5-2007

An Evaluation of the Design Requirements of the H-1 Upgrades Helicopter Blade Fold Racks

Matthew D. Funk
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Matthew D. Funk entitled "An Evaluation of the Design Requirements of the H-1 Upgrades Helicopter Blade Fold Racks." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Robert B. Richards, Major Professor

We have read this thesis and recommend its acceptance:

Frank G. Collins, Rodney C. Allison

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a thesis written by Matthew D. Funk entitled "An Evaluation of the Design Requirements of the H-1 Upgrades Helicopter Blade Fold Racks." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Robert B Richards

Major Professor

We have read this thesis
and recommend its acceptance:

Frank G Collins

Rodney C Allison

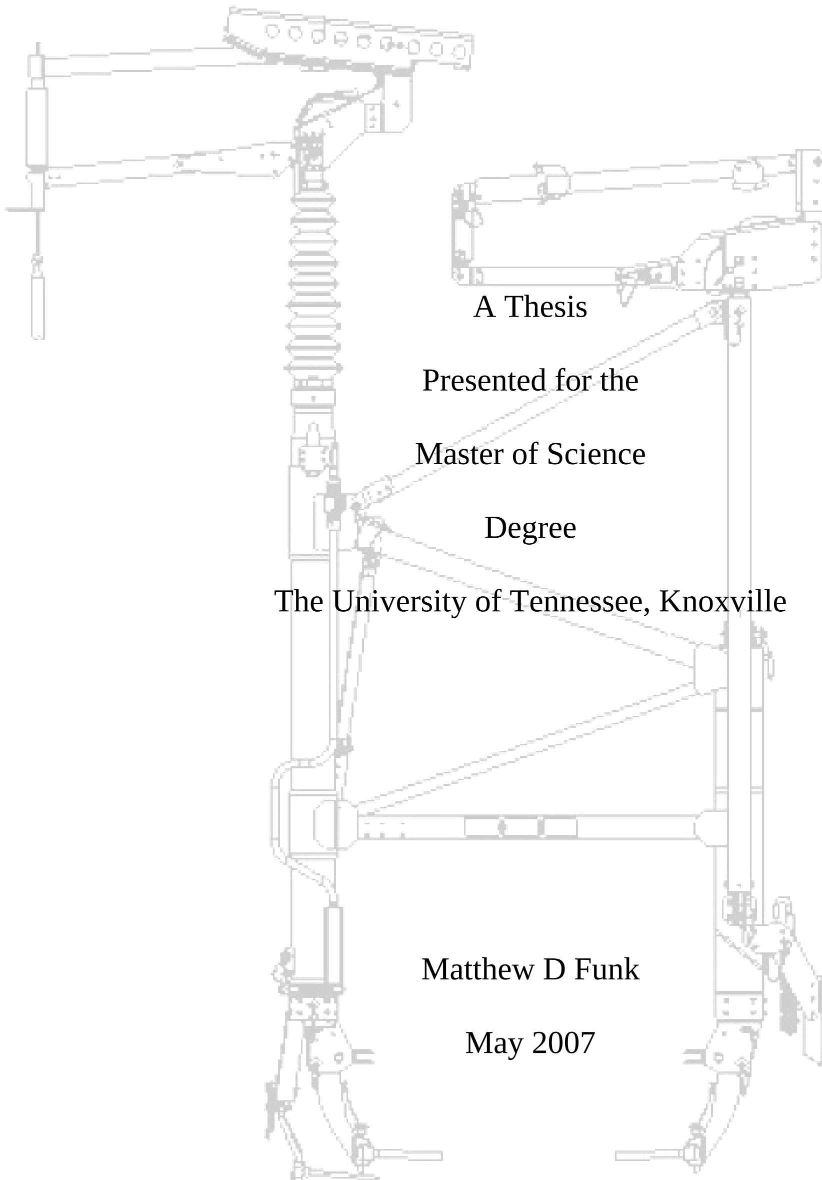
Accepted for the Council:

Linda Painter

Interim Dean of Graduate Studies

(Original signatures are on file with official student records.)

AN EVALUATION OF THE DESIGN REQUIREMENTS OF THE H-1 UPGRADES HELICOPTER BLADE FOLD RACKS



A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Matthew D Funk

May 2007

ABSTRACT

The United States Marine Corps contracted Bell Helicopter Textron Inc. (BHTI) to develop and field new versions of the aging UH-1N and AH-1W helicopters. As part of the development effort of the H-1 Upgrades, BHTI was tasked with development of a folding rotor system and the associated equipment necessary to support main rotor folding operations. The blade fold equipment (BFE) was constrained throughout the development process by a list of conflicting requirements. The requirements for commonality, versatility, simplicity, light weight, rapid application, and durability, while each was generally reasonable, could not be satisfied with one set of equipment. The resulting BFE was ineffective for everyday use.

The purpose of this thesis was to evaluate the design requirements of the BFE, specifically the blade fold racks. An investigation of the source of requirements was conducted, followed by interviews with system experts and end users. Additional data were gathered during the program-sponsored test events from January through May 2005.

In order to develop a suitable and effective set of BFE, the H-1 Upgrades program should reduce the set of design requirements on the new blade fold racks, specifically:

1. Modify the H-1 Upgrades aircraft to incorporate an automatic folding rotor system or a blade indexing motor.

2. Redesign the blade fold racks for a reduced set of configurations and load conditions.

3. Consider a simple, one piece, clamping blade fold rack.

PREFACE

The majority of the information contained within this thesis was obtained during a support of the H-1 Upgrades Engineering, Manufacturing, and Development flight test phase at Patuxent River, Maryland. The author's participation in these flight and ground test events prompted this topic as one for possible further investigation. The research, results and discussion, and conclusions and recommendations presented are solely the opinion of the author and should not be construed as an official position of the United States Department of Defense, The United States Marine Corps, The United States Navy, the Naval Air Systems Command, the Bell Helicopter Textron Corporation, or the University of Tennessee.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BHTI	Bell Helicopter Textron, Inc.
BFE	Blade fold equipment
BFR	Blade fold rack
EMD	Engineering, manufacturing, and development
kt	knots (nautical miles per hour)
NAS	Naval Air Station
OPEVAL	Operational Evaluation
Pax River	Patuxent River, Maryland
RBLT	Rotor brake locking tool
SE	Support equipment
USN	United States Navy
USMC	United States Marine Corps

CHAPTER 1: INTRODUCTION

OBJECTIVE

The United States Marine Corps (USMC) contracted Bell Helicopter Textron Incorporated (BHTI) to develop and field an upgrade to the existing UH-1N Huey and AH-1W Cobra helicopters. The program, called "H-1 Upgrades", was responsible for engineering, manufacturing, and development (EMD) of the UH-1Y "Iroquios" and AH-1Z "Super Cobra" helicopters. The new helicopters featured many upgrades to the existing design, including replacement of the old two-blade main rotor system with a more advanced four-blade design. In order to minimize the aircraft footprint main rotor folding was required, which as a minimum had to fold two opposing blades of the four-bladed rotor. As such, the H-1 Upgrades program and BHTI were tasked with developing the support equipment (SE) and procedures for folding the new rotor design.

One of the critical items of SE developed under the H-1 Upgrades program was the helicopter blade fold rack (BFR). The BFRs were required to solve a complex problem, which was to facilitate a simple, effective blade folding process. The purpose of this thesis was to evaluate the design requirements of the H-1 Upgrades helicopter blade fold racks.

BACKGROUND

The majority of the evaluation and data collection cited herein took place between 2003 and 2005 at Naval Air Station Patuxent River, Maryland (NAS Pax River). In 2006, the H-1 Upgrades program proceeded to Operational Evaluation (OPEVAL), which has not yet been completed. Upon completion of OPEVAL, a formal report of all areas of suitability and effectiveness will be released from the operational testers to the Naval acquisition community. The OPEVAL report should provide final resolution as to the effectiveness and suitability of the blade fold system as a long-term solution for use by the fleet.

The blade fold racks went through several design iterations, described later. At the time of this report, "BFR 4 and BFR 5" were the current, most recent BFRs, and were being evaluated in OPEVAL. BFR 4 and BFR 5 are referred to as the "current" or "most recent" designs throughout this report.

STATEMENT OF THE PROBLEM

As part of the H-1 Upgrades development effort, BHTI was tasked to develop the support equipment necessary for folding the main rotor blades. The blade fold support equipment was required to meet a host of conflicting requirements: for example, the racks had to be strong enough to withstand the force of a 100 kt wind on the main rotor blades but light enough for one man to lift and install. The equipment had to be simple in design and easy to use, but had to support three separate configurations, had to be common to two different aircraft, and had to have multiple moving parts to accommodate the aircraft design. These conflicting requirements presented designers with an insurmountable problem; there was no practical solution that could meet all the design requirements, which is shown later in this paper.

Another problem with the program approach to the BFR design was that no dedicated testing or evaluation of the racks was performed. No test plan was written, and no report was prepared. This SE will have a major impact on the operational efficiency of the final, fielded aircraft, and should have earned a dedicated evaluation period, early in the flight test program. This thesis will evaluate the design requirements of the BFRs and recommend changes to that set of requirements that would result in a more successful BFR design.

DESCRIPTION OF THE H-1 UPGRADES AIRCRAFT

AH-1Z SUPER COBRA

The AH-1Z Super Cobra was a tandem two-seat attack helicopter with a 4-bladed single main rotor and an anti-torque tail rotor, powered by two T700-GE-401 turbo-shaft engines. The AH-1Z was an upgrade from the AH-1W, which included the following modifications: a bearingless rigid main rotor head with composite rotor blades and a blade-fold system; a new main transmission and a new auxiliary power unit; a new tail rotor system, a new target sight system, and larger wings for increased weapons carriage. In addition, the AH-1Z was equipped with a new integrated cockpit that included upgrades to the communication, navigation, and electronic warfare systems as well as an integrated helmet mounted display system. The AH-1Z was also equipped with a four-axis stabilization and control augmentation system. The overall aircraft length with rotors turning was approximately 58 feet, the height to the top of the main rotor hub was 13 feet 2 inches, and the skid width was approximately 7 ft. The maximum design gross weight of the aircraft was 18,500 pounds with specification mission gross weights ranging from 17,065 to 17,867 pounds. A complete description of the AH-1Z test aircraft is contained in references 1 and 2. One of the test aircraft, Bu No. 166479, is pictured in Figure 1.

UH-1Y IROQUOIS

The UH-1Y Iroquois was a dual piloted utility helicopter with a 4-bladed single main rotor and an anti-torque tail rotor, powered by two T700-GE-401C turbo-shaft engines. The drive system of the UH-1Y was identical to the AH-1Z, which included the main rotor, transmission, tail rotor drive system, and tail boom. The UH-1Y also had a new fuel system with 380 gallons of internal fuel, provisions for 10 newly developed crashworthy troops seats, and a permanent fast rope installation. In addition, the UH-1Y was equipped with a new integrated cockpit that included upgrades to the communication, navigation, and electronic warfare systems. The UH-1Y also had a four axis stability and control augmentation system. The UH-1Y length with rotors turning was approximately 58 feet, and the height to the top of the main rotor hub was 13 feet 3 inches. Maximum gross weight, jacking weight, and towing weight was 18,500 pounds. Specification mission takeoff gross weights for the UH-1Y ranged from 17,603 pounds to 18,098 pounds. A complete description of the UH-1Y aircraft is contained references 1 and 3. One of the test aircraft, Bu No. 166476, is pictured in Figure 2.

