A Study of Bearingless Rotor-Hub System

by

Yoshiyuki Niwa

The 3rd Research Center, Technical Research & Development Institute, Japan Defense Agency
Tachikawa, Tokyo, JAPAN

and

Shun-Ichi Bandoh

Kawasaki Heavy Industry
Kagamigahara, Gifu, JAPAN

Abstract

A basic principle of Bearingless Rotor-Hub System has decided at the beginning of study. The study consists of 3 phases,

(1) Research of each element.

(2) Ground test

(3) Flight test

Specially the research of element is the most important. Because many troubles have been occurred.

At first torsion element which had function of feathering and lead lag hinge was studied. To get a good combination of torsion stiffness and bending stiffness, cross section of torsion element has been changed from original one to X shape and to asterisk shape again. Also newly V beam concept to fix a bending point was introduced to prevent S shape transformation in lead-lag motion.

Original pitch-housing equipped elastomeric damper in it was designed to get lead-lag damping by means of its transformation.. But this shape showed so poor lead-lag damping that shape was changed. In new shape open space to install a damper on the top and bottom in pitch-housing was filled, then elastomeric damper was installed outside of it. Consequently good lead-lag damping was obtained.

Also flapping plate which had a function of flapping hinge was studied. Cross section was changed from original one to new one.

An elastomeric damper was studied, too.

During study, original principal was not changed, but shape of each element was changed drastically.

On the ground test, retired OH-6 installed new Bearingless Rotor-Hub System was used and vibration characteristics test was done.

In flight test, modified OH-6J installing new Bearingless Rotor-Hub System instead of original one was used. About 100 hours flight test was conducted. Ground and air resonance did not occurred.

Finally technology of Bearingless Rotor-Hub System has been established before the start of development of OHX.

1 Introduction

After World War II, research & development of aircraft was prohibited in Japan. It was opened in 1953, but the technology concerning with a helicopter had been progressed very much in these 8 years. As specially rotor system of helicopter is very important part and a characteristics of rotor system decides characteristics of entire helicopter., many companies concentrated their power to research and development of rotor system. As a result, many patents using metal material were acquired concerning with rotor system, specially rotor hub system. Because rotor hub has very complicate mechanism to solve technical problem,. At the beginning of 1960's research of composite material applying to aircraft was started in many countries and applied to secondary structure of aircraft gradually. At the beginning of 1980's, though many studies of rotor-hub using composite material had been started in the world, mesh of patent was so large at that time that there was enough space to enter, so that start of the research of rotor-hub was decided.

2 Draft of Research

It was considered that the retirement of OH-6 which was used by JSDG would be retired at the end of 1990's..

Recently improvement of maneuverability was required, because, NOE flight was required to escape from enemy's fire. Research had to be finished before the start of development OHX and the results of research had to be applied to OHX.

Then OHX was estimated that weight was almost 7~8,000lbs..,may be, below 10,000lbs..

Also basic principle of new technology was decided as following,

(1) to use a composite material.

(2) to eliminate a bearing from each axis completely.

(3) to be isolated each axis.

(4) to use a elastomeric damper for getting lead-lag damping.

Research schedule was decided ,too. It was shown in Table 1.

Table 1　Schedule of Research

83	84	85	86	87	88	89	90	91	92	93	94	
Research of Elements ○ Torsion Element ○ Pitch-Housing ○ Hub Plate ○ Lead-Lag Damper				Ground Test		Flight Test			Development OHX			

Research was divided in 3 phases, that is,

(1) Research of elements,

(2) Ground test.

(3) Flight test.

In order to use OH-6 on the ground and in flight test , each test model was designed to apply OH-6, and every step the possibility to expand new technology to 10,000lbs. class helicopter was confirmed analytically. .

3 Implementation of Research

The scheme of new rotor-hub system is shown in Fig. 1 and the first design is shown in Fig. 2.

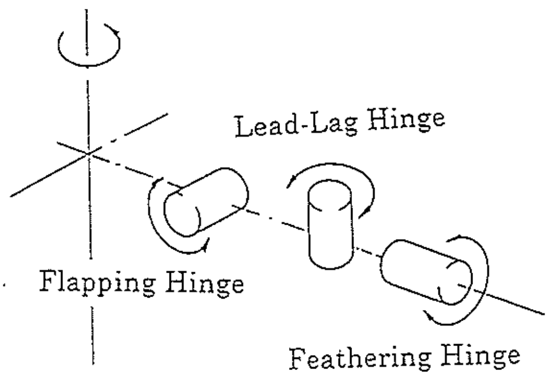


Fig. 1　Image of 3 Hinges

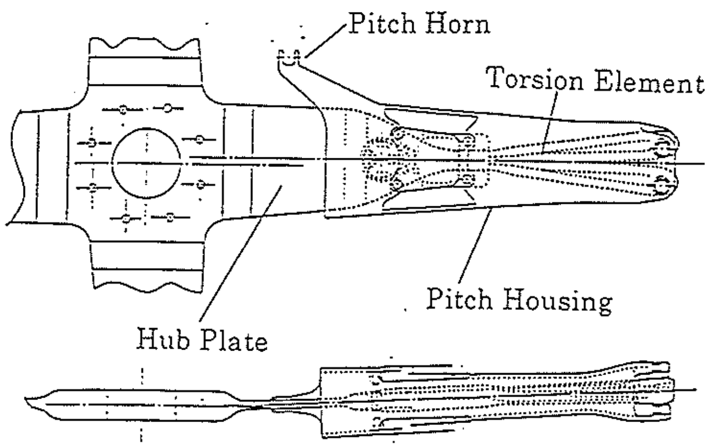


Fig. 2　First Design of Hingeless Rotor-Hub System

3..1 Research of elements

3.1.1 Torsion Element

Torsion element has a function of feathering hinge and lead-lag hinge.

