GAHEL : GENERAL CODE FOR HELICOPTER DYNAMICS

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The reduction of vibrations is a fundamental step in the development of a new helicopter. Nevertheless most of the programs used during the preliminary plan impose the general architecture of the helicopter without taking enough into account vibration criteria. It is harmful to the reliability of the rotorcraft, to the performances for military helicopters and to the crew and passengers comfort. More over the needed modifications can be difficult to achieve because of price and delays.
For these reasons EUROCOPTER has decided five years ago to develop a new engineer tool called GAHEL (General Architecture of Helicopter) containing relatively simple models which enable to avoid fundamental problems by providing some general architecture parameters, and to optimize the anti-vibration devices. The ultimate aim of the tool is to make it possible to define a virtual helicopter optimized from a dynamic point of view.

Introduction

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For these reasons EUROCOPTER has decided five years ago to develop a new engineer tool called GAHEL (General Architecture of Helicopter) containing relatively simple models which enable to avoid fundamental problems by providing some general architecture parameters, and to optimize the anti-vibration devices.
GAHEL is mainly used for dynamics tuning both in the cases of aircraft development and improvements research. The ultimate aim of the tool is to make it possible to define a virtual helicopter optimized from a dynamic point of view.

This paper provides an overview of GAHEL contents including the validation method and the development strategy.

1- GAHEL contents

GAHEL is made of a set of a dozen programs connected to a database. The programs cover most of the basic dynamic potential problems that can occur on aircraft.
The programs can be divided into several parts:
- Modal calculation
- Stability analysis
- Anti-vibration devices optimization
- Parametric study

GAHEL general organization is presented in Fig. 1

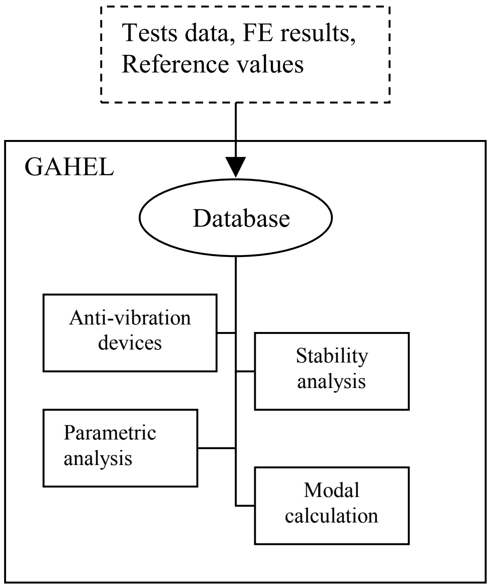

Fig. 1: GAHEL general organization

1-1 Database organization

The database includes technical characteristics for different helicopter sections:

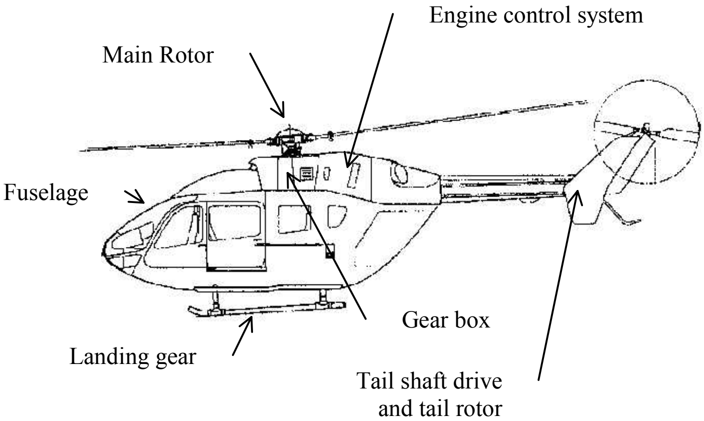

Fig. 2: Helicopter sections included in GAHEL

The database is fulfilled for the EUROCOPTER range. Several data sets are available if different versions of a section exist.

Most of the parameters are determined from definition drawings. Nevertheless some specific data are provided by measurements results (i.e. lead lag damper characteristics) and finite elements calculations (i.e. fuselage modes) too.

