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Experimental and Numerical Investigation on Helicopter Ground Resonance with Composite Flexures

Référence : DY04

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The ground resonance experiments of a helicopter rotor system with the 4-bladed, 2m diameter, small scale soft in-plane hingeless rotor are carried out. And the parameters for the experiments are blade pitch angle, stiffness of the gimbals spring, flexure inclination angle and ply angles of the composite flexures. Blade flap-lag coupling is introduced by changing flexure inclination angle, and blade pitch-lag coupling by using bending-torsion coupling of the symmetric composite layers. And to represent the motion and structural stiffness of helicopter fuselage(pitch and roll) and landing gears, the gimbals is used.

For the numerical analysis, finite element formulation based on the Hamilton's principle is used. The blade is assumed as elastic beam, and quasi-steady strip theory is used to obtain aerodynamic forces. Unsteady aerodynamic effects are introduced through dynamic inflow approximately. For parametric study, measured values of blade lag damping is compared with the numerical results. And it is shown that combined positive flap-lag coupling with negative pitch-lag coupling has a stabilizing effect on the ground resonance.

Introduction

The purely mechanical self-excited helicopter oscillations commonly referred to as ground resonance have been studied extensively since Coleman and Feingold[1] identified the basic mechanism for helicopters with articulated rotors. This dynamic instability is generally caused by coupling of blade regressing lag mode and fuselage motions. An instability is appeared when the rotating lag frequency is less than 1/rev, as is typical for an articulated and soft in-plane hingeless and bearingless rotors. The instability can occur even in the absence of aerodynamic forces. But aerodynamic forces have strong influence on the aeromechanical instability like ground resonance for the case of hingeless and bearingless rotors. With the advent of soft in-plane hingeless rotors by the advantage of mechanical simplicity, the ground resonance became one of the major concern for the hingeless and bearingless rotors.[2]

Bousman[3]~[5] investigated aeroelastic and aeromechanical stability of hingeless rotor with kinematic coupling. He introduced pitch-lag coupling by using geometrically skewed flexure, and also introduced flap-lag coupling by changing pitch angle inboard of the flexures. And he showed that both flap-lag and pitch-lag coupling affect aeroelastic and aeromechanical stability of the hingeless helicopter rotor strongly.

Jung and Kim[6][7] investigated the effects of transverse shear and structural damping on the aeroelastic response of stiff-in-plane composite helicopter blade. They introduced the shear correction factor (SCF) to account for the sectional distribution of shear and improved the prediction of transverse shear behavior of composite rotor. And Kim et al.[8] studied the stress distributions across rectangular and thin-walled box sections, and determined the SCF for the sections with consideration of bending-shear and extension-shear couplings.

The objective of this paper is to investigate systematically the ground resonance stability characteristics of a hingeless rotor system by the experimental and the numerical methods. The experimental system, ERASA(Experimental Rotor Aeroelastic Stability Apparatus) is composed of the 4-bladed hingeless rotor of 2 m diameter and the gimbals system which represents the elastic stiffness of the helicopter fuselage and landing gear as shown in Fig. 1. The results obtained by the ERASA compared with the numerical prediction by the developed computer program.