As OH-6 equipped manual control system, torsion stiffness of torsion element was decided 0.2 kg-m/deg. at the beginning of research.

Change of torsion element is shown in Fig. 3

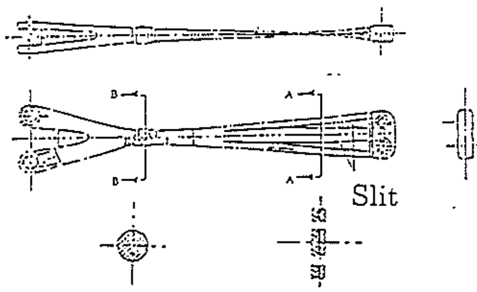


Fig. 3 (1)

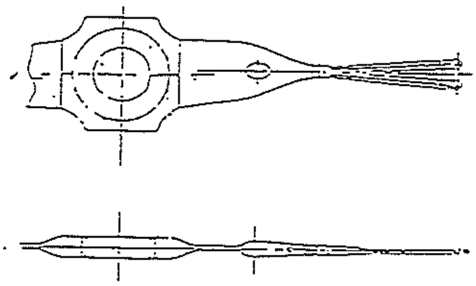


Fig. 3 (2)

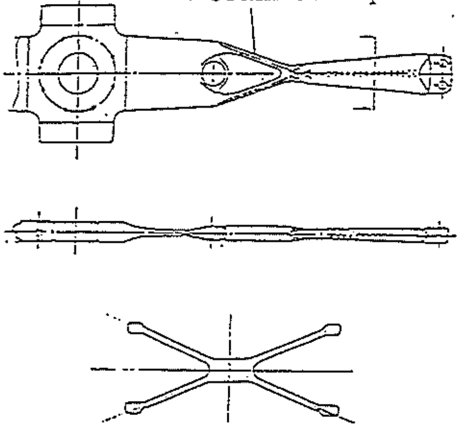


Fig. 3 (3)

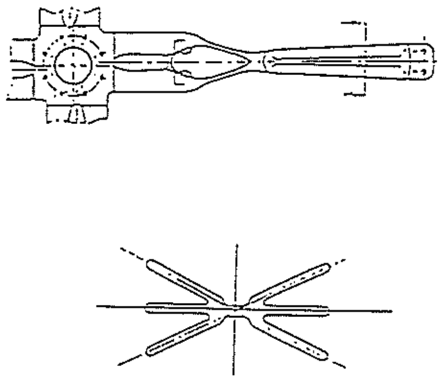


Fig. 3 (4)

Fig. 3 Change of Torsion Element

At first trial, slits were designed in torsion element to achieve torsion stiffness. It's shown in Fig. 3(1) . As a result of test, 0.23 was obtained and fatigue life was satisfied, but crack was generated at the end of slit on neck portion. Carbon fiber was wound up to protect generation of crack, therefore generation of crack was stopped, though lateral bending stiffness (lead-lag direction) was not sufficient.

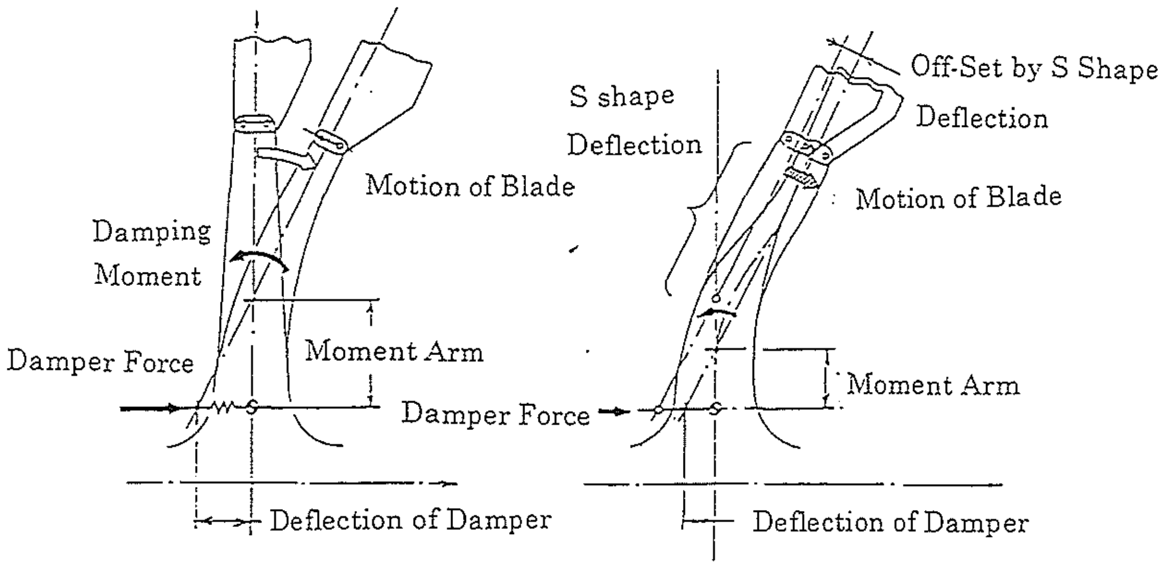
At the second trial, material changed from glass fiber to Kevler to increase bending stiffness keeping torsion stiffness. Slits were adopted and treatment to protect generation of crack was done. It's shown in Fig. 3(2) . As a result of test, torsion stiffness and fatigue life were cleared, but bending stiffness was not increased.

