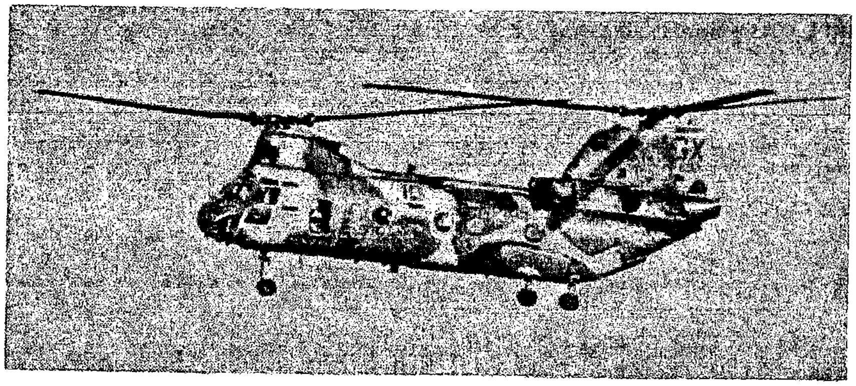
CH-46 Blade Stall During the Conduct of Dynamic Component Upgrade and Fuselage Strain Survey Tests

Lieutenant Colonel Mike L'Heureux USMC
Naval Rotary Wing Aircraft Test Squadron



INTRODUCTION

This paper examines an in-flight blade stall occurrence during the conduct of Aircraft Testing conducted at Naval Air Warfare Center, Patuxent River MD. It gives a background of the testing, a short synopsis of the events leading up to the stall event, a brief description of the event itself, a description of the initial team response, follow on actions, lessons learned, and team recommendations.

BACKGROUND

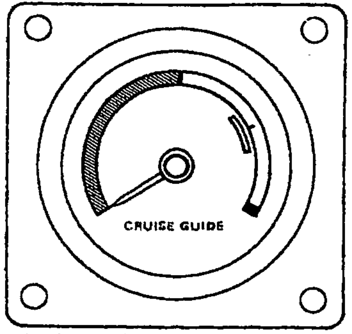
The H-46 Sea Knight has been in service since the early 1960's. There are high time aircraft in the current inventory that have accumulated close to 12,000 flight hours. The airframe is currently cleared to 12,500 flight hours. At current and forecast usage rates there exists a shortfall of aircraft for the Marine medium lift and the Navy vertical replenishment (VERTREP) missions until follow on aircraft are procured. It will take an extension of aircraft useful life to 20,000 flight hours to address this shortfall. The Dynamic Component Upgrade (DCU) was developed to address life extension of the rotor and drive systems. Boeing Helicopters (BHC) was contracted to design, manufacture, and test the new rotor and drive system components. The basic design of the new rotor and drive system is the same as the current system with the inclusion of numerous improvements and the manufacture of dynamic components with PH 13-8Mo stainless steel vice the 17-4PH stainless steel. The scope of testing planned by Boeing was considered insufficient by Naval Air Systems Command (NAVAIR 4.3.3). As a result, NAVAIR tasked Naval Air Warfare Center-Aircraft Division (NAWC-AD) to complete the necessary testing and provide airborne data tapes to Boeing to calculate fatigue lives. After the program was initiated, the question of fuselage fatigue life was raised. As a result, NAVAIR tasked NAWC-AD to instrument critical fuselage components and to process all fuselage data to present to a third party (Aerostructures) to calculate fuselage fatigue lives. The testing was completed in May of 1997 and encompassed a series of engineering and mission aircraft maneuvers conducted during a varied matrix of loading conditions, density altitudes, and flight conditions.