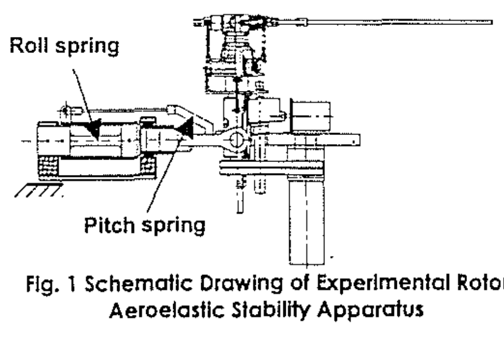

Fig. 1 Schematic Drawing of Experimental Rotor Aeroelastic Stability Apparatus

Experiment

1. Gimbals

The gimbals that can be used to simulate the motion of the helicopter fuselage and landing gear is installed as shown in Fig. 1. Only pitching and rolling motions of the body are considered. Therefore the gimbals is designed to allow the rotor system to have such motions. And the frequency characteristics of the helicopter body can be varied by changing the springs installed inside the gimbals. The gimbals is a type of cylinder in which a roll spring is linked between fixed end and the rotor system. A pitch spring pivoted above the cylinder is linked to the rotor. The roll spring is a type of torsion spring, and the pitch spring is a type of bending spring. And it is possible to change both springs. To prevent the coupling of the two body motions, the axes of pitching and rolling motions are placed on the C.G. point of the rotor equipment. It is possible to move C.G. point to the axes of the rolling and the pitching motions by using movable balancing mass. The dynamic characteristics of the each gimbals spring set is shown in table 1. Body inertia makes difference between baseline 1 and baseline 2.

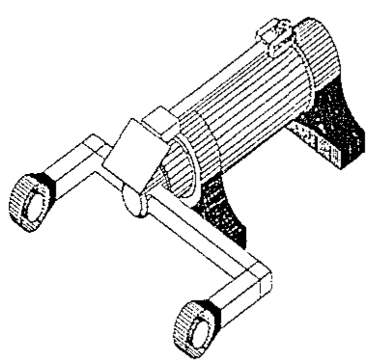

Fig. 2 3-D View of the Gimbals

			Frequency	Inertia (kgm^2)
Spring Set I	Base-line 1	Body Pitch	1.66 Hz	14.73
		Body Roll	3.19 Hz	17.36
	Base-line 2	Body Pitch	2.00 Hz	10.12
		Body Roll	3.80 Hz	12.21
Spring Set II		Body Pitch	3.19 Hz	14.73
		Body Roll	3.42 Hz	17.36

Table 1 Gimbals Dynamic Characteristics

2. Blade

Blade flap-lag coupling is introduced by changing flexure inclination angle as shown in Fig. 3. And it is possible to change inclination angle for 0, ±15, ±30, ±45, ±60, ±75, ±90 degrees. Positive inclination angle makes positive flap-lag coupling(flap up-lag back coupling).

Blade pitch-lag coupling is introduced by using bending-torsion coupling of the symmetric composite layers as shown in Fig. 4. For the experiments of the combined flap-lag and pitch-lag coupled blade, the isotropic flexure is replaced by the composite flexure. And the lay-up angle of the composite flexure is [$30°_6$ / $0°_{17}$ / $30°_6$]. The material properties of the composite ply(HFG HT 145/RS 1222) is shown in table 2. For each blade configuration, the rotating(at 600 rpm) and the non-rotating lag frequencies are given in table 3.

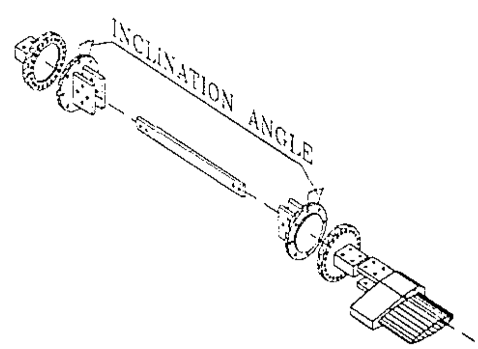

Fig. 3 Inclination Angle Adjustment to Introduce Flap-Lag Coupling

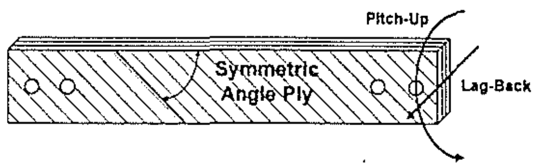

Fig. 4 Composite Flexure to Introduce Negative Pitch-Lag Coupling

HFG HT 145/RS 1222	
Longitudinal Modulus E_L	122.5 Gpa
Transverse Modulus E_T	7.9 Gpa
Shear Modulus G_{LT}	3.6 Gpa
Major Poisson's Ration ν_{LT}	0.3
Ply Thickness	0.15 mm
Density	1500 kg/m^3