Photo by Troy Lancaster, H-1 Upgrades

FIGURE 1: AH-1Z SUPER COBRA

Photo by Troy Lancaster, H-1 Upgrades

FIGURE 2: UH-1Y IROQUOIS

DESCRIPTION OF BLADE FOLD SUPPORT EQUIPMENT

GENERAL

The H-1 Upgrades aircraft utilized the same main rotor system on both aircraft types. The main rotor system was designed to fold in order to save space on the flight and hangar decks aboard ship, and in order to be quickly deployable after air transport within a C-17 or other large cargo aircraft. However, in order to save weight, cost, and complexity, the program office and BHTI decided very early in the development program not to incorporate an automatically folding rotor system. Most ship-based helicopters at the time were using an automatic folding rotor system. This would prove to be a driving decision later in the program. Instead of an automatic folding system, a manual folding main rotor system with electric assist was designed and implemented. The electric assist consisted of two parts; a flight control indicator on the cockpit display, to assist the operator in correctly placing the cyclic stick for folding; and an electric blade pin pulling motor. All movement, folding, and securing of the rotor blades was manual.

The main rotor had four blades, and each was marked with a color for recognition. The blue and red blades were the two folding blades, opposite each other on the rotor system, and were equipped with the electric pin pulling motors. Each main rotor blade consisted of an inboard cuff section and an outboard blade. The motors and pins were located at the junction of the blade to the cuff. This junction can be seen in Figure 1 and Figure 2 as the enlarged area at roughly 25% span from rotor hub to blade tip. The orange and green blades were the non-folding blades and manual removal of the blade pin was required in the event that these blades were to be folded or removed.

The blade fold support equipment for one aircraft consisted of three main parts: two BFRs, two rotor brake locking tools, and the blade support pole. All three segments were required to support one folding evolution on one aircraft, as well as some additional equipment and tools. The equipment is described in the following paragraphs.

BLADE FOLD RACKS

The BFRs consisted of a large "strongback" frame with a blade securing jaw that attached at the top. One BFR was to be pinned in place on the aircraft nose and another on the tail boom, and once the rotor blades were indexed into the jaws atop the BFRs, the jaws were locked down, securing the blades. Longitudinal stability of the racks was provided by an angle brace that pinned in place farther inboard on the nose or tail boom. In addition, a second blade securing jaw could be pinned in place to provide a locking jaw for each of the remaining two blades, if desired. See Figure 3 for a graphical representation of the strongback with both attached blade securing jaws.

As a result of the nature of the rotor design and the folding mechanism, the folding blades had to slide through the jaws as the rotor was indexed. The blade (one front and one back) slid across the trailing edge roller, which also served to hold the rotor blade in the rack. The roller also provided the folding moment on the blade and as the blade folded, the roller aligned the blades in pairs, two forward and two aft. As a result of the need for the blade to slide, the blade jaws had delryn pads placed on the upper and lower surfaces, to reduce friction and to avoid damage to the blade.

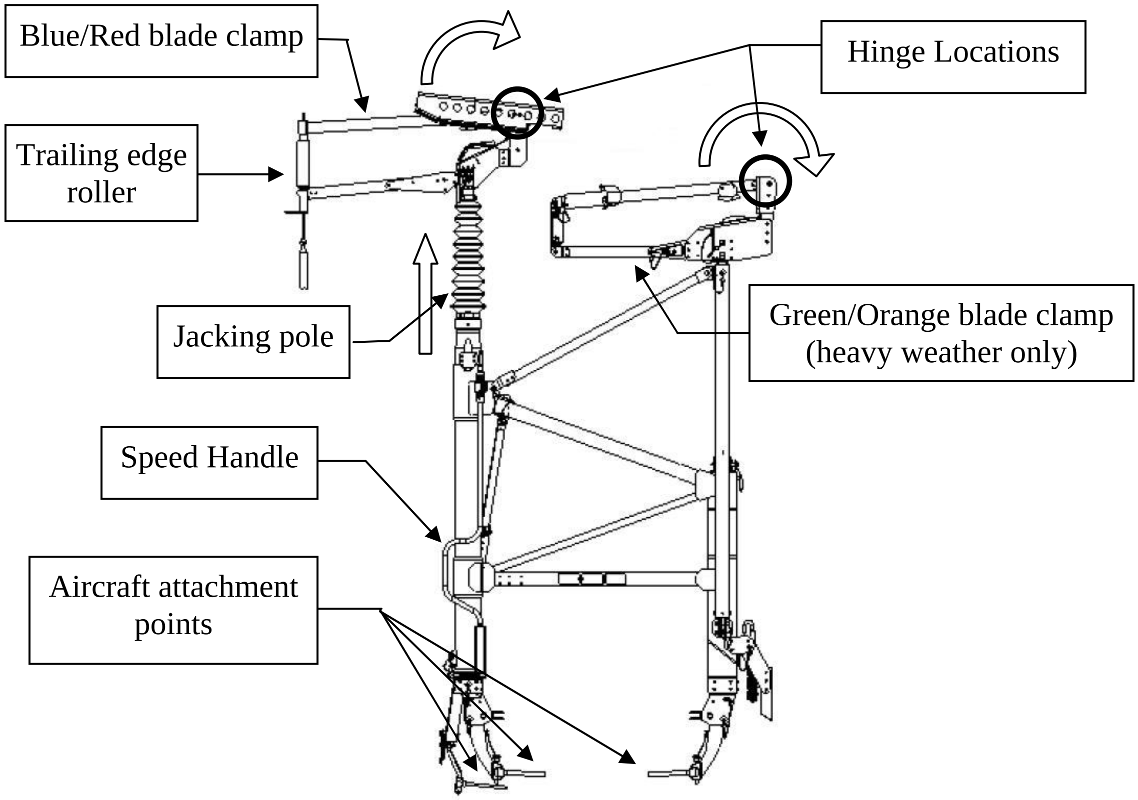


FIGURE 3: BLADE FOLD RACK

In order to reduce the force required throughout the blade fold evolution, the racks provided a jacking mechanism to lift the blades prior to unpinning and folding the main rotor. The jacking was provided by a coarse threaded shaft, which was actuated using a speed wrench in a standard ½" square drive at the base of the BFR. Late in the design cycle, a clip was added to secure the speed wrench to the BFR, for convenience.

The second blade securing jaw was used in the heavy weather configuration, and was similar to the first in method of operation. It could be pinned in place after the strongback and first jaws were already installed. Three pin locations were required, two on the vertical support and one on the other side of the strongback, at the base of the jacking pole. The heavy weather rack did not provide jacking; the blade had to be lifted slightly to install the jaw. Once in place and supporting the blade, the arm across the top of the heavy weather rack was pinned in place.

ROTOR BRAKE LOCKING TOOLS

The H-1 Upgrades aircraft were each provided with a rotor brake, but the rotor brake would not maintain hydraulic pressure when the aircraft was off, and so it did not provide a reliable means of securing the main rotor against rotational freeplay, or chatter. As a result, a rotor brake locking tool (RBLT) was developed. Two RBLTs were required to properly secure the main rotor, one to restrain the main rotor from rotational movement in each direction. The RBLTs were bolted to the rotor brake discs inside the aircraft panels, and locked the main rotor by securing the brake disc from freeplay.

BLADE SUPPORT POLE

In order to ensure that the rotor blades engaged smoothly into the BFRs, a blade support pole, or "crutch pole" was provided. This allowed a crewmember to hold the tip of the blade while standing on the ground, to minimize vertical flapping of the blade and the risk of damage to the blade. The crutch pole was approximately 8 feet long and was designed to slide over the tip of the rotor blade. Later in the design and test process, a net was added to the crutch pole to keep it from sliding too far onto the rotor blade, which could result in damage to the main rotor trim tab. Also, a second, longer pole (17 feet long) was later added to allow a second crewmember to push or pull on the main rotor blade from the ground.

ADDITIONAL EQUIPMENT

In the normal configuration, the folding blade was secured in the BFR while the non-folding blade was strapped to the BFR. The strap was applied by throwing a leader over the rotor blade and pulling the strap across. The leader was weighted with lead shot sewn into the material at the end of the leader. Once in place, the strap was pinned below the blade on the BFR. This provided enough downward force to minimize blade flapping in windy conditions and to keep the restrained blade from contacting the BFR in moderate weather and wind conditions.

When the rotor blades were not folded, the rotor tips were secured using a “sack” that slipped over the rotor tip and was tied back to the skids. Each rotor blade had one tip sock. This configuration was used in benign weather and wind conditions for short-term storage of the aircraft in the fully spread condition.

SYSTEM CONFIGURATIONS

Normal Weather

The blade fold support equipment was designed to work with several configurations. The first, and most common configuration was the “normal weather” configuration. This was the fastest folded condition to apply and was versatile enough to suffice in nearly all weather conditions. In the normal weather configuration, the blue and red blades are folded and secured in the BFRs, while the orange and green blades remain unfolded and are secured by a large nylon strap to the BFR. The normal weather configuration was designed to restrain the rotor in winds up to 60 knots in any direction,

FIGURE 4: AH-1Z IN THE NORMAL WEATHER CONFIGURATION

as well as during aircraft movement and elevator operations. The straps, used only in the normal weather configuration, were yellow, and are shown in Figure 4.

Heavy Weather

The other configuration often used was the heavy weather configuration. In the heavy weather configuration, the blue and red blades are folded and secured by the BFRs, as in the normal weather configuration, but the orange and green blades are also secured by the secondary racks of the BFRs, which had to be added to the strongback. The orange and green blades remained unfolded and aligned fore and aft. This configuration of the SE was designed to withstand winds up to 100 knots in any direction. This required that in the heavy weather configuration, all four main rotor blades were secured by locking jaws on a rigid metal frame. In Figure 5, the heavy weather racks can be seen securing the unfolded blades of the main rotor. Because the heavy weather jaws were not

Photo by Matthew Funk, H-1 Upgrades

FIGURE 5: UH-1Y IN THE HEAVY WEATHER CONFIGURATION

provided jacking, the orange and green blades had to be lifted into place using the blade support pole. The heavy weather jaws are the lower rack on both the front and rear BFR.

