st Century (USAF 2014). Figure 4 provides an overview of RERP modifications.

The RERP alteration that yields the largest impact on the C-5's capability and service life is the engine upgrade. The original TF-39 engine is replaced with a commercial-off-the-shelf (COTS) General Electric CF6-80C2L1F turbofan engine (F138-GE-100 military designation). This provides the C-5M with increased takeoff thrust (General Electric Aviation 2015). The CF6-80C2L1F is commonly used on commercial aircraft such as the 747 and 767. This engine provides more power, while also requiring fewer overhauls and service events. This means that RERP will reduce C-5 downtime, and increase its mission capable rate. Before RERP modification, C-5 engines were required to be removed for maintenance every 2,000 hours. With RERP, the maintenance interval is extended to every 10,000 hours (Tirpak 2010).

In addition to the engine modifications the RERP "will provide upgrades to wing attachment fittings; new thrust reversers and Auxiliary Power Units; upgrades to the electrical, hydraulic, fuel, fire suppression, landing gear, and pressurization/air conditioning systems; and airframe structural modifications. These aircraft improvements increase payload capability and access to Communication, Navigation, Surveillance/Air Traffic Management airspace". The modification is a three-year process. The first year consists of advance procurement of material with longer than 12 months for purchase and delivery, the second year consists of material procurement and fabrication, and the third year is the actual installation process (DOD 2016).

Cost Effectiveness of Modernization vs. Procurement

Even after both the Institute for Defense Analysis and Lockheed Martin completed studies showing that upgrading the C-5 would be cost-effective if it was retained in the strategic airlift fleet long enough, the question still remained of whether spending money for improving strategic airlift should be directed toward C-5 improvements, or toward some other use, such as adding more C-17s, or even some of both (Institute for Defense Analysis 2000). C-17 procurement, C-5 modernization, and C-5 replacement were all considered as alternative ways to upgrade the US strategic airlift fleet.

When comparing the various C-5 and C-17 combinations, the procurement costs, life-cycle cost, and length of life-cycle were considered to determine which strategy would be most cost effective while not compromising capability. Table 1 below compares unit cost, hour cost, and production rate of modernizing the C-5 fleet and buying more C-17s (in FY 2008 dollars). Procurement of more C-17s was shown to be significantly more expensive than the cost to modernize the C-5 fleet, even after Air Force estimates revealed program cost increases. Originally, 112 C-5's were scheduled to receive both the AMP and RERP upgrades. However, both modernization efforts experienced cost and scheduling problems that required cutting the number of aircraft receiving both modifications to 52 (Leonard & Wallace 2014). In 2007, the Air Force stated that the per-aircraft costs for C-5 AMP/RERP had increased to $146.7 million, while Lockheed Martin stood by its $83 million price commitment, ($118 million if you included additional costs like training and spare parts).

	Modernize C-5 Fleet	Buy More C-17s
Average Procurement Unit Cost[11]	$97 Million*	$280 Million
Est. Flying Hour Cost[12]	$23,075**	$11,330
Production Rate	~12 aircraft/ year	~15 aircraft/year
Aircraft Life Remaining	26,000 hours	30,000 hours
Notes * These costs have and will likely fluctuate over time. The procurement cost of future C-17s will likely be lower than the average, as learning increases and fixed costs are amortized over a longer production run. **Aircraft Reimbursable Rates (per Flying Hour) reflect amortization of modernization programs, but not procurement costs. Because the C-5 AMP and RERP modernization programs are in their early phases, these costs strongly affect the hourly cost to operate the C-5. The C-17 is not implementing a modernization plans on the scale of AMP and RERP.		

Table 1. C-5 Modernization vs. C-17 Procurement (Bolkcom 2008)

With the Air Force estimates, the C-5 program indicated a breach of the Nunn-McCurdy Act[2] which prompted the Air Force to reduce the number of C-5's to be modified, in order to stay within the planned budget (Defense Industry Daily 2014). The number of aircraft scheduled to receive both modifications was cut from 112 to 52. The restructured program decreased costs by $9.1 billion, but resulted in a higher unit cost than originally estimated- $160.5 million for both modifications versus $96.1 million originally estimated in then-year (TY) dollars (GAO 2009).

