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## MH-53J SERVICE LIFE EXTENSION PROGRAM, A SPECIAL OPERATIONAL FORCES ROTORCRAFT WINNER

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### ABSTRACT

This paper presents a summary of the airvehicle modifications (largely structural) that were made and the airworthiness qualification flight test program that was conducted to expand the operational gross weight capability and enhance the structural integrity of the subject helicopter. The impact on both vibration and dynamic component retirement times are discussed. The paper includes both technical and cost information to support program benefits of this modernization approach, *but will address only the basic airvehicle, including its rotor/drive and propulsion systems*. Discussion of special mission equipment peculiar to the special operational forces mission and most shipboard operations features, can not be included.



### BACKGROUND

To support the United States capability to conduct Special Operations, the Congress of the United States authorized a comprehensive Special Operations Force (SOF) enhancement program. Legislation further directed that DoD reorganize command structure by creating a Unified Command for Special Operations (USSOCOM). Within the DoD budget, a separate Major Program Force Category, known as Program 11, was established for all SOF budgeting activity. Under these procedures the Service Departments continued to execute SOF programs for USSOCOM using Program 11 funds. This applied to major systems acquisition programs and modernization efforts such as the USAF H-53 variants.

A key congressional concern in examining the DoD's ability to execute special operations has been the status of SOF aviation capabilities. In 1987, the Joint Special Operations Agency (JSOA) provided a SOF Aviation Requirements List to the Congress outlining the enhancements necessary to meet war-plan requirements.

To meet wartime/contingency planning needs, one of these enhanced requirements was the H-53 PAVE LOW weapon system, with the development of an Emergency War Planning (EWP) capability.

When combined with the accomplishment of a Service Life Extension Program, and a Shipboard Operation Program (SLEP/SBO), an increase in the EWP gross weight (GW) from 42,000 to 50,000 lbs was required to provide a capable air vehicle beyond the year 2000 to meet the demanding combination of payload and fuel for SOF contingency and wartime taskings. Combat search and rescue (CSAR) operational requirements were also addressed, to meet the future DoD long range helicopter needs. An important result of the PAVE LOW EWP capability is the ability to self-deploy to extreme ranges at max GW which allows for a limited number of weapon systems to be strategically based. Tactical missions with flight times in excess of 10 hrs are sometimes required.

The Department of the Air Force issued, several Program Management Directives (PMDs) for Class V Modifications to upgrade the MH-53J with Phase II Special Operations Forces (SOF) improvements. This modification was to upgrade the 41 Air Force H-53's to the MH-53J (SLEP/SBO) with shipboard compatibility and was intended to increase contingency and wartime max operating GW with a congressionally directed completion date of the end of FY90. Specifically, it required: "Design and engineer the increase in maximum H-53 gross operating weight from 42,000 to 50,000 lbs primarily for contingency and wartime operations similar to the C-130 and C-141 emergency war planning (EWP) capability".

In compliance with the PMDs, extensive airframe modifications were accomplished at the former Pensacola Naval Aviation Depot.

## ORIGINAL CH-53A CONFIGURATION

The original CH-53A was designed primarily for the movement of cargo, equipment, and troops. It features a single lifting rotor, with an anti-torque tail rotor, and twin turboshaft engines. The fuselage consists of a molded fiberglass pilot's compartment with an electronics compartment beneath. This is attached to the all-metal semi-monocoque cabin section structure, transition section, and tail pylon. Sponsons on either side of the fuselage contain fuel cells and house the retractable main landing gear. The main rotor pylon atop the cabin section houses the main transmission, its oil cooler, and the APU. The turbine engines are mounted in nacelles on each side of the aircraft, and drive the transmission through engine nose gearboxes and shafting. Each engine had an inlet particle separator for sand and dust protection, but without infrared suppression. A horizontal stabilizer is mounted on the upper right side of the tail pylon. The intermediate gear box is installed in the lower portion of the pylon with a shaft extending upward to the tail rotor gearbox at the top of the pylon.

Entrance into the aircraft is accomplished through a door at the forward end of the cabin on the starboard side. A two-piece ramp, with an upper and lower door configuration (power actuated) at the aft end of the cabin (transition section) facilitates ease of cargo handling in conjunction with a self-contained cargo winch system.

The CH-53A was originally designed using a GW of 33,500 lbs and a structural design load factor of 3.0 g's. The maximum allowable GW has increased to 42,000 lbs with an appropriate load factor reduction. Additional mission requirements mandate that the structural integrity of the airframe had to be upgraded for even higher operating weights.

## H-53 MODEL EVOLUTION

Since the original CH-53A, several successors have been used by the USAF, including the HH-53B, HH-53C, CH-53C, HH-53H, and now the MH-53J (SLEP/SBO). Many other variants have been/are operated by the US Navy & Marine Corp.

