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ITLE : MATERIALS, STRUCTURES AND PROCESS MODELING / EFFICIENT TOOLS FOR REDUCING THE DEVELOPMENT AND MAINTENANCE COSTS OF ROTORCRAFT

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In-service behavior and processes are being increasingly modeled as a way of reducing the time and cost of developing and of certifying new helicopters. Indeed this technique eliminates numerous iterations between specimen or part manufacture, tests and measurements. This paper gives several examples of helicopter part manufacture in a wide variety of fields, from forging blanks to manufacturing dynamic components or electrical harnesses.

1. OBJECTIVES

The certification of an aircraft entails proving that its design and manufacture satisfy a number of specific technical criteria and reliability requirements.

Ten or so years ago, most of these substantiations were provided by testing, i.e. from elementary tests to characterize the material up to tests on complete assemblies (airframe, gearbox, etc.), and followed by flight tests.

Likewise when there were major changes in the manufacturing process or the geometry or non-conformities with respect to the target specifications, these tests had to be partly or completely repeated.

The advent of automated production (integrated CADAM system) combined with powerful computing resources has led to the growing use of modeling to shorten development cycles and to substantiate technological changes in order to:

- meet the airworthiness requirements,
- satisfy customer requests more effectively,
- improve the performance of our products,
- adapt to the industrial constraints (supplier continuity, work offset contracts).

2. MAIN PRINCIPLES

As a general rule, process and behavior modeling can only be a fully-fledged part of certification when the modeling results are shown to be representative.

A prerequisite for modeling is therefore a comprehensive knowledge of the phenomenon being analyzed, notably in terms of:

a) The input parameters, which can be the fundamental data of the part material (mechanical, electrical and thermal characterization, friction coefficient, etc.). This data often comes from simple tests (e.g. static test, fatigue test on specimens).
Any difficulties the scientist may have in analytically modeling each aspect of the phenomenon can be overcome by a more 'macroscopic' approach, i.e. by introducing more general data that already incorporates potential interactions (e.g. effect of the friction coefficient combined with surface roughness and the type of lubricant, or the effect of corrosion, the effect of aging on the characteristics of composites, etc.). All this data is derived from tests that are more complex but still based on test specimens.

To reduce the number of tests at these levels, these elementary results are stored in databases so that the simulation capability of the model is progressively enhanced.

b) The important controllable parameters for the process being analyzed, i.e. load, pressure, temperature, time, etc.

c) The types of models (finite elements, analytical models, integral equations, etc.). Their selection is primarily based on the type of input data, the phenomenon being modeled and the tradeoff between the computing speed and the required accuracy of the results.

d) The results generated by these models must be validated, always by simple tests of varying scope that attempt to cover a representative range of real cases. Experimental plans are often employed to reduce the number of analysis cases.
Specific tests are also developed to shorten the validation times by determining a suitable tradeoff between the following factors:

- The representativeness of the test compared to the real case
- The speed with which the results are obtained
- The cost of manufacturing the elementary and validation test specimens.

3. FIELDS OF APPLICATION

The development of CAD/CAM has created an extremely wide variety of modeling applications covering all the definition and manufacturing phases. A case in point is the manufacture of a helicopter gearbox where the models can be applied to:

- generate the blanks, for example, using forging and casting simulation software.
- model the gears and bearings operating in their environment (deformed casing, lubricating condition). For instance, by extending these computations to analyze gear pitting behavior or fretting of assemblies and fits, the casings, bearings and gears can be correctly designed in the definition phase.
- machine parts by software to simulate machine tool paths or the behavior of cutting tools.
- inspect parts by modeling measuring machines so that both inspection time and result interpretation can be optimized. Applying modeling to non-destructive testing (ultrasonic, eddy current) also enables the inspection process to be quickly optimized in the prototype phase.

Similar applications are also available for composite materials technology and for connections.

4. TYPICAL APPLICATIONS

As we have seen, there is an enormous potential for modeling applications and this paper will be limited to a few examples focusing on manufacturing processes and on the in-service behavior of parts.

