A Study on Aeroelastic Stability Improvement of Hingeless Hub System in Hover and Forward Flight Using Composite Materials

Deog-Kwan Kim, Joune-Ho Kim, Keun-Woong Song, Young-Jung Kee, Gene Joo
Korea Aerospace Research Institute
Daejeon, Korea

Abstract

Recent studies have indicated that composite hingeless hub system can be more aeroelastically stable than metallic hybrid hub system, which is made of metal and engineering plastics (torlon). Existing metallic hybrid hingeless hub system was replaced with composite materials to improve aeroelastic stability from the general idea that that the structural damping of composite material is larger than metal's. Another idea is the weight reduction effect. In the view point of weight, the composite materials are preferred to the metallic materials[1]. To validate this idea experimentally for composite rotor hub system, both metal and composite hub systems have been developed and small-scaled (Froude-scale) rotor test was performed. Especially, the composite hub flexure was designed with sectional properties of existing metallic hybrid hub by using Classical Laminate Theory (CLT).[2]

Two types of blade were designed and fabricated. The one was rectangular standard blade and the other was paddle-type advanced blade. These blades were attached to both metallic hybrid hub and composite hub. The quantitative comparisons of natural frequency analysis were summarized and good agreements could be observed in view point of dynamic characteristics.

There were two kinds of tests using each hub and each blade, which were hover test and forward flight test in a wind tunnel. First, the aeroelastic stability test was performed by using a metallic hybrid hub system with a standard blade at hover and forward flight condition. Second, the same test has been done by using a metallic hybrid hub system with a paddle type blade. Last, the same test was done by using a composite hub system with a paddle type blade.

This hingeless rotor system was fabricated for testing in 2-m diameter. General Small-scaled Rotor Test System(GSRTS) and 3m x 4m Low Speed Wind Tunnel (LSWT) in the Korea Aerospace Research Institute (KARI) were used for these tests. The GSRTS was designed for general rotor test including Froude and limited Mach scale test. For stability test, small-scaled composite blades were designed by using CORDAS which had been developed in KARI. CORDAS has a function of blade sectional design such as composite sequencing, stiffness, mass, etc. These blades were designed based on the Froude scaled property of existing full scale blade of Lynx and were fabricated for Froude test. The concept of the present hingeless hub system is similar to that of Lynx, which is one of Westland's helicopters. The normal operating rotational speed(Ω) for froude scaled test is about 780rpm. The designed first lag frequency and first flap frequency is about 0.76Ω ? and 1.27Ω. In order to compare amount of damping improvement, the lag frequencies of the two different hub systems were almost similarly matched and natural mode shapes were also similar. Before starting to test, the dynamic characteristics of these hingeless rotor systems are estimated by using FLIGHTLAB, which was commercially developed by Advanced Rotorcraft Technology, Inc. (ART) in USA. Frequency diagram at each collective pitch angles and vibratory load at each flight conditions were calculated. Through the blade bench test, the sectional properties of fabricated blades were measured. These measured data were updated to FLIGHTLAB input data.

The hover test was accomplished at –2, 0, 2, 4, 6 and 8 degree of collective pitch angle, and the forward flight test was done at 0.1 and 0.25 of advance ratio, respectively. The analysis and test results of frequencies were compared. 1st Flap and 1st Lag Frequencies was agreed well each other and the results are presented in this paper. However, a little discrepancy is occurred in 1st torsion frequency.

Second, the 1st lagwise damping value of composite hub system was measured by exciting swashplate driven by hydraulic actuator and the results are presented. The well-known MBA (Moving Block Analysis) technique was applied to calculate and determine the lag damping in rotating frame[3]. The aeroelastic stability improvement of hingeless rotor system by applying composite material could be verified and identified by test.

Introduction

Research background

Helicopter main rotor system has important functions to generate thrust, moment and control force in hover and forward flight. So, this rotor system is one of the key parts of helicopter. To make thrust, moment and control force as the only rotor system, the mechanism of rotor system is very complex and the weight of rotor system is quite heavy. These complexity and heaviness of rotor are not so good to helicopter performance and operating cost in aspect of drag increase, payload decrease and short maintenance period.

Various rotor systems have been developed to overcome these complexity and heaviness. So, the hingeless rotor system has been developed to remove mechanical flap and lag hinge from articulated rotor system which has three mechanical hinges such as flap, lag and feathering. Furthermore, the bearingless rotor system has been developed to remove mechanical feathering hinge from hingeless rotor system. New light materials like elastomeric and composite materials have been applied to rotor system to reduce rotor weight. These hingeless and bearingless rotor systems have the advantage of high controllability in addition to simplicity and lightness. This means that these rotor systems have large moment at rotor hub centre compared with articulated rotor. Nevertheless, these rotor systems have a little low stability due to the structural coupling of elastic parts (flexure or flexbeam and torque tube) which has the role of virtual hinge like mechanical hinge of articulated rotor system [4,5].

Also, rotor system is exposed to high stress and vibration in hover and forward flight. These high stress and vibration will make the cause of short fatigue life for rotor system. To enhance fatigue life of rotor system, new materials have been applied. One of these materials is composite materials. Composite materials have important role on fatigue life enhancement of rotor and helicopter stability improvement. Specially, 1st lag stability is so important in aspect of ground and air resonance. Through comparison of these metallic hybrid hub and composite hub, the aeroelastic stability improvement of hingeless rotor system by applying composite material would be verified.