Project Status Prior to Stall Episode

Approximately forty flight hours of testing had been previously accomplished at the Boeing Wilmington Test Facility. Plans to ferry the aircraft to the NAS Patuxent River Air Station (Pax) were accelerated to permit a planned shutdown of the Wilmington Facility. Shortly before aircraft transfer, the team held a data review with NAVAIR, Boeing engineers and flight test representatives. This review included a Boeing pilot debrief and summary review of Boeing flown test matrix. The aircraft departed Wilmington and arrived at NAS Patuxent River in March of 1996. While the government was performing routine maintenance acceptance inspections at NAS Patuxent, Boeing discovered some vendor quality issues with the aft and forward swashplates which halted testing for about 4 months. During this time Boeing conducted a thorough review of all DCU parts and requested Pax halt planned evaluation flights in the interim. To keep the test program on track, the program office substituted a pre DCU stationary forward swashplate in the forward swashplate assembly. The forward swashplate assembly (1/2 DCU and 1/2 pre-DCU) was delivered from Naval Depot Cherry Point NC in June. The test team received NAVAIR flight clearance for the assembly in July of 96. Post maintenance functional check flights and instrumentation re-installation and calibration were accomplished during August and September. The first flight at Patuxent was flown in 11 October 1996.

Critical Parameters/The Cruise Guide Indicator (CGI)

The flight included monitoring of defined "critical parameter" data by real time telemetry processing. The critical parameters were composed primarily of the mechanical links, blade and fuselage aerostructure, and dynamic components where aerodynamic flight loads were transmitted to mechanical structural loads. One critical parameter, that also defines stall in the H-46 is the Cruise Guide Indicator (CGI). This instrument was included into the aircraft during it's initial design phase after positive pilot comments. The purpose for including it into the pilots instrument panel was that it gives real time indication of incipient blade stall. Retreating blade stall can be encountered when operating the helicopter at high airspeeds, high gross weight, high altitudes, and in turbulence, or when maneuvering in a combination of the above conditions. Lift is proportional to blade angle of attack and relative wind velocity over the blade. On the retreating blade, the resultant velocity is equal to the rotational velocity, minus the forward speed of the helicopter. Therefore, as airspeed is increased, a corresponding increase in retreating blade angle is required to maintain lift. When the retreating blade angle reaches critical angle of attack, blade stall occurs. During a stall sequence extremely large structural loads are transmitted to various rotating and stationary components. Constant application of loads of this magnitude will result in material failure and loss of aircraft control. Blade stall is the primary limiting factor for forward speeds for all conventionally designed helicopters. Most helicopters have an elaborate system of charts that define the correct maximum operating speeds. The reason these charts are so elaborate is due to the fact that forward airspeed limits are so dependent on aircraft weight, operating altitude, and angle of bank/maneuvering. The H-46 CGI employs two strain gauges on the forward and aft rotor systems each that measure structural loads directly. The airspeed limit in the operators manual is 145 KIAS or CGI limit, whichever is lower. The only time that charts are used is if the CGI is inoperative. There is one cockpit gauge only, located on the pilots (right) side of the instrument panel. The gauge is presented in figure 1. Steady state operation in the green (cross-hatched area) is allowed with occasional spikes in the yellow/avoid (white) area. Steady operation in the avoid area is not allowed and requires decreasing forward airspeed to resume operation in the green. Operation in the red (dark) area is prohibited, and an indication of fully developed stall requiring immediate increase of rotor rpm, reduction of collective pitch, reduction of airspeed, or, if maneuvering, a decrease in the severity of the maneuver.



Cruise Guide Indicator (CGI)
Figure 1

The Flight

The first flight at Patuxent was flown on 11 October 1996. This consisted of 1.3 flight hours in the Pax local flying area under day VMC conditions. The tests were comprised of; engineering flying qualities including qualitative evaluations. The briefed sequence of events included; vertical take off to hover, maximum continuous power climbs at 70 knots indicated airspeed (KIAS) to the working altitude of 2000 ft density altitude (Hd), acceleration and steady state flight at 98 KIAS and 2000 ft Hd, longitudinal doublets to 2 inches cyclic displacement at 98 KIAS, followed by constant altitude/airspeed turns from 15° to

60° angle of bank building up in 15° increments. During a sixty degree angle of bank right level turn at 22,800 pounds and forward center of gravity CH-46E bureau number 153355 experienced incipient blade stall indicated by increased airframe vibration and a departure of the cruise guide indicator (CGI) from the edge of the green band area to the red prohibited region.. During the recovery sequence, the aircraft experienced a pitch oscillation episode that resulted in exceeding peak static and oscillatory limits on various components in addition to aircraft damage.

Excerpt from Flight Daily

The sequence of events was subsequently described in the flight daily;

"Constant altitude/airspeed turns were uneventful until a 60° right turn was executed. After stabilizing in the turn with 100% torque set, the pilot at the controls (PAC) noticed the CGI progress from the green zone into the red prohibited zone where the needle pegged. The PAC initiated immediate left lateral cyclic to return the aircraft to a level attitude and reduce the severity of the maneuver. Upon reaching a wings level attitude, the aircraft suddenly, and without any conscious pilot input started to nose down causing the crew to experience a less than one "g" condition. At the same time as the aircraft's nose dipped, a shudder in the airframe was felt by the entire crew. The aircrew was concerned with aircraft integrity at this point (especially after the project engineer radioed from the TM room "what was that!"). The PAC commenced an approach to a nearby field, the project engineer radioed that the aircraft appeared normal, but a few parameters were not working and that it would be prudent to return to base (RTB). After RTB and landing at Pax, a post flight revealed the fairing on the aft pylon was gouged."[1]

Results

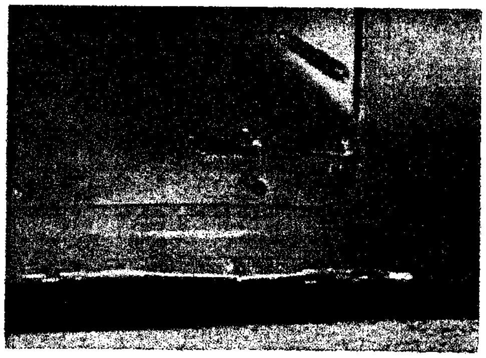
The test plan specified that any excursion of oscillatory, warning, static, or peak limits would require a cessation of testing and all data sent to Boeing for engineering investigation and recommendation prior to resuming flight test. A quick review of data by the Pax test team while the aircraft was in flight revealed that empirical retreating blade tip speeds (ERITS) data, CGI, and forward/aft collective pitch link loads indicated blade stall. In addition, the following excursions were noted and confirmed by further Boeing analysis; forward blade lead/lag, forward/aft rotor shaft torque's, forward/aft longitudinal rigid links, aft collective pitch link, and aft drive scissors exceeded upper oscillatory limits. analysis also showed that the aft longitudinal link load exceeded peak static limits. A detailed aircraft inspection revealed that in addition to the aft fairing scoring

---

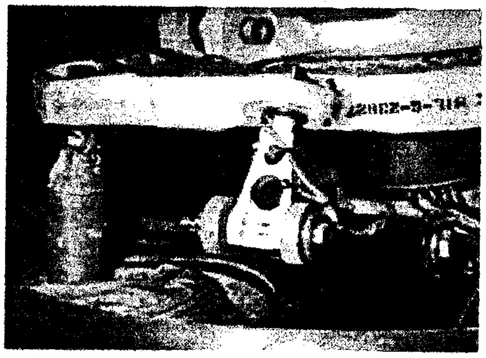
[1] Maj. Treworgy, Eric. DCU PROJECT. Flight Report for Flight X-57. Attack Assault Branch, RWATS, NAS Patuxent River MD. 1996.

mentioned in the flight daily (figures 2 and 3)., there was evidence of scoring on the aft (rotating scissors) drive arm (figure 4) and a crack on the front frame of the number one engine (figure 5, previously repaired with weld).

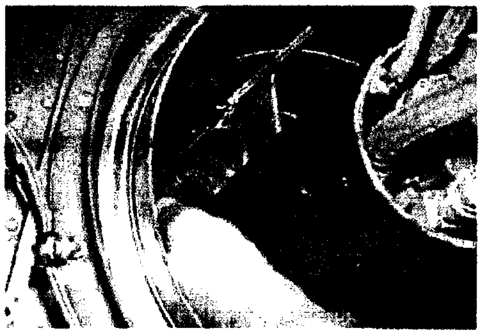
Aft Fairing Right Side
Figure 2



Aft Fairing Left Side
Figure 3



Aft Drive Arm
Figure 4



Front Frame Number 1 Engine Intake
Figure 5

Team Response

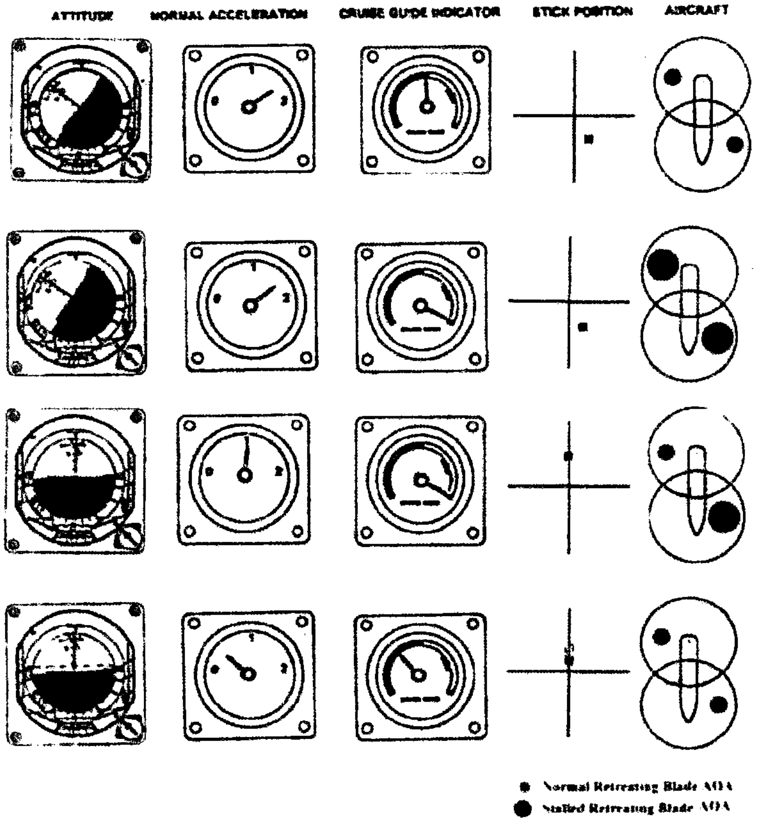
In addition to sending the airborne data tapes to Boeing, the team performed a detailed non-destructive inspection of all components involved in peak and oscillatory limit excursions to include all supporting aircraft structure. The aft longitudinal link, aft drive arm, and number one engine were removed and replaced. The team amended the test plan to remove 60° angle of bank points (current NATOPS limit is 45°) and added blade stall precautionary/recovery procedures to the hazard condition table.

Lessons Learned

Aircraft Dynamics and Stall Response

The aircrew had previously experienced aircraft blade stall only during straight and level flight. Aircraft blade stall characteristics in straight and level flight are relatively benign. The onset of incipient blade stall is indicated by an increase in one per revolution vibrations and progression of the needle on the CGI gauge from the green through the yellow avoid region to the red prohibited region. During the right turn, the aircraft exhibited the expected response, The pilots recovered from the stalled condition by rolling wings level. Another factor, which will be more fully explored in the next paragraph, is that during recovery, the pilots never reduced the collective pitch setting. In a constant altitude constant angle of bank steady state turn, the turn rate is directly related to pitch rate, the cyclic control position is slightly aft of trimmed position in constant altitude wings level flight at the same airspeed. As the aircraft rolled to wings level, the cyclic was translated forward by the pilot to maintain a level fuselage attitude. Due to the more fully stalled condition of the aft rotor system as compared to the forward rotor system longitudinal effectiveness was reduced, causing additional forward cyclic to unconsciously be applied. In addition, in a tandem design, forward cyclic increases the aft rotor system collective pitch, increasing stall.

When the aircraft returned to wings level flight, and the aft rotor system was no longer in the disturbed air flow of the forward rotor system, the stall condition abruptly ended, the longitudinal control effectiveness abruptly returned. This caused a violent nose down pitch, the aircraft went from a positive 1.8 "g" flight, to positive .3 "g". The ensuing damage occurred during the recovery which also included a pitch oscillation episode. This is a documented deficiency that has been known to occur during rapid longitudinal cyclic inputs and is due to a differential air speed hold (DASH) actuator phase shift phenomena. A graphical representation of this sequence of events is presented in figure 6.



Aircraft Blade Stall Event Sequence
Figure 6

The above graphical representation of events was deduced from the data collected with real time telemetry, in addition to air crew interviews of the event. By examining the data, which, in addition to vehicle state parameters/rates included control positions/structural loads, the cause of aircraft damage became readily apparent.