The HH-53B, equipped with T64-GE-3 engines, was basically a CH-53A modified for the USAF combat aircrew recovery (CAR) mission. Changes included an in-flight pressure refueling system using a retractable probe, auxiliary droppable fuel tanks mounted outboard of each sponson, a hydraulically powered rescue hoist above the cabin personnel door, along with armament and armor protection.

The HH-53C upgraded the HH-53B by using T64-GE-7 engines. A cantilevered support for the external auxiliary fuel tanks was used. It also had several advanced avionics systems.

The HH-53H, a.k.a. the PAVE LOW III, enabled the H-53 to perform search and rescue (SAR) missions under total darkness and/or adverse weather. All were retrofitted with T64-GE-7A engines. The structurally significant changes from the HH-53B/C's include a nose modification to support new mission equipment and provisions for two 650 gal (in lieu of 450 gal) auxiliary tanks.

The latest variant, the MH-53J, a.k.a. the MH-53J (SLEP/SBO) and is the basis for this paper. This configuration incorporates numerous structural modifications including improved main rotor blades and a more reliable main rotor head along with upgraded engines. Substantial changes in the mission equipment package (MEP) were made, allowing for safer, more effective means to navigate at low altitudes in total darkness and/or adverse weather over all types of topography, including mountainous terrain.

Details of the mission equipment package (MEP) upgrade with its integrated electronic warfare capability are not presented in this paper, but key airvehicle elements of the MH-53J Service Life Extension Program (SLEP) and shipboard operations (SBO) features are:

- ✓ *IMPROVED MAIN ROTOR BLADES (IRB)*  
(airfoil change, NACA 0011 to SC 1095;  
blade chord increased, 2.167 to 2.417 ft.; &  
blade twist increased,  $-6^{\circ}$  to  $-10.67^{\circ}$ ),
- ✓ *ELASTOMERIC MAIN ROTOR HEAD (ERH)*  
*ASSEMBLY with AUTO BLADE FOLD for SBO,*
- ✓ *T64-GE-100 ENGINES,*
- ✓ *INCREASED STRENGTH ACCESSORY*  
*GEARBOX SUPPORT STRUCTURE,*
- ✓ *AUTO TAIL PYLON FOLD SYSTEM for SBO,*
- ✓ *RH-53D MAIN / NOSE LANDING GEAR and*  
*MODIFIED LANDING GEAR BACK-UP*  
*STRUCTURE.*
- ✓ *STRONGER ALLOY TAIL PYLON SKINS*  
*without CHEMICAL MILLING,*
- ✓ *STRUCTURAL ENHANCEMENTS in AFT*  
*FUSELAGE and TAIL PYLON AREAS,*
- ✓ *STRONGER FUSELAGE UPPER/SIDE SKINS,*  
*WITH INCREASED THICKNESS,*
- ✓ *IMPROVED / REPLACED AIRCRAFT*  
*ELECTRICAL WIRING SYSTEM,*
- ✓ *NEW AIRCRAFT HYDRAULIC TUBING,*
- ✓ *EXHAUST COOLER, for AUX POWER PLANT*
- ✓ *COLLECTIVE DAMPER.*

In addition to these modifications and additional external mission equipment (altering the aerodynamic profile), an increase in the collective rigging (+ 1.6 degs) was also incorporated.

Side view and plan form view drawings of the MH-53J (SLEP/SBO) are in Figure 1. More detail concerning selected structural modifications follow.