Main rotor: type (hinged, Spheriflex, Starflex), main rotor characteristics (blades number, rotational speeds, radius, inertia, static moment, eccentricity, twist, aerodynamics data, modal data…)

Tail rotor: Ditto

Fuselage : mass, inertia, gravity center, modal data.

Landing gear: type (wheel or skid), geometric and material description.

Main gearbox & tail gearbox:: transmitted power, inertia

Tail rotor drive: shafts description : shafts number, material, cross-section, length, bearings position

Suspensions: geometrical description, mechanical characteristics.

Drive train : geometry, inertia, stiffness and damping.

Engine : controller system data

1-2 Modal calculation

Modes of the fuselage on ground :

Whenever a ground resonance study is undertaken, the modes of the fuselage on ground are computed (frequencies and modal mass are required)
The optimization procedure consists in placing the frequencies in a area specified (far from the excitation frequency Ω - ω_δ).

Wheel landing gear :

The wheel landing gear is assimilated to perfect springs and dampers in the three axes for each wheel (Fig. 3).

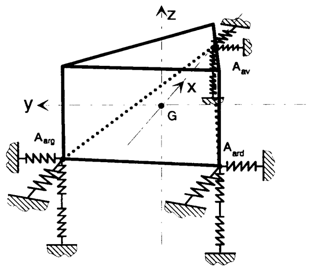

Fig. 3 : Landing gear modelling

Skid landing gear :

The structure is modeled by finites elements with beam elements (6 degrees of freedom per node). The fuselage is modeled by one element (mass + inertia). The displacements of the elements in contact with the ground are blocked in the plane. (The calculations shown this boundary conditions are the most representative).

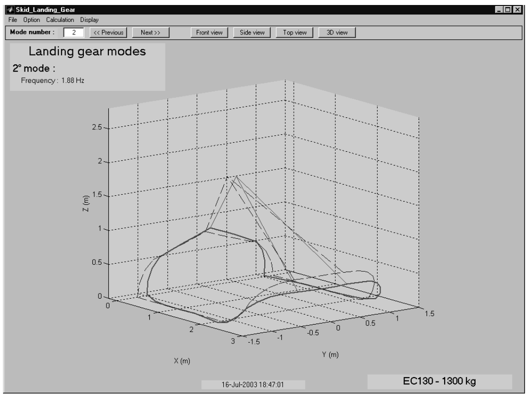

Fig. 4 pitch mode of the EC130B4

Blade modes

The blade is modeled with a finited elements model. The model can be adapted to each rotor type (articulated as well as hingless rotor). For interblade rotors all the blades are modeled.

The code provides for each mode the frequency, the mode shape and the generalized mass The main aim of the model is to adjust the modes frequencies.

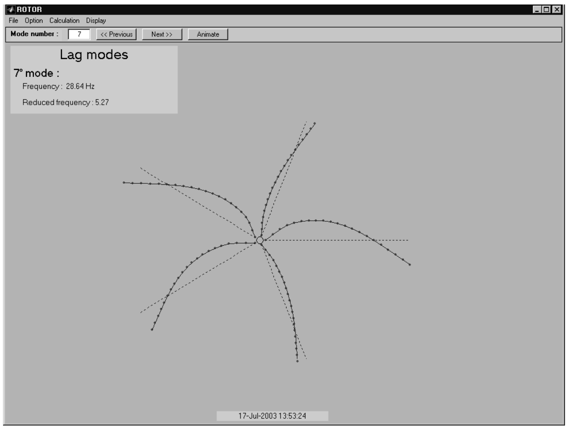

Fig. 5: lag mode of the EC155 Interblade rotor

The modal shear forces are evaluated analytically [5] and [6].

Torsion modes of the drive train

The dynamic analysis of the helicopter drive train is mainly focused on two points:

- Suitable tuning of the system's torsion modes, providing a proper separation from bΩ as well as 2bΩ excitation frequencies. The lead-lag stiffness of the blades is often adjusted to raise this mode over bΩ and obtain a sufficient safety margin with respect to this excitation.
- Stability which depends on the engine control system. This point will be discussed in the next part.

