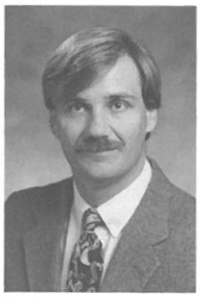
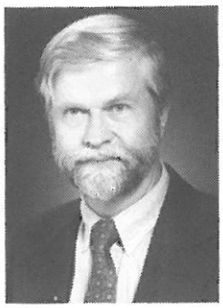
Technical Note
UH-60A Airloads Program Azimuth Reference Correction



Robert M. Kufeld
Flight Vehicle Research and Technology Division
NASA Ames Research Center
Moffett Field, CA



William G. Bousman
Aeroflightdynamics Directorate (AMRDEC)
U.S. Army Research, Development, and Engineering Command
Moffett Field, CA

Recent investigation of airloads data from the Army/NASA UH-60A Airloads Program has revealed an important error in the azimuthal reference used for comparison with rotorcraft analyses. A 7° difference exists between flight test and analysis reference systems because of the offset of the elastomeric bearing from the hub axis. Most previously published data applied this 7° shift in the wrong direction. Correction to published data, therefore, requires a 14° shift to the left for azimuthally referenced data. The correction of the reference error has significantly improved correlation of comprehensive and especially coupled CFD analyses with the UH-60A Airloads Program data. Most publications prior to January 2005 utilize data with the incorrect azimuth reference. A list of affected Army/NASA publications is included in this paper.

Introduction

From August 1993 to February 1994 test data were obtained under the Army/NASA UH-60A Airloads Program (Ref. 1). A UH-60A helicopter was extensively instrumented for flight test measurements. A range of steady and unsteady flight test points were flown. The installation of pressure transducers on one blade allowed measurement of aerodynamic loads at nine radial stations. Strain gauges on another blade allowed measurement of structural loads at various radial stations. Numerous measurements of control position and loads, blade orientation, flight conditions, and aircraft configuration were made. This wealth of data has been an invaluable source for furthering understanding of rotorcraft aeromechanics. It is one of the most complete, thoroughly investigated, and extensively studied wind tunnel or flight test databases.

Discussion

The flight test data obtained in the UH-60A Airloads Program are time based and were acquired at various sample rates, depending upon the measured parameters. These data are stored in the master TRENDS database at the NASA Ames Research Center. An azimuth encoder was used to provide azimuthal references and the zero azimuth reference for the TRENDS database aligns the center of the rotor hub, the center of the elastomeric bearing, points on the blade quarter-chord, and the rotating beacon light on the tail (Fig. 1). This convention provided an accurate means to zero the azimuth measurement in the flight test (and zero the lag angle measurement as well).

For comparison with analyses and other test data, it is more usual and convenient to use azimuthally based data and to define the zero azimuth reference to be parallel to the pitch axis. UH-60A airloads data that are used for comparison with analyses are, therefore, converted to a plot database (P/DB) coordinate system. In the P/DB system the pitch axis is aligned parallel to the aircraft centerline. This orientation of the hub is shown in Fig. 2.

The elastomeric bearing is offset from the hub axis by 1.83 inches, and the elastomeric hinge focal point is 14.89 inches from the center of rotation. Hence this offset creates a 7.0° angle between the pitch axis and the line connecting the center of the rotor hub with the elastomeric bearing (Fig. 3). It follows that there is a 7.0° difference between the TRENDS and P/DB azimuth references. When the rotor is at 0° azimuth in the TRENDS convention, the hub is at −7° relative to the aircraft centerline. Therefore, 0° azimuth in TRENDS is equivalent to −7° azimuth in P/DB. Converting TRENDS referenced data to P/DB requires that the azimuth angle be shifted by −7.0°.

Prior to January 2005, the azimuth shift from TRENDS to P/DB was incorrectly applied as +7.0°. To correct previously published P/DB data, the +7.0° shift must be removed and the −7.0° shift added. This results in a net −14.0° shift. Data plotted versus azimuth will be seen to shift to the left by 14.0°, as shown in Fig. 4. Note that the definition of zero lag-angle is not changed by this azimuth shift.