Applied rotor system

The chosen rotor system to verify stability improvement and weight reduction is hingeless rotor system since technology level of this rotor is better than that of bearingless rotor system. Also, in aspect of obtaining chance of the technical data, the hingeless rotor system is better. Through Super Lynx Offset program in 2000, the technical data and characteristics on metallic hingeless rotor system of Super Lynx could be obtained. So, the model of hingeless rotor system model could be designed similar to that of Super Lynx. The size of this model is 1/6 scaled of a real full size rotor system. First, to analogy characteristics of Lynx, the hybrid metallic hub system was fabricated. Second, the composite hub system was integrated by replacing these flexure parts.

Model rotor system and research phases

The first phase is to design and make standard benchmarking rotor system. The flexure part of benchmarking hub was made of engineering plastic (torlon) to make soft-in-plane in 1st lag frequency similar to that of Lynx. The other parts were made of metallic materials like steel, aluminium, steel wire, etc. After that, two types of blades which would be attached to hub system were designed and manufactured. The one is rectangular standard composite blade. The other is paddle type advanced composite blade.

Analysis for model 1 rotor which was hybrid metallic hub with standard blade was conducted using comprehensive code FLIGHTLAB. The FLIGHTLAB has the function of flight load and frequency calculation [6]. Rotor test for model 1 was conducted by using KARI GSRTS. The result of analysis and test was compared. Next, Analysis for model 2 rotor which was hybrid metallic hub with advanced blade was conducted by using comprehensive code FLIGHTLAB and also, Rotor test for model 2 was conducted using KARI GSRTS. Results of analysis and test were compared.

The second phase, the composite hub flexure was designed and manufactured. The existing flexure of hybrid metallic hub was replaced with this new composite flexure. Model 3 rotor was this composite hub and standard blade. Model 4 rotor was composite hub and advanced rotor. The analysis and the test procedure were same with Model 1 and 2 rotor case.

The third phase, the model 1 & model 3 rotor was compared. Through this comparison, stability improvement was verified and proved about standard blade. Also, the model 2 & 4 rotor was compared. Through this comparison, stability improvement was verified and proved about advanced blade.

Index	Standard Blade	Advanced Blade
Hybrid Metallic Hub	Model 1	Model 2

Composite Hub	Model 3	Model 4

Table 1. Model Rotors to be applied

Rotor system design approach

General rotor system design approach was adopted to be applied to model rotor system design. To design small-scaled rotor, the requirement of model rotor was established based on characteristics of Lynx and other hingeless rotor systems. The mass and stiffness distribution of model blade was obtained from froude scaling down of existing blade of Lynx. The dynamic characteristics of Model Rotor were established by initial sizing and calculation. Fig. 1 shows the preliminary rotor design process to be applied to this rotor model .

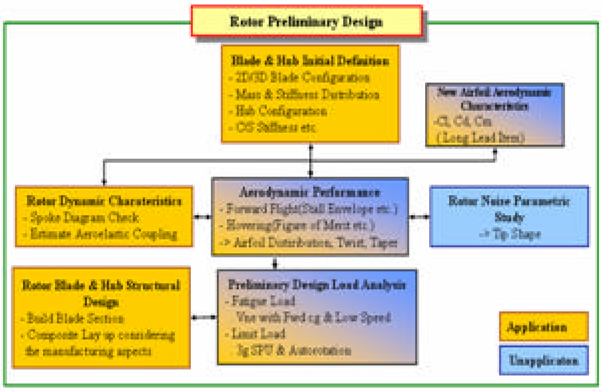


Fig. 1 Rotor Design Process

Main contents summary

Rotor test facility used in this study is introduced briefly. The analysis tool and process are introduced and explained. The rotor model design procedure to be applied will be described. The manufacturing process of model rotor was described shortly. The result of analysis, test and comparison will be showed.

Rotor Test Facility in KARI

GSRTS

KARI General Small-scaled Rotor Test System (GSRTS) was established in 1999. This rotor test rig has the function of performance test by mach scale test and aeroelastic test by froude scale. This test rig has the actuation system to excite swashplate to simulate unstable environment by using hydraulic actuator which is one of three actuators installed under swashplate. This test rig has the air snubber system which can fix and release the main body at gimbals. The pitch and roll spring have been installed and can be exchanged according to various helicopter model to simulate ground and air resonance. The hover and forward flight test for small rotor can be conducted under those conditions. The hover test is usually conducted in ground safety fence. The forward flight test is done at KARI LSWT. The main specification of KARI GSRTS is summarized at Table 1. and the general view is showed at Fig. 2 [7]

Function	• Rotor Diameter : 2m • Froude & Mach Scaled Test
Rpm	• Max. 2100rpm
Driving Motor	• Motor Type : Electrical AC Motor • 40 hp (20hp X 2)
Hub Type	• Default : Articulate Hub • Extension - Hingeless hub - Bearingless Hub
Test Items	• Aeroelastic Stability Test at Hover and Forward Flight • Ground and Air Resonance Test • Performance Test

