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IMPACT OF EMP ON AIR OPERATIONS.

by

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ABSTRACT

The Defense Threat Reduction Agency has developed and published a standard that addresses protecting aircraft from the effects of electromagnetic pulse while in flight. With a requirement to be compliant with this standard for all critical weapon systems, the C-17 remains untested. The significant delay in meeting the standard has produced the possibility of an interim solution. Using the problem/solution framework I have proposed three alternatives, maintain the existing timeline for compliance and do nothing, make flight publication procedure changes that do not require structural changes to the aircraft, or begin taking the necessary steps to come into compliance with the published standard. The criteria used to analyze the alternatives were cost, implementation practicality, and technical feasibility. Although access to specific budget details was not available, estimates were sufficient enough to consider each of the alternatives and identify a least and most expensive solution. With consideration given for the likelihood of an EMP event that would threaten an inflight C-17, there was not enough evidence to force a change to the current EMP testing and hardening schedule.

I: Introduction

The C-17 is, “the workhorse for the U.S. Air Force in wartime and in peace.”[1] Air Force Gen Paul Selva, commander, Air Mobility Command said the C-17 was, “… the most versatile, most capable, most ready airlifter ever built.”[2] The C-17 has flown an average of over 136,000 hours a year in its 22 years of service and an average of over 250,000 hours a year in the past ten.[3] It has broken over 33 world records, more than any other in airlift history, with the USAF flying well over 3 million hours.[4]

The C-17 is able to maintain a significant advantage, because of the numerous computer systems integrated throughout the aircraft. More than ten computers control systems such as the turbofan engines, flight controls, and spoilers.[5] This makes the C-17 a fly-by-wire aircraft, which means that a computer, not the pilot, is directly communicating with the various aircraft systems.[6] Without functioning computers, a pilots’ input to those various systems has no effect, turning the plane, in the best-case scenario, into a glider.

The computer systems on the C-17 also make it, along with all electronic devices, vulnerable to electromagnetic pulse (EMP), a scientifically recognized occurrence that can be caused by either solar flares or high altitude EMP (HEMP).[7] Prior to the 1990’s, testing was conducted on aircraft prior to determine their resilience, and survivability, to EMP, but between the early 1990’s and 2000’s, budget cuts and the perceived reduction in threat brought testing to a halt.[8]

In early 2000, Congress created a committee to determine at what level the threat of EMP was for the United States, its infrastructure, and the military.[9] This committee made its first report in 2004 and identified not only a great number of vulnerabilities but also direct threats.[10] Several actions were taken in response to this report including the creation of the Defense Threat

Reduction Agency (DTRA), an agency within the Department of Defense (DoD). DTRA is the official agency for combating weapons of mass destruction (WMD) and determining the methods of nuclear survivability. DoD INSTRUCTION 3150.09, *The Chemical, biological, Radiological, and Nuclear (CBRN) Survivability Policy*, defines nuclear survivability as, "The capability of a system or infrastructure to withstand exposure to nuclear environments without suffering loss of ability to accomplish its designated mission throughout its life cycle."[11] This instruction goes on to say, "Nuclear survivability may be accomplished by hardening, timely re- supply, redundancy, mitigation techniques (including operational techniques), or a combination. *Includes EMP survivability*" (italics added).[12] Based on the DoD Instruction, and as part of DTRAs responsibility, they regularly update Military Standards (MIL-STD) specifically related to survivability in the event of an EMP. These MIL-STD's address the, "…design margin, performance metrics, and test protocols for HEMP protection of military aircraft with nuclear EMP survivability."[13]

One specific standard, the MIL-STD-3023, *HEMP [High-altitude EMP] Protection for Military Aircraft*, addresses the risk of flight in an EMP environment.[14] Unfortunately, the Air Force has been slow to incorporate this standard per a memorandum to the Chairman of the Defense Science Board (DSB) from the DSB Task Force.[15] While delays in permanently addressing the EMP threat to aircraft continue, little or no action has been taken to address an interim solution.

The lack of action is evidenced from a simple review of the current flight publications and manuals for the C-17 aircraft, which include no information concerning the survivability, airworthiness, and the pre/post actions to be taken relative to an EMP event. This begs the question and is the purpose of this research, "Should the C-17 weapon system be exposed to an

EMP event, it will likely be unable to maintain mission ready status. With the potential for catastrophic aircraft failure and the decade long delay in EMP hardening, is there an interim solution the Air Force take to decrease the risk an EMP event poses to continued flight of the C-17 before more permanent solutions can be put in place?"