Air Transportability

The final configuration of the blade fold support equipment was the air transportability configuration, in which all four blades are folded and secured by the BFRs. This configuration is similar to the heavy weather configuration, except that the remaining two blades are folded in order to further reduce the overall width of the folded aircraft. The same BFR hardware was employed as in the heavy weather configuration, and the same basic rack as the normal weather configuration. Folding of the two additional blades required manual removal of the blade restraining pins on the green and orange blades, because only the red and blue blades were equipped with pin-pulling motors, so it was a labor-intensive process and was not often utilized. In the air transportability configuration, the system was designed to withstand large vertical,

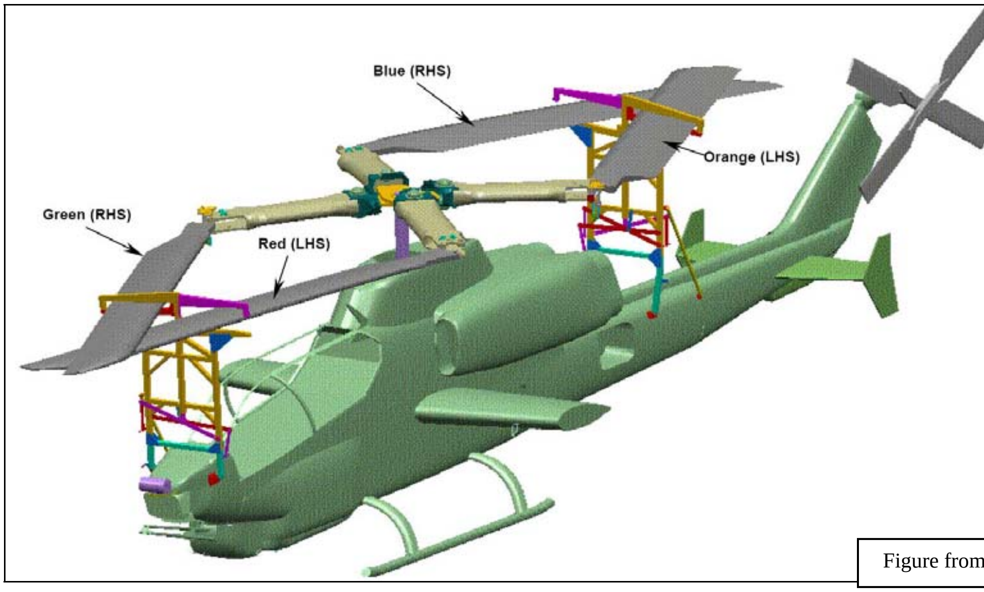


Figure from reference 15

FIGURE 6: AH-1Z IN THE AIR TRANSPORTABILITY CONFIGURATION

lateral, and longitudinal forces, as well as vibrations, but not high wind and weather loads. Figure 6 shows the air transportability configuration (reference 15).

H-1 UPGRADES MAIN ROTOR FOLDING PROCEDURE

The first step in the main rotor folding procedure was to position the main rotor swash plate for the fold. This was accomplished on hydraulic power, by positioning the pilot's cyclic stick in a location indicated by the pilot display panel. Once in place, the cyclic was pinned at its base and hydraulic power was secured. The main rotor blades were pre-positioned with the red and blue blades in the front right and back left quadrants. Next, the BFRs were assembled and installed on the aircraft. The rack on the aircraft nose was pinned at its base and raised into position, and the angle brace was added last. On the aft rack, the angle brace and one of the base pins, both on the same side of the aircraft, were secured. The BFR was then rotated in to position and the second base pin was installed. Once the main rotor was in position and the BFRs were in place, two of the main rotor blades (the red and blue blades) were positioned into the fold racks, and the jacking pole was used to raise the red and blue blades into position for the fold. Jacking was provided to relieve stress on the attachment points, and was accomplished by hand, using a ratchet-style driving handle, or speed handle. The rotor-mounted electric motors would then pull one of the two blade retaining pins on each of the secured blades, leaving the red and blue blades attached by one pin each. The remaining pin served as the pivot point for folding the blade. In the original design, the main rotor would then be indexed clockwise (counter-rotation) by manually turning the tail rotor, while the folding blades remained secured by the racks, forcing the blades to fold about the remaining blade retaining pin. See Figure 7 and Figure 8 for a graphical representation of the fold sequence.

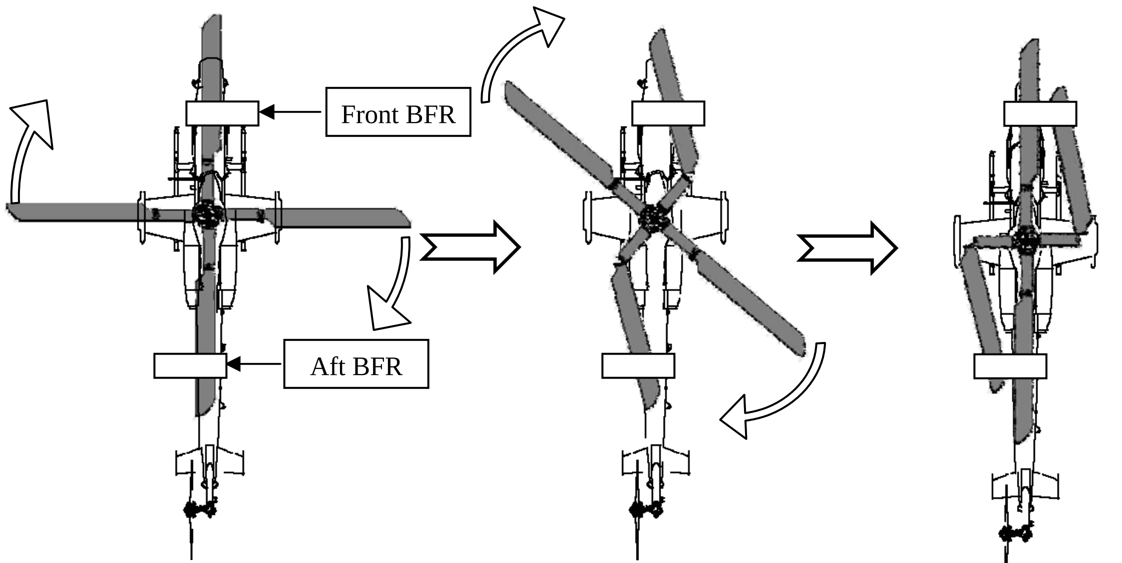


FIGURE 7: BLADE FOLD SEQUENCE

Figure sourced from BHTI, modified by Matthew Funk

Photo by Troy Lancaster, H-1 Upgrades

FIGURE 8: BLADE FOLD PROCESS

CHAPTER 2: CONFLICTING DESIGN REQUIREMENTS

The design requirements of the blade fold support equipment were overwhelming. The system was supposed to be functional in the normal weather, the heavy weather, and the air transportability configurations, in all weather states, in all loading conditions, and durable enough to last the life of the aircraft in highly corrosive and harsh environments. It was to require minimal manpower for installation and removal, and yet had to be installed and removed very quickly to support a high operational tempo. It had to be lightweight yet extremely strong, simple yet durable, and secure yet adaptable.

VERSATILITY

The blade fold system was required to be extremely versatile. It had to support the normal weather, heavy weather, and air transportability configurations of two different aircraft. It had to allow the blades to be jacked up during the fold sequence and had to allow the folding blade to slide through the BFR as the rotor was indexed into position. The racks had to be simple enough for rapid installation but complex enough to support a dynamic process in three folded configurations on two aircraft. This alone was enough to require a complex piece of machinery.

STRUCTURAL INTEGRITY

The blade fold system also had to withstand significant axial loads, due to wind, vibration, and normal load factors applied to the blades. The heavy weather configuration had to use the same base unit as the normal weather configuration for simplicity, but also had to withstand 100 kt winds from any direction. The forces that result from 100 knots of wind across the two main rotor blades were astounding – 1074 lb in the vertical axis and 223 lb horizontal (15). The same rack had to withstand longitudinal and lateral loadings, as well as a +4.5 to -2.0 g vertical load factor and ±3.0 g horizontal load factor during air transportability, which resulted in up to 1,918 lb applied at one of the tailboom attachment fittings (15). The unnecessarily excessive structural strength requirements resulted in an over-designed and heavy BFR.

EASE OF USE

The racks were required to be single man portable, which meant that they were supposed to weigh less than 50 pounds per piece of equipment. The number of pieces had to be kept to a minimum to ensure rapid installation and to minimize the aircraft specific tools and support equipment requirements. The racks had to provide ample grip to be installed at night and in the rain and winds, and they had to be very clearly marked for the same reasons. The racks were to be designed so as to minimize the number of flight deck crewmembers that were required for installation. They needed to be installed from ground level, to minimize risk of injury to personnel and also to speed the process of installation. For ease of use, the BFRs needed to be simple, clearly marked, and user-friendly. Unfortunately, this was quite difficult, given the complexity that was required by the requirement for versatility.

AIRCRAFT INTERFACE

The blade fold racks had a pre-determined aircraft interface, because the aircraft design was finalized. There were three attachment points available for each rack, two directly under the rack and one closer to the aircraft center for the angle brace. The limited freedom of aircraft interface limited the design of the racks. The installation procedures had to be simple for speed and ease of use. The racks were not to interfere with aircraft equipment or procedures, and needed to minimize the risk of inadvertent damage to the aircraft. The racks needed to be gentle on the rotor blades, and yet had to secure them in extreme conditions and loading. The nature of the fold procedure required that the blades be able to slide through the rack during the fold process. This was possibly the most significant hurdle to overcome, because it was nearly impossible to design a rack that held the blades securely in a variety of conditions, yet still allowed them to slide freely during the process.

SHIP INTERFACE

The blade fold racks were required to be stored on the ship, and because interior storage is of such high value, the racks will inevitably spend a lot of time outside in the salt-water environment. The racks needed to minimize the required storage and logistical footprint, as well as the amount of new or specific tools required. The racks needed to be easily pre-staged for aircraft before arrival, and they needed to utilize a safe installation procedure. The racks needed to be quickly and easily moveable in order to facilitate aircraft movement on the flight deck. The ship interface requirements demanded a simple, robust design that was small and durable. This conflicted with other requirements that drove a more complex, bulky design.

ENVIRONMENTS

The racks were required to withstand prolonged use in a military environment by the USMC, in all deployment areas. The required environments included desert, at sea, mountains, and arctic locations. The racks were not provided storage crates and so they would be subject to the ambient environment at all times. The marines found that the best place for storage of the racks aboard ship was in the unoccupied aircraft parking spot. This requires the racks to be chained down to the abrasive flight deck and subject to wind, sun, rain, and sea spray at all times. The racks had to have minimal maintenance, and yet they had moving components that must be reliable. They were also so big that the racks had to be pre-staged before aircraft arrival at an operational area; they were too big to be carried inside the aircraft. This is a significant logistical impact on military operations and supportability of the H-1 Upgrades aircraft because it meant that another aircraft or vehicle must move the support equipment to the desired aircraft location, before the aircraft can deploy to that location. This required that the racks be extremely robust to tolerate the harsh environments, which was in direct conflict with the requirements for moving parts and multiple configurations, which require maintenance to ensure reliability.

