ISSN : 2321-9416

Indo - American Journal of Mechanical Engineering

www.iajme.org

Email : iajme.editor@gmail.com or editor@iajme.org

HIGH-VELOCITY BIRD STRIKE ANALYSIS ON AIRCRAFT LEADING EDGE USING SPH METHOD

Mr. M. Anil Kumar [1], K. Ashish Vardhan [2], K. Satyanarayana [3], K. Yaswanth Kasi Raju [4], D. Prasanth [5]

[1]Assistant Professor,Department of Mechanical Engineering
Pragati Engineering College (Autonomous)
(Affiliated to JNTUK)
Kakinada District, Surampalem -533437
[2,3,4,5,]Students, Department of Mechanical Engineering
Pragati Engineering College (Autonomous)
(Affiliated to JNTUK) Kakinada District, Surampalem -533437

Mail.Id: alekhya.g@pragati.ac.in, Mail.Id:ashishmb4k@gmail.com
Mail.Id: satyakadari2@gmail.com, Mail.Id: suhasini556677@gamil.com
Mail.Id: dharmadiprasanth704@gmail.com

ABSTRACT

Bird strike poses a major threat to aircraft structural integrity, particularly during takeoff and landing phases. At high impact velocities, a bird behaves as a soft hydrodynamic body rather than an elastic solid, producing high-intensity, short-duration loads on aircraft structures.

This study investigates high-velocity bird strike impact on an aircraft leading edge structure using the Smooth Particle Hydrodynamics (SPH) method. Numerical simulations are performed using ANSYS AUTODYN and explicit dynamic solvers. The bird is modeled as a soft body using an appropriate equation of state (EOS), and the leading edge is modeled using carbon fiber composite material.

---

1. INTRODUCTION

Bird strike incidents cause:

- Structural damage
- Engine ingestion failures
- Economic loss exceeding $1 billion annually

Regulatory standards such as FAR Part 25 require that aircraft structures withstand specified bird impact scenarios.

Key characteristics of bird strike:

- High strain rate loading
- Millisecond duration impact
- Large deformation
- Fluid-like projectile behavior

Traditional design approach:

Build → Test → Redesign → Retest

This process is costly and time-consuming. Hence, numerical simulation methods are increasingly adopted.

2. PHYSICS OF BIRD STRIKE IMPACT

At typical aircraft velocities (150–300 knots):

2.1 Shock (Hugoniot) Pressure

Initial shock pressure approximated by water hammer equation:

$$P = \rho_0 c_0 v$$

For higher velocities:

$$P_c = \frac{\rho_P c_P \rho_T c_T}{\rho_P c_P + \rho_T c_T} v$$

Where:

- ρ = density
- c = wave velocity
- v = impact velocity

This shock pressure governs initial structural response.

$$P_H = \rho_0 v_s v_0$$

$$p_c = \rho_P v_{SP} v_0 \left[\frac{\rho_T v_{ST}}{\rho_P v_{SP} + \rho_T v_{ST}} \right]$$

where pc is the pressure at the center of the impact zone, and the subscripts P and T represent projectile and target. The

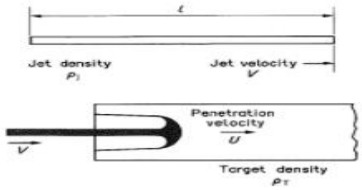
- Bird material strength << generated impact stress
- Bird behaves hydrodynamically

Two major pressure components:

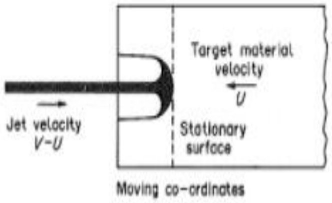
1. Hugoniot (Shock) Pressure
2. Steady-State Pressure

shockwave velocities SP v and ST v for the projectile and the target can be computed from the linear Hugoniot equation.

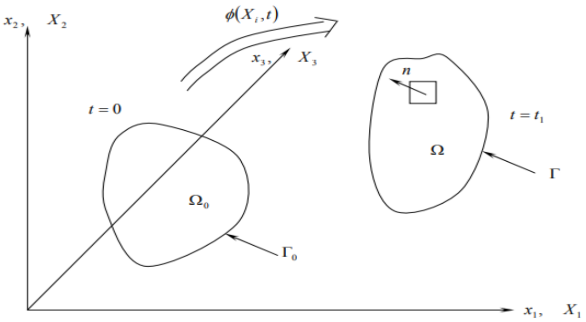
$$\frac{1}{2}\rho_j (V-U)^2 = \frac{1}{2}\rho_T U^2.$$



A survey of shaped-charge jet penetration models

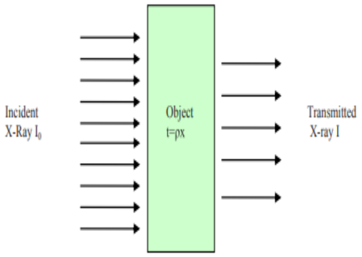


A technique based on x-ray attenuation theory is developed utilizing flash x-ray image to measure the powder metal jet density. The digitized image presents gray scale of each pixel that is proportional to intensity of the x-ray energy. The density profile along jet length at a particular moment is obtained by measuring the center line gray level assuming no density gradient in the radial direction. Jet density profiles at different times are obtained from multiple images.