4.1 Ti 10.2.3 FORGINGS

Several NH90 and EC120 parts are made from a new grade of Titanium (Ti 10.2.3) in order to satisfy the requirements for weight, fatigue strength and corrosion resistance (Fig 1). However the forging process for this material only produces the required mechanical and metallurgical characteristics when a number of the process application parameters are complied with.
Compared to the conventional test/dissection techniques, the time to finalize the process sheets for the NH90 hubs and sleeves was substantially reduced thanks to the use of the FORGE 2 software in collaboration with the company *Aubert et Duval.*

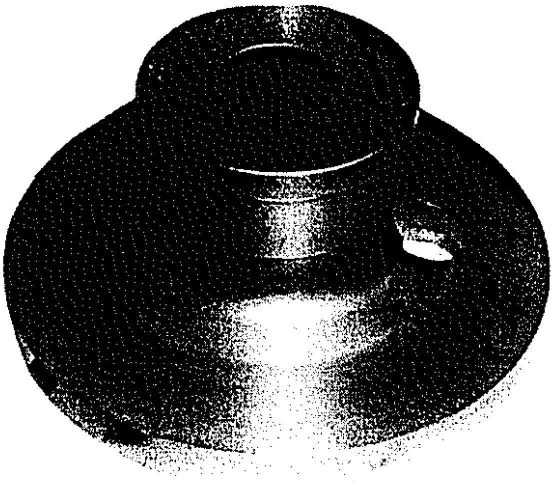

Fig 1 : Blank for NH90 Hub

This software uses data on the stress, strain and temperature behavior law and the thermal and hot frictional characteristics to simulate several cases of material behavior during the forging operation (deformation and temperature maps, grain flow, stress distribution, etc.). On the basis of die filling criteria and part zone heating, it has proved possible to optimize the pre-blank shapes and thereby guarantee forging in the α-ß domain and a deformation rate compatible with satisfactory mechanical properties of the part (Fig 2).
Since the model was validated using a technology part, its application to the NH90 parts reduced the development time of the forging processes and

dissections of standard parts by 80%, which was also true for the reinforced version of the naval NH90 sleeves (validation via simulation runs and results from the land version).

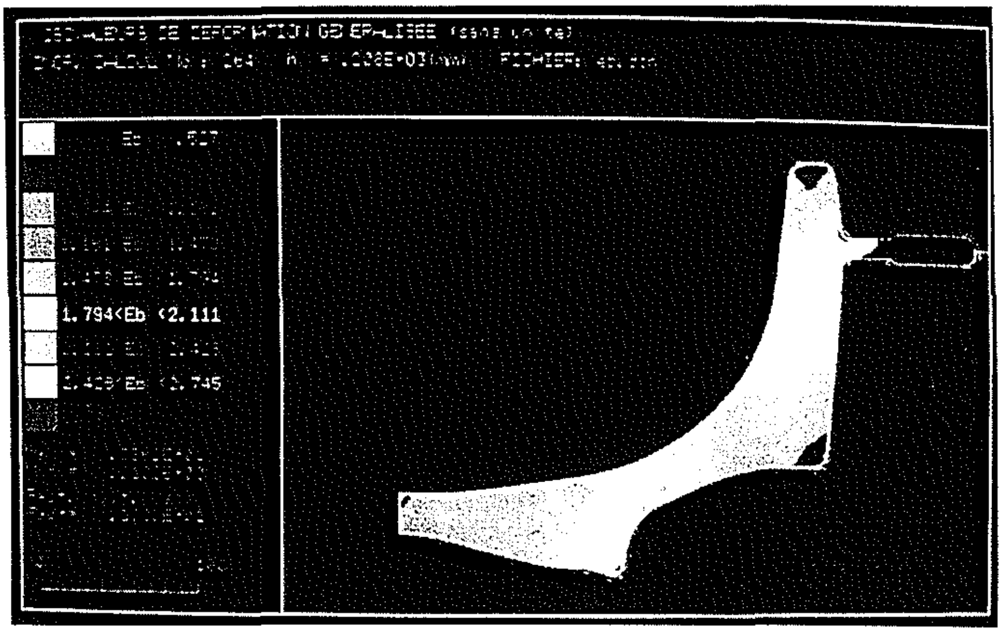

Fig 2 : Modeling of Post-forging Deformation

The modeling approach also has a major impact with respect to changes in the manufacturing processes of vital part blanks. Such changes may be caused, for instance, by modifications to the production equipment or by supplier restructuring.
At this level, modeling is all the more important as it permits these manufacturing process changes to be substantiated by computation and simple mechanical and metallurgical tests, whereas previously fatigue tests on real parts were required.

