FURTHER IMPROVEMENTS TO THE S-61 HELICOPTER

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Abstract

This paper presents new flight test data for a number of characteristics, including hover performance and vibrations of the S-61 helicopter, equipped with new composite main rotor blades that were designed and developed by Carson Helicopters. Also discussed are various other improvements that would provide further gains in the efficiency, range and productivity of the aircraft.

Introduction

Carson Helicopters and other operators are now using new composite main rotor blades on S-61 helicopters. These blades were designed and developed by Carson and are described in detail in Reference 1. The Supplementary Type Certificate (STC) for the composite blades was received by Carson from the FAA in January 2003. It is important to note that no modifications to the aircraft are required to use these blades in place of the standard metal blades on an S-61.They simply are a replacement for the metal blades that provide significantly improved performance, lower maintenance and increased safety margins in aircraft operation with no significant change in loads on the aircraft. Currently the composite blades are in production with eight sets of blades in use by Carson on their S-61's and eight sets in use by other operators. The operators have generally been enthusiastic about the performance of the aircraft with these composite blades, noting a number of such improvements. From one operator:

1. "Cruise true airspeed is increased by 10-15 kts"
2. "Improved climb performance (350 fpm)"
3. "Improved high altitude performance"
4. "Fuel flow reduced by 150 lb/hr at high speed"

Or quoting another operator, "the enhanced lifting capacity in hover makes this helicopter a much safer One Engine Inoperative (OEI) aircraft" and "the pilots flying two S-61N models cannot say enough about the increased performance of their aircraft at all temperatures and altitudes". All of these comments as well as the experience of Carson Helicopters generally support the results of the flight test program conducted by Carson to obtain the STC.

Use of these new blades has resulted in a significant rise in the productivity of the S-61 in logging operations. The hourly rate of moving timber by Carson has been increased by almost 30%, from 140,000 lbs/hr with metal blades to 180,000 lbs/hr with the composite blades. The range and speed of the aircraft have been markedly increased making fire fighting and heavy lift operations more efficient and productive. The added capability of the aircraft makes it a very attractive candidate for many other roles such as air-sea rescue. These improvements have been achieved with lower vibratory loads at high airspeeds and altitudes. The transmission torque in operation is lower at a given weight due to the new rotor .

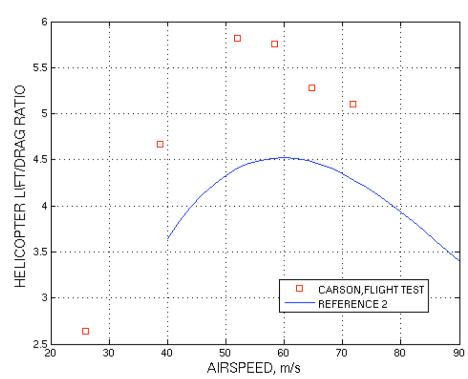

Figure 1. Efficiency of S-61 with Carson Blades at 20500 lbs Gross Weight

The overall efficiency of the S-61 with

Carson composite rotor blades is shown in Figure 1, where the measured aircraft lift-to-drag ratio (L/D) is shown compared to a projected L/D for future helicopters with “new generation airfoils and blade planforms” presented in Reference 2. It can be seen that the future is already here.

Additional flight test results are discussed here that relate to other aspects of the aircraft characteristics with these improved rotor blades that are not included in Reference 1. These include detailed hover performance, vibratory control loads at increased gross weight and 1P and 5P vibrations over the airspeed range.

The performance gains achieved operating the S-61 with new blades have resulted in consideration of other aerodynamic improvements to the aircraft by Carson. This paper describes some of these modifications under consideration. Aerodynamic improvements include fuselage drag reduction, an adjustable elevator to control fuselage attitude in cruise and a new tail rotor design

Discussion

Hover Performance

Figure 2 shows a comparison between the measured hover performance out of ground effect for the S-61 equipped with the new Carson blades and the same aircraft equipped with the standard metal blades. A significant gain in hover performance is shown with the new blades. Note that the saving in power becomes larger as the weight coefficient (Cw) is increased, as would be expected from the use of advanced airfoils and increased twist. It is interesting to note that the new composite blades, due to the use of these airfoils, do not exhibit any measurable loss in efficiency with blade tip Mach number over the range of rpm investigated in these hover tests, while the metal blades with NACA 0012 airfoils show a significant degradation in performance as the rpm is increased from 100% to 106%. Performance of the composite blades includes data at both 100% and 106% rotor speed, while the metal blade results for comparison are only shown for 100% rotor speed.