The drive train is modeled by a spring mass system and converted into a state space system.

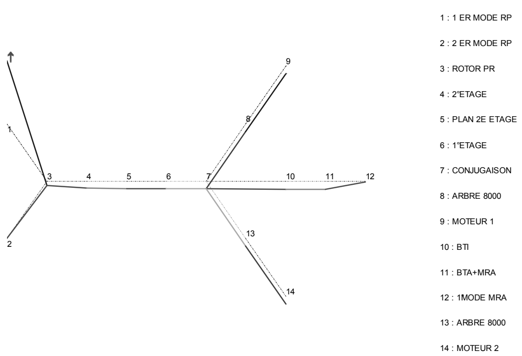

Fig.6: First drive train modes

Response to an excitation can be evaluated by computing Bode diagrams

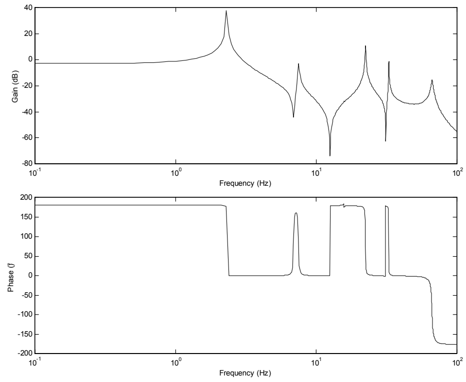

Fig.7: Dynamic mast response to an excitation on the engines

Tail rotor drive

The tail shaft can be classified in two categories:
Sub-critical: Every natural frequency is superimposed to the speed of the tail rotor drive shaft.
Super-critical: one of the frequencies is computed under the drive velocity.
The model computes the first five natural frequencies and modes and the margins are displayed with a graphic study taking the rotor bΩ frequencies and the tail drive speed into account.

1-3 Stability analysis

Ground resonance stability

Ground resonance can occur whenever the frequency of the fuselage on the ground is close to the lead-lag frequency in the fixed coordinate system (linked to the aircraft) (Fig. 3).

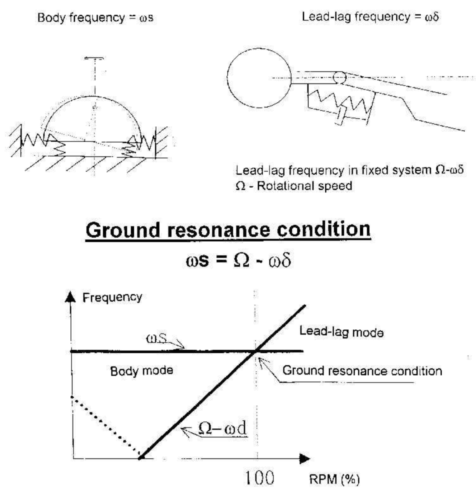

Fig.8: Ground resonance phenomenon

Obtaining sufficient stability margins is one concern of prime importance in the helicopter design.
The ground resonance study requires to know accurately the dynamic characteristics of the aircraft on ground and of the blades lag behavior.

The model is based on the ground resonance theory developed by Coleman.
The first blades lead-lag mode and the hub in-plane movement are the degrees of freedom taken into account in the analysis. A rigid body with pitch and roll rotations represents the helicopter fuselage. The equations can be simplified if the rotor is considered as isotropic.

The rotor operating limits can be evaluated by analyzing the damping rate and the frequencies of the involved modes.