CHAPTER 3: METHODOLOGY

INADEQUATE EVALUATION

One of the complicating factors throughout the H-1 Upgrades program was the fact that the BFRs were never fully evaluated. Throughout the flight test program, no dedicated set of tests was conducted with the goal of fully evaluating the BFRs. A small set of testing was conducted under the "Force to Fold" investigation described later in this paper. Several modifications to the aircraft and BFR were considered and briefly evaluated, but only with the objective of reducing the force required to fold; this investigation did not address the adequacy of the BFRs to support day-to-day fleet operations. The racks were evaluated partially during crew proficiency training prior to the initial shipboard tests of the aircraft, or "Sea Trials", but by that time the program was in its final phases of aircraft evaluation, and the purpose of the exercise was crew training on the current system, not evaluation and improvement of the system.

The racks were never allocated a dedicated evaluation with trained test personnel that would have given credibility and significance to the evaluation. No cognizant test engineer/system expert was assigned or tasked with evaluation of the racks, which would have resulted in recommendations to the program office to correct the deficiencies. There was no evaluation performed by trained test pilots or test engineers, because the only crew qualified for installation of the racks onto the aircraft was the Marine maintenance crew. This meant that all evaluations were performed by non-test personnel. No rating scale could be applied to the task, so very little quantitative data could be compiled. Data gathering was performed by observation and by interviews of users' likes and dislikes of the system.

Significant use data and user comments were attained during Sea Trials. This evaluation included a four-hour meeting in which the operational users of the equipment spoke to the author (Sea Trials lead) and the BFR designer, during which time the users listed all deficiencies and shortcomings of the existing equipment. Again, all comments were subjective opinions of the maintenance crew, and not quantified by a rating scale, test instrument, or formal evaluation training. However, these were experienced users familiar with a wide range of support equipment throughout the Navy/Marine Corps fleet. The list of shortcoming is included in the appendix of this report.

INTERVIEWS

Several interviews were conducted, which are referenced in the "Works Consulted" of this paper. The litany of design requirements became apparent during an interview with Mr. Mike Southerland, the designer of the final BFR, during Sea Trials in May 2005. The primary research interview was with Mr. Jack Greely. Mr. Greely was the SE lead for the H-1 Upgrades program, and has spent over 20 years working with support equipment, primarily for helicopter development programs. Mr. Greely was a member of the H-1 Upgrades team for four years prior to the author's involvement, and his extensive e-mail records and meeting notes were consulted, as well. Additional interviews were conducted with H-1 pilots, ship deck handlers, and flight deck personnel.

ADDITIONAL RESEARCH

Additional research was also conducted to determine the source of the BFR design requirements. The requirements for weather conditions first arrive in the program specifications (references 4 and 5), but it is unknown how or why they were added to the aircraft specifications. There were no requirements for the implementation of the folding process, only that the main rotor was required to fold and could use a combination of automatic and manual means. The implementation of the folding rotor was the result of a design trade study by Bell Helicopter, which was not releasable to the author.

CHAPTER 4: DESIGN ITERATIONS

INITIAL DESIGN

The initial design of the BFRs, shown in Figure 9, was created by Norco, Inc., and delivered in 2002. The racks did not meet the majority of the users' requirements and were too large and cumbersome for safe installation. This failure was the first sign of difficulty in development of a satisfactory BFR. The H-1 Upgrades team and BHTI collectively decided that not only were the racks too deficient for fielding, but that an entirely new design was required. In addition, a "tiger team" was assembled of senior government and contractor personnel that determined that the best course of action was for Bell Aero, a division of BHTI, to build the racks. Little space in this paper is devoted to the initial Norco design, because it was delivered and rejected before the author came aboard the program. Nevertheless, it is notable that the first attempt to design a set of blade fold racks with the given design requirements was a complete failure, and modification was not feasible. The first iteration was so bad that it was scrapped completely. It is also notable that the original design is similar in form to the final BFE.

SECOND DESIGN

The second iteration, designed and build by Bell Aero, was much closer to the most recent design iteration than the original Norco racks. The functionality was essentially the same as the most resent design, but additional effort was made to keep the racks as small and portable as possible. This design iteration utilized a three-piece main rack for portability (strongback and two jaw assemblies), the jacking pole for relief of

Photo by Jack Greely, H-1 Upgrades

FIGURE 9: ORIGINAL BFR DESIGN

stress on the restraining pins, and a roller design to allow the blades to translate longitudinally as they fold. Users soon found that assembly of the strongback to the jacking pole was tedious, and were soon leaving the two pieces together as one assembly. The heavy weather assembly was added as needed. The RBLT was also tedious to install, and users soon found that one RBLT was not enough; two were required.

This design iteration got much closer to meeting the main requirements than before, but still fell significantly short. The rack was too heavy, requiring a minimum of two marines to move each of the racks to the aircraft, plus one more if the heavy weather jaws were required. The design required a man to climb aloft in heavy weather to secure the unfolded blades in the heavy weather configuration. The strongback physically interfered with the target sight system on the AH-1Z. It could also be dropped during installation, resulting in damage to the expensive aircraft windscreen. The racks were not marked for installation, making the process more difficult than was necessary. The racks consisted of three separate parts that were to be pinned together after installation of the strongback. These pins had to be accounted for at all times and the holes on mating pieces were difficult to line up during assembly, particularly at night. The rotor brake locking tools, though functional, required removal of an aircraft panel for access to each of the rotor brake discs, and the panel could not be replaced once the RBLT was installed. In a long-term application, this would have allowed corrosion and foreign objects to get inside the aircraft structure and result in an undetermined amount of long-term damage. The RBLTs also required additional tools that were not in the current shipboard inventory, which was an additional logistical and supportability impact.

BFR 4 AND BFR 5

BFR 4 and BFR 5 were delivered in spring 2005 and still failed to meet the impossible set of requirements, though improvements had been made. Design modifications had been made to address usability, things like markings for installation, grip tape, cables for the removable pins, and attachment points on the rack for storage of the BFR specific tools. However, the racks were still too heavy for a single man to carry and install, they still required additional tooling, and they still presented a risk of damage to aircraft if they were not installed properly. Mating parts were still difficult to pin together. The racks still required that a man climb aloft to secure the heavy weather racks, and the installation procedure of the RBLTs was still cumbersome and clumsy.

BLADE FOLD FORCE INVESTIGATION

During the build up to the program's initial shipboard suitability tests (sea trials), many blade folding evolutions were performed for proficiency of the deck crew and to ensure that the aircraft and equipment was robust. Throughout these evolutions, the tail rotor was being hand-turned to index the main rotor, and it became apparent that the forces applied to the tail rotor were possibly damaging. The BHTI rotor and drive systems group was asked what the limit of tail rotor applied force was, and they determined that in order to prevent damage to the tail rotor, the force applied at the tail rotor tip must be limited to 100 lbs. A series of tests determined that the main rotor could not be reliably folded within the 100 lb force limitation. This meant that the existing blade fold procedures were inadequate and could result in major damage to the aircraft if continued. In addition, the test aircraft at this time were stored in hangars and not exposed to rain, dirt, or corrosion. It was obvious that in a dirty or corrosive environment, the forces would increase as the moving parts corroded, which would subsequently increase the force required and risk of major aircraft damage in an operational environment. Additional testing ensued, in an effort to find a way to minimize the amount of force required to fold the main rotor blades. The following methods were attempted, but would ultimately fail to reduce the force to an acceptable level. With each attempt, multiple folding and unfolding evolutions were conducted to determine the effect on the required force. In most cases, the aircraft was flown between each fold cycle, to maintain more operationally representative data.

Reduced Torque on Blade Pins

The first suggestion by BHTI to reduce the blade folding force required was to reduce the applied torque on the blade retaining pins, which would have reduced the friction in the pivot joint. A series of folding evolutions was conducted at multiple levels of reduced pin torque. Each time, the pins were removed and re-installed at a new torque setting, at decreasing percentages of the original torque. Some benefit was realized, but not enough to eliminate the risk to the tail rotor. Moreover, this approach would have required a completely new set of development tests on the main rotor, resulting in significant schedule slip and funding required. The long-term effects of reduced torque on rotor behavior and fatigue were unknown. Reduced blade pin torque was not feasible and did not improve the problem.

Jacking Height Effects

During discussions of the force to fold, it was noted that the jacking position of the main rotor blades for folding might not be the ideal position to minimize forces. The procedure had always been to raise the jacking pole as high as it would go, but the height of the rack had been determined based on fatigue life of the pin pulling motor, and once a height was found that met the requirements, the “ideal” rotor blade height had never been determined. In addition, during the rotor design, the blades had been predicted to statically droop less than they actually did, so the computer model of the rotor could not be used to determine the theoretical best location because it did not have an accurate representation of static rotor blade characteristics. Subsequently, a six-inch extension to the jacking pole was created in order to evaluate the effects of jacking height. Because the movement of the jacking pole was greater than six inches, the extension allowed testers to evaluate any height from the full down position to six inches above the maximum height of the jacking pole. Folding evolutions were conducted at various heights above and below the full extension height of the jacking pole, in approximately ½ inch increments. Some improvement was realized when the height of the jacking pole was three rotations of the jacking handle below the full extension location, about one-half inch below full extension. As in the case of the rotor pin torque investigation, this effect was insignificant in the overall force required to fold the blades and a full investigation of jacking effects was not completed. Jacking height effects were not significant enough to correct the problem.

LUBRICATION

Another potential method of reducing the force required to fold was to lubricate the pivot location of the main rotor. This method was attempted in conjunction with the investigation of reduced blade pin torque, in the hope that a reduction in torque with an applied lubricant may solve the problem. Initially, in the hangar, lubrication seemed to reduce the required forces. Unfortunately, the test team found that once the aircraft was released for flight, the lubrication attracted dirt and grime, resulting in an increase in force required to fold. Once the rotor components were removed, cleaned, and reassembled without the lubricant, the force required returned to its original levels. Moreover, the application of lubricant would have been a new maintenance procedure that would have been required on every fold evolution, requiring additional man power for support, further increasing the time required to unfold and prep the aircraft for flight, and adding a risky procedure that required a man to climb atop the aircraft during every fold operation. Lubrication of the rotor parts increased required maintenance and contributed to the problem of excessive force required to fold the blades.

SWASH PLATE RIGGING

BHTI conducted an investigation of various main rotor swash plate positions in an attempt to reduce the force required to fold. The BFRs were designed for the main rotor to be perpendicular to the rotor mast, in order to minimize torsion on the pivot point and vertical motion of the folding blades throughout the fold. In the tested configuration, the pinning locations of the cyclic did not result in a perpendicular orientation of the rotor plane to the rotor mast. The evaluation of swash plate position resulted in a significant reduction of force. In the tested conditions the force required dropped from 135 lb required to 97 lb. However, a change in the cyclic pinning positions would have required a flight control software change as well as a hardware change, and was deemed inappropriate for implementation prior to sea trials and OPEVAL. In addition, a force required of 97 lb was not considered to be sufficiently low, because the team agreed that forces would climb in an operational environment, so forces in the hangar conditions needed to be consistently much lower than the 100 lb limit. Swash plate rigging showed the most potential for at least partial correction of the excessive force requirement, but still did not make enough of an impact to solve the problem.

A FINAL ATTEMPT

As a final attempt to mitigate the force to fold, Bell Aero sent the BFR designer to Pax River to modify the BFRs. The blade contact points were modified with a larger, low friction, contact pad. This would have reduced the secure attachment of the blade by the rack, because a soft neoprene-type compound was used for the blade contact patch. The roller was modified with a harder compound in an attempt to keep the rotor trailing edge from "digging in" to the roller. The result of this evaluation was that, as with the investigation of lubricants, the force required to fold the rotor increased. A small benefit was realized in certain circumstances, but in most evolutions, the force remained the same or was greater than before the modification.

ADDITION OF BLADE HANDLING POLE

Finally, after all the investigations of methods to reduce the force required to fold, BHTI and Bell Aero determined that there was no feasible way to consistently reduce the force to an acceptable level. The only way to fold the blades, then, was by application of force directly to the main rotor blade instead of using the tail rotor. Consideration was given to use of a rope tied to the top of the crutch pole, but during shipboard operations the rope handler would be at risk of falling overboard. Deck handlers needed to be able to push on the blades during folding instead of pulling on it. In order to accomplish this, another piece of support equipment was developed. The blade handling pole was a seventeen-foot long metal pole that attached near top of the blade support pole. This meant that two people were now required to support the main rotor blade, one on the support pole to limit the vertical deflection of the main rotor blade, and another on the blade-handling pole applying the force. In addition, while aboard ship, the blades on one side of the aircraft are not over the flight deck so application of force on the outboard blades was impossible. The blade handling pole can be seen in use in Figure 10.

The results of this approach were that 1) an additional piece of equipment was required to the already cumbersome list of equipment, 2) an additional person was required to complete the blade fold procedure, and 3) the risk of damage to the aircraft still existed, if a deck crewman attempted to index the main rotor using the tail rotor. This approach, while functional, was a work around at best. It solved none of the problems and required a significant increase in effort and equipment.

Photo by Troy Lancaster, H-1 Upgrades

FIGURE 10: BLADE SUPPORT POLE AND BLADE HANDLING POLE IN USE

CHAPTER 5: RESULTS AND DISCUSSION

The following results, discussion, and conclusions are the sole opinion of the author, based on his analysis of the program issues. They do not represent the views or intentions of the H-1Upgrades program office or of BHTI. The following paragraphs present an analysis of contributing factors that led ultimately to the development of BFE that were unsuitable for operational use, followed by a recommended set of design compromises. Throughout the course of design iterations, no attempt was made to compromise design requirements in order to achieve success, and no effort was placed on investigation of possible aircraft modifications that could minimize the blade folding associated problems. The only way to field a successful set of BFE was to limit the requirements of the equipment, so that a robust, lightweight, simple BFR could be fielded.

USERS DISSATISFIED

The true judge of the BFRs will ultimately be the end user, the USMC support crew that will use the equipment on a daily basis. The Marines are known for finding a way to make something work. Still, during the sea trials test period, the author hosted a meeting to discuss the feasibility of the BFR design as the long-term solution for fleet use. The result of two hours of discussion was a list of 23 deficiencies and issues with the design. The marines felt that the BFRs were completely inadequate for fleet introduction. Some of the noted deficiencies of the tested design are listed below:

1. Inadequate blade protection on the forward and aft heavy weather rack.

2. Interference of the jacking pole with the heavy weather rack blade attachment.
3. Inadequate handles on the blade handling pole.

The full list of noted blade fold SE issues can be found in the appendix of this paper. These noted deficiencies are significant in nature and are spread across all aspects of the BFE. The marines who were aboard the ship during sea trials and participated in this meeting were part of the operational test squadron that would provide the final evaluation of the aircraft. Nine months later, when the aircraft entered OPEVAL and was turned over to these same marines, the BFE remained unchanged. Although the OPEVAL report is not yet released, it is reasonable to conclude that the same Marines will still consider the BFRs inadequate.

COMPROMISE

The history of the BFE has been one of compromise. The initial decision to design a manual folding system was a compromise against cost. The design requirement to support multiple configurations and all weather conditions was a compromise of commonality and simplicity in support equipment requirements. The system restraints are summarized well in reference 8, which was a trip report by the BFR designer following the final attempt to modify the BFE. The purpose of this trip and BFR modification was to determine the feasibility of multiple options for reduction in the force required to fold the H-1 Upgrades aircraft, prior to the sea trials test period. As previously noted, the trip was not successful and led to the development of the blade handling pole as a work around solution. The summary is below:

> "The H-1 upgrade Aircraft are required to fold with only powered Pin Pullers. Other fleet Aircraft employ Rotor Phasing, Pitch Lock, and Blade Sweep actuators. In addition, H-1 upgrade heavy weather requirements are to restrain Blades without damage in 100 kt conditions. Existing fleet Aircraft fold racks restrain only 60 kt winds. H-1 upgrade Racks are designed to maximize commonality- one Rack set will fold both Cobra and Huey Aircraft, for both shipboard use and C-5 transportability. These requirements force a heavy and complex Rack System, while maximizing Aircraft performance and reliability, and minimizing procurement and direct operating costs."

PRIORITIES

One of the main problems with the blade fold support equipment was the approach that had been taken by the program. Because of the cost and magnitude of design changes to the aircraft, there was strong reluctance to correct blade folding problems by a change to the aircraft design, but there was no way to address the problem through changes in the support equipment. There were simply too many requirements for the SE to meet; it was impossible for the SE to correct deficiencies to the aircraft and rotor system design. Throughout the program, it was always too expensive and would have taken too long to correctly address the aircraft deficiencies. The program charter was primarily development of a flight vehicle, and the BFRs were considered a supportability issue, not a flight issue. This belief was so pervasive that no study was conducted to evaluate the feasibility and cost of implementation of an automatic folding rotor; the option was eliminated without in-depth consideration.

COST AND SCHEDULE

Another issue that inhibited correction of the problem was that the program was continually under schedule and budget pressure. The general attitude was that the program had to go forward because the end user, the USMC, needed the upgraded aircraft, and they needed it “now”. And it was true. The USMC did need the aircraft, and the program was under very high pressure from high-ranking officials in the government, military, and BHTI. The program was already significantly over budget as a result of schedule slip to more than twice the original planned timeline for aircraft development. As a result, anything that was considered to be manageable was generally ignored in favor of higher priority problems. The H-1 Upgrades program was at risk of cancellation, which would have denied the marines of this much needed capability upgrade. This manifested itself on a smaller scale, because the program had to keep “moving forward” in order to avoid the appearance of a program that couldn’t be fixed, and must be cancelled. This meant that interim milestones had to be met on schedule, and in the case of sea trials, it meant performing the final evaluation on a blade fold system that, in the opinion of the users, was not ready for fleet use. Finally, when BHTI implemented the blade handling pole, they assured the program office that this solution was “just for OPEVAL” and that a new design would be delivered after OPEVAL. At the time of publishing this paper, no new support has been developed, tested, or delivered.

Possible Solutions

Reduced Load Conditions

One way to improve on the BFE would be to redesign the equipment with fewer design requirements and more freedoms of design. If the BFRs did not have to withstand a 1.5g lateral loading in the air transportability configuration, the racks could have been smaller and lighter. A separate set of equipment could have been added for the rarely used configuration of air transportability.

Another way to reduce required load conditions was to support only one set of weather conditions. The MH-60S aircraft utilizes an automatically folding rotor system with small, lightweight blade support racks that are designed for use in winds up to 60 kts. For more extreme weather conditions, the aircraft must be stored in the hangar. If one weather configuration had been chosen for the H-1 Upgrades, the racks would not have been required to have a separate heavy weather rack that pinned in place; instead, the entire rack system could have been a one piece design that was suitable for all planned conditions.

Still another way to reduce the complexity of the BFR design was to design a more robust main rotor, so that the folding blades could be placed in the racks after folding rather than before. This way, the blades would not have to be allowed to move through the racks during the fold cycle, allowing for a simple, secure blade restraint. This too would be similar to H-60 series helicopters, in that the racks are placed on the rotor system after the fold cycle is complete, so that once placed in the racks, the blades never move. This change to the H-1 Upgrades would also alleviate the risk of damage to the tail rotor by eliminating the high force required to fold. Finally, this would have greatly reduced the complexity of the BFR by eliminating the need for both jacking and sliding of the rotor blade. The racks could have been a simple clamp design to secure the blade, rather than a complicated pad and roller system. It is possible that there would have to be operational restrictions on the new BFRs if they were designed to a smaller load set, but this is a trade study that never took place to determine the operational feasibility of such a set of limits. The reduction in weather configurations could have greatly reduced the complexity and increased reliability of the BFRs by elimination of the moving parts on the system.

REDUCED CONFIGURATIONS

One more way to improve the functionality of the BFE would have been to limit the number of configurations that one set of equipment needs to meet. For example, if the racks were designed to support both aircraft type in only the normal weather configuration, savings could be realized in weight, complexity, and ease of installation. There is an obvious benefit to using the same set of BFRs for both the UH-1Y and the AH-1Z, but there is limited gain by using the same set of equipment for the air transportability configuration as in the heavy weather configuration. If the racks were not the same set of equipment that is used for air transportability and heavy weather, the resultant loads on the rack would be much less, resulting in a smaller and lighter BFR. Also, the number of parts and complexity of installation could have been greatly reduced, making the racks simpler, more robust, and more reliable.

Simplified Design

Another way to minimize the BFE requirements list would be to simplify the design. Specifically, the heavy weather configuration could utilize all the same equipment as the normal weather configuration, including the large yellow blade securing strap, but could also implement a second, vertical brace that would attach under the unfolded blade in nearly the same way that the current heavy weather attachment does. The design and installation could be greatly simplified by continued use of the strap to secure the unfolded blade, so the heavy weather support could be just a flat pad on a vertical pole, with no need for moving, locking jaws that are difficult and time consuming to install. The blade would be secured by the pole underneath and the strap above. The other advantage of this approach would be that the unfolded blade would not have to be released prior to application of the heavy weather attachment, rather, the heavy weather support could be pinned in place while the blade remained secured by the yellow strap. It is possible that this approach would not meet the lateral load requirements that the main rotor will encounter in the 100 kt reverse flow wind condition, but as stated before, a limitation could be placed on the aircraft that would require hangar storage in winds of this magnitude. This limitation would have minimal impact on the user and is prudent anyway.

Automatic Folding

A possible solution to the deficient blade fold system would have been, during initial aircraft development, to design an automatic folding rotor system. Other shipboard aircraft have used automatic folding four (or more) bladed rotor systems for decades. An automatic folding system would have been expensive to implement, and would have carried an associated weight gain, but the benefits in shipboard suitability would have been great. The aircraft would be able to support a greater operational tempo as a result of faster folding and unfolding cycles. The aircraft would have required less support maintenance as a result of the reduced manpower required for folding and unfolding. Finally, an automatic folding rotor system would have reduced risk to aircraft and to personnel, because of the inherently dangerous blade folding procedure.