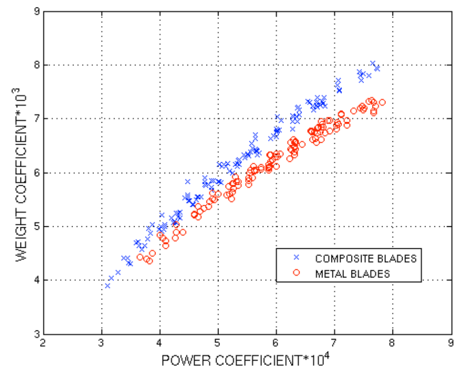

Figure 2. Hover Performance Comparison

The isolated figure of merit for the new composite rotor can be determined from these two sets of flight data and the whirl tower results for the metal blade. The following relationship relates the figure of merit of the aircraft (Mac) and the figure of merit of the isolated rotor (Mr) for two different rotor systems on the same aircraft at the same power:

(Mac/Mr)m=(Mac/Mr)c   at constant power

Using this relationship, a figure of merit of .79-.80 is obtained for the composite main rotor at a typical operating gross weight for the aircraft. This gain in hover efficiency for the complete aircraft corresponds to a significant payload increase in hover as well as an improvement in OEI performance as noted above. Recently, a Carson helicopter taking off, fully loaded on a 90° F day, lost an engine shortly after takeoff and returned to the field without incident.

Cruise Performance

It has been noted above that significant gains in airspeed and reductions in fuel consumption accrue from the use on this new rotor. This increased efficiency of the main rotor has led Carson to examine some additional ways to improve the aircraft cruise performance. Fuselage drag reduction is attractive as the baseline aircraft has a relatively high flat plate area of about 35 sq ft in cruise at aft cg, where the fuselage is close to its minimum drag attitude. One significant contribution to the flat plate area arises from the landing gear (without sponsons) that can easily reduced. Adding fairings to the landing gear assembly, which is made up of round tubes, are estimated to produce a flat plate area reduction of 3 to 4 sq ft.

Flight test measurements indicate that the fuselage drag in cruise varies significantly with fuselage attitude, i.e., center of gravity (cg) position (Ref 1). A sizeable increase in power required for level flight was measured at the most forward cg location where the fuselage has a nose down attitude as distinct from the most aft location during flight tests. A means of reducing the dependence of fuselage attitude on cg position is desirable. This is, of course, not a new observation, although helicopter manufacturers have not taken steps to alleviate this source of increased drag, probably considering that the effect is small. When the cg is at or near to its most aft location on the S-61, the fuselage attitude is near to the minimum drag attitude, zero pitch angle. The significant increase in fuselage drag due to the nose down fuselage attitude when the cg is at or near to its forward limit, corresponds to about a 10% increase in torque at an airspeed of 130 kts, 2000 ft density altitude. This is equivalent to a fuselage drag increase of approximately 6 sq ft as the cg is moved from the aft position to the forward position.

By adding a controllable elevator, adjustable by the pilot, the fuselage attitude in cruise can be made independent of cg position. The current horizontal tail on the aircraft can be readily modified to provide an adjustable elevator that will supply the requisite pitching moment to balance the cg movement at cruise airspeeds. Flight tests will take place later in the year. At some point, it also becomes interesting to consider the gain might be obtained by providing additional forward shaft tilt to reduce the cyclic pitch required for trim. A diagram shown in Figure 3 indicates the relationships among the significant quantities of interest, the longitudinal cyclic pitch, the longitudinal flap angle relative to the shaft, and the shaft pitch attitude (or angle of attack in level flight) as required by the balance of forces at a given airspeed and altitude. This diagram is based on the approximation that the pitch attitude of the tip path plane is essentially determined by fuselage drag, and the swash plate pitch attitude is determined by the tip path attitude and the flap angle relative to the swash plate. This latter quantity is determined for a given advance ratio and swash plate attitude in level flight. Then the moment required by the main rotor to provide moment balance (due to cg position, fuselage moment, horizontal tail moment, etc) determines the flap angle relative to the shaft and thus the shaft attitude. The cyclic required to trim is then found corresponding to this shaft attitude. The fuselage attitude is determined by the shaft tilt in the fuselage. The controllable elevator, by adjusting the moment required by the main rotor (the flap angle relative to the shaft), provides the flexibility to trade off stick position(cyclic pitch) and fuselage attitude. A desirable cruise condition that minimizes vibration is likely to be near to or at the point on the diagram where the flap angle relative to the shaft is zero. The elevator is adjusted to require zero moment from the rotor to trim at this point. Then, for most efficient cruise at this airspeed, the shaft incidence is selected such that the fuselage is at its minimum drag attitude.

