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“Fatigue analysis on a helicopter skid landing gear”

by

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"Put it to them

briefly, so they will read it;

clearly, so they will appreciate it;

picturesquely, so they will remember it; and, above all,

accurately, so they will be guided by its light."

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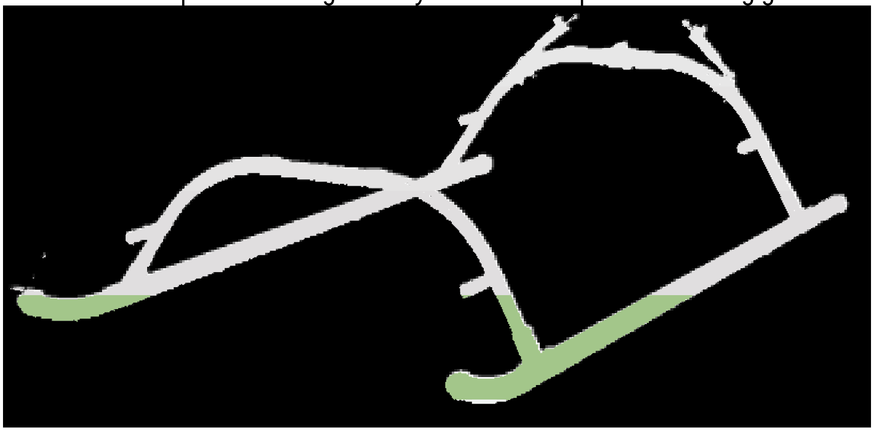
1. INTRODUCTION

In the past months MECAER had to perform a fatigue analysis on a helicopter skid landing gear.



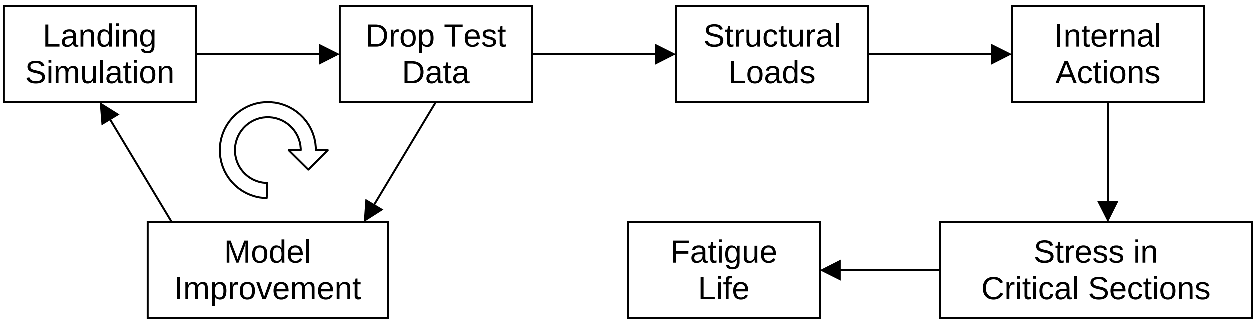
The skid landing gear requirement gives a fatigue spectrum with different sinking speeds (1.32 m/s, 0.98 m/s and 0.47 m/s) and landing conditions (level, level + drag, level + side and 1 skid).

Force and deflection data referred to fuselage attachments were available only limitedly to few drop tests; as a result of the fact that these data weren't sufficient to define the fatigue life of the skid landing gear and being impossible besides extremely expensive to perform a drop test for each of the landing conditions, MECAER Technical Department staff chose ADAMS to simulate the helicopter landings, using the existing data as a benchmark.

The choice was a bit hazardous because, keeping in mind the past experience with a FEM explicit code, a multi-body program as ADAMS is thought to be more suitable and oriented towards mechanical components with parts that allow relative movements as occurs, for instance, with an air/oil shock absorber or a retraction mechanism; in fact, a skid landing gear is made up by tapered aluminum tubes linked together by rivets and which assure the primarily function of energy absorbing only by their controlled structural deformation.

There were a lot of starting difficulties to create a good model that describes the real cross tube behavior with a multi-body code using only rigid elements; only with ADAMS/Flex toolkit it was possible to achieve good results with an appreciable cost and time saving.

