HOST, a General Helicopter Simulation Tool for Germany and France

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ABSTRACT

The paper presents the main features of the HOST (Helicopter Overall Simulation Tool) software. It shows how the open architecture allows easy evolutions of the physical models and any association of them in various application fields. The main functions of HOST like trim calculations, time domain simulation and equivalent linear system determination are briefly described.

Some examples of application are given for handling qualities, rotor stability in forward flight, loads calculations and inverse simulation.

This new helicopter simulation code was chosen as a common basis for tool harmonisation between Eurocopter, ONERA and DLR. Some early achievements of this cooperation concerning dynamic engine models, parametric wake distortion, induced velocity models and parametric identification are presented.

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NOTATIONS

(A), (B)	Stability and control matrices of linear system
$[\hat{L}]$	Gain matrix
[M]	Apparent-mass matrix
R	Rotor radius
Rpower	Highest power of the Legendre polynomials used for the radial inflow distributions
$(X), (\dot{X}), (\ddot{X})$	State vector and time derivatives
(X_0), (X_{ic}), (X_{is})	Harmonic components of the state vector
(U)	Input control vector
$(v_{i0}, v_{i1c}, v_{i1s})$	First harmonic coefficients of the induced velocity field on the main rotor
Ω,OMG-RP	Rotational speed of the rotor
φ, PHI	Roll angle
θ, TETA	Pitch angle
ψ, PSI	Heading
Z	Altitude
NZ	Load factor
DDZ	Collective pitch (%)
DDL,DDM	Lateral and longitudinal pitch (%)
DDN	Pedal position (%)
PHEL,QHEL,RHEL	Angular speed components in helicopter frame

HOST GENESIS

Tools Harmonisation

The use of computers for scientific applications started some 20 to 30 years ago and was accompanied by the development of many tools in many different fields. In this very beginning of the computer age, people were in front of a white page and everything had to be created. Little experience of programming made that it was done more in accordance with individual feeling rather than with well-defined standards. As in any starting human activity, competition and inventiveness were the rule. Each one had to answer to his own needs and did it by his own way.

The helicopter activity was not an exception and a lot of rotor and helicopter simulation codes appeared in the seventies and early eighties. In the former Aérospatiale Helicopter Division, aerodynamicists developed elastic blade calculation tools for the prediction of dynamic loads that had to include a dynamic model of the blade. On their side, dynamicists made very similar codes for stability analysis, including blade aerodynamics models. In the same company, many tools were thus available coming from the same physical basis and addressing different aspects of a same global problem by different ways.

Information coming from diverse codes can highlight discrepancies in the results and make ask good questions… It needs however to make calculations more than once, which means consuming much manpower. In addition, the consistency of the results obtained by different tools is never guaranteed and it can be a problem.

A need for standardisation of the rotor models rapidly appeared inside Aérospatiale. In 1985, a team composed of people from both aerodynamic and dynamic departments developed the R85 model [1,2], a unique rotor code capable of rigid and elastic blade simulation. It solved the problem for a while but the work was not over.

Importance of the specifications

In that time a disk model only was used in the helicopter simulation code for trim, time history and stability calculations. This proved to be enough as far as calculations do not have to be conducted in the rotor limits area. The need for a blade element model appeared during the EUROFAR tilt-rotor study. In fixed-wing mode the inflow through the rotor disk is very important. It makes that the usual assumption of the disk model that the inflow is small when compared to the blade speed is no longer valid. It was considered that the simplest way to solve this problem was to implement the R85 rigid blade model inside the helicopter simulation code S80.

It was not straightforward and asked for a lot of code adjustments. R85 had been developed as an isolated rotor code and was designed only for trim calculations and stability analysis using a Floquet method. Keeping all the S80 options operative implied adapting the rotor model to time history and linear model calculations, linear models being used for stability and transfer functions analysis in S80. One of the basic assumptions in R85 was that the blade was at trim, which means that the harmonic components of the hinge moment are zero. This was not consistent with the need for time history calculations that required significant modifications in the rotor code. The problem was even more complex for the computation of linear model and this capability was abandoned in with the blade element model in the helicopter simulation code.

When implemented inside the S80 simulation model, the rigid blade element rotor model was quite different from the original R85 code. Simplifications brought by the specific implementation of the rotor model inside the helicopter code made that many capabilities developed for the isolated rotor were not available in the helicopter simulation: elastic blade or lead-lag degree of freedom of the rigid blade for example. If the former was not really needed, the latter had been skipped only to save some computation time for on-line applications. The need to analyse an air resonance problem asked for the lead-lag degree of freedom inside the S80 rotor model. Keeping it was not more expensive than skipping it. Once removed, putting it again was a huge job.

This illustrates another risk in model development: all possible applications of the model have to be clearly specified at the very beginning of the project. It is a pity to have all the model features necessary to deal with an urgent problem available, but not all in the same tool. A late adjustment can be very expensive and may even ask for a completely new development. Doing it at minimum cost led to two different tools with the resulting induced expenses for code management and validation and the harmonisation problem again came out…

HOST specifications

In the very beginning of the nineties, the decision was taken to face this harmonisation problem. The overall goal was to define and develop a code structure that would allow making work together any pieces of model developed in Eurocopter, provided that they fulfilled limited constraints to be specified.

The previous experience with codes existing at that time was taken in account and a substantial effort devoted to the specification activity. The people in charge of the code development as well as users have been questioned to understand their needs and the daily problems they had to solve. All the material coming from these discussions had been analysed and synthesised.

A unique tool was necessary that could as well address vehicle problems (loads calculation, tail part definition) than control law design or pilot-in-the-loop simulation. It would guarantee the consistency of all the analyses conducted in Eurocopter.

This unique tool had to be modular and made of one kernel in charge of all the general functions on one side and of separate physical models on the other. These models would simulate the physics of the phenomena and could be put together to represent any system made of a combination of existing parts: isolated rotor, classical single-rotor helicopter, tilt-rotor aircraft… The kernel would make possible three different kinds of calculations: trim, time history and calculation of a linear model. It had to achieve the management of options and provide general tasks like result analysis or simulation driving by flight recorded data.

It had to be possible to develop separately the models, in different departments and without a huge coordination work and to combine them as soon as needed.

Pilot-in-the-loop simulation had to be considered with minor modifications to the code. Deliveries for this use had to be automatic and as short as possible.

HOST DESCRIPTION

Basic features

The modular structure expected for HOST implies the definition of the physical model behaviour and of the data exchanges between them. The HOST kernel manages all general functions using a limited number of pre-defined functions for all the models and is in charge of data exchanges.

The functions of HOST are based on three main utilities: the trim calculation, the time domain simulation and the calculation of linear equivalent system. The others are obtained by pre- and post-processing routines and are a combination of that three ones.

To meet the requirements, all physical models have a time domain representation and all the calculations are done with imposed conditions: environment, movement (location, speed, acceleration), input controls, internal state, external forces, etc… Each simulation step is split into a *cinematic path* and a *force path*. In the first path, the models transmit the movement and the controls. In the second one, they are in charge of the calculations of forces and of the imbalance state: state functions (for trim calculations), and first or second order time derivatives of state variables depending of the order of the system (for time domain simulation and linear system calculation).

To insure that all the models will have all the needed data, HOST builds a global tree structure (fig. 1) based on all individual data exchanges.

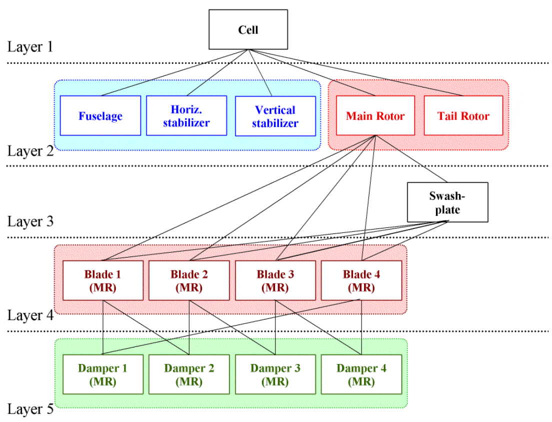


Fig. 1 : Example of tree structure

This structure contains several layers. All the items belonging to the same layer have no data exchange. This allows calling them in any order without problem. Based on this structure, the items are then ordered from the first of the first layer to the last of the last layer. During calculations, they are simply processed sequentially without any reference to the tree structure or to data exchanges. During the *cinematic path*, they are processed in the increasing order, and in the reverse order during the *force path*.

The pre-defined functions of the physical models are divided in two sets of routines. The first one contains the initialisation routines: reset of all common data, input of configuration description and of physical data, input of optional data, pre-calculation initialisations. The second one is made of the simulation routines for kinematics and forces calculations. If necessary, the models may use separate routines for time domain simulation and for trim calculation.

HOST main functions

Trim calculations

The trim calculation method is based on a harmonic representation of the movement and of the internal state. This representation is fully managed by HOST and the physical models never have to do harmonic to temporal transformation or harmonic analysis. This avoids the duplication of the processing and greatly simplifies the code.

For the harmonic representation of each state variable, HOST uses an equivalent harmonic representation of the corresponding state function. The trim is searched for the whole internal state taking into account the flight conditions and a trim law. A trim law defines the way in which the trim has to be found. It gives the parameters to be imposed (for example acceleration, power, flap angle…) and the parameters to set free to obtain the desired result (environment and movement parameters, input controls…). Almost all the parameters managed by HOST can be used to define a trim law.