Air resonance stability

Air resonance is a coupling phenomenon between the rolling movement of the fuselage and the blades lag movement. It can be defined as an extension of ground resonance. Air resonance occurs when the rotor load factor is high or upon a turn at altitude …
Dynamic displacements on fuselage roll axis induce a pitch increment on the back blade followed by a flap reaction generating a lag reaction.
This phenomenon generates instabilities and can jeopardize rotorcraft safety.
An analytical model has been developed in order to represent the dynamic behavior of the aircraft for low frequencies [0, 10 Hz]. The fuselage is considered as a rigid body with yaw, pitch and roll rotation as well as vertical, lateral and longitudinal translation.
The blades are assumed to be rigid. The degrees of freedom taken into account are the pitch, lead-lag and flapping movements. The other involved degrees of freedom correspond to torsion angles between drive train components: rotor mast, Main gearbox, tail rotor and engine(s).
The model is linearized around stabilized point in turn (most critical flight case for air resonance). The stability is evaluated by calculating the response to an excitation on the collective pitch or the cyclic pitch.

Drive train stability

The risk is to have a coupling effect between drive train modes and engine control system response. It can have an influence on the aircraft safety by generating important torque oscillations and by degrading handling qualities.

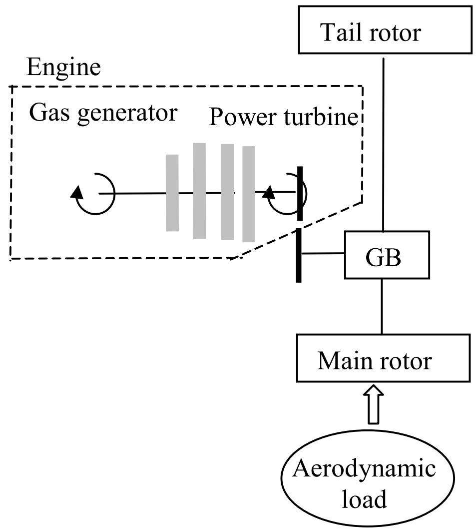

Fig. 9: Drive train coupled to the engine control system

Finding a compromise between accelerations and drive train stability is a major problem, mainly as interblade technology because there is no damping of the lead-lag dampers on the 1st drive train mode.
High engine governor gains will ensure satisfactory accelerations but may lead to unstable coupling of the first drive train mode according to engine behavior.

A similar analytical model to the previous one is used for the helicopter and its drive train. Firstly it is converted into a state-space system. Secondly it is connected to two other state space systems which model the gas generator controller and the power turbine controller.

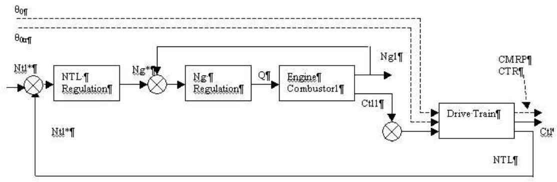

Fig. 10: Overview of the drive train -engine model

Stability margin can be evaluated from Bode diagram. The state-space model makes it possible to calculate time-related response to a collective pitch excitation.

1-4 Anti-vibration devices

The anti vibration devices are broken down into 3 classes:

- rotor hub
- rotor-to-fuselage interface - upper deck
- fuselage

Three categories (passive, semi-active and active systems) are distinguished in these three classes. These technologies are described in Fig. 11.

	PASSIVE	SEMI ACTIVE	ACTIVE
ROTOR HUB	RESONATORS : -PENDULUM MASS -BIFILAR -HUB ABSORBER -ROLLER ABSORBER	Auto-tuned Hub absorber	HHC IBC
UPPER DECK	BBQ SARIB ARIS RESONATORS	Auto-tuned SARIB	ACSR
CABIN	MECHANICAL RESONATORS	Auto-tuned resonators	Cabin actuators

Fig.11: Summary of anti vibration devices.

Dynamic absorbers

Blade or hub-mounted dynamic absorbers (pendulum mass, bifilar, hub or roller absorber) are the most popular anti vibration devices used in helicopters. The resonance tuning of these dynamic absorbers must be close to the rotor harmonic to be reduced.
The code allows computing the characteristics of dynamics absorbers in terms of geometry and tuning characteristics.

Upper deck suspensions

EUROCOPTER was one of the first helicopter manufacturers to offer a focal point suspension system, so-called "barbecue", on the market. This system was applied to the SA 330 Puma. The idea was to use soft elements to filter vibrations in the gearbox sump. The satisfactory results obtained in SA 330 boosted the development of several derivatives in AS 332, Dauphin and Ecureuil. A simplification is produced with the use of laminated elastomeric mounts and flexible composite bars.

New generations of suspension systems were developed in recent years such as SARIB® (which is a mechanical device) and ARIS® (which is an hydromechanical one).

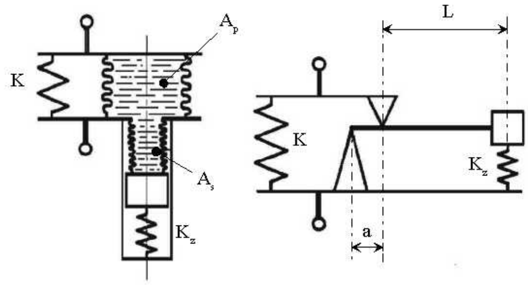

Fig.12: ARIS Anti-Resonance isolation system

SARIB® is an anti-resonance isolation system, consisting of 4 individual units equi-spaced around the gearbox as it is shown in Fig. 12. One of those units includes a leaf spring, the flapper arm and flapper mass. The leaf spring is designed with two parallel flanges at the stiff end. One bolt connects, through the outer bearing, the leaf spring, to a bracket on the gearbox deck and another bolt connects the leaf spring to a gearbox strut. Elastomeric bearings are provided at both connections.

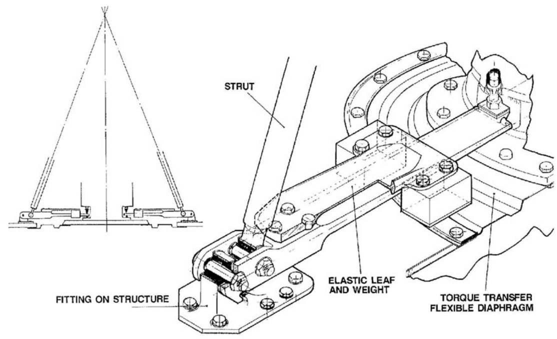

Fig.13: SARIB Anti-Resonance isolation system

The elastic side of the leaf spring is supported at the bottom of the gearbox. The amplification needed for flapper mass oscillation is generated by the flapper arms and their connections to the stiff part of the leaf spring, close to the gearbox strut. A membrane provided between the bottom of the gearbox and the fuselage transmits the rotor torque. Excellent vibration levels were achieved with SARIB® isolation for different missions and weapon configurations.

Analytical models have been developed for tall these anti-vibration devices. The fuselage is considered as a rigid body. It enables parametric sweeping and preliminary tuning (i.e. for the SARIB optimization of the flapping mass and the lever arm).

1-5 Parametric study for preliminary rotor dimensioning

Introduction

The rotor produces most of the helicopter vibrations. Therefore one of the most important point is the rotor modeling. A parametric study for the rotor dimensioning has been made in order to develop a general design strategy. The study has been managed on the large EUROCOPTER range.

A parametric study reflects the technology used at a given date and it must be regularly updated. Moreover the study is valid only to a point.

Evaluation of rotor characteristics

A basic analytical model and a statistic study make it possible to provide a first evaluation of all rotor and blade characteristics from the helicopter maximum all-up weight and the blades number.

Evaluation of hub-load

A semi-empirical approach has been researched in order to evaluate the hub load due to blade flapping. In order to limit the consequences of the numerous aeroelastic coupling effects (which are particularly important in transition flight cases), the study has been made for a 140 kt flight case.

Proceeding

From the blade modal calculation the modal root shear can be easily evaluated. Nevertheless the modal participation is required to assess the hub load. The whole difficulty lies in the fact that aerodynamic loads applied to the blade can only be evaluated by an aeroelasticity calculation.
In order to get round the difficulty and to be able to provide preliminary hub load evaluation, the first step has been to evaluate the relative modal participation by applying on the finite element model a simplified airload distribution.
The next step was to quantify the amplitude response for each harmonics. The study has pointed out the exponential decrease of potential energy (Ep) injected into the blade versus the harmonics (n) (Scheinman has already observed a similar phenomenon [8]).