Why lateral bending stiffness is problem? It is shown in Fig. 4 .

Basically transformation in (1) is expected to obtain good lead-lad damping, but transformation became S shape in (2) , therefore damping effect was reduced by reduction of damper's displacement and moment arm. Quantity of torsion stiffness and bending stiffness were discussed again. As a result of it, it was cleared that torsion stiffness could be increased for manual control, new target of torsion stiffness was decided for 0.38kg-m/deg..

Following this cross section of torsion element was entirely redesigned to X shape to prevent S shape transformation and V beam concept was introduced so as transformation occurred around fixed point. Also material was changed from glass fiber to Kevler. to improve bending stiffness. It's shown in Fig. 3(3). But fatigue life was not satisfied.

Then Material was changed to glass fiber again, but as using glass fiber torsion stiffness was reduced, cross section redesigned asterisk shape to increase torsion stiffness. It is shown in Fig. 3(4). As a result of test, torsion stiffness was 0.36kg-m/deg., fatigue life was cleared, bending stiffness was enough and displacement to get lead-lag damping was sufficient. All problems occurred during research have been solved.

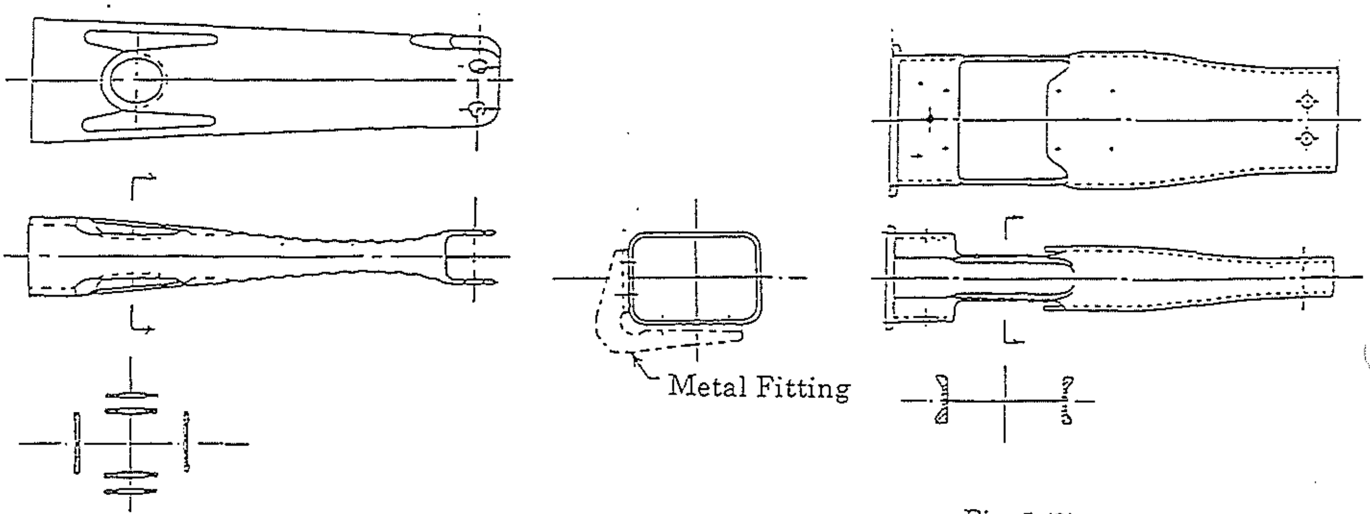


(1) Original (2) Effect of S Shape Deflection

Fig. 4 Transformation of Torsion Element

3.1.2 Pitch-housing

Pitch-housing has a function of installation of lead-lag damper and pitch horn.
Change of Pitch housing is shown in Fig. 5



Fig, 5 (1)

Fig. 5 (2)