The trim solution is obtained using a Newton method. The currently studied systems have up to several hundred influencing parameters. This number can be reduced using the isotropic conditions. Each remaining parameter is perturbed to get its influence on the complete configuration. The harmonic analysis of the state functions and of the selected outputs give the influence matrix used in the Newton method. The convergence scheme iterates with the same matrix to reach the solution. As the matrix calculation is time consuming, it is only done again when the matrix becomes inaccurate.

The user defines the number of harmonics used to find the solution independently for each rotor and for the helicopter (response to the B/rev for an isotropic rotor or to all harmonics for non-isotropic rotor). He can also select the trim law or define a specific trim law.

Time domain simulation

HOST organisation makes it the most basic function of HOST. Various integration methods are available. They all work on the same two sets of vectors containing respectively the movement (helicopter and rotors) and the internal state variables. The time evolution of any input control or any environment or configuration parameter can be imposed. This can be done through a graphical interface or using existing flight data files or previous simulation results.

The data structure allows an easy management of the time domain simulation. It can be stopped, analysed and continued with modified input control evolution. It can be restarted at the beginning without new trim calculations. For real-time purpose and use on flight simulator, it is also easy to take a snapshot of the simulation, and to restart it exactly at that time.

Equivalent linear system

Equivalent linear systems are used to study handling qualities and rotor or helicopter stability. They are obtained after trim calculation for fixed flight conditions. The response to perturbations of input controls, movement components and internal state is obtained using the same routines used for time domain simulation. For second order systems, the linear system is of the form:

$$(\ddot{x}) = (a')(\dot{x}) + (a)(x) + (b)(U)$$

where (x) is the state vector and (U) the input control vector.

This can be expressed as a first order system as follows:

$$\begin{pmatrix} \dot{x} \\ \ddot{x} \end{pmatrix} = \begin{pmatrix} (0) & (Id) \\ (a) & (a') \end{pmatrix} \begin{pmatrix} x \\ \dot{x} \end{pmatrix} + \begin{pmatrix} (0) \\ (b) \end{pmatrix} (U)$$

i.e.: $$(\dot{X}) = (A)(X) + (B)(U)$$

By that mean, all first and second order components can be studied through a single first order linear system. Before use, the linear system is submitted to two successive treatments: the inertial coupling correction and the quasi-static reduction. The inertial coupling takes into account the fact that the perturbations are applied on a system with a zero mean acceleration and not with the accelerations corresponding to the perturbations. After that, the system is reduced to the desired one. In this second step, all non-significant parameters are eliminated.

Once again, the user can completely determine the components he wants to keep and their order. It is then possible to study a simple 8 degrees of freedom aircraft configuration, or a much more complex elastic-blade rotor configuration. It is also possible to obtain the contribution of some parts of the helicopter and to study the effect of the linear system on all the outputs of the models.

Generally, to study the stability of periodic systems, the evolution of a perturbation is examined over a whole revolution. In HOST, the stability is done using the periodic components of the state variables.

In the case of a periodic system, the equivalent linear system depends on the azimuth:

$$\Delta(\ddot{X}) = (A_\psi).\Delta(\dot{X}) + (B_\psi).\Delta(X) + (C_\psi).\Delta(U)$$

To obtain a linear system with constant coefficients, the state vector is replaced by:

$$(X) = (X_0) + \sum_i \left[(X_{ic}).\cos(i\psi) + (X_{is}).\sin(i\psi)\right]$$

where the harmonic components are time functions. The time derivatives of the harmonic components are obtained from the time derivatives of the state vector:

$$\begin{aligned} (V) &= (\dot{X}) \\ &= (V_0) + \sum_i \left[(V_{ic}).\cos(i\psi) + (V_{is}).\sin(i\psi)\right] \\ &= (\dot{X}_0) \quad + \sum_i \left[\left((\dot{X}_{ic}) + i\Omega.(X_{is})\right).\cos(i\psi)\right. \\ &\qquad \left. + \left((\dot{X}_{is}) - i\Omega.(X_{ic})\right).\sin(i\psi)\right] \end{aligned}$$

$$\begin{aligned} (\Gamma) &= (\ddot{X}) \\ &= (\Gamma_0) \quad + \sum_i \left[(\Gamma_{ic}).\cos(i\psi) + (\Gamma_{is}).\sin(i\psi)\right] \\ &= (\ddot{X}_0) \\ &\quad + \sum_i \left[\left((\ddot{X}_{ic}) + 2i\Omega.(\dot{X}_{is}) - (i\Omega)^2.(X_{ic})\right).\cos(i\psi)\right] \\ &\quad + \sum_i \left[\left((\ddot{X}_{is}) - 2i\Omega.(\dot{X}_{ic}) - (i\Omega)^2.(X_{is})\right).\sin(i\psi)\right] \end{aligned}$$

Perturbing the input controls (U), the harmonic components $(X_0),(X_{ic}),(X_{is})$, and their first time derivatives $(\dot{X}_0),(\dot{X}_{ic}),(\dot{X}_{is})$, the harmonic analysis of the acceleration over one revolution gives their second time derivatives:

$$\begin{aligned} (\ddot{X}_0) &= (\Gamma_0) \\ (\ddot{X}_{ic}) &= (\Gamma_{ic}) - 2i\Omega.(\dot{X}_{is}) + (i\Omega)^2.(X_{ic}) \\ (\ddot{X}_{is}) &= (\Gamma_{is}) + 2i\Omega.(\dot{X}_{ic}) + (i\Omega)^2.(X_{is}) \end{aligned}$$

From which, the equivalent linear system with constant coefficients may be deduced:

$$\Delta \begin{pmatrix} \ddot{X}_0 \\ \ddot{X}_{ic} \\ \ddot{X}_{is} \end{pmatrix} = \begin{pmatrix} A_{00} & A_{0C} & A_{0S} \\ A_{C0} & A_{CC} & A_{CS} \\ A_{S0} & A_{SC} & A_{SS} \end{pmatrix} .\Delta \begin{pmatrix} \dot{X}_0 \\ \dot{X}_{ic} \\ \dot{X}_{is} \end{pmatrix} + \begin{pmatrix} B_{00} & B_{0C} & B_{0S} \\ B_{C0} & B_{CC} & B_{CS} \\ B_{S0} & B_{SC} & B_{SS} \end{pmatrix} .\Delta \begin{pmatrix} X_0 \\ X_{ic} \\ X_{is} \end{pmatrix} + \begin{pmatrix} C_0 \\ C_C \\ C_S \end{pmatrix} .\Delta(U)$$

This second order system contains all the information required to study coupled location/speed perturbations. It results from this that collective, progressing and regressing modes may be analysed. As shown previously, it is transformed in a first order system, and is processed in a completely generic way. It allows using very simple methods of analysis to study quite complex configurations.

Software development

Though HOST is based on an object representation, an object oriented programming language was not chosen. The FORTRAN language, more widely used for scientific software programming, was preferred.

The software is organised in three layers: the kernel, the interface routines and the physical models. The kernel contains all generic routines: tree structure generation, input/output management, man/machine interface, trim calculations, time dependant simulation, linear system calculation, etc … All that routines perform general treatments without any knowledge about the studied configuration (helicopter, isolated rotor or anything else). On the other hand, the physical models use very specialised routines with predefined data and variables totally independent of HOST variables. They have to be developed using a time domain representation and to fit the basic functions defined by HOST. The interface routines define for each physical model how it will work with the others. For that, they check that they are correctly plugged in, and set the input/output data exchanges with HOST. Each model has a main interface routine to deal with the required functions. By that mean, a single call is enough to manage any physical model. This highly simplifies the model integration in HOST kernel: a few lines are enough to enable or disable the model for all HOST functions without knowing anything about the code.

This modular structure gives to HOST a high flexibility and makes it easy and safe to evolve. The development of a new model never reacts on existing ones except in case of new connection rules.

Physical models

All the physical models existing in previous aeromechanics simulation codes such as R85 for isolated rotor and S80 for complete helicopter were split into elementary models such as blade, damper, aerodynamic components, etc… When needed, the formulation was changed to a time domain one. In particular, it was the case for the elastic blade model [1-3] for which the second time derivatives of the generalised coordinates were extracted from the Lagrange's equations. Basically the models were unchanged and the first validation tests of HOST showed a perfect comparison with existing codes, saving all the validations made for years.

From the beginning, just by the fact that all the models were gathered in the same code and processed with the same general functions of the HOST kernel, their potential was highly increased. The same data set provides the material for handling qualities, stability and load calculations.