It is important to note that you cannot make a direct comparison between C-5 and C-17 costs. "The scope-time considered (e.g. Fly-away cost, procurement cost, life-cycle cost), rate of production assumed, and procurement method used (e.g. multi-year procurement, annual procurement, supplemental procurement) all [affect] cost estimates and comparisons." (Bolkcom 2008). Additionally, the cost per hour comparison does not account for differences in payload and performance. The C-5M is able to carry a 285,000 lb. payload at .77 Mach speed, whereas the C-17 can carry a 170,900 lb. payload with .74 Mach speed.[3] Although, the C-5M has a higher

[2] The Nunn-McCurdy Act requires the DOD to report to Congress whenever a Major Defense Acquisition Program experiences cost overruns that exceeds certain thresholds. (Schwartz & O'Connor, 2016)
[3] Lockheed Martin reports that the C-5M Super Galaxy has a max payload of 285,000 lbs. For operational purposes, the US Air Force reports max cargo ability as 270,000 lbs. (USAF 2014; Lockheed Martin 2016).

cost per flying hour, it can carry nearly 100,000 lbs. more cargo, at a faster speed, reducing its cost/pound/mile—making it the more efficient choice for many missions.

In addition to just the basic cost comparison of C-5 modernization vs. C-17 procurement, the Institute for Defense Analyses (IDA) studied the cost and reliability implications of nine different C-17 and C-5 procurement options. A summary of their findings in found in Table 2 below. Nine different combinations of upgrades and procurements were considered as possible keys to optimizing the strategic airlift fleet while minimizing costs. The IDA "measured cost effectiveness in terms of the estimated life-cycle cost (LCC) for each alternative, and found that "... the least costly option is Alternative 6, a full upgrade to the C-5 fleet with no additional C-17s." and that "...the $5 billion required for the upgrades in Alt 6 more than pays for itself in reduced operating costs over the 40-year period examined" (Bolkcom 2008). According to McQuien, "[t]he Air Force will realize 4:1 savings in C-5 Operations and Support costs savings through 2040 – based on Lockheed Martin's estimate for the program, for every $1 invested in C-5 modernization the Air Force will save $4" (McQuien 2007). Modernizing the full C-5 fleet was found to be more cost effective than any other combination of partial modernization and procurement.

Altern-ative	MTM/D	C-5A upgrade	C-5B upgrade	# + C-17	LCC Con-stant $B	LCC Discounted $B	LCC Then-year $B
1	24.9	-	-	0	60.5	32.9	98.5
2	27.1	-	-	20	72.4	40.8	115.5
3	30.1	-	-	45	87.3	50.4	137.0
4	27.8	-	Full	20	70.2	40.4	110.6
5	30.7	-	Full	45	85.1	50.0	132.1
6	27.2	Full	Full	0	56.7	32.5	89.5
7	32.3	Full	Full	45	83.5	50.0	127.9
8	27.7	-	Full	75	80.2	49.0	120.9
9	27.9	-	-	132	88.3	55.4	129.3

Source: *Analysis of Alternatives for Out- and Over-Size Strategic Airlift: Reliability and Cost Analyses*. Institute for Defense Analyses. IDA Paper P-3500. March 2000. Tables 2 and 3 combined by CRS.
[1] All cost estimates expressed in $FY2000. Constant dollars allow comparisons over different time periods without inflation. Discounted dollars are adjusted to account for the year in which funds are expended. OMB discount factor of 2.9% per year used. Then-year dollars represent the estimated actual outlay of funds through 2040, including inflation.

Table 2. Life-Cycle Cost (LCC) Estimates of Potential Alternatives to Modernizing the Strategic Airlift Fleet

According to the Air Force, the unit cost per RERP modernization is estimated at $90 million in 2009 dollars ($101.12 million in 2016 dollars). By comparison, the C-17 procurement price is relatively higher per unit. The Air Force lists the unit price at $202.3 million in 1998 dollars ($299.15 million in 2016) (USAF 2014; USAF 2015). Aside from having the capacity and capability edge, the C-5M manages to surpass the C-17 in cost effectiveness thereby making C-5 modernization a more cost effective option than continued C-17 procurement. It is also more cost effective for life-cycle management cost than that of the C-17. However, it should be noted that because fewer C-17s are produced due in part to the RERP program keeping C-5s in the Air Force inventory the unit cost per C-17 is higher.

Capabilities and Capacity of C-5 vs. Contenders

Being an alternative replacement for the C-5, the Boeing C-17 Globemaster III provides some of the capabilities of the C-5, but falls short in many dimensions. Developed around the end of the Cold War, and entering service in 1995, the C-17 was introduced as a replacement for the aging C-141 Starlifter, as well as to undertake some of the strategic lift duties of the C-5. Although the C-17 has a smaller range and payload, it is designed to takeoff from small, austere fields or runways as short as 3,000 feet (USAF 2015; Boeing 2016).

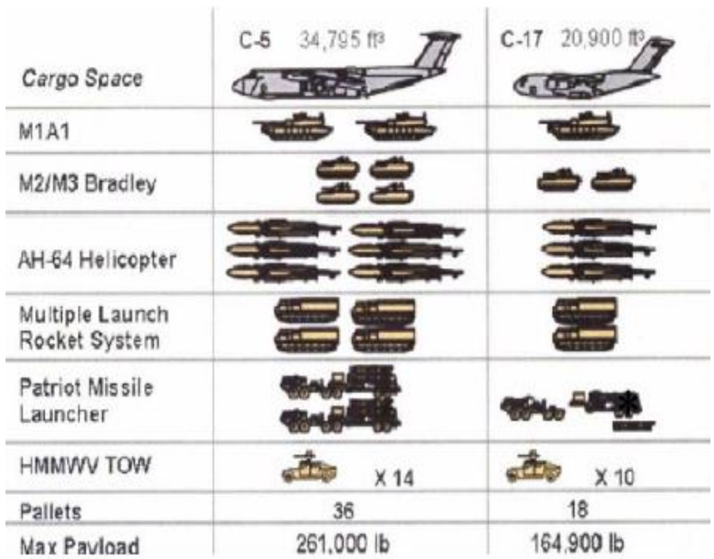

Figure 3. Comparison of C-5 and C-17 (Bolkcom 2007)

With longer range and greater speed, the C-5M Super Galaxy offers the U.S. Air Force world class strategic airlift capabilities. It is able to carry greater quantities of cargo much farther than its modern C-17 counterpart. The C-5M also provides for additional passenger seating (unlike the C-17, which must be configured for that purpose) which enables it to transport unit elements with equipment in a single aircraft. It can also carry equipment a much further range than its closest counterpart, Antonov An-124 Ruslan (AN-124)[4]. Despite its age, the C-5M offers

[4] The Ukrainian built AN-124 Ruslan is the largest heavy lift aircraft in the world. It was built for the Soviet Air Force in the 1980s (MacFarquhar 2014).

a continued strategic edge to the U.S. military well into the next few decades. See figure 3 for a comparison of C-5 and C-17 capabilities.

Conclusion

As O&M costs rise amid a decreasing base budget, the need for more cost effective measures to maintain the American strategic and technological edge is more pronounced than ever. In some cases, modernization has proven to be the more cost efficient means of retaining required military capabilities.

As demonstrated by the C-5M, American airlift capabilities can be maintained via modernization, while simultaneously reducing the logistical footprint of cyclical maintenance upkeep. The USAF’s approach has been to retire obsolete aircraft and modernize the newer variants, maintaining the nation’s capability for rapid global mobility. The new variant of the C-5 not only reduces the need for the procurement of new C-17s, it also reduces maintenance per flying hour and extends the aircraft service life. Via both AMP and RERP modernization programs, the C-5M brings a Cold War weapons system platform into the 21st Century and extends its service life beyond 2040. By modernizing this existing aircraft, the DOD provided a cost effective alternative to system replacement.

Much of the current major DOD weapons systems were developed during the Cold War, and were intended for use if that conflict ever became hot. Over the decades since the Berlin Wall fell, the battlefield has changed significantly for the United States military, and new threats emerged which require newer counter measures. For many such weapons system platforms, the acquisition of replacements is outweighed in cost effectiveness by simply modernizing existing platforms. Technology has advanced exponentially since the Cold War, and the addition of new technologies including navigation, communication, armor, and other systems, into already strongly performing platforms, has extended the time that they can remain operationally effective. However, when considering modernization of weapons systems, cost should not be the primary driver; the warfighter’s operational requirements must be paramount.

This case-study demonstrates that modernizing an existing weapons system can be an efficient and operationally effective option to deliver the warfighter with state-of-the-art systems. With the projected constrained DOD budgets, extending the life of existing systems via upgrades will, in some cases, offer an alternative strategy to maintain required capabilities. This is especially true as the gradient of technological changes continues to increase, on a time-scale much shorter than the time needed to develop new weapon systems. Recognizing this trend, the U.S. Air Force recently established an Open Architecture Management Office at Wright Patterson Air Force Base (Brackens, 2016). The use of an open architecture will enable systems to be more easily modernized as technology changes. Since technological superiority continues to be a cornerstone of U.S. military strategy, the DOD must continue to find ways to maintain this superiority in as a cost-effective way as possible.

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