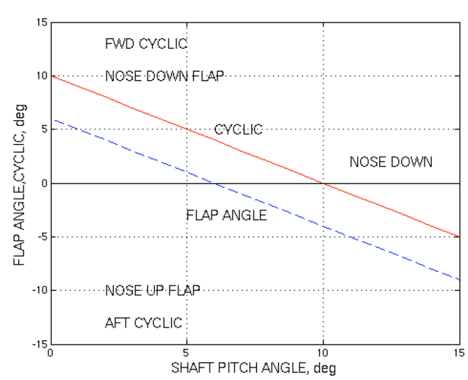

Figure 3. Trim Relationships in Cruise

Control loads

In Reference 1, flight test data was presented that shows with this composite rotor, the oscillatory loads in the S-61control system are well below the endurance limits of the components, and do not exhibit the increase in control loads with airspeed that is typically seen on most helicopters (Ref 3). These load increases with airspeed are particularly evident on the S-61 with metal blades (Ref 1). Since the writing of Reference 1, flight tests have also been conducted with the S-61 at an increased gross weight of 22,000 lbs with the ultimate objective of obtaining FAA approval for operation at this increased gross weight. The peak-to-peak oscillatory loads measured in the blade pitch control rod at three gross weights are compared in Figure 4. It can be seen that there is little or no change in the measured peak-to-peak oscillatory load with either gross weight or airspeed indicating the superiority of the new airfoils and blade design. Also note that all the measured loads are well below the endurance limit of +/-900 lbs for this component. Similar results are obtained for other critical components indicating that the loads produced by this advanced rotor do not effect the aircraft component lifetimes. No change in the airframe is required to use the composite blades.

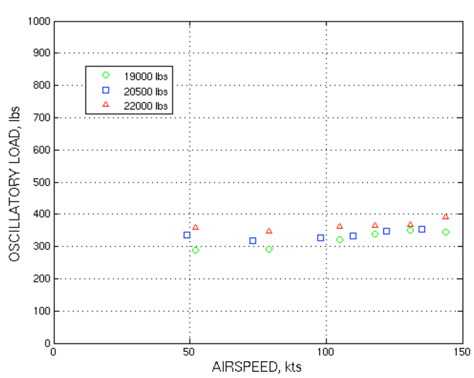

Figure 4. Oscillatory Loads in the Pitch Control Rod for various Gross Weights

Vibrations

Extensive measurements and tracking experience has been gained operating these new composite blades. Some flight tests were conducted with a Chadwick system to determine the sensitivity to tracking adjustments and to make the resulting vibration measurements. All tracking adjustments to date have been made with root pitch adjustments. The blades do not have adjustable trim tabs and there is no indication from the flight experience that they are necessary. The results show low levels of one-per rev (1P) vibration in flight and are generally below the comfort threshold of 0.2 ips (inches per second). This is in large part due to the use of hard tooling in the blade manufacture, and the precision of manufacture of the blades. Interchangeability of the blades has been clearly demonstrated by flying one of the prototype blades with four production blades. Figure 5 shows the 1P lateral vibration at two gross weights as a function of airspeed at the cockpit centerline. The relatively high level level of 1P at 70 kts at low gross weight, slightly above 0.2 ips, is due to tail shake. Figure 6 shows a low level of vertical 1P vibration, particularly at the high gross weight, in the cockpit, as a function of airspeed. Note the level at 20500 lbs well below the 0.2 ips comfort limit.