APPLICATIONS

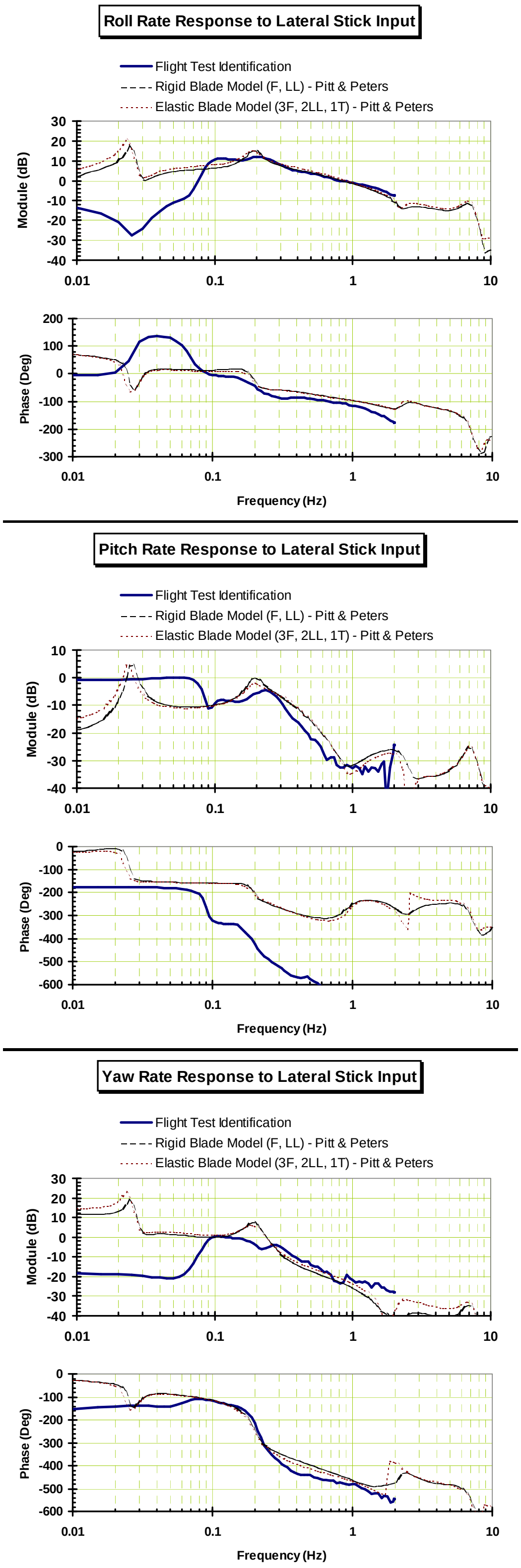
As for any new tool, a learning time was necessary for users when HOST operation started. They however soon realised that it opened new possibilities and allowed more efficient work. The following paragraphs illustrate some of these aspects.

Rotor flight loads calculations

With the previous tools used in Eurocopter, blade elastic modelling was only available in an isolated rotor model. Rotor dynamic loads calculation was thus a two-step process. The helicopter trim was first computed using the S80 helicopter simulation model. The resulting rotor balance was then introduced as input in the isolated rotor model that was trimmed so as to match the same force components.

This implied user-made operations that always are time consuming as well as source of mistakes. The necessary effort could be very high when calculations were made at the limits of the flight envelope, which is nevertheless often required in flight loads analysis.
It is not easy to get fully converged results in such extreme flight cases and find it with two different tools is even much more difficult. There are discrepancies in the physics of the phenomena and in the models themselves that make that the trim obtained in a limit case with the rigid blade model cannot be met with the elastic blade tool. When the required helicopter trim was reached, it happened that the rotor model did not converge with the resulting force components. It need to start again, look for a different equilibrium and try again the isolated rotor calculation… until successful.

HOST well improved this process. The helicopter trim can be directly calculated with the elastic blade model, avoiding thus any transfer of data and reducing the risk of error. It also guarantees that the resulting rotor balance is now fully consistent with the helicopter trim. Difficulties in the convergence process are not completely avoided but their solution is made much easier. One calculation is enough to be aware of the problem. In addition HOST new functions eases the way out. User-defined trim laws allow reaching the result by the shortest path. Storage and loading of previous trim results make possible to save any progress towards the investigated flight case and start again from there. Time history calculations allow exploring the vicinity of a trim point and getting a transient flight case when equilibrium cannot be reached.



<u>Fig 2 :</u> AS 332 L2 100Kt Level flight Influence of the elastic blade model on the response to lateral stick input

Experience proved that the whole process is much improved. Extreme flight conditions could require up to four or five hours of work to come to the solution in the past. They never ask for more than half-an-hour with HOST. An even higher ratio exists for more standard cases, because of the removal of user-made data transfer. HOST proved to be a big step forward in this area.

Elastic blade model for flight mechanics

In addition to the usual flight loads calculations, HOST allows to apply the elastic blade model to other problems.

The influence of the blade modes on flight mechanics aspects like control response has been checked. For example, Figure 2 presents the response of an AS 332 Super Puma L2 helicopter to lateral stick input in 100 Kt level flight conditions. The flight identified transfer functions have been extracted from flight measurements [4] and are drawn with a thick full line. HOST simulation results with both rigid (flap and lead-lag degrees of freedom) and elastic blade models (3 flapping, 2 lead-lag and 1 torsion modes) are superimposed. Linear models (size 22 for the rigid blade and 46 for the elastic blade) have been calculated through a small perturbation technique and the model transfer functions derived from them [4].

It can be seen that both simulation results are very similar, either for direct response or cross-coupling effects. This is not a scoop and the usual assumption of flight mechanics studies that the rigid blade approximation is enough in the piloting frequency range is still valid.

Similar calculations have been done on a Bo105 helicopter equipped with a rigid rotor that seems to give a more important effect. More analysis is necessary to conclude on this aspect.

Elastic blade calculation in flight mechanics area was not a goal of HOST development. It is however a result that not only trim but also time-history and linear model calculations with elastic blade model are now possible. It does not ask for a special effort: developing a new model according to HOST rules guarantees that all HOST functions as well as results processing tools (like transfer function or stability analysis) are available.

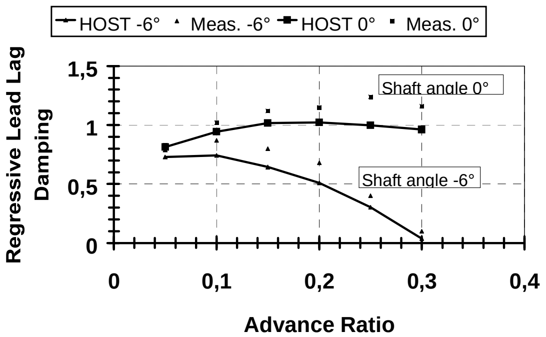
Rotor stability

The stability analysis method of HOST enables the study of collective, progressing and regressing modes.

The regressing lag mode damping evolution versus advance ratio is generally considered as quite difficult to predict. It was then interesting to compare HOST calculations with experimental results. The U.S. Army Aeroflightdynamics Directorate obtained tests results presented in [5] at realistic tip speeds on a hingeless isolated rotor. The given model description was used to generate the HOST data files.

Elastic blade calculations were conducted with flap, lag and torsion modes using the Meijer-Drees induced velocity model. The linear equivalent system was constituted of the mean and first cyclic components of each mode and of their first time derivatives.

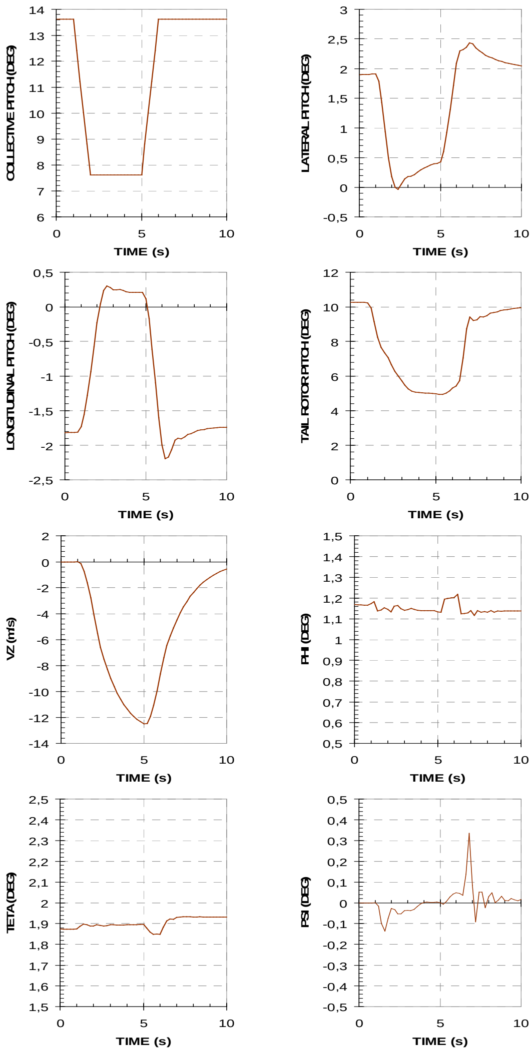
The results presented on fig. 3 were obtained with an additional structural damping of 0.6%. It can be seen that the damping trend is well predicted for both shaft angles (0° and -6°).



<u>Fig. 3 :</u> Regressing lag mode damping

Inverse simulation

The method used by HOST is a time simulation with objectives on outputs of the models. The user can select one or more outputs and the controls required to fit the desired behaviour. The choice of the outputs is not limited to trajectory: loads, rotor behaviour, speed or helicopter attitude may all be used in this kind of inverse simulation. The process can be combined with imposed evolutions on the remaining input controls.