Table 2 Material Properties of the Composite Ply

	Non-rotating Lag Frequency	Rotating Lag Frequency (at 600 rpm)
Aluminum(Al7075)	3.13 Hz	7.00 Hz
Composite-B	2.75 Hz	6.85 Hz
Aluminum (Inclination 15°)	2.99 Hz	7.23 Hz
Composite-B (Inclination 15°)	2.70 Hz	6.93 Hz

Table 3 Rotating and Non-rotating Lag Frequencies of the Blade

3. Data Acquisition and Procedure

For sensing the blade lag motion and the motion of the body rolling and pitching motions, strain gages are used. The strain gages attached to blade flexures formed full bridges to sense the lag mode which affects the ground resonance. Since varied instantaneous C.G. of the four blades have an influence on the body rolling and pitching motions. Strain gages attached to the rolling and pitching springs of the gimbals are used to sense the body motions.

The signals from the strain gages are transmitted to the 36-pole slip-ring, and then that signals are passed to strain conditioning amplifier where amplified 1000 times and filtered. And it is necessary to filter those signals for eliminating high frequency noise from AC servo motors(main motor and the motor for changing collective pitch of the blade) and step motor(for exciting cyclic pitch of the blade).

The moving block method is used to compute frequencies and damping from the strain gage signals. For this purpose, the signals are sampled at the rate of 100 Hz during 10.24 seconds by using 16 channel data acquisition system. Moving block analysis is done with the LabVIEW™ VIs(Virtual Instruments).

The Procedure for the ground resonance experiments is shown in Fig. 5. And at least five transient records were obtained and processed at each case.

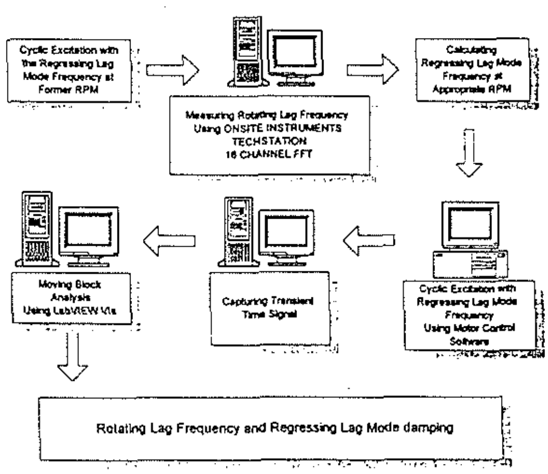

Fig. 5 Experimental Procedure

Analysis

For numerical study, the computer code for ground resonance is developed for hingeless rotor using a finite element formulation based on Hamilton's principle. The main blade is assumed as elastic beam. The helicopter fuselage is modeled as five spring constants representing five degrees of freedom: longitudinal, lateral and vertical translations, and pitch and roll rotations. Quasi-steady strip theory is used to obtain aerodynamic forces, and non-circulatory forces are also included. Unsteady aerodynamic effects are introduced approximately through a dynamic induced inflow modeling.[9]

Results

The frequencies and the dampings corresponding to different body and blade modes are presented with changing rotating speed for each blade and body configuration. And the experimental results are compared with the numerical predictions.

1. Baseline

Fig. 6 shows a satisfactory agreement of calculated rotating frequencies of lag mode with measured values. In Fig. 7 and 8, results for a zero collective pitch are presented with rotating speed Ω. The frequencies corresponding to different body and blade modes in the fixed reference frame are shown in Fig. 7. Fig. 8 presents damping for the regressing lag mode. The predicted results show a weak ground resonance instability for a range of rpm ($380<\Omega<420$) caused by the crossing of regressing lag mode and body pitch mode and strong instability ($540<\Omega<650$) caused by the crossing of regressing lag mode and body roll mode.