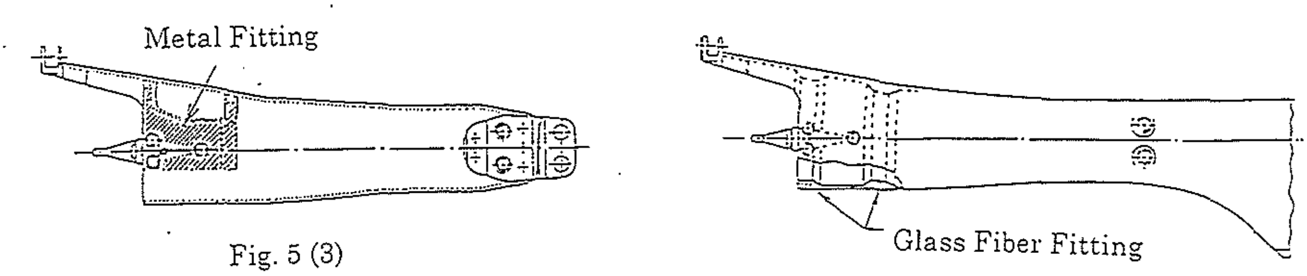


Fig. 5 (3)

Fig. 5 (4)

Fig. 5 Change of Pitch Housing

As shown in figure 2, pitch housing had bridge part which supported normal load on pitch housing, because it was informed that this time elstomeric damper could not support compression load. Then elstomric damper was installed in open space at the top and bottom. As a result, torsion stiffness of pitch housing was not enough, the transformation of bridge part became parallelogram which was not expected. Also it was cleared that root portion of bridge part yielded
The next trial, on the end of root part of pitch housing metal fitting was attached to reinforce it and bridge part was reinforced by glass fiber to increase torsion stiffness and to prevent parallelogram transformation.. It□s shown in Fig. 5(2) .The problems were solved, but newly problems that weight increased attaching metal fitting and aerodynamic drag in bridge part were increased were happened. During study, the news that elastomeric damper could support compression load was informed. Later this is mentioned in Lead-lag Damper paragraph. So cross section was changed from square to ellipse to reduce aerodynamic drag and position of lead-lag damper was changed from open space of bridge part to outside of pitch housing, as a result of test, open space was filled up. Also metal fitting was attached to increase torsion stiffness, but other problems that weight increased and fatigue life was not sufficient occurred. It□s shown in Fig. 5(3).

Finally metal fitting was changed to composite one, then those were solved. It□s shown in Fig. 5(4).

3.1.3 Hub Plate

Hub plate has a function of flapping hinge. Target of hub-plate has to have appropriate hinge off-set and enough fatigue life for bending load to ups and downs direction in condition under 7 tons centrifugal force and ±15 deg. twist.

Change of hub plate is shown in Fig. 6.

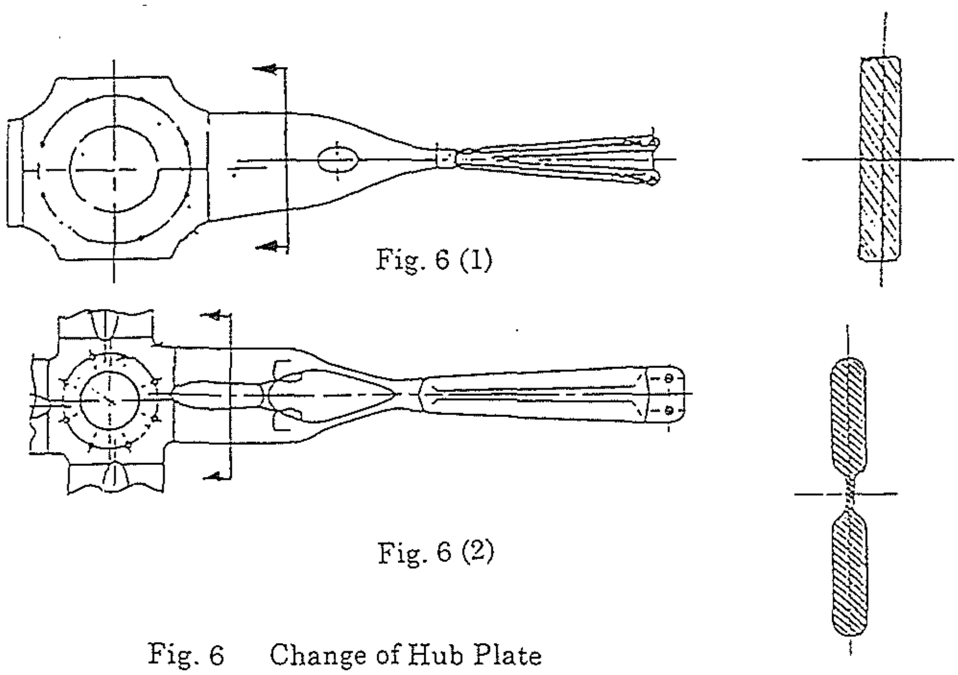


Fig. 6 (1)

Fig. 6 (2)

Fig. 6 Change of Hub Plate

At the first trial, simple plate spring type with square cross section was used. It is shown in Fig. 6(1). As a result of test, crack generated at the center portion of it, because the width of hub plate was so wide comparing to length that transformation of it became saddle shape.

Cross section was changed to prevent this transformation like H shape; front side and rear side was thick, center part was thin. This is shown in Fig. 6(2).