4.2 CASING/BEARING BEHAVIOR

The spalling behavior of a gearbox bearing depends on several factors related to:

- the characteristics of the casing and bearing (shape, stiffness).
- tribological parameters (surface roughness, oil film) measured in simple tests.
- the flight or deformation loads on the gearbox assembly at operating temperature.

A mixed model of finite elements (for computing load distributions on complex bearings) and analytical method (to integrate the operating stresses) is used to generate charts of bearing contact pressure distribution versus assembly play, operating temperature, etc.

The model was validated on bearing test rigs (ball and roller bearings) and this software, which was applied in the development of the EC120 bearings, gave very satisfactory results as indicated below:

- Pre-project launched in 11/93
- First assembly of gearbox in April 1995
- First flight in June 1995
- No modifications made to the definition up to certification in December 1996

4.3 PITTING AND FRETTING BEHAVIOR

Some helicopter dynamic components have service life limits (SLL) to allow for the loss in characteristics caused by the phenomena of gear pitting on gears and assembly fretting.

The ultimate aim of the research in this field is to develop a software tool capable of using the CAD-based part definition to integrate any risks of pitting or fatigue fretting damage occurring and thereby directly optimize part definition and extend part service life.

As regards fretting, the use of loss coefficients, derived from elementary test data, generates very conservative results.

Current work is focusing on validating a more accurate method that integrates the special conditions of each real situation. This method uses a mechanical contact finite element (FE) computational model to locate a part on a map of fretting and fatigue damage versus applied loading. The part is defined by its CAD geometry, its material (elastoplastic behavior) and its surface treatment (elastic properties, friction coefficient). Such damage maps are based on fatigue tests with different materials/surface treatments (Fig 3).

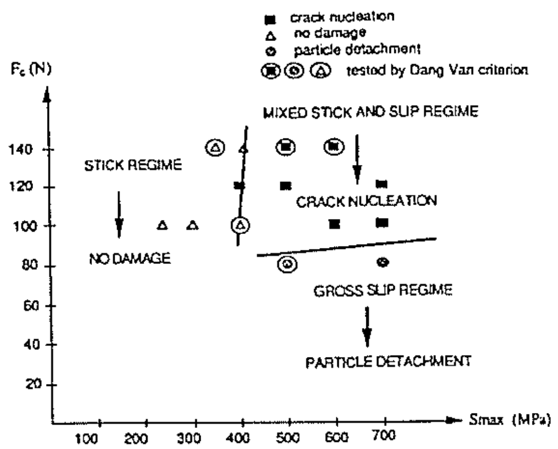

Fig 3 Material Response Fretting Fatigue Maps on 32 CDV 13

Thanks to this method, it will therefore be possible:

- Either to change the part or subassembly geometry during the definition process in order to modify the local stresses (contact force or working load) and so relocate the operating point outside the zone where fretting damage occurs.
- Or to change the damage zone limit by selecting a material or surface treatment that is more favorable with respect to fretting-induced damage.

As regards pitting (fig 4), the PRINCE software developed by INSA at Lyon defines the loads on teeth. The software optimizes the design through comparisons with a database containing test data from real configurations.

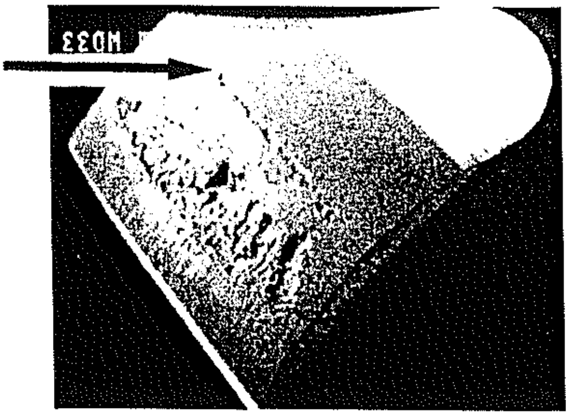

Fig 4 : Pitting on gearing

Current research - and notably the European ASETT program - will further improve this approach by integrating a tooth-scale FE model to determine the timewise stress variations in the tooth and to locally analyze fatigue.

