HELICOPTER TAIL ROTOR ANALYSIS: EXPERIENCE IN AGUSTA WITH ADAMS

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Abstract

The purpose of the present paper is to illustrate some major results obtained from the dynamic simulation of a partially flexible tail rotor model of an Agusta helicopter. The aim is to investigate the features of ADAMS as a mechanical system simulation tool with an application to a case of interest for Agusta.

1. Introduction

The numerical modeling of a mechanical system able to describe its dynamic and kinematic behavior continuously with the time, appears as a powerful tool to acquire a deeper knowledge of how the single components work. Namely it might help to recognize and evaluate the load paths to better understand what they are and how they change depending, for instance, on different (*i.e.* time varying) configurations and initial or boundary conditions.
Especially for a complex mechanical system like a helicopter rotor, such a modeling might offer the opportunity of exploring and testing various operating and even unusual or extreme conditions for which experimental testing would require high costs and also long times.
On the other hand, however, it is understandable that the degree of confidence we can put in such a simulation depends on its validation / correlation by experimental data. That is, physical testing allows to validate the accuracy of the simulation results.
The correlated model presents itself also as a powerful mean of ′planning′ experimental tests, pointing out, for instance, configurations which are more critical than others and that are then worthy to be tested.
A multibody approach based program like ADAMS is quite suitable for this aim as, just to mention the most evident features in this sense, it is capable to manage a detailed structural and kinematic modeling of systems including parts connected together by means of dampers, hinges, sleeves, and other similar kinds of joints. Moreover, considering the complexity of the dynamics and the aerodynamics of a helicopter rotor (blade flexibility, unsteady aerodynamic loading) ADAMS offers the possibility of introducing structural flexibility interfacing well with widely used FEA programs and also allows an extensive use of user-written subroutines for the aerodynamic simulation.
The present paper is focused on the following subject. The origin of the work here presented has to be related to the intention to introduce in Agusta a new software having the capacities of ADAMS, exploring the features which were thought to well integrate the simulation tools extensively used at present in Agusta. In this context some significant results are illustrated coming from the dynamic simulation of the tail rotor of an Agusta helicopter.
Furthermore a particular tail rotor subsystem which will be subjected to experimental testing in the next future, is considered, reproducing the experimental setting. The first aim is to explore

different configurations of the system in order to put into evidence the most critical or significant one. In this context, as aforementioned, an experimental validation is necessary, but, as a first step anticipating the test results, just a numeric investigation is presented.

The paper is organised as follows: after a short introduction describing a helicopter tail rotor and its major features (dynamics, aerodynamics and mechanics) (Section 2); Section 3 is focused on the main characteristics of the complete tail rotor model. Section 4 illustrates the major results obtained from the dynamic simulation; similarly Section 5 presents the tail rotor subsystem model and some results. Finally in Section 6 there are some concludings and remarks.

2. Tail rotor main features

2.1 Rotor dynamics and aerodynamics

The tail rotor of a helicopter is placed at the rear end of the fuselage; its main function is to develop the force required to counter the torque acting on the vehicle as a consequence of the torque provided to keep the main rotor rotating. Moments and forces generated by the tail rotor also permit helicopter control and maneuvering.
The tail rotor presented here is a fully articulated type, that is each blade is connected to the rotor’s central hub by a set of hinges, which allow movement:

- out of the rotor disk plane (outwards and inwards, flapping motion)
- in the disk plane (rearwards and forwards, lagging motion)
- around its longitudinal, or feathering axis (pitching or feathering motion)

Generally speaking, the tail rotor hub rotates at an almost constant angular rate, as the result of the torque provided by the engines through a gear train, which receives the power from the main rotor gear train.
The pilot can control the thrust force generated by the tail rotor by varying the collective pitch angle of the blades; this happens through a control chain ending at the rotor with a servoactuator operating system which consists basically of a control rod able to move outwards and inwards; this causes an increase or a decrease of the blades pitch, depending on the features of the installation.
Briefly, the behavior of a rotor can be considered as essentially dominated by four phenomena; Fig.1 shows schematically what they are and how they influence one another.

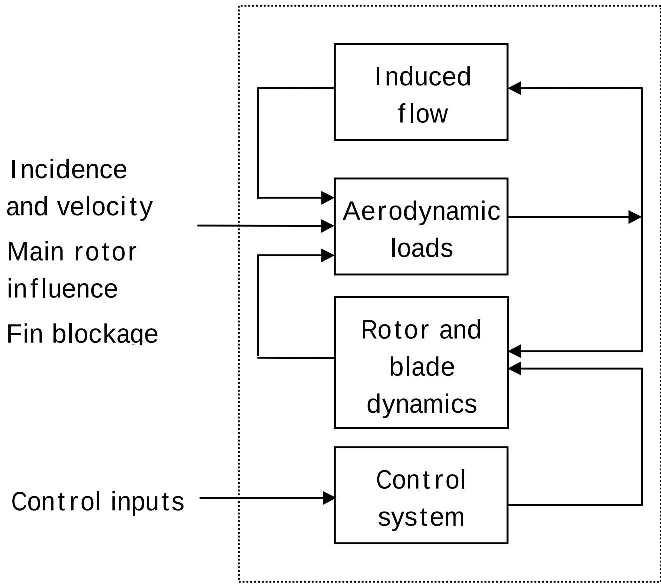

Fig. 1 - Rotor dynamics and aerodynamics

The figure puts into evidence the interaction between dynamics and aerodynamics: the control inputs influence directly the aerodynamic loads acting on the blade, which, in turn, act as forcing inputs for the rotor and blade dynamics (both rigid body and elastic modes for the blade and gyroscopic phenomena like precession); the loop is closed by taking into account the effects of blade motion and induced flow on the aerodynamic behavior of the blade lifting surface.
Moreover, the tail rotor is not an isolated system, but is subjected to the influence of the fuselage (structural dynamics, fin blockage) and of the main rotor (wake effects).
It should be clear from the above brief description how complex and ambitious is modeling a helicopter rotor behavior in all its aspects.

2.2 Mechanical and functional description

The tail rotor assembly (Fig.2) is made up of a mast, hub, two scissors assemblies, four pitch control rods, slider, spider, four dampers, four blades and control (extension) rod.

The hub allows the connection of the four blades.
The four pitch control rods are connected to the blades at one end and to the spider forked arms at the other end.
The dampers are connected to the blades at one end and to the hub at the other end.
All the aforementioned components, except the extension rod, are rotating parts.

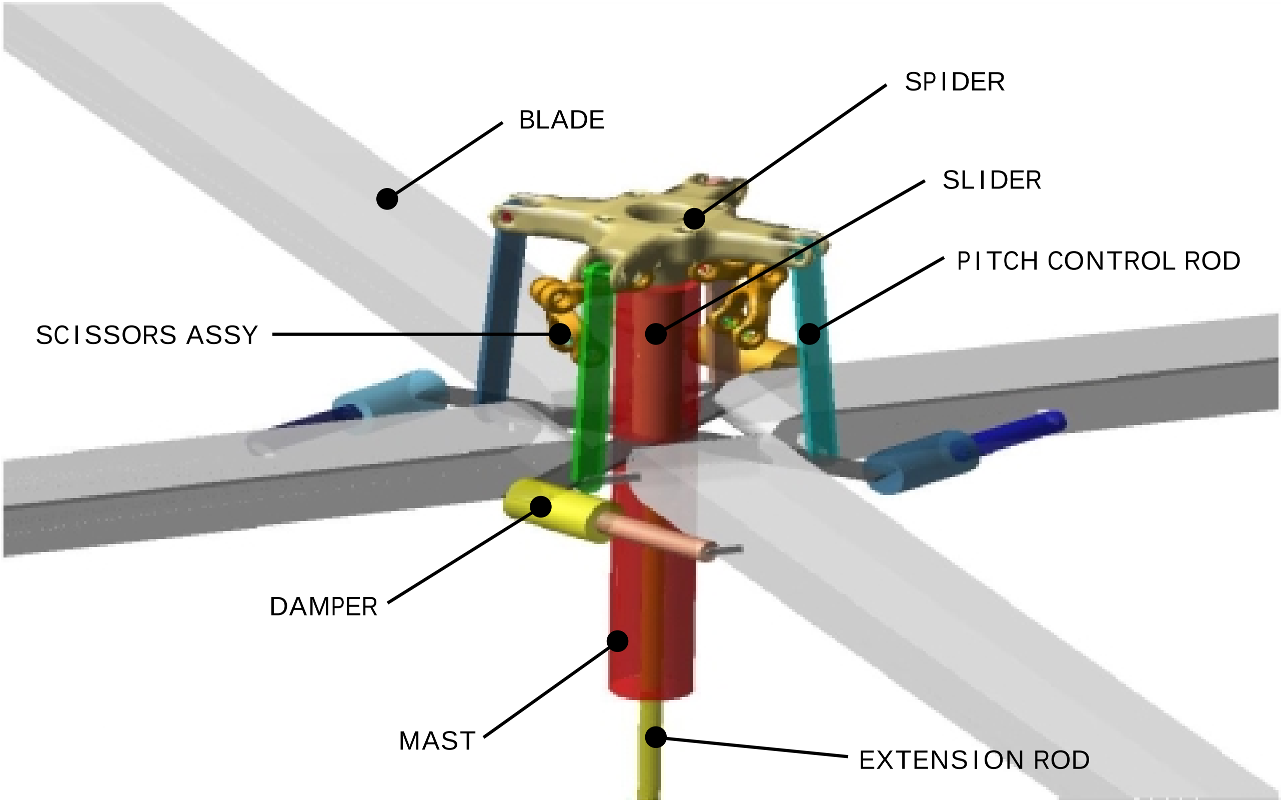

Fig. 2 - Tail rotor assembly

From a mechanical point of view the functions of the tail rotor main components can be described as follows.
The power provided to the tail rotor by the gear train is transmitted to the rotor hub by the mast.
The variation of the collective pitch of the blades for the thrust control is possible due to a translational movement (inwards and outwards) of the four pitch control rods.
The spider-slider assembly rotates together with the hub-blades system and translates together with the extension rod, which is moved by a servoactuator system.
The two scissors assemblies keep the spider-slider assembly rotating together with the hub.
The dampers have the function of damping the lag movement.

