

Bringing Relevance to Freshman Aerospace Engineering: Demonstration of Model Scale Comanche Helicopter Lag Mode Damper*

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To attract and encourage first-year undergraduates to undertake their studies in aerospace engineering, a single credit course was developed, entitled ENAE-100 The Aerospace Engineering Profession. A key element of this course is the illustration of the engineering process of design, test and evaluation as applied to aerospace engineering applications. A classroom demonstration was developed using a 1/6th model-scale helicopter lag mode damper that has similar properties to a model-scale damper used in the industrial helicopter model. The energy analysis for this classroom experiment is well within the skill level of the first year undergraduate.

SUMMARY OF EDUCATIONAL ASPECTS OF THIS PAPER

1. The paper discusses materials for a course in Aerospace Engineering, ENAE-100: The Aerospace Engineering Profession (1 credit hour).
2. Students of the Aerospace Engineering department are taught in this course.
3. The level of this course is Freshman (first year undergraduate).
4. The mode of presentation is classroom laboratory demonstration.
5. The material presented is a required introduction to the aerospace engineering profession.
6. The hours required to cover the material is 1 hour per week (1 credit course).
7. Student homework or revision hours required per week is approximately 3 hours.
8. Novel aspects presented in this course increase the relevance of complex aerospace systems in the Freshman engineering curriculum. This goal is achieved by demonstrating a model-scale lag mode damper used in aeromechanical stability augmentation of helicopter rotors. In particular, the model-scale RAH-66 Comanche helicopter lag mode is demonstrated. Illustration of work and energy dissipation concepts via hysteresis cycle measurements and a simplified linearized energy analysis are provided.

INTRODUCTION

TO ENCOURAGE persistence and improve retention among first year undergraduates who undertake their studies in aerospace engineering, a single credit course was developed entitled *ENAE-100 The Aerospace Engineering Profession*. The primary goals of this course are to attract and retain potential Aerospace Engineering majors by emphasizing the unique vehicle technologies developed in the aerospace industry including helicopters, airplanes, satellites and manned spacecraft, along with the often unique and exploratory missions that these vehicles perform.

A critical challenge in the education of engineers is to bring relevance into the classroom, so that students can understand the motivation behind learning the necessary, but often abstract, mathematics and physics necessary to succeed in a challenging engineering program of study. However, complex vehicles such as helicopters, airplanes, and spacecraft present unique challenges when used to illustrate fundamental engineering principles in the classroom curriculum. These aerospace systems are costly and complex, and generally not easily made available to the student for inspection, as might be done with more readily available industrial equipment such as a circular saw [1]. One method to partially accomplish the goal of bringing aerospace systems into the classroom in a physical hands-on sense is to rely on examination of key components at either full- or model-scale.

A key element of the ENAE-100 course is the illustration of the engineering process of design,

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Fig. 1. The Comanche helicopter under development by the Boeing-Sikorsky team incorporates an advanced bearingless rotor system that increases reliability by replacing pitch bearings, lag hinges, and flap hinges used in conventional articulated rotor systems with a flexbeam/torque tube arrangement. *Courtesy: Sikorsky Aircraft.*

test and evaluation as applied to aerospace engineering applications. The RAH-66 Comanche helicopter, shown in Fig. 1, is currently in the flying prototype stage of development and was used to motivate the critical need for damping systems to achieve stringent vibration reduction

and aeromechanical stability augmentation specifications in helicopters.

A classroom demonstration was developed using a 1/6th model scale helicopter lag mode damper that has similar properties to a model scale damper used in the industrial model-scale helicopter model

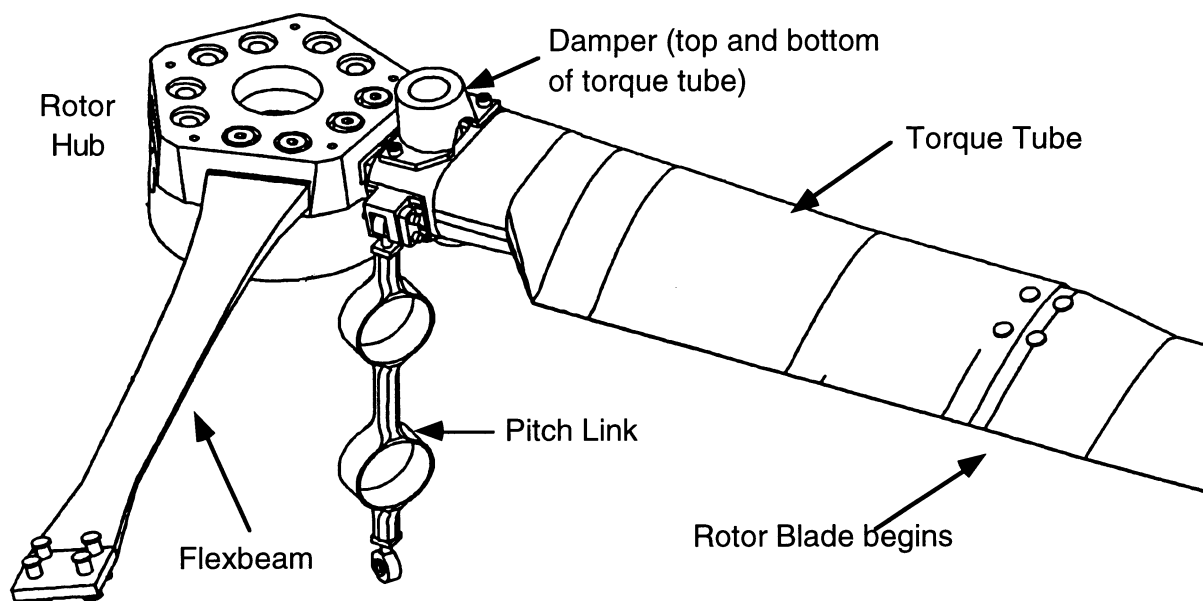


Fig. 2. The model-scale rotor hub of the Comanche helicopter under development by the Boeing-Sikorsky illustrating the location and configuration of the lag mode damper used to augment aeromechanical stability of its bearingless rotor [2]. *Courtesy: Boeing Helicopter*

rotor hub at Boeing Helicopters [2], as shown in Fig. 2.

The primary objective of this demonstration was:

- to provide a sense of relevance to concepts of work and energy dissipation via dampers.

Additional objectives were to illustrate:

- test and evaluation of model-scale devices before moving to full-scale prototypes;
- reduction of a complex problem (helicopter rotor dynamics) into manageable sub problems (such as lag mode damper design and performance);
- usage of shakers, load cells, and LVDTs in mechanical testing;
- the work diagram for a damper and how to infer energy dissipation from hysteresis cycle data;
- nonlinear behavior and linearization via equivalent viscous damping concept.

The computations required to complete the analysis for this lab are well within the skill level of the first year undergraduate, although the design details of the damper are beyond expected knowledge and skills.

For a classroom demonstration to be effective, it must be well motivated, so that the motivation for using lag mode dampers is outlined below. Current advanced rotor designs achieve the objective of reducing life-cycle costs and improving hub designs, and realize superior handling qualities by replacing flap and lag hinges and the pitch bearing with a flexbeam/torque tube assembly. The out-of-plane rotor flap mode is typically well damped due to aerodynamic forces, as are the torsional rotor modes or pitch modes. The in-plane rotor mode, or lag mode, has relatively little aerodynamic damping. Due to stress and weight considerations, advanced rotors are designed as soft in-plane rotors, so that the regressive lag mode frequency is nominally 0.7/rev, or 70% of the rotor RPM. Thus, hingeless and bearingless rotor systems are susceptible to aeromechanical instabilities such as air and ground resonance [3]. Ground resonance is a coalescence of the rotor lag mode with landing gear modes while the helicopter is on the ground. Air resonance is a coalescence of the rotor lag mode with a fuselage mode while the helicopter is in high speed forward flight.

In conventional articulated rotors, these instabilities are mitigated using hydraulic dampers; however, they are prone to leakage problems. Most existing hingeless and bearingless helicopter rotor designs, including the RAH-66 Comanche helicopter, have elastomeric lag dampers. Elastomeric dampers have the advantage of having no moving parts, and eliminate the leakage problems that are present in hydraulic dampers. However, elastomeric dampers exhibit nonlinear behavior which is strongly dependent on frequency, temperature and loading conditions such as preload and amplitude of motion. Also, the damping in

elastomeric dampers reduces drastically for low amplitudes, thus causing limit-cycle oscillations that are detrimental to the operation of the rotor system. These low amplitude oscillations are caused by dual-frequency motion in the lag direction [4]. In order to circumvent the problems associated with the elastomeric dampers, Fluidlastic™ dampers have been proposed [2, 5, 6]. Fluidlastic™ dampers use elastomers in conjunction with fluids. The fluids add a viscous component to the energy dissipation mechanism in the dampers. Moreover, the inclusion of fluid expands the dynamic range of forces generated by the damper [5]. Panda *et al.* [6] tested Fluidlastic™ lag dampers in a 1/6th Froude-scale rotor model and showed that the limit-cycle instabilities that were observed with elastomeric dampers can be eliminated. A comparison between elastomeric and Fluidlastic™ dampers shows that the former have stiffness and damping properties that are nonlinear functions of the displacement amplitude whereas the latter exhibit relatively constant properties [2].

The objective of the classroom demonstration was to illustrate the concept of energy dissipation via dampers, since the primary benefit of damping is to reduce the detrimental effects of structural resonance. The demonstration was developed using 1/6th Froude-scale Fluidlastic™ dampers fabricated at Lord Corporation, in a teaming arrangement between university and industry for educational purposes. The demonstration was also used to motivate advanced modeling studies [7–11], and the development of advanced damper technology [11, 12] at the Alfred Gessow Rotorcraft Center in collaboration with Lord Corporation.

CLASSROOM DEMONSTRATION

To study the hysteresis characteristics of Fluidlastic™ dampers, an experimental setup was designed and built as shown in Fig. 3. The setup was designed to excite the dampers in the shear direction, which translates to lead/lag motion when mounted in a bearingless rotor system. A 4 lbf (17.8 N) Ling Dynamics shaker with a peak-to-peak displacement of 0.2 in (5.0 mm) was mounted in the horizontal position to excite the damper. A circular clasp was designed to fit around the flange of the damper and the shaker was connected to this clasp through a 5 lbf (22.25 N) range Sensotec load cell that measured the force input of the shaker. The diametrically opposite end of the clasp was connected to the core of a Lucas Schaevitz LVDT which measured the displacement of the damper flange. A sinusoidal signal of 10 Hz frequency was input to the shaker using a Hewlett Packard 3325A function generator in conjunction with a power amplifier. The force amplitude was controlled by changing the gain on the amplifier. The load cell and LVDT signals were

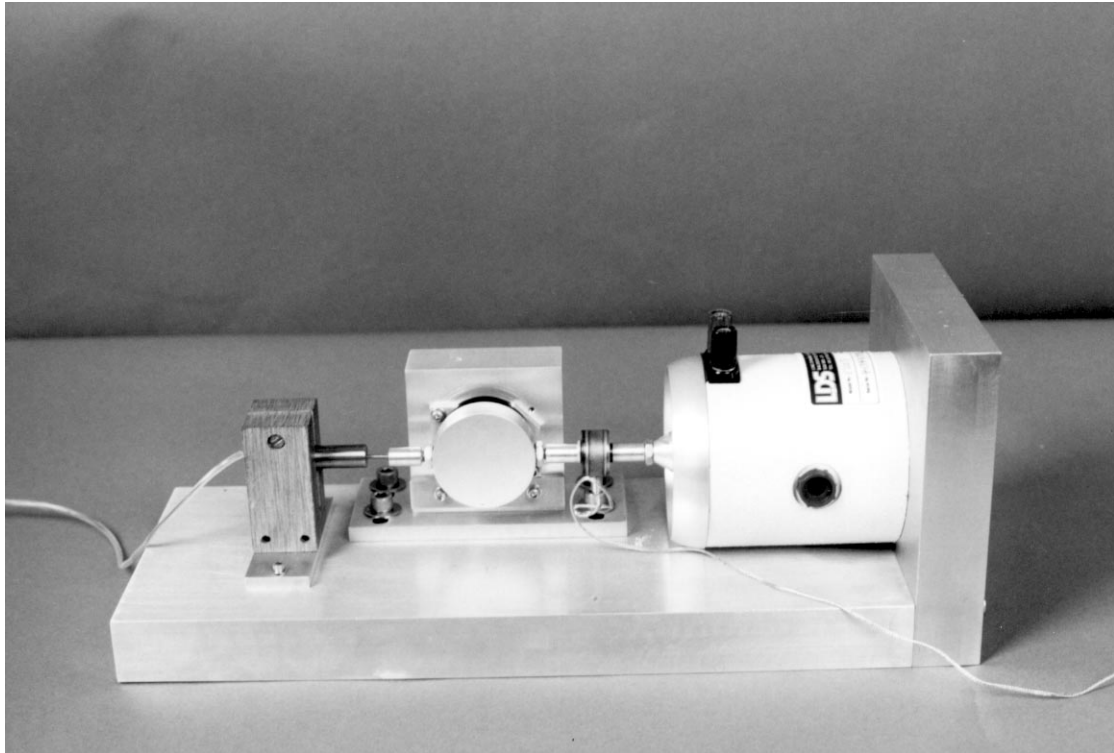


Fig. 3. The test frame for the 1/6th model scale Comanche lag mode damper uses a 4 lb shaker to excite the flange of the damper in the lag mode direction. A load cell measures the shaker force output, and an LVDT measures the damper flange displacement.

recorded using a Tektronix TDS-420 digitizing oscilloscope.

Three sets of data were taken for displacement amplitudes corresponding to peak displacements of 0.25 mm, 0.75 mm and 1.25 mm. The procedure is described in Table 1.

EXPERIMENTAL RESULTS AND DISCUSSION

Figure 4 shows the hysteresis diagram of force vs. displacement for the lag mode damper taken at 10 Hz, which is the nominal regressive lag mode

Table 1. Procedure for classroom demonstration of model-scale Comanche helicopter lag mode damper

- 1 Setup will be assembled by Teaching Assistant
- 2 Set frequency to 10 Hz on function generator.
- 3 Set gain on shaker amplifier such that displacement amplitude is 0.01 inches (0.25 mm), as measured by LVDT.
- 4 Measure force and displacement time histories using the digitizing oscilloscope.
- 5 Plot force versus displacement.
- 6 Count squares within the loop to calculate enclosed area. The area gives the energy dissipated, U . You may select your own area calculation method.
- 7 Calculate equivalent viscous damping constant using equation (2). Ensure correct units are used.
- 8 Change the gain in the amplifier such that displacement amplitudes are 0.03 inches (0.75 mm) and 0.05 inches (1.25 mm). Repeat steps 4–8 for each case.
- 9 Plot the three equivalent viscous damping constants (from Step 8) versus the displacement amplitude using software of your choice.

frequency for the 1/6th model-scale rotor. The shapes are very close to that of a damper with a linear stiffness component and predominantly viscoelastic damping with a small component of Coulomb friction. As the peak amplitude increased, the 10 Hz hysteresis cycle enclosed more area, indicating that the damper was dissipating a greater amount of energy.

For a linear hydraulic damper, the force-velocity relationship is given by:

$$F = c\dot{x} \quad (1)$$

where F is the applied force, c is the viscous (Newtonian) damping constant, and \dot{x} is the velocity of the damper flange. The equivalent viscous damping was developed by equating the energy dissipated by the nonlinear Fluidlastic™ damper to that dissipated by a linear viscous damper. Thus, the equivalent viscous damping constant of the Fluidlastic™ damper is given by:

$$C_{eq} = \frac{U}{2\pi^2 f X_0^2} \quad (2)$$

where U is the energy dissipated by the damper calculated from the area enclosed by the hysteresis loop, f is the frequency of excitation [Hz], and X_0 is the displacement amplitude. The area inside the hysteresis loop was calculated by estimating the number of grid squares inside the loop and applying the appropriate scaling factors. However, students were encouraged to use a software program to analyze the data more thoroughly.

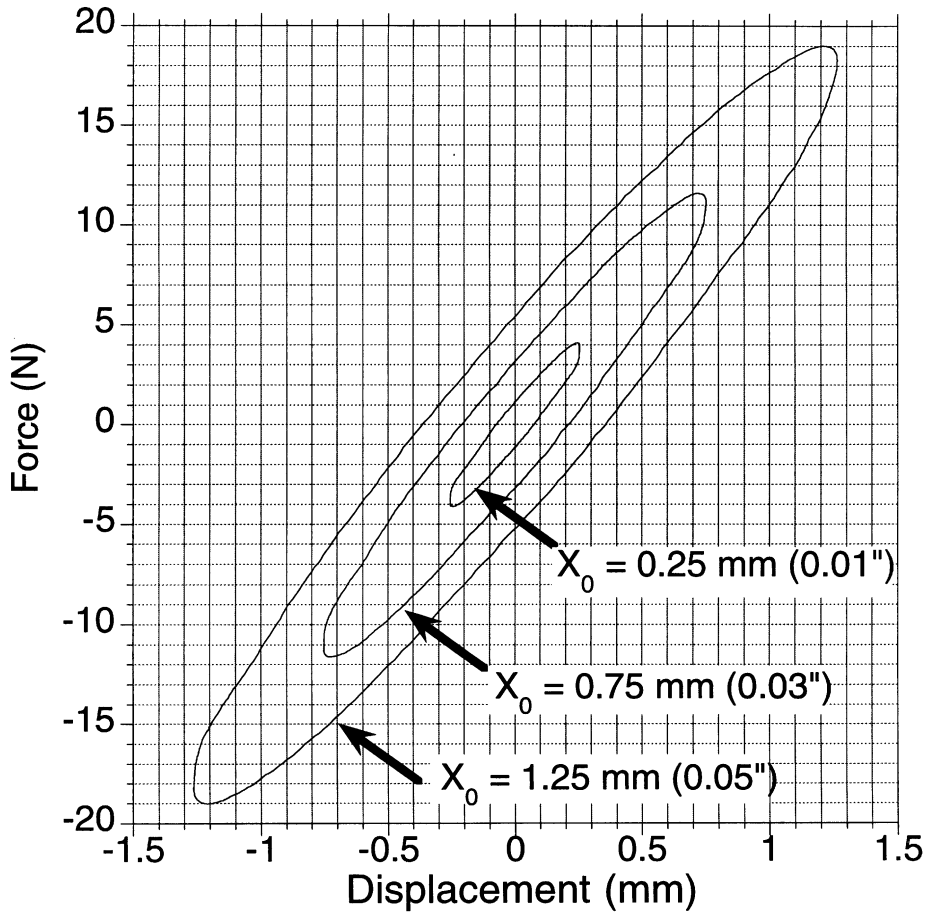


Fig. 4. Work diagram derived from force vs. displacement hysteresis cycles at 10 Hz for peak sinusoidal displacements of 0.25 mm, 0.75 mm, and 1.25 mm.

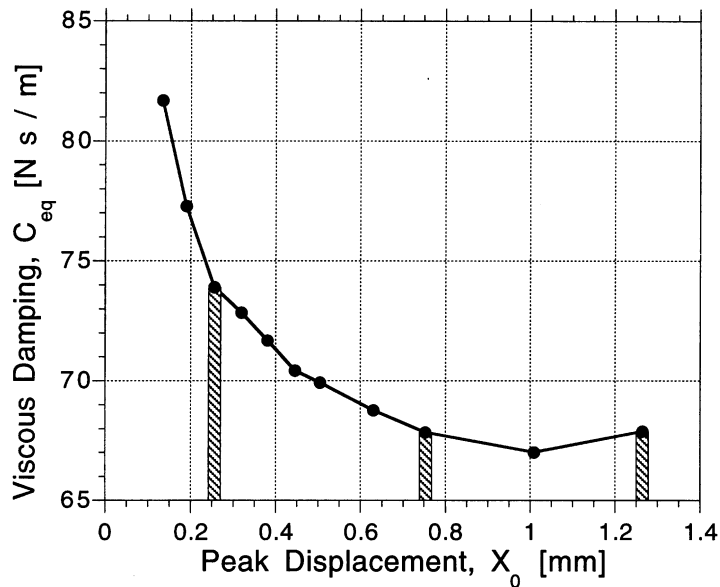


Fig. 5. The equivalent viscous damping is plotted vs. amplitudes of 0.25 mm, 0.75 mm, and 1.25 mm based on calculating the area inside the 10 Hz hysteresis cycle or work diagram to determine the energy dissipated by the damper.

The resulting plot of equivalent viscous damping versus amplitude of excitation is shown in Fig. 5. The three measurements at 0.25 mm, 0.75 mm and 1.25 mm are shown as bars, among measurements taken prior to the classroom demonstration using

a finer mesh of peak displacements. Because of the presence of Coulomb friction in the LVDT, the viscous damping is a function of peak displacement, although the deviation from the nominal value of $C_{eq} = 75 \text{ N s / m}$ is less than 10%.

CONCLUSIONS

A classroom experiment was developed to demonstrate the performance of a fluid-elastomeric damper for the 1/6 model-scale Comanche rotor hub. The demonstration illustrated concepts of work and energy dissipation via use of dampers. In the experiment, usage of basic mechanical testing equipment was illustrated, including use of LVDTs, load cells, and shakers, a function generator, and a digitizing oscilloscope. The Force versus Displacement hysteresis cycle, or work diagram, was measured in the experiment. The hysteresis data was then used to calculate the area in the work diagram loop to infer the energy dissipated, and then a simple formula was used to determine the equivalent viscous

damping constant. The computations required to reduce the experimental data to a useful form for interpretation were of sufficiently small scope that students could complete the lab report in under two hours. Our experiment was conducted using a Fluidlastic™ lag mode damper, but it could also be performed using a vibration isolation bushing or other rubber/elastomeric/fluid-based vibration isolation device.

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