The input data to this model includes, as usual, the part geometry (CAD), plus the material and its thermochemical treatment, the engine torque and the surface defined by the elastic properties and the friction coefficient specific not only to the treatment but also to the surface roughness produced by the manufacturing process (Fig 5).

The pitting damage criteria are based on elementary fatigue tests (bending or roller tests). The model is validated by tests on a representative gear rig (FZG tests)

The model output data consists of:

- the geometric definition of the part, optimized for pitting damage,
- the tribofinish definition conditions of the parts,
- the acceptable tolerances on the profile.

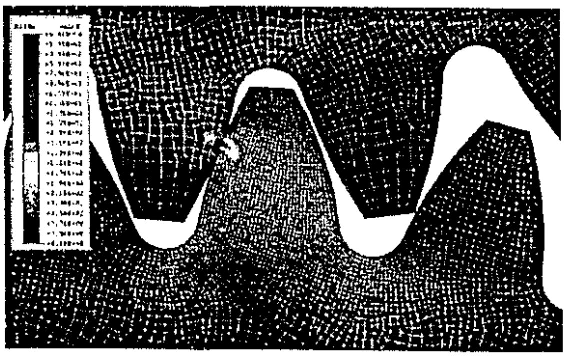

Fig 5 : Modeling of Tooth Loads

The initial results from the current version of this type of model were applied to optimize the definition (which remained unchanged throughout the certification phase) of the EC 120 MGB pinion bearing surfaces, and to demonstrate the interchangeability of the spiral bevel pinions and gearwheels on the EC 135 TGB.

Once again the testing time (of the gearbox or in flight) required to validate process changes can be drastically shortened because the damage-inducing phenomena and their link with the manufacturing processes (thermochemical treatment, grinding) are understood.

4.4 MODELING MACHINING PROCESSES

Several aspects of the part machining process can be treated by simulation:

- Modeling of the machine environment (turntable, fixtures, tool and tool holder) and of the machine kinematics. In particular, the modeling of a *Gleason* spiral bevel gear grinding machine (SPIRO- MO type), based on an initial record of the teeth surface from a 3D-measuring machine, has now allowed the corrections to be applied on line and the optimized profile to be obtained directly without any iteration.
- Definition of the machine tool trajectories in the environment (to avoid any interference with the tools). This simulation can also be run for the tracing pin trajectories during checks on the measuring machine.
- Optimization of the machining passes.

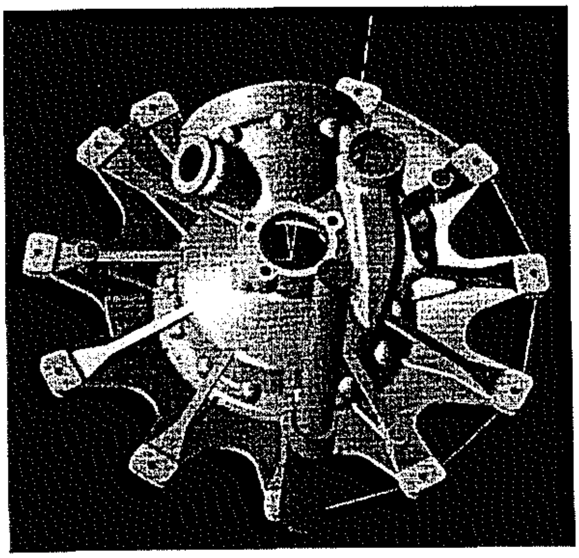

Fig 6 Modeling of TGB Casing Machining

The type of modeling can be associated with cutting tool behavior modeling. For instance, the TOOLS (CAPITOOL and TOOL LIGHT) software programs use simplified tests results to simulate the breakup of chips during specific machining operations with a given machine tool/material combination. (Fig 7).