<u>Fig. 4 :</u> Test case of inverse simulation - Response to collective pitch with zero angular speed

The error estimator (E) is the mean value on a fixed time step ΔT_{error} of the discrepancy between the objective vector (Obj) and the output vector (Out). To make possible the comparison between different control evolutions, it is necessary to memorise the state at the initial time step and to restore it after the simulation. The influence matrix of the input controls on the discrepancy vector is obtained by a perturbation method:

$$u(t)=u_0 \qquad \text{for } 0\leq t \leq\Delta T_{error} \Rightarrow (E_0)$$
$$u(t)=u_0+(\Delta u/\Delta T_{error}).t \qquad \text{for } 0\leq t \leq\Delta T_{error}$$
$$\Rightarrow (E)=(E_0)+ (\Delta(E)/\Delta u)_.\ \Delta u\ .$$

The process is then based on an iterative scheme:

- storage of the current state,
- estimation of error on the time step ΔT_{error} using the current evolution of the input controls,
- calculation of the correction on input control evolution corresponding to the error cancellation (it is possible to iterate with the error estimation for difficult manoeuvres with highly non linear evolutions),
- restoration of the previous state,
- simulation with the new control evolution on an inverse simulation time step ΔT_{inv} greater than the integration time step Δt and smaller than the error estimation time step ΔT_{error}.

Figure 4 gives an example on a test case with an imposed decrease of the collective pitch and maintaining the pitch, roll and yaw angles using an inverse simulation with a zero angular speed objective. This simulation was done with a numerical rotor model using ΔT_{inv}=0.1s and ΔT_{error} =0.5s. It shows a very good behaviour of the method with only local discrepancies during transient phases with fast variations of the flight conditions.

A more difficult calculation test was conducted on a looping for a Panther helicopter (fig. 5). In this case the four controls were used to fit the angular speed and the load factor. Despite noisy angular rates obtained from flight test measurements, figure 6 shows a good agreement between flight (dotted line) and simulation (continuous line). This result was slightly more difficult to obtain. The basic parameters were the same than for the previous case (ΔT_{inv}=0.1s and ΔT_{error} =0.5s), but it was necessary to let the code iterate up to 3 times on each inverse simulation time step ΔT_{inv} to better fit the objective evolution (essentially to go through the upper part of the loop).

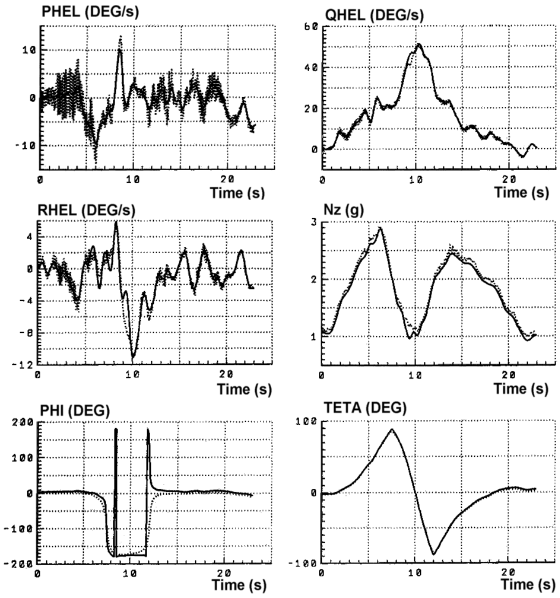


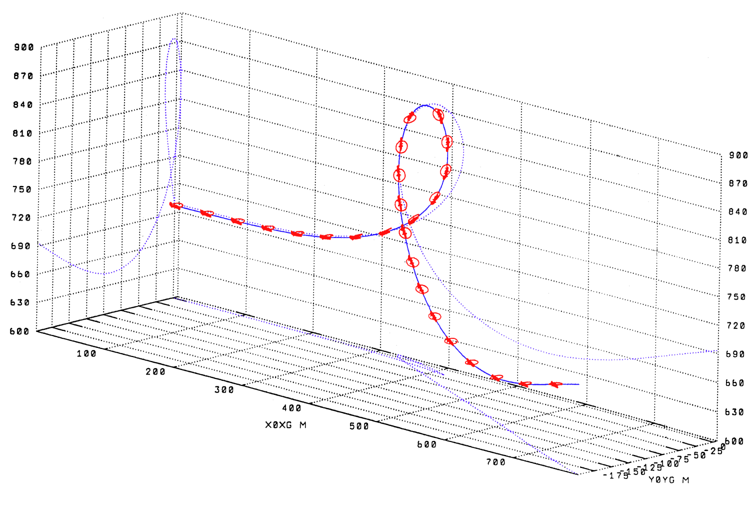
Fig. 6 : Looping of a Panther helicopter

This new function is available for any physical models whatever complex they are. Taking benefit of the HOST structure, it was developed and finalised in only three weeks.

THE HOST GROUP

The HOST development was well advanced when former MBB and Aérospatiale helicopter divisions merged and built Eurocopter. Both had their own tools available and once again tool harmonisation was in question. HOST was already available and was a structure able to receive models coming from different sources. As MBB did not have a similar unique tool, HOST was chosen as the starting point of Eurocopter's aeromechanics code that will

Fig. 5 : Calculated trajectory of a Panther helicopter looping



incorporate models coming from both sides.

Not only industry is interested in helicopter flight simulation. Research establishments also spend a considerable effort to improve and validate simulation tools. Due to historical reasons, ONERA started their flight mechanics activity with Aérospatiale S80 simulation code and naturally switched to HOST when it was available. After Eurocopter foundation it seemed desirable that DLR and ONERA research activities in the helicopter area be harmonised. For flight mechanics codes only DLR was missing. It was disappointing, especially when their well-known expertise in this field was considered. DLR was thus invited and agreed to join the HOST users, making HOST to be shared by the German-French helicopter community. It is expected that four partners working on the same code will optimise manpower spending and make research results directly available to everybody.

The following part of the paper presents some early achievements of this cooperation.

Flight mechanics improvements taken from SIMH (DLR)

DLR's experience in flight dynamics modelling, validation and real-time applications was documented in several publications based on the DLR developed helicopter simulation platform SIMH [6-8].

In a first step two modelling approaches were taken from SIMH and implemented into the HOST environment.

Parametric wake distortion approach

In several publications during last years it was pointed out that the cross-coupling prediction deficiency of non-linear helicopter simulations could partly be solved by an improved description of the downwash dynamics. Starting from Pitt & Peters approach, driving the dynamics of longitudinal and lateral variations of the inflow by the dynamics of aerodynamic pitch and roll moment variation an extended approach was formulated taking into account the tip path plane motion on the distortion of the wake. In a kind of precalculation using a vortex ring approach [9] the effect was investigated and estimated to get a global parametric approach fitting into the well known Pitt & Peters dynamic downwash description.

This model has been implemented into HOST as an additional option of the rotor model. It can be used when the necessary observations, namely total angular velocity of the tip path plane in pitch and roll, are fed into the rotor model as additional observations, and if the Pitt & Peters induced velocity model is selected. The parameters of this model can be set to different values for the longitudinal and lateral axes, and can be functions of the speed of the helicopter.

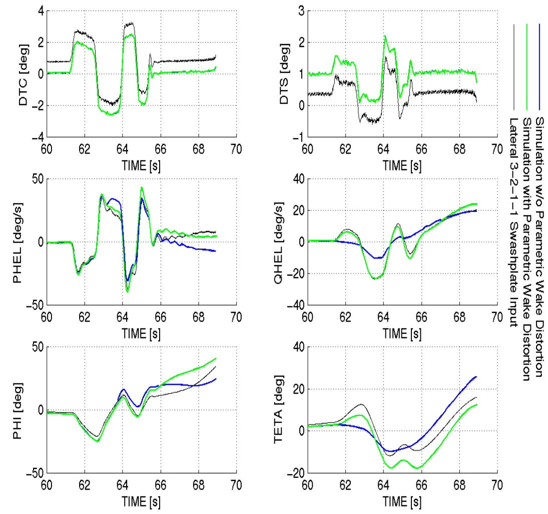
Mathematical model and implementation realisation

The model formulation is a direct extension of the Pitt & Peters induced velocity model. The longitudinal and lateral axes are considered separately, and the blade dynamics are taken into account as well as the rotational velocities.

$$[M]\begin{bmatrix}\dot{\lambda}_0\\ \dot{\lambda}_s\\ \dot{\lambda}_c\end{bmatrix}+\left[\hat{L}\right]^{-1}\begin{bmatrix}\lambda_0\\ \lambda_s\\ \lambda_c\end{bmatrix}=\begin{bmatrix}C_z\\ C_l\\ C_m\end{bmatrix}_{ae}+\frac{1}{\Omega}\left[\hat{L}\right]^{-1}\begin{bmatrix}0\\ K_p\left(p-\dot{\beta}_s\right)\\ K_q\left(q-\dot{\beta}_c\right)\end{bmatrix}$$

The model can be activated by using a rotor option switch.

To demonstrate the model improvement achieved, for a BO 105 configuration a validation run with a lateral 3-2-1-1 control input in hover was performed and the simulation output compared with the flight test data. Figure 7 shows the comparison.



<u>Fig. 7 :</u> Effect of parametric wake distortion - Comparison between flight test and simulation result

Dynamic engine modelling

Another point of main emphasis in model development of DLR was the improvement of the dynamic yaw response of helicopters due to collective input or required main rotor torque variations, respectively. To improve the prediction of this coupling response an engine model was formulated describing the dynamics of the engine-drive-train-rotor system. The investigations and results are described in detail in [10]. The model, implemented in the offline code SIMH and the real-time system simulator of DLR and validated for the BO105 with its ALLISON engines was transferred to the HOST environment. The implementation can be described as follows

Allison 250 C20 engine

The BO105 research helicopter at DLR is powered by two Allison 250 C20 B engines, which are twin shaft gas turbine engines with free running gas generator turbines. The power turbine is mechanically linked with the helicopter rotor drive through a gearbox. The engine is controlled by a dual-governor system, regulating fuel flow in dependence of both rotor speed (gas generator and power turbine) and compressor outlet pressure. Also a feed forward of pilot collective control setting is provided. Under normal flight conditions power turbine rotor speed is governed to the "100% n_2"-point (6016 rpm), corresponding to a main rotor speed of 44.4 rad/s for the BO105 helicopter.