3.1.4 Lead-lag Damper

Target was that sufficient lead-lag damping was obtained and tan δ was about 0.6.

Change of damper is shown in Fig. 7.

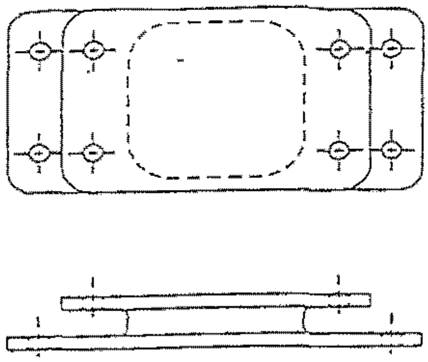


Fig. 7(1)

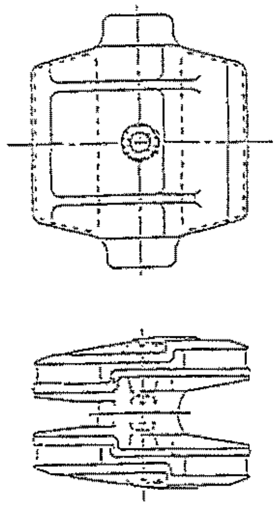


Fig. 7(2)

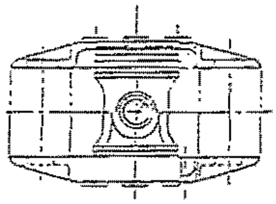


Fig. 7(3)

Fig. 7 Change of Elastomeric Damper

First one could not support compression load and was set inside of pitch housing. Fig. 7(1). As a result of test, tan δ was about 0.4 and also transformation of pitch housing was not good mentioned in pitch housing. During discussion, the solution was found that elastomeric damper was able to support compression load by multi-layer, that was, increasing number of metal plate.

Then position of damper was changed to outside pitch hosing. It's shown in Fig. 7(2). As a result of test, it was cleared that tan δ was 0.62 and sufficient damping was obtained.

Final one is shown in Fig. 7 (3).

3.2 Ground Test

After finishing of the element research, new rotor -hub system has been tested combining with each element to confirm the function as rotor-hub system on the ground. Rotor-Hub System was newly manufactured reflecting in the result of element test and installed retired OH-6J . It's shown in Fig. 8 and Photo. 1. Before being carried out ground test, stiffness test, static strength test and fatigue test was conducted. It's shown that stiffness was almost as same as estimation, static strength was cleared and fatigue life was enough. Ground resonance which is the most important problem in helicopter was tested. The result is shown in Fig. 9. The result shows that ground resonance was stable with enough damping.

