FOREIGN OBJECT DAMAGE AND FAN BLADE OUT

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1. Introduction

Bird strikes in a turbofan engine as well as fan blade-outs can result in serious damage to the engine. For each new engine model, design requirements prescribe to demonstrate the ability to withstand those phenomena using appropriate test on full engine. In order to design the engine and notably to increase the engine efficiency, the engine manufacturers usually validate their design before the full engine test on partial tests using only few blades. As a supplement to those tests, they also do analysis with non-linear transient structural code to predict and optimise the design and improve the behaviour of the engine in such cases.

Therefore, all the components –i.e. parts of the engine and the bird- have to be modelled with the adequate accuracy in order to predict properly the behaviour of the engine with a good correlation with experiments. That requires both:

- Accurate modelling of the material behaviour including non-linear effect including plasticity or damage,
- Adapted numerical methods to make possible the modelling of specifics behaviours such as the bursting out of the bird after the impact.

This paper aims to describe the key points of the simulation and of the modelling in the event of fan blade-out and bird impact. Successively for the both cases:

- The design requirements are quickly reminded in order to define clearly the stakes of the tests, as well as those of the simulations. It allows us also to list, from the beginning, the main challenges which must be undertaken by the simulation.
- Then, the different steps of the simulation are described. Blade-outs and bird strikes are indeed dynamic phenomena and involve rotating parts. Some precautions have to be taken to be able to compare numerical results with the reality.
- The main characteristics of each analysis are discussed afterwards. These discussions involve the way the different parts are modelled in terms of numerical elements and material models used. Two key points are particularly addressed in this section. The first one is the original way used to describe the behaviour of the bird: as the classical finite element is not able to treat completely the bird fragmentation after the impact, one uses SPH (Smooth Particle Hydrodynamics) method. The second one concerns a specific model used to represent the damage and the rupture. As such model usually suffers from pathological mesh dependence, it is generally coupled to a proper numerical method in order to avoid it. In our case, a delay damage model is then included in the classical definition of the evolution of the damage.
- Some examples of results are eventually described.

To start with, some basis are given in the range of fast transient dynamic simulation.

Finally, the reader has to bear in mind that this document mainly deals with to the metallic blades. If the methodologies, meshes, fundamental basis etc. are on the whole shared between metallic blades and other technologies, this document deals only with the specific key points of the metallic modelling.

2. Fast transient dynamics basis

2.1. Algorithm

All the phenomena discussed hereafter have the common characteristic of being very short time phenomena (about a few milli-seconds long). The main events only last half a round for an ingestion and is rarely longer than one or two rotation for a blade-out (that is if one is only interested in the blades and the casing). The phenomena to model are then eminently dynamic. In such case, during all the duration of the event, one has to solve the following equation for all point of the mesh of the structure:

$$[M]\ddot{U}(t) + [K]U(t) = F_{ext}(t)$$

where *[M]* is the mass matrix of the structure, $U(t)$, $\ddot{U}(t)$ the displacement and acceleration of the nodes of the mesh, functions of time, *[K]* the updated stiffness matrix and $F_{ext}(t)$ the external forces applied on the nodes.

In addition to the classical spatial discretization corresponding to finite element, one has to use a proper numerical integration scheme in order to solve the equation in time. In dynamic cases, such as the one studied here, it is more convenient to use explicit schemes as the Newmark ones [1]. It mainly consists in a Taylor series development [2] of the displacement and velocity leading to the following expressions of the discretized displacement U^t and velocities $\dot{U}^t$ at time *t*, under certain conditions of the approximation of the residual integral:

$$\begin{cases} U^{t+\Delta t} = U^t + \Delta t \dot{U}^t + \dfrac{\Delta t^2}{2}\ddot{U}^t \\ \dot{U}^{t+\Delta t} = \dot{U}^t + \dfrac{\Delta t^2}{2}\left(\ddot{U}^t + \ddot{U}^{t+\Delta t}\right) \end{cases}$$

where Δt is the step time of the schemes. This specific form is known as the central difference method. Knowing the values of all variables at time *t*, it is then possible to calculate the displacement at the next time step without any iteration, *i.e.* explicitly. Knowing the actual rigidity of the material, it is then possible to solve the equilibrium equation and determine the acceleration at the next step, then the velocity and the displacement at the next step and so on.

If this scheme presents many advantages, it has a major inconvenient. It is conditionally stable [3]. In other terms, a specific condition on the step time has to be respected in order not to diverge. This condition is given hereafter and expresses the fact that the step time must not be bigger than the time needed for the wave to cross (at the celerity $c = \sqrt{E/\rho}$) the smallest element of the structure (characterized by its smallest length l_{min}).