Abstract

The Canadian Forces have been performing instrumented rotor track and balance (RTB) on rotary wing aircraft since the late 1970’s. Airworthiness policy has always required that following rotor control pitch link, rotor blade trim tab, or rotor balance weight adjustment, a dedicated maintenance test flight using test flight qualified aircrew is performed to verify serviceability of the aircraft. Over the years, RTB technology has progressed from scheduled temporary fit wiring and equipment, to more frequent inspections using hard-wired aircraft with walk-on kit, to fully automated Health and Usage Monitoring Systems (HUMS) RTB installations. It was assessed that technology had progressed to the point that removal of the operational impediment of performing maintenance test flights for small rotor adjustments could be achieved.

This paper will describe the process used in building a business and technical case for a small rotor adjustment policy for the CH146 Griffon helicopter. Development work in preparing the Instructions for Continuing Airworthiness for a Controlled Service Introduction trial will be discussed. Experience gained during the trial will be offered, including what was successful and what was not. Recommendations on areas of improvement for HUMS RTB technology and processes will be offered.

Introduction

The CH146 Griffon helicopter has a HUMS which, when in a recognized flight regime, performs scheduled automated and/or pilot requested vibration analyses of the main rotor, tail rotor, and airframe. This capability is unique on the CH146 in the Canadian Forces (CF) as other rotary wing fleets require the installation of RTB equipment and dedicated personnel to conduct the RTB data acquisition. The CH146 HUMS ground station provides the maintenance technician an indication of the vibratory state of the helicopter by flagging main rotor and tail rotor vibration that has exceeded monitoring or maintenance limits.

Current CF airworthiness policy [1] requires that following RTB (or rotor smoothing) adjustments to the main rotor weights, pitch links, or blade tabs and tail rotor pitch links or blade weights, a dedicated test flight with test-qualified aircrew [2] be conducted to verify serviceability of the aircraft. This policy is a major impediment to implementing a small rotor adjustment (SRA) program on the CH146. One of the benefits of a permanently fitted RTB (or HUMS) system is the capability to implement small rotor adjustments at shorter intervals. An SRA program can be used to reduce and maintain airframe vibration at a lower state. This inherently leads to lower operating costs as it reduces damage caused by exposure of the helicopter’s avionics, dynamic components, and airframe to higher than optimal vibration conditions.

A review of existing fleet maintenance data identified potentially significant cost benefits if operational flights instead of dedicated test flights were used to acquire RTB data and verify
the impact of RTB adjustments. With clearly defined adjustment limitations, the risk of performing an adjustment to an incorrect blade or in an opposite direction was deemed minimal and acceptable. Based on the potential cost benefits, increased aircraft operational availability, and the ability to better manage maintenance requirements, approval was granted to perform a Controlled Service Introduction (CSI) of a SRA program.

**CH146 Rotor Smoothing**

The CH146 Griffon uses three accelerometers orthogonally mounted to the cockpit dashboard, an optical blade tracker installed in the nose panel, and a swash plate mounted magnetic interrupter to acquire the vibration, track, and phase data required to perform main rotor RTB. Two accelerometers and an optical azimuth marker are mounted to a bracket on the tail rotor gearbox to acquire the vibration and phase data required to perform tail rotor RTB. The tail rotor optical azimuth marker is the only RTB component not permanently fitted to the aircraft.

Main rotor vibration and balance data is automatically acquired by the HUMS without pilot intervention when the system recognizes that the aircraft is in one of eight flight regimes. The eight regimes are Idle, Flat Pitch On Ground (FPOG), Hover, Climb, Slow, Normal Cruise (NORM), Velocity Not to Exceed (VNE), and Let Down (LETD). The HUMS uses main rotor speed (Nr), indicated air speed (IAS), combined engine torque (Comb Eng Q), collective pitch position, engine gas generator speeds (Ng), rotor brake, and weight-on-gear signals to determine the regime. The conditions that, generally, define the differences between regimes are shown in Table 1.

<table>
<thead>
<tr>
<th>Regime</th>
<th>Defining Conditions</th>
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<tr>
<td>IDLE</td>
<td>On Ground, Nr 60 to 65%, Comb Eng Q &lt; 50%, Collective –20 to +30%</td>
</tr>
<tr>
<td>FPOG</td>
<td>On Ground, Nr 90 to 110%, Comb Eng Q &lt; 30%, Collective –20 to +30%</td>
</tr>
<tr>
<td>HOVER</td>
<td>In Air, IAS &lt; 40 knots</td>
</tr>
<tr>
<td>CLIMB</td>
<td>In Air, IAS 50 to 70 knots, Comb Eng Q &gt; 50%</td>
</tr>
<tr>
<td>SLOW</td>
<td>In Air, IAS 70 to 100 knots</td>
</tr>
<tr>
<td>NORM</td>
<td>In Air, IAS 100 to 130 knots</td>
</tr>
<tr>
<td>VNE</td>
<td>In Air, IAS 130 to 140 knots</td>
</tr>
<tr>
<td>LETD</td>
<td>In Air, IAS 40 to 80 knots, Comb Eng Q &lt; 50%</td>
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</table>

Tail rotor vibration data is automatically acquired by the HUMS when in the FPOG and NORM regimes only. Tail rotor balance data is not automatically acquired in these regimes due to the temporary fit installation of the tail rotor optical azimuth marker and the sensitivity of vibration to tail rotor flight conditions. The difference between vibration and balance data is the acquisition of phase information to locate the imbalance location.

Pilot requested main and tail rotor vibration, and balance data can also be acquired though use of the HUMS Control Panel (HCP), Figure 1, on the aircraft pedestal. The pilot sets the aircraft in the required regime conditions, selects the RTB mode on the panel, and selects the TAKE DATA switch to acquire the data. A sensor fault light (SNS) or a regime (RGM) fault light may illuminate if a sensor required is at fault or the aircraft conditions do not match any of the eight set RTB regimes. The HCP does not indicate what regime is being recognized (e.g. CLIMB versus LETD) only that one of the regimes was recognized at the time of TAKE DATA switch selection.

Main rotor track and balance on the CH146 consists of two distinct phases; the initial phase (INT-LOW) and the flight phase (FLY-LOW). Each phase uses a separate diagnostic
program on the Data Retrieval Unit (DRU) to calculate any required adjustments and to predict main rotor vibration, should the recommended adjustments be implemented. The later phase is referred to as rotor smoothing. The DRU is used to download data from the aircraft to the HUMS ground station and to perform the RTB diagnostics.

The initial phase is required after major rotor component replacement or if the aircraft rotor system balance weights, blade tabs, or rotor control pitch links are set to a neutral position. The initial phase uses the IDLE, FPOG and HOVER regimes to correctly set the blade track to nominal and reduce vibration to safe levels for further flight. The flight phase performs further vibration reduction in the FPOG, HOVER and other off ground regimes by allowing the blade track to deviate from the nominal set in the initial phase in order to reduce vibration.

The RTB diagnostic programs on the DRU can use either the previous set of regime results or the latest set of regime results, acquired automatically or as acquired by the pilot. The default setting is to use the latest pilot acquired results only. The latest pilot acquired results are from the data acquired during the last aircraft operation, rotor start to rotor stop. The DRU diagnostic program does not require data from all regimes but the effectiveness of the recommended effect across all of the regimes may be reduced should the diagnostic program only use a subset of the regimes.

Tail rotor balance on the CH146 also consists of two distinct phases; the FPOG regime radial balance (TAIL-BAL) and the NORM regime (TAIL-TRK) axial balance phases. Each phase uses a separate diagnostic program on the DRU to calculate any required adjustments and to predict tail rotor vibration, should the recommended adjustments be implemented. Main and tail rotor balance diagnostic algorithms use a resolve-to-limit approach [3] to achieve acceptable vibration below a maintenance limit, not to reduce vibration to zero, but to minimize the number of adjustments required to achieve acceptable vibration. The DRU resolve-to-limit values are generally lower than the marginal vibration limits on the HUMS ground station.

The HUMS ground station alerts the technician if main rotor or tail rotor vibration exceeds marginal or high vibration limits. Figure 2 provides a sample HUMS ground station screen for monitoring tail rotor vibration. Marginal, high, and unacceptable vibration limits are defined by regime and accelerometer axis. Exceeding a marginal limit allows the technician to start planning maintenance for the aircraft. Consistently exceeding a high vibration limit requires correction in no later than 15 flying hours. Exceeding an unacceptable vibration limit renders the aircraft unserviceable where-is, as-is.

### Setting Adjustment Limits

The DRU diagnostic algorithms use a series of regime and accelerometer axis specific sensitivity factors and phase lag coefficients to recommend hub weight, pitch link and blade tab adjustments. The sensitivity factors are generally in the form of inches-per-second (ips) per unit of adjustment (e.g. 0.18 ips per degree of blade tab adjustment in the NORM regime for the vertical axis). The algorithms do not use data from all regimes or axes. Table 1 provides the regime descriptions and the axes are in the lateral (LAT), vertical (VERT), and...
fore/aft (F/A) directions. Specific regimes/axes also have an algorithm-weighting factor assigned. This allows the algorithms to use data that will have a greater impact across multiple regimes. The relative weightings by regime and axis are shown in Figure 3.

A conservative approach was used in determining the small adjustment sizes that would be permitted. Regardless of regime/axis weighting, the highest sensitivity factor for an adjustment type (hub weight, pitch link, etc) would be used to minimize the impact of an adjustment made in the wrong direction or to the wrong blade. By using the highest sensitivity factor, regardless of regime, a wrong way adjustment in one regime should not adversely affect other regimes.

The maximum allowable small adjustment would also be based on the amount of vibration requiring correction. The size was limited such that only vibration in the marginal range, typically 0.3 to 0.5 ips, would be correctable using a SRA approach. This would reduce the risk of a wrong direction/wrong blade correction causing vibration to increase above the unserviceable where-is, as-is limits, typically 1.0 ips and greater. Additionally, if the wrong direction/wrong blade adjustment increased vibration levels into the high range (0.5 to 1.0 ips) then the SRA approach would be abandoned and corrections would require a dedicated test flight instead of an operational flight.
Based on using a “worst case” sensitivity factor and limiting the correction to 0.5 ips or less, the maximum adjustment sizes permitted are shown in Table 2. The adjustment limits are net change limits. For example, the recommended pitch link lengthening on one blade also has to account for the recommended shortening of a pitch link on another blade. This provides further risk reduction if a wrong direction/wrong blade adjustment is made. Since most vibration corrections are split between two blades the adjustment size will be smaller than if all of the 0.5 ips vibration requiring correction was made on a single blade.

It became clear during the sensitivity factor review that due to the course adjustment capability of the tail rotor pitch links, only a half turn at a time, any recommendations for adjustment of the tail rotor pitch links could not use a SRA approach. A tail rotor pitch link adjusted in the wrong direction or to the wrong blade could change the vibration levels from marginal to unacceptable. Tail rotor adjustments for chord wise or span wise balance could still be performed using a SRA approach.

Table 2 Net Change Adjustment Limits

<table>
<thead>
<tr>
<th>Adjustment Type</th>
<th>Limit</th>
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<tr>
<td>Main Rotor Pitch Link Lower Rod End</td>
<td>12 Flats</td>
</tr>
<tr>
<td>Main Rotor Outboard Trim Tab</td>
<td>3 Degrees</td>
</tr>
<tr>
<td>Main Rotor Hub Weight</td>
<td>4 Large Hub Weights</td>
</tr>
<tr>
<td>Tail Rotor Span Wise Inboard Weight</td>
<td>12 Grams</td>
</tr>
<tr>
<td>Tail Rotor Span Wise Outboard Weight</td>
<td>8 Grams</td>
</tr>
<tr>
<td>Tail Rotor Chord Wise Weight</td>
<td>16 Grams</td>
</tr>
</tbody>
</table>

This did not deter further development of a SRA policy. Bell Helicopters Textron had prepared a Maintenance Credit Development Plan for the CH146 using the DSTO developed HUMSSAVE utility [4]. One of the credits identified that could be pursued was the use of small adjustments to reduce the number of maintenance test flights following RTB adjustments [5]. Using the SRA limits for hub weight, pitch links, and blade tabs, a review of fleet maintenance data was performed over a four-month period from July to October 2003. The review of the data was conducted in order to determine the range of typical rotor smoothing adjustments, Figure 4, performed in the field.

Figure 4 Comparison SRA Limit to Typical Adjustments – Main Rotor Pitch Link

By implementing the small adjustment allowance, 66.9% of main rotor smoothing flights and
63.8% of tail rotor-balancing flights conducted during the study period could have been accomplished using an operational flight instead of a dedicated maintenance test flight. This would have avoided 276 dedicated maintenance test flights, or $535K in operating and support costs over the four-month period.

The proposed changes in no way affected the current maintenance procedures for verification and independent checks of the adjustments performed. There is the additional safety benefit that by instilling a philosophy of making smaller adjustments at shorter intervals, the impact of making a large adjustment in the wrong direction or to the wrong blade is reduced. Non-linearity effects that can occur with larger adjustments would also be reduced.

**Airworthiness Policy Review**

Implementing a program to reduce aircraft vibration using small rotor adjustments without revising maintenance, or functional check flight (FCF), flight policy could lead to reduced operational availability. Bechoefer and Revor [6] using RTB data from Goodrich IMD-HUMS equipped CH-53E helicopters determined that, without a FCF policy change, a HUMS equipped aircraft using small RTB adjustments could require increased FCFs and reduced availability. The study also determined that significant reductions in FCFs could occur if a policy change was implemented.

A proposal was made to the CF Technical Airworthiness Authority (TAA) to support a revision to the standing flight test orders (FTOs). The approach was based on the size of adjustments not being sufficient to render the aircraft unsafe should an adjustment be made in the wrong direction, or to the wrong blade, with the aircraft in a marginal vibration state. This approach would permit an operational flight to be used to confirm the effect of any adjustments instead of a dedicated maintenance test flight. The HUMS would be required to confirm the effect of the adjustments as the corrective impact would unlikely be felt by the aircrew but would certainly have a beneficial impact on the airframe systems. The only caveat from the TAA was that the adjustment limits be validated.

The Operational Airworthiness Authority (OAA) was next to review the proposed approach and concurred with the TAA. The OAA was the gatekeeper to change the FTOs policies and took some courage, as there would be fewer requirements for maintenance test flight qualified aircrew. They understood the underlying principle of a SRA policy that aircraft would return to operational status sooner after maintenance and aircraft availability for all operators would improve. The third member of the CF airworthiness program, the Airworthiness Investigative Authority (AIA), also concurred with the TAA and OAA that the approach was sound.

Existing operational and maintenance procedures were reviewed in order to define a SRA process that would be flexible, yet manage risk to an acceptable level. The process developed would form the Instructions for Continuing Airworthiness (ICAs) to be evaluated during the CSI trial.

**Development of Instructions for Continuing Airworthiness**

The ICAs consisted of revisions to the existing flight manual operating procedures, the aircraft maintenance procedures, and the equipment codes and inspection requirements (ECIR). The ECIR defines the flight test requirements on a component-by-component basis. The ECIR changes were fairly straightforward. Specific components, such as main rotor control pitch links, required the addition of notes to permit use of an operational flight, should the adjustment size be within SRA limits and the aircraft was in a normal or marginal vibratory state. Key to the SRA process is that the adjustments are made only to aircraft that have a serviceable status. This was a departure from existing procedures where a partial test card would have to be completed by a maintenance test flight aircrew on a dedicated test flight.
The flight manual operating procedure changes mainly consisted of improvements in HUMS control panel operations and the specific regime conditions required to ensure an improved regime capture rate. Aircrew missing regimes was not necessarily an omission on their part. The information in the existing flight manual was not specific enough to ensure that the regime captured was the one required. For example, the CLIMB and LETD regimes were originally described as requiring an approximate 1000 feet/minute ascent or 1000 feet per minute descent, respectively. In reality the HUMS does not use climb rate as a regime defining parameter. Other than a slight difference in indicated airspeed (IAS), the defining parameter is actually combined engine torque being greater than 50% for the CLIMB regime and less than 50% for the LETD regime, Table 1.

To improve regime capture, notes were added to the flight manual procedures to preclude data collection in an unintended regime. For example, operating the aircraft at exactly 100 knots IAS may result in NORM regime or SLOW regime data capture, so the procedure was revised to “Target 120 knots to acquire NORM regime data”. Operating the aircraft on borderline regime conditions also can incur problems due to small differences in the digital air data supplied to the HUMS by the Air Data Computer and the data displayed on the pitot-static system driven cockpit instruments.

The majority of the ICA changes affected the aircraft maintenance manual procedures. The specificity of the regime conditions required in the flight manual was replicated in the maintenance manual. Additionally, changes were required to address the following issues:

- The use of automatically acquired versus pilot requested data;
- The minimum set of regimes required to formulate an adjustment diagnosis;
- The loss of track data capability at night;
- The definition of adjustment net change;
- The permitted combination of adjustment types;
- The use of predicted condition to implement adjustments; and,
- The minimum time required confirming the adjustment effect.

Aircraft RTB condition is monitored on the HUMS ground station by reviewing the trend of automatically acquired vibration data. The automatically acquired data is gathered during multiple flights, weather conditions, and various aircraft gross weights. It is not guaranteed that data from all of the required RTB regimes is collected during the previous flight. Therefore, for the purposes of using SRA, the HUMS technician, upon observing a trend into a marginal vibration state, requires pilot requested RTB data to perform the adjustment diagnosis. The pilot can acquire the RTB data for the six flight mode RTB regimes using the HUMS control panel during an operational flight.

Regardless of a request for the aircrew to acquire the RTB data in all six flight mode regimes, regimes are permitted to be missing from the data set acquired. Based on the regime weighting factors and sensitivity factors described earlier, the four most important regimes for RTB diagnosis are FPOG, HOVER, NORM, and LETD. If the CLIMB and VNE regimes are missing from the data set then the adjustment diagnosis can still be performed.

The operational impact of placing reflective tape on the main rotor blades for night tracking was addressed. When in the flight mode for RTB, track spread is sacrificed to improve vibration condition. Accordingly, track data in the flight mode diagnostics has a very low weighting in the diagnostic algorithms. Track data would still be acquired for trending purposes during daytime automatic data acquisition. Additionally, it is standard practice to retain the HUMS Control Panel tracker mode switch in the DAY position. This prevents interference of the blade tracker infrared (IR) light source with night-vision goggles.
operations. If the switch were in the NIGHT position, the IR light source would illuminate without warning to the aircrew during automatic acquisition of RTB data.

**Small Rotor Adjustment Decision Process Development**

The adjustment limits are based on a concept of net change. The maximum amount of positive adjustment is added to the maximum amount of negative adjustment to obtain an adjustment range. For example, if the adjustments specified are “plus 6 flats on the red pitch link, plus 3 flats on the green pitch link, minus 4 flats on the blue pitch link, and minus 2 flats on the orange pitch link” then the net change is 10 flats; 6 flats (red) plus 4 flats (blue). The exact wording and examples used required revision for clarity. If the adjustments recommended exceeded these limits then the aircraft RTB condition would be monitored until appropriate maintenance could be planned or until the vibration possibly increased into the high range.

Since the SRA adjustment limits included definitions for hub weights, pitch links, and blade tabs adjustments and the RTB diagnostics recommendation could include all three types, some guidance on the use of combined adjustments was provided. A combination of all three adjustments types was permitted as long as all three were, individually, within the SRA adjustment limits. The rationale for allowing this is that the adjustment types generally dominate correcting vibration in one type of regime or axis (e.g. hub weights for lateral vibration, pitch links for low speed vertical vibration and blade tabs for higher speed vertical vibration).

Sometimes the adjustments recommended may not necessarily improve vibration conditions for a specific regime. Guidance was provided that if the SRA adjustments would not have a general positive impact on predicted vibration then the adjustments should not be made. The aircraft RTB condition would be monitored until appropriate maintenance could be planned.

A key element to the SRA process was the placement of a time limit on when the impact of the adjustments had to be verified using an operational flight. The time limit was imposed to account for unintentionally missed regime captures by the aircrew. If the adjustment impact could not be verified within five flying hours then a dedicated test flight was required to capture the data.

The majority of decisions and SRA process were collated into a decision tree. The condensed decision process, Figure 5, provides guidance on how to acquire the data for the diagnostics, the minimum number of regimes required, the aircraft vibration state, the adjustment sizes, the predicted benefit, and the timely verification of the adjustments.

**Figure 5 SRA Decision Process**

```
Marginal vibration state?
  ↓
Adequate data for diagnosis?
  ↓
Adjustments within SRA limits?
  ↓
General predicted improvement?
  ↓
Confirming data acquired in time?
```
Initiation of Controlled Service Introduction

The TAA recommended, and the OAA concurred, that a CSI trial be conducted to evaluate the SRA adjustment limits selected. Confirmation of the theoretical versus actual impact of the SRA adjustment sizes on the vibration state of the aircraft was required before approval of the SRA process for the rest of the fleet could be granted. The CSI trial of the SRA process was initiated to be performed by the Land Aviation Test Evaluation Flight at 403 Helicopter Operational Training Squadron in Gagetown, New Brunswick. The objectives of the trial were to:

- Assess the procedures (ICAs) for small rotor adjustments over a six month period;
- Identify the reduction in vibration level resulting from incremental adjustment;
- Determine the number of iterations required and the impact on Operations; and,
- Compare the number of maintenance hours and test flights required between the existing and proposed procedures.

The trial began in February 2005 with the intention of collecting a number of sets of main rotor and tail rotor SRA cases. A Flight Test Exclusion was provided by the fleet Aircraft Engineering Officer to allow the Squadron to operate the aircraft and perform maintenance with the SRA procedures.

Controlled Service Introduction Experience

The SRA trial started with a goal of collecting twenty sets of main rotor and tail rotor adjustments, and their impact on aircraft vibration, within a six-month period. The trial period required extension twice until February 2006 in an effort to acquire the twenty sets of adjustments. It was found that once aircraft main rotor vibration had been reduced to Normal levels (0.0 to 0.3 ips) the aircraft tended to remain at Normal levels for extended periods of time. Problems were also encountered in acquiring tail rotor adjustment data sets.

A review of the Squadron rotor smoothing maintenance actions and person-hours to accomplish the maintenance actions was performed for a one-year period prior to the SRA trial (3405 flying hours, 14 aircraft) and during the one year SRA trial period (3031 flying hours, 13 aircraft). Figure 6 illustrates the pre-SRA and during SRA rates of rotor smoothing maintenance actions and person hours per flying hour for the Squadron.

Contrary to supposition prior to the SRA trial, the rate of rotor smoothing maintenance actions for the main rotor per flying hour decreased by 16.1% and the person-hour rate decreased by 24.0%. Prior to the trial, it was supposed that smaller adjustments made at shorter intervals would result in a higher maintenance action rate and person-hour rate. It is possible that by keeping the aircraft in a lower state of vibration, large adjustments possibly necessitating additional small corrections were avoided, thereby reducing the maintenance
and person-hour rates. Examining the instances of adjustments with no subsequent increase in flying hours, it was found that during the SRA period there was a 21.4% reduction in additional rotor adjustments. The reductions in maintenance action rate and person-hours rate also occurred for tail rotor adjustments at 29.3% and 35.6% respectively.

**Impact on Operational Availability**

The operational availability of the aircraft at the Squadron in the year prior (quarters Q1 to Q4) to the SRA period and in the year during the SRA period (quarters SRA Q5 to SRA Q8) was reviewed, Figure 7. Prior to the SRA period, operational availability had declined 12.5% with corresponding increases in preventative (4.6%) and corrective (7.8%) maintenance. During the SRA period, operational availability recovered by 9.0% with a minor increase in preventative maintenance (1.4%). Of note was the decrease in corrective maintenance (10.3%) required for the aircraft during the SRA period.

![Figure 7  CH146 Aircraft Availability Prior to and During SRA Period](image)

Using the allowable net change limits, the pre-SRA and during SRA number of adjustments and average net change adjustment size was determined for the main rotor pitch links, hub weights, and blade tabs, Table 3. In all of the main rotor (MR) adjustment types, the average net change adjustment size decreased during the SRA period. A smaller net change adjustment size indicates that lower levels of vibration were being corrected during the SRA period as compared to the year prior. This also indicates that the aircraft were, generally, operating at lower levels of vibration during the SRA period. The same decrease in net change adjustment size did not occur for the tail rotor adjustment types.

| Table 3  Adjustments Comparison Pre-SRA Period versus During SRA Period |
|---------------------------------|---------------------------------|---------------------------------|
|                                  | Pre SRA                         | During SRA                      |
|                                  | Adj* / Ave**                    | Adj / Ave                       |
| Main Rotor Pitch Link (flats)    | 61 / 10.6                       | 47 / 7.1                        |
| Main Rotor Hub Weights (large weights) | 26 / 3.2                     | 35 / 2.9                        |
| Main Rotor Outboard Blade Tab (degrees) | 22 / 2.8                     | 10 / 1.8                        |
| Tail Rotor Chord Weight (grams)  | 17 / 7.2                        | 11 / 13.2                       |
| Tail Rotor Span Wise Inboard Weight (grams) | 13 / 6.5                    | 5 / 17.0                        |
| Tail Rotor Span Wise Outboard Weight (grams) | 3 / 5.7                     | 6 / 6.3                        |
During the pre-SRA period, 60.3% of the 68 main rotor adjustment actions were within the
net change adjustment limits. During the SRA period this rate increased to 70.4% of 71 main
rotor adjustment actions. For the tail rotor, only 50% of the 26 adjustment actions during the
pre-SRA period would have been eligible compared to 56.3% of 16 adjustment actions
eligible during the SRA period.

For the purposes of assessing the impact on vibration of the small adjustment, only 17 main
rotor cases could be gathered and none were gathered for the tail rotor during the SRA period.
For the main rotor, a number of the 50 adjustment actions that met the net change
requirements were not eligible due to rotor adjustments for component replacement, vibration
levels were in the High as opposed to Marginal range, the supporting validation information
could not be collected in time, or the opportunity was overlooked.

Automating the method of deciding upon an SRA approach similar to the US Army Vibration
Management Enhancement Program (VMEP) system [7] developed with Intelligent
Automation Corporation (IAC), or the Goodrich IMD-HUMS for the UH-60A/L [8] would
reduce the amount of missed SRA opportunities. However, avoiding 17 out of a possible 50
dedicated maintenance test flights does have its benefits. As a SRA policy on the main rotor
is adapted and used by maintenance organizations, the rate of operational flights used instead
of dedicated maintenance test flights will only increase.

**Tail Rotor Trial Assessment**

The lack of tail rotor adjustment validation cases was frustrating but, in hindsight,
understandable. Having to install and then remove the tail rotor optical azimuth marker to
acquire balance data was an impediment. Not having automatically acquired tail rotor
balance data and having to rely on aircrew initiated balance data for trend monitoring also
proved to be an impediment. Data acquisition problems related to exposed tail rotor
accelerometer and optical azimuth marker installations contributed, as did condition of the
reflective tape on the tail rotor.

The number of tail rotor pitch link adjustments (12 pre-SRA, 4 during SRA) for tail rotor
axial vibration limited the number of opportunities to use an SRA approach. Tail rotor pitch
link adjustments precluded the use of operational flight to validate the adjustment impact due
to the potential for a large increase in vibration should the adjustment be made to an incorrect
blade or incorrect direction. A trend review of the automatically acquired tail rotor vibration
(not balance) data identified that tail rotor vibration data was not acquired often enough to
provide a meaningful trend indication. The Tail Vib Axial and Tail Vib Radial analyses are
performed when the aircraft is recognized as being in the FPOG and NORM regimes
according to a schedule of analyses by analysis priority. The Tail Vib analyses had a priority
of 5 in the FPOG and 3 in the NORM regime, respectively. The higher the priority, the
earlier in the regime the analysis will be performed.

At 403 Squadron during a single operation (rotor start to rotor stop), the aircraft routinely
operate in the FPOG regime to complete the 17 vibration analyses in the schedule. The
aircraft, however, do not routinely operate at this Squadron in the NORM regime. Based on
their priority assignment, the Tail Vib analyses were numbers 30 and 31 in the list of 33
analyses to be performed when in the NORM regime. Their analysis priority was revised to 5
in September 2005 so that they would be performed as analyses 14 and 15 out of 33. This
improved the capture rate of Tail Vib analyses in the NORM regime but did not address the
lack of consistent aircrew initiated balance data.

Missing RTB regime information was not unique to the tail rotor as some regimes for the
main rotor SRA process were also intermittently acquired. A method for warning technicians
of lapsed scheduled analyses will provide earlier indications of gaps in data or sensor faults.
Since the SRA trial, the CH146 HUMS has been upgraded to use Smiths Aerospace AHUMSTM Analysis Execution Monitoring method for flagging vibration analyses that have not been performed with set time limits. Tail rotor balance data is not currently acquired automatically by the HUMS due to the temporary fit azimuth marker and the sensitivity of tail rotor vibration to anti-torque control adjustment. Aircrew control of aircraft operating condition in the FPOG and NORM regimes is thought to be essential to establishing a reliable set of amplitude and phase data for balancing diagnostics. The absence of automatically acquired balance data will impede using statistical methods of deriving recommended adjustments.

Another factor for the difference in tail rotor to main rotor adjustment cases is the diagnostic limits set in the Data Retrieval Unit. For the main rotor, regime and axis dependant resolve-to-limit values of 0.05 to 0.25 ips are used whereas for the tail rotor it is 1.5 ips for axial vibration and 0.25 ips for radial vibration. The lower main rotor resolve to limit values resulted in more frequent adjustment recommendations. For the tail rotor, radial balance adjustments would only be recommended if radial vibration were above 0.25 ips. The technician would have to manually request an adjustment calculation if the tail rotor radial vibration were below 0.25 ips.

### Adjustment Validation

The main airworthiness purpose of the Controlled Service Introduction was to evaluate the impact of the net change adjustments on aircraft vibration. The evaluation was necessary to determine if the effect of the net change adjustment size reflected the adjustment sensitivity factors used to determine the SRA net change limits. Larger than intended vibration impact would indicate that the net change, if applied incorrectly, could increase vibration to exceed the unserviceable where-is, as-is limits. There was only one documented case in which a movement was made in the wrong direction. Aircraft 146445 had a four flat pitch link movement adjusted in the wrong direction on one blade with correct adjustments on two other blades. Even though the pitch link was adjusted in the wrong direction, the amount of vibration induced into the rotor (from 0.40 ips to 0.86 ips) only increased into the High range and did not exceed the aircraft unserviceable limit. The error was corrected and all vibration levels fell within SRA guidelines.

Assessing the impact of the net changes was not straightforward. Decreases in vibration for some regimes and axes were offset by increases in other regimes and axes. Figure 8 shows typical data for one aircraft using two sequential pre-adjustment and two post adjustment vibration data points for only two of the six flight regimes. Adding another twelve lines for the other four flight regimes and three axes to a trend graph would further complicate the assessment of net change benefit. In this case, the net change in composite vibration (vector sum of all three axes) for the LETD regime was 0.29 ips after a net change adjustment of seven pitch link flats. This equates to a 0.5 ips reduction for a twelve flat pitch link adjustment, corresponding to the theoretical impact of the pitch link net change adjustment limit.
Initial assessment of the beneficial impact based on individual pre and post adjustment vibration amplitudes by regime and accelerometer axis was inconclusive. Using an average of pre and post adjustment vibration amplitudes by regime and axis improved assessment of the impact and identified a marginal benefit. The benefit is also supported by the reduction in average net change adjustment during the SRA period discussed earlier.

Using an average of the last “x of y” data points to determine an adjustment recommendation is not new. The Smiths Aerospace GenHUMS system uses a “composite record set” for determining RTB adjustments. Branhof, et al [9] at IAC with the US Army (Redstone Arsenal) have developed systems to statistically determine the predominant vibration amplitude and phase values for calculating adjustments where the aircraft is flown most often.

Development of a condition indicator (CI) for aircraft RTB using composite vibration (vector sum of all three axes) by regime and weighted by aircraft usage spectrum time in regime would be a better method for determining overall net change impact instead of a “by axis” and “by regime” approach. The data from the SRA trial will require review to validate this approach.

**Conclusions**

Current HUMS technology enables the use of a Small Rotor Adjustment (SRA) policy on the CH146 Griffon main rotor system. The benefits of the policy can be improved with changes to HUMS capabilities, mainly to improve data acquisition.

The switch to using operational flights instead of dedicated maintenance test flights for verification of small RTB adjustments cannot be directed by a policy change. Training and information sessions are necessary to ensure a successful fleet wide implementation of a SRA policy.

The decision to use an SRA approach cannot be based solely on vibration exceeding a pre-set limit. A SRA approach requires a decision process to ensure that the adjustments are implemented safely and will not be an additional maintenance burden. RTB procedures will require revision to include the SRA approach.

Using a SRA approach will improve aircraft availability through reduced test flight requirements, and reduced RTB maintenance actions. Maintaining aircraft at lower levels of
Rotor vibration can contribute to reduced overall corrective maintenance on all aircraft systems.

Performing SRA does not lead to increased RTB maintenance actions and costs. When aircraft operate in a reduced vibration state, small adjustments reduce the requirement for second or third corrective adjustments compared to large RTB adjustments for large vibration corrections.

Missing regime data resulting from sensor faults, lack of automated acquisition, reduced flight time in regime, or omission will reduce the benefits of a SRA approach. Confirmation of regime capture or advisement of missing data would alleviate this impact.

The change in aircraft vibration state following a small rotor adjustment on an individual case basis may seem marginal or negligible. It has to be understood that the benefit is longer term reduced aircraft vibration and the associated reduction in maintenance across the fleet.

The validation of the tail rotor SRA process was not successful and will have to be reassessed. The marginal impact on main rotor vibration supports the SRA net change adjustment limits as being safe to employ in a SRA program.

Regardless of the marginal impact on an individual aircraft basis, a SRA process for the main rotor is worth implementing for the following reasons:

- The reduction in dedicated maintenance test flights, including the requirements for maintenance test flight qualified aircrew and the use of yearly flying rate hours for test flights;
- The reduction in iterative RTB adjustments to correct larger vibration states and the associated flights to capture validation data;
- The general reduction in aircraft vibration state and its beneficial impact on all airframe systems and components;
- The decreased maintenance actions and maintenance hours required to perform RTB; and,
- The overall contribution of the process to increasing aircraft availability rates.

**Recommendations**

The following recommendations for improving HUMS systems and RTB capabilities are offered based on the SRA Controlled Service Introduction experience on the CH146 fleet.

To eliminate the burden of temporary kit installation and improve data acquisition reliability, components requiring phase information for balancing have permanently installed non-optical azimuth sensors.

To improve data acquisition for trend monitoring, components requiring in-situ balancing have automatically acquired data in the regimes used for balancing diagnostics.

To improve regime data capture rates by aircrew, RTB/balancing procedures for regime data acquisition are displayed and scripted for aircrew use.

To ensure data from critical regimes for RTB diagnostics are acquired, the regime sensed by the HUMS is displayed during the RTB/balancing procedure prior to the aircrew initiating data acquisition.

To reduce gaps in data and improve trend monitoring, some form of Analysis Execution Monitoring is implemented to advise the technician when specific analyses have not been performed within a predetermined period of operation.
To reduce the impact of varying operational usage between units, systems using a schedule of analyses when in regime, bridge operations to complete the list of analyses to be performed instead of restarting the list upon each rotor start.

To improve RTB diagnostics efficacy, RTB recommendations for adjustments use some form of regime specific multiple record averaging of vibration amplitude and phase.

To improve usage of an SRA approach, the HUMS system uses a rules base to simplify the SRA decision process and alert the technician. For example, is the approach allowable, provide recommendations on whether to perform the adjustments, to continue to monitor aircraft vibration, or make the adjustments using a dedicated maintenance flight.

Acknowledgments

The authors would like to acknowledge the support provided by 403 Helicopter Operational Training Squadron and the Land Aviation Test Evaluation Facility, Gagetown, New Brunswick and the in performing the SRA trial. In addition, the contributions from the members of the HUMS maintenance section at 403 HOTS Gagetown.
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