ROTOR INDEXING MOTOR

One way to partially implement automatic folding would be to incorporate a rotor indexing motor. This motor could automatically or manually rotate the main rotor during the folding process. This would eliminate the need for two of the flight deck personnel, speed up the process, and most importantly, would eliminate the risk of damage to the aircraft tail rotor. It would also greatly speed the process of main rotor folding while still using the existing equipment. The motor could be integrated into the rotor brake disc by interlocking on the disc shaft or by putting teeth around the outside of the rotor brake disc for a gear to turn the disc. The motor could also be used to eliminate the RBLT and associated tools, if designed to lock the rotor brake in place once the fold cycle was complete.

It is notable that this idea of a blade indexing motor is not original. Other manufacturers have incorporated a similar design since the 1960s. The idea for automatic indexing was proposed at preliminary design review of the H-1 Upgrades, and was rejected. This idea would be inexpensive, simple to integrate, and would alleviate the most serious of the folding deficiencies. It could eliminate the need for two RBLTs per aircraft while still utilizing the current BFRs. The current manual method could still be used as a backup in the event that the motor didn't work properly.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

From the beginning, the H-1 Upgrades BFE was over-constrained by the list of requirements that the equipment was supposed to meet. Without an automatic blade folding system, the aircraft SE was asked to compensate for the aircraft deficiency. That, plus a limited budget, short schedule, and low priority inevitably resulted in a design which, in the opinion of the author, is neither effective nor suitable for introduction to the fleet.

The true source of the problem was the lack of implementation of the folding mechanism into the main rotor, a problem that could have been corrected very early in the aircraft design process. In order to meet the user requirements, the aircraft should have had an automatic folding system with a single, secure configuration to be used under all conditions, and a second set of equipment for air transportability. This would have eliminated the need for moving parts on the BFE, and would have greatly reduced the total number of parts by only supporting one configuration, instead of three. It would have also aided in rapid installation and removal of the racks by virtue of simplicity. A folding rotor system would have also resulted in reduced manning requirements, reduced support equipment requirements, and a reduced aircraft logistical footprint. Unfortunately, because of priorities, once the problems with the BFE were identified, the program was already four years into a flight test program, and any change to the main rotor system would have required re-qualification of the entire flight envelope - a move that was deemed to be far too expensive and far too high risk for the program. In addition, the program was under schedule and budget pressure from the beginning and therefore management was averse to major design changes if there was a potential work-around available, which there seemed to be. As a result, efforts to correct the deficiencies in the blade fold implementation concentrated on modifications to the support equipment, an approach that could never have corrected the root problem.

The design requirements for the BFE limited the development process from the time when a manual folding rotor system was selected. The only way that successful BFE could have been developed was for the program to reduce the requirements of the BFE, to be used in a limited set of environmental conditions or a limited set of configurations. However, by forcing designers to plan for all conditions, even those that will be rarely or never encountered, the BFE that resulted was a set of equipment that was ineffective in everyday use. Selection of a limited set of design requirements would have resulted in a simple, robust, and user-friendly design that would have met the vast majority of the desired conditions.

The force required to fold was a major aircraft problem that could not be mitigated by changes to the support equipment. Until an aircraft change is implemented that eliminates this problem, there will continue to be a risk of significant aircraft damage from unacceptable forces applied to the tail rotor. A relatively easy way to solve this problem would be to incorporate a blade indexing motor that automatically turns the main rotor during folding evolutions. The motor could be integrated easily by applying force to the rotor brake disc, either through teeth around the outside of the disc or by interlock to the disc shaft.

If the BFE had been designed for shipboard and land based storage only, and not for air transportability, the load requirements on the BFR would have been greatly reduced, both in the vertical and in the lateral direction. This would have allowed a much lighter, simpler design to be implemented. If the BFE was required to support only the normal weather configuration like other shipboard aircraft, the design could have been one piece, with a much simpler installation and fewer parts required. And finally, if the main rotor were more robust so that the rotor blades did not have to move through the BFR, then the design would have been a very simple yet very secure clamp for the blades. The combination of these three concessions would have resulted in a light, simple, robust, and reliable design that was easy and fast to install.

RECOMMENDATIONS

The H-1 Upgrades BFE is critical to program success. The equipment affects the aircraft readiness, deployability, and suitability. A simplified BFR design could greatly reduce the complexity of installation and decrease the time required for before and after flight maintenance, resulting in an increased operational tempo at no cost in manpower. In the author's opinion, the H-1 Upgrades program should do the following:

1. Redesign the H-1 Upgrades main rotor to incorporate an automatic folding rotor system.

2. Redesign the blade fold racks for a reduced set of configurations, eliminating the air transportability and heavy weather configuration requirements for this set of equipment.

3. Redesign the blade fold racks using a reduced load set.

4. Simplify the design of the heavy weather equipment to utilize the normal configuration equipment with an additional vertical brace.

5. Consider changes to the main rotor system to allow the blades to be placed in the blade fold rack at the completion of the folding process, rather than at the beginning.

6. Consider a simple, one-piece, clamping blade fold rack.

7. Consider incorporation of an automatic blade indexing motor.

WORKS CONSULTED

WORKS CONSULTED

1. http://pma276public.navair.navy.mil/pma276public/history.asp, USMC Light/Attack Helicopter Program, History.

2. http://www.globalsecurity.org/military/systems/aircraft/ah-1z.htm, Military, Systems, Aircraft, Rotary, Attack, AH-1Z.

3. http://www.globalsecurity.org/military/systems/aircraft/uh-1y.htm Military, Systems, Aircraft, Rotary, Attack, UH-1 Iroquois (Huey).

4. SD-549-21, *Performance Specification for the AH-1W Upgrade Aircraft*, Rev 8, 09 October 1996.

5. SD-549-22, *Performance Specification for the UH-1N Upgrade Aircraft*, Rev 7, 09 October 1996.

6. Greely, John G., Senior NAVAIR Support Equipment Engineer, Interviewed in building 514, Patuxent River, MD.

7. Newcomer, John, White Paper, *H-1 Upgrades Support Equipment, Blade Fold Rack Suitability,* 07 March 2005.

8. Southerland, Michael, Summary Report, *Trip Report-Pax Y-2 Blade fold evaluation. March 23-24, 2005,* Memo #: MJS033105.

9. Southerland, Michael, BFR designer, Interviewed on 10 May 2005 aboard USS BATAAN.

10. H-1 Upgrades Report No. 449-099-072, *Crew Interface Section Functional Test Procedure H-1 Blade Fold Control System*, 21 July 2000.

11. Greely, John G, Microsoft Excel file, *BFR Sea Trials*, 16 May 2005.

12. Greely, John G, Microsoft Excel File, *H1-BFR-FFR-Squawk 040917*, 10 May 2005.

13. A1-H60SA-NFM-000, *NATOPS Flight Manual Navy Model MH-60S Aircraft*, 15 March 2005.

14. H-1 Upgrades Report No. 449-099-072, *Crew Interface Section Functional Test Procedure H-1 Blade Fold Control System, UH-1Y EMD Aircraft, 55002 and 55003*, Basic, dated 21 July 2000

15. H-1 Upgrades Report No. 449-930-023, *AH-1Z Deck Strength / Mooring / Air Transport Suitability Report*, Revision A dated 31 May 2001.

16. H-1 Upgrades Report No. 450-930-023, *UH-1Y Deck Strength / Mooring / Air Transport Suitability Report*, Revision A dated 15 June 2001.

17. H-1 Upgrades Report No. 449-993-085, *AH-1Z Aircraft and Systems Description*, 17 May 2000.

18. H-1 Upgrades Report No. 450-993-069, *UH-1Y Aircraft and Systems Description*, 25 May 2000.

APPENDIX

TABLE 1: BFR 4 AND 5 DEFICIENCIES

ISSUE NO.	DEFICIENCY	CORRECTIVE ACTION
FFR-001 / #1 & 6 & 28 & 43	The BFR attach fittings that mate to the A/C hoop fittings (ref. 449-030-156-103/-104) exhibited an extremely tight fit during aircraft fit checks. These fittings are present on both the left and right hand side of the aircraft. Both fits with the aircraft were tight.	Slightly modify the tolerance of the BFR fittings to provide a tiny bit more clearance. Additionally, surface finish will be removed on the BP from the lower region of the part. The existing parts are 17-4PH, and are corrosion resistant.
FFR-002 / #29	The BFR attach fitting that mates to the A/C clevis fitting (ref. 449-030-160-103) exhibited an extremely tight fit during aircraft fit checks. The fitting mates into a clevis fitting on the aircraft that has over time, had lots of paint build-up. The fitting on the BFR is designed to fill the width of the clevis, generating a nice solid fit. Minimal play in the fitting is desired during loading of the rack in the fore/aft direction.	Slightly modify the tolerance of the BFR fitting to provide a tiny bit more clearance.
FFR-003 / #3	Three different assemblies that possess telescoping features on the BFR have a soft captivation method that appears to be insufficient. The assemblies have a spring-loaded ball detent that, if telescoped too far, engages a hole in the outer tube and prevents the tube from dropping out of the assembly. During the design phase, stainless steel ball detents were selected for their corrosion preventative characteristics. However, during the assembly phase of BFRs CK001, CK002, and CK003, it was noted that these stainless steel detent balls were scoring the interior surfaces of the tubes they were mounted into. As a result, the detents were threaded down into their housing to reduce this condition. The captivation effectiveness was affected as a result during the functional testing. Fast tube extraction yields inadequate captivation.	Switch the spring loaded ball detents to acetyl, and adjust to proper height per drawing requirements. The scoring problem will be corrected through a material change, and the tube captivation effectiveness will be increased as a result of properly adjusting the spring plungers to the correct height.
FFR-004 / #4 & 5 & 50	The telescoping features on the strut assemblies of both the forward rack and the aft rack seem to bind during adjustment. The inner tube of the extended blade support assembly also requires a better wear surface due to repeated plunging during adjustment.	Provide supplemental acetyl wear surfaces, where applicable. Hard anodize inner tube surfaces to provide better wear surface characteristics.