Table 1 Specification of KARI GSRTS

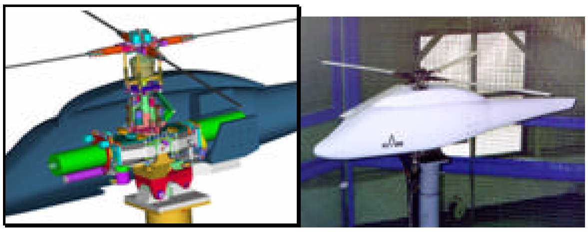


Fig. 2 General View of KARI GSRTS

LSWT

KARI LSWT (Low Speed Wind Tunnel) was established in 1998. The type of LSWT is single returned. The overall dimension is about 32m x 13m x 83m (W x H x L). The main structure is welded steel plate. The width and height of maximum cross section are 11.5m and 8.6m. The flow straighteners are 3 screens (1.6mm mesh) and 9.5mm x 305mm Honeycomb. KARI has an experience for various model types of wind tunnel test such as airplane, car, ship, motorcycle and etc. The main specification of KARI LSWT is described in Table 2 [8]. The general view of KARI LSWT is showed Fig 3.

Table 2 Main Specification of KARI LSWT

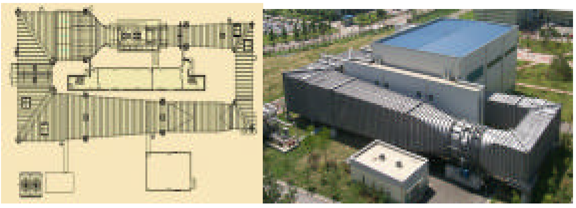


Fig. 3 General view of KARI LSWT

Analysis Tool Applied to This Study

CORDAS

KARI had developed software which had the function of design and analysis for composite blade in 1998. This software was named as CORDAS which stood for COmposite Rotor blade Design and Analysis Software.[9] This software gives sectional properties and natural frequencies with rotor rpm. The sectional design of composite blade can be done. The lay-up sequencing of composite material can be given. Main function and characteristics are described in Table 3.

Type	Results
Static Analysis	- Centre of gravity - Stiffness - Elastic Centre - mass per length - Mass moment of Inertia
Dynamic Analysis	- Natural Frequencies - Natural Modes

Table 3 Main Functions of CORDAS

FLIGHTLAB

KARI has used comprehensive software, FLIGHTLAB which is a commercial software product developed by Advanced Rotorcraft Technology, Inc (ART) to facilitate the development and utilization of flight vehicle dynamics models in simulation applications. In this study, the blade load and blade natural frequency calculation was conducted by using FLIGHTLAB. The finite element model for the designed rotor can be modelled. The isolated rotor model in FLIGHTLAB was applied to give the load and frequency results. Quasi-unsteady airload was applied and 3 Peter's He induced velocity was given to obtain flight load along the rotor radius.

Hybrid Metallic Rotor Model

$\Delta q/q_0(\%)$	$\Delta\alpha$	$\Delta T(^\circ C)$	$w/U_0(\%)$
+/-0.30 4m x 3m	+/-0.10	5 -120 m/s +/-0.3	2,800,000 0.07

Hybrid Metallic Hub

The hybrid metallic hub mode was designed. The initial sizing of model was started from 1/6 scaled data obtained from the rotor size of full scale Super Lynx. The full scale rotor radius is 6,400mm. The rotor radius of model rotor system is about 1,066mm. The scaled down process and initial size are showed in Fig. 4.

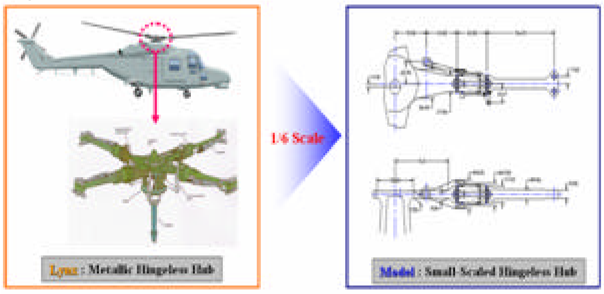


Fig. 4 Scaled down process and initial size of model hub system

Detail parts were designed based on above initial sizing. Major components of this model hub system are hub plates, feathering hinge and flexure. Hub plates are composed of upper and lower plate. These plates are combined by central upper and lower cap of which the centre has spline to transmit rotating force and torque from shaft to rotor. The feathering hinge assembly is composed of tie-bar rounded by high strength steel wire, needle-roller bearings to allow free rotating and housing to wrap the tie-bar and bearing. The flexure was initially designed by using titanium materials but this cannot meet 1^{st} lag frequency requirement. So, the material was changed with torlon which is one of the engineering plastic. After this, the frequency requirement could be satisfied. This hub system fabricated and was attached to KARI GSTRS. More details are showed in Fig. 5