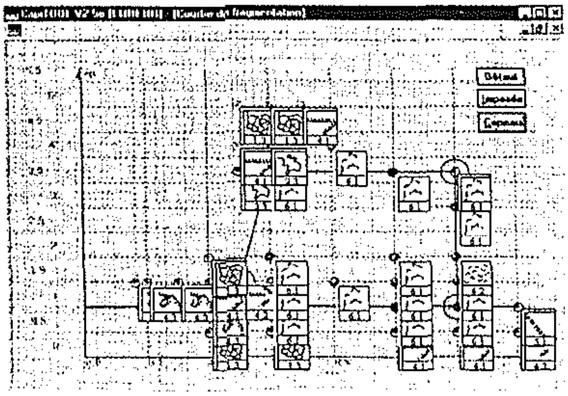

Fig 7 : Chip Breakup Envelope versus Machine Pass Depth and Feed

Integrating these models in the planning units cuts the time required for finalizing the development phase of a new material or new parts by about 20%, and the machining time by 15-20%.

4.5 MODELING THE SHOT BLASTING PROCESS

The fatigue service life of parts can be increased by applying compressive surface stresses via various process, including shot blasting. In this technique, small steel balls are projected at high speed against the material in question; however this process must be optimized for the applications in terms of ball diameter and hardness, speeds and overlap ratio.

A model can also be used for this type of application to predict the surface stress distribution through the material thickness and for forecasting the part deformation.

For new materials, the input data only requires performing cyclic compressive/tensile tests on test specimens.

The model results are validated by X-ray diffraction measurements of the residual stresses. (fig 8).

Here again, this tool not only cuts the process development time by a factor of 10 but it may also avoid the need for tests on real parts when the charts of applied residual stress versus residual deformation are not compatible with the dimensional tolerances required by the definition.

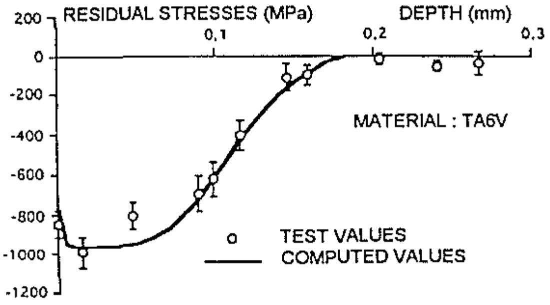

Fig 8 Measurement/Model Correlation of the Stress Profile for a Shot-Blasted Titanium Part

4.6 MODELING THE RTM PROCESS (Resin Transfer Matrix)

RTM technology has now come to maturity for certain parts, which have been introduced in series production on aircraft, but it is still under development for primary structures. It is particularly adapted for the production of small/medium sized components of complex geometry, for which the possibility of reducing the number of individual parts is the main parameter for cost reduction, e.g. the use of RTM technology for making the tail rotor blade of 365 N4 reduced the number of different materials by 50 % with a correlative production cost reduction of 20 %.

The main problem still preventing wider use of RTM for primary structures is the duration and cost of development and validation of parts. Due to the technology itself and because the properties of the component are given not only by the material but also by the design (in particular of the fibers preform) and the process parameters, each part has to be treated as a new one as for castings or forgings. Regarding this development cost/duration problem AEROSPATIALE has developed software tools for the simulation and the automation of the manufacturing process which result in a reduction of the time and cost of optimization of the first component and also , in a reduction of cost of inspection through a good process monitoring.
The model inputs are as follows:

- The part shape file (CAD)
- The type of textile material (type of yarn, weaving, stack-up)
- The type of resin (gel temperature, viscosity)
- The fabric permeability, determined by elementary tests which measure the time taken by a reference liquid to impregnate a representative specimen of the textile used.

Based on flow laws (Darcy's law), the analytical model integrates the process control parameters (resin injection pressure, flowrate, temperature, injection point).

The feasibility of a part can then be determined using the plots produced by the model and the die filling times (Fig 9).

This model cuts the development time and costs by indicating design changes to the tool or part, as with the NH90 cockpit beam.