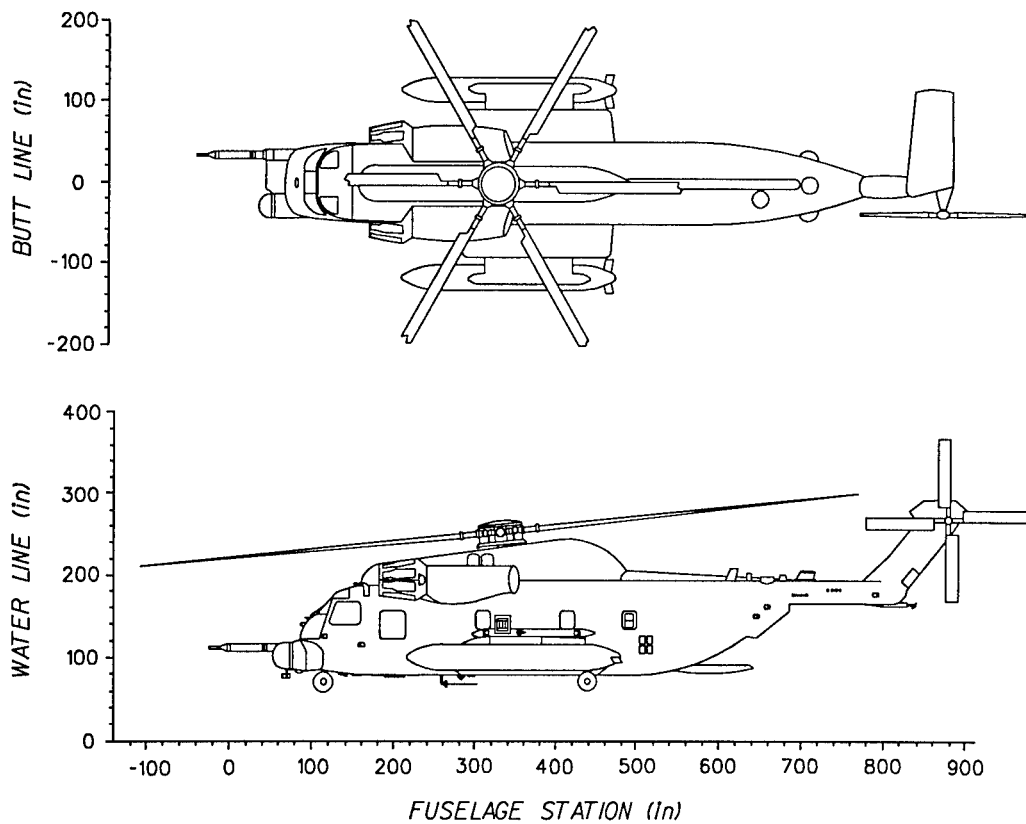


Figure 1. MH-53J (SLEP/SBO) Side View and Plan Form with Coordinate System.

## STRUCTURAL MODIFICATIONS

Two major areas of structure modifications will be described here. The design efforts were performed by the Georgia Tech Research Institute (GTRI) with assistance of its subcontractor, the Sikorsky Aircraft Corp for the WR-ALC.

The RH-53D landing gear was purchased "off the shelf", thus requiring new airframe landing gear support structure. The effects of the mission loadings (mass distribution) changes and new max GW were both analyzed. Mass properties were redefined and used by Sikorsky, in generating new flight and ground loads (fuselage shears, moments, & torsions). A finite element model (FEM) was utilized to determine internal loads in individual airframe members.

There were a total of 34 areas with negative margins of safety (MS) in the landing gear support structure.

Cost avoidance issues associated with various design approaches were very sensitive. One of the design goals was to minimize the amount of structural modification while restoring positive margins of safety, without jiggling the airframe. Avoiding any type of maintenance requirement to further increase support cost was paramount. The design modifications and their analytical justifications were documented and a proof kit installation was made at the former Pensacola NADEP, followed by all fleet aircraft. Figure 2 illustrates the magnitude of these strength enhancements. Their unit recurring cost was approximately \$85,000.

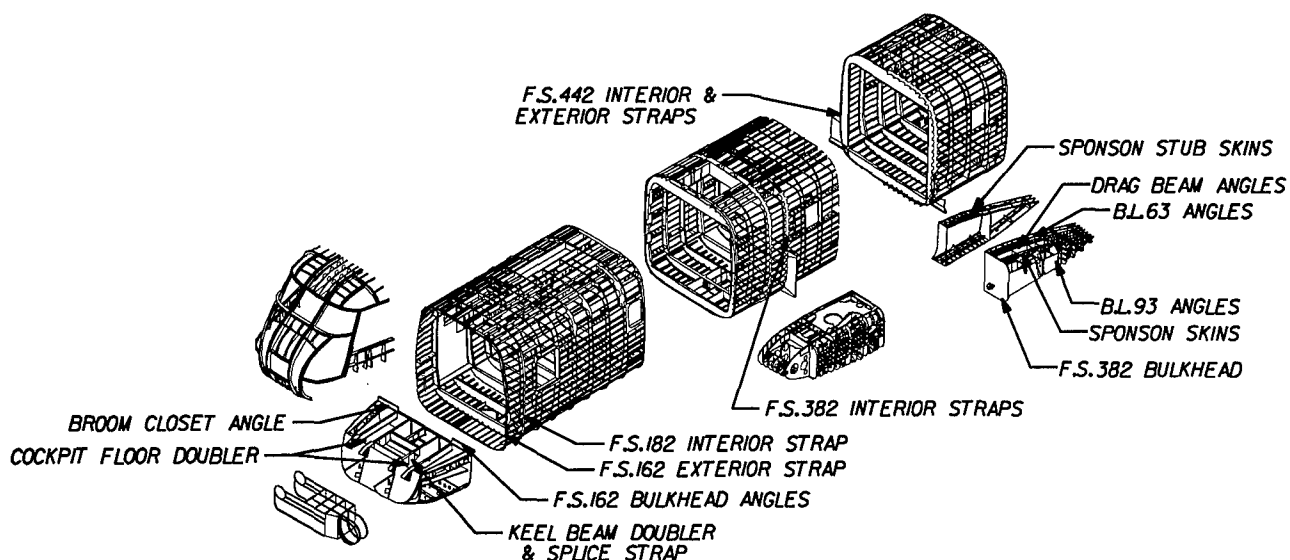


Figure 2. Landing Gear Support Structure Modifications.

