The S-61/Sea King with Carson Composite Blades
Part 1

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Abstract

This paper is in two parts. The first part of this paper describes various improvements that Carson Helicopters is developing in their program to modernize the S61. The new composite main rotor blades, designed and developed by Carson Helicopters, have produced significant gains the aircraft payload and range. The new rotor blades were approved by the FAA in 2003, and more than 60 sets are currently in use by Carson and other commercial operators. Also, a version of these blades modified for a folding hub is currently installed on Royal Navy Sea King helicopters. Six sets are in operational use on Sea Kings in Afghanistan. As a result of the success of these blades and the significant gains in performance provided, Carson Helicopters has been developing other improvements for the aircraft. These include a glass cockpit, vibration reduction and a new tail rotor. The first part of the paper describes these improvements. The second part of the paper will discuss the results of a flight test program conducted on a Sea King and present various results obtained. QinetiQ conducted the flight test program on the Sea King.

Discussion

Carson Helicopters new composite main rotor blades for the S61 received an STC from the FAA in 2003. The blades use advanced airfoil sections, have swept tips and are constructed of composite materials. The rotor blades are in commercial use in the USA, Canada, South America, and Africa. The blade development is described in Reference 1. These new blades have yielded significant performance gains for the S61 that are reflected in FAA approved supplements to the S61 flight manuals (References 2 and 3 for example). Reference 2 deals with increased hover performance in and out of ground effect and Reference 3 with increased Category A performance. The approval process is in progress with EASA.

Hover Figure of Merit

Flight test as well as operational experience has demonstrated that the efficiency of the new rotor is high. It was of interest to determine the value of the hover figure of merit of the new rotor. Since no isolated rotor ground tests were conducted on the new rotor, direct measurements of the rotor performance were not available.

Therefore, an approach using flight test data from the aircraft with both sets on blades and thrust stand measurements for the metal baseline blades was developed. First, an aircraft figure of merit (M_{AC}) is defined based on the weight (W) and total power required to hover (P_T):

$$M_{AC} = .707W^{1.5}/P_T \qquad (1)$$

The isolated rotor figure of merit (M_R), which is the quantity of interest, based on rotor thrust (T) and main rotor power to hover (P_R), is defined by the relationship:

$$M_R = .707T^{1.5}/P_R \qquad (2)$$

Equation (1) divided by Equation (2) yields:

$$M_{AC}/M_R = (W/T)^{1.5} \times (P_R/P_T) \qquad (3)$$

If the same aircraft is compared in hover with two different main rotors, one composite and one metal at the same total power (P_T), the ratio of main rotor power (P_R) to total power (P_R/P_T), is equal, independent of the main rotor design. Although the fuselage download may vary slightly with different main rotor designs, this small effect can be neglected in the current discussion. Consequently, the ratio of aircraft figure of merit (M_{AC}) to rotor figure of merit (M_R) is the same in these two instances, independent of the main rotor characteristics, and so the following relationship between the various figures of merit exists. (The final subscript refers to the aircraft with composite ($_C$) or metal ($_M$) main rotor blades.)

$$M_{RC} = M_{RM} \times (M_{ACC}/M_{ACM}) \qquad (4)$$

Carson flight test data gives the aircraft figure of merit (M_{AC}) when it is equipped with each rotor. Now, since thrust stand data are available for the baseline metal blades, giving the figure of merit of the metal blade rotor (M_{RM}), all the quantities Equation (4) are determined by experiment and M_{RC} can be calculated.

Recall that Equation (4) is true at constant total power ($P_{TC} = P_{TM}$) and it is desirable to find the corresponding rotor thrust coefficient. The rotor figure of merit (M_R) is a function of rotor power. The rotor power was measured in flight test with metal blades and this information is used to determine the rotor figure of merit corresponding to the total power condition used in evaluating Equation (4), and consequently the figure of merit of the composite rotor corresponding to the power condition. The thrust of the more efficient composite rotor is greater than that of the metal rotor at this condition. The thrust coefficient of the composite rotor is now found from the calculated composite rotor figure of merit determined by Equation (4). Thus, the thrust coefficient corresponding to each condition is determined. No assumptions regarding download, blockage etc are involved in this approach. The results of this analysis, based on flight data, are shown in Fig. 1 indicating the very high figure of merit of the Carson rotor. Generally the aircraft figure of merit with the composite rotor is 13 to 14% higher than that of the aircraft with metal blades at the same total power.