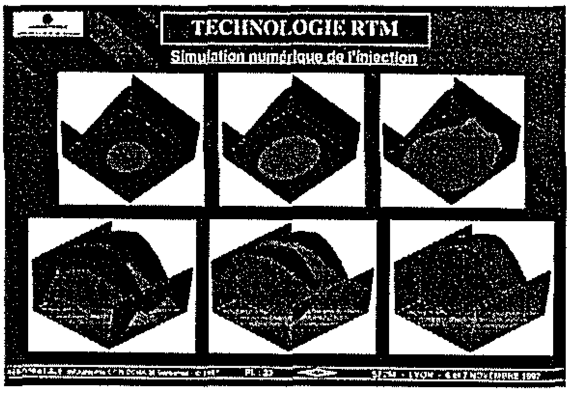

Fig 9 Simulation of RTM Part Filling

4.7 MODELING OF THE SHIELDING PROCESS ON ELECTRICAL HARNESSES

To suitably protect civil and especially military aircraft against EMI, it is necessary to design shielding for electrical harnesses. Since the cost and weight penalty of shielding each cable individually would be prohibitive, the method adopted is to apply metal braiding over the harness (overshielding) (fig 10) .

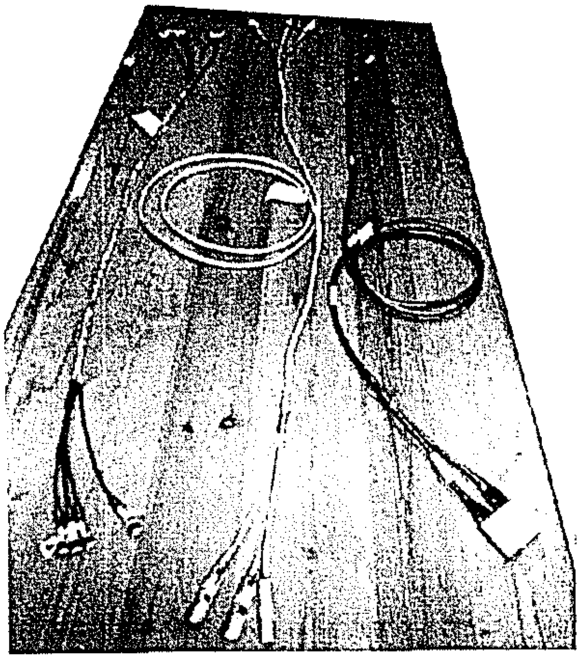

Fig 10 Shielding of an Electrical Harness

The model inputs describe the type of materials used, their electromagnetic characteristics, the harness definition (number of strands, individual shielding)

Developed from an analytical model and an optimizing function, the software generates the transfer function for the assembly (harness and shielding) and outputs the weight versus the weaving angles (Fig 11).

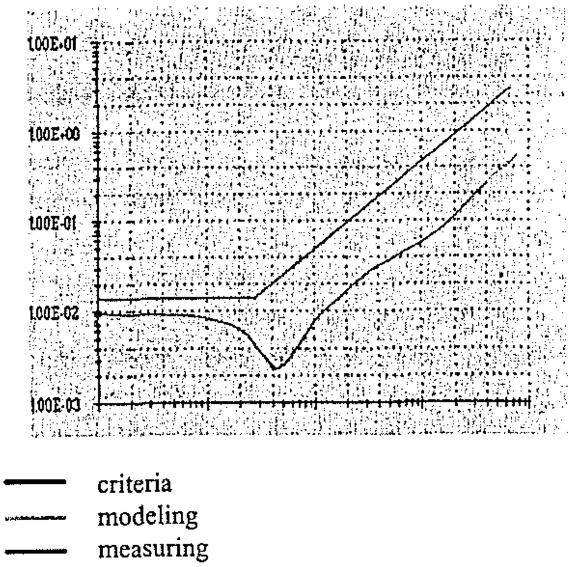

Fig 11 : Modeling of the Transfer Function

With this model, it is possible to define shielding in one week compared to the several months required by the iterative specimen test/measurement method. The model's weight optimizing function generates weight savings of 15 % of the total weight of the harness overshielding on the Tiger (at a given performance)

5. CONCLUSIONS

Simulation tools therefore open up a wide range of possible applications. Indeed these tools fundamentally shift the balance of the certification costs towards computational simulation and away from costly testing (tests on real parts and flight tests).

By applying this method in the development phase, it has been possible to substantially shorten the design and manufacturing cycles for prototype parts and to guarantee optimum design.

The extension of this concept to the production phase means that changes in manufacturing processes (or in the definition) can be substantiated by simplified tests, thereby guaranteeing quicker integration of commercially available technological advances in our products.

Integrating and linking up these models in the CAD systems should therefore further enhance concurrent engineering concepts from development through to series production.