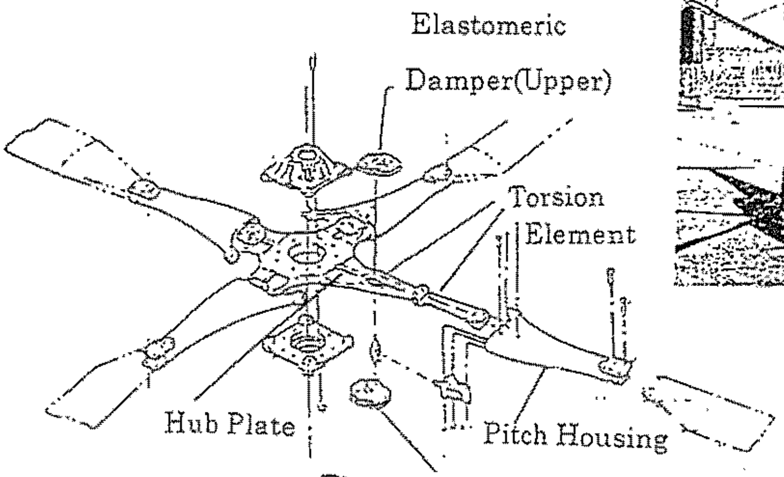


Fig. 8 Rotor-Hub System for Ground Test

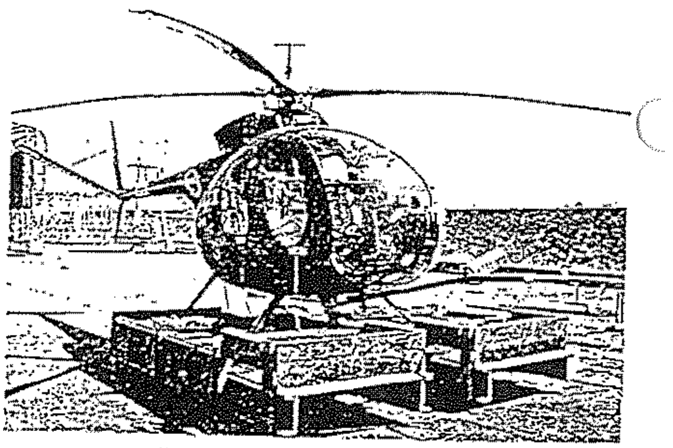


Photo 1 New Rotor-Hub System Installed OH-6J

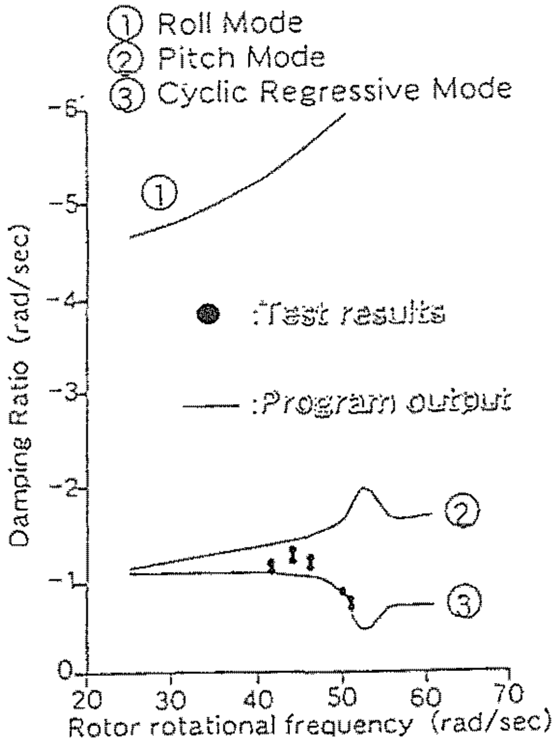


Fig. 9 Result of Ground Test

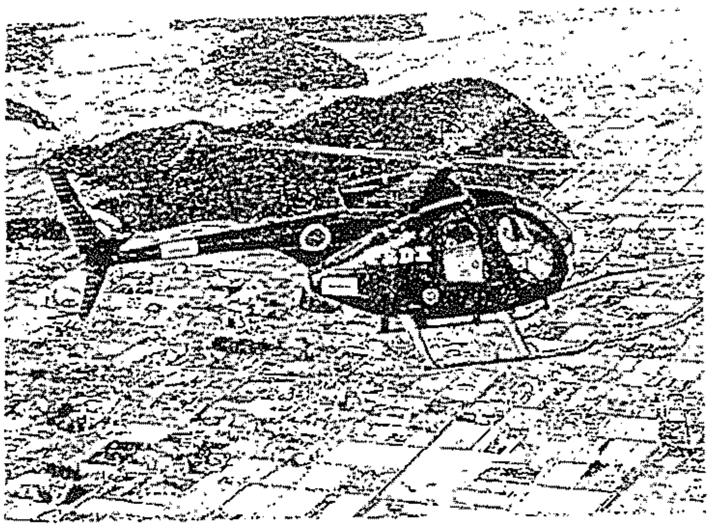


Photo. 2 One Scene of Flight Test

3.3 Flight test

It is shown that the bearingless rotor-hub system used composite material is able to apply to flight test from the results of ground test. Therefore flight test was carried out to confirm improvement of maneuverability and characteristics of air resonance. In the test, modified OH-6 equipped new rotor-hub system belonging to JSDGF was used. From the results of ground test, the followings were changed,

1 position of connecting point between pitch-housing and blade to fold a blade.
2 to reduce a gap between pitch-housing and blade to prevent reduction of damping effect.
3 reduction of weight of pitch-housing.
4 way how to installed a damper.

The new rotor system is shown in Fig. 10 and Picture of OH-6J installed it is shown Photo. 2.