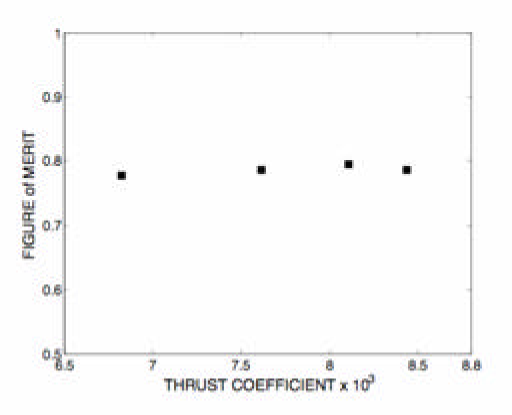

Figure 1. Figure of Merit of Carson Rotor from Flight test

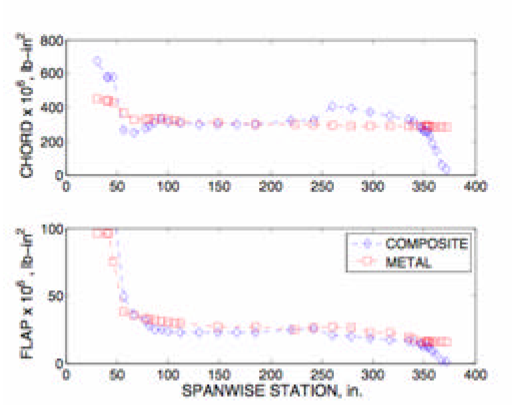

Figure 2. Comparison of Flapwise and Chordwise Stiffness of Metal and Composite Blades

Composite Blade Stiffness

An important design feature of these composite rotor blades needs to be emphasized at this point. The spanwise distribution of flap and chord stiffness of these advanced blades are essentially the same as those of the metal blades. Figure 2 compares the stiffness values. This stiffness matching was a design objective. The mass characteristics also match the metal blades closely and consequently the composite blades have very similar dynamic characteristics to the metal blades. This design requirement for the new composite blades was achieved. The torsional characteristics are not shown here, but experimental values determined on the aircraft in flight, show that the torsion frequency (about 7.7 P at operating RPM) is somewhat higher than that of the metal blade. Other features of the blade design have been reported in Reference 1. This matching results in no change in the dynamic characteristics of the aircraft or the handling qualities of the aircraft although Carson pilots have reported that it appears easier maintain a hover with the new blades.

Glass Cockpit

The glass cockpit is well on its way to replacing the conventional instrument panel in all types of aircraft. To continue modernization and improvement of the S61, Carson is flight testing a glass cockpit for this aircraft. Vector Aerospace Helicopter Services has successfully flown a fully integrated glass cockpit from Sagem Avionics in a Carson S61. Carson's major design objectives in the development of the glass cockpit configuration for the S61 are to develop a user friendly system, as well as one that is maintenance friendly, and also of low cost. Test flying is currently underway and it is expected that this modification will be available for the aircraft in the fall. The unit is shock mounted and experiences very little vibration. It is configured such that it can easily be incorporated in other helicopters of similar size.

Five identical display screens are used in place of the more usual four. The central screen contains the engine instrument displays. The pilot and copilot have two screens each. One screen contains flight instruments and the other display is selectable with maps/airfield approaches, and other options available. The caution panel has been separated from these displays and located below the small GPS and transceiver screens rather than having a caution appear as a pop-up on one of the main screens.

All modern sensors are incorporated with the glass cockpit, replacing the original 1959 equipment in the aircraft. The sensors achieve redundancy by using special dual elements as necessary for IFR flight.

Cockpit Vibration

Attention to detail can lead to significant gains in vibration reduction. In this connection, Carson has found the Honeywell/Chadwick VXP system analyzer/balancer to be very useful for measurement and adjustment to reduce vibration. The S61 is normally equipped with a very effective bifilar in-plane absorber mounted on the rotor hub that significantly reduces lateral vibrations in the aircraft fuselage. This type of vibration absorber has the distinct advantage of retuning with rotor speed.