3. ADAMS model description

As anticipated in the introduction of the present paper, the aim of a multibody modeling of the tail rotor of an Agusta helicopter is to investigate the features of ADAMS as a mechanical system simulation tool, through an application to a case of interest for Agusta.
The attention has been focused on the following points:

1) evaluating the load sharing among the different components of the rotating control chain, during continuous time simulation,
2) analyzing the effect of flexibility of some components and

3) kinematic simulation.

The spider, the slider, the scissors assemblies and the control rod have been modeled as flexible bodies. The blades have been modeled as rigid bodies. This was sufficient for a first evaluation of the loads acting on the control chain. The time varying trim loads (aerodynamic and inertial loads), for a certain critical flight condition, have been evaluated through the aeroelastic code CAMRAD/JA [1] and subsequently applied to each blade as concentrated forces and moments at the hinges location.
Each of the four dampers has been modeled as an assembly of two rigid bodies with a suitable elastic-viscous force acting between them.
The steps followed to define the final model are:

- kinematic behavior of a very first completely rigid model has been studied.
- subsequently this model has been replaced by a partially flexible one, introducing for some components their flexible representation, using I-DEAS [2] pre-processing and MSC/NASTRAN [3] .
- finally, the trim loads of CAMRAD/JA have been introduced in ADAMS.

4. Results

4.1 Kinematic results[1]

The complete model has globally one degree of freedom, which is the rotation relative to ground about the rotor axis. A constant angular rate law (*i.e.* a STEP like law) has been imposed to the whole system, while a time varying law (*i.e.* a Fourier series like law) has been introduced for the trim aerodynamic and inertial resultant moments in flap and lag and for the flap, lag and pitch rotations; the kinematic pitch-flap coupling is also reproduced through the model geometry.
Figs. 3, 4 and 5 illustrate the flap, the pitch and the lag time histories respectively, for the four blades.

[1] All numerical values have been scaled with an appropriate scale factor.

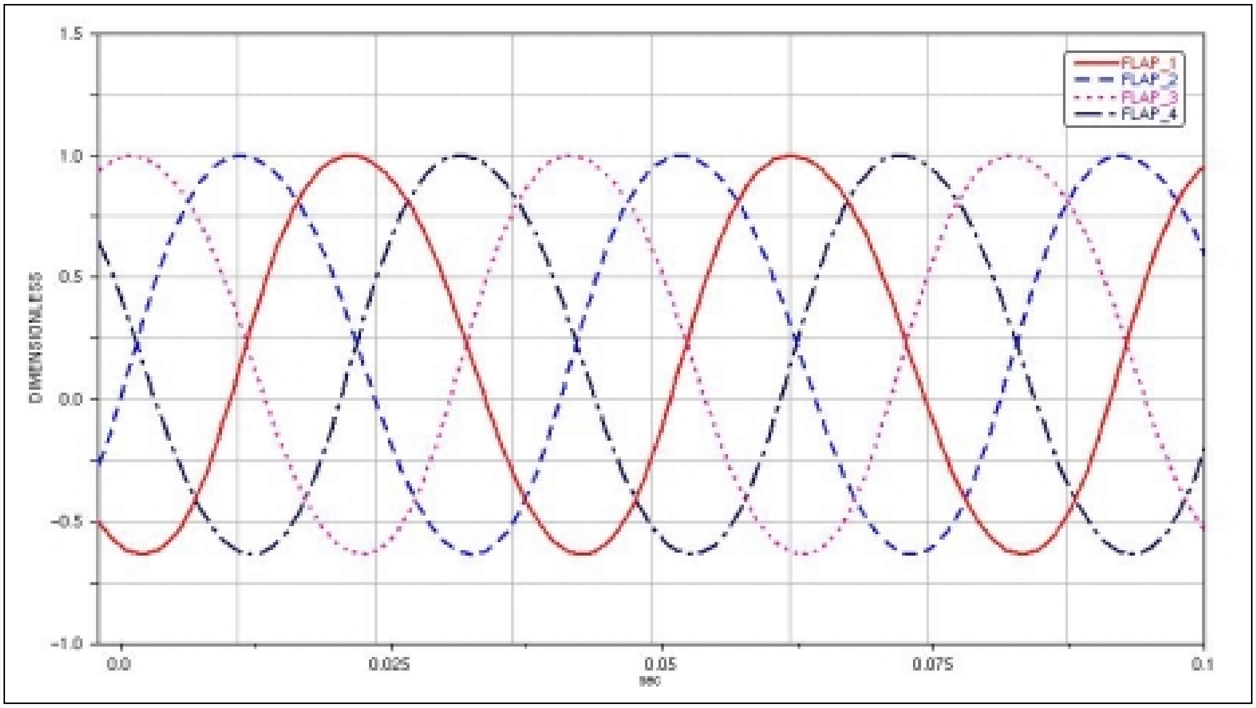

Fig. 3 – Flap movement

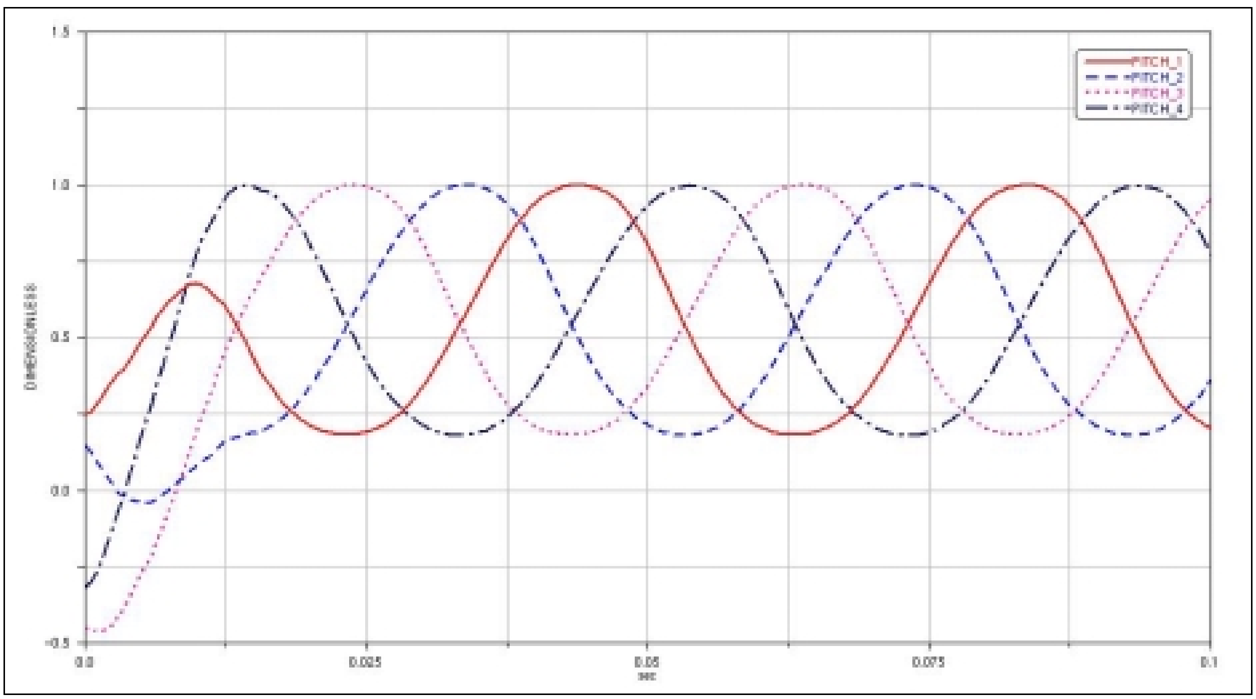

Fig. 4 – Pitch movement

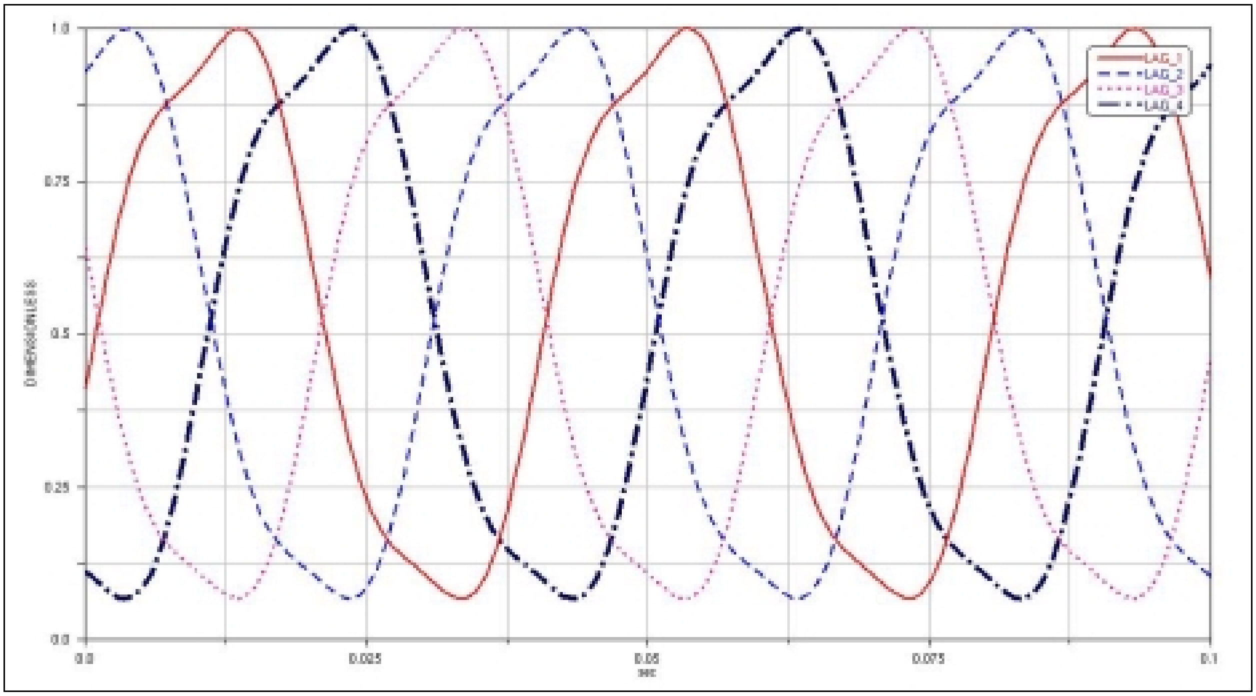

Fig. 5 - Lag movement

Fig. 6 shows the time variation of the four dampers' stroke, while in Fig. 7 the results of the Fourier analysis are presented. The peaks found through this analysis are in good accordance with the known dynamic characteristics of the tail rotor system.