Well before the establishment of a formal SLEP, Sikorsky had designed and improved the upper left pylon fold hinge (pylon side); because numerous cracks had occurred in a number of aircraft of all using services, both US and foreign. Many H-53's had other distressed areas in the aft fuselage and pylon area which prompted the WR-ALC to more thoroughly investigate this area during SLEP.

Specific distress areas bubbled up as a result of the Kuwait liberation (Operations Desert Shield/Desert Storm). Twelve MH-53J's experienced structural problems. These aircraft ranged in life from just over 5,000 hrs to 7,300 flt hrs, with an average of approximately 6,200 flt hrs, indicating simply a long term fatigue problem.

This resulted in fatigue strength enhancements designed by GTRI, which included beef-ups of the aft fuselage left upper fitting tang and tail pylon left upper fitting forward arm. A material change in the

left upper aft fuselage longeron from 2020-T6 aluminum to quarter hard 301 stainless steel. A left upper longeron strap (fuselage side) and circumferential strap was added at FS 689.5. Pending modifications include a tail pylon left upper fitting aft flange beef-up and a beef-up at the control rod cutout in FS 776 bulkhead. The general area of these structural enhancements is illustrated in Figure 3. The unit modification kit cost was approx. \$15,000.

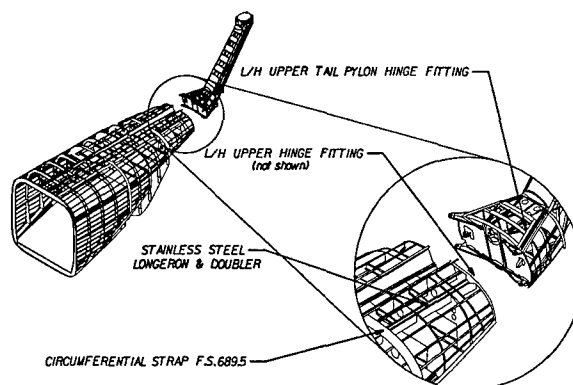


Figure 3. Aft Fuselage / Tail Pylon.

Many other structural enhancements using improved components developed by Sikorsky for Navy H-53 variants were obviously part of SLEP but not discussed here. Firms assisting the WR-ALC in these areas included SRL and E-Systems (Serv Air) in the US and the Israeli Aircraft Industry.

**FLIGHT TEST PROGRAM SCOPE**

This test program was an essential element of the Airworthiness Qualification process for the MH-53J (SLEP/SBO). It was designated a Limited QT&E Program in accordance with AFM 80-5. It is a.k.a. the Structural Modification Flight Test (SMFT) in USAF documents. Its purpose was to obtain test data to qualify the aircraft for operations at  $GW \leq 50,000$  lbs and resubstantiate all component retirement times. Its cost was approximately \$14M; excluding government in-house expenses, spanning 20 flying mos.

Specific test tasks and the approximate productive flight hour of testing accomplished are in the table below:

• <b>SHAKEDOWN and COLLECTIVE OPTIMIZATION</b>	<b>40 hrs</b>
• <b>AFCS EVALUATION</b>	<b>20</b>
• <b>FLIGHT PERFORMANCE</b>	<b>50</b>
• <b>HIGH ELEVATION EVALUATION</b>	<b>13</b>
• <b>FLIGHT STRAIN SURVEY</b>	<b>60</b>
• <b>TAIL ROTOR STRAIN SURVEY</b>	<b>7</b>
• <b>IN-FLIGHT REFUELING</b>	<b>4</b>
• <b>MISSION MANEUVER</b>	<b>3</b>
• <b>SLOPE LANDINGS</b>	<b>2</b>
• <b>AFCS VERT GYRO VIB SURVEY</b>	<b>7</b>
• <b>AUTOROTATIONAL FLARE EVAL</b>	<b>5</b>
• <b>SIMULATOR VALIDATION and FLYING QUALITIES</b>	<b>15</b>
	<b>226 hrs</b>

It also provides revised Flight Manual performance charts, and inputs regarding flying qualities and other operational limitations. Operational capability of the

helicopter was enhanced by optimizing the maximum collective control available to utilize full T-64-GE-100 power, up to helicopter transmission limits.

Paper page limitations do not permit discussion of all facets of these tests; only a few items of special interest are included.

**COLLECTIVE OPTIMIZATION**

The first critical issue was increasing the collective up stop to permit full use of available engine power when operating below transmission limits. Figure 4 illustrates the loss in available power for the original (all previous models) collective rigging.