The engine is modelled by a linearised second order state space model, which is derived from a sophisticated 22nd order fully non-linear model, describing all necessary engine dynamic and thermodynamic quantities. The obtained second order model

$$\begin{pmatrix} \dot{n}_1 \\ \dot{n}_2 \end{pmatrix} = \begin{bmatrix} -\frac{1}{\tau_1} & 0 \\ k_2 & -\frac{1}{\tau_2} \end{bmatrix} \cdot \begin{pmatrix} n_1 \\ n_2 \end{pmatrix} + \begin{pmatrix} k_1 \\ k_3 \end{pmatrix} \cdot w_f - \begin{pmatrix} 0 \\ \bar{k}_4 \end{pmatrix} \cdot N_{eng}$$

Only accounting for the power and gas turbine inertia, it is a good approximation of the dynamic engine as a function of fuel flow and external moment and is therefore well suited for application in helicopter (real time) simulation.

After short reformulation of the above equation the differential equations for gas generator (1) speed and power turbine (2) moment are obtained:

$$\dot{n}_1 = -\frac{1}{\tau_1} \cdot n_1 + k_1 \cdot w_f \qquad (1)$$

and

$$N_{eng} = -\frac{1}{\bar{k}_4^*} \cdot \dot{n}_2 - \frac{1}{\bar{k}_4 \cdot \tau_2} \cdot n_2 + \frac{k_2}{\bar{k}_4} \cdot n_1 + \frac{k_3}{\bar{k}_4} \cdot w_f \qquad (2)$$

From equation (1) we can see, that the n_1 rotor speed and with that the produced amount of gas is directly governed by the fuel flow. The engine torque again is linear dependent on the produced gas flow and thus on n_1 rotor speed. The direct dependence of rotor torque on thermal gas flow energy supplied by the fuel injection is expressed by the third term in equation (2). The torque increase or decrease for external rotor slow down or speed up respectively is considered in the second term. Finally the factor $1/\bar{k}_4^*$ is directly correlated with the power turbine inertia. The model is applicable to similar engines than the Allison, because the coefficients are physically meaningful or their values can be estimated for similar engines.

Governor

The control of the fuel flow is formulated as follows

$$\dot{w}_f = \frac{1}{\tau_{gov}} \cdot \left(-k_n \cdot (\Omega - \Omega_{nom}) + k_\Delta \cdot DT0 - w_f \right)$$

The governor implemented up to now is only a proportional governor. The integral and derivative terms have been neglected and are subject to investigations using the parameter identification tool.

HOST implementation

The model has been implemented as an additional “specific engine model” of the existing “ENGINE” model. The main asset of this model is its fully parametrical nature, which allows to model any engine with hydromechanical governor, provided it has been identified according to the formulation used. In addition the transmission model was modified to allow for validation purposes a trim calculation with offsets in rotor speed from nominal values.

Two validation runs for BO 105 configuration were performed, a collective 3-2-1-1 input and a pedal 3-2-1-1 input in hover. In Figure 8, the prediction capability for the rotor rpm variations is shown.

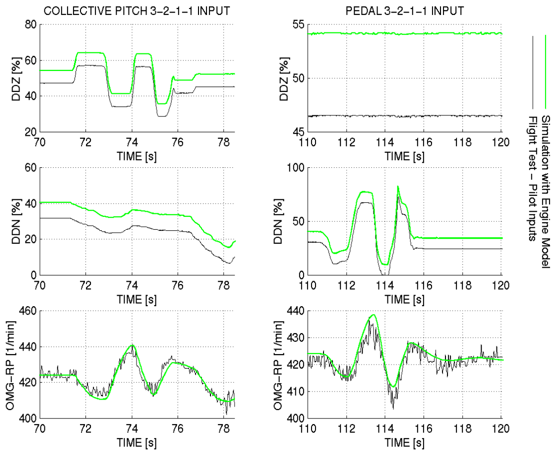


Fig. 8 : Rotor rpm-variations predicted by the dynamic engine model - Comparison between flight test and simulation result

Modelling of the rotor induced velocities (ONERA)

ONERA develops models for rotorcraft simulation in different areas: aerodynamics, acoustics, aeroelastic studies, ... Concerning helicopter flight dynamics, ONERA has contributed to the modelling development of the Eurocopter's simulation codes (named successively S80, then S89 and today HOST) for many years. In order to give an example of these contributions, here is presented a synthesis about the modelling of the induced velocity field by a rotor.

Two kinds of modelling approaches can be distinguished:

- the models representing the rotor inflow with a finite number of states (using commonly a Fourier's decomposition for the azimuthal variations),
- the vortex wake models allowing to compute the induced velocity vector at any location (rotor inflow and interferences) with the Biot and Savart induction law.

Finite states rotor inflow models

First harmonic inflow

Up until now, the most widely used rotor inflow models for helicopter flight mechanics have been limited to the first harmonic approximation with a linear radial distribution along the blade span. The number of states is reduced to the three Fourier's coefficients, namely:

(v_{i0}) the mean inflow,

(v_{i1c}, v_{i1s}) the longitudinal and lateral inflow gradients.

Hence the local downwash at the location (r, ψ) on the rotor is calculated with the usual expression:

$$V_{iz}(\bar{r},\psi) = V_{i0} + \bar{r}.\left(V_{i1c}.\cos(\psi) + V_{i1s}.\sin(\psi)\right)$$

with $\bar{r} = \dfrac{r}{R}$

By this way the computational cost is reduced allowing real-time simulations.

* Steady inflow models:

Initially in S80, the Meijer-Drees model [11] was used with an empirical time lag on the mean downwash. The Coleman model [12] was introduced in S89 by ONERA for the Common Baseline Model used in the GARTEUR AG06 [13]. Later we added the Blake and White model [14], which improves the prediction of the lateral control required to trim the helicopter for transitional forward speeds [15].

The differences between these simple models are mainly due to the way to account for the wake skew angle in the computation of the longitudinal inflow gradient (v_{i1c}).

All these analytical models are based originally on a quasi-steady assumption. A significant upgrade for dynamic simulations was achieved with the Pitt & Peters model [16].

* Dynamic inflow:

ONERA showed in [17], that the simulation of the on-axis responses, particularly for pitch control inputs in forward flight, is well improved by this first harmonic - first order dynamic inflow model. The pitch to roll cross-responses in forward flight (80 Kt. Bo105) are also better predicted [17]. These positive effects on the flight dynamic simulation of a hingeless rotor helicopter like the Bo105 are one of the most important results pointed out by the GARTEUR AG06 [13].

But as noticed in [17], the dynamic inflow on the main rotor represented with the Pitt & Peters model has no significant effect near hover on the cross-coupling. That is why ONERA worked on the rotor wake distortions. First it was verified in [17], that the most important effects could be modelled with linear extensions of the inflow gradients (v_{i1c}, v_{i1s}), proportionally to the pitch and roll motions of the rotor tip-path-plane. Then as mentioned previously, an extensive parametric study was performed with a flexible vortex rings wake model. The effects of the airspeed, the location of the centre of rotation, the climb-descent rate and the rotor thrust were investigated in [9]. Finally as also reported in [9], the modelling of this database by a neural network provided a close form assessment of these distortion effects, which was implemented in HOST to complete the dynamic inflow model.

The rotor wake distortion effects are important at low speeds. However in forward flights (approximately for $\mu > 0.15$, depending on the thrust and on the vertical speed), other phenomena seem to prevail as sources of pitch-roll coupling (e.g. compressibility, unsteady aerodynamics coupled with blade flexibility and torsion, etc.).

With these first harmonic models, the induced velocity field on the rotor is represented by a disc (due to the linear distribution) moving vertically with (v_{i0}) and tilting with (v_{i1c}, v_{i1s}). Now a more realistic representation requires to take into account the higher harmonics and the non-linear distributions along the blades span, which is more compatible with the level of realism of a elastic blade model.

Higher inflow modes

* Adaptable finite state dynamic inflow model:

Peters and He developed in [18-20] a more comprehensive theory not limited in harmonics and allowing to account for non-linear radial inflow distributions.

The presentation that we proposed here, shows that this finite state dynamic inflow theory is inspired by the "Proper Orthogonal Decomposition" (POD) method [21]. The POD techniques allow to transform a partial derivative equation into an ordinary differential equation. In order to be decomposed into mono-dimensional variables, the studied physical multi-dimensional variable (here the induced velocity which is time and space dependent $v_i(t, x, y, z)$) must be projected on an orthogonal basis. One difficulty is to determine the adequate form functions representing the vectors of this orthogonal basis.

For the choice of a pertinent basis, both models [16 and 18] took advantage of the work of Kinner [22], who demonstrated the first that the Legendre's polynomial functions in ellipsoidal coordinates are well suited for the rotor aerodynamic studies. Indeed, these Legendre's functions allow to account for a discontinuity through a circular disc, while still satisfying Laplace's equation. Therefore these orthogonal functions are ideal candidates to represent the pressure field associated with a rotor disc, since, as it is well known, the flow through a lifting rotor is submitted to a discontinuity of pressure. For the azimuthal variation, the classical Fourier's decomposition is applied.