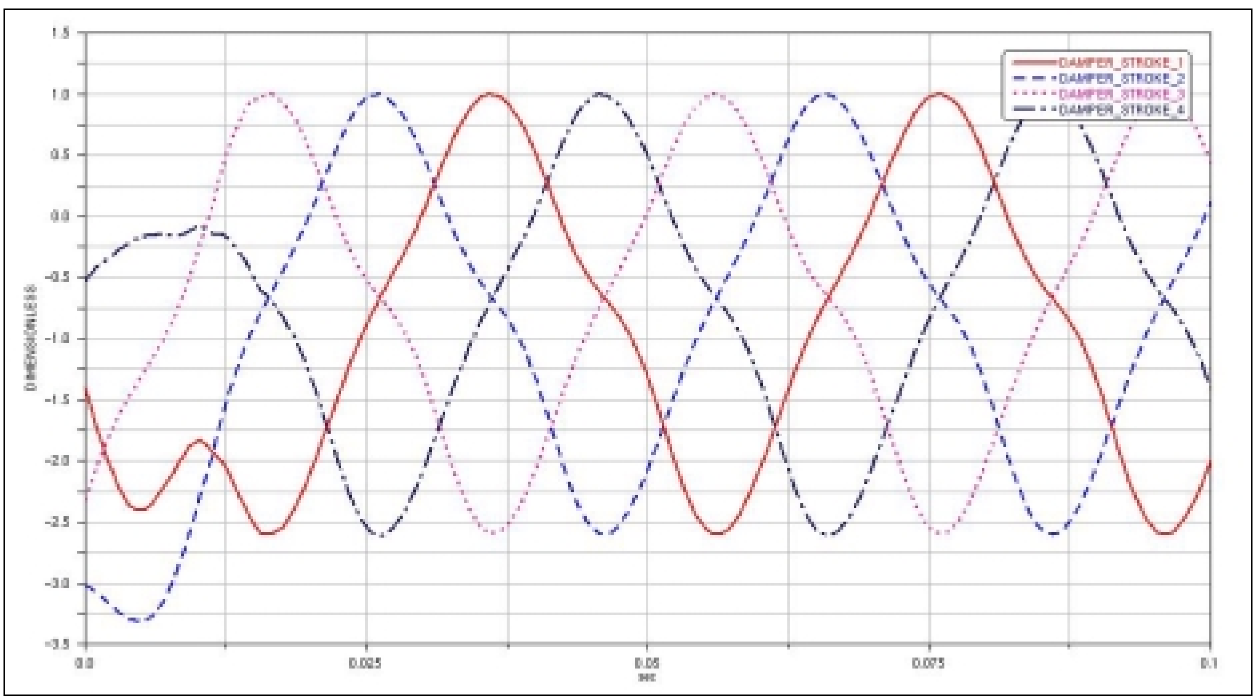

Fig.6 – Dampers' stroke

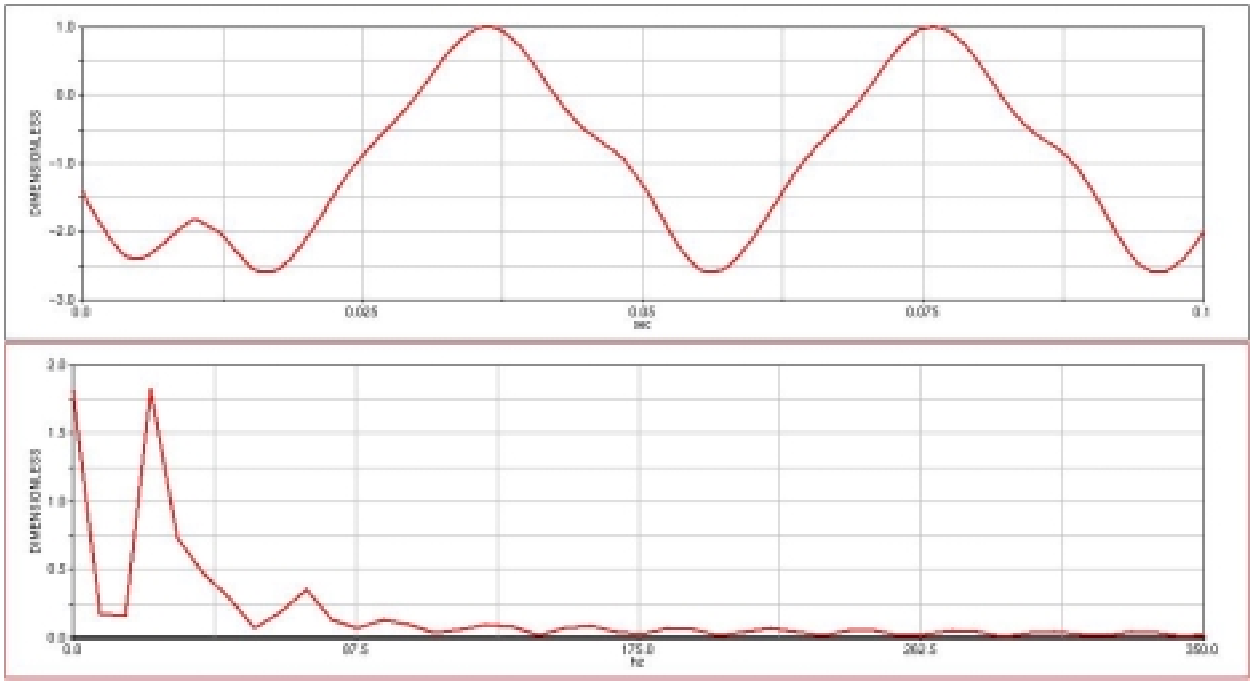

Fig. 7 – Fourier analysis of one of the dampers' stroke

4.2 Load survey results

It is interesting to see a comparison between the rigid and flexible cases.

Fig. 8 shows the axial load of one pitch control rod, together with the load acting on the corresponding spider arm when a flexible or a rigid spider is considered. It is interesting to note the redistribution of load between the two wings, in the flexible case (equal distribution of the shear load - spider shear load left and right wings).

Fig . 9 presents the Fourier analysis of the axial load of Fig. 8.