However because of the nature of the fuselage mode shapes and combined response of the fuselage to vertical and in-plane forces at the rotor hub, as discussed in Reference 4, there still remains a significant vertical vibration in the cockpit while the lateral vibration is low. This aircraft may be equipped with a classical vibration damper consisting of a flexible mounting for the battery in the nose of the aircraft designed to reduce vertical vibration at 5 per rev in the cockpit. This unit was originally sold as an accessory for the aircraft. In many instances these units were not installed in the aircraft. Often, the units that were installed were not carefully maintained. If not regularly maintained, the unit tends, after some usage, to amplify vertical vibrations rather than damp them as illustrated by flight data taken by Carson in a study of the effectiveness of the damper presented below. Also, it may be noted that this system is often tuned to damp vibrations at five times the original design rpm of the aircraft (100%NR). However, the normal operating rpm of the aircraft in commercial use is 103% NR. Carson made comparative measurements with the device tuned to 100% and 103% (5P). Tuning to 103% coupled with maintaining the system properly has produced a dramatic reduction in cockpit vertical vibration. Figure 3 presents the results of surveys of vertical vibration peak amplitude at 5P in the cockpit in ips. A number of cases are shown. For a reference, the vibration levels at rotor speeds of 100% and 106% are shown for the aircraft at mid cg at various airspeeds with no absorber installed. A number of results are added at an indicated airspeed of 110 kts, mid cg, 103% NR. First, a case with the absorber tuned to 100% as installed in the aircraft is shown, and in this case the vibration is increased above that of the aircraft with no absorber to the high level of 0.73 ips due to lack of recent maintenance. Tuning the absorber to 100% after maintenance reduces the amplitude to a level of 0.41ips, a little below that of the aircraft with no absorber. Removing the battery from the absorber gives a point in between these two, consistent with the other data. Then the absorber was retuned to 103%, using a shake table. This produced a dramatic reduction in vibration level to about onequarter (0.08 to 0.1 ips) of the amplitude at 100%, a very comfortable level.

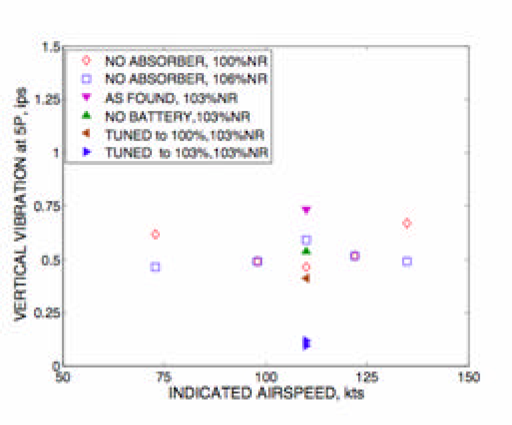

Figure 3. Vertical Vibration at 5P in the S61 Cockpit. Gross Weight = 20000 lbs., various Altitudes

Tail Rotor Balance

A second area where attention to detail gives rise to improvement is associated with balancing the tail rotor. The complete tail rotor assembly is normally statically balanced in the shop, before installation on the aircraft. However, the high rotational speed of the tail rotor and its location at the top of the pylon makes it difficult to achieve a static balance of the rotor assembly with the precision that is desirable for truly smooth operation in the pylon, tail cone region.

The VXP system is used in flight in the aircraft to refine the balance of the tail rotor and thus reduce vibration in the pylon, tail cone area and occasional cracking of the skin that occurs in this region.

These last two developments illustrate how significant improvements in the vibration characteristics of a rotorcraft can be achieved with relatively simple and reliable equipment, and an approach with careful attention to detail.

New Tail Rotor Design

Carson is currently developing new composite tail rotor blades for the S61. The standard metal tail rotor blades are untwisted and have a symmetrical airfoil section (NACA 0012). This design has a low hover efficiency, and a tendency to experience tip stall at a thrust coefficient in the operating range (5). The hover efficiency of the metal blades measured on a thrust stand is shown in Figure 4. Hover trim at sea level and a gross weight of 20000 lbs corresponds to a thrust coefficient of C_T of .017. The desired maximum operational thrust coefficient of the tail rotor is estimated to be C_T = .021, determined by trim and maneuver limits at altitude. The current metal blades experience tip stall at a C_T about 10% higher than a steady hover trim (.0186), and the figure of merit decreases rapidly with increasing thrust coefficient at this C_T and above.