2. Effects of pitch angle

Fig. 9 shows results for a collective pitch of 4° about the regressing lag mode damping. The correlation of damping with experiment and computation is less satisfactory. Fig. 10 presents the effects of collective pitch on the on the regressing lag mode damping. For better presentation, only numerical results are compared. At resonance, the positive collective pitch aggravates the instability boundary(induced by larger aerodynamic forces). Under 350 rpm, the effect of collective pitch on the regressing lag mode is negligible.

3. Effects of gimbals spring stiffness

Fig. 11 shows Coleman diagram for spring set II. Fig. 12 and Fig. 13 shows regressing lag mode damping. Spring set II makes natural frequencies of body roll and body pitch mode relatively close. So it seems like that there is one instability region. In the resonance region, the added instability is more severe.

4. Effects of flap-lag coupling

Fig. 14 shows rotating lag frequencies for baseline 2. Coleman diagram is shown in Fig. 15 for baseline 2. Fig. 16 shows regressing lag mode damping with changing rotor speed for baseline 2. The results show a satisfactory agreement. Stability characteristics of lag mode in hover are shown in Fig. 17. Fig. 18 presents rotating lag frequencies for inclination angle of 15°. Fig. 19 shows Coleman diagram for inclination angle of 15°. Fig. 20 and Fig. 21 shows regressing lag mode damping. In Fig. 20 numerical and experimental data are fairly good matched. The effects of flap-lag coupling on the ground resonance are same as those of pitch angle. It is because changing of pitch angle is done inboard of flexures in the experiment. So the flap-lag coupling makes instability more severe too. Excluding resonance region, inclination angle makes regressing lag mode more stable.

5. Effects of combined coupling (positive flap-lag coupling with negative pitch-lag coupling)

Fig. 22 shows rotating lag frequencies and Fig. 23 shows regerssing lag mode dampings for combined flap-lag with pitch-lag coupling. Analysis for this case is not available. In Fig. 23 only combined coupling has an stabilizing effect on ground resonance. Regressing lag mode damping for combined coupling is higher than any other configurations in all region.

Concluding Remarks

The ground resonance stability is investigated. The experimental results are compared with numerical predictions, and the following conclusions have been drawn.

1. The results show that a weak ground resonance instability is caused by the crossing of regressing lag mode and body pitch mode, and the strong instability is caused by the crossing of regressing lag mode and body roll mode.
2. Higher collective pitch angle increases instability in the unstable regions.
3. When natural frequencies of body roll and body pitch mode are relatively close, it seems like that there is one instability region. In the resonance region, the added instability is more severe.
4. Flap-lag coupling makes instability more severe. Excluding resonance region, flap-lag coupling makes regressing lag mode more stable.
5. Combination of positive flap-lag coupling and negative pitch-lag coupling has a stabilizing effect on the ground resonance.

Acknowledgement

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References

1. Coleman, R. P. and Feingold, A. M., "Theory of Self-Excited Mechanical Oscillation of Helicopter Rotors with Hinged Blades", NACA TR-1351, 1956.
2. Chopra, I., "Perspectives in Aeromechanical Stability of Helicopter Rotors", American Helicopter Society National Specialists' Meeting on Rotorcraft Dynamics, Arlington, Texas, Nov. 1989.
3. Bousman, W. G., Sharpe, D. L., Ormiston, R. A., "An Experimental Study of Techniques for Increasing the Lead-Lag Damping of Soft In-plane Hingeless Rotors.", Preprint No. 1035, Preceedings AHS 32nd National Forum, Washington D. C., May 1976
4. Bousman, W. G., "The Effects of Structural Flap-Lag and Pitch-Lag Coupling on Soft In-plane Hingeless Rotor Stability in Hover.", NASA TP 3002, AVSCOM TR 89-A-002, 1990
5. Bousman, W. G., "An Experimental Investigation of the Effects of Aeroelastic Couplings on Aeromechanical Stability of a Hingeless Rotor Helicopter.", Journal of the American Helicopter Society, Jan. 1981.
6. Jung S. N. and Kim S. J.,"Aeroelastic Response of Composite Rotor Blades Considering Transverse Shear and Structural Damping.", AIAA Journal, vol. 32, No. 4, pp820-827, April 1994
7. Jung, S. N. and Kim, S. J., "Effect of Transverse Shear on Aeroelastic Stability of a Composite Rotor Blade," AIAA Journal, Vol. 33, No. 8, pp. 1541-1543, 1995
8. Kim, S. J., Yoon, K. W., and Jung, S. N., "Shear Correction Factors for Thin-Walled Composite Boxbeam Considering Non-classical Behaviors," Journal of Composite Materials, Vol. 30, No. 10, pp. 1133-1149, 1996.
9. P. P. Friedmann, C. Venkatesan, "Influence of Various Unsteady Aerodynamic Models on the Aeromechanical Stability of a Helicopter in Ground Resonance.", Journal of the American Helicopter Society, Jan. 1986.