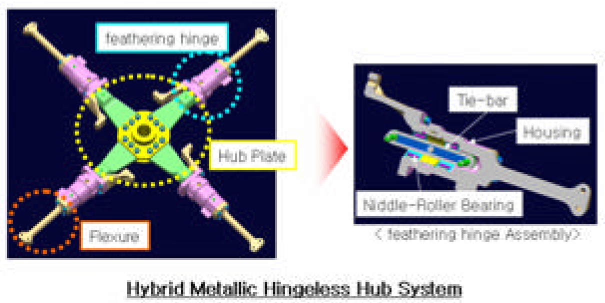


Fig. 5 Simple Configuration of Hybrid Metallic Hingeless Hub System

Small-scaled Composite Blade

Two types of small-scaled composite blades were designed and manufactured. The one is standard blade which has rectangular tip shape and constant chord length. This blade was designed using 3 airfoils which are NPL 9618, NPL9615 and NPL9617. The radial position of airfoil and airfoil type is similar to metal blade of Lynx [10]. This small-scaled composite blade was designed to be matched with froude scale of metal blade of Lynx. The dynamic characteristics of Lynx and rotor model were similar as possible. The blade design and the calculation of sectional properties like mass per unit length, centre of gravity, sectional stiffness, etc. were conducted by using CORDAS. The platform of this blade and sectional construction are showed in Fig. 6. The calculation results of standard blade sectional properties were summarized in Table 4.

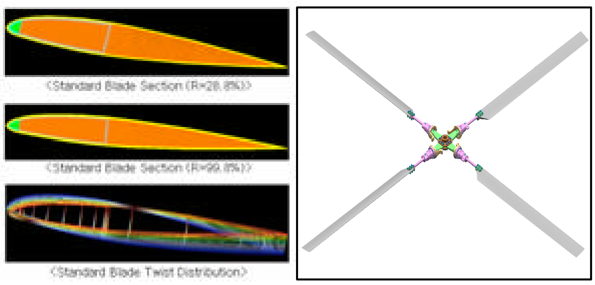


Fig. 6 Blade section construction of standard blade

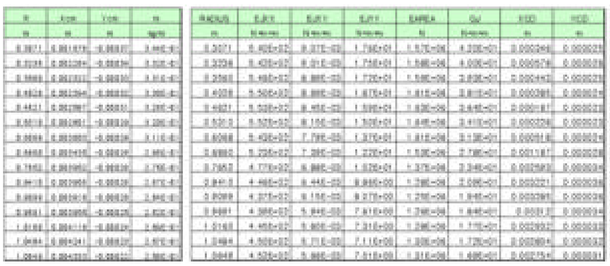


Table 4 The sectional properties of standard blade

The other is advanced blade which has paddle-type tip shape similar to BERP of Super Lynx. The chord length is variable from 84%R to Tip. This blade was designed using 3 airfoils which were RAE 9648, RAE 9645 and RAE9634. The radial position of airfoil and airfoil type is similar to CMRB (Composite Main Rotor Blade) of Super Lynx [12]. This small-scaled composite blade was designed to be matched with froude scale of CMRB of Lynx. The dynamic characteristics of Super Lynx and rotor model attached with advanced blade were similar as possible. The blade design and the calculation of sectional properties calculation like mass distribution, centre of gravity, sectional stiffness, etc. were conducted by using CORDAS also. The platform of this blade and sectional construction are showed in Fig. 7

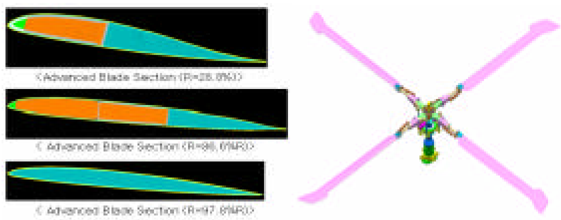


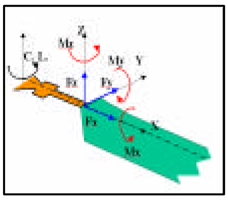
Fig. 7 Blade section construction of advanced blade

Rotor Model 1

The Rotor Model 1 is composed of hybrid metallic hingeless hub and standard composite blade. Before the manufacture, the stability was examined by FLIGHTLAB Calculation. Sectional properties of hub model were calculated by using CATIA's anaysis tool. The input data was made by using calculated properties of these hub and standard blade properties. The FLIGHTLAB input file for rotor models was established. Through FLIGHTLAB calculation, the spanwise load data can be obtained. These load data were given to hub stress analysis and blade strain analysis to check the static strength and safety. The flight conditions are assumed as 2 limit load case. The first case is for hover flight condition. The maximum collective pitch is 15 degree. The second case is for forward flight condition. The maximum forward flight speed is 0.4 advance ratio. The rotor rpm is about 780 rpm which is obtained from froude scaled methodology based on Lynx normal operational speed 340 rpm [11]. The detailed hub load results are showed Fig. 8

< Flight Condition for Operation>

- Hover Condition : coll.=15 deg
  * Vortex Wake Model
- Forward Flight Condi. : Mu = 0.4
  * Peter' s/He 3-states inflow Model



Flight Condition		Fx		Fy		Fz	
Force		Radial Shear		Lag Shear		Flap Shear	
Unit		lbf	N	lbf	N	lbf	N
Hover	Coll. =15 Deg	226.90	1009.25	-8.172	-36.349	23.080	102.660
Forward Flight	Mu =0.4	233.50	1038.61	-2.910	-12.944	22.350	99.413

Flight Condition		Mx		My		Mz	
Moment		Torsional Moment		Flatwise Bending Moment		Edgewise Bending Moment	
Unit		lbf•ft	N•m	lbf•ft	N•m	lbf•ft	N•m
Hover	Coll. =15 Deg	0.131	0.178	-4.293	-5.820	-0.806	-1.093
Forward Flight	Mu =0.4	-0.005	-0.006	-4.455	-6.040	0.591	0.801

Fig. 8 The Flight condition to be applied and hub load results

The spanwise load distribution for model 1 rotor was calculated and spanwise blade strain also was calculated by applying simple Euler's beam theory. Natural Frequency for model 1 rotor was calculated at each 10% rpm increase in vacuum condition and quasi-steady aerodynamic force condition. The 1st lag frequency is about 0.76Ω. The 1st Flap frequency is about 1.25Ω. Fig. 9 shows the fanplot diagram at zero collective pitch condition for each vacuum and aerodynamic force. And Fig. 10 shows the natural mode shape for 1st and 2nd mode. The damping ratio for 1st lag frequency was obtained at each collective angle from -5 degree to 15 degree. The damping was all positive. These damping data will be compared with test results following paragraphs.

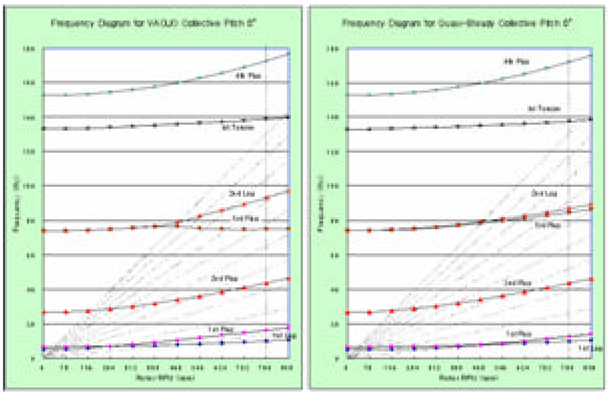


Fig. 9 The Fanplot diagram for Model 1 rotor from Analysis

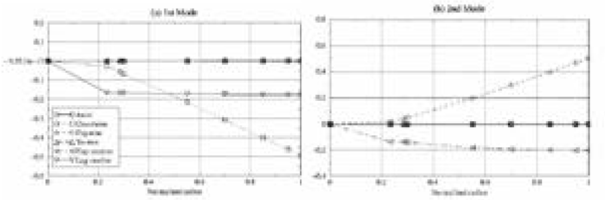


Fig. 10 The 1st and 2nd natural mode shape for model 1 rotor

After this analysis by using FLIGHTLAB, the model 1 was manufactured and installed at KARI GSRTS. Before tests, the basic sectional properties of manufactured blade was obtained by using bench test [13]. These data will be updated at FLIGHTLAB input data and recalculated at each test conditions. Fig. 11 shows the blade bench test for standard blade. The hover and forward flight test conditions were established.

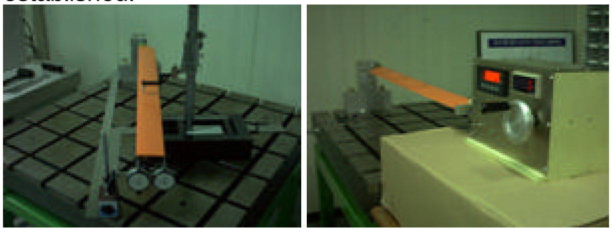


Fig. 11 Bench Test for Standard Blade

After installing the model 1 rotor system to KARI GSRTS, the basic test was performed to check whether the signal output is good or not. The rotor tracking and dynamic balancing were conducted. The tracking was done by adjusting of blade pitch angle. The dynamic balancing was done by using thin leafs as a weight such as various thin washers and tapes at blade attachment plate hole and surface of blade. The DAQ(Data AcQuisition) program was designed by LabVIEW software and the MBA(Moving Block Analysis) methodology which has been used in popular was applied to get damping value [14]. The DAQ system was summarized at Fig. 12. Strain gauges were attached to the standard blade. Model 1 rotor which is installed at GSRTS are showed Fig. 13.

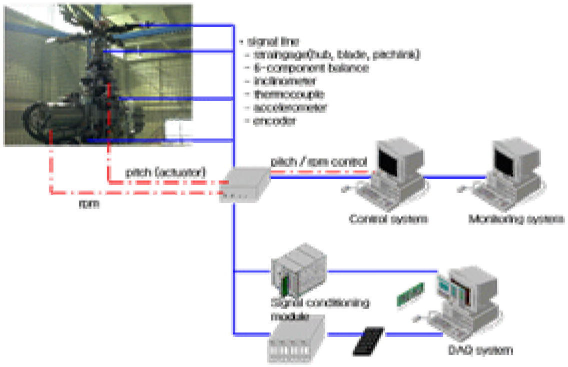


Fig. 12 DAQ System for GSRTS

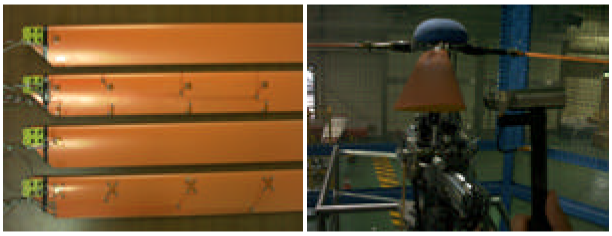


Fig. 13 Blade gauge and installed model 1 rotor at GSRTS

The frequency and damping ratio were obtained at each collective angle in hover. The damping are also compared in forward flight condition. Fig14 shows the ground hover test in KARI GSRTS and Forward flight test in KARI LSWT. The final compared results are showed Fig. 14 and Fig. 15