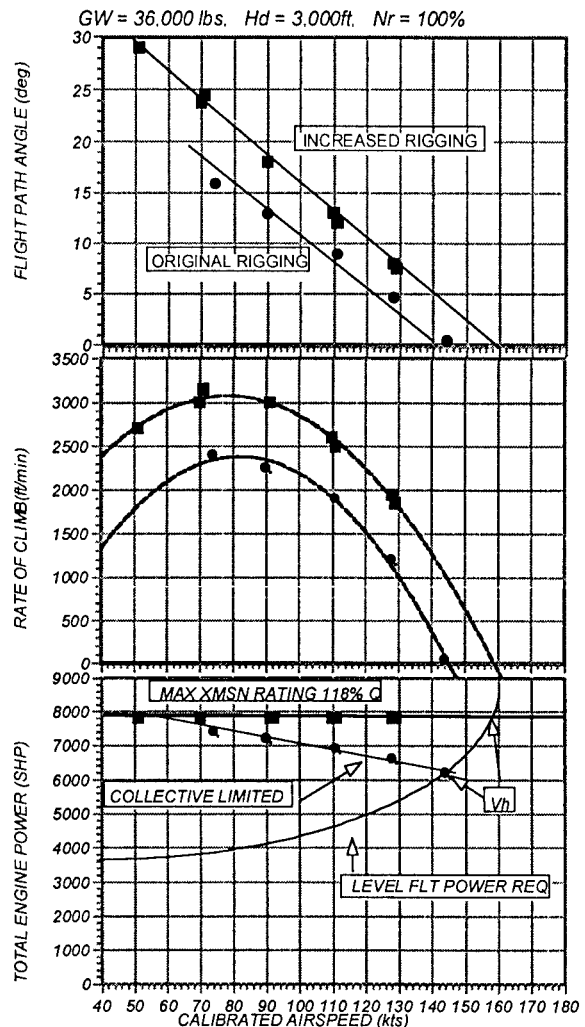


Figure 4. Effect of Collective Up-Rig Setting.

The increase in rate of climb and its impact on flight path angle which enhances Terrain Following/Terrain Avoidance (TF/TA) performance from this additional engine power are clear. This is based on a collective up-rig of  $1.6^\circ$ , which could also increase max airspeeds.

Not all aspects of this rigging increase were beneficial. Rotor downwash during operation on the ground is necessarily increased but reducing the ground operation rotor speed ( $N_r$ ) from 100% to 95% can minimize its impact. In addition, clearances between the main rotor blades and the airframe are reduced during blade/pylon fold operations. This folding is critical to shipboard operation with over the deck wind. These reduced clearances will require careful monitoring during the folding process.

The increase in maximum up collective has an associated decrease in the maximum down collective due to the fixed actuator length. This naturally impacts rotor speed control during autorotation. While the rates of descent are decreased, obviously desirable, the maximum rotor speed with full down collective is also reduced. Thus, very light GWs fall below the previous 90% min  $N_r$ . This can occur only at density altitudes less than 4,000 ft at near the minimum aircraft flying weight.

Because the increased safety associated with improved agility during TF/TA flight is of substantial importance for SOF missions, and the probability of a dual engine failure at very lightweight is so remote, *the advantages of increased collective rigging far outweighed its disadvantages.*

### HIGH ELEVATION IGE TESTING

Both civil and military aircraft are routinely tested in-ground-effect (IGE) at one of three mountain test sites. These are Leadville, CO

(9927 ft. AGL), Coyote Flats, CA (9980 ft. AGL) and Alamosa, CO (7536 ft.). Because the MH-53J (SLEP/SBO) critical altitude is approximately 7,000 to 8,000 feet, the Colorado test site was selected.

Hover performance was accomplished using the tethered hover technique, because it offers precise height control during IGE work and allows for a wide variation in power. The helicopter is hovered at light GW connected to a "dead man" through a cable containing a load cell. Both engine power and  $N_r$  were varied for non-dimensional parameters in terms of weight and power coefficients.

A most important area of high elevation testing is determining the adequacy of tail rotor effectiveness in sideward/rearward flight. This is comparable to hovering in windy conditions. These tests are run using a pace vehicle to track airspeed on an open runway under near zero wind conditions. Tail rotor effectiveness is a function of density altitude, which at the Alamosa Airport ranged from 8,000 to 9,500 ft. on actual test days. Sideward flight measurements of tail rotor control remaining were made at several GW and together with similar data measured at the Sikorsky Developmental Flight Center, West Palm Beach, FL (near sea level elevation) were consolidated into the overall low speed performance capability shown in Figure 5.