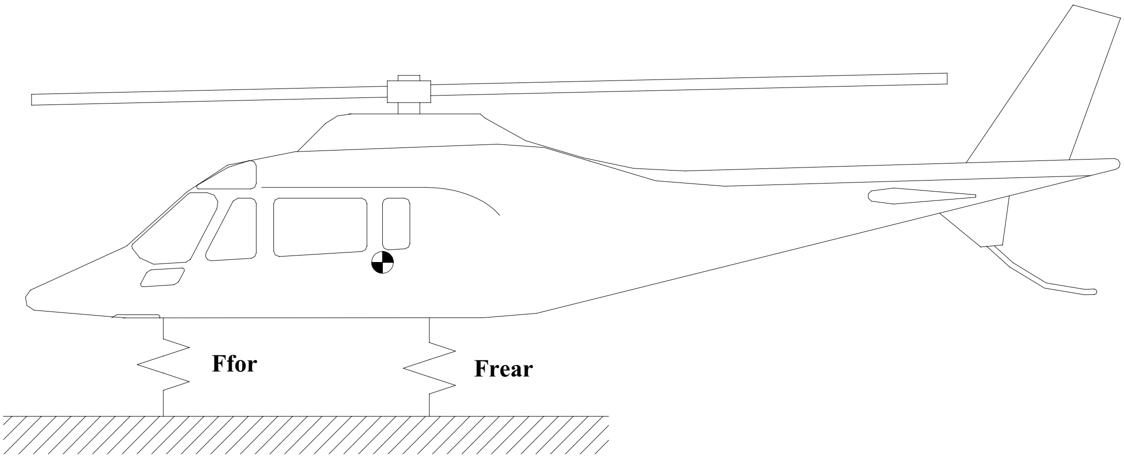
For the fatigue analysis, being known the material and the geometry of the entire skid landing gear, the following scheme was adopted:



Briefly, when the ADAMS model is validated by the comparison with the drop test data, the internal actions can be calculated from the structural loads; the most critical sections, which from experience are those near attachments, are chosen evaluating the position of the maximum stress in relation with the different landing conditions.
Once known the stress, the fatigue life evaluation can be done considering the fatigue life data available from material database.

2. TWO-DIMENSIONAL MODEL

We starts with a two-dimensional (2D) model in which the skid landing gear is schematized by two equivalent springs that reproduce the two cross tubes behavior; each spring characteristic is introduced in ADAMS by means of a force-deflection spline, obtained by a NASTRAN non-linear analysis.



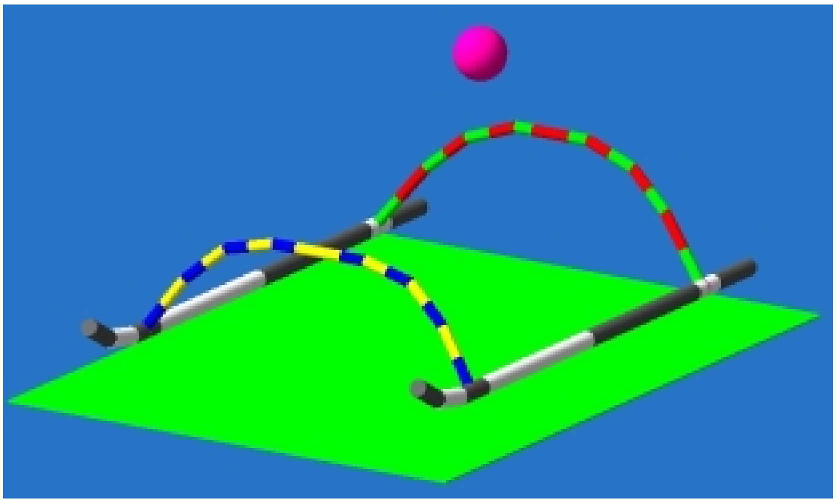
This model, even if it shows a great accuracy respect to drop test data, is not suitable for a fatigue analysis because only the vertical reactions in the fuselage attachment can be calculated, without the possibility of getting the internal action trend in the cross tubes.

3. TRHEE-DIMENSIONAL MODEL

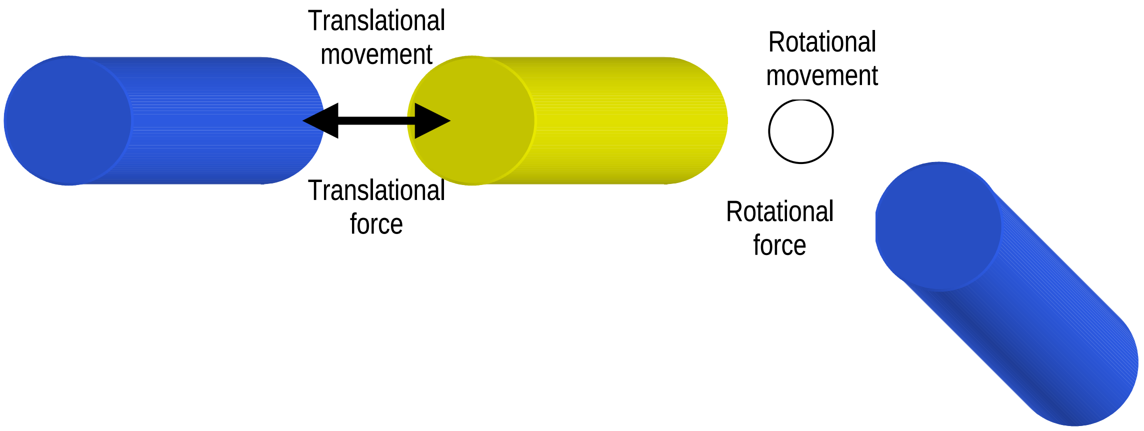
The need for a spatial schematization of the cross-tubes inspired the three-dimensional (3D) model; the major problem lays on the fact that it's necessary to consider the non-linearity coming from material plastic behavior and great deformations encountered during the landings with a considerable side movement of the cross tube tips.