Fig. 13 Hover Test (left) and Forward Flight Test in the LSWT (right)

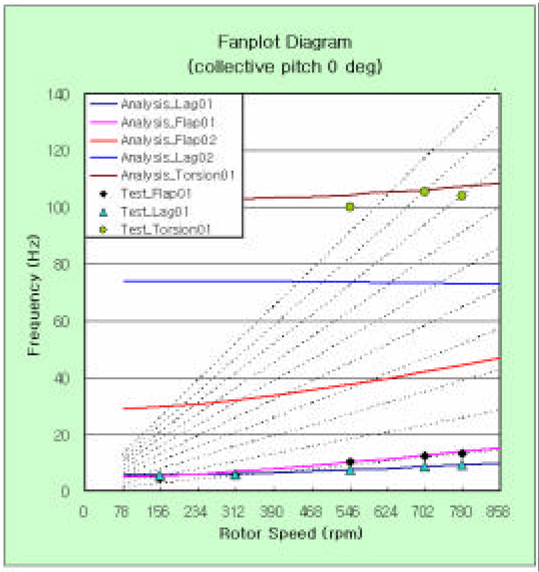


Fig. 14 Natural Frequency Comparison between analysis and test

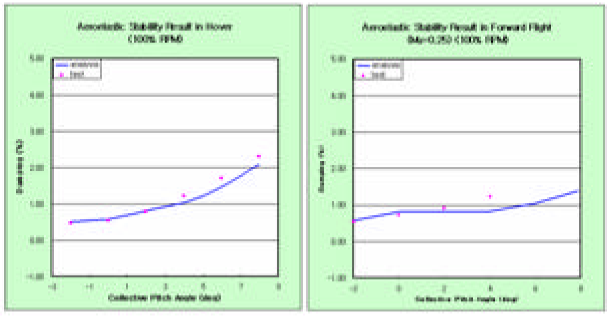


Fig. 15 Damping Comparison between analysis and test for Model 1 rotor

<u>Rotor Model 2</u>

The Rotor Model 2 is composed of hybrid metallic hingeless hub and advnaced composite blade. Before the manufacture, the stability was examined by FLIGHTLAB Calculation. The sectional properties for advanced blade was calculated by using CORDAS. The rotor model for FLIGHTLAB was established. Through FLIGHTLAB calculation, the spanwise load data can be obtained. These load data were given to hub stress analysis again and the safety was acquired. Also, through the strain analysis for advanced blade, the static strength and safety can be acquired. Fig. 16 shows the simple strain analysis results conducted by using simple Euler's beam theory. The flight condition is assumed as the same condition of model 1 rotor.

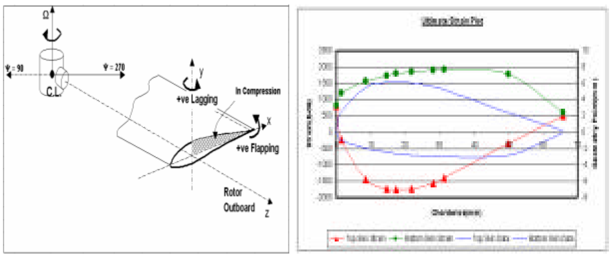


Fig. 16 The Blade Strain Analysis for Advanced Blade.

The spanwise load distribution for model 2 rotor was calculated. Natural Frequency for model 2 rotor was calculated in same manner of model 1 rotor. The 1st lag frequency is about 0.76Ω. The 1st Flap frequency is about 1.25 Ω. The mode shape was also obtained. These data are similar to model 1 rotor. So, it means that these model rotors are much dynamically similar. Before testing, this model 2 rotor was also recalculated based on bench test for advanced blade. Fig. 17 shows the bench test for obtaining advanced blade's sectional properties

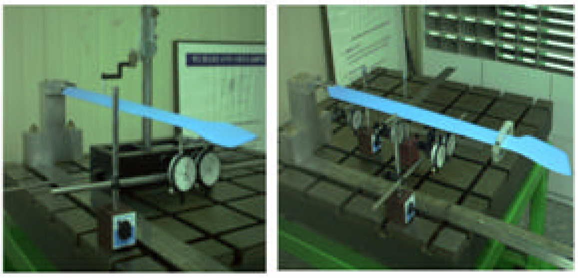


Fig. 17 Bench Test for Advanced Blade

The frequency and damping ratio were obtained at each collective pitch angle in hover. The damping ratio is also compared in forward flight condition. The final compared results are shown Fig. 18 and Fig. 19