TABLE 1: CONTINUED

ISSUE NO.	DEFICIENCY	CORRECTIVE ACTION
FFR-005 / #7	The strongback assembly of both the forward rack and the aft rack should possess knurling in the region of common hand-hold areas.	Add non-skid tape to required regions. Knurling cannot be accomplished on existing units, therefore non-skid tape applied to the region will provide the required grip.
FFR-006 / #8	The jacking pole contains a swivel assembly that interfaces the blade-handling pole. This interface is designed to allow an operator to install or remove the BFR system from either the aft or forward position, on either aircraft. The swivel interface is difficult engage when the BFR, (fore or aft) is already installed onto the aircraft.	Encourage BFR operators to practice using this method. This tool feature was under utilized during the functional testing. More practice by operators may reveal that the functionality of the swivel is adequate. **Therefore, no rework unless additional information comes out of sea trials.**
FFR-007 / #12	The swaged ball cable assembly that resides at the outboard end of the folding blade clamp assembly binds slightly when adjusted to/from the different available positions. The swaged balls bind in the root of the “butterfly” fitting located on the end of the lower arm of the folding blade clamp.	Modify the dimensions of the butterfly fitting so that the swaged ball cable assembly can slip into position a little easier. Consideration will have to be given to the overall stability of the design. In other words, the stability of the swaged ball in the butterfly fitting, once the arm is in the capture or secure positions should not be compromised to facilitate easier installation.
FFR-008 / #13	Strap storage for the folding blade strap throw-over. The current design does not have a storage location for the straps. The straps are very long, and easily become entangled around objects and people when left un-stored.	Allow the customer to continue using the assembly in the current design, and possibly **develop a recommendation for improvement based on a record of experience after sea trials.**
FFR-009 / #19 & 27 & 38 & 56	The throw-over portion of the extended blade strap seems marginally long. The throw-over process requires a longer piece of lead material because the strap itself is too heavy, and presents too much “windage” in a shipboard environment to throw over repeatedly. In addition, the overall length of the load carrying portion of the strap was too long to effectively restrain the blade. Another design suggestion from the customer included modifying the length of the extension portion of the strap to allow operator to walk the strap over the tip of the blade. This is not recommended because damage to the trim tabs could occur with the strap in close proximity during this type of procedure.	Lengthen the piece of throw over strap used to facilitate the transfer of the extended blade strap from one side of the blade to the other.
FFR-010 / #17	The extended blade strap support had problems feeding its way over the trailing edge of the extended blade once thrown over the top. The width variations provide edges that snag on the trailing edge.	Provide a modified design that tapers and transitions from one width to another, allowing for better pull over of the strap across the trailing edge.

TABLE 1: CONTINUED

ISSUE NO.	DEFICIENCY	CORRECTIVE ACTION
FFR-011 / #18	The lead weight of the extended blade strap support is too large in diameter. It presents a dent risk in its current configuration.	Redesign the lead weight with a portion of rubber, (i.e. rubber ball, rubber tube) consisting of the same weight, that could be thrown over in lieu of a bag of lead shot. This presents a reduced risk of FOD, and potentially less damage to the aircraft blades during throw-over.
FFR-012 / #20	The inner tube of the extended blade support structure exhibits too much free movement with respect to the outer tube of the extended blade support structure.	Increase the dimensions of the aluminum wear pads by just enough to consume excessive play. Add additional acetyl wear pads that extend along the length of the tube, so that the wear surfaces are acetyl, and the bearing surfaces remain aluminum in those regions that require them.
FFR-013 / #21 & 31	Rotor brake does not fit into the required envelope.	Redesign the rotor brake tool to properly fit and function within the given envelope.
FFR-014 / #65	The NORCO pins do not store into the storage utility belt bolted to the base of the strongback assembly.	Hard anodize the piece parts, and verify holes will accept the current design of the NORCO pins.
FFR-015 / #22	The forward strongback fouled the TSS.	Redesign the strongback, (ref. HD-100020) to allow for a modified height of the lower cross tube. **(Note: Commonality between aft and forward strongbacks drives a small change will have to result in the aft third strut to maintain proper fit with aft rack).**
FFR-016 / #24 & 52	Clearance of the forward third strut joint structure with the AH-1Z canopy in the extended position. Inadequate overlap between the lower inner tube and the outer tube add to this concern.	Modifications of the lower translating joint to prevent excessive play during inboard loading. This would entail making the interface a little more of a lap joint, instead of the limited overlap currently designed. Replace the protruding heads of the fastener collar with a riveted joint that could be shaved flush, providing less potential of damage in the event that contact occurs.
FFR-017 / #25 & 26	The engagement of the upper folding blade clamp arm into the lower folding blade clamp arm is inadequate. When positioned in the capture mode, the upper arm does not engage the lower arm sufficiently to transfer folding loads in the lower arm of the folding blade clamp.	Redesign the lower arm to allow for more interaction between the tip of the upper arm and the end of the lower arm on the folding blade clamp during capture configuration.
FFR-018 / #30	Flex shaft extension arm sticks beyond the top of the strongback assembly.	Leave current assembly as is. The assembly itself may be removed from the rack, and replaced by a more common hand tool, therefore rework to alleviate this condition would be dependent on whether or not the extension arm stays on the assembly at all. (Human Factors Issue)

TABLE 1: CONTINUED

ISSUE NO.	DEFICIENCY	CORRECTIVE ACTION
FFR-019 / #32	The design of the HD-100021-101 fitting and the mating fitting on HD-1000031 may foster the 'spin-out' of the bushings.	A modification of the design might be required based on the results of the investigation. Pictures and other data from the functional test will be used to evaluate if the bushings were in fact installed prior to functional testing. If no design errors are revealed, then the design will remain unchanged.
FFR-020/ #33	The jack lockout key has a design error that prevents the key from being locked out because it is too long by .200 inches.	Modify the applicable dimension to allow proper fit.
FFR-021	The lockout arm is susceptible to damage during non-use. This is the jack lockout arm that is used to secure the jack lockout key. This system is used to prevent downward jack drift during periods of non-use in the loaded condition.	Change the material and design to provide a more substantial assembly capable of more abuse.
FFR-022 / #67	Painted surfaces of the tool are subject to repeated wear, partly because the tool will see such frequent use, and also because tool is not stored in a case or other protective storage media.	Investigate the possibility of powder coating the assembly to provide a more wear resistant finish for components of the BFR seeing contact with the ground. Not all components of the BFR may be candidates for powder coating, partly because of the heat required to cure the finish onto the parts. Many of the BFR welded assemblies are aged only at 350 degrees F. If the powder coating temperature is higher, or similar, it may have detrimental affects to the strength. Other detriments include warpage. If powder coating proves to be unavailable for our applications, then the default will be to continue using the same finishing specifications used by all other H-1 Upgrade SE.
FFR-023 / #68	ID of the round tube on the welded assembly has an inadequate wear surface.	Modify drawing requirements to selectively hard anodize ID of HD-100020-301. The proposed solution has a $500.00 impact per strongback.
FFR-024 / #35 & 37	Upper arm flexibility during fold is unacceptable. The folding loads produced some unexpected deflections. These deflections may be the result of a optical illusion resulting from the spring in the end of the folding blade clamp to stack, thus resulting in rotation about the main hinge point of the folding blade clamp upper arm.. This rotation could be falsely perceived as deflection. A design investigation will reveal whether this is the case or not.	Redesign upper arm of folding blade clamp to provide additional rigidity during folding loads. A re-evaluation of folding loads will be conducted to validate folding loads that were experienced during testing.

TABLE 1: CONTINUED

ISSUE NO.	DEFICIENCY	CORRECTIVE ACTION
FFR-025 / #36	Lower arm flexibility enhances difficulty during adjustment of folding blade clamp assembly from capture mode to secure mode.	Modify the existing design to provide more rigidity during adjustment between configurations.
FFR-026 / #69	The roller of the folding blade clamp needs to be more substantial. The roller material is currently a little too pliable for the loads that are exerted onto it during a fold/unfold.	Redesign the roller to incorporate a new material(s), less likely to gouge during fold/unfold with the trailing edge bearing up against it. The material selection need to also be sensitive to the trailing edge.
FFR-027 / #70	The upper inboard pin on the extended blade support clamp binds during pin extraction. The pin currently locates itself through three close tolerance bushed holes.	Redesign to loosen the tolerances of the ream on the bushed hole to alleviate condition.
FFR-028 / #44 & 45 & 71	The GF-100024-1010 assemblies were not used. Capt. Abate requested that the assemblies go away. During functional testing, Snap-On extension handles were used in lieu of the designed extension arm with no detriment to performance.	Remove and replace the designed extension arm with an off-the-shelf Snap-On 3/8" drive that can be stored on the rack in a similar position. The off-the-shelf component will have to be assigned a dash number and be made into a "make from" assembly. Without this, provisions cannot easily be made on the rack to store the Snap-On component.
FFR-029 / #42 & 48	Redesign of the extended blade support structure to allow for installation from the ground. Captain Abate requested a complete redesign of the extended blade support structure to allow for its installation from the ground.	This is considered a new design requirement. Discussion with the customer about use of ladders and stands to position this component of the BFR on onto the rack after aircraft has been moved to off-spot. **No redesign until further evaluation of requirements has been conducted with customer.**
FFR-030 / #51	The separation of the dogleg fitting from the aft NORCO pin. The captivation method of the dogleg fitting on the forward third strut has been questioned by a couple of operators. Some feel that the current configuration presents a small risk of damaging the aircraft during installation into the aircraft fitting.	Continue to install the rack using the current design. **More definitive results with regards to this concern will be obtained upon completion of sea trials.**
FFR-031/ #53 & 57 & 72	The jack lockout feature is a two-piece operation. The current design uses a two-piece design to effectively lock out the potential downward drift of the jacking pole actuator during long term positioning in the loaded condition.	Continue to use the current design. **Make more informed decisions about the design and possibly its applicability after sea trials.** It may turn out that the actuator design will not sufficiently drift even in the unlocked condition to warrant the lockout device.

TABLE 1: CONTINUED

ISSUE NO.	DEFICIENCY	CORRECTIVE ACTION
FFR-032 / #54	Marking – Marking was left off of the functional test units to allow for real time assessment of marking locations during the functional test. Several recommendations were given to help operators use the BFR system more efficiently. Some of the recommendations are as follows: 1. Mark the strongback to help indicate the position of the extended blade during a shipboard fold.· Mark each jacking pole assembly with large letters indicating whether it is a forward jacking pole or an aft jacking pole.	Change design to mark with painted labels.
FFR-033 / #15 & 16 & 47 & 55	The lower arm comes into close proximity of the lower surface of the blade during blade approach. The actual clearance as measured during the functional fold test was about 2 inches. This clearance my not be adequate in a shipboard environment. Additionally, if procedurally the blade is allowed to drop out of the folding blade clamp, a potential exists to damage the underside of the blade when the blade contacts the lower arm of the folding blade clamp.	Redesign to provide a buffer surface that will protect the blade in the event of contact between the blade and the lower arm of the folding blade clamp.
FFR-034	The interface of the blade-handling pole to the swivel assembly provide for an awkward interface due to the length of the pole while installing/removing onto/from aircraft.	**No action until further data can be obtained after sea trials.**
FFR-035	The interface of the blade-handling pole to the swivel assembly provide for an awkward interface due to the length of the pole while installing/removing onto/from aircraft.	**No action until further data can be obtained after sea trials.**
FFR-036 / #9 & 10 & 11 & 49	The design of the blade handling pole head should be optimized to reduce weight and complexity.	Redesign the head of the blade handling pole to reduce weight, and complexity.
FFR-037 / #63	The interface of the blade-handling pole needs a non-slip surface for better grip during blade control.	Redesign to accommodate mixing grit into the paint for that region of the tube. This would allow for less machining, more strength, and less weight than the knurling option. Also, rework to existing units could be accomplished that would match the production design change.