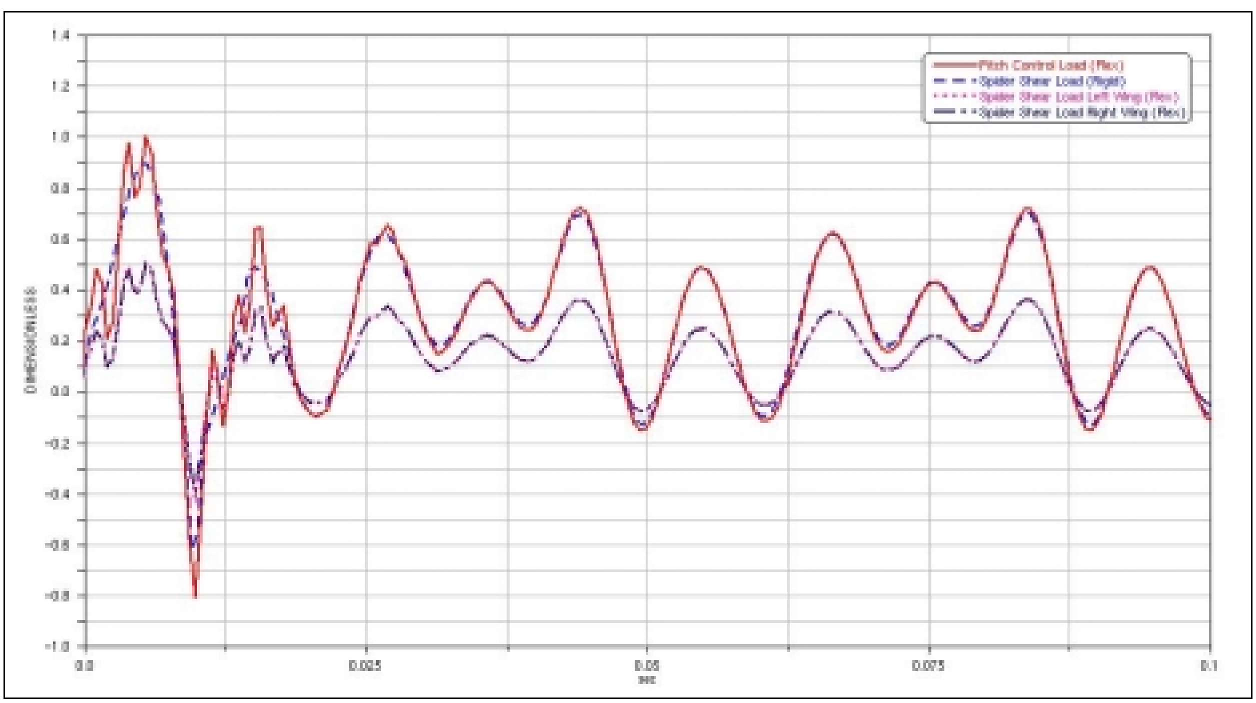

Fig. 8 – Comparison rigid vs. flexible

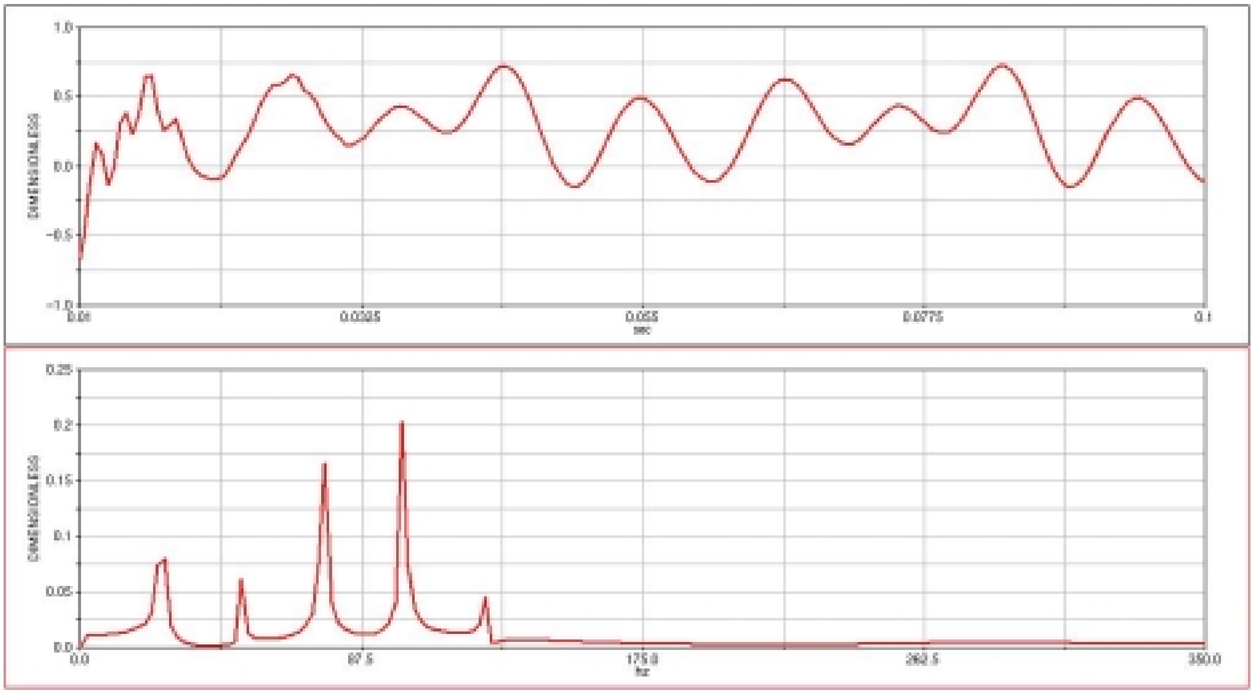

Fig. 9 – Fourier analysis

Fig. 10 illustrates the control rod axial load in both cases; it can be seen how the trend becomes smooth after a rough initial transitory phase, also numerical dependent. The signals are quite similar, but however, the control rod has a high axial stiffness. Moreover it can be seen how the main frequency is a 4x revolution, as expected.

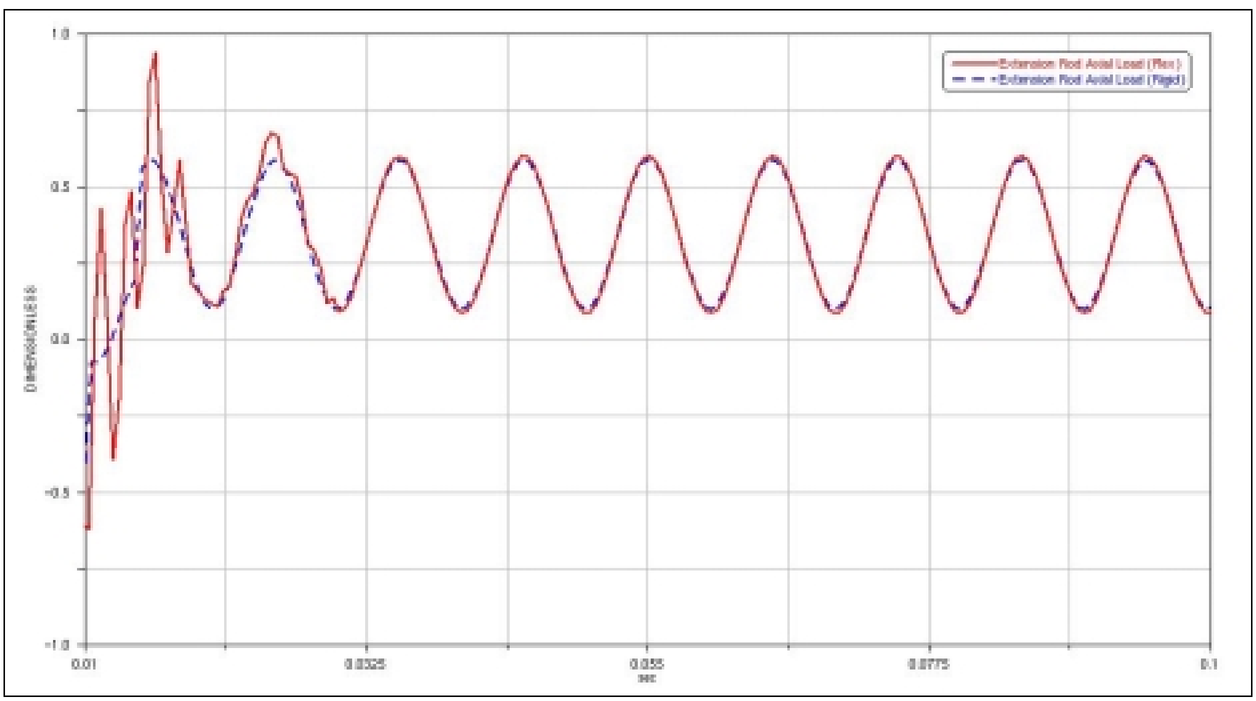

Fig. 10 – Extension rod axial load: rigid vs. flexible

Fig. 11 shows the stabilised signal corresponding to the T_Z force (*i.e.* the force in the hub plane) on the upper half scissors, together with the Fourier analysis. The component frequencies have a 1x rev, a 3x rev and a 5x rev, as expected.

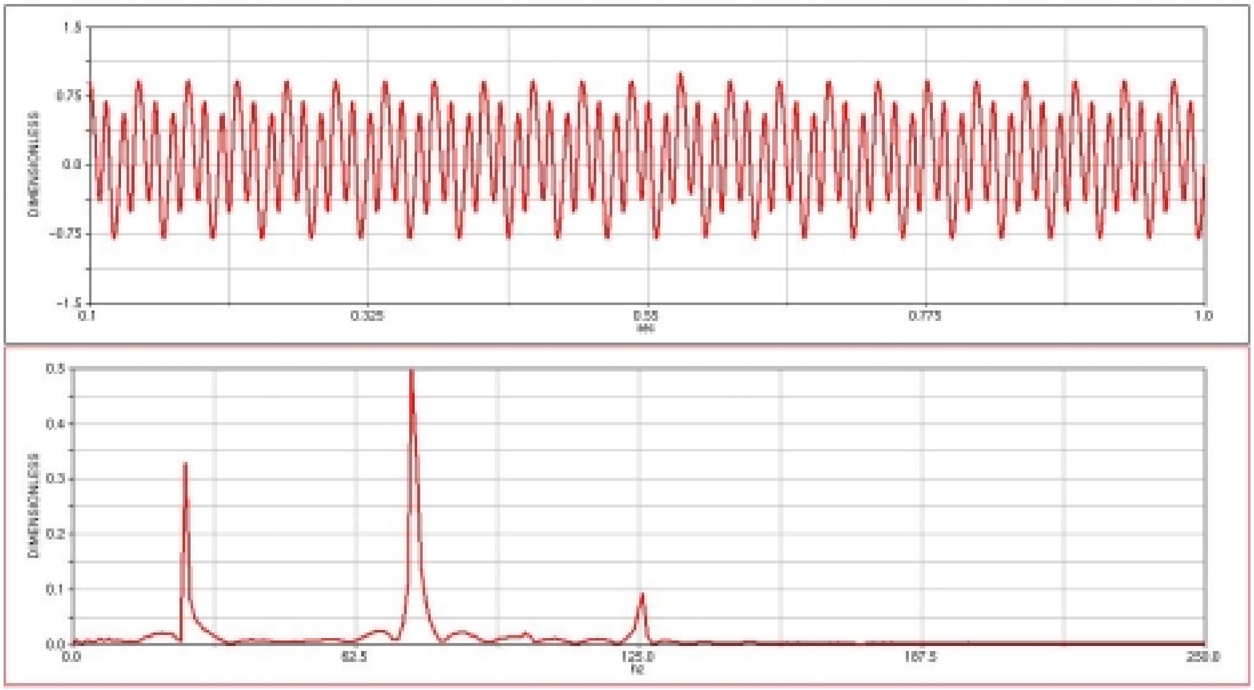

Fig. 11- T_Z force on the upper half scissors (stabilized signal)

Fig. 12 puts into evidence, through a Fourier analysis of the Tz force, a very high frequency that actually characterizes the transitory phase and corresponds to a high frequency torsional mode of the spider.

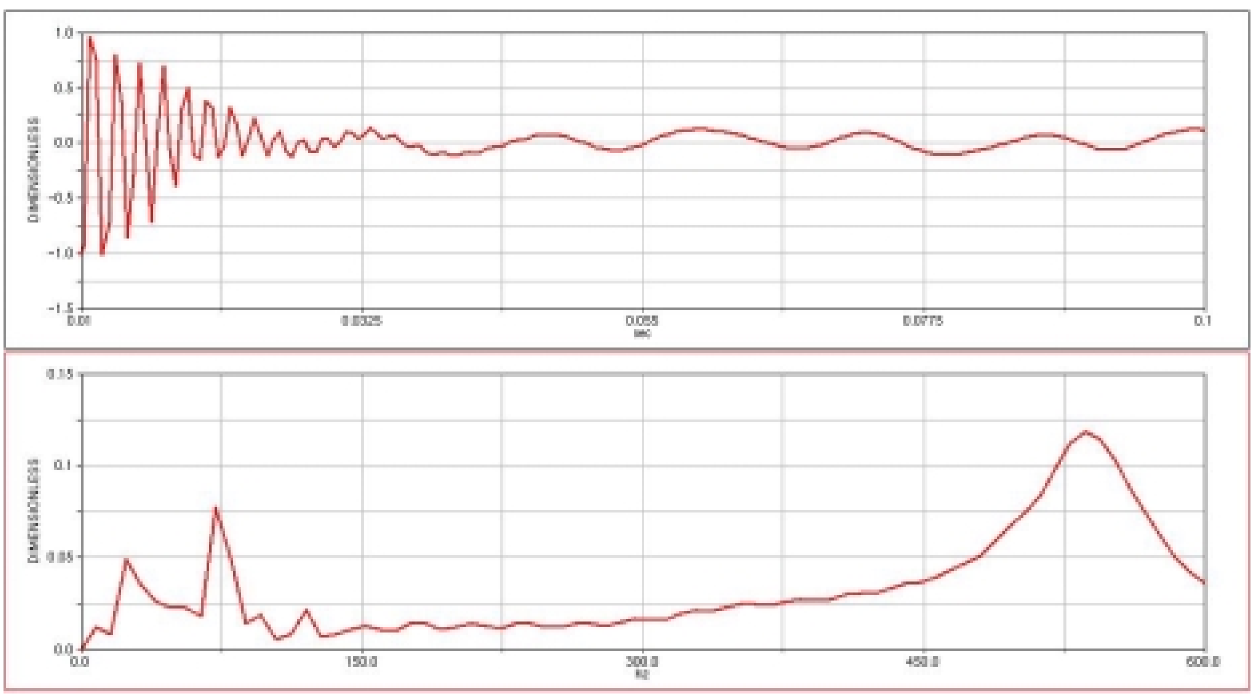

Fig. 12- T_Z force on the upper half scissors (transitory phase)

Fig 13 shows a comparison flexible vs. rigid for the moments at the fitting between the slider and the mast in the hub plane.