The Laplace's partial derivatives equation expressed in the ellipsoidal coordinate system can be split into three ordinary differential equations (ODE). The general form of the solutions of these ODE have for basis: the trigonometric functions ($\cos(h\psi)$ and $\sin(h\psi)$) and the Legendre's associated polynomials.

Finally, each component of the induced velocity vector at a point on the rotor is expressed through a double development, for example for the downwash component:

$$w_i(\bar{r},\psi,\bar{t}) = \sum_{h=0}^{\infty} \sum_{\substack{f=h+1,\\ h+3,\ldots}}^{\infty} \phi_f^h(\bar{r}) \times \left[w_{ic}{}_f^h(\bar{t}).\cos(h\psi) + w_{is}{}_f^h(\bar{t}).\sin(h\psi) \right]$$

- in Fourier's series for the azimuthal variations (h is the harmonic number),
- by means of Legendre's polynomials for the radial distributions (f is the radial mode shape number associated with the harmonic h).

$(\bar{r}, \bar{t})$ are the non-dimensional radius and time variables.

As explained in [18], $\left(\phi_f^h\right)$ are the radial shape functions corresponding to the normalised Legendre's polynomials of the first kind. The standard normalisation is done for $\left(\bar{r} \in [-1,1]\right)$. In order to have an orthonormal basis, adapted to describe the radial inflow distribution along the blade span [0,1], these radial functions are divided by the ellipsoidal coordinate $\left(\nu = \sqrt{1-\bar{r}^2}\text{, on the rotor}\right)$:

$$\phi_f^h = \frac{\overline{P}_f^h(\nu)}{\nu}$$

According to the POD interpretation, the time dependent inflow states: $\left(w_{icf}^{\ h}\right)$ for the cosine terms and $\left(w_{isf}^{\ h}\right)$ for the sine terms, are the eigen-modes of the induced flow field on the rotor. Their dynamics are governed by the first order differential equations coming from the fundamental mass and momentum conservation equations:

$$\overbrace{[M]\left\{\begin{matrix}\vdots\\ \left\{\overset{*}{w}_{ic}{}_f^h\right\}\\ \vdots\end{matrix}\right\}}^{Unsteadiness} + \overbrace{\left[\tilde{L}_c\right]^{-1}.[V]\left\{\begin{matrix}\vdots\\ \left\{w_{ic}{}_f^h\right\}\\ \vdots\end{matrix}\right\}}^{Convection\ part} = \overbrace{\frac{1}{2}\left\{\begin{matrix}\vdots\\ \left\{\tau_c{}_f^h\right\}\\ \vdots\end{matrix}\right\}}^{Excitation}$$

$$[M]\left\{\begin{matrix}\vdots\\ \left\{\overset{*}{w}_{is}{}_f^h\right\}\\ \vdots\end{matrix}\right\} + \left[\tilde{L}_s\right]^{-1}.[V]\left\{\begin{matrix}\vdots\\ \left\{w_{is}{}_f^h\right\}\\ \vdots\end{matrix}\right\} = \frac{1}{2}\left\{\begin{matrix}\vdots\\ \left\{\tau_s{}_f^h\right\}\\ \vdots\end{matrix}\right\}$$

In [18-20] was detailed the calculation of the different terms:

- apparent-mass matrix [M] for the dynamic part,
- gains matrices [L] and the mass-flow matrix [V] for the convection part,
- the vector of the generalised forces [τ].

After this summary of the approach, some key points will be highlighted.

- Choice of the order of the coupled dynamic system “lift excitation – inflow response” :

The excitation terms on the right hand side are calculated from the rotor lift distribution, with the same kind of Fourier-Legendre's analysis and at the same order than those wanted by the user to describe the inflow. The choice of the number of harmonics (Nh) and of the highest order (Nf) for the radial polynomials is therefore fundamental.

The analysis of the lift distribution rotating with each blade should be sufficiently detailed to excite the flow field in the bandwidth for which the modelling is intended for. The richer the excitation is, the more realistic will be the dynamic inflow distribution. Later, we intend to study the application of the POD techniques to select the most representative form functions. Some mathematical methods could be helpful to determine the most important eigen-modes contributors to represent the “energy” of the flow field.

- Limiting assumptions :

Besides the classical assumptions of this theory developed for an incompressible potential flow with small perturbations, some more implicit hypothesis should be brought to the fore.

Concerning the wake, in the comparisons with the vortex method, it should be kept in mind that there is no representation of the vortices. Therefore the Blade Vortex Interactions (BVI) can not be captured, thus this model is not suited for the aero-acoustic studies. Moreover, the general form of the wake is supposed to be a rectilinear cylindrical geometry (hence without distortions). This simple prescribed geometry is assumed for the calculation of the gain matrices.

* Place of this model among the other inflow models available in HOST:

On the side of the analytical models, two groups should be distinguished:

- the models without a real dynamic (despite of the empirical time lag added for the mean inflow), are more suited to the trims calculations (Coleman, Meijer-Drees). This group has been completed with the introduction of the Blake and White model [14,15] ;
- the dynamic inflow modelling [16], which is more dedicated to the dynamic simulations.

On the side of the numerical models, a vortex-lattice wake model "METAR" has been used up until now only for the trim computations of the induced velocity field on the main rotor.

Therefore the idea arose to complete the spectrum of the rotor inflow modelling. Indeed, there is an actual gap between the three state models and the complex non-uniform flow field induced by a vortex lattice method. The development of the circular vortices model [15 and 17], can be seen as a first attempt to fill this lack from the side of the vortex approach. The model is less time consuming than the classical vortex lattice models requiring a numerical integration of the influence of each vortex segment. Therefore it is already used for dynamic simulations.

The generalised finite state dynamic inflow model previously presented is ideally suited to fulfil the needs of the HOST user, who can be interested in performing with his tool very different kinds of simulations for performance-trims, dynamic studies in the time or frequency domain, real-time or non-real-time flight dynamics, rotor aerodynamics and aeroelastic analysis. Indeed, thanks to its finite dynamic state formulation, the model can be adapted to a wide range of problems.

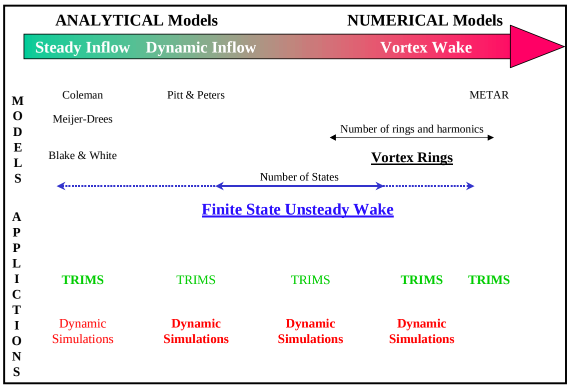


Fig. 9 : Status of the rotor inflow models available in HOST

As shown on this synoptic table (fig. 9), by the choice of the number of states, the complexity of the dynamic inflow field can be tuned: from the most simple one (dynamic uniform inflow), through the first harmonic dynamic inflow model corresponding to the Pitt & Peters model, toward more realistic non-uniform fields approaching the complex distributions obtained with the vortex methods.

Compared with the state of the art of the rotor vortex models, an important point, which should be underlined, is that this approach is particularly adequate for the flight dynamic simulations. Indeed, the time marching vortex models are still rarely used because of their complexity and computational cost, whereas the Finite State Unsteady Wake approach ("FiSuW") is already based on a dynamic formulation. On the other hand, the blade vortex interactions are not represented, but these local impulsive pressure variations are more essential for aero-acoustic studies than for the purposes of the flight dynamics.

Thus this adaptable finite state dynamic inflow model was implemented in HOST during the ONERA/DLR engineers exchange program.

The three states version gives the same improvements brought by the Pitt & Peters model. Then by increasing the number of states, the realism of the induced velocity field on the rotor is enhanced.

All the rotor inflow fields presented in this paper have been computed for the main rotor of the Bo105 helicopter in trimmed level flight at 80kts.

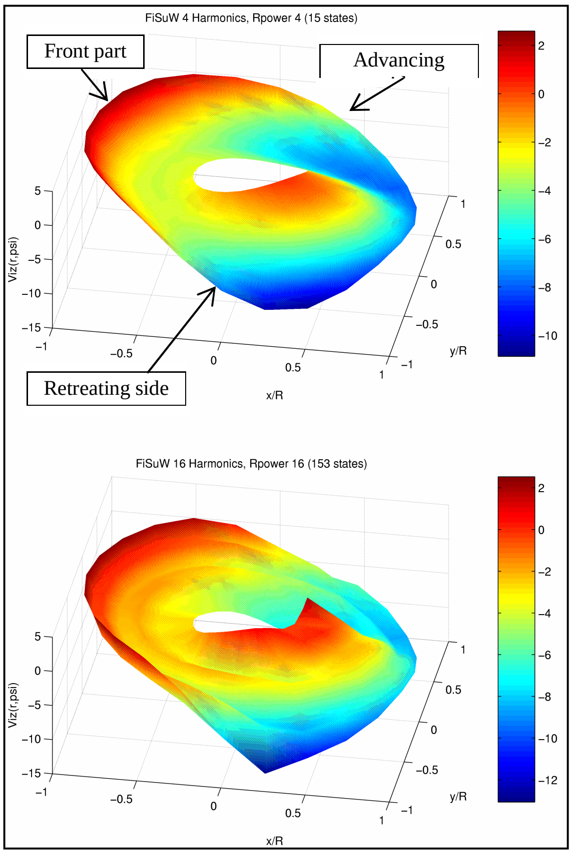


Fig. 10 : rotor induced velocity field calculated with FiSuW (Bo105 trimmed at 80kts)

On figure 10 are compared the rotor downwash distributions computed with the Finite State Unsteady Wake model ("FiSuW"), respectively with 15 states (i.e. 4 harmonics, Rpower = 4) and with 153 states (i.e. 16 harmonics, Rpower = 16).