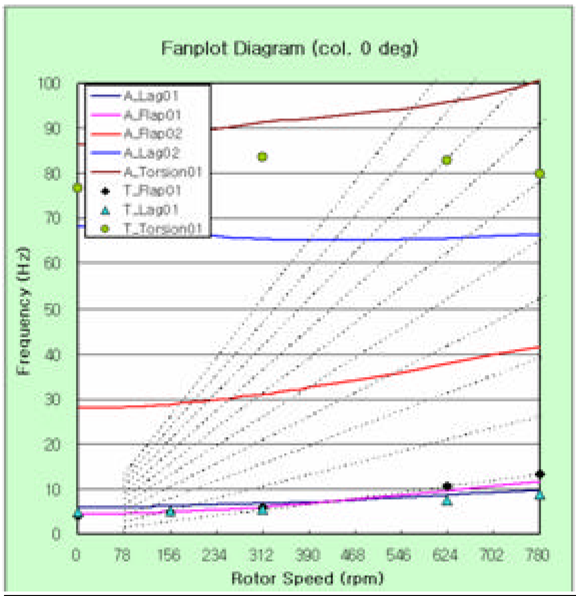


Fig. 18 Natural Frequency Comparison between analysis and test for model 2

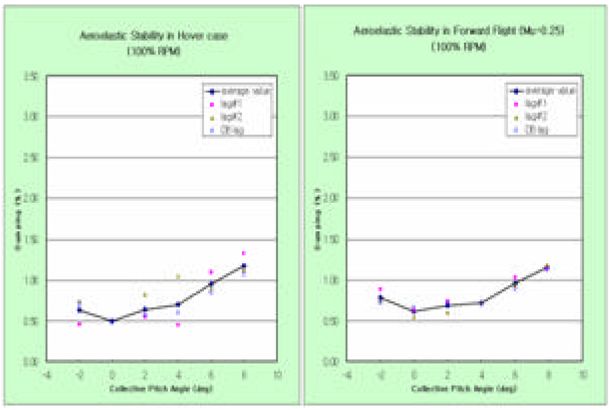
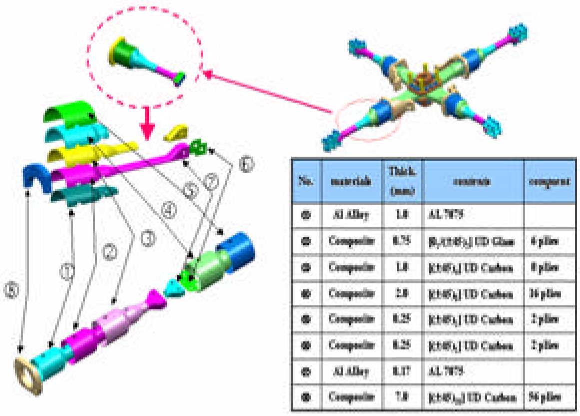


Fig. 19 Test result of Damping at hover and forward flight for Model 2 rotor

Composite Rotor Model

Composite Hub

The Composite hub mode was designed. The size of model is same with hybrid metallic hub. The only difference is the flexure and housing of feathering hinge assembly. This part was exchanged with composite materials which are unidirectional glass fibre and unidirectional carbon. Initial layup sequencing and desired sectional properties was performed by using Classical Laminate Theory (CLT). And the stress value was obtained by using NASTRAN. The detail information of these composite flexure and housing is shown at Fig. 20. This composite hub parts are very complicated. Final specification of these parts was decided by iteration between dynamic calculation and stress analysis. Fig. 21 shows the manufactured composite hub parts. Before starting test, the structural test for composite parts was also conducted.



No.	materials	Thick. (mm)	contents	component
[illegible]	Al Alloy	1.0	AL 7075	
[illegible]	Composite	0.75	[0/(±45)] UD Glass	6 plies
[illegible]	Composite	1.0	[(±45)] UD Carbon	8 plies
[illegible]	Composite	2.0	[(±45)] UD Carbon	16 plies
[illegible]	Composite	0.25	[(±45)] UD Carbon	2 plies
[illegible]	Composite	0.25	[(±45)] UD Carbon	2 plies
[illegible]	Al Alloy	0.17	AL 7075	
[illegible]	Composite	7.0	[(±45)] UD Carbon	56 plies

Fig. 20 Layup pattern and sequencing of Composite Hub Parts

Fig. 21 Composite hub part

Rotor Model 3

The Rotor Model 3 consists of composite hingeless hub and standard composite blade. Before the manufacture, the stability was examined by FLIGHTLAB Calculation. Sectional properties of hub model was calculated by using CLT. The input data was made by these properties of composite hub and standard blade. The FLIGHTLAB input file for rotor model 3 was established. Through FLIGHTLAB calculation, the spanwise load data can be obtained. These load data was given to hub stress analysis and blade strain analysis to check the static strength and safety. The flight condition are assumed as similar to hybrid metallic rotor case. The 1st lag frequency is about 0.76Ω. The 1st flap frequency is about 1.25 Ω. The mode shape was also obtained. These data are similar to model 1 rotor. Fig. 22 shows the frequency and damping ratio results

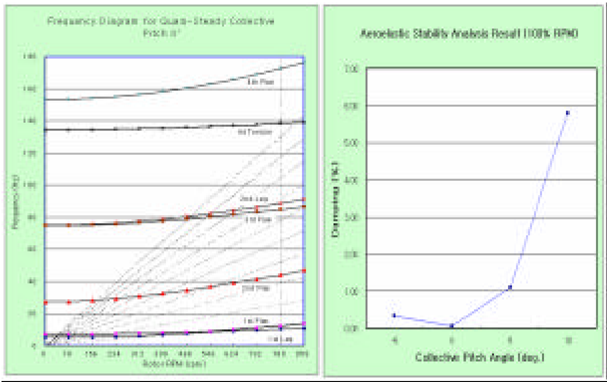


Fig. 22 Fanplot Diagram and Damping results for Model 3 Rotor

These analysis results are showed that the model 3 rotor is similar to model 1 rotor. Test were omitted for that reason why the project time schedule was very tight. So, the model 4 rotor was conducted.