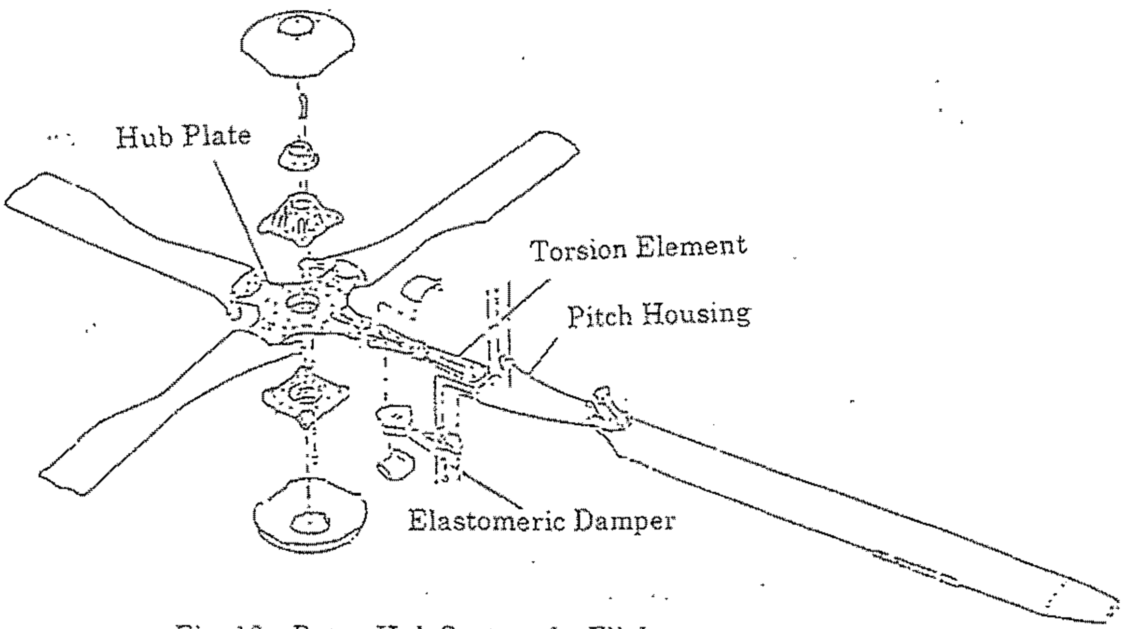


Fig. 10 Rotor-Hub System for Flight test

Before carrying out flight test, stiffness test, static strength test and fatigue test had been done. Stiffness was almost as same as anticipated value and static strength and fatigue strength satisfied target value. As result of flight test, this system had enough attenuation rate for air resonance in entire speed range. Because result of analysis was agreed very much with test result. It is shown in Fig. 11.

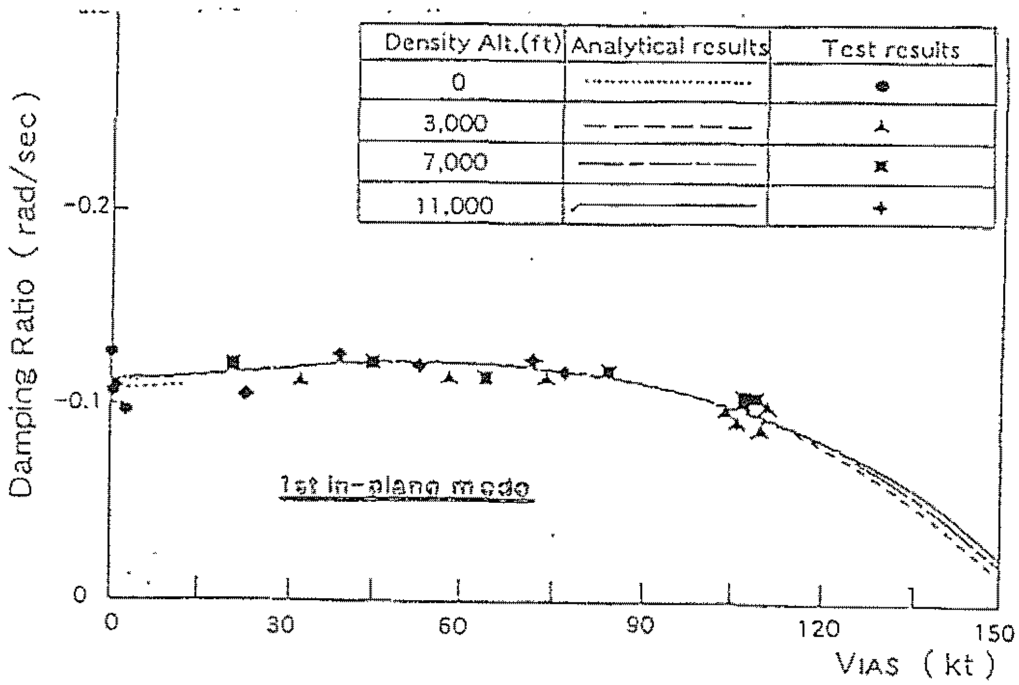
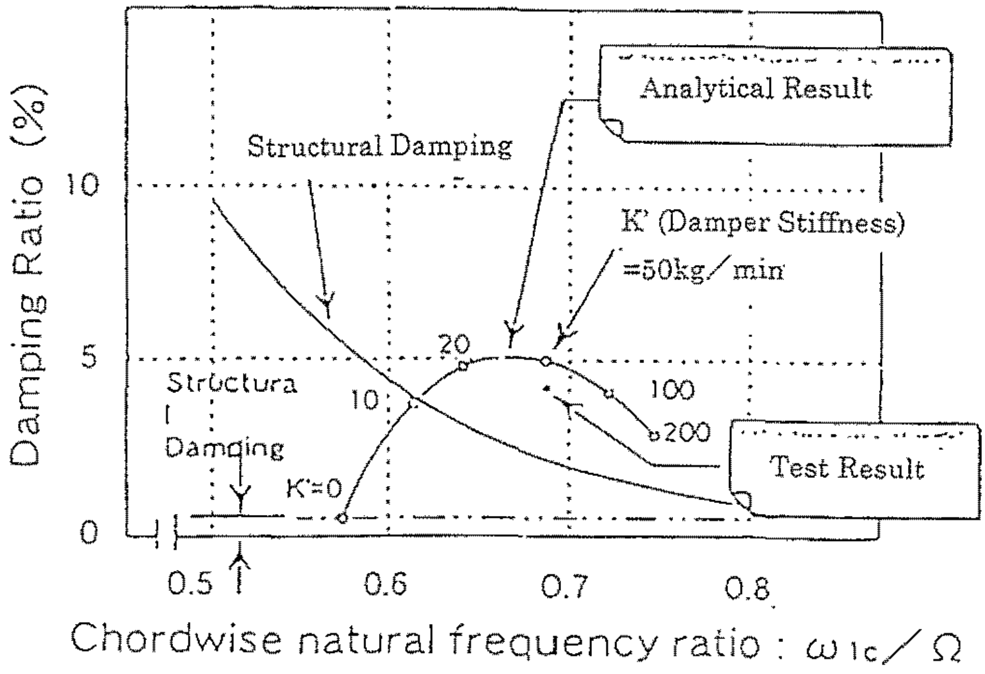


Fig. 11 Result of Flight Test

4 Analysis Method

During study, beam theory to large transformation and vibration and FEM(Finite Element Method) to stress distribution and etc. were used. Those were tuned up in each step of research to improve the accuracy of calculation comparing test results with analysis. Some of result of analysis are shown in Fig. 12.