The main tendencies are quite well captured by the truncated version at 4 harmonics:

- the area of the highest downwash, which may be viewed as a "thalweg", has a "horse-shoe form" around the rotor centre with the curvature in the inner fore rotor half and the two branches on the aft part;
- on the front rotor part: the upwash in the tip-peripheral part of the rotor is followed by a downwash with a high slope in the inner part ;
- on the back part: a downwash prevails both on the advancing and retreating sides, the two branches of the "horse-shoe thalweg" are separated by an upwash tendency from the root of blade in the

rear position ("the watershed" appears at a azimuth around 350 deg).

By increasing the number of states, the representation tends toward the realism of an induced velocity field computed with a vortex wake model. For example with the truncated model at 16 harmonics (i.e. 153 states, see Fig. 10), the details corresponding to the sharp evolutions are better captured thanks to the highest order modes. For instance, a double peak near the root of the blade in the rear position appears now, that was ignored by the 15 states model. The radial variations are caught by the higher order polynomials.

The future activities concerning the FiSuW approach will be to evaluate the interest of the higher inflow modes for helicopter flight dynamics. The model will be extended to account for the ground effect and to compute the interferences (induced velocities outside of the rotor).

Vortex Wake Models

A rotor wake model using vortex rings and segments was developed by ONERA especially for the needs of the helicopter flight dynamic simulation.

The model was presented in details in [9,15,17]. The continuous helical trailing vortex-lines are discretized into groups of concentric and coplanar rings. The shed and bound vortices are simulated with radial segments, distributed respectively on the rings and on the blades as shown on Fig. 11.

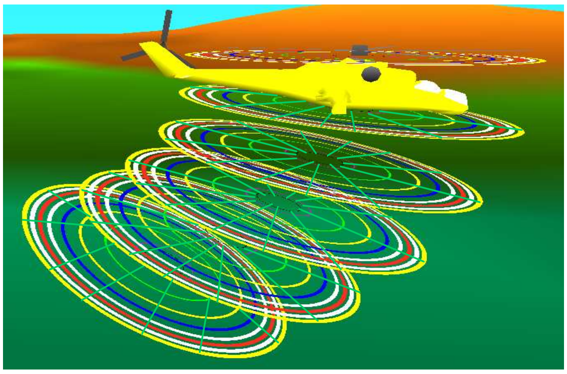


Fig. 11 : The vortex rings wake model

Interferences on the rear elements

The vortex rings model was initially dedicated to the computation of the induced velocities by the main rotor on the tail components (horizontal and vertical stabilisers, tail rotor).

The dynamic interactions have an impact on the flight dynamics, when the helicopter behaviour is not predominated by the rotors responses to control inputs excitations. For example, after a collective input in forward flight, the main rotor wake downwash on the horizontal stabiliser will influence the phugoïde mode and the angle of attack oscillation (see [17]).

Concerning the trim calculations, the latest results about the pitch-up effect (due to the main rotor downwash on the horizontal tail), were presented in [15]. A good prediction of the pitch-bump can be achieved with an elliptical wake contraction. On Fig. 12, the simulation with all the trailing vortices ("root vortices + inner wake + tip vortices"), is compared with the flight test data provided by EC.

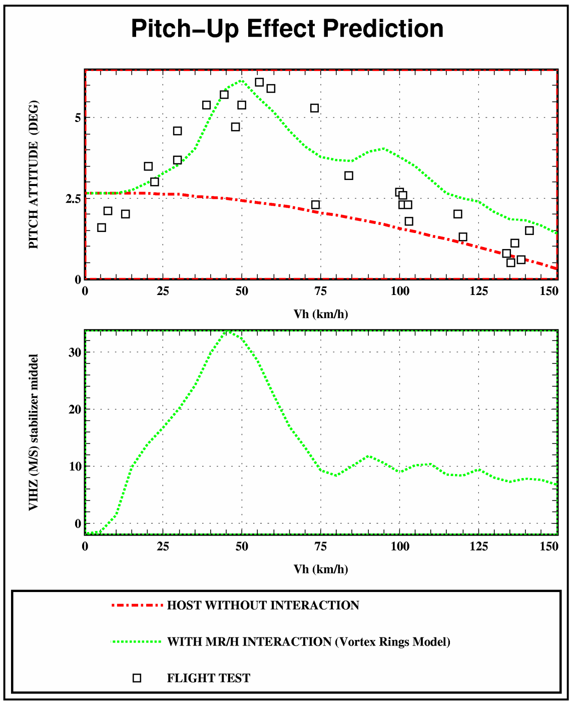


Fig. 12 : Pitch-up effect predicted with an elliptic contraction of the vortex rings rotor wake model

The forward speeds, where this phenomenon occurs, as well as its magnitude, are quite well predicted. Only above 90 km/h, the downwash on the stabiliser is a little overestimated.

Main rotor inflow

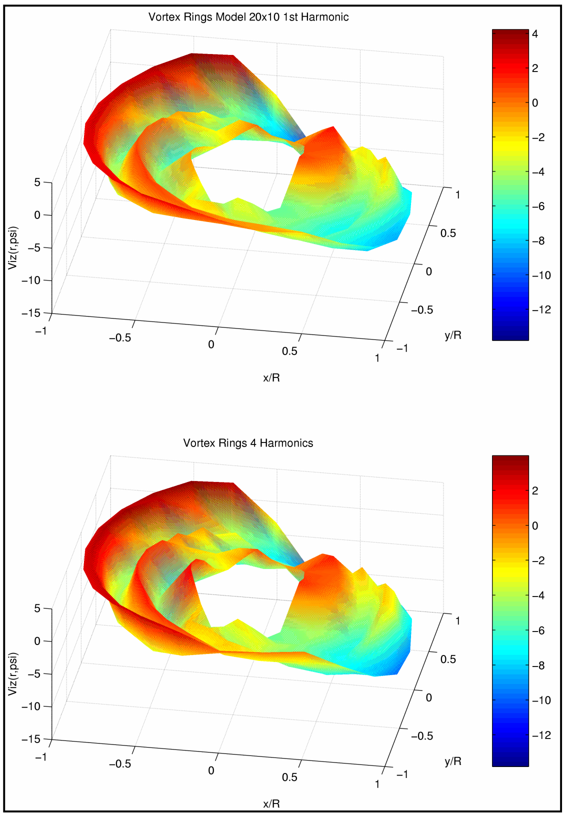
* Wake distortions:

The ability of the flexible vortex rings model to catch the wake distortions due to pitch and roll rates was demonstrated in [17]. Then a comprehensive study was performed in [9], by computing the induced velocity field on the main rotor with both the rigid and the distorted wake models. The main result is that the modelling of the rotor wake distortions improve substantially the pitch-roll coupling simulation, which seems to be physically funded at low speeds.

* Induced velocity field in a close-loop:

The latest implemented functionality in HOST consists in calculating the main rotor inflow in a close-loop during the trim iterative process. The convergence of this inner loop is reached with a relaxation method.

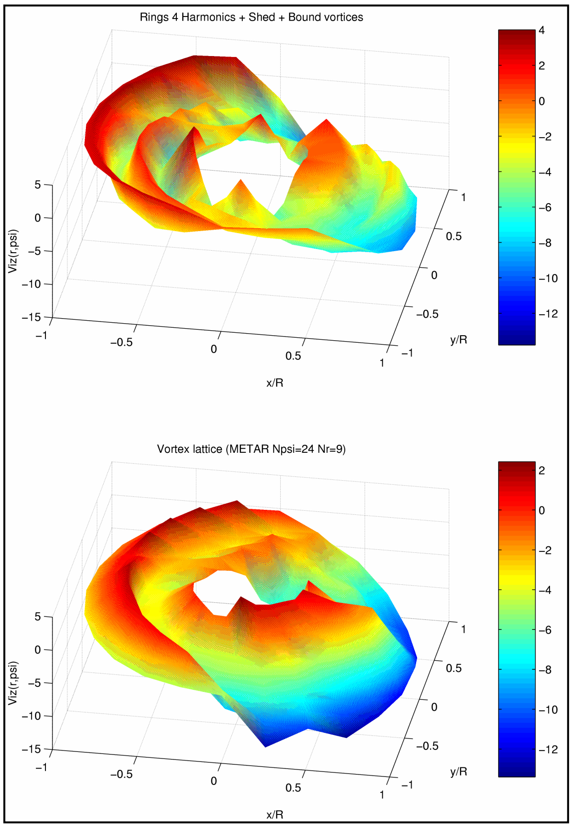
As explained in [15], the user can choose the number of rings and the number of harmonics of the vortex-strength distributions on the rings. Two examples of downwash fields are shown on Fig. 13, with twenty groups of ten rings (all the radial trailing vortices), and with the vorticity distributions truncated respectively at the first harmonic (three vortex strength coefficients for each ring) and at the fourth harmonic (nine coefficients of vorticity for each ring).



<u>Fig. 13 :</u> Main rotor induced velocity fields computed with the vortex rings wake model (Bo105 trimmed at 80 kts)

The details of the inflow distribution are sharper with four harmonics. For example, the higher harmonics make appear peaks azimuthwise distributed at the top of the upwash "waves". But the model limited to the first harmonic is already quite representative.

The comparison of Fig. 13 and 14 shows that the most important part of the downwash is induced by the trailing vortices (rings). In our model, the shed vortices, (generated by the variations of the blade circulation from one azimuth to the following), have a little impact on the trim computation of the rotor inflow. As noticed for the higher harmonics, the blade bound vortices increase the peak values and the sharpness of the inflow distribution.



<u>Fig. 14 :</u> Main rotor induced velocity fields computed with the vortex rings+shed+bound vortices model and with the vortex lattice METAR (Bo105 trimmed at 80 kts)

Finally all the previous induced velocity fields may be compared with those computed with the vortex lattice model ("METAR"). Among the rotor inflow models presently available in HOST, this is the most realistic one for the trim computations in forward flight. This prescribed wake model is composed of the helicoidal meshes of square pattern vortices generated by each blade; it was implemented in HOST by EC.

A future activity could be to investigate the interest of these vortex wake models for dynamic simulations. A free wake version of the vortex lattice model could be integrated in a next release of the HOST code.

As a conclusion about the rotor inflow modelling, the status presented here shows that the HOST user has now a wide range of models, allowing him to choose and to adapt the degree of realism the best suited for his application.

Introduction of a parameter estimation in HOST (CERT)

Simulations of helicopter models provide sometimes bad fitting between computation calculus and measurements. For example, it may be difficult to get good behaviour prediction at once on pitch rate and yaw rate. The off axis responses in pitch and roll are often poorly described.

In classical identification situations, the parameters of black box models are tuned to improve a fitting criterion. At a first look, the adjustment of parameters inside a physical non-linear model is more difficult to justify. Nevertheless the so-called physical models contain empirical or bad known sub models concerning interactions for instance. These uncertainties may be represented by parameters to be tuned by identification.

It suggests the use of optimisation tools to improve the simulation models, proposed here as a connection between identification and simulation techniques. A new functionality was then introduced in HOST to provide a common tool for users to tune parameters inside a HOST session.

Identification technique

A classical output error minimisation technique was chosen with the second order Newton-Raphson procedure [23]. The estimated parameters are obtained from an iterative procedure using the first gradient and an approximation of the second gradient of the output error criterion. These gradients are computed from the sensitivity functions; differences between simulations processed with present nominal parameters and slightly modified parameters. But at each sampling time, all the outputs of the nominal and modified simulation are needed. In these conditions parallel simulations have to be proceeded in HOST in order to avoid the loading of a high number of simulations (number of tuned parameters plus one). This constraint is obviously related to the choice of the Newton Raphson procedure selected for its good performances when many parameters are unknown. It would not be the case using conjugate gradients technique for instance.

To obtain a well-conditioned problem with correct sensitivity about all parameters, it is generally necessary to fit measurements and simulation results on several concatenated runs and this possibility had to be added to the standard HOST simulation management. A special care was also taken to detect and solve the case of the insensitive parameters.

The condition number of the second gradient matrix defined by the maximum to minimum eigen values ratio is controlled to process a regular pseudo inverse. Boundaries on the parameters variations are defined and the optimisation research is projected on the parameter constraints when they are not satisfied.

Connection HOST – PID

A PID functionality was needed to be introduced in HOST [24] but with simplicity requirements for development people and users.

1. The software connection uses as much as possible the organisation scheme of HOST. All the identification routines are put in an identification directory. Few standard routines are modified and inside each of them, there is few modified statements commented and skipped if the PID option is not selected. All the new variables needed for identification are introduced in completely new common files.
2. Standard routines and procedures are already available to be directly used for identification :
   - Definition of trim conditions to start the simulations
   - Piloting the simulation from data read in a SEE file

- Definition of parameters to process effect of parameter sweeps on static characteristics
- Selection of desired outputs for inverse simulations.

These last two topics are convenient to defined parameters to be tuned and outputs used to build the fitting criterion.

3. During a HOST session an autonomous identification menu is opened. Repeated identifications can be performed inside this menu without useless windows or mouse manipulations. The connection with other standard processing such as plots or result analysis can be obtained directly.

   A standard user is not at all disturbed by the identification functionality. The interactive management of the identification procedure is coherent with the whole HOST philosophy.

Example of tuned parameters for a wake distortion model

This identification functionality was tested about the estimation of two parameters of a wake distortion model [6,25], to improve the longitudinal-lateral coupling behaviour of the aircraft.

Let K_p wake distortion parameter in roll

K_q wake distortion parameter in pitch

With:

$\lambda_0 \quad \lambda_c \quad \lambda_s$ collective, longitudinal and lateral components of induced velocity

$\beta_c \quad \beta_s$ longitudinal and lateral flapping

$p \quad q$ roll and pitch rates

The dynamic inflow becomes:

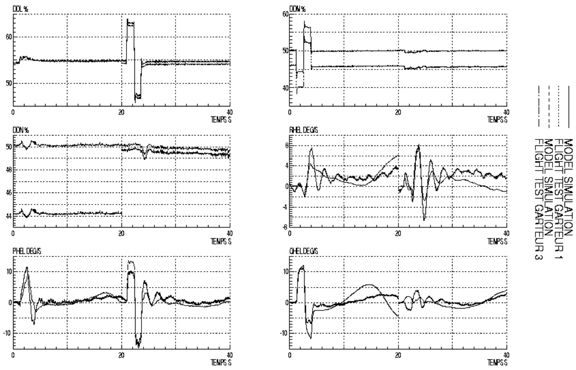
$$[M]\begin{bmatrix}\dot{\lambda}_0\\ \dot{\lambda}_s\\ \dot{\lambda}_c\end{bmatrix}+\left[\hat{L}\right]^{-1}\begin{bmatrix}\lambda_0\\ \lambda_s\\ \lambda_c\end{bmatrix}=\begin{bmatrix}C_z\\ C_l\\ C_m\end{bmatrix}_{ae}+\frac{1}{\Omega}\left[\hat{L}\right]^{-1}\begin{bmatrix}0\\ K_p\left(p-\dot{\beta}_s\right)\\ K_q\left(q-\dot{\beta}_c\right)\end{bmatrix}$$

Two runs related to longitudinal and lateral control inputs describe a forward flight at 150 km/h longitudinal speed.

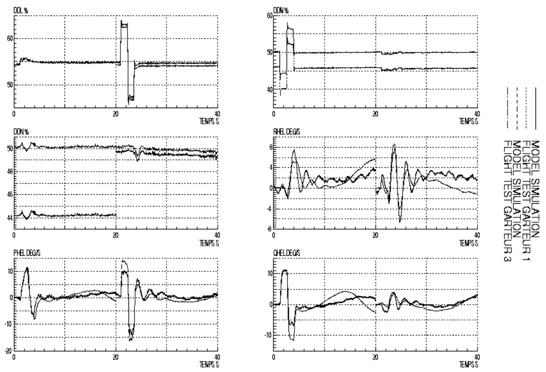
The optimisation process only uses the first 5 seconds of each run.

On the figures 1 and 2 are compared flight data and simulation on the same graphic.

The control inputs		and the observations	
DDM	lateral input	PHEL	roll rate
DDL	longitudinal input	QHEL	pitch rate
DDN	pedals	RHEL	yaw rate



<u>Fig. 15 :</u> Forward flight - *Kp*=0 *Kq*=0



<u>Fig. 16 :</u> Forward flight - *Kp*=0.68 *Kq*=1.68

It can be observed that the estimated parameters improve the pitch/roll coupling prediction for the forward flight.

CONCLUSIONS

The harmosation of Eurocopter's tools for Aeromechanics studies has been reached through the development of HOST. It now gathers all the models that were previously separately utilised and allows conducting calculations with different model levels, from the basic rotor disc model with first harmonic inflow to the most sophisticated elastic blade rotor with vortex wake model. It enables to calculate any combination of existing parts, from an isolated rotor to a full helicopter or a tilt rotor aircraft. For any considered configuration, the basic HOST functions (trim, time history, linear model) are provided and generic pre and post-processing tools available: simulation driven by test data, inverse simulation, linear model analysis…

HOST is thus a successful development that has been welcomed by its daily users, who were soon aware of the new capabilities it brings when compared to the previous generation tools and of the resulting efficiency improvement. The benefit of the modular structure defined for HOST was highlighted by new developments in both kernel (inverse simulation) and physical models (implementation of new models). People in charge of the tool can find it a bit harder for they have to comply with new development rules, but it is counterbalanced by improvements in the management of the code. With HOST a real-time version, automatically generated by splitting any unnecessary part, can be delivered and tested in less than two hours.

Such a tool is however never finished and always needs further improvements and validation. This will be made in a more efficient way thanks to the creation of the German-French HOST group where research and industry people will work together. First achievements were presented herein but are only a very first step. Up to now the partners have mainly invested in HOST, either for the code development or for changing their internal tools. It is now the time to get the return. Any new development will be made available to all partners, which will save a lot of efforts for code development. In addition, it will allow a much wider validation. The results of new model changes will be compared by the partners to their own experimental databases, which will give much more information about how it can improve identified model deficiencies. Validation is really a key aspect in the physical modelling area and consumes at least as much efforts as code development.

The German–French helicopter community now has a unique tool. The challenge for them is now to make it advance.

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