Rotor Model 4

The Rotor Model 4 is composed of Composite hingeless hub and advanced composite blade. Before test, the stability was examined by FLIGHTLAB calculation. The rotor model for FLIGHTLAB was established by using existing test data. Through FLIGHTLAB calculation, the frequency and damping data was obtained and compared with test results. 1st flap and lag frequencies as test results are well matched with analysis. 1st torsion frequency of test result was 6% overestimated rather than analysis. Fig. 23 shows these results. Fig. 24 shows the damping test results. 1st lag damping properties are all positive.

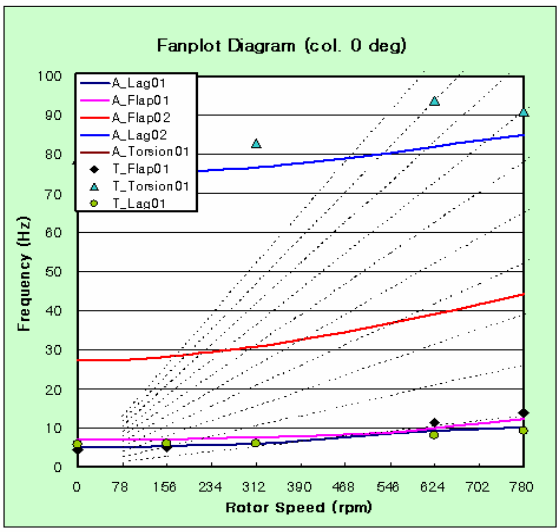


Fig. 23 Natural Frequency Comparison between analysis and test for model 4

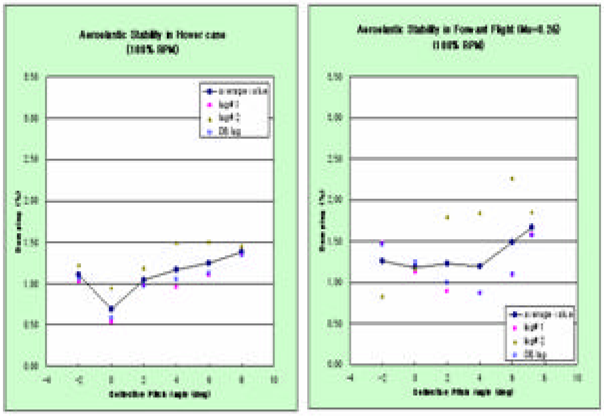


Fig. 24 Test result of Damping at hover and forward flight for Model 4 rotor

Summary

The test results of damping ratio for Model 1, 2 and 4 at hover and forward flight condition were summarized. All damping values of test are positive. The 1st lag damping value of Model 4 which is the composite hub with advanced blade is 40% larger than that of Model 2 which is the metallic hybrid hub with advanced blade. Fig. 25 shows the results of the damping test.

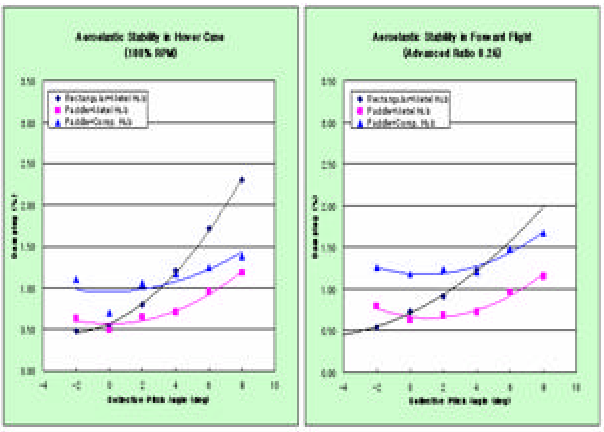


Fig. 25 Comparison of Measured Damping Value of Metallic and Composite Hub System for Model 1,2&4

Conclusions

Aeroelastic stability of composite hingeless hub system was improved about 30%~40% more than metallic hub system by comparing the damping value obtained from the ground hover and wind tunnel tests. Therefore, if existing metallic hub system is replaced with composite hub based on dynamic similarity, the replaced composite hub system will be more aeroelastically stable than metallic hub system. In addition, the weight reduction of hub system is considerable. To compare the weight of replaced parts, approximately 56% weight reduction was achieved. This means that the rotor performance and the capability of payload will be increased. It indicates the importance of design points to apply composite and replace existing metallic parts with composite ones.

These results can be applied to an extended small-scaled model to a full scale hub part. One of these applicable systems is the existing metallic hingeless hub system, Lynx. This can be replaced with composite hub system, and also the aeroelastic stability will be more improved. Thus there is a possibility of decrease in existing hydraulic damper size. Additionally, it brings about weight reduction and the margin of payloads will be improved.

The results of this study will be applied to current Korea national project for the development of Next Generation Rotor System, which can be applied to Korea Helicopter Program

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