TABLE 1: CONTINUED

ISSUE NO.	DEFICIENCY	CORRECTIVE ACTION
FFR-038	The extended blade lockout interface was very cumbersome to use. It relies very heavily on blade position, and should be re-evaluated. The current design relies on springs, and over-center mechanisms that are overly complicated for the application they serve.	Redesign the interface to utilize a limited adjustable rigid system in lieu of over-center mechanism.
aircraft #1 / #2	Deflection of the A/C fitting and local skin was noted during aft BFR install	(None to date.)
aircraft #2 / 61 & 62 & 64	Air Transport configuration; change to removing the blades?? Maj. wants to know. Chris for action	(None to date.)
FFR - / #39	issue with very loose parts during installation of extended blade support - - extended blade clamp had been unpinned on the ground, and was fully broken down into its most 'open' configuration prior to loading COULD BE INCORPORATED INTO FFR-019	lower, upper, and diagonal arm. Issue with loose arms hitting people as it is installed. TBD on proposed fix.
FFR- / #40	required additional personnel to support the extended blade itself during the installation of this gear	procedural or if after sea trials we need to lower the clamp to accommodate the blade droop. Basic question is what will be the elevation of the production fixed blade be?
FFR- / #41	issue with the upper arm pad punching a hole in the top of the blade. - upper arm was rotated over into position	(None to date.)
aircraft #3 / #34 & 46 & 58 & 59 & 60	excessive force required to initiate fold - excessive force on tail rotor	(None to date.)
FFR- / #14	The internal stop of the actuator design needs to be reviewed for its robustness.	Chris will look into this with manufacturer to make sure that the stop can tolerate the loads.

TABLE 2: SEA TRIALS BLADE FOLD ISSUES

DEFICIENCY	DISCUSSION
Inadequate blade retention of the Blade Handling Pole (Crutch Pole)	Although in ideal conditions the retention straps will engage the end of the blade tip, in normal conditions the straps tend to get out of position with the slightest misalignment of the Pole or wind condition. **A large hole meshed sock would improve the design.**
The requirement for the B-4 stand on the flight deck for the installation of the Extended Blade Support Assembly (Heavy Weather Rack) is not required so long shipboard compatible ladders are identified for that function.	Pub issue. **Eliminate the reference to the B-4 stand for the installation of the heavy weather rack. Identify ladders similar to the V-22 Little Giant Ladders with tie down rings.**
Inadequate design of quick release pin installation.	A global review of the pin insertion tolerances needs to be done. The excessive operator compensation required to assemble the BFR is unacceptable. **Although the loads need to be addressed in the design, the capability to insert the pins in a darkened ship environment is essential.**
Inadequate design of Aft Rack telescopic Strut Assembly	Initial discussions were in the direction of deleting the telescopic capability. As the discussion continued, the ability to stow the strut in a less susceptible configuration was found to be a better. **The relocation of the procedural step that extends the strut to a location prior to the installation of the rack on the aircraft should improve the installation issue**.
Inadequate design of Aft Rack telescopic Strut Assembly	The inner tube of the extended blade support structure exhibits too much free movement with respect to the outer tube of the extended blade support structure. **Investigate increasing the overlap length within the interface to improve the condition.**
Inadequate design of the Forward and Aft folding blade clamp rollers	Although the material was changed to improve the condition, the new material continues to degrade within very few folds. **Investigate a new design approach to eliminate the degradation of the blade retention device. Is a roller required? Would a Delryn pad be adequate without degrading the trailing edge of the blade.**
Inadequate design of the folding blade (throw over) strap.	Initial discussions were in the direction of lengthening or changing the configuration somehow to improve the ability of the crew to get the strap over the blade. **As the discussion continued, most agreed that crew proficiency and possible local mods would eliminate this issue.**
Inadequate design of the fixed blade (throw over) strap.	Lengthen or change the configuration somehow to improve the ability of the crew to get the strap over the blade. **Investigate lengthening the strap as a solution.**

TABLE 2: CONTINUED

DEFICIENCY	DISCUSSION
Inadequate design of the fixed blade (throw over) strap.	The extended blade strap support had problems feeding its way over the trailing edge of the extended blade once thrown over the top. The width variations provide edges that snag on the trailing edge. Although the transition has been improved, there continues to be snag issues with the design. **Improving the transience will eliminate this issue.**
Inadequate retention of the Forward and Aft Rack speed handle	Depending on the condition of the speed handle and the manufacturer, the speed handle retention ring that retains the handle of the speed handle can be too restrictive to allow the handle to be easily removed. **Investigate moving the retaining ring an additional .5 inches upward.**
Unnecessary component on the Forward and Aft Jacking Poles	The Blade guard installed on the top clamp of the Forward and Aft Jacking Pole Assembly has no purpose. Although the design was driven by information on the rotor system that proved conservative, the actual movement of the blades do not seem to require the guard. **Investigate the possibility of removing the guard and adding protective material to the blade side of the upper clamp.**
Component on the Forward and Aft Jacking Poles interferes with the installation of the heavy weather rack	When the upper arm (in the extended position) on the heavy weather rack is placed over the non folding rack the arm contacts the Blade Guard. The design was forced to have a telescopic capability on the arm to allow the arm to clear the Blade Guard. **Investigate the elimination of the guard and the removal of the telescoping component on the upper arm.**
Unnecessary lower clamping position on the Forward and Aft Jacking Pole.	The lower clamp arm on the Forward and Aft Jacking Pole has two positions; Normal and Heavy Weather. During folds at Sea Trials, the Heavy Weather position was used during the first fold and was never placed back in the Normal position throughout Sea Trials. **Investigate the removal of the two position capability on the lower arm.**
Inadequate blade protection on the forward and aft heavy weather rack.	During the installation of the forward and aft heavy weather rack, if the blade is positioned incorrectly, the blade can contact metal surfaces on the lower arm. **Investigate the application of a larger Delryn pad to adequately protect the blade during the installation of the heavy weather rack.**
Over-complex design of the heavy weather rack.	With the issues associated with the installation of the pins, the use of ladders to install, and the somewhat uncontrolled placement of the upper clamp over the non-folding blade, there is a desire to simplify the design of the rack. During Sea Trials, H-60 aircraft secured their blades with a clamp device that seemed considerably easier to use. **Investigate the possibility of using a clamp style blade interface on the heavy weather rack.**

TABLE 2: CONTINUED

DEFICIENCY	DISCUSSION
Inadequate handles on the Blade Handling Pole (crutch pole).	Although the conditions during Sea Trials were considered moderate, there was an instance that the man on the crutch pole lost his grip on the pole. During degraded weather the opportunity to loose control of the crutch pole is increased significantly due to the lack of any high friction surface to hold the pole. **Investigate the application of grip tape or some other high friction surface on the handling areas of the pole.**
Excessive weight of the Blade Handling Pole (crutch pole).	During Sea Trials personnel noted that there was significant effort applied to getting the crutch pole in place and managing while it was in place. **Investigate a weight reduction program for the crutch pole, possibly a design similar to the H-60 clamp.**
Lack of data associated with the optimum elevation of the blade for the least force to fold the blades	Although the additional pole attached to the crutch pole allowed for the movement of the rotor system during fold, the forces were still in the 80 pound range. During a test at Pax, there was a test that demonstrated that the pivot pin was significantly relieved when the blade was extended another 4.5 inches past the maximum elevation of the Jacking Pole blade clamp. Although this does not categorically indicate that the binding in the joint is relieved when the blade is lifted past the maximum reach of the BFR, it is certainly worth investigating a better elevation for the blade during folding to reduce the force to fold. **Investigate the binding loads of the pivot joint at various blade elevations.**
Excessive turns required to raise the Forward and Aft Jacking Poles.	The Aft Jacking pole requires 82 revolutions to raise the blade clamp to the maximum elevation. The Forward Jacking Pole requires a similar amount. The crews that folded during Sea Trials all commented that the time it took to raise the Jacking Pole was excessive and that the force to raise could be considerably more. **Investigate the use of a lower gear ratio on the Jacking Pole raising mechanism.**
Inadequate 3d strut NORCO Pin Assembly storage.	The mechanism to secure the 3d strut NORCO Pin Assembly inadequately retains the assembly. The NORCO Pin does not freely install into the pin holes and the retaining mechanism for the other end of the Assembly allows the end to become loose.
Unnecessary telescoping section on the Forward Stongback.	During operations at Sea Trials it was noted that the telescoping capability on the Forward Strongback that allows the crew to attach the 3d strut when the Strongback is at 45 degree orientation was not used. When asked if it was a capability that could be used in some situations, the answer was that it was not necessary. **Investigate the elimination of the telescopic capability and use the newly available length of square tubing to stiffen the joint on the required telescoping section (AH-1Z to/from UH-1Y configurations) by create a longer overlap .**
Inadequate design of the Rotor Brake Tool.	Rotor Brake Tool is difficult to install in both aircraft. With the ship motion, the port installation on the UH-1Y is particularly dangerous for personnel climbing on the aircraft. **Investigate the actual requirement for the rotor brake and if it is still required make it easier to install.**

TABLE 2: CONTINUED

DEFICIENCY	DISCUSSION
Inadequate protection for the non-folding blade on the Jacking Pole.	In the event that a non-folding blade is rotated too far and the blade contacts the rack, there are no provisions for protecting the trailing edge of the blade. Especially during darkened ship, there is a considerable possibility that the blade can contact the rack. **Investigate the addition of a protective surface to prevent damage to the blade.**
Lack of adequate marking on the telescoping components.	During the operation of telescoping the 3d struts it is very easy to go past the pinning hole, especially during a darkened ship condition. Although loosening the hole tolerances will help, a visual indicator that is readily visible with NVG compatible lights will make the operation significantly easier. **Investigate the marking of the hole positions with NVG compatible markings.**

VITA

Matthew Funk was born in Virginia and raised in Virginia, North Carolina, and Ohio. He graduated from Olmsted Falls High School in Olmsted Falls, OH, in 1994. Upon graduating from Ohio University with a Bachelor of Science degree in Mechanical Engineering and a Minor in Mathematics in November 1998, he came to work at the Patuxent River NAS in January 1999. He worked for the Ship Suitability, Rotary Wing branch and was selected to attend the United States Naval Test Pilot School in Patuxent River, Maryland. Upon graduating from the United States Naval Test Pilot School in 2002, he was soon assigned to the H-1 Upgrades program as the Ship Suitability lead engineer. As his time passed with H-1 Upgrades, he was additionally assigned to be the lead engineer for IMC certification, Structural Demonstration, and Height-Velocity envelope development. In December 2005 he was selected as the Lead Test Engineer for the H-1 Upgrades Program. As the H-1 Upgrades flight test program wound down, in May 2006 Mr. Funk was re-assigned as the Lead Test Engineer for the Naval Unmanned Combat Aerial System, where he continues to work today.