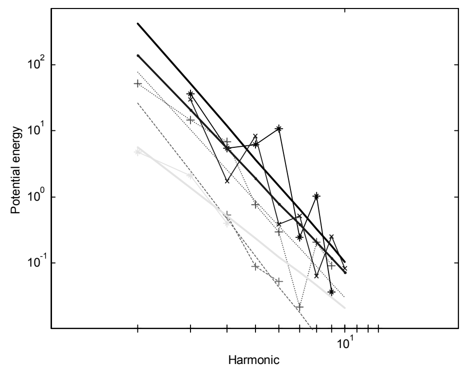

Fig. 14 Potential energy versus harmonics for EUROCOPTER helicopetrs

Ep seems to be given by $\log(Ep) = a\ \log(n) + b$. The coefficient a is approximately constant where as b increases versus Ω c where Ω is the nominal rotor speed and c the chord

In this way the participation of the flapping modes and then the hub load can be assessed.

The Fig. 15 summarizes the principle of the approach.

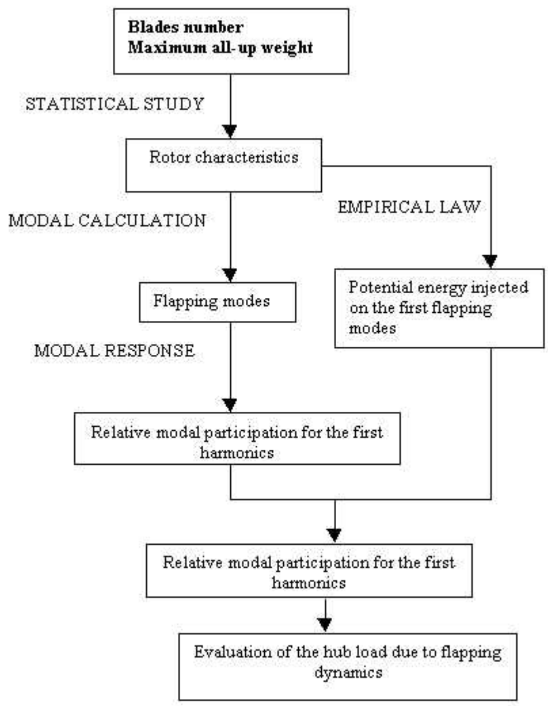

Fig.15: Parametric study overview

Results

This simple model is sufficient to provide the hub load envelope with a reasonable error margin from very basic input data. The results provided by this parametric study have been compared to hub-load identification (with in-flight measurements of the blade bending moments). The error doesn't not exceed 25%.

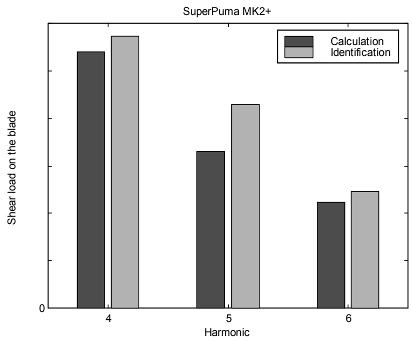

Fig. 17 Evaluation of the shear force on blade root for the EC225

2- Validation method

Each code developed and integrated in GAHEL must be validated. The devices used to do this can be divided in two categories: the first involves using a previous computing tool provided to give satisfactory results. The second method involves using test results.
The same conditions are to be applied for both. Moreover, a non-regression of the codes must be demonstrated whenever modifications are made. Every option delivered must be tested.

In the following parts different examples are presented in order to illustrate the validation process.

2-1 Tail drive shaft:

GAHEL

This study is based on an analytic model made with finite elements. Beam elements are selected with displacement in two directions and bending rotation.
The mass and stiffness matrices are manufactured, the eigen values and vectors are computed. The first three bending frequencies are determined. Fig. 18 presents the architecture of the Super puma MKII tail rotor drive as used in GAHEL.