3.1. VIRTUAL WORK PRINCIPLE MODEL

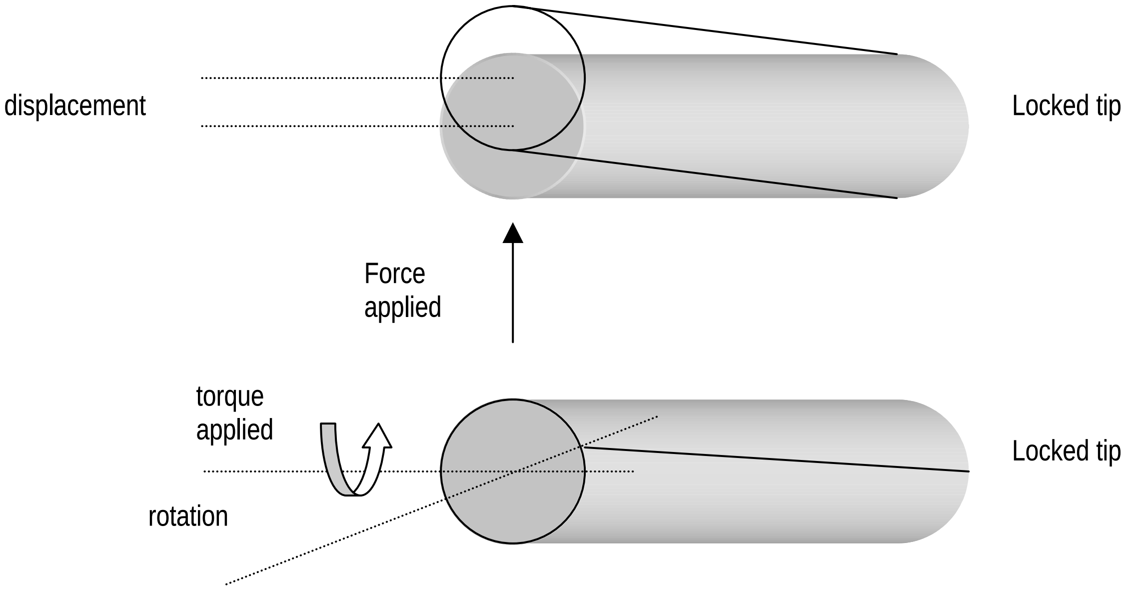
The skid landing gear is schematized with cylinders that are connected one another by means of different joints with a rotational and translational stiffness determined by the virtual work principle.



Both cross tubes are divided into 8 main parts, each made up by two cylinders.
The two cylinders of the same main part have only a translational relative degree of freedom; an equivalent spring reproduces the tension and compression stiffness.
Two main parts are connected by a rotational joint with an equivalent rotational spring.
As regards the skids, they are made by 7 parts without the translational degree of freedom.



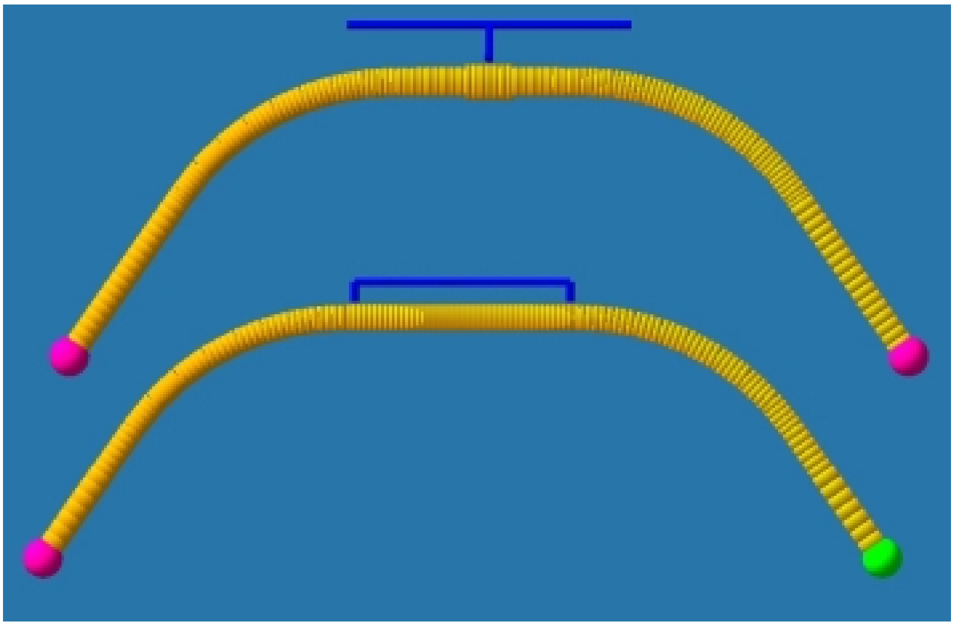
The equivalent stiffness of the spring-damper and torque vector feature of the ADAMS model is introduced as splines of force-displacement and torque-rotation respectively; as illustrated in the next figure, the splines are obtained applying different value of force and moment to one of the tip of each main part and locking the other tip and calculating the displacement and rotation with a FEM non-linear analysis performed by MSC NASTRAN/PATRAN:



This model is not satisfying because of the great number of main parts required in order to achieve the same behavior of the real cross tube with an expensive and long work with MSC NASTRAN/PATRAN; it also advisable to use a routine to create the numerous features in ADAMS with a dramatic time saving.

