

The logo for HTC08, featuring the letters 'HTC' in a bold, italicized font with a swoosh underneath, followed by '08' in a similar style.

STRASBOURG, 30/09 – 01/10

**Simulating
Ice Impact on
Helicopter Parts**



Expertise in Multiphysics and Analysis



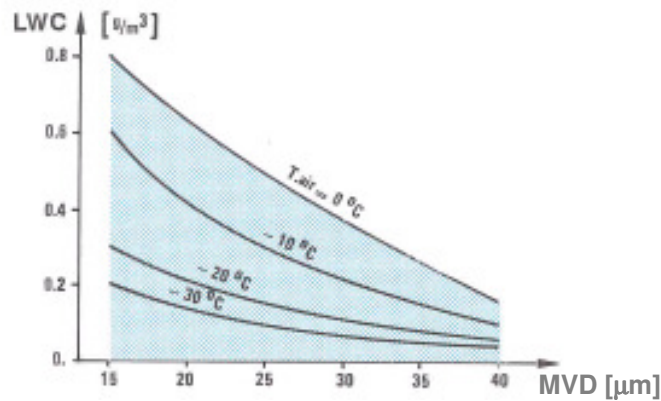
eurocopter
an EADS Company

ABSTRACT

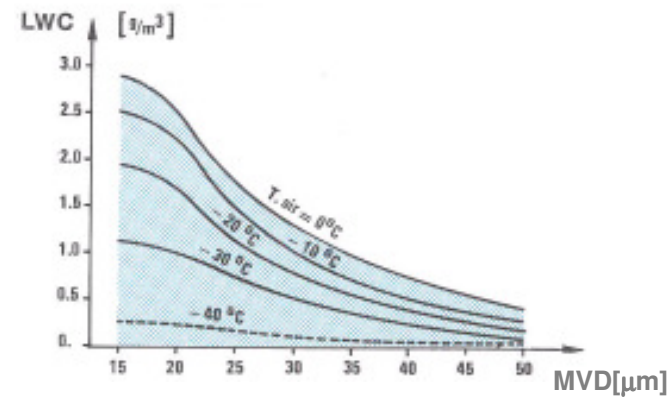
- Ice impact on critical helicopter parts is one of the safety issues considered by regulations requirements. Indeed, damages could occur principally during or after flight in icing conditions, when ice could shed off from the structure, the hub or other optional equipment under the action of aerodynamic forces, vibrations or local heating, and possibly strike helicopter critical parts, for instance the blades. A return of mission and a safe landing need therefore to be guaranteed, but the possibility to continue flight operations before planned aircraft inspections is however the next goal to match with.
- For that purpose, refined numerical simulation of ice impact could help to better understand the key parameters that will drive damage caused to the helicopter, replacing numerous costly tests and completing more conservative approaches. A RADIOSS model of ice was thus performed with SPH methodology, and validated with various publications from the web presenting ice impact on rigid and flexible plates. Influence studies were also carried out to evaluate the appropriate number of particles.
- Experimental tests were supported by EUROCOPTER for calibrating deviatoric ice behavior, while Hugoniot data were found out from bibliographic analysis.

INTRODUCTION

- Icing conditions occurred by combination of 3 parameters:
 - ❖ Liquid Water Content [g/m^3]
 - ❖ Median Volume Diameter [μm] representing droplet size
 - ❖ Outside Air Temperature [$^{\circ}\text{C}$]
- Characterization of icing conditions by standard FAR29 Appendix C



CONTINUOUS MAXIMUM
ICING CONDITIONS



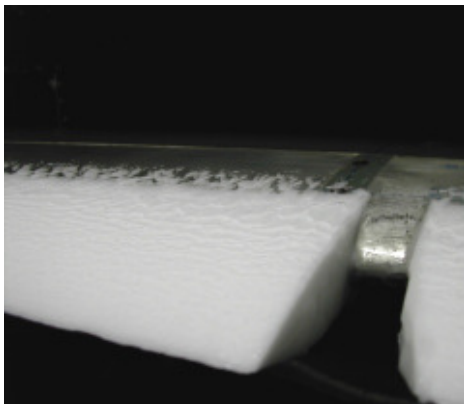
INTERMITTENT MAXIMUM
ICING CONDITIONS

PROBLEM DEFINITION

- Consequences of icing conditions for helicopters:
 - ❖ Less aerodynamic performance for blades and rotors
 - ❖ Blockage of air intake and outlet for cooling, pressure inlet, engines...
 - ❖ Locking of dynamic systems parts
 - ❖ Loss of equilibrium and vibrations
 - ❖ Loss of visibility for windshields
 - ❖ Weight increase
 - ❖ Flight envelope reduction
 - ❖ **Ice impact when detachment from support**
 - ⇒ Damage?
 - ⇒ Guaranty of safe return or continuous flight operations?



Super Puma in icing conditions



« Rime ice » on blades



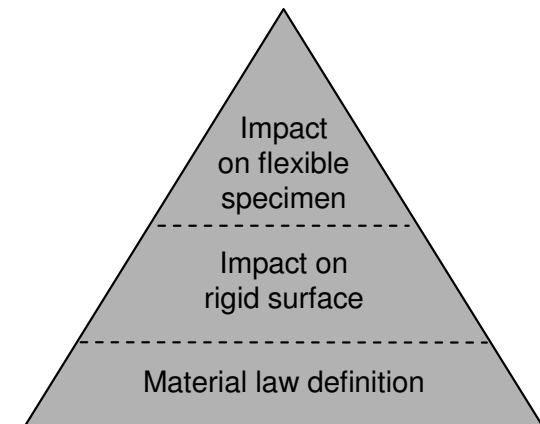
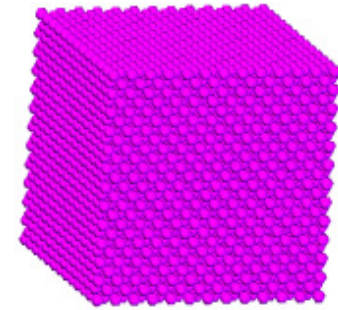
« Mixed ice » on blades



« Glaze ice » on blades

ANALYSIS with RADIOSS

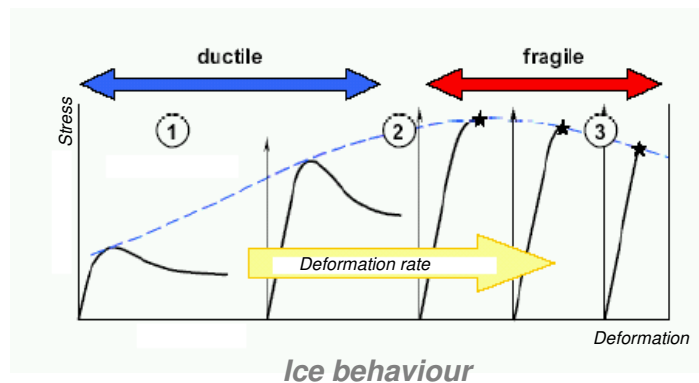
- Ice RADIOSS model made in SPH
 - ❖ Cubic centered faces net
 - ❖ SPH properties calculated according to ice mass
 - ❖ Influence studies carried out to determine particles density w.r.t CPU time and results accuracy
- Building block approach used for model validation
 - ❖ Step 1: material law definition
 - Compression, flexion and shear tests “Static loop”
 - Impacts on shock table “Dynamic loop”
 - All tests performed at “Centre d’Essais Aéronautiques de Toulouse” in the frame of EC225 helicopter certification
 - ❖ Step 2: validation of parameters by impact on rigid surface
 - 90° and 45° impact angle
 - Reference [1] – see slide 12
 - ❖ Step 3: final validation by impact of flexible specimens
 - Metallic plate - reference [2] see slide 12
 - Composite plate - reference [3] see slide 12



Building block approach

ANALYSIS with RADIOSS

- Step 1: Which material law?
 - ❖ Ice behavior depending on deformation rate (ductile at low rates and brittle at high rates)
 - ❖ Validation of material parameters (Johnson-Cook) thanks to “static tests”
 - ❖ Hydrodynamic coefficients C_i are evaluated thanks to Hugoniot polar shock (see reference [4])
 - ❖ Validation of Equation of State thanks to dynamic tests on shock table



The stress - strain relationship for the material under tension is:

$$\sigma = (A + B\varepsilon_p^n)$$

The compression relationship is given in terms of pressure, p :

$$p = C_0 + C_1\mu + C_2\mu^2 + C_3\mu^3 + (C_4 + C_5\mu)E_n$$

where $\mu = \rho / \rho_0 - 1$

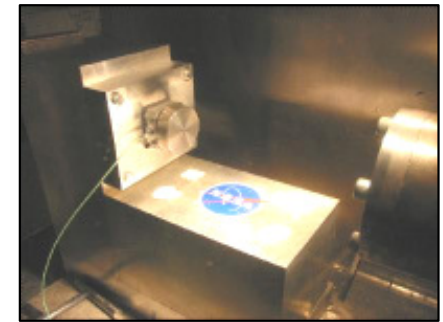
$C_0, C_1, C_2, C_3, C_4, C_5$ = Hydrodynamic constants

E_n = Energy per unit of initial volume

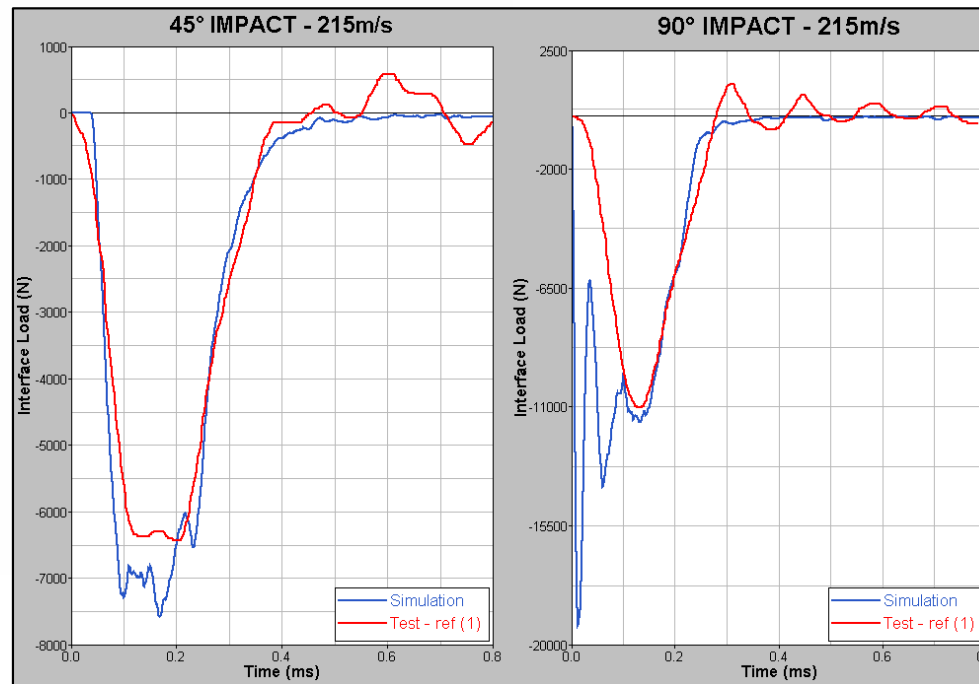
Hydrodynamic law in RADIOSS

ANALYSIS with RADIOSS

- Step 2: Impact on rigid surface – 90° & 45° impact angles – Reference [1]
 - ❖ Ice cylinder: diameter = 17,5mm – height = 42,2mm – mass = 9,17g
 - ❖ Influence study on mesh density
 - ❖ Impact velocity: 215m/s



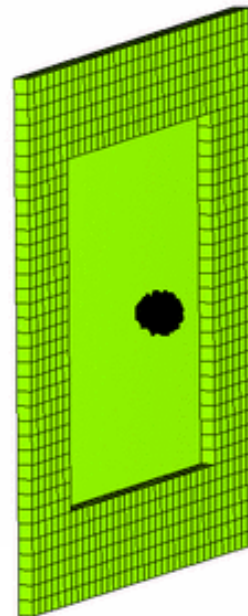
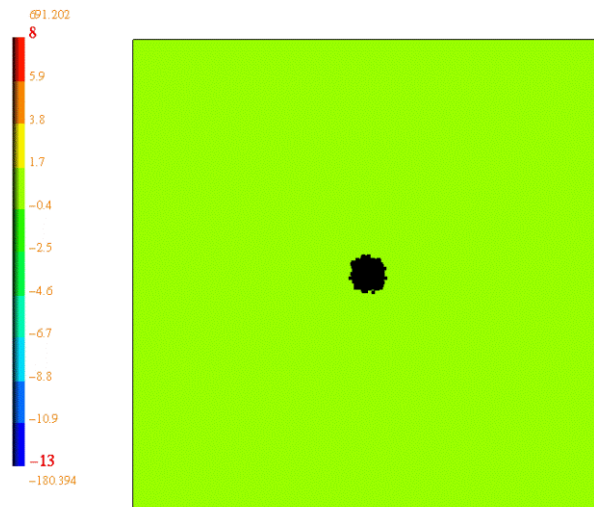
Test article with helium gas gun and rigid load cell – ref [1]



ANALYSIS with RADIOSS

- Step 3: Impact on flexible aluminum plate – Reference [2]
 - ❖ Ice sphere: diameter = 25,4mm – mass = 7,75g
 - ❖ 2014-T4 aluminium - 0,91mm thick
 - ❖ Influence study on boundary condition and mesh density
 - ❖ Impact velocity (90°): 192m/s

Plate deflection (mm)



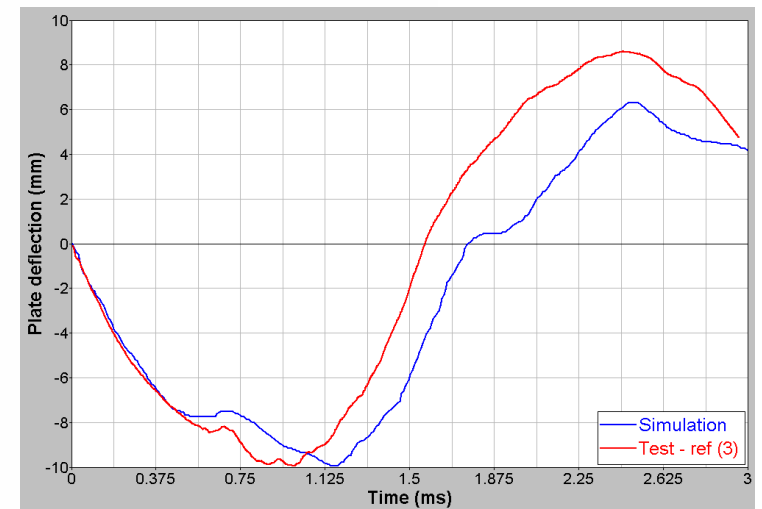
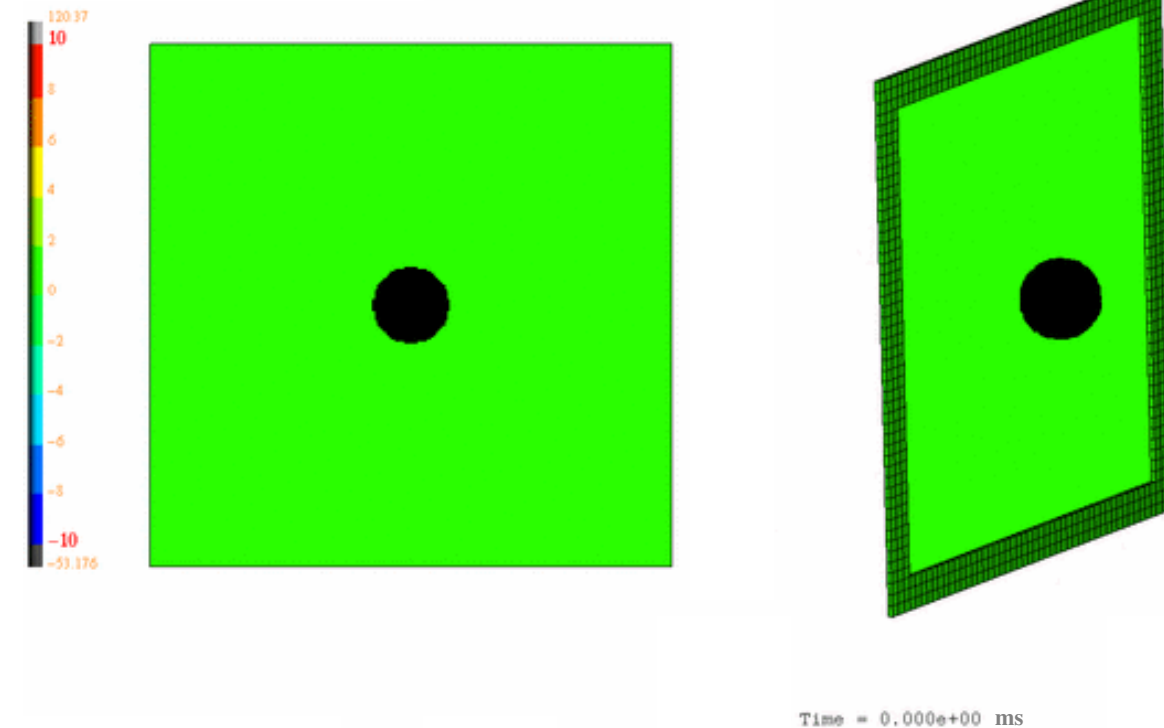
Time = 0.000e+00 ms

	Permanent plate deflection [mm]
Simulation	11.03
Test	11.20

ANALYSIS with RADIOSS

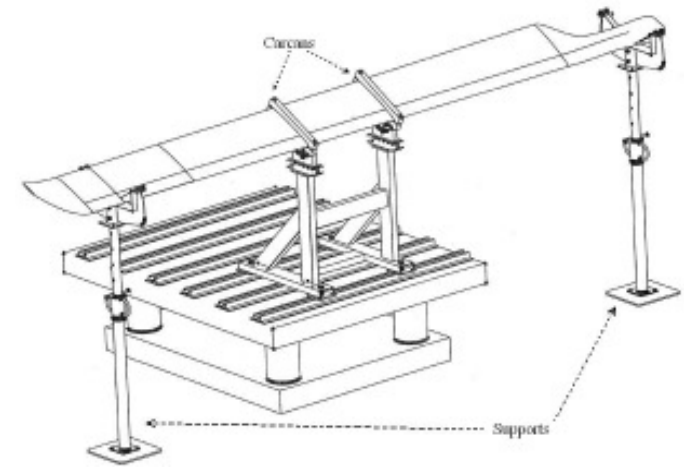
- Step 3: Impact on flexible composite plate – Reference [3]
 - ❖ Ice sphere: diameter = 42,7mm – mass = 36,84g
 - ❖ 8 plies of carbon epoxy fabric – 2,44mm thick
 - ❖ Influence study on boundary condition and mesh density
 - ❖ Impact velocity (90°): 73,2m/s

Plate deflection (mm)

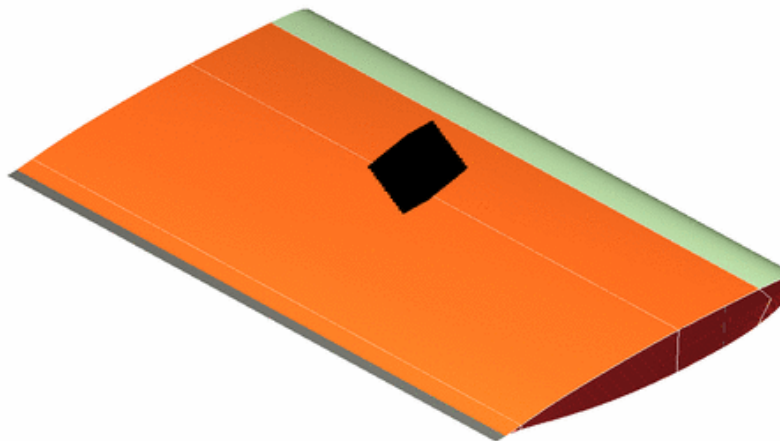


ANALYSIS with RADIOSS

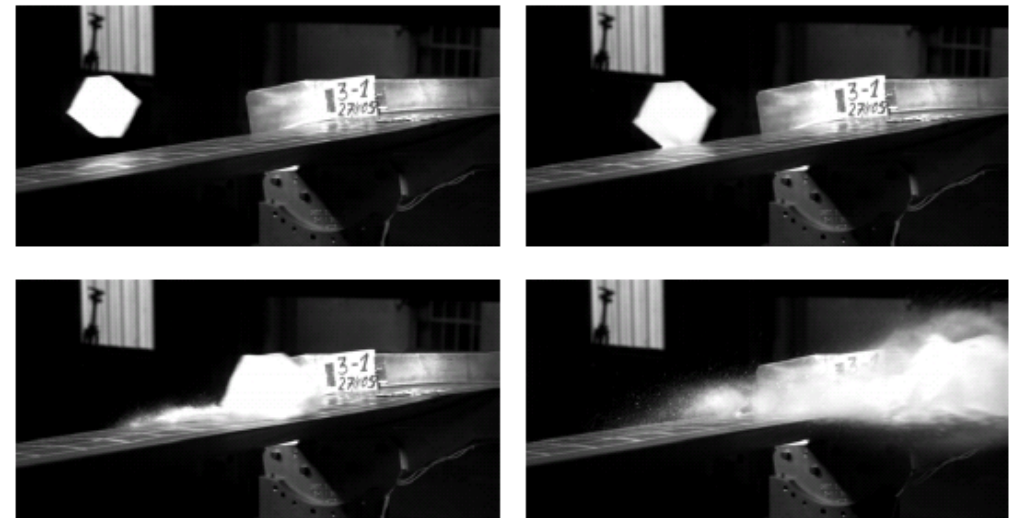
- Step 4... Example of impact on blades
 - ❖ Ice cube: length = 70mm - mass = 310g
 - ❖ Impact velocity: 130m/s
 - ❖ Impact angle: 12°



Typical test article for blade certification test to ice impact



Time = 0.000e+00 ms



Example of certification test (performed at CEAT)

DISCUSSIONS & CONCLUSION

- EUROCOPTER first approach for ice model validation
- Some developments still required before use for certification/qualification purpose
 - ❖ Difference between pure ice and real helicopter ice (material law, failure mechanisms...)
 - ❖ Validation for higher mass of ice block
 - ❖ Improvement of composite delamination or failure modelling for blades impact
- Encouraging study which would help to:
 - ❖ Better understand the key parameters of damage after ice impacts (mass, speed, impact angle till rebound...)
 - ❖ Decrease the number of development and certification tests
 - ❖ Evaluate damage of helicopter critical parts after impact to determine residual static or fatigue strength to allow safe return or continuous mission flight
 - ❖ Define “design rules” for helicopter parts subjected to ice impact

ACKNOWLEDGEMENTS & REFERENCES

- Acknowledgments

EMA and EUROCOPTER would like to thank Mr Pierre Brillant for his intensive work on this subject, as well as Mr CASTELLETTI and Mr AIROLDI from Politecnico di Milano for their support.

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- [4] Russian internet web site for shock polar and Hugoniot data
www.ficp.ac.ru/rusbank

QUESTIONS?

Thank you