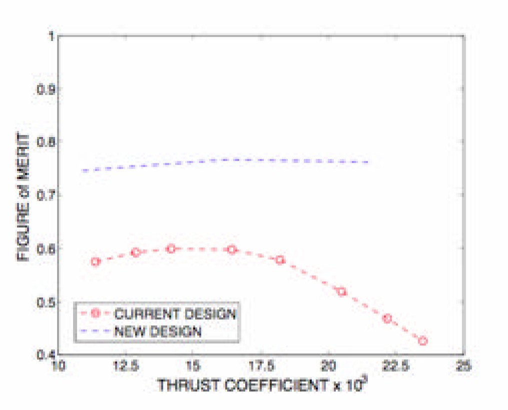

Figure 4. Comparison of Tail Rotor Figure of Merit

The predicted hover performance of the new Carson design is compared to the current tail rotor in Figure 4. The new design has 8 degrees of linear twist and a rectangular planform. It uses the same advanced airfoils as the main rotor (RC(4) and RC(3) series). This is the second design that has been studied by Carson. The earlier design had a swept, tapered tip that increases hover efficiency, but also contributes to high steady control loads. These high loads are difficult to accommodate with the design of the mechanical control yaw control system in the aircraft. If the steady control loads are significantly different from the metal blades, lost motion will occur due to cable stretch.

The improvement in figure of merit shown for the new design in a hover trim at sea level 20000 lbs gross weight corresponds to a saving of about 65 HP. If this power saving is transmitted to the main rotor, an increase in main rotor thrust of about 400-450 lbs is predicted.

As with the main rotor, the design objective of achieving mass and stiffness characteristics that are a match of the metal tail rotor blade is critical. The steady control load generated by the tail rotor is primarily determined by the inertial properties of the blade as the RC series of airfoils have very low pitching moments. In addition, matching should minimize the possibility of encountering new or unforeseen dynamic problems with the new tail rotor blade. The overall design objective along with improved efficiency is that the new composite blade will simply be a replacement for the metal blade as is the case with the main rotor where no changes in the aircraft are required to use the new blades. Ground testing of the new composite design is scheduled to commence in July and flight tests will start later in the fall.

Concluding Remark

Carson's program to upgrade the S61 continues, producing significant improvements that modernize this older aircraft and make it very competitive in today's market.

The S-61/Sea King with Carson Composite Blades
Part 2 – QinetiQ Sea King Test Programme

Introduction

The British Royal Navy (RN) and Royal Air Force (RAF) operate the Westland Sea King helicopter in various configurations. Since 1987 the Westland Sea King in RN and RAF service has been fitted with composite Main Rotor Blades (MRBs) and a tail rotor fitted with 6 metal blades. Although the MRBs are of composite construction, they are aerodynamically equivalent to the original Sikorsky metal MRB which used the NACA 0012 aerofoil and had 8 degrees of twist.

In late 2005 and 2006, the UK Ministry of Defence (MoD) were examining ways of increasing the performance of the Sea King as part of the Future Rotorcraft Capability (FRC) Programme. One of the options under consideration was the use of Carson advanced composite MRBs which had FAA approval to be fitted to the Sikorsky S-61 (the civilian equivalent of the Sea King) (1). In 2006 QinetiQ were approached by the MoD to undertake a Technology Demonstration Programme (TDP) for the Carson MRBs fitted to the UK Sea King. This programme was designed to assess the likely performance improvement offered by the Carson MRBs within the existing Sea King flight envelope.

When QinetiQ were approached to carry out the TDP, the Carson MRB had only been produced in a 'long spar' version for the S-61. In order to maintain the same overall rotor diameter, Sea King helicopters with folding main rotor heads are fitted with a 'short spar' blade which is 4” shorter than the S-61 blade. Although a short spar Carson MRB had never been produced, Carson Helicopters had made provision in the original design to produce both long and short spar blades. In order to produce the short spar blade, 4” of constant cross section, non lift section was removed from the blade root. The blade cuff was then fitted to the MRB in an identical manner to the long spar blade. In support of the UK MoD TDP, Carson Helicopters produced a set of short spar blades which were loaned to the MoD for evaluation.

The Carson MRBs were fitted to a QinetiQ owned Sea King HU Mk 5 test aircraft which was comprehensively instrumented for aircraft handling and performance testing. The aircraft was also fitted with additional flight load measurement instrumentation for safety of flight purposes. The load measurement instrumentation could be monitored in real time onboard the aircraft. The first flight of the UK Sea King Carson MRB TDP took place on 20 September 2006. A total of 24 hours of test flying were completed in support of the TDP.

The TDP yielded a number of important results. The aircraft handling was found to be not significantly different from the unmodified configuration, vibration was broadly similar, hover performance was significantly improved and power consumption in level flight was reduced. Overall, the results obtained were in agreement with those obtained by Carson Helicopters using the S-61. Although the TDP was conducted within the existing flight envelope, the results obtained suggested that a significant increase in the forward flight envelope was possible.

Following the successful completion of the TDP, QinetiQ approached the MoD to offer a programme of work to clear the Carson MRBs to be fitted to the RN Sea King HC Mk 4 'Commando' variant. This led to an Urgent Operational Requirement (UOR) being issued by the MoD to modify the Sea King HC Mk 4 to support operations in Afghanistan. The UOR required the forward speed of the Sea King to be increased at altitude and also required an increase in maximum take off weight at high altitude. The UOR called for Carson MRBs and a five composite blade tail rotor produced by Agusta Westland (AW) to be fitted to the aircraft. The tail rotor had been produced by AW for the Mk 42B variant of the Sea King used by the Indian Navy and featured 5 cambered composite blades which were the same length and chord as the original metal blades. The tail rotor had been shown to significantly increase performance in low speed flight (6) and it was hoped that use of this tail rotor would produce benefits in the expanded forward flight envelope.

QinetiQ were appointed as the Prime Contractor by MoD for the programme of work to certify the main and tail rotor modifications for the Sea King HC Mk 4. The modification was embodied as a Service Modification (SM) with QinetiQ as the Design Organisation. The modification is the most significant modification ever fitted to a British military helicopter as an SM and is thought to be the most complex modification made to a helicopter in the UK by a non helicopter manufacturer.

Although the 'long spar' version of the Carson MRBs had been certified by the FAA, the 'short spar' version had not. Also, different certification requirements exist for a modification to a UK military helicopter compared with those for FAA certification. It was therefore necessary for a comprehensive certification programme to be conducted to support the SM. This involved flight tests supported by a large amount of theoretical work and analysis. QinetiQ took responsibility for the flight tests, definition of the expanded flight envelope and determining the MRB fatigue life. AW supported the programme by determining the fatigue life of the new tail rotor assembly, the dynamic aircraft components and flying controls when operated to the expanded flight envelope.

Instrumentation

In order to support the flight test phase of the project, it was necessary to fit a new instrumentation system to the trials aircraft which was the same QinetiQ Sea King that had been used for the TDP. This instrumentation system was designed, manufactured and installed by QinetiQ and used to support the testing in a period of just over 5 months. The instrumentation system allowed on board monitoring of data by Flight Test Engineers and Test Pilots and could accept data telemetered from the ground to the aircraft (such as wind information). The instrumentation system allowed measurement of handling and performance parameters and flight loads. Measured parameters included:

Main and tail rotor blade angles.
Main and tail rotor torque.
Main and tail rotor head loads.
Main and tail rotor blade loads.
Flying control loads.
Engine operating parameters.
Control positions.
Accurate airspeed at low and high speed.

A total of 249 parameters were measured. 101 were rotating parameters on the main rotor and 28 were rotating parameters on the tail rotor. The instrumentation system was found to be very reliable and its advanced design significantly increased the rate at which the flight testing could be conducted as a result of the purpose made real time displays.

Flight Tests

An extensive flight trials programme was conducted using QinetiQ owned Sea King HU Mk 5, tail number XZ575. This flight test programme was conducted in partnership with the Ministry of Defence as part of the Aircraft Test and Evaluation Centre (ATEC). In addition to the instrumentation system, the aircraft was fitted with a number of other modifications including a system to allow the longitudinal Centre of Gravity position to be varied by adding lead ballast.

The flight test programme was designed with the following aims:

- Determine the compatibility of the modified rotors with the engine control system (the Westland Sea King is fitted with Rolls Royce Gnome Engines which are controlled by limited authority 'Fuel Computers').
- Determine if the airspeed system was affected by change in main rotor (the pitot-static ports are close to the main rotor).
- Define an increased forward flight envelope for the modified aircraft.
- Examine the handling qualities of the modified aircraft.
- Assess the level of vibration experienced by the modified aircraft.
- Gather flight loads data to allow fatigue lives to be determined.
- Quantify the performance improvement offered by the new rotors.
- Assess handling and loads on the main rotor at high rotor tip Mach number.
- Define a new low speed flight envelope for the modified aircraft.

The testing was carried out in three phases. The first phase was carried out in the spring of 2007 at Boscombe Down in the UK. This phase of testing addressed initial rotor compatibility issues and envelope expansion and load survey tests to a maximum of 5000ft Density Altitude (DA). Following completion of the first phase of testing, the aircraft was transported to Gunnison, Colorado (7678ft AMSL) in the US by RAF C-17 aircraft to commence the second phase high altitude testing. This testing concentrated on low speed envelope definition and envelope expansion and flight load measurement at high altitude. Part way through the phase two testing, sufficient data had been gathered to support an initial operating capability for the RN. The first flight of a RN Sea King HC Mk 4 fitted with Carson MRBs took place on 15 September 2007 when an 846 Squadron aircraft conducted its initial flight as part of RN high altitude training in Cyprus. The first RN flight took place just over 8 months from the start of the project.

The third and final phase of the test programme was again conducted from Gunnison Colorado in the US. Testing took place in winter 2008 in cold temperatures (down to -26°C) in order to generate high rotor tip Mach numbers and allow this portion of the flight envelope to be expanded. Additional flight loads data was also gathered with the aim of removing some of the conservatism in the initial fatigue lives which had been calculated.

A total of 302 hours were flown in support of the programme. This included dedicated flight tests, maintenance test flight requirements and ferry flights. In addition to the two main test sites at Boscombe Down in the UK and Gunnison in the US, the following additional sites were utilised in the US to allow testing to be conducted at a range of altitudes and temperatures:

- Hays Regional Airport, Kansas, 1998ft elevation.
- Montrose Regional Airport, Colorado, 5759ft elevation.
- Grand Junction Regional Airport, Colorado, 4858ft elevation.
- Telluride Regional Airport, Colorado, 9078ft elevation.

All the test sites used were found to be suitable for helicopter testing and provided good support to the test programme. Gunnison, Colorado was ideally suited for high altitude helicopter testing as it had good facilities and predictable weather conditions. This allowed rapid progress to be made and a very high flying rate was achieved.

Test results

NOTE: Certain figures are presented with the numerical values removed from one axis. This has been done due to the RESTRICTED nature of the data.

Vibration

The Carson S-61 aircraft are fitted with the Sikorsky Bifilar main rotor vibration absorber. However, the Sea King aircraft in RAF and RN service are not. Prior to the start of the test programme, there was a concern that vibration may be increased with Carson MRBs fitted to the UK Sea King, particularly within an expanded flight envelope.

The testing showed that the vibration of the modified aircraft was subjectively not significantly different from the unmodified aircraft although, as expected, vibration was higher than experienced by the Carson S-61 aircraft fitted with the Bifilar. The modified aircraft passed the in service vibration checks using the same limits as specified for the unmodified aircraft. Although work continues in the area of vibration assessment and reduction, including the possible use of the Bifilar vibration absorber, the results of the QinetiQ test programme have been confirmed by RN in service experience.

Low Speed Flight Envelope

The modified aircraft was fitted with improved main and tail rotors. Both of these modifications would be expected to increase the size of the Low Speed Flight Envelope (LSFE). The improved hover performance offered by the main rotor would reduce the required tail rotor thrust and the new tail rotor offered the potential to generate increased thrust for the same power. A comprehensive LSFE definition test programme was carried out which attempted to define an increased LSFE for the modified aircraft. The test programme included tests to examine the impact of Centre of Gravity (CG) position and height above ground on the LSFE. The criterion used to define the low speed flight envelope was the ability to maintain a 10% margin in tail rotor pitch in all flight conditions.

A comparison of the LSFE for the modified and standard aircraft is shown in Fig. 1. It should be noted that it was not possible to maintain a 10% tail rotor pitch margin throughout the LSFE defined for the standard aircraft so in reality the increase in LSFE for the modified aircraft is actually greater than Fig. 1 indicates. Nevertheless, it can be seen that the modified aircraft LSFE has increased by approximately 580 kg (1280lb) at all altitudes where the low speed envelope is not limited by the Maximum All Up Mass (MAUM) limit for the aircraft. This increase in LSFE offers significant operational benefits to the RN Sea King HC Mk 4.

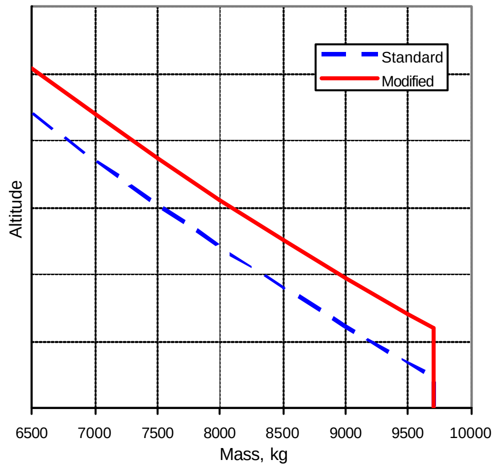

Figure 1 – Comparison of low speed flight envelopes for the standard and modified aircraft.

One important phenomenon that was found during the testing was the affect of longitudinal CG position on the tail rotor pitch required to maintain low speed flight. Figure 2 shows a comparison of tail rotor pitch required for relative winds from the right with the CG at a forward and aft position. Both sets of data were gathered at the same referred mass[1]. Figure 2 shows that at the critical wind azimuth of approximately 60 degrees, with the CG at a forward position, approximately 10% more tail rotor pitch is required. This effect is thought to be due to an adverse interaction of the main rotor vortices with the tail rotor. The more forward CG position moves the aft portion of the

[1] Referred mass is the aircraft mass 'referred' to Sea Level conditions and is defined as the actual mass divided by the relative air density multiplied by the square of rotor speed non-dimensionalised with respect to a reference value.

main rotor disc closer to the tail rotor as aft cyclic pitch is applied to compensate for the forward CG. This result demonstrates the importance of gathering test data at a range of operating conditions. If the low speed envelope had been defined based on aft CG test data then insufficient tail rotor authority would have been available at forward CG.

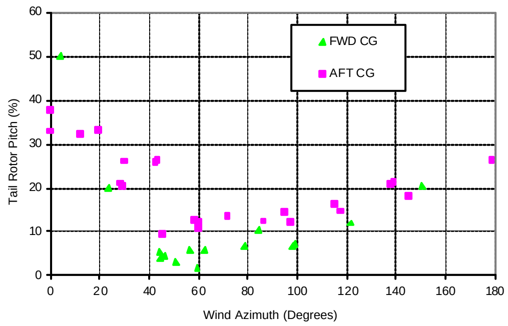

Figure 2 – Tail rotor pitch in low speed flight at forward and aft CG position.

Pressure Error Corrections

Testing was carried out in order to determine if the change in main rotor had a noticeable effect on the Pressure Error Correction (PEC) for the pitot-static system fitted to the aircraft. Although it was considered unlikely that any effect would be present, the pitot-static vents are mounted above the cockpit area directly below the main rotor. Therefore, it was possible that a change in main rotor downwash characteristics could alter the PEC. Tests were carried out using a trailing pitot-static 'bomb' and a DGPS system. The results of the testing showed that the PEC for the modified aircraft was not significantly different from that for the standard aircraft.

Engine control system

The Carson S-61 aircraft are fitted with engines which have a simple hydro-mechanical control system which maintains rotor speed based on a pilot controlled engine speed lever position. The Westland Sea King in service with the RN and RAF is fitted with 'fuel computers'. These fuel computers include a collective pitch anticipation function which aims to minimise transient rotor droop by accelerating the engine based on pilot collective pitch inputs. As this system relies on being able to 'anticipate' the engine power demand resulting from a collective pitch input, a change in rotor system could potentially adversely affect the transient droop performance of the engine control system.

A number of tests were carried out to examine transient droop characteristics at a range of altitudes. Transient droop performance remained good and was not significantly different from the standard aircraft. Further tests were also conducted to examine engine and drivetrain stability and other engine operating characteristics. The engine control system was found to be compatible with the modified aircraft without modification and no objectionable characteristics were encountered.

Hover performance

The hover performance of the modified aircraft was measured during tethered hover testing. The performance data gathered is shown in Fig. 3 and compared with data for the standard aircraft gathered previously using the same airframe prior to modification.

From Fig. 3 it can be seen that a hover performance increase of up to 780kg (1720 lb) referred mass has been demonstrated. In more practical terms, the increased hover performance allowed the test aircraft to hover at its MAUM at 10,000ft Density Altitude.

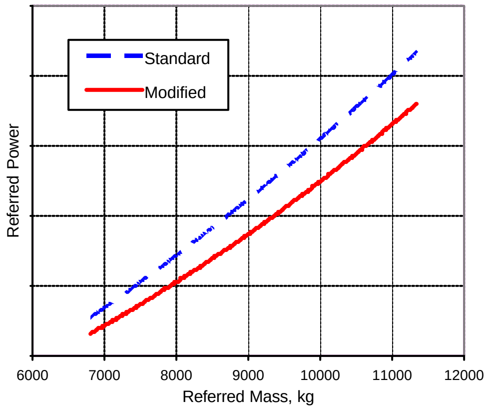

Figure 3 – Comparison of hover performance for modified and standard aircraft configurations.

Handling qualities

The handling qualities of the modified aircraft were assessed throughout the test programme which included testing throughout the expanded flight envelope. As would be expected, the modified tail rotor offered significantly increased control power in low speed flight which was found to improve low speed handling. In forward flight handling qualities were similar to the standard aircraft at low altitude. However, at high altitude the delay in the onset of retreating blade stall significantly enhanced aircraft handling. During the high altitude test programme where handling was assessed at 12,000ft Density Altitude, one Test Pilot commented that handling and performance had improved so much that it was like flying the unmodified aircraft at Sea Level.

Forward flight envelope.

One of the main aims of the test programme was to increase the forward speed of the Sea King HC Mk 4. Testing was conducted to define an expanded forward flight envelope in accordance with the UK Defence Standards. This testing was conducted to define the largest flight envelope within which acceptable handling and the required component life could be achieved. In accordance with the UK Defence standards it was also necessary to conduct tests up to 20% beyond the flight envelope intended for service use. This involved conducting tests to the maximum design forward speed for the Sea King, not only at Sea Level, where this speed has previously been substantiated, but also at high altitude. In tests carried out at low altitude, it was found that the maximum achievable forward speed was limited by collective pitch whereas at higher altitude speed became limited by handling or control loads.

A comparison of the main rotor stall boundary for the standard and modified rotors is shown in Fig. 4. The significant potential benefits in forward speed are clearly demonstrated. The stall boundary for the modified aircraft fitted with the Carson rotor translates to a potential increase in forward speed for the Sea King HC Mk 4 of up to 50 Knots Indicated Air Speed (KIAS). However, an increase of this magnitude may have an adverse impact on aircraft component lives. In service RN aircraft are currently benefiting from an increase in forward speed of up to 35 KIAS. Further analysis and test work may allow this to be further increased.

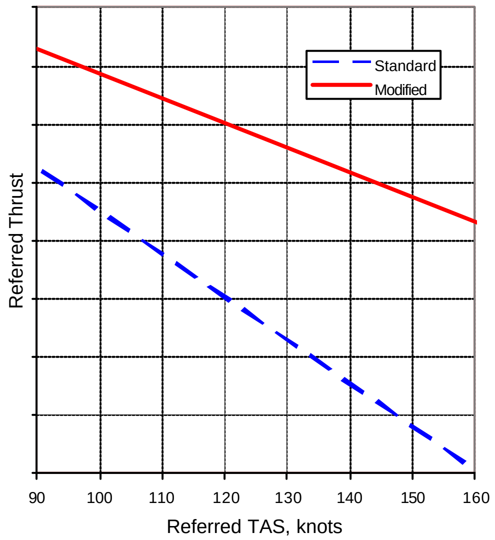

Figure 4 – Main rotor stall boundaries for the standard and modified aircraft.

Conclusion

The RN Sea King HC Mk 4 has been modified by QinetiQ by adding Carson MRBs and an AW 5 blade tail rotor. This has led to a significant increase in performance which has allowed the modified aircraft to be deployed to Afghanistan by the RN. The performance improvements are so significant that many experienced Sea King operators have said the modification has transformed the Sea King into what feels like a new aircraft.

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