The TRENDS to P/DB conversion program has been modified to correct this reference azimuth error. A correction to rotor azimuth position in the P/DB format affects all the azimuth-based quantities: airloads (pressure, normal force, chord force, pitching moment), structural loads (pushrod load, damper load, normal and edgewise bending moment, torsion moment, main rotor upper shaft bending moment), and deflections (flap, lead-lag, and pitch angles at the hinge focal point). Note that a change in reference for the main rotor upper shaft bending moment may affect the trim conditions defined in analyses. Corrected P/DB files may be identified by:

1) The first three lines are descriptive data. The third line shows the time when the data were extracted from the TRENDS database. All the files generated before 2005 have an incorrect azimuth reference.

2) There are some narrative lines at the end of the files. The "MODIFICATION" line has been changed from "None" to "Azimuth reference corrected (JAN2005)."

Manuscript received February 2005; accepted March 2005.

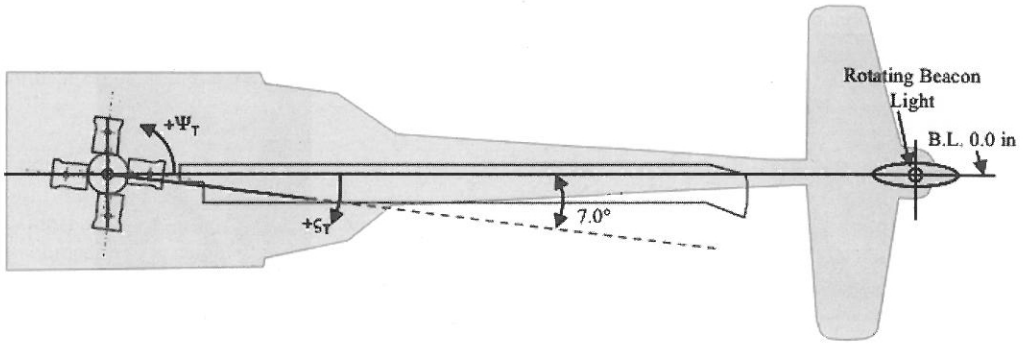


Fig. 1. Definition of TRENDS zero azimuth reference (zero lag angle shown).

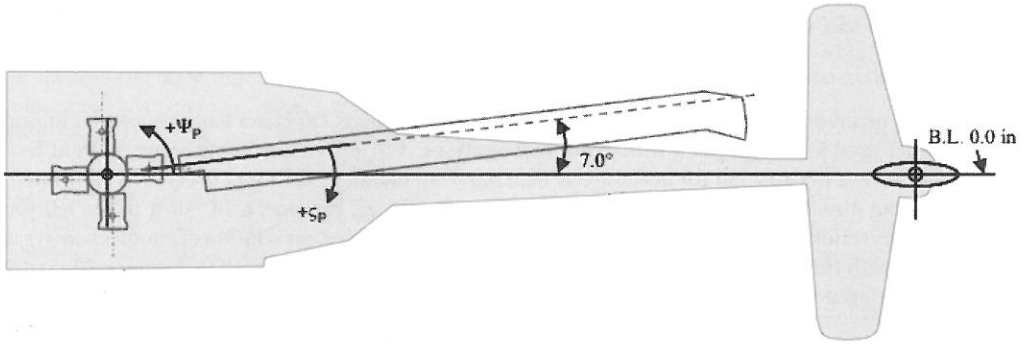


Fig. 2. Definition of plot database (P/DB) zero azimuth reference (zero lag angle shown).