This paper will use the problem/solution framework for researching alternatives to the problem what action should be taken with regards to EMP procedures for the C-17. Key issues and challenges to the research will be reviewed before analyzing a set of criteria against each alternative. This will lead to a recommendation and final conclusions based on which alternative best fits with the identified criteria.

II: Background/Literature Review

On July 8th, 1962 just after 2300 hours Honolulu time, a Thor missile was launched from Johnston Island and detonated a nuclear payload at approximately 250,000 miles above the Earth's surface.[16] The high altitude nuclear detonation was classified as Starfish Prime and had six major scientific objectives, nearly all of them focused on the ability to detect nuclear detonation at high altitude. The remaining objective focused on evaluating the ability to destroy a nuclear missile at high altitude.[17]

A preliminary report, *A Quick Look at the technical results of Starfish Prime*, was released in August of 1962 and to the public in March of 1989. The heavily redacted 71 page technical report noted several unexpected complications with the detection equipment, but that by and large, the event was considered a success. While the detection devices within the immediate region of the detonation failed, "Magnetic field disturbances were measured around the world."[18] In the aftermath of the Starfish Prime detonation, reports would identify several incidents in which permanent damage to electrical lines and equipment was attributed to the blast. This included up to eight known satellites that operated in Low Earth Orbit, the region in which the detonation occurred, that were completely destroyed.[19] Perhaps even more troubling was the simultaneous destruction of a series of streetlights in Oahu Hawaii, located 800 miles from the epicenter of the detonation.[20] It was at this moment the potentially devastating effects of electromagnetic pulse, commonly referred to as EMP became known.

The Nuclear Matters Handbook (NMHB) defines EMP as an instantaneous interaction of gamma and X-rays with the atoms in the air emitting a large number of low-frequency electromagnetic radiation (EMR) photons, produced when a nuclear detonation occurs at or near the Earth's surface or high altitude.[21] The NMHB states that, "At increased EMP levels, certain electronic components can be destroyed."[22] Furthermore, "It is possible the effects of electronics failing instantaneously in items such as vehicles, *aircraft*, and life-sustaining equipment …" (Italics added).[23]

EMP can be similarly produced by solar flares, known as Coronal Mass Ejection (CME), in which the atmosphere is charged in much the same way as a high altitude nuclear detonation, causing EMR photons that can hit the Earth's surface. The first recorded CME was by Richard Carrington in 1859. Noted as the Carrington Event, it caused significant damage to the worldwide telegraph networks that shocked operators and set telegraph paper on fire.[24] The Carrington Event is considered the most powerful known CME; however, they are still capable of significant damage. A CME in 1972, "… knocked out long-distance telephone communications across Illinois" while a similar level CME in 1989 disrupted the power lines in Quebec, Canada nearly blacking out the entire province.[25] There are no recorded events in which CMEs caused damage to aircraft either on the ground or in the air. However, in January of 2012, a CME was significant enough that up to eight Delta flights that were planned to traverse the northern polar route had been moved farther south due to concerns about the potential impact to communications.[26]

Determining the threat of either a CME or a high altitude EMP (HEMP) is difficult. None-the-less, a fair amount of scientific research provides estimates for CME events. Specifically, it is estimated events like those seen in Quebec and Illinois are expected every 50 years while the Carrington Event would be expected every 150 years.[27] Predicting a HEMP event is an order or magnitude more difficult than predicting a CME as it depends entirely on people to make the decision to launch a nuclear weapon. Carl Bailik of *Wall Street Journal Online* perhaps said it best in his article, "Pondering the Chances of a Nuclear Attack", as, "Predicting the Unpredictable."[28] He discusses a 2005 survey released by Senator Richard Lugar of Indiana on the odds of such an attack, where some estimated the risk at 70% over the next ten years.[29] Fortunately, this did not happen, but it highlights the difficulty in predicting such an event. Another attempt at estimating the risk was completed by Stanford Professor Emeritus, Martin Hellman, who predicted that a child born in 2009 had a 10% chance of "suffering an early death due to nuclear war."[30] He devoted a book to his research on the subject and believed that, "… either humanity would end war or war would end humanity."[31] None-the-less, it is all about risk management, and the DTRA has developed standards because it believes the risk is high enough that action should be taken.

There have been several movies, television shows, and books, which make use of an EMP weapon and/or discuss the probability of attack both in the present and in the future. Some of the more popular examples are: *Ocean's 11,* a movie in which an EMP device is used to temporarily blackout Las Vegas; *Revolution*, a television series in which an EMP disables all electrical devices on the planet; and *One Second After*, a book detailing the offshore launch of three ICBM's for a HEMP detonation that destroys all electrical devices from phones to critical infrastructure across the entire Unites States.[32,33,34] Each of these is a work of fiction; however, there are a number of unclassified documents that discuss the potential of a HEMP attack on the United States and its military.

In the 2004 report to Congress titled, *The Report of the Commission to assess the Threat to the U.S. from Electromagnetic Pulse Attack*, Congressman Roscoe Bartlett of Maryland recounted a discussion in Vienna that included the Soviet Ambassador to the U.S. During that meeting, the Ambassador said that, "… we have the ultimate ability to bring you down … without fear of retaliation"[35] It was assumed that this was a threat of the use of an EMP from an offshore launch location. The same report references the possibility that Iran and North Korea may also be developing an EMP weapon for use against the United States.[36] A formerly classified report that remains heavily redacted was approved for public release and concluded that "China may consider (as an option) the employment of HEMP … against the Taiwan electronic infrastructure or against a U.S. CVBG [Carrier Battle Group]."[37]

Regardless of the probability of a HEMP attack on the United States and its military forces, the threat has long been considered significant enough that decades of ongoing research and preparation have been made toward the goal of protecting military assets, specifically, aircraft. Dr. Carl E. Baum conducted some of the most notable research in this area between 1980 and 1990. He developed and used the Air Force Weapons Lab Transmission-Line Aircraft Simulator (ATLAS-I), referred to as the Trestle. This 12-story tall, entirely wooden structure was secretly used to bombard Air Force aircraft with up to .2 terawatts of electricity (10 to the 12th watts).[38] While only a small percentage of the potential EMP output of a HEMP detonation, it was likely the most that could be produced at that time any place anywhere in the world. Dr. Baum passed away in December of 2010 and his Trestle has not been turned on in over 20 years.

It would appear that after the breakup of the Soviet Union, the importance placed on the testing and hardening of military aircraft greatly diminished. There are no available records showing the status of aircraft testing since this time until the early 2000's. This would imply that the C-17, which was not operationally ready until 1995, is not hardened against the effects of a HEMP event. With a total U.S. Air Force order of 223 C-17's, and a procurement schedule through at least 2010, this 202.3 million dollar aircraft includes no details relative to EMR, EMP, or HEMP.[39,40] The source documents for making this determination are the flight manual, Technical Order (TO) 1C-17A-1, also known as the "Dash One", and Air Force Instruction (AFI) 11-2C-17 volume 3, also known as the "Vol Three". These two documents numbering 2189 and 262 pages respectively are the definitive source for operation of the C-17 and in determining what course of action should be taken for any known emergency.

Emergency procedures are often referred to as having been "written in blood". This is not to suggest that procedures are purposely absent from emergency checklists but more to suggest that we are unable to predict certain events. So, until a particular event occurs on an aircraft, there is no procedure for it; thus it takes such an event (often involving the loss of aircraft and/or life) to produce a set of procedures that might possibly counter such an event should it occur again. So, the fact that of the six pages listing emergency procedures in the Dash One do not refer to any type of EMP event, could be construed as meaning it is not a threat, or that simply it is an unknown threat. However, in the 114 years of flight, a certain amount of assumptions can be made, such as, an engine may fail, a fire may occur, or a rapid decompression is a possibility. The only possible relation to an EMP event might be, "Four Engine Flameout."[41] This particular emergency assumes that the engines may still be spinning, which means there is some amount of thrust and power to electrical and hydraulic systems. Of the 32 different systems described in the Dash One, nearly every one of them requires an operational computer to properly function. Should all computer based systems fail, the "Four Engine Flameout" procedure is likely not a viable option.

Several weapons systems within the AF have been identified as requiring EMP survivability.[42] Initial testing for the B-2 was estimated to take nearly nine months and, the congressional mandated DoD reports of 2013 and 2015 that would have updated the testing schedule have not been released.[43] Furthermore, the cost of the C-17, the potential cargo payload, and the lives of the crew and passengers are too great to ignore. With such considerable delays in completing the survivability testing and the significant threat to the aircraft and lives, interim procedures makes sense.

Some assumptions are needed for this analysis. The first is the assumption that EMP will affect aircraft electrical systems in such a way as to threaten its survivability, specifically, the C-17. The reasoning for this assumption will become clear during the analysis but it is based on existing research into EMP and electrical systems. Without the foresight necessary to determine exactly when a Carrington Event will occur or the ability to detonate a nuclear weapon at high altitude, while flying a C-17 within the vicinity of either, it is necessary to use existing research on EMP to ultimately make this assumption. Academic research countering the threat of EMP from a high-altitude nuclear detonation is nearly nonexistent. The conclusions drawn from all material found countering the level of threat seem to agree that additional research is necessary and are unable to discount the possibility.[44] This will be further addressed in the literature review. The second assumption is that there is an adversary or non-state actor that has the knowledge, ability and resolution to perpetrate a HEMP event. This assumption is based on the research and discussions from Congressional hearings owing to the fact that real threats exist from nation states and the potential threat from non-state actors.[45] However, some research has indicated that cost of acquiring a missile, fuel, and launch system to actually fire an EMP weapon at the United States is too significant.[46] This may place the option out of reach for a terrorist group or non-state actor but certainly not an entity such as North Korea or Iran. Finally, an assumption that existing procedures within the C-17 flight publications do not address possible HEMP events. This assumption is based off a thorough review of existing flight publications and the absence of any reference to flight through or around a HEMP event. As it turns out there is no reference to EMP, electromagnetic radiation, CME, or any related event.

Research in the area of EMP is quite minimal, and there is even less on the EMP effects to aircraft. Information related to the survivability of military aircraft to EMP shows that only one aircraft has successfully passed EMP testing with several others still pending.[47] Dr. John Kuspa, Chief, Nuclear Survivability, Office of the Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense Programs, tracks information related to the survivability of all identified military weapon systems. His 2010 report stated that only the E4-B has successfully completed EMP testing with over 300 currently identified systems that require EMP survivability. He goes on to state that like the 2004 and 2008 reports, Congress is expecting updates every other year beginning in 2009. To date, no report beyond 2008 has been submitted. Lawmakers have some level of interest in identifying and hardening systems to EMP, but little progress is being made and what progress is made is slow. Dr. Kuspa's report supports the requirement that testing and hardening of the C-17 should be accomplished. He states that, "MIL-STDs were largely weakened or ignored" and experts disagree on the needed standards of the Air Force.[48]

The Office of the Deputy Assistant Secretary of Defense for Nuclear Matters has produced an online book, NMHB 2016, which uses several DoD instructions as source material, making the book not only informative but also authoritative. It goes into great detail concerning the effects of nuclear detonations on personnel, weapon systems, and infrastructure. It includes a lengthy appendix on HEMP and EMP effects along with the methods, equipment, and techniques to use for testing against weapon systems and makes reference to the E4-B aircraft, but no others. As mentioned, this book also includes several of the MIL-STDs that should be in effect for all weapon systems that have been identified as requiring survivability.

In 2005, Nick Schwellenbach criticized the results of the EMP Commission and its recommendations to, "safeguard the nation's critical infrastructure against EMP, at an estimated cost of $1 billion a year over one or two decades."[49] The paper suggests several skeptics of the effects of EMP but offers only commentary from three individuals: John Pike, a self proclaimed subject matter expert on defense, space and intelligence policy; Richard Garwin, an award winning and recognized physicist; and Phillip Coyle, former assistant secretary of defense.[50,51] The article does not discount the effects of EMP and instead acknowledges the possibility. Schwellenback focuses on the delivery methods, costs, and likelihood of a nuclear warhead EMP attack on the United States. Garwin stated that, "there is just not enough analysis to say what kind of effect an EMP-maximized fission weapon could produce."[52] Schwellenbach's material for his article included Dr. Carl Baum, whom he called an EMP expert, and Baum told him, "[H]e thought the effects of EMP are still a huge unknown and needed further study."[53]

J. Steinberger, a Nobel Prize winning physicist references the Starfish Prime experiment and his interest in calculating the level of gamma rays (these create the EMP effect) mathematically. His nine-page paper uses seven pages of very complex math to find the EMP field strength from a nuclear explosion at high altitude. It quite difficult to follow the math but he ultimately believes that, "specialized HEMP weapons of substantially higher HEMP yields, as are sometimes imagined, are not possible."[54] However, he goes on to say that, "effects to be expected from such electromagnetic pulses are however far from obvious, and difficult to calculate or to evaluate experimentally."[55] Unfortunately his paper is somewhat tarnished by his research into the effects from Starfish Prime on the island of Oahu. He develops his conclusions into the damage based on two phone calls made in 2006 to the Hawaiian Telephone Company and Hawaiian Electrical Company concerning the 1962 detonation. One of the calls is to the manager of customer services who states that there was absolutely no damage. The other call netted even more questionable results with the individual stating that no one he had talked to knew anything about any damage. He ends his paper by acknowledging that it is not clear so much money should be invested into EMP hardening as the 2004 EMP Commission suggests.

Some of the most detailed information concerning potential effects and an action plan for protection against EMP comes from a commission that was established in 2001 to specifically address the concerns over an EMP attack. *The Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack* released reports in 2004 and 2008 detailing damages, preventative measures, and likelihood of an attack in the next 15 years from an EMP weapon.[56] The executive report of 2004 refers to Starfish data, Russian HEMP testing, President's National Security Telecommunications Advisory Committee (NSTAC), and results from its own commission sponsored studies. The commission conceded that, "only limited EMP vulnerability testing had been accomplished for modern electronic systems and components" and that, “Very little research and development addressing EMP-related system response protection and recovery issues has been done for more than a decade.”[57,58] The 2008 report focused on critical national infrastructures and was comprised of the same committee members. This commission ultimately concluded that, “the Federal Government does not today have sufficiently robust capabilities for reliably assessing and managing EMP threats” and that time and resources should be identified to remedy that assessment.[59]

A “Quick Look” at the Technical Results of Starfish Prime, was also reviewed and included some useful data though the majority of the results regarding the effects of EMP on both communications and intensity were deleted. The report indicates that the majority of the devices established to measure X ray yield and effects (this would give some indication of the EMP intensity) were either damaged or not properly positioned at the time of the detonation.[60] No speculation is available for the cause of any damage or issues with data collection though in an included report completed five days after the blast an interesting observation is included. It stated that detectors located on the island of Maui probably failed due to, “unexpectedly large electromagnetic signal and inadequate shielding.”[61] The preponderance of the available analysis is based on photographic and video evidence that provide support for the overall premise of the report, which is that the results could be used for nuclear detection systems.[62]

The final publications included in the literature review are the Dash One and Vol Three. These definitive publications provide aircrew members the exacting detail required for both normal and emergency operation of the C-17. The Dash One breaks down emergency procedures into two categories, critical and non-critical. Of the 22 critical procedures, 10 of which related to fire, four stand out as procedures that could possibly come into play during an EMP event. Those procedures are, loss of engines, loss of generators, loss of pressurization, and fire. The one non-critical procedure that could come into play is loss of communications or navigation.

The Vol Three is the authoritative guidance document when it comes to executing missions and flying the C-17. The most relevant section may be the minimum equipment list, or MEL. This specifies the number of equipment that must exist for operational missions to be conducted, e.g. of the four engines available, all of them are required. A section on nuclear threats does exist, which makes reference to EMP. It states that an EMP can damage electrical equipment and, "The best protection is a combination of shielding, distance from the blast, and limited time of exposure."[63] No additional information exists about how to shield equipment or if any shielding already exists.

The lack of reference to EMP in the flight publications leaves the aircrew with no options should a catastrophic EMP event occur. As more information about EMPs is released aircrew become educated about the potential threat and its implications upon flight operations. With the MIL-STD in place for a decade and no resolution in sight, aircrews will desire an interim procedure until proper testing and hardening is finally completed.

III: Research Criteria

The criteria are cost, ability to implement solution, and technical feasibility. Each of these major categories is broken down into three minor categories to account for the potential ambiguity between the alternatives a scale will be used to rank each of the criteria from one to three. A ranking of one in any particular criterion is meant to suggest it is the best in category. The ending analysis will include a chart that displays each criterion and its relative ranking. This will assist in making the recommendation but not be the only factor. The risk of an inflight C-17 experiencing an EMP event will also be considered.

The cost category will be used to measure the financial viability of an interim solution, especially since a budget will already be necessary for the permanent solution to fully test and EMP harden the C-17. This is itself a significant cost therefore any interim solution whose cost is too high will not stand up to scrutiny. While actual cost data is not available so estimates will be made based on other known costs. The three subcategories used to measure cost are research, aircraft, and implementation. Research includes all costs that occur prior to actually implementing an alternative and all other costs will be included in the implementation subcategory. Aircraft costs are those costs that are required with respect to changes to the C-17 or any of the onboard aircraft systems.

The ability to implement category includes timeliness, training, and disruption to operations. Ranking these criterions against each alternative will determine how likely a solution would be selected for implementation. Timeliness will measure how quickly an alternative can be fully implemented. Training will be used to measure the level of complexity each alternative is to implement. Less complex alternatives will mean less training required and little or no flying hours required for training. Disruption to operations will include how long the overall implementation takes but also how involved it will be. More training, more aircraft changes, and more time to implement will be considered a greater disruption to operations.

Finally, the technical feasibility category includes existing technology, technical resources, and technical difficulty. The existing technology subcategory will be used to measure whether or not any research time is required for an alternative and technical resources will measure how many people, computer, and equipment resources are required. Technical difficulty will measure the overall difficulty in implementing an alternative. Solutions that are extremely difficult to implement, require a high number of resources, and require new technologies will be considered less likely to be recommended.

IV: Alternatives

Recognizing that a MIL-STD is published concerning the protection of aircraft against HEMP and that the Air Force is testing/hardening its aircraft against EMP, three alternatives are being analyzed that could offer some interim solution. They alternatives are accept the risk or maintain the status quo, make procedural updates only, or accelerate the testing timeline.

Accepting the risk will mean making no changes or modifications to flight publications, procedures, or the aircraft itself. Daily operations would continue unaffected and any subsequent EMP event would potentially mean loss of aircraft and/or loss of life. Recommending this option would assume that the risk is no greater than the inherent risk already associated with flying. The second alternative is based on making only procedural and publication changes. It assumes no changes or modifications to the aircraft and would include logistical and operational changes along with the necessary training. This would still be a relatively significant change that, if chosen, assumes a medium risk. Additionally, this alternative has the potential added benefit of being an accepted interim solution for other United States and allied military aircraft. Accelerating the existing timeline for EMP testing is the final alternative. It would include changes to flight publications and procedures, training, and any aircraft modifications deemed necessary. This alternative suggests that the threat of EMP is high and any EMP event would have a catastrophic impact on an inflight C-17.

V: Research Analysis

The first alternative assumes the risk and has the least bearing across the research criteria. The costs associated with this particular alternative, i.e., research, aircraft, and implementation is zero. No change would be made to flight publications, TOs, training programs, maintenance, aircraft components or systems, or flight operations. Planners, aircrew, maintainers, and users would continue as they have been and be completely unaffected by this alternative. When it comes to the ability to implement this alternative, it would similarly have zero impact and could be implemented immediately and, for all intents and purposes, it is already implemented. The timeliness, training, and disruption to operations are also zero. This also means that the technical feasibility of the alternative is not a factor as nothing is being implemented. No new technology, resource or difficulty is required. Accepting the status quo would mean that an EMP event associated with an inflight C-17 could damage it significantly enough to prevent it from continuing flight. Depending on location, flight conditions, and time of time, the potential exists for the complete loss of the aircraft, aircrew, passengers and cargo. Therefore, selection of this alternative means the perceived threat of an EMP event should be at its lowest.

The second alternative makes only publication and procedural changes. Though not specifically analyzed, one example of a procedural change might include installing the sunshades on all aircraft windows to provide shielding from the damaging effects of EMP.[64] This assumes some level or warning prior to flight through an EMP affected area. Making such a procedural change would impact several areas within the operations of the C-17 to include, publications, training, flight, simulator, evaluations, and testing. Due to the number of operations, initial cost would be fairly substantial especially for research, publishing, and shipping. All other publications are electronic and would thus cost much less by comparison. Costs associated with simulator and flight operations would be minimal as neither should require additional flight time for practicing new procedures. A requirement for any procedural change considered should include no increase in flight hours. If additional flying hours were required for training and evaluation, costs would quickly become quite significant. Each flying hour includes costs for fuel, maintenance, aircraft inspections, and the time necessary accomplish them. Because the costs associated with all the associated operations are well known, the only substantial variable is the cost for research. The example suggested above would have a minimal research cost that could greatly increase its potential as a solution. A second requirement for any proposed procedural change should include a research cost ceiling recognizing it is an interim solution. By definition, this alternative would not include any costs relative to aircraft.

The ability to implement is a variable that should also be a requirement for any procedural change as well. It is important to consider the current level of complexity for the current EMP testing and hardening plan to ensure that any interim solution does not exceed that level. In the example above, implementation would be minimal to listed areas of operations. Outside of the specific change, implementation of a procedure is a known quantity. Publications occur on a regular basis and are often more than just a change in grammar or semantics, they include changes to existing procedures, which are quickly incorporated into the everyday operations of the aircrew. The timeliness, based on previous updates, would be minimal. Once an update is released, it is disseminated throughout the C-17 community. The training associated with any procedural change has the potential to be fairly minimal as well. Aircrew could incorporate training into their next scheduled quarterly simulator, if necessary. Disruption to operations should also be limited as no EMP related procedure would impede existing flying as it would not be considered a safety of flight issue.

Finally, the technical feasibility of implementing a procedural change is also a well-known process. Each area of operations regularly absorbs updated material and the associated procedural changes that accompany it. It is uncommon for a drastic change in procedures to occur; however, flight safety changes are a priority and implemented immediately. They incorporate the necessary updates to training along with proficiency and evaluation criteria.

This alternative would be a good solution if the perceived threat of an EMP event were greater than the basic risk in flying yet less than it being an absolute certainty. Because the process of updating procedures occurs often enough, the biggest unknown would be research necessary to determine what procedural solutions should be implemented. The solution remains a viable option especially with the suggested requirements. No new technology would be necessary to implement this alternative however, it would require technical resources and would have some level of technical difficulty.

The final alternative is the acceleration of the current EMP testing timeline. It is likely the most expensive option. The assumption that all costs associated with the actual EMP testing phase are well known seems sound based on the existing aircraft testing. However, so as to not disrupt the current schedule, accelerating testing could double the existing costs. This is based on the additional equipment that would need to be purchased, facilities and infrastructure built, and personnel hired. The ATLAS-I was a one of a kind facility and testing aircraft has unique requirements, versus for example a computer, which would essentially mean an across the board doubling of all existing assets necessary for EMP testing. Doubling the existing budget clearly makes this the most expensive option. Costs associated with research, aircraft and implementation would all be high.

The ability to implement this alternative solution is well within the capabilities of the DRPA and other government and commercial testing bodies as it is a process that is already in place. The disruption to existing operations has already been factored as the testing associated with MIL-STD-3023 is already a requirement. Timeliness is a critical factor for this alternative and is only an option if it allows for the actual acceleration of the testing. The training requirements associated with accelerating the testing have been factored into the process. Overall, the ability to implement the solution would be expected to not change in anyway other than the actual implementation timeline.

Finally, the technical feasibility is similarly well known since the process is currently in place. The necessary technologies and technological knowledge required to make this feasible are well understood and already exist. The greatest obstacles will be related to resources, most importantly, personnel. The skillset and expertise required for EMP testing are very unique and as such the timeline to ramp up the necessary numbers to support operations and testing of the C-17 will be difficult. The technical difficulty would not be increased, per se, it would essentially just be replicated.

IV: Results

	Accept the risk/Status quo	Procedural only changes	Accelerate testing
Cost			
Research	**1**	**2**	**3**
Aircraft	**1**	**2**	**3**
Implementation	**1**	**2**	**3**
Ability to implement			
Timeliness	**1**	**2**	**3**
Training	**1**	**3**	**2**
Disruption to operations	**1**	**3**	**2**
Technical feasibility			
Existing technology	**1**	**2**	**3**
Technical resources	**1**	**2**	**3**
Technical difficulty	**1**	**2**	**3**

Category Analysis Results
1 – Best in category, 2 – Second best in category, 3 – Worst in category

Accepting the risk/Status quo alternative receive a ranking of one for each of the cost criteria as it by definition includes no additional funding in each of the specific cost criteria used. This alternative is also ranked as one for each of the ability to implement criteria as there is no implementation required. Finally, for all technical feasibility criteria, a ranking of one is given because no technological changes are made nor required.

Procedural only changes is ranked as two in each of the cost criteria. Costs associated with the aircraft would be minimal as part of the requirements for an acceptable solution, however there would be some level of costs associated with both research and implementation criteria. Those two cost centers could be each given a ceiling, however, that cost would be less than the alternative, accelerate training, and more than, accept the risk. Overall, the criteria within, ability to implement, are ranked as third with the timeliness criteria ranked second. If a procedural change isn't quicker to implement than accelerating testing alternative, it does not qualify as a valid option. The criteria training and disruption to operations would be expected to be third relative to the accelerate testing alternative solution. Once final testing of the C-17 is completed a permanent solution would be expected, which would be an EMP hardened aircraft. Such a solution should require minimal training and thus a reduced disruption to operations versus an interim procedural solution. In the criterion category, technical feasibility, both technical difficulty and existing technology is ranked two. Any level of difficulty greater than the accelerating of testing would not meet the requirements of a procedural change. The same holds true for existing technology. The technical resources criterion could be argued as a third or second ranking based on the unknown research requirements needed for the procedural change and the resource requirements for EMP testing, which are known. Ultimately a ranking of two is given as any procedural change requiring greater resources than accelerating the testing would not be a viable solution.

Accelerating the testing is ranked third for each of the cost criteria. Costs would exceed those budgeted for the current testing schedule and by definition, would exceed any costs associated with a procedural change solution. The ability to implement criterion, timeliness, would be ranked third based on the level of complexity required to duplicate existing EMP testing facilities. Training and disruption to operations, criteria would be second based on the explanation given for procedural only ranking. Finally, in the technical feasibility category of criteria, each one is ranked as third. Assuming that a level of duplication in EMP testing facilities would be required to accelerate testing, the overall technical complexity would be significantly greater than the other two solutions.

Based on the rankings given to each of the criteria, charted above, the overall rankings are as follows: accept the risk/status quo, is ranked number one for all criteria; procedural only changes alternative is ranked second in seven of the nine categories making it ranked second overall; accelerate testing alternative is ranked third in seven of the nine categories, ranking it third overall.

V: Recommendations and Conclusion

The purpose of this analysis was to determine in an interim solution was a necessity based on the significant delays experienced in completing the full cycle of EMP testing and hardening of the C-17. This would not be an issue had MIL-STD-3023 been complied with in a timely manner. This standard has been in place for at least six years and reports show that at least 47 weapon systems have been identified as requiring the ability to survive an EMP event yet still have not met the standard.[65] The C-17, as previously characterized, is a critical weapons system for the USAF and at over 200 million dollars to produce, cargo payloads that could easily exceed aircraft costs, and the lives of aircrew with a potential passenger load that could surpass 100, the analysis of an interim solution would seem to make sense.

Based on the results accepting the risk is the highest ranked option followed by procedure only changes and then accelerating the testing. The solution ranking also follows the level or risk probability from low, medium and then high. By assuming the lowest probability of risk from an EMP event with an inflight C-17, the solution, accepting the risk/status quo, makes the most sense and matches with the results of the analysis. While the threat to an aircraft from an EMP event is considered medium, the threat of an occurrence of an EMP event may be considered to be low.[66] Though the specific level of risk was not itself analyzed in this paper, there is data to support that it is low. Retired General Robert Marsh, Chairman of the President's Commission on Critical Infrastructure Protection, said that he believed the threat was low in his congressional subcommittee testimony.[67] The fact that delays in completing the testing perhaps also points to the expected low probability of risk. Considering this low threat level and the outcome of the alternative solutions analyzed, it is therefore the recommended solution that the Air Force accept the risk and maintain the status quo with regards to the current timeline for EMP testing and hardening of C-17 aircraft. This completely negates the need for research, budgeting, implementation, and training.

An additional conclusion was made in the process of completing this analysis concerning the potential for further research. With regards to the alternative solution, procedural only changes, specific changes were not analyzed and it could be of value to do so. Putting in place specific eligibility criteria, such as a cost ceiling, maximum implementation time, and use of existing technology it may be determined that a cost effective solution exists that also increases the survivability of an inflight C-17. This would assume the timeline for EMP testing of the C-17 is still an appreciably distant eventuality. However, it would also provide the option for testing to be further delayed if budget, complexity, or implementation conditions would be improved.

Finally, in discussions with the Air Force C-17 flight manager, another EMP related research topic was discussed. As the Air Force continues towards a paperless cockpit and the use of an electronic tablet increases in place of paper, what effect would an EMP have on those devices? As of this month, it has just been approved that paper flight publications are no longer required when flying as long as a properly updated iPad is available for each crewmember. There are still other paper products that are required as part of any C-17 flight, so it is not quite paperless yet. However, this is a significant step towards a paperless cockpit and it seems unlikely that Apple or the Air Force have done any EMP testing of the iPad. Without those paper flight publications or an electronic tablet pilots would be unable to fly approaches, departures, or deal with inflight emergencies.

There are also some unanswered questions that could serve as possible future research topics and if answered, would be helpful in all EMP related research. For example, knowing what the actual level of threat is would be very helpful in determining a timeline for preparedness. As previously noted, it is difficult to assess the actual threat level, however, perhaps it could be determined relative to the threat of an actual nuclear attack. If and EMP event is less likely than a ground burst detonation, then it would make sense that it should be a smaller priority when it comes to research and budget. Ultimately it would be very valuable to know what the actual effects of EMP are when it comes to aircraft and electronics. Could it bring down an airplane, will it disrupt or destroy critical infrastructure, and can it easily be deployed and launched? Assuming that an EMP event is capable of bringing down an airplane, is it possible to completely protect against such an event? Boeing's 747 E-4B is an EMP hardened aircraft that successfully passed testing but simulating the actual effects of EMP from a nuclear blast can only truly be done by detonating a nuclear weapon, something that is unlikely to happen in the name of research.[68]

What is known, is that a MIL-STD exists specifically addressing the HEMP requirements for C-17, simulation facilities have been designed and built, and a timeline for testing is in place. These actions assume that a level of threat is believed to exist and hardening should be implemented. Because of the existence of a threat and the current status of C-17 aircraft, analysis for an interim solution was conducted concerning three possible outcomes. It was concluded that no changes be made and the status quo should be maintained.

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