The virtual work principle philosophy, even if it’s correct from a theoretical viewpoint, can lead incorrect result due to MSC NASTRAN/PATRAN problems during non-linear analysis, especially when the analysis goes into the plastic part of the material characteristic curve.

3.2. BUILT-IN FLEXIBLE BODY MODEL



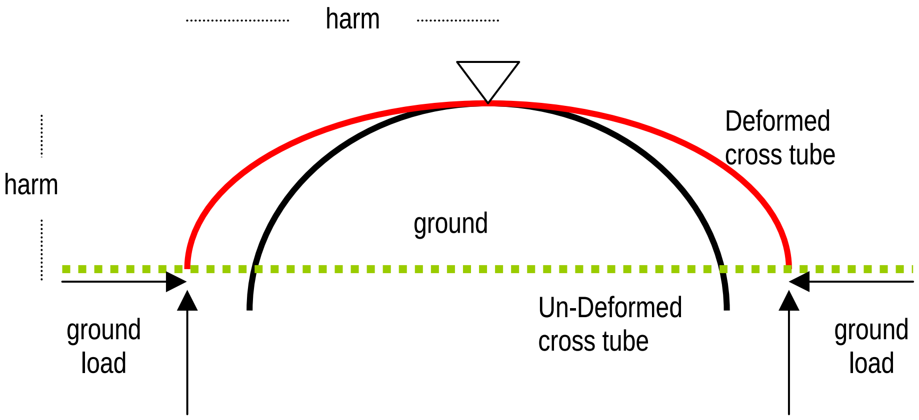
The skid landing gear is schematized using the ADAMS built-in flexible body feature with the correct taper trend.
Each single cross tube reveals an optimum linear behavior if compared with the FEM one but it's almost impossible to run a landing simulation with so many elements.

So the conclusion of these two early 3D model is that it's necessary to adopt the assumed mode method of modeling flexible bodies, the so-called modal flexibility; a limitation of this technique lays on the fact that it considers only the linear part of the characteristic curve of the material. As we saw from experimental test result, if the landings engage only partially the material plastic range, the preceding technique can be successfully used together with a plastic correction.

4. FLEX MODEL

4.1. INTRODUCTION

The aim of ADAMS simulation is to find the structural loads and their harm respect to the critical sections from which it is possible to calculate the internal action and subsequently the stress.
From the past experiences, it is sufficient to consider only the bending moment in the critical section, neglecting the shear and the compression/tension.
The time history of both load and its harm respect to the most critical sections for all the landing conditions are necessary to find the worst bending moment during all the compression phase; the bending moment trend can be achieved by a static equilibrium of each cross tube knowing at its tips the ground load and the harms as depicted below:
It is fundamental to use the harm of the ground loads caring about the deformed shape assumed by the cross tube during its compression for preventing the risk of considering a moment of greater magnitude than in reality, especially as regard the horizontal ground reaction due to friction.

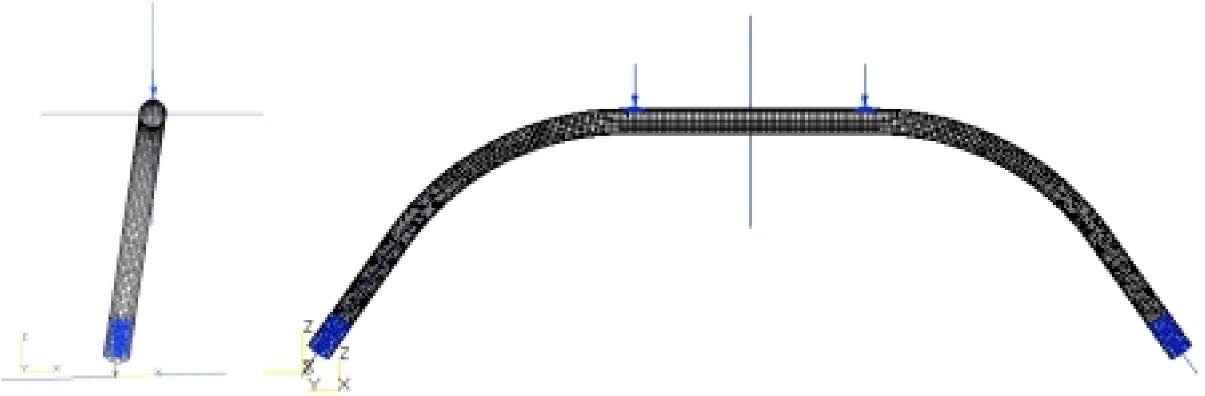


The ADAMS model is validated not only considering the drop test as benchmark but also performing a comparison between the force-deflection curve obtained by FEM analysis and another one coming from a similar analysis made by ADAMS (see paragraph 4.2).
Looking to the current aviation requirements, the JAR/FAR 27.501 “Ground loading conditions: landing gear with skids” suggests to calculate the ground load for the level + drag, level + side and 1 skid landing conditions from the level landing condition, avoiding to perform long simulations.
The level landing fatigue stress definition is done by three basic steps:

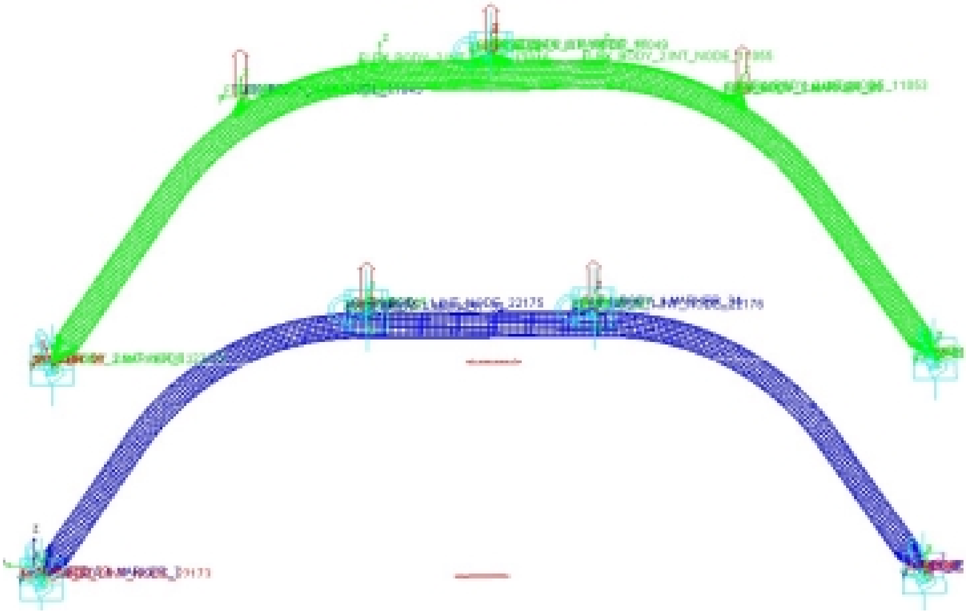
1. FEM linear modes analysis performed by MSC PATRAN/NASTRAN as regards the forward and backward cross tubes;
2. Dynamic Simulation performed by MDI ADAMS/Flex; the limit of this methodology lies on the fact that this approach can not take into account material plasticity, assuming material linear stiffness; as regard non-linear deformations, the program is able to reproduce them if the real bodies is schematised not in a unique flexible body.
3. Plastic Stress Correction with a MATLAB program

4.2. CHECK FEM/ADAMS MODEL

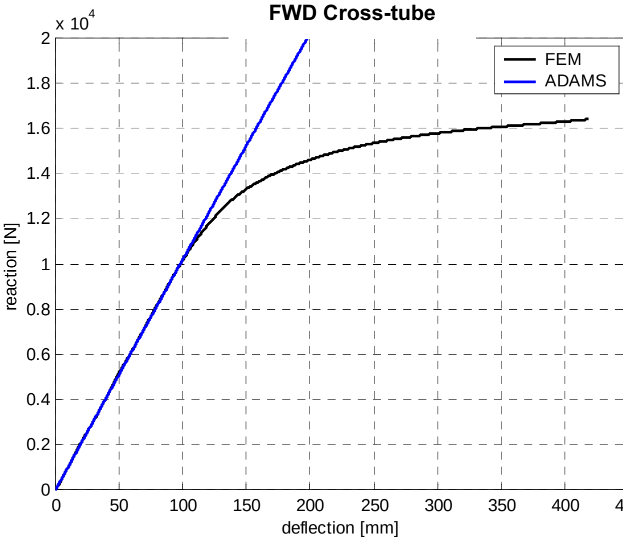
It was useful to compare the result of the compression analysis performed by the FEM code with a similar one made with ADAMS, in order to validate the ADAMS cross tube model for the linear range of the material characteristic curve.
The next figure shows the PATRAN/NASTRAN model of the forward cross-tube, where the arrows are the forces on the attachment points.