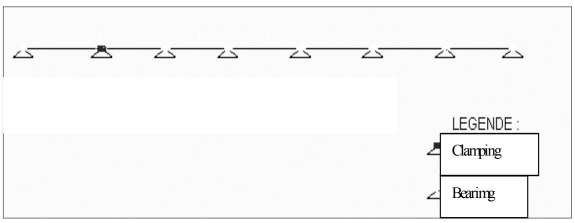

Fig.18: Super Puma MKII tail drive architecture.

The first bending modes computed are:
167.5 Hz: resonance of the first section
171.5 Hz: resonance of the central section
185 Hz.
The modal deflection of the second vibration mode is given in Fig. 19.

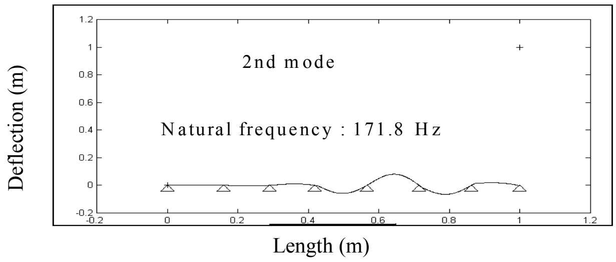

Fig.*19: 2nd modal deflection: GAHEL computation*

Test on the aircraft:

The purpose of the test is to identify the natural vibration modes of the tail rotor drive.
The study was limited to the second frequency: 170Hz, resonance on the central section.

F.E. model

The F.E. model is embodied with SAMCEF application. The elements used are beams with displacement and rotation in all directions.
The displacement in the X (length) and Y (bending) directions are fixed on the nodes connected to a bearing element.
The results for the first bending frequencies are:
165.5 Hz: resonance of the first section.
170 Hz: resonance of the central section.
183.7 Hz.

The modal deflection of the second mode is presented in Fig. 20.

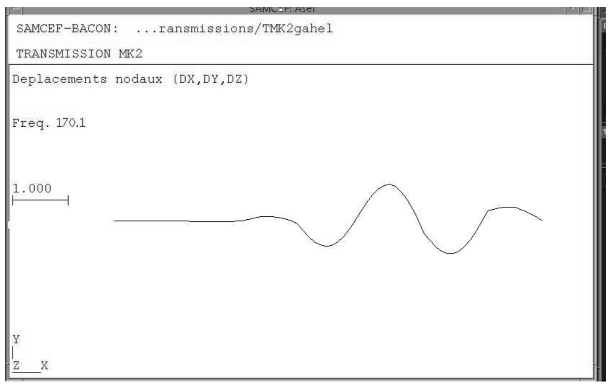

Fig.20: 2nd modal deflection: SAMCEF computation.

Summary

The results are summarized in the following table:

	FE model	TEST *	GAHEL
1st mode			167.5 Hz
2nd mode	170 Hz	170 Hz	171.5 Hz
3rd mode	183.7 Hz		185 Hz

*: Only the second mode was measured during this test.

The correlation between the three values is satisfactory. The GAHEL tail rotor drive model provides acceptable results.

2-2 Drive train

The validation proceeds on the first drive train mode of the Super Puma MKII.
The simulations undertaken with the analytic model and flight test results in the prototype are compared.

The transfer function study shows that two modes of resonance are produced either when the rotor is excited with the collective lever (θ_0) or when the fuselage is excited in yaw. Excitations with the cyclic stick do not produce any drive train / rotor / fuselage coupling.
The first mode frequency is 2.7 Hz and the second is 6Hz.

The parameters measured on the drive train already instrumented, are the main rotor mast and the engine shaft torque.
A preliminary study undertaken by EUROCOPTER shows that the engine governing system tends to amplify resonance in the 2.7 Hz but is insensitive to vibrations around 6 Hz.
The tests were thus intended to detect the 2.7 Hz mode.
Excitations were generated by the automatic flight control system with the collective lever. The excitation was sinusoid.

Fig. 21 presents a comparison between the temporal responses for parameters measured and determined with a GAHEL simulation throughout the mast torque excitation period.
The amplitudes are the same and a resonance occurs at the same frequencies.

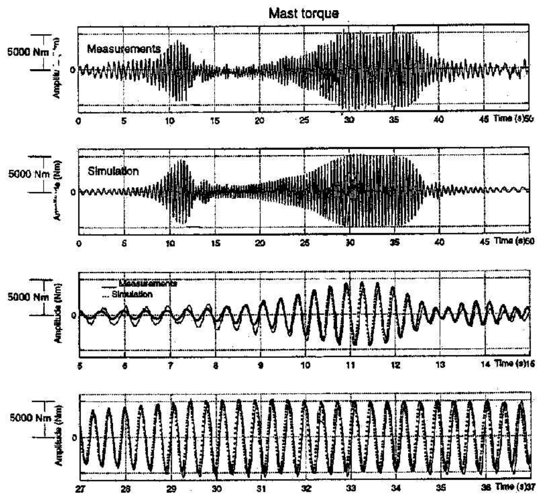

Fig.21: Drive train identification: calculation/measurement comparison.

2-3 Conclusion:

The same method is applied for every computing program. The reference codes used for comparison purposes with GAHEL can be programs already validated in the past.
Many flight and rig test results are available in EUROCOPTER Dynamics Department for comparison with GAHEL results.

3-Developement strategy

The objective is to have at the engineers disposal a reliable, easy to use tool which provides all fundamental dynamics simulation. Moreover this tool has to remain easy to develop for the other models integration required by the new needs.

GAHEL is developed in a unified environment. It means the units' architecture is standard which enable the engineers to reuse most of the interface functions and to concentrate their work only on the scientific development.
GAHEL runs on PC, which makes easier the access for the users.
Matlab application is used both to develop the interface and to generate most of the codes. It is well adapted to the GAHEL technical development because of its high matrix computing capabilities and the large range of functions. Time calculation and maintenance tasking (consecutive to Matlab version upgrading) remain reasonable.
The ability to call external programs (Fortran…) is used for the integration of helpful codes developed in the past.
Each program is validated and the code non- is checked for any modification.

Conclusion

GAHEL is a new general code for helicopter dynamics. It includes a set of computing programs and a technical database. The numerous applications highlight the reliability and the performances of the tool.

Aeronautic tests are technically difficult to prepare and expensive to perform. The general trend is to develop a new generation of tools that will help certify a new aircraft or rotorcraft with a minimum of tests.
GAHEL is now going to play a significant role in this new approach and to become a complementary tool to high-performance codes (as Host) which require a very accurate aircraft definition.

GAHEL development is permanent in order to adapt the tool to the new needs (extend the application field) and to improve the user-friendliness.
The current developments deal with the link between the different units in order to connect directly the outputs of a unit and the input of another one. In medium term it should make it possible to define entirely a virtual helicopter.

References

[1] : B. Vignal - R. Ferrer
A new general code for helicopter dynamics
25 th European rotorcraft Forum, 15-18 September 1999 - Rome

[2] : T. Krysinski
Active control of aeromechanical stability,.
AGARG symposium, Ottawa Canada, May 1996.

[3] : R.P. Coleman and AM Ingold
Theory of self-exited mechanical Oscillations of rotors with hinged blades, NACA report 1351, 1958.

[4] : P. Almeras
*Active control of aeromechanical stability applied by EUROCOPTER,*23 th European Rotorcraft Forum, Dresden, Germany, September 1997.

[5] : R. H. Blackwell, *Blade Design for Reduced Helicopter Vibration,* American Helicopter Society, 1981

[6] : Robert B. Taylor, *Helicopter vibration reduction by rotor blade modal shaping,* American Helicopter Society, 1982

[7] : E. Hashish, *An improved Rotor/Airframe Coupling Method for Nastran Airframe Vibration analysis*, Journal of the American Helicopter Society, 1992

[8] : Scheinman J. *A tabulation of Helicopter Rotor-Blade Differential Pressures, Stresses and motions as Measured in Flight*, NASA TMX-952, 1964.