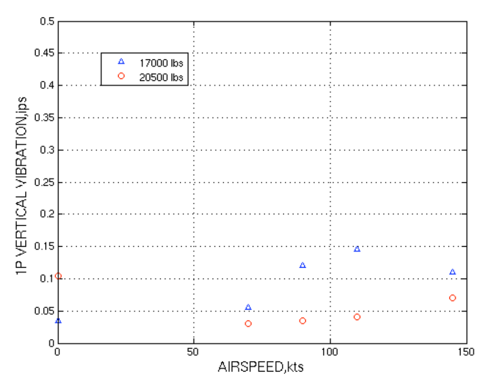

Figure 5. One-Per-Rev Vertical Vibrations In Cockpit with Composite Blades

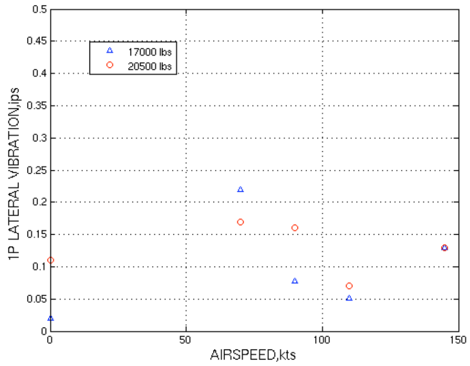

Figure 6. One-Per-Rev Lateral Vibrations in Cockpit with Composite Blades

Figure 7 compares the lateral five-per-rev (5P) at a station between the pilot and copilots seat for the metal and composite blades during the Carson flight test program. The five-per-rev vibrations are quite similar for the aircraft equipped with either the metal or composite blades as would be expected since the composite blades were designed to have similar dynamic characteristics to the metal blades (Reference 1). Figure 8 shows the vertical 5P at the same location. Again, there is little difference between the two rotors and this is typically the result in all flight conditions investigated. Note that this aircraft did not have the vertical battery absorber, located near the cockpit, installed for these 5P measurements.

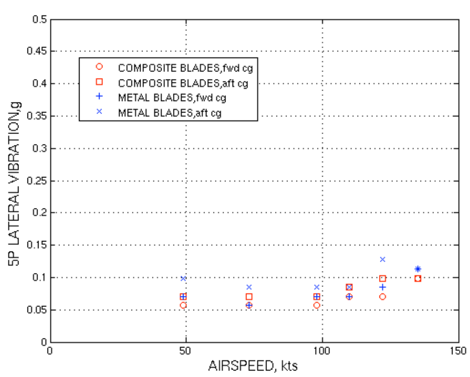

Figure 7. Five-per-Rev Lateral Vibrations in Cockpit. Comparison of Composite and Metal Blades.

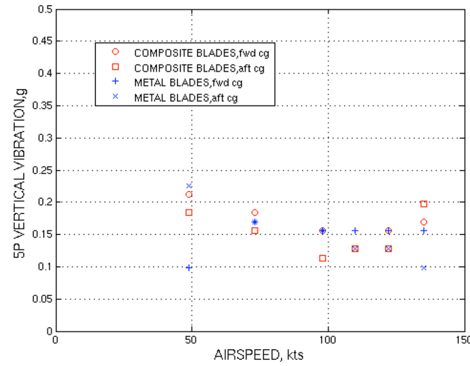

Figure 8. Five-per-Rev Vertical Vibrations in Cockpit.

Tail Rotor

The improved performance achieved with the main rotor has led to study of an improved design tail rotor. The current tail rotor with its untwisted blades and symmetrical airfoil section exhibits low efficiency, especially at high thrust coefficients as required for trim at high altitude and high gross weight. In fact, flight conditions can be reached with the aircraft where the tail rotor can no longer produce the required thrust to balance the main rotor torque. A prototype design tail rotor has been tested to evaluate dynamic characteristics and loads near hover and plans are to start flight testing in the fall. These static tests, which were primarily directed towards measurement of the dynamic characteristics of the new tail rotor, also qualitatively confirmed the improvement in efficiency. This new tail rotor design incorporates advanced airfoils and twist. New airfoils are predicted to provide a marked improvement in efficiency and are particularly significant for a tail rotor which operates over a much wider thrust coefficient range that the main rotor.

Concluding Remark

Improvements in helicopter rotor efficiency make important the consideration of additional modifications which focus on improving the range, payload and performance. All such changes will lead to gains in productivity and usefulness of the helicopter

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