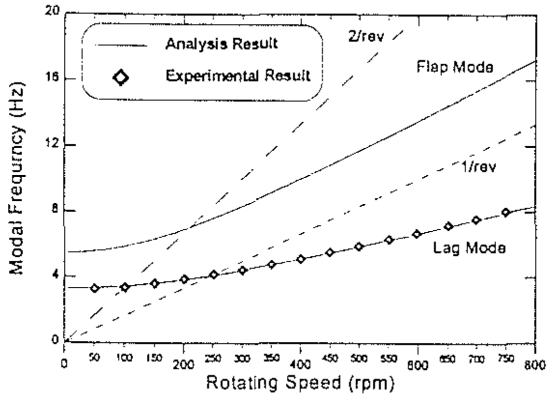

Fig. 6 Fanplot(isotropic, no inclination)

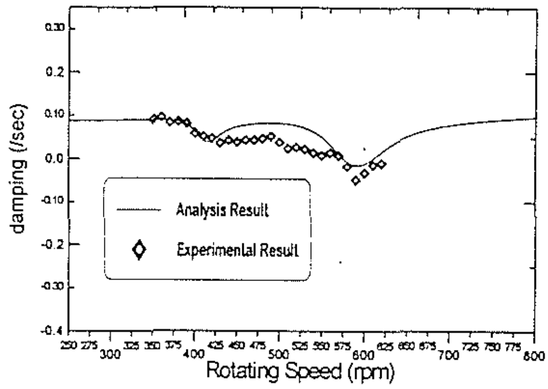

Fig. 9 Regressing Lag Mode Damping
(Collective Pitch Angle : 4 deg.)

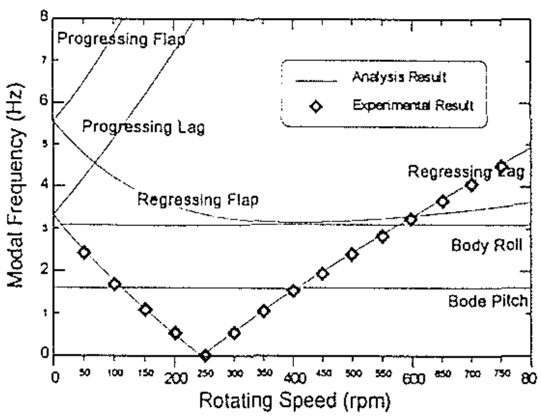

Fig. 7 Coleman Diagram
(isotropic, no inclination)