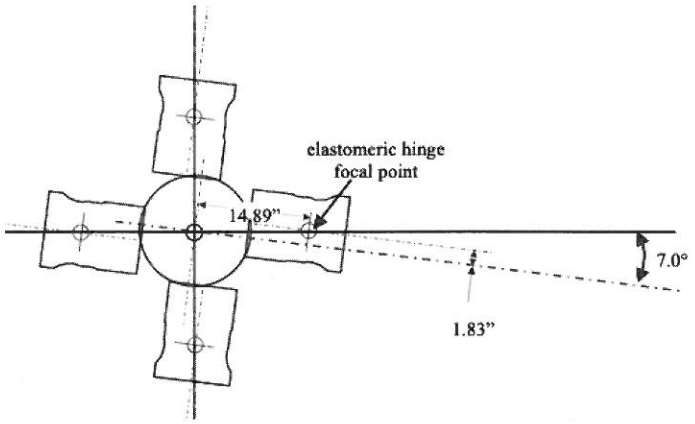


Fig. 3. UH-60A hub geometry.

Publications

The correction to the UH-60 Airloads Program data affects a significant number of publications. Publications with NASA and U.S. Army authors are listed as References 1–18. Additionally, the UH-60A Airloads Program data with the incorrect phase reference have been used extensively by industry and by the U.S. Rotorcraft Centers of Excellence, and numerous papers by authors from these institutions will be affected.

The 14.0° phase shift has changed the understanding of the predictive capability of analysis tools for rotor airloads. Much of our validation experience is based on the UH-60A flight test database. In particular, comprehensive analyses that were previously off by as much as 45° in phase have improved to more respectable agreement (Refs. 2, 3). Comparisons using computational fluid dynamics (CFD) have now been shown to resolve any questions of phase discrepancy between UH-60A test and analysis (Ref. 4). This is particularly true for high-speed test conditions

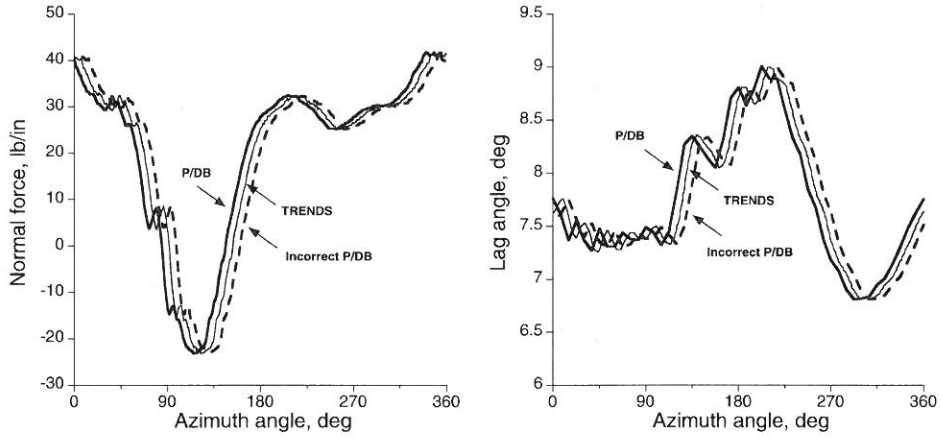


Fig. 4. Example of shifted data.

where the phase lag has been a notable, unsolved problem in rotorcraft aeromechanics (Ref. 5). The advances in CFD and coupling between CFD and comprehensive structural analysis have been facilitated under the NRTC/RITA Airloads Workshop where these problems have been extensively investigated.

Acknowledgments

Contributing to this note were William G. Bousman, Thomas H. Maier, Robert A. Ormiston, Mark A. Potsdam, and Hyeonsoo Yeo of the U.S. Army Aeroflightdynamics Directorate, and Wayne Johnson and Robert M. Kufeld of NASA Ames Research Center. Investigation into this discrepancy was prompted by queries from Jay Dryer, working with DARPA. His careful attempts to understand the complex UH-60A database are appreciated.

References

[1]Kufeld, R. M., Balough, D. L., Cross, J. L., Studebaker, K. L., Jennison, C. D., and Bousman, W. G., "Flight Testing the UH-60A Airloads Aircraft," American Helicopter Society 50th Annual Forum Proceedings, Washington, DC, May 11–13, 1994.