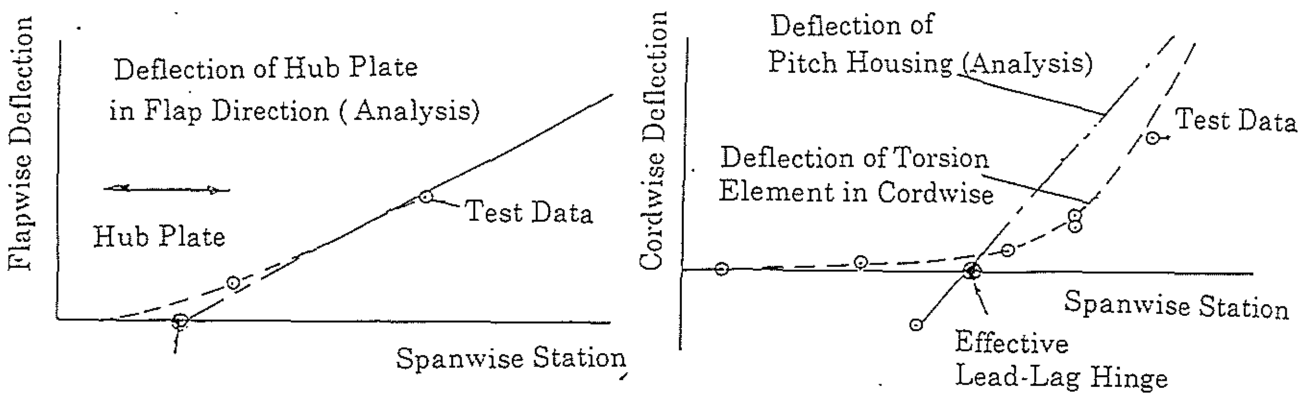


Fig. 12 Comparison of Test and Analysis

5 Conclusion

- ○ Technology for bearingless rotor-hub system using composite material has been established.
- ○ This research has been finished as schedule before the start of development of OHX.
- ○ Each axis (feathering,, lead-lag and flapping) was isolated as basic principle.(no coupling motion) (Fig. 13)

It was very lucky that the solutions were found when many troubles were occurred during element research.

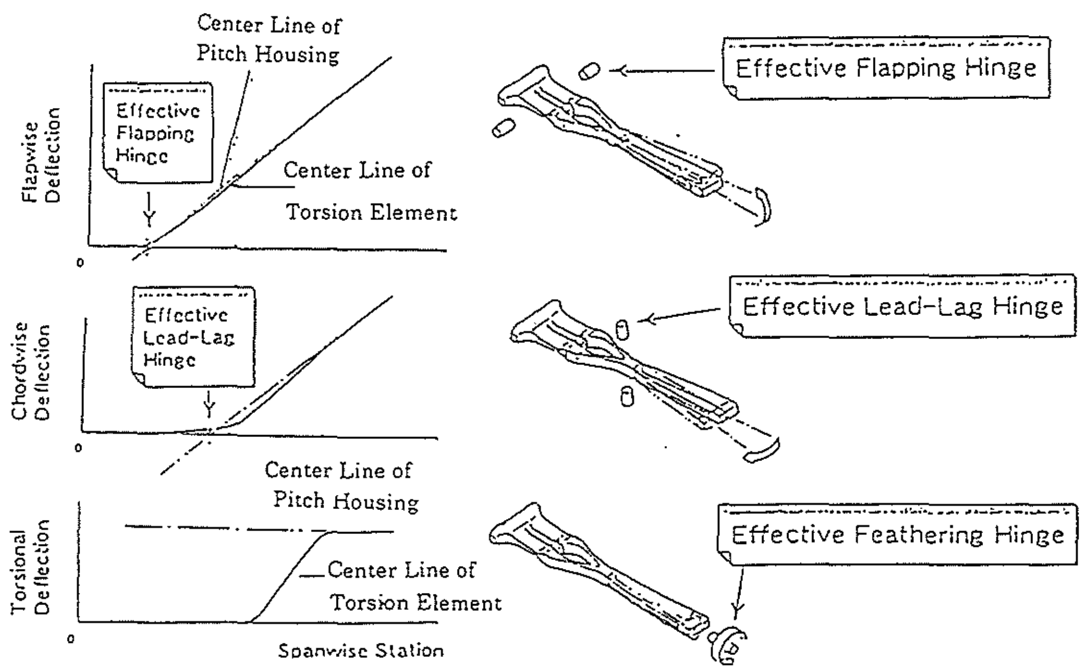


Fig. 13 Effective Hinge