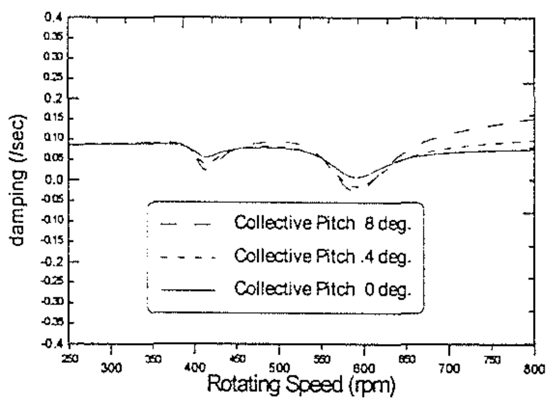

Fig. 10 Effect of Collevtive Pitch Angle

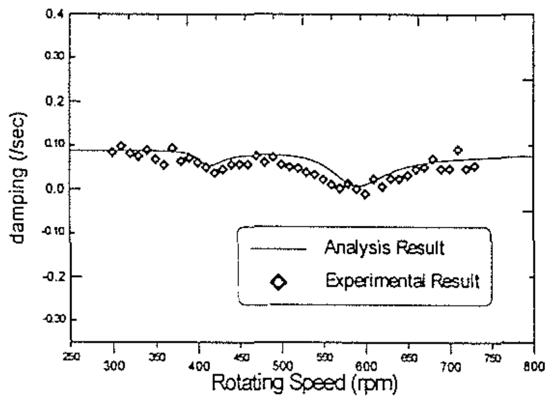

Fig. 8 Regessing Lag Mode Damping
(isotropic, no inclination angle)

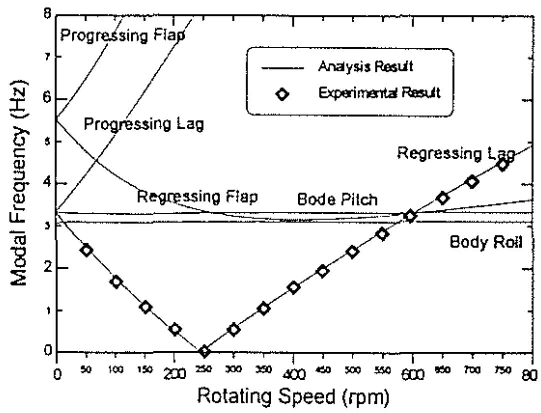

Fig. 11 Coleman Diagram (Spring Set II)

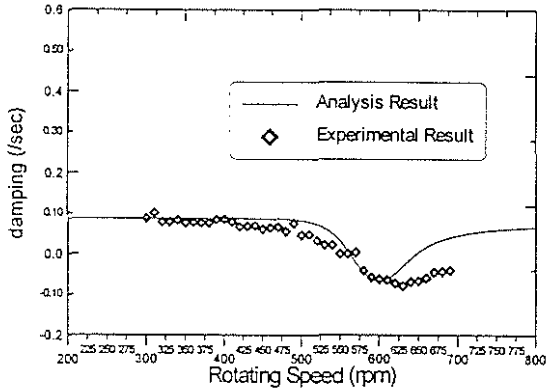

Fig. 12 Regressing Lag Mode Damping
(Spring Set II)

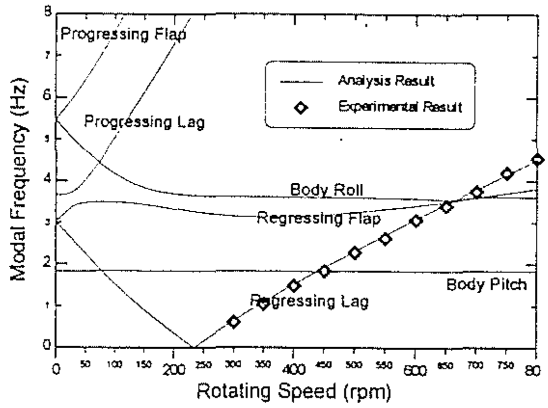

Fig. 15 Coleman Diagram baseline 2

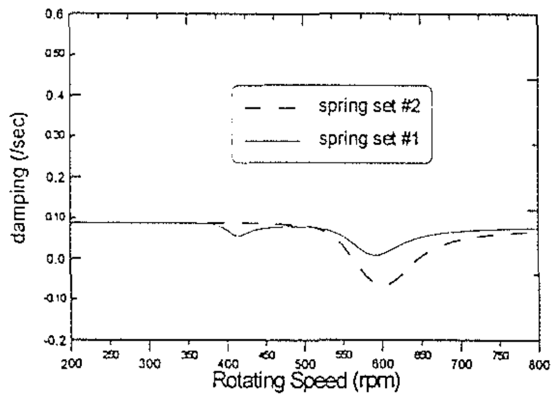

Fig. 13 Effect of gimbal spring stiffness

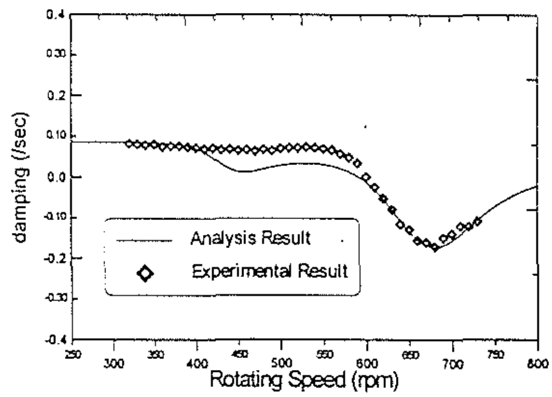

Fig. 16 Regressing Lag Mode Damping (baseline 2)

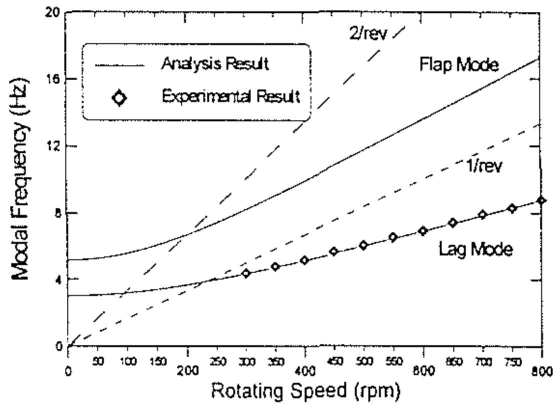

Fig. 14 Fanplot (baseline 2)

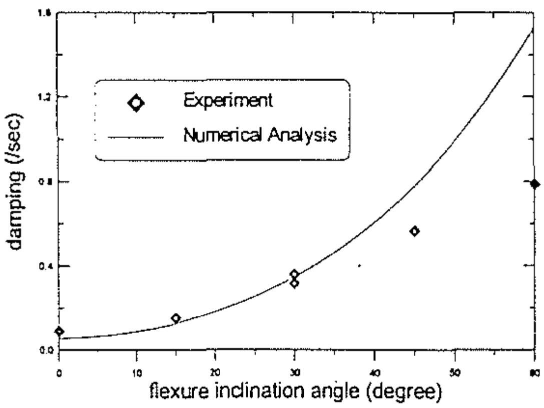

Fig. 17 Lag Mode Damping in Hover (600 rpm)

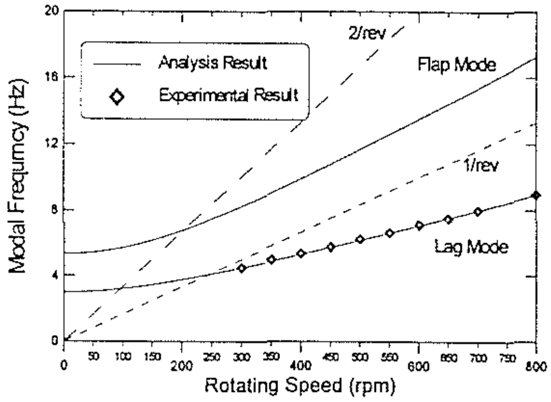

Fig. 18 Fanplot with inclination angle (15 deg.)

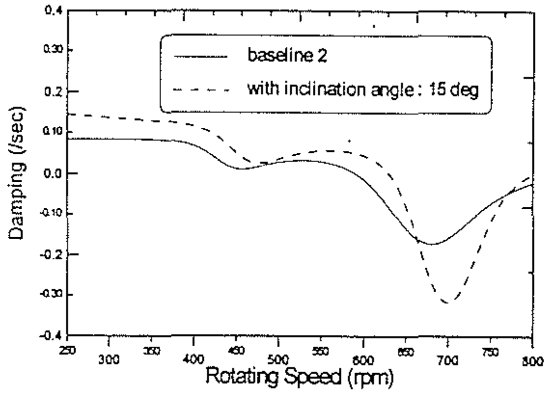

Fig. 21 Effect of inclination angle

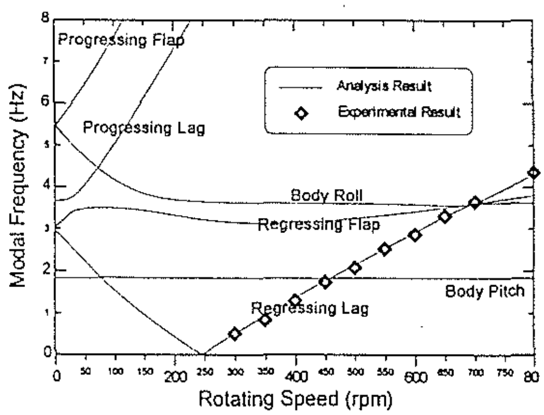

Fig. 19 Coleman Diagram with inclination angle (15 deg.)

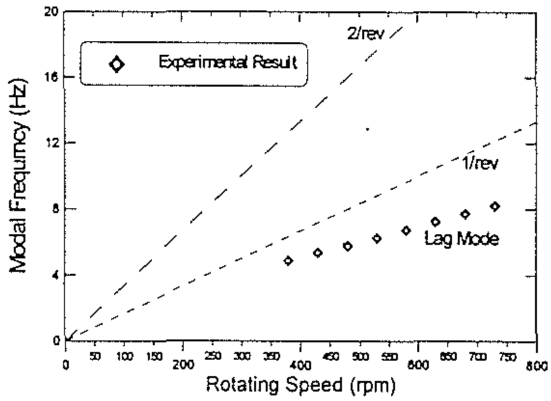

Fig. 22 Fanplot(Combined Coupling)

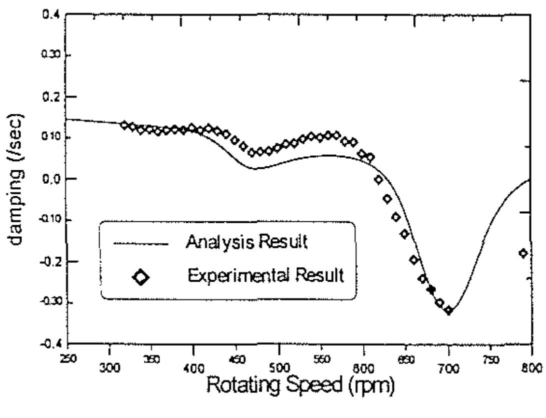

Fig. 20 Regressig Lag Mode Damping with inclination angle (15 deg.)

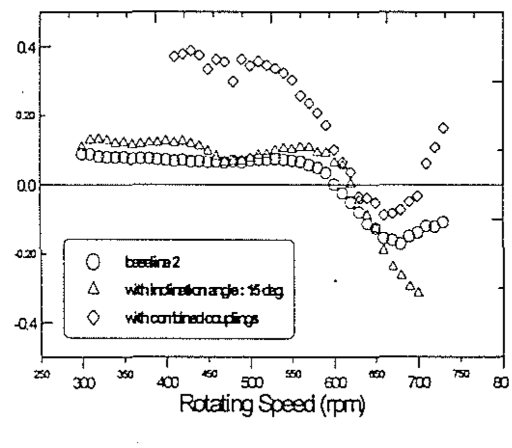

Fig. 23 Effect of Combined Coupling