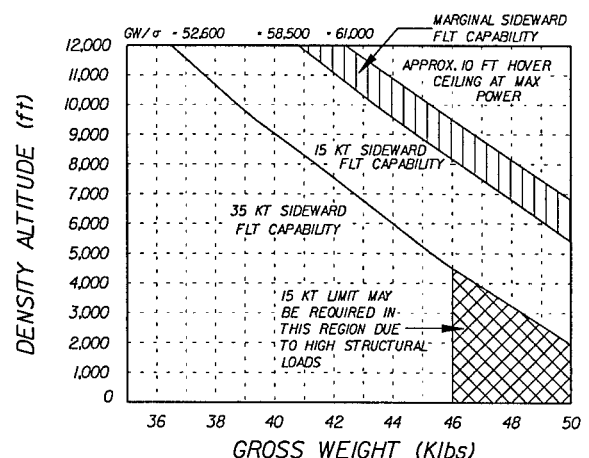


Figure 5. Low Speed Performance Capability.



## AUTOROTATIONAL FLARE EVAL

All helicopters have significant reductions in their power-off glide capability with increasing GW and density altitude. Since the MH-53J has increased in maximum GW by almost 50% with the same rotor diameter and only a small increase in rotor inertia, this was of particular concern.

Therefore, these tests were dedicated to developing the optimum heavy GW autorotational flare technique for the MH-53J (SLEP/SBO) incorporating the 1.6° increase collective for inclusion in the Flight Manual.

The increased collective rigging also produced lower autorotational rotor speeds. All maneuvers were flown with the collective on the bottom stop. Initial testing was accomplished at approximately 2000 ft pressure altitude so that the maneuver would terminate by 1000 ft AGL. Subsequent tests were accomplished to the runway using a 200 ft AGL flare, with an initial loading of 42,000 lbs. The most promising combinations of pitch rate, max pitch attitude and airspeeds were also flown at 46,000, and 37,000 lbs. The test results are outlined below.

- Best Entry Airspeed--- 90 to 100 KIAS.
- Flare Rate---Approx. 4 deg/sec allowing aircraft to decelerate while paralleling ground varying slightly with GW.
- Flare Attitude--- A factor of pilot comfort tolerance. Higher flare attitudes lowered landing speeds. The max flare attitudes were 30 to 35 degs.
- Flare Altitude---Entered at 200 ft AGL, recovering by 40-60 ft AGL, but if accomplished to ground, would require a 140-160 ft minimum entry altitude.
- Flare Duration---The flare was continued (with the aircraft paralleling the ground) until the pitch attitude reached between 30 and 35 degs nose-up.

- Landing Attitude---Once the flare was completed, the nose was aggressively pushed over to a 10 deg landing attitude.
- Landing Airspeed---Actual touchdowns were not accomplished. The projected landing airspeed was a function of
- GW/CG and landing sink rate. *The aircraft is not nearly capable of a zero forward airspeed autorotational landing.*
- Rotor Speed RPM---Nr increased during the flare as long as a positive pitch rate was applied with an airspeed > 60 KIAS.

Configuration (GW/CG)	Steady State Nr (%)	Maximum Nr(%)
37,000	93	97
42,000	96	102
46,000	103-104	111-112

- *The Final Technique*---Enter the flare at an airspeed of 90 to 100 KIAS. Flare at 140 to 160 ft AGL. Flare at a rate that is sufficient to stop the sink rate (approximately 4 deg/sec) but not cause a ballooning affect. Continue to increase the pitch attitude until the aircraft has slowed sufficiently for landing, resulting in a max pitch attitude of 30-35 degs. When pitch rate has stops, aggressively pitch the nose down to a 10 degs (landing attitude). Pull approximately 1/3 collective pitch when reaching 10 degs landing attitude. After aligning the aircraft with the flight path, pull the remaining collective to cushion the landing. Plan to roll the aircraft on the ground at 30 to 45 knots.

## VIBRATION MONITORING SYSTEM

The objective of the flight vibration survey was to gather baseline data for Maintenance Manual incorporation, to support the Vibration Monitoring System (VMS) usage for field vibration maintenance

troubleshooting. VMS was developed by Chadwick-Helmuth Company for the MH-53J fleet. It monitors vibration levels at key airframe locations and interfaces with the Chadwick-Helmuth 8500 Rotor Track and Balance System and the ground based "VIBRALOG" vibration tracking software used by both the USAF and the US Navy. Prototype VMSs had been installed on two H-53's at Kirtland AFB for flight testing prior to the SLEP modification. The purpose here is to present some pre-SLEP and post-SLEP comparisons to illustrate the vibration improvements materializing from SLEP. See Fig. 6 for locations of the airframe and drivetrain velocimeters.

A few comparisons of the vibratory amplitudes in terms of inches per second (ips) in Figure 7. These are for a range of fuselage stations and cover the directions listed in the figure, some at 1/M and others at 6/M, all flown at 120 KIAS. The data shown in this figure is fleet averages from the Kirtland AFB data base. The reduction in vibratory levels shown is believed to result from aft fuselage stiffening and the incorporation of the ERH.

The SMFT data base is more specific covering steady stabilized conditions over the entire envelope.

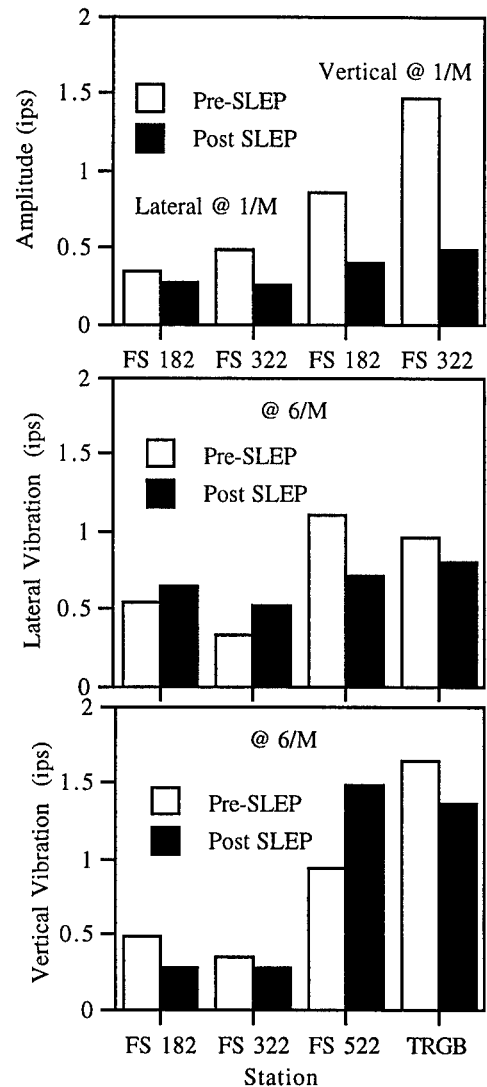


Figure 7. Vibration Levels.

### FLIGHT STRAIN SURVEY

The total flight strain survey involved approximately 75 productive flight test hours covering the normal full flight envelope of the helicopter. Structural demonstration maneuvers are not included because they sometimes involve severe blade stall and are well outside maneuvers needed for determining component retirement times. Most every other flight condition involved in service use was flown. This included in-flight refueling, tactical mission maneuvers such as rapid return to target, slope landings, and a special tailrotor strain survey because the tailrotor components had a high probability of substantially reduced retirement times. The basic GW/CG envelope for various rotor speed / altitude conditions that constituted the flight strain survey is illustrated in Figure 8. The shaded area on the fwd CG side is that portion of the envelope that could not be released for load reasons, which resulted from the large nose down attitudes in high speed flight at these forward CG extremes.

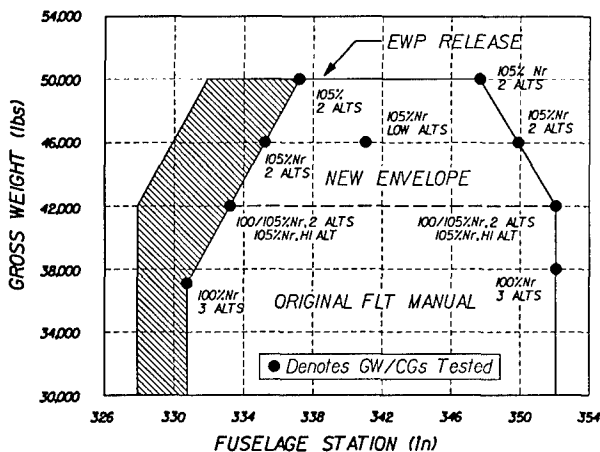


Figure 8. GW/CG Envelope.

The severity of blade stall is expressed by Sikorsky in terms of Equivalent Retreating Blade Tip Speed (ERTS). ERTS represents a normalization of blade loading for correlating vibratory loads (a function of GW, Hd, and g)

with retreating blade tip speed (a function of Nr and true airspeed).

A calculated load factor/airspeed stall projection is at Figure 9, which was validated by these flight tests.

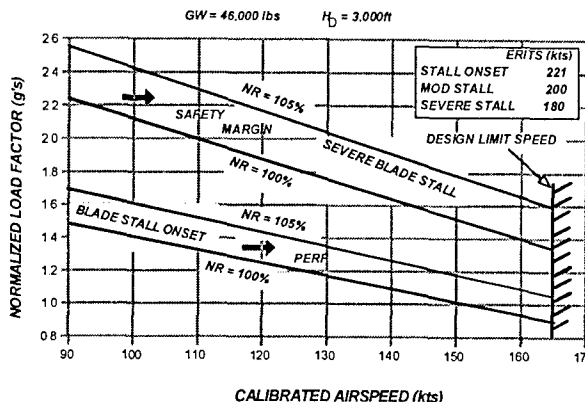


Figure 9. Load Factor/Airspeed Variations with Blade Stall.