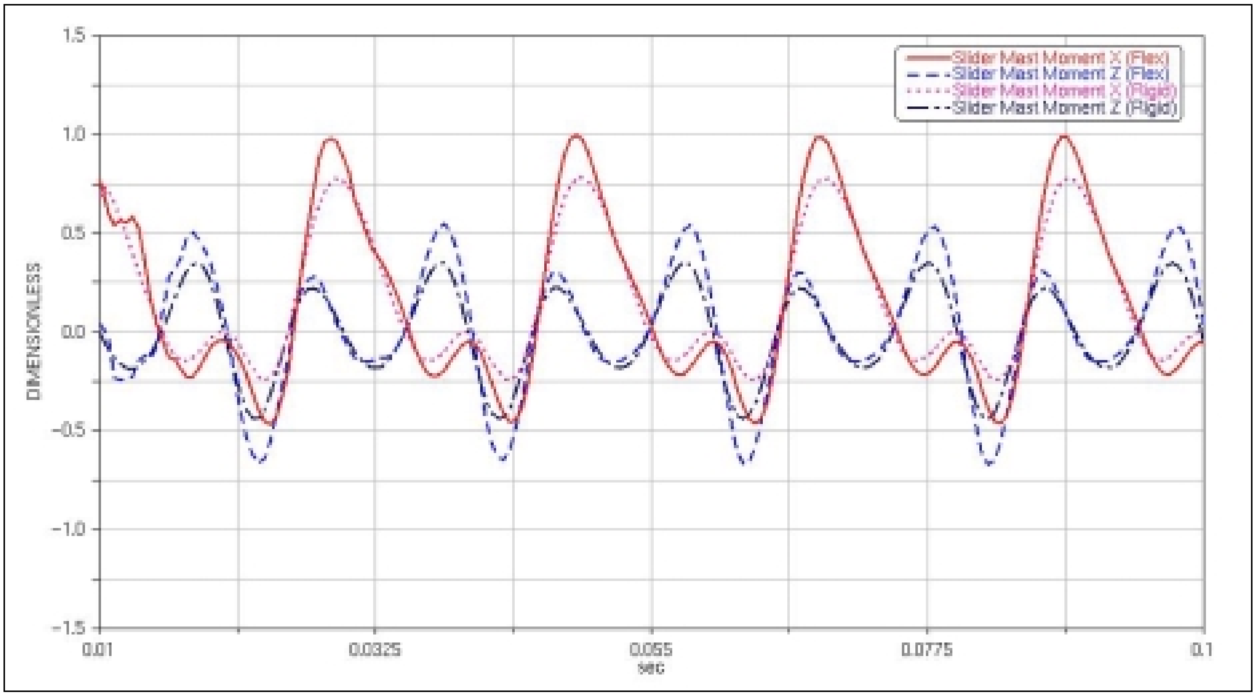

Fig.13 - Slider- mast moments (rigid vs flexible)

5. Description of the reduced model

As mentioned in the introduction, the main aim of modeling this rotor subsystem is to reproduce an experimental test setting to investigate different configurations and therefore put into evidence the most significant ones, from a structural point of view (*i.e.* FEA studies of individual parts).
The chosen subsystem is completely flexible and includes just the slider, the spider, the control rod and the two scissors assemblies (see Fig. 14 below)

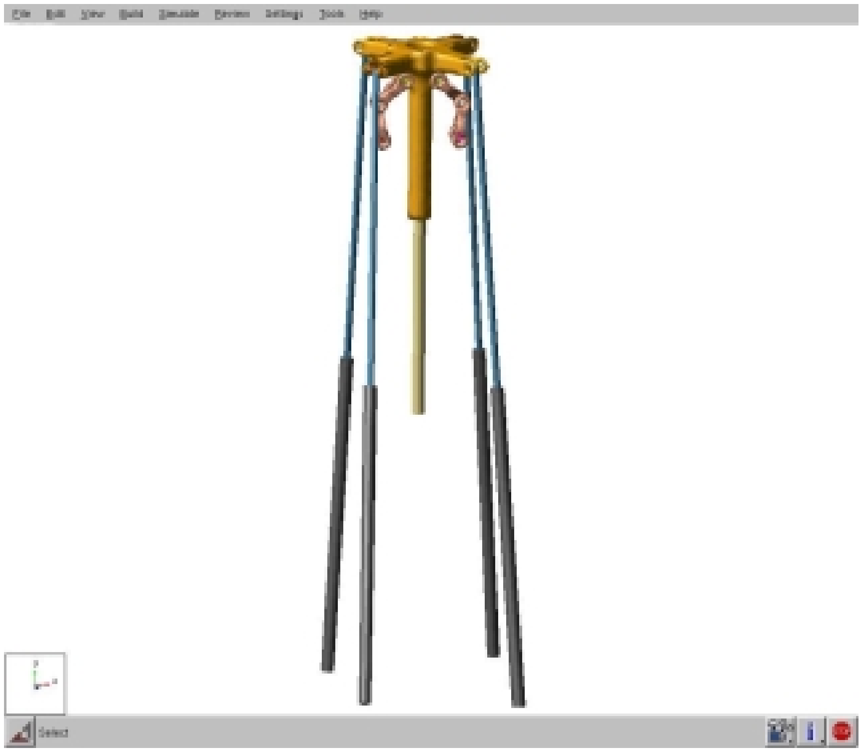

Fig 14 - Tail rotor reduced ADAMS model

The test rig consists of four actuators fitted at the spider's arms at one end and at the rig at the other end. The system is fixed at the rig so that only the flexible modes are present.
The ADAMS model reproduces the phase lagged forces of the actuators; it has one degree of freedom left which is the axial translation. A time dependent law (*i.e.* a multi-step like law) has been introduced in order to permit the configuration changes.
At the moment no modeling of contact features such as bushings (*e.g.* at the fitting surfaces between the slider and the ground, that is the test rig) is present.

5.1 Results

Below are presented the most important results for the upper and lower half scissors. The values are ploted as a function of the different axial positions of the control rod. As can be noted from Figs. 15 and 16 the torque and bending moment have different trends. ADAMS simulation therefore has permitted to get different loading conditions for the half scissors to be studied through a FE analysis in I-DEAS, putting into evidence the most critical loading combinations.