[2]Yeo, H., and Johnson, W., "Assessment of Comprehensive Analysis Calculation of Airloads on Helicopter Rotors," American Helicopter Society 4th Decennial Specialists' Conference on Aeromechanics, San Francisco, CA, January 21–23, 2004.

[3]Lim, J. W., and Anastassiades, T., "Correlation of 2GCHAS Analysis with Experimental Data," *Journal of the American Helicopter Society*, Vol. 40, (4), October 1995, pp. 18–33.

[4]Potsdam, M. A., Yeo, H., and Johnson, W., "Rotor Airloads Prediction Using Loose Aerodynamic/Structural Coupling," American Helicopter Society 60th Annual Forum, Baltimore, MD, June 7–11, 2004.

[5]Bousman, W. G., "Putting the Aero Back into Aeroelasticity," 8th ARO Workshop on Aeroelasticity of Rotorcraft Systems, University Park, PA, October 18–20, 1999.

[6]Coleman, C. P., and Bousman, W. G., "Aerodynamic Limitations of the UH-60A Rotor," American Helicopter Society Aeromechanics Specialists Conference, San Francisco, CA, January 19–21, 1994.

[7]Kufeld, R. M., Cross, J. L., and Bousman, W. G., "A Survey of Rotor Loads Distribution in Maneuvering Flight," American Helicopter Society Aeromechanics Specialists Conference, San Francisco, CA, January 19–21, 1994.

[8]Kufeld, R. M., and Bousman, W. G., "High Load Conditions on a UH-60A in Maneuvering Flight," American Helicopter Society 51st Annual Forum Proceedings, Ft. Worth, TX, May 9–11, 1995.

[9]Lim, J. W., "Analytical Investigation of UH-60A Flight Blade Airloads and Loads Data," American Helicopter Society 51st Annual Forum Proceedings, Ft. Worth, TX, May 9–11, 1995.

[10]Tung, C., Bousman, W. G., and Low, S., "A Comparison of Airload Data Between Model-Scale Rotor and Full-Scale Flight Test," American Helicopter Society 2nd International Aeromechanics Specialists' Conference, Bridgeport, CT, October 11–13, 1995.

[11]Kufeld, R. M., and Bousman, W. G., "UH-60A Helicopter Rotor Airloads Measured in Flight," *The Aeronautical Journal*, Vol. 101, (1005), May 1997, pp. 217–227.

[12]Bousman, W. G., "A Note on Torsional Dynamic Scaling," *Journal of the American Helicopter Society*, Vol. 43, (2), April 1998, pp. 172–175.

[13]Nguyen, K., and Johnson, W., "Evaluation of Dynamic Stall Models with UH-60A Airloads Flight Test Data," AHS International 54th Annual Forum Proceedings, Washington, DC, May 20–22, 1998.

[14]Bousman, W. G., "A Qualitative Examination of Dynamic Stall from Flight Test Data," *Journal of the American Helicopter Society*, Vol. 43, (4), October 1998, pp. 279–295.

[15]Yeo, H., and Johnson, W., "Assessment of Comprehensive Analysis Calculation of Structural Loads on Rotors," American Helicopter Society 60th Annual Forum Proceedings, Baltimore, MD, June 7–10, 2004.

[16]Kufeld, R. M., and Johnson, W., "The Effect of Control System Stiffness Models on Dynamic Stall Behavior of a Helicopter," *Journal of the American Helicopter Society*, Vol. 45, (4), October 2000, pp. 263–269.

[17]Yeo, H., and Shinoda, P. M., "Investigation of Rotor Loads and Vibration at Transition Speed," American Helicopter Society 58th Annual Forum Proceedings, Montreal, Canada, June 11–13, 2002.

[18]Ormiston, R. A., "An Investigation of the Mechanical Airloads Problem for Evaluating Rotor Blade Structural Dynamics Analysis," American Helicopter Society 4th Decennial Specialists' Conference on Aeromechanics, San Francisco, CA, January 21–23, 2004.