### RESUBSTANTIATION of CRTs

This flight strain survey data was used in the resubstantiation of component retirement times (CRTs) of the MH-53J (SLEP/SBO). Every dynamic component was considered as well as selected airframe components such as the tail pylon fold hinges. This resubstantiation was necessary because of the increased flight envelope, a revised mission usage spectrum, frequent use of 105% Nr to minimize loads, and improved technologies available for the acquisition and analysis of flight strain data since the last resubstantiation in the mid 1980's. The basic approach used was safe-life (deterministic) methodology, also known as the TOS/ $\mu - 3\sigma$  method. Here TOS is top of data scatter,  $\mu$  is the mean and  $\sigma$  is the standard deviation. Another technology upgrade was the extensive use of rainflow cycle counting of vibratory loads.

The results of this resubstantiation process were a "mixed bag" with regard to increase and decreases in retirement times. The

normal expectation of reductions with increased GW was sometimes off-set by the use of higher  $N_r$  and redefined max allowable airspeeds ( $V_{NE}$ ). Some parts that did not originally have retirement times were now subjected to mandatory removals; increases were justifiable for others. To list them here would require more detail than paper page limitations permit. The compelling point is that the resubstantiation significantly reduces maintenance risk and increases safety.

Additional effort ongoing at GTRI to reanalysis the CRT picture is using a probabilistic rather than deterministic methodology. The probabilistic methodology promulgated herein enables CRT as well as system level maintenance to be managed as a function of reliability (i.e. probability of operating without sustaining a fatigue crack) by utilizing statistical inference.

## SUMMARY

The modernized MH-53J SLEP/SBO is the latest variant of one of the US Military's most important helicopters. It continues to service our nation well, frequently in harms way, as the center piece of the Special Operational Forces' rotary wing aircraft. Its makeup culminates a long line of successful H-53's maturing through a most effective modification process. The total mission capability of this SOF helicopter far exceeds the dreams of helicopter designers who first conceived it as a simple cargo helicopter. Its maximum gross weight has increased nearly 50% along with improvements in range capability. Incorporation of improved rotor blades and advanced T-64 engines has increased low speed climb and high speed maneuver capabilities.

At an approximate nonrecurring engineering cost of \$40M (excluding government in-house management cost) and a unit recurring cost of \$2.4M, it represents a most cost

effective workhorse relative to a new design, particularly in light of the small fleet quantity (40+) needed for SOF. This does not counter the point that new technology can produce even better helicopters than the MH-53J, but recognizes the cost effectiveness of the modification process. It has served well as the nation waits for the truly advanced tiltrotor configuration, the V-22 Osprey, with much superior range and reaction times for SOF missions.

Whether or not this program could have been more efficient, if managed by an original equipment manufacturer (OEM) and a firm with the capability to perform hardware modifications at other than a government depot, will never be known. But the success of the approach used can not be denied.

The many MH-53J successes as a SOF helicopter have been well publicized by the US press, such as Somalia, Liberia, Bosnia, and now Yugoslavia; with combined humanitarian support and rescue efforts. In our opinion, the sketch below illustrates the pinnacle of its success. It can be seen flying a pathfinder mission, leading US Army Apaches into Iraq, on the first night of the air war which liberated Kuwait. These missions were to knock out radar warning devices in advance of other attacking coalition forces aircraft. This demonstrated its combat worth in the era of modern warfare. That's a *Special Operational Forces Rotorcraft Winner*.



## ACKNOWLEDGEMENTS

The authors of this paper want to acknowledge the support of a few of the many individuals that contributed significantly to the MH-53J program and specifically to the preparation of this paper.

For a program of this magnitude many individuals (far to numerous to mention here), elements of industry, and government agencies worked diligently toward its success. The authors of this paper want to acknowledge three individuals who made specific contributions to this paper. The first is Mr. Charles "Chuck" Idone of the WR-ALC. formally the project manager during critical years of the modification work. His diligence in digging for important facts presented herein are greatly appreciated. The second is Mr. Doug Friend, of GTRI's Aerospace and Transportation Laboratory, who was the Georgia Tech onsite representative during the Structural Modification Flight Test program and who provided much of the information published herein. Finally, Ms. Jerry Clark is recognized for her untiring effort in putting to paper and editing our basic story.

The concluding photocopy is the art work of Ronald Wong, of St. Albans, Herts in Great Britain. He entitled it "Kickoff!" and graciously authorized its inclusion herein.

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