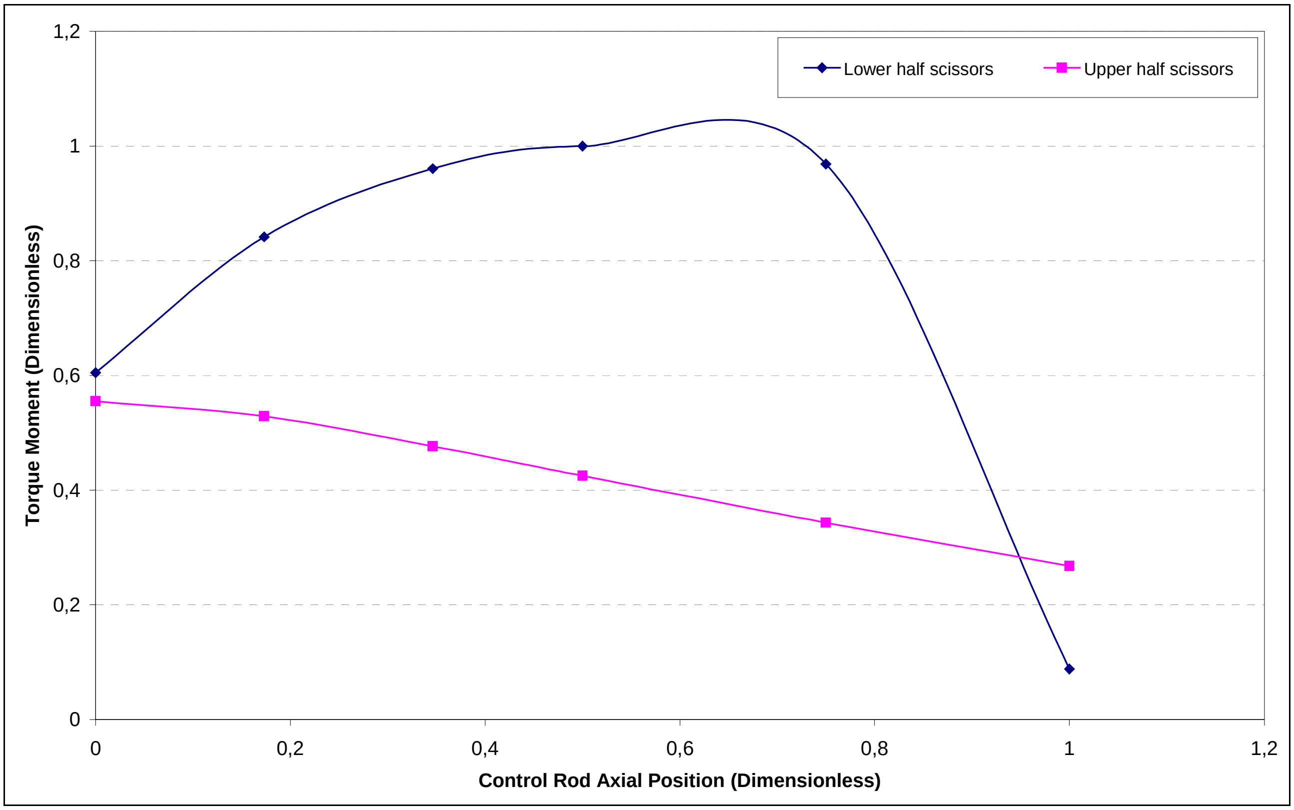

Fig. 15 - Torque

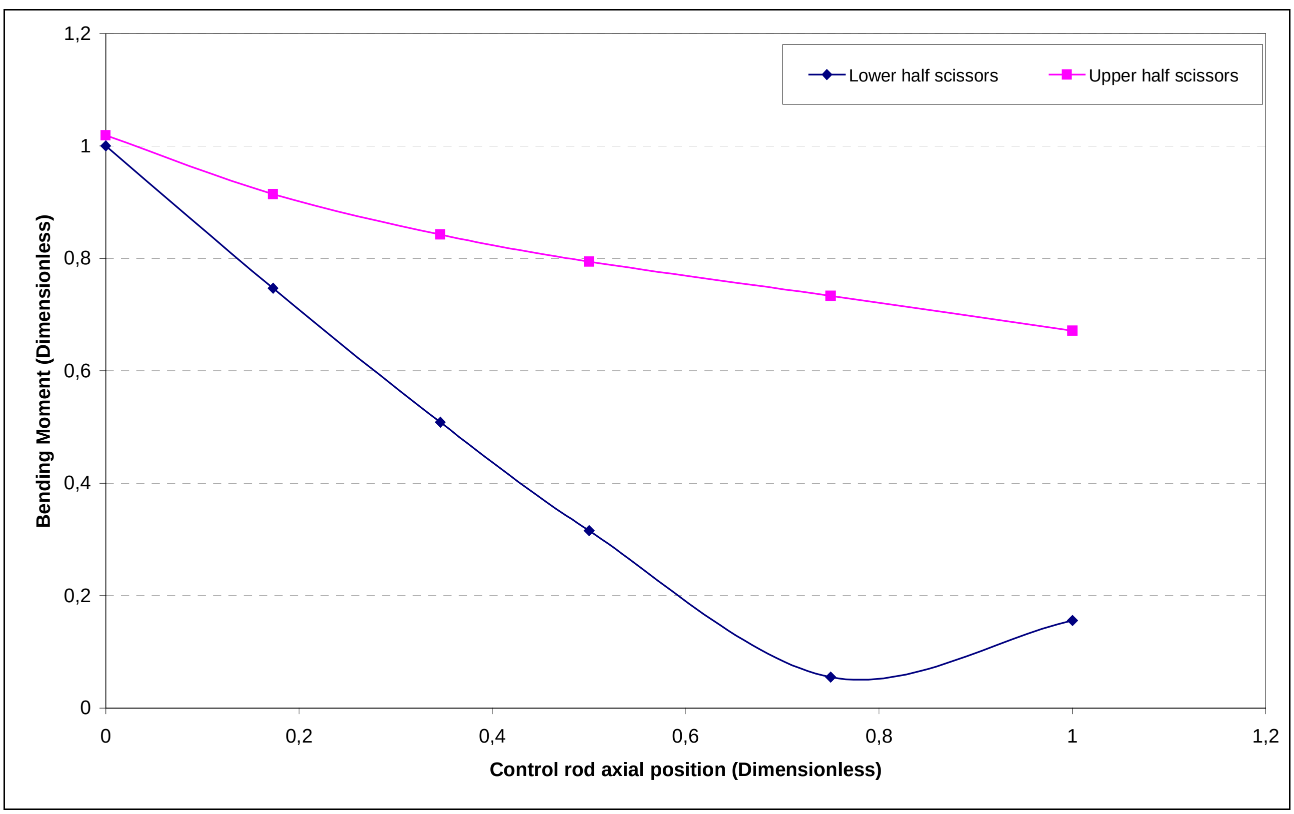

Fig. 16 - Bending moment

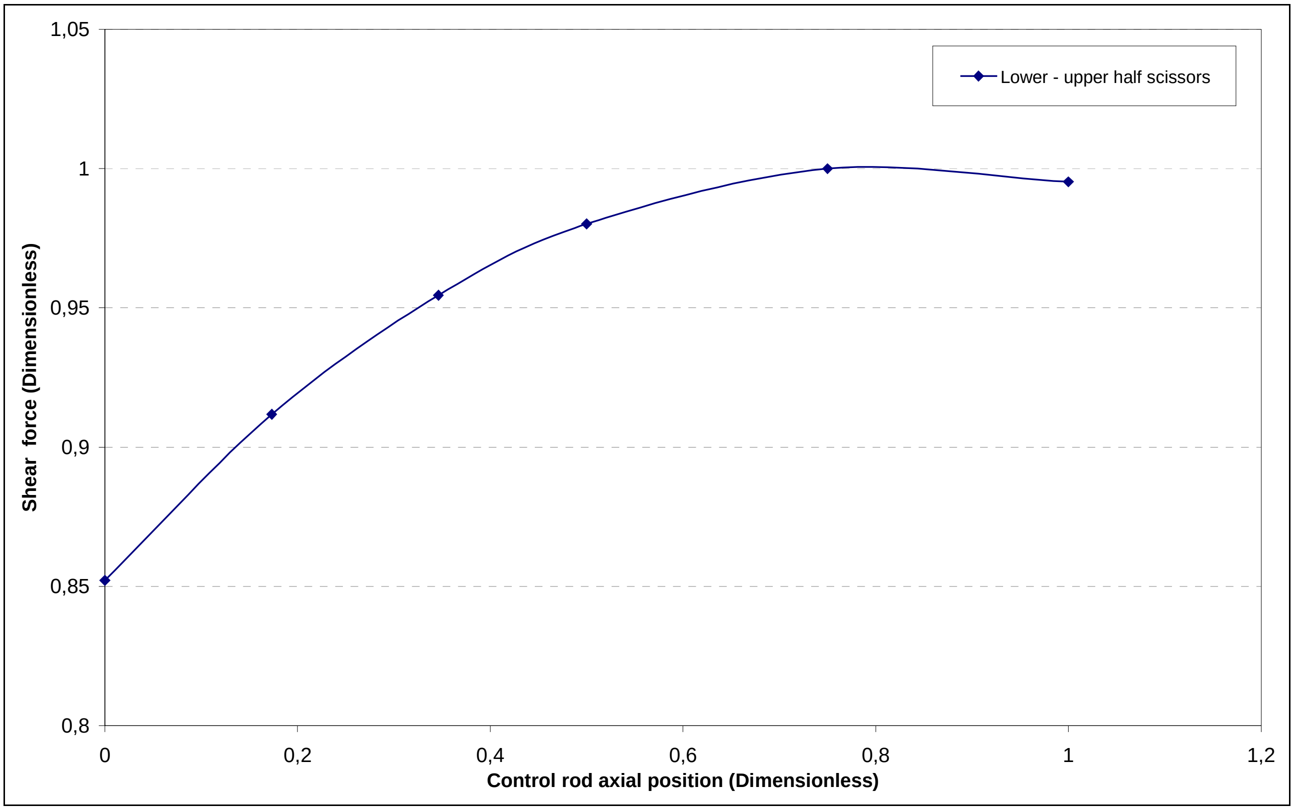

Fig. 17 - Shear force

6. Conclusions

First of all it is worth underlining once more that the object of the present work is the result of a very first investigation of ADAMS's features applied to a case of interest for Agusta, a tail rotor system. The results obtained from the simulations performed are satisfactory, but much work sill needs to be done in some areas and I will mention some of them below.

That is, it would be of some interest to introduce, in the complete tail rotor model, flexibility for other parts, such as the pitch control rods, the mast and the hub. A further step should be to model the contacts between the slider and the mast.

The trim loads (aerodynamic and inertial loads) for this application have been calculated 'outside' ADAMS, and subsequently applied as concentrated forces on the rigid blades. A possible development could be to set up a 'global approach' including load generation within ADAMS.

REFERENCES

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[2] I-DEAS MASTER SERIES *Modeling & Simulation User's Guide Version 6A.*

[3] MSC/NASTRAN *User's Guides*,*Version 70.5*

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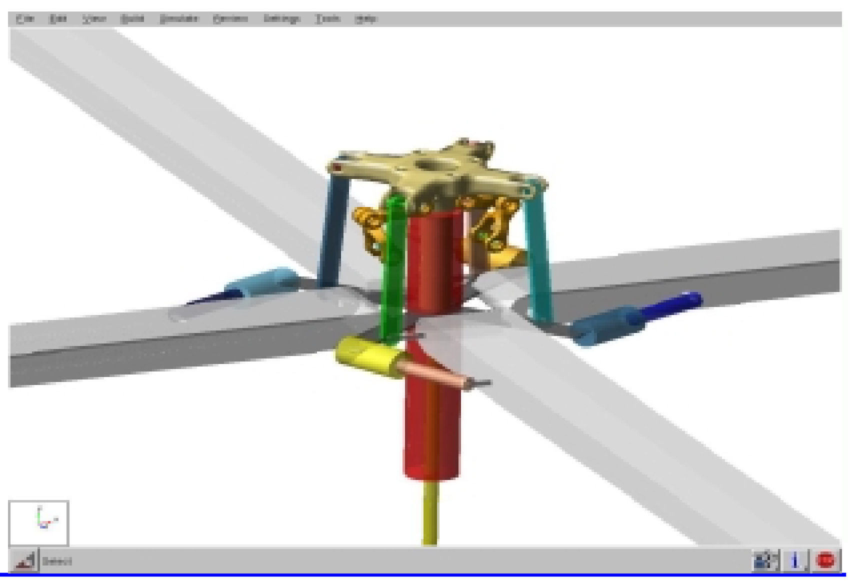
HELICOPTER TAIL ROTOR ANALYSIS : EXPERIENCE IN AGUSTA WITH ADAMS

AGUSTA



AGUSTA

OBJECTIVE

TO INVESTIGATE THE FEATURES OF ADAMS AS A MECHANICAL SYSTEM SIMULATION TOOL THROUGH AN APPLICATION TO A CASE OF INTEREST FOR AGUSTA:

THE TAIL ROTOR OF A NEW AGUSTA HELICOPTER

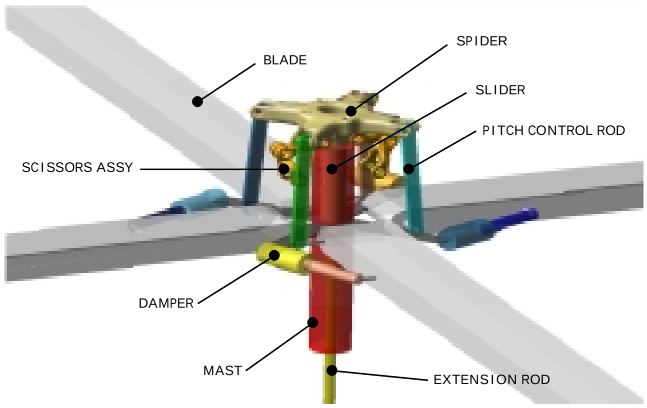
AGUSTA

POINTS OF INTEREST

THE ATTENTION HAS BEEN FOCUSED ON THE FOLLOWING POINTS :

- EVALUATING THE LOAD SHARING TIME HISTORY
- ANALYSING FLEXIBILITY EFFECTS OF SOME PARTS
- KINEMATIC SIMULATION
- MODELING A SUBSYSTEM FOR AN EXPERIMENTAL TEST SET UP

AGUSTA



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ADAMS MODEL DESCRIPTION

- FLEXIBLE BODIES:
  SPIDER, SLIDER, SCISSORS ASSY AND CONTROL ROD
- RIGID BODIES:
  BLADES, HUB AND MAST
- DAMPERS MODELED AS ELASTO-VISCOUS FORCE
- TRIM FORCES FOR A FLIGHT CONDITION EVALUATED WITH CAMRAD/JA (AEROELASTIC CODE)

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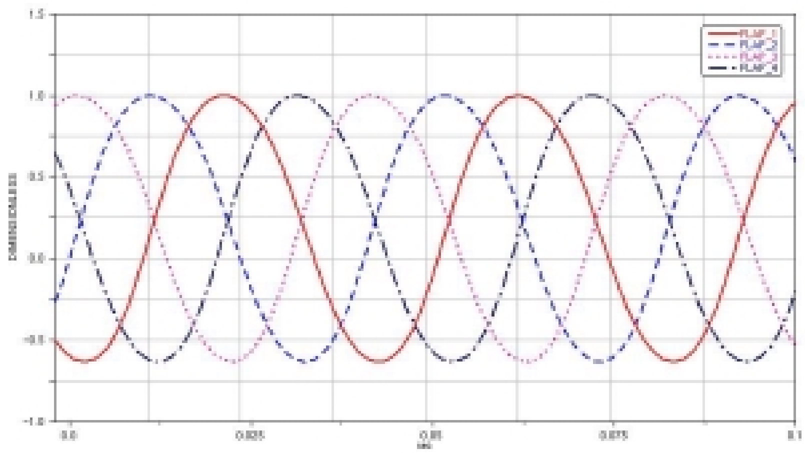
FLAP



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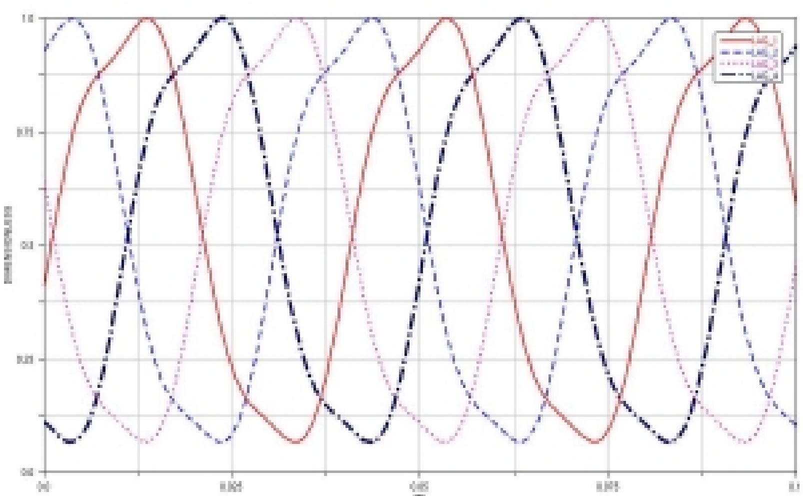
LAG



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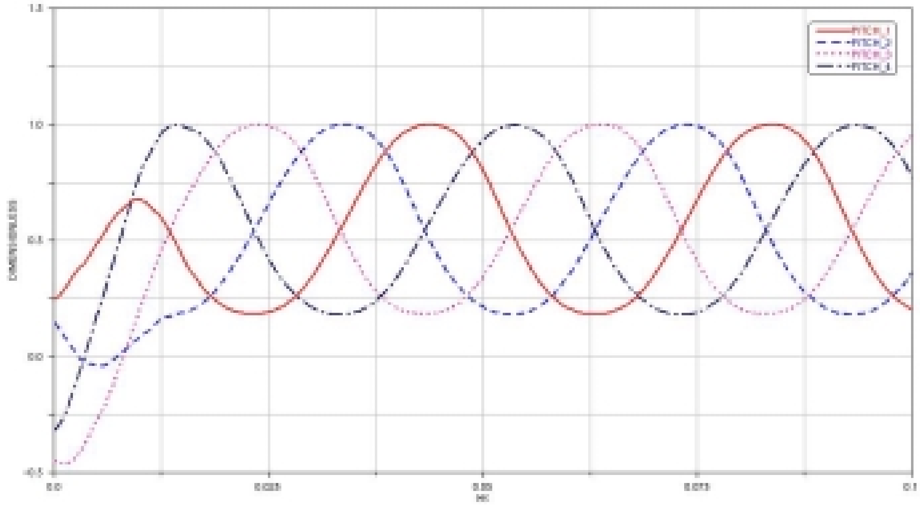
PITCH



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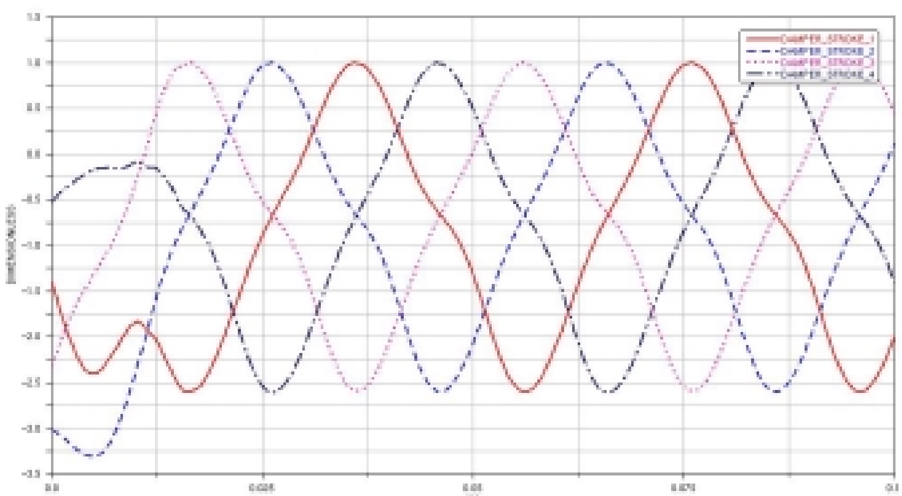
DAMPER STROKE



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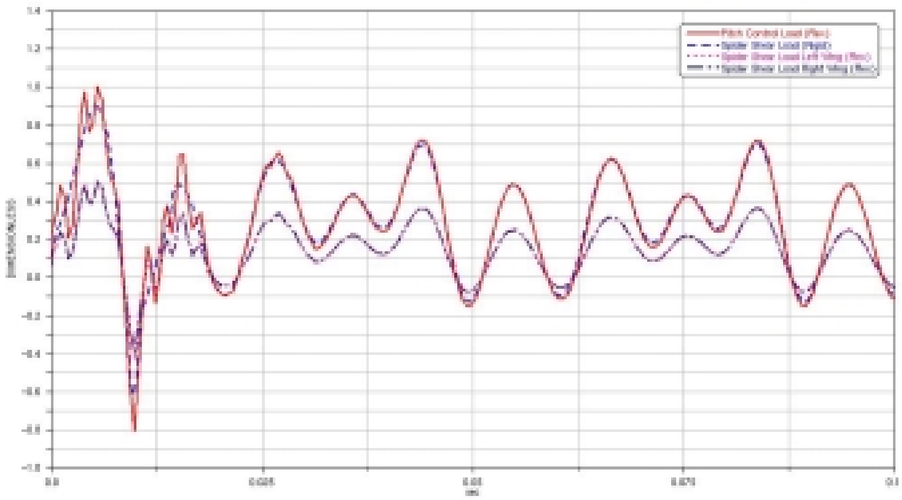
PITCH CONTROL ROD - AXIAL LOAD



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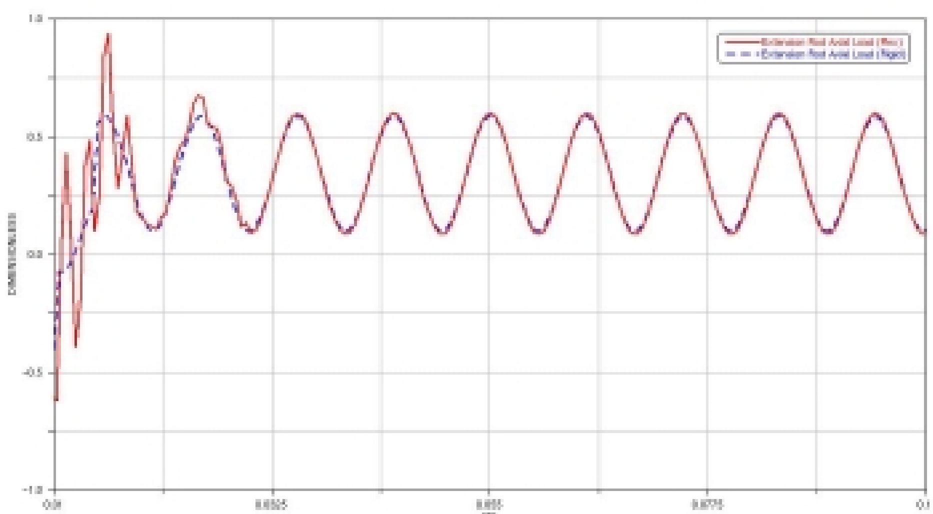
EXTENSION ROD AXIAL LOAD: RIGID VS. FLEXIBLE



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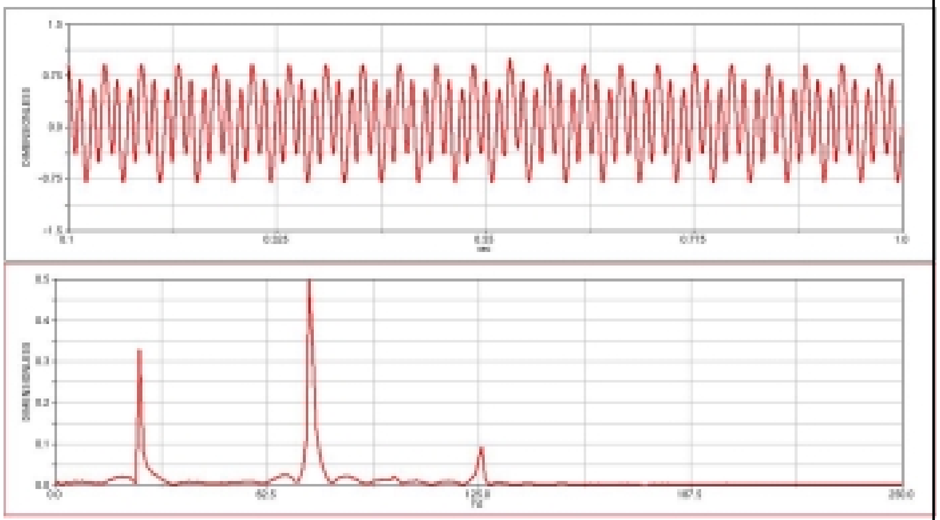
T_Z FORCE ON THE UPPER HALF SCISSORS



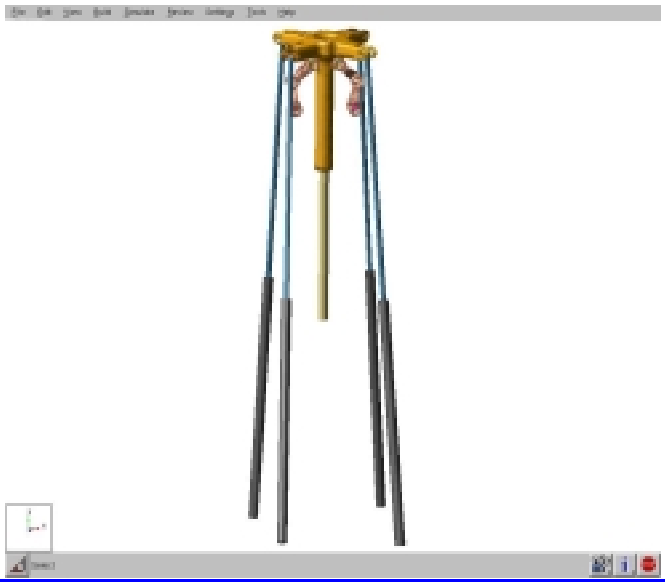
REDUCED MODEL

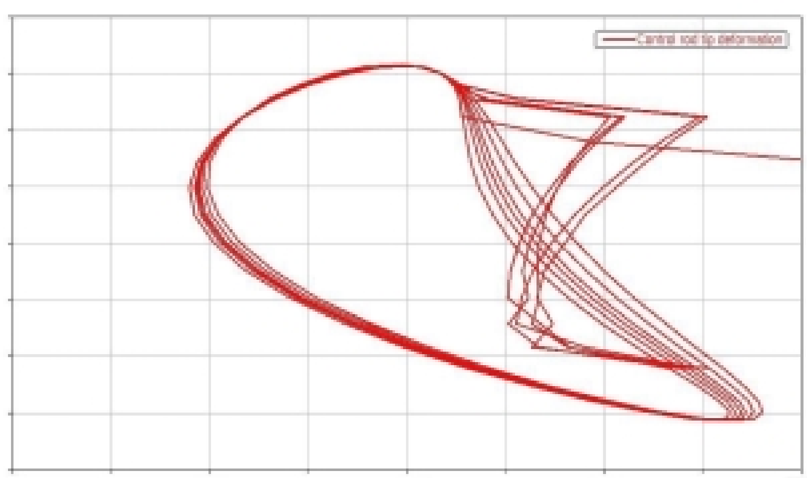
THE SUBSYSTEM IS COMPLETELY FLEXIBLE AND IS MADE UP OF:

SPIDER,
SCISSORS ASSY,
SLIDER AND
CONTROL ROD

THE FOUR ACTUATORS ARE MODELED AS:

TWO SLIDING RIGID BODIES WITH A DYNAMIC FORCE ACTING BETWEEN THEM





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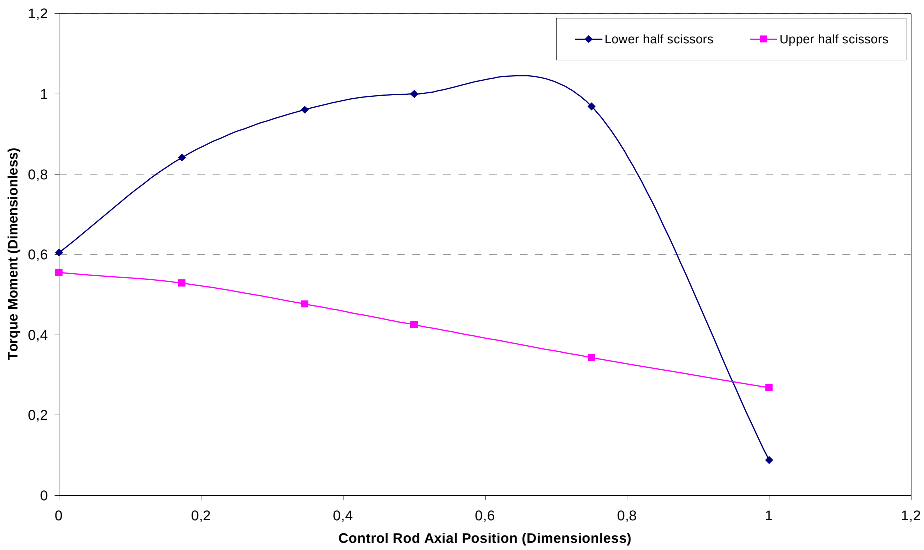
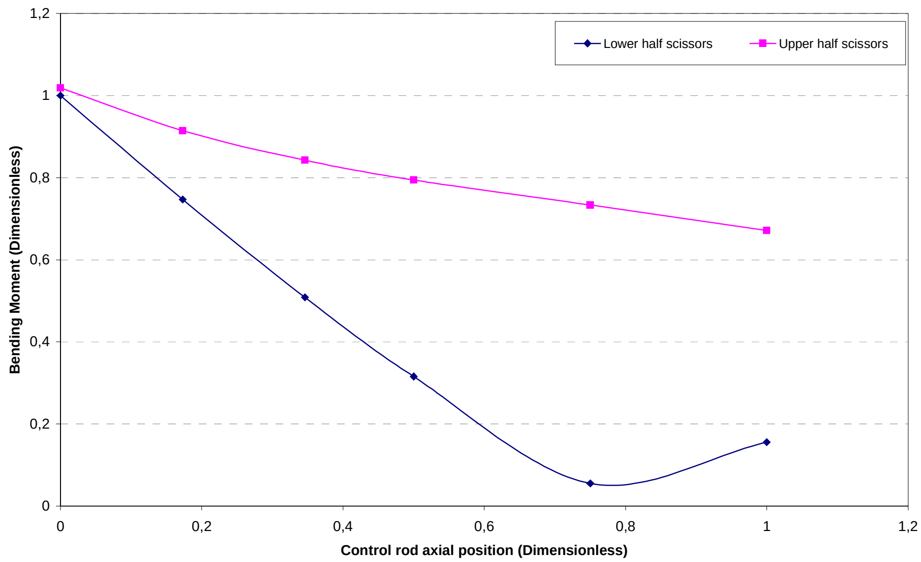
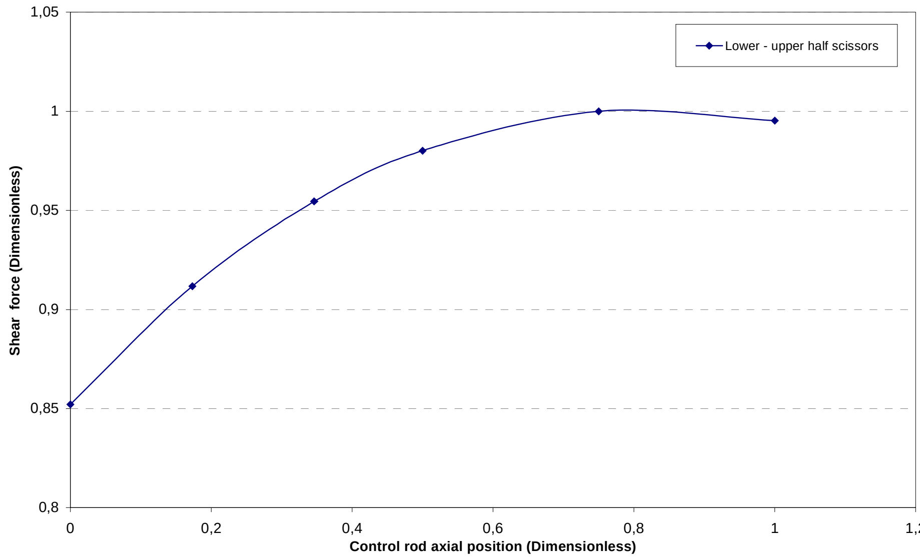


Lower half scissors
Upper half scissors
Torque Moment (Dimensionless)
Control Rod Axial Position (Dimensionless)
0
0,2
0,4
0,6
0,8
1
1,2



Lower half scissors
Upper half scissors
Bending Moment (Dimensionless)
Control rod axial position (Dimensionless)
0
0,2
0,4
0,6
0,8
1
1,2



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CONCLUSIONS

THE RESULTS OBTAINED ARE SATISFACTORY.

MUCH WORK NEEDS TO BE DONE IN THE FOLLOWING AREAS:

- INTRODUCE, FLEXIBILITY OF:
  PITCH CONTROL RODS, MAST AND HUB.
- MODEL THE CONTACTS BETWEEN THE SLIDER AND THE MAST.
- THE TRIM LOADS GENERATION WITHIN ADAMS.

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