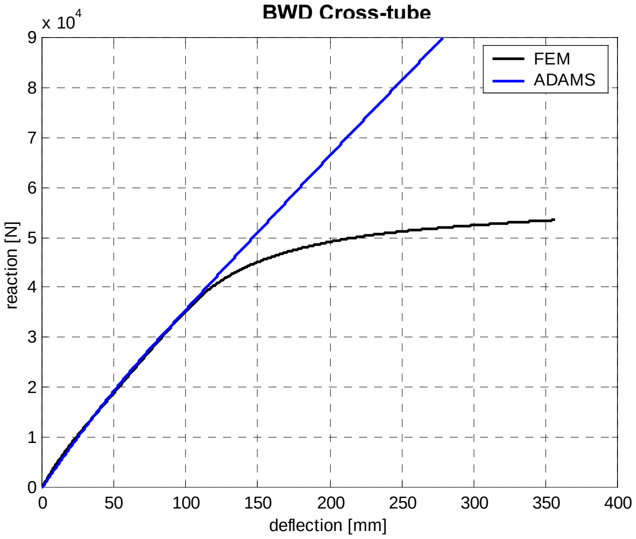


The figure below, instead, represents the simultaneous check on both cross tubes in order to validate the ADAMS Flex model with the same tip and fuselage attachment constraints, force direction and magnitude and cross tubes attitude of the FEM model.



The following figures show the force-deflection curve for both FWD and BWD cross-tube: the black curve is obtained by a FEM non-linear analysis that considers material and geometrical non-linearity while the blue one comes from FEM natural modes-ADAMS/Flex with linear trend.



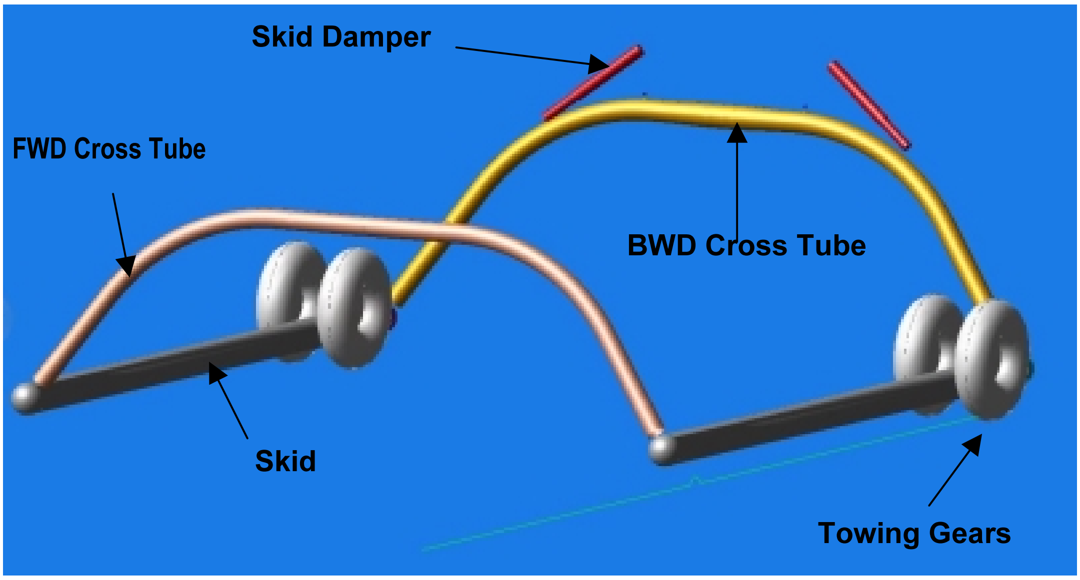


4.3. *MODEL DESCRIPTION*

The helicopter model is made by the following parts:

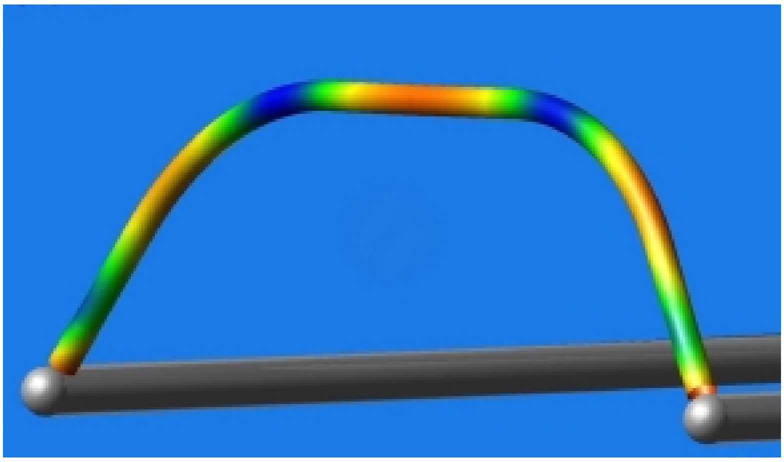
- helicopter fuselage, modeled as a rigid body,
- forward cross tube, schematized as a flexible body,
- backward cross tube, schematized as a flexible body,
- left skid, modeled as a rigid body,
- right skid, modeled as a rigid body,
- skid dampers, schematized by the spring-damper feature,
- forward left attachment assy of the skid landing gear to the fuselage,
- forward right attachment assy of the skid landing gear to the fuselage,
- backward central attachment assy of the skid landing gear to the fuselage, schematized by the bushing feature with the stiffness of the real attachment,
- backward cross tube stops, with equivalent contact forces in order to reproduce the same stiffness of the real stops.

All the preceding parts have the same mass and about the same inertial moments of the real parts.



The forces applied directly or indirectly to the skid landing gear for all landing conditions are:

- gravitational force,
- contact force on the backward cross tube stops,
- contact forces on the forward cross tube attachment assy, that reproduce the bottoming of the attachment when the forward cross tube moves perpendicularly to the helicopter longitudinal plane,
- single force that reproduce the ground friction with a static friction coefficient of 0.5 and a dynamic one of 0.39



For the simulation of the level landing drop test the skid landing gear starts falling down, touches the ground and experiments a cross tube deformation with the skid damper active; this model was optimized comparing the force diagram with those of the real level landing drop test; in particular a great effort was due to find the correct value of the parameters of the contact force algorithm and friction coefficient.

For the other landing conditions in compliance with the JAR/FAR requirements, the skid landing gear is constrained in different ways as regards each landing conditions and the force applied are those calculated for each landing condition after MATLAB energy equivalence.

Here below are listed the different peculiarities of each landing model:

4.3.1. Level landing

The level landing model from which the maximum load will be used for all the other landing conditions has the following characteristic:

- 4 contact forces, two for each skid, that reproduce the ground behavior during impact; the comparison with the drop test data result was helpful to optimize the contact parameters;

4.3.2. Level + Drag

In accordance with JAR/FAR 27.501, the model for landing with drag has the following characteristics:

- a joint placed in the center of gravity that allows only a vertical and pitching movement to the helicopter,
- 4 single force applied at both cross tubes tips that reproduce the drag reaction of 50 percent,
- a single force placed in the center of gravity equal to the sum of the maximum vertical reaction determined at the same simulation time step during the level landing drop test simulation.

4.3.3. Level + Side

In accordance with JAR/FAR 27.501, the model for landing with side has the following characteristics:

- a translational joint placed in the center of gravity that allows only a vertical movement to the helicopter,
- 4 single force applied at both cross tubes tips that reproduce the side reaction of 25 percent, 2 force acting inward while the other 2 acting outward,
- a single force placed in the center of gravity equal to the sum of the maximum vertical reaction determined at the same simulation time step during the level landing drop test simulation.

4.3.4. 1 Skid

The model for 1 skid landing has the following characteristics:

- a fixed joint placed in the center of gravity, as if the helicopter is hanged,
- 2 single force applied at the same tip of both cross tubes that reproduce the sum of the maximum vertical reaction determined at the same simulation time step during the level landing drop test simulation.

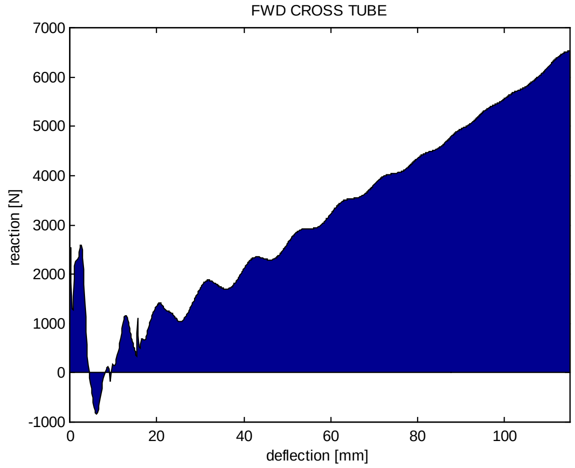
4.4. PLASTIC STRESS CORRECTION WITH MATLAB PROGRAM

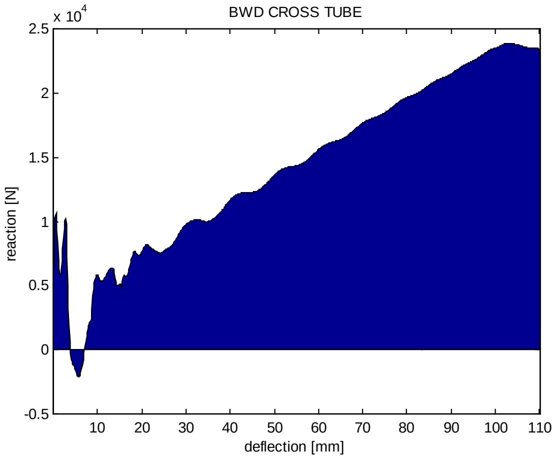
The data collected from ADAMS/Flex simulation are then processed by a MATALAB program that is able to calculate a good approximation of the stress distribution over both FWD and BWD cross tube.

Briefly, the most important phases are:

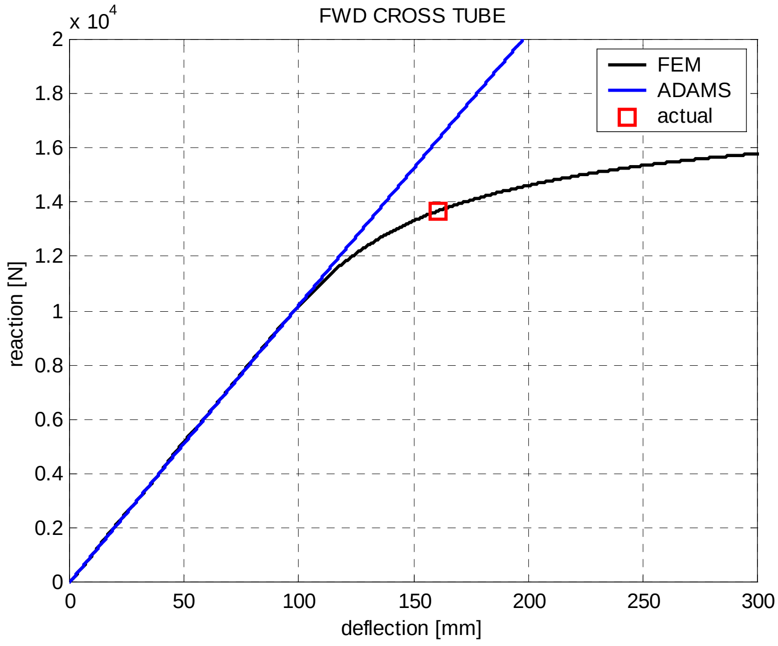
- Deformation Energy equivalence

  The MATLAB program calculates the total energy absorbed by the skid landing gear during the level landing simulation with the time history of the FWD and BWD attachment force and deflection as input data, whose typical trend is reported in the following figures:





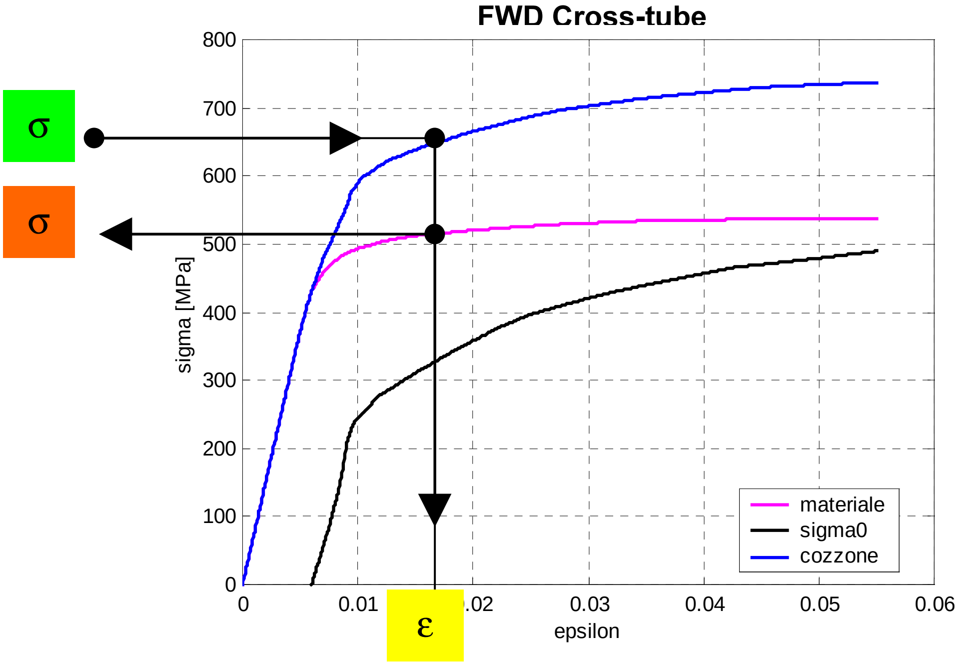
Then the program determines the maximum vertical and lateral force and the corresponding displacements of both cross tubes using the non-linear FEM force-deflection curves as function to integrate in order to have the same deformation energy.



- Resultant Bending Moment determination
  The program calculates the bending moment in the section of fatigue interest, considering also the force coming from dampers and engaged stops with the harms found in the preceding phase.
- Stress determination with Cozzone Procedure
  Known the internal action in the critical section, a linear stress is determined and, if it overcomes the yield stress of the material, the Cozzone Procedure is applied in order to take into account also the plastic collaboration of the material, which gives a stress relief in the external loaded part.
  From the bending moment Mi , the linear stress σ is calculated with the following formula:

  $$\sigma = Mi\frac{R\_ext}{I}$$

  If this stress is greater than the yield stress of the material, the Cozzone procedure must be applied: entering in the Cozzone diagram with the preceding stress σ , the corresponding strain ε is obtained by the interception between the upper curve (blue) and the horizontal line of σ stress; then, entering with this strain in the σm curve, the maximum value of stress is determined.
  The benchmark with the strain gauges results was encouraging because of the minimum difference between real and analytical values.



5. CONCLUSION

The outcome of this experience allow us to advise ADAMS with its Flexible Body toolkit to every engineer who must perform a dynamic analysis of landing with a skid landing gear when the material plastic field is not deeply involved, until there will not be a toolkit that let link together the typical capabilities of a multi-body code and of finite element program.
The benchmark with the level landing drop test results was fundamental to validate our model, especially as regards the contact forces.

6. REFERENCES

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