X-ray beam energy intensity attenuates when it transmits through a material. The intensity of incident x-ray energy is I0, the intensity attenuates to I after it transmitted through the material with mass density and thickness x.

$$I = I_0 \exp(-\mu_{eff}\rho x),\ \mu_{eff} = \frac{\mu}{\rho}$$



$$\rho = -\ln(I/I_0)/\mu_{eff}x$$

3. GOVERNING EQUATIONS

Bird strike is governed by conservation laws:

3.1 Conservation of Mass

$$\frac{D\rho}{Dt} + \rho\nabla\cdot v = 0$$

3.2 Conservation of Linear Momentum

$$\rho\frac{Dv}{Dt} = \nabla\cdot\sigma + \rho b$$

3.3 Conservation of Energy

$$\rho\frac{DE}{Dt} = \sigma : \nabla v$$

These nonlinear 3D equations are solved numerically.

$$\sigma_{ij,j} + \rho b_i = \rho\dot{v}_i$$

4. NUMERICAL METHODS FOR BIRD STRIKE

Several modeling approaches exist:

4.1 Lagrangian Method

- Mesh follows material
- Good for solids
- Suffers severe mesh distortion
- Causes negative volume errors

4.2 Eulerian Method

- Mesh fixed in space
- Good for fluids
- High computational cost
- Requires large domain

4.3 Arbitrary Lagrangian Eulerian (ALE)

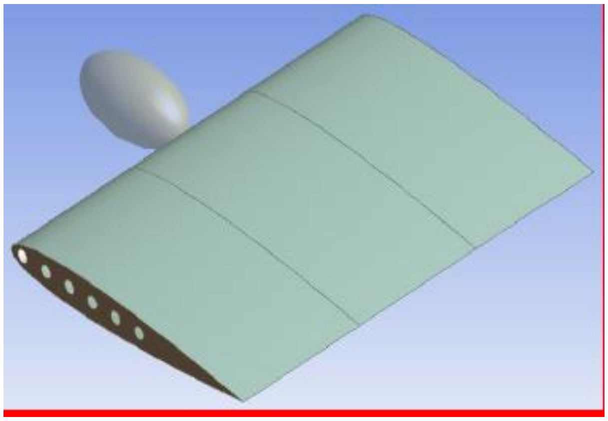
- Combines Lagrangian + Eulerian
- Handles fluid-structure interaction
- Computationally intensive

4.4 Smooth Particle Hydrodynamics (SPH)

- Meshless method
- Bird modeled as interacting particles
- Avoids mesh distortion
- Ideal for large deformation

SPH is selected for this study.

5. BIRD MODELING



5.1 Geometry

Common shapes:

- Cylinder
- Hemispherical cylinder
- Ellipsoid
- Rugby ball

SPH bird modeled as cylindrical body with hemispherical ends.

Spaceclaim:

SpaceClaim is a solid modeling CAD (computer-aided design) software that runs on Microsoft Windows and developed by SpaceClaim Corporation. The company is headquartered in Concord, Massachusetts.

SpaceClaim Corporation was founded in 2005 to develop 3D solid modeling software for mechanical engineering. Its first CAD application was launched in 2007 and used an approach to solid modeling where design concepts are created by pulling, moving, filling, combining, and reusing 3D shapes.[1] It was acquired by Ansys in May 2014, Inc, and was integrated in subsequent versions of Ansys Simulation packages as a built-in 3D modeler.

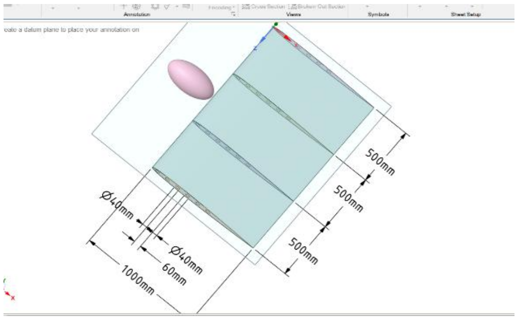
SpaceClaim Corporation markets SpaceClaim Engineer directly to end-user and indirectly by other channels. SpaceClaim also licenses its software for OEMs, such as ANSYS,[3] Flow International Corporation,[4] CatalCAD, and Ignite Technology which markets a version of SpaceClaim for jewelry design.

Geometry details

5.2 Material Modeling

Bird treated as:

- 90% water + 10% air



- Density ≈ 1000 kg/m³

Equation of State (EOS) governs pressure response.

Porosity study suggests 30–40% gives realistic Hugoniot pressures.

6. LEADING EDGE STRUCTURE

Material: Carbon Fiber Composite

Advantages:

- High strength-to-weight ratio
- Good energy absorption
- Widely used in aerospace

Failure modeled using strain-based damage criteria.

7. EQUATION OF STATE (EOS)

7.1 Air – Perfect Gas EOS

$$P = (\gamma - 1)\rho E$$

$\gamma = 1.4$

7.2 High Explosive (TNT) – JWL EOS

$$P = Ae^{-R_1 V} + Be^{-R_2 V} + \omega \frac{E}{V}$$

Used for blast simulations.

8. ANSYS AUTODYN METHODOLOGY

AUTODYN selected for:

- Explicit dynamic solver
- SPH capability
- Fluid-structure interaction
- Large deformation handling

Workflow:

