Shaft Bending Moment Strain-Gauge Bridge Azimuth Reference

Summary

The phase reference for the shaft bending moment measurement in the TRENDS data base has been found to be incorrect. Documentation for this measurement is not adequate to determine the correct phase reference, but evidence based on similar test installations as well as measurements made during the flight test program, have indicated that the shaft bending measurement is aligned with blade 4. The correct reference, then, requires a rotation of 90 deg.

Purpose

The purpose of this note is to define the azimuth reference angle for the shaft bending moment measurement. The phase reference currently in the TRENDS data base is incorrect, as is the phase reference for data that have been extracted from the data base.

Discussion

Two strain-gauge bridges were installed on the main rotor shaft of the UH–60A used to obtain flight data during the NASA/Army UH–60A Airloads Program, flown at Ames Research Center in 1993 and 1994. The two bridges were slightly offset in height, to allow the derivation of hub shears from the measured differences in moments. The upper bridge, mnemonic RQ12, was functional for the entire flight test program. The lower bridge, mnemonic RQ11, was never operative. The phase reference for the bending moment bridge RQ12 in the TRENDS data base is zero deg, that is, it is aligned with blade 1.

In reviewing flight test data to determine the relationships between control inputs, blade flapping response, and shaft bending, it has been determined that the RQ12 phase reference is incorrect. A review of instrumentation records has been unsuccessful in obtaining specific information relative to the instrumentation installation for this strain-gauge bridge. However, a letter from Sikorsky Aircraft recommending the installation of the two bridges provides information on the normal installation of these gauges. Under normal conditions, the two bridges are offset by 90 deg in phase. The first bridge is aligned with blades 1 and 3, and the second bridge is aligned with blades 2 and 4.

A resolution of the phase reference problem is possible using data from a series of tests that were run on Flight 83 with the aircraft on the ground and the collective set to flat pitch. For these tests one-inch stick inputs were made in each of the four ordinal directions. The counters from these tests are listed in Table 1. The hub moments from shaft bending moment and blade flapping can be compared for these test cases and, in this way, the relative phase references determined. The rotor hub moment, M_H, is estimated from both the shaft bending moment, M_{Hs}, and from blade flapping, $M_{H\beta}$

$$M_H \cong M_{Hs} \tag{1}$$

$$M_H = M_{H\beta} \cong 2e_\beta CF \sin\beta \tag{2}$$

where e_β is the offset of the elastomeric bearing focal point, CF is the centrifugal force at the bearing focal point, and β is the blade first harmonic flap angle. The hub moment equivalency indicated in eq. (1) is valid only if the first harmonic hub shears can be neglected. For eq. (2), the equivalency holds only if errors introduced by lag motion and radial stretching of the elastomeric bearing are small. Figure 1 compares the hub moment derived from flap angle measurements on the four blades with the measured shaft bending moment for all of the test conditions in Table 1. A linear regression shows the slope is within 0.8% of perfect agreement and the coefficient of determination, r^2, is 0.9979. This suggests that for these test conditions, the hub moment approximations noted in eqs. (1) and (2) are satisfactory.

The hub moments from blade flapping are compared to the RQ12 measurement for the first revolution of data from Counter 8315 in Fig. 2. An examination of these waveforms shows that the RQ12 bridge is aligned with blades 2 and 4, and a positive bending moment is obtained when blade 4 flapping is positive. This indicates that the measurements from TRENDS need to be rotated by –90 deg to be properly referenced to other measurements in the data base.

The steady moments in the aircraft axes are dependent upon the first harmonic moments in the rotating system. Aircraft roll moment, positive right wing down, is defined as

$$M_x = -M_H(\psi)\sin\psi = -M_{H1\mathrm{s}} \tag{3}$$

where $M_{H1\mathrm{s}}$ is the first harmonic sine Fourier coefficient of the moment. The aircraft pitching moment, positive nose up, is

$$M_y = -M_H(\psi)\cos\psi = -M_{H1\mathrm{c}} \tag{4}$$

where $M_{H1\mathrm{c}}$ is the first harmonic cosine Fourier coefficient. The current harmonic values of shaft bending calculated from the TRENDS data are uncorrected and must be rotated through –90 deg to obtain the correct values

$$\begin{Bmatrix} (M_{H1\mathrm{c}})_c \\ (M_{H1\mathrm{s}})_c \end{Bmatrix} = \begin{bmatrix} \cos\phi & \sin\phi \\ -\sin\phi & \cos\phi \end{bmatrix} \begin{Bmatrix} (M_{H1\mathrm{c}})_u \\ (M_{H1\mathrm{s}})_u \end{Bmatrix} \tag{5}$$

The corrected first harmonic values, then, are

$$\begin{aligned} (M_{H1\mathrm{c}})_c &= -(M_{H1\mathrm{s}})_u \\ (M_{H1\mathrm{s}})_c &= (M_{H1\mathrm{c}})_u \end{aligned} \tag{6}$$

and the corrected roll and pitch moments are

$$\begin{aligned} M_x &= -(M_{H1\mathrm{s}})_c = -(M_{H1\mathrm{c}})_u \\ M_y &= -(M_{H1\mathrm{c}})_c = (M_{H1\mathrm{s}})_u \end{aligned} \tag{7}$$

The rotor moments in the aircraft axes for Counter 8534 can be calculated as an example. For the first revolution of data for this counter, the uncorrected first harmonic cosine and sine bending moments are 6884 ft-lb and –2583 ft-lb respectively. The aircraft roll and pitch moments, then, are

$$\begin{aligned} M_x &= -6884 \ \text{ft-lb} \\ M_y &= -2583 \ \text{ft-lb} \end{aligned} \tag{8}$$

The roll and pitch moments in the aircraft axes can be calculated from both the blade flapping and from the shaft bending. This has been done for all of the data in Table 1 and the results are shown in Fig. 3. There appears to be an angular misalignment between the two sets of measurements with the moments derived from shaft bending appearing less coupled between pitch and roll. If the data from Table 1 are used to derive a phase angle relationship between the two sets of measurements, then the best fit gives a rotation angle of –99.7 deg instead of the –90 deg that has been used here. The source of this 9.7 deg discrepancy is not known.

William G. Bousman
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Table 1. – On-ground hub moment checks.

FLIGHT	COUNTER	DESCRIPTION	DURATION
FLT 83	CTR 8311	GROUND RUN,FLAT PITCH,100%NR	4.99 Seconds
FLT 83	CTR 8312	GROUND RUN,1"FWD STK,100%NR	4.99 Seconds
FLT 83	CTR 8313	GROUND RUN,1"AFT STK,100%NR	4.99 Seconds
FLT 83	CTR 8314	GROUND RUN,1"RT STK,100%NR	4.99 Seconds
FLT 83	CTR 8315	GROUND RUN,1"LT STK,100%NR	4.99 Seconds

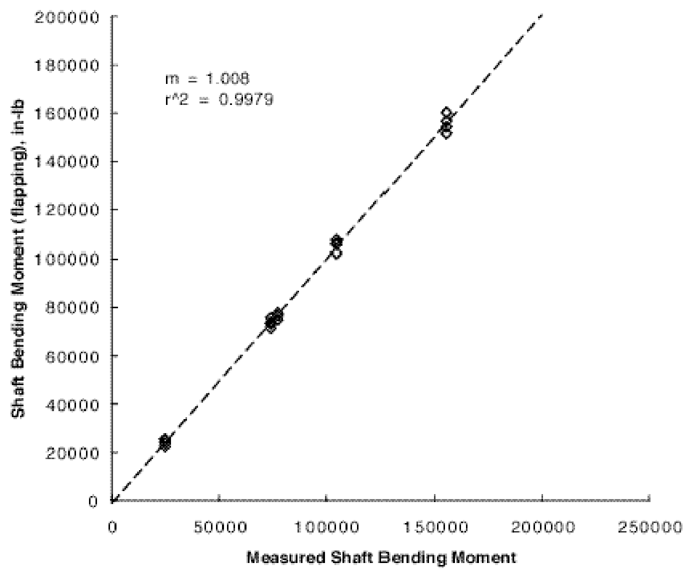

Figure 1. – Magnitude of the first harmonic of the hub moment derived from blade flap angle measurements on four blades as a function of the first harmonic shaft bending moment; on-ground moment checks on Flight 83. The dashed line indicates perfect agreement.

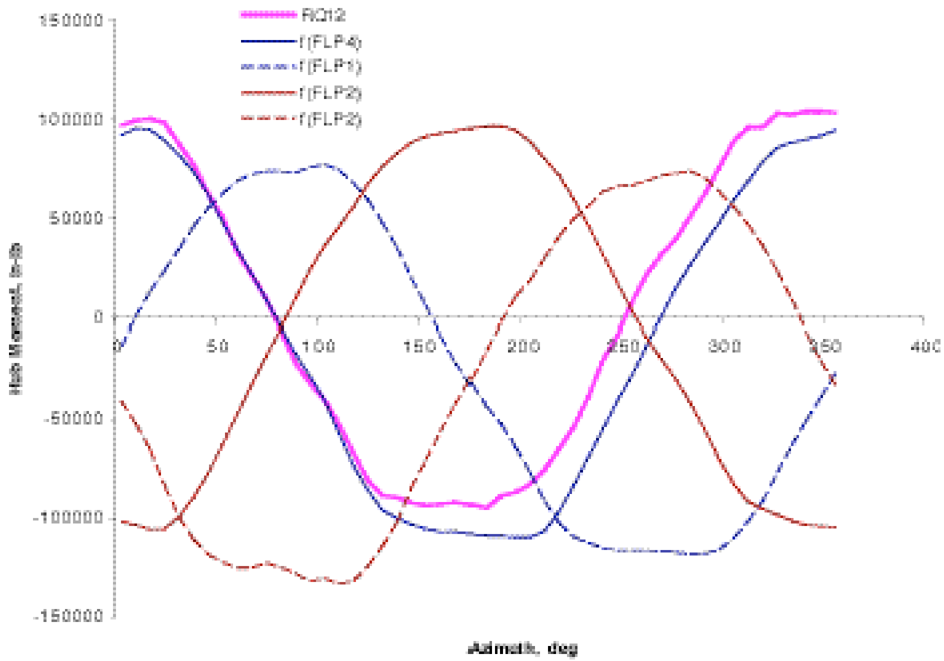

Figure 2. – Hub moments derived from blade flapping compared to the measured shaft bending moment (RQ12); 1-inch left stick input, Counter 8315.

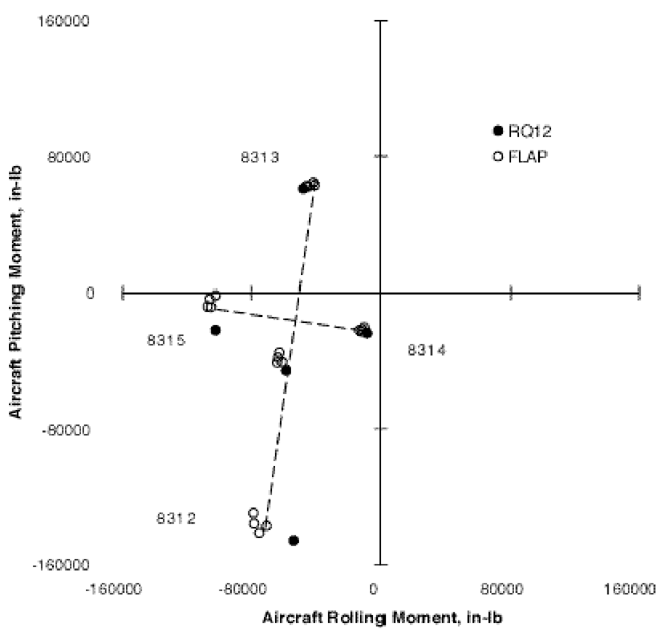

Figure 3. – Comparison of hub moments derived from blade flapping and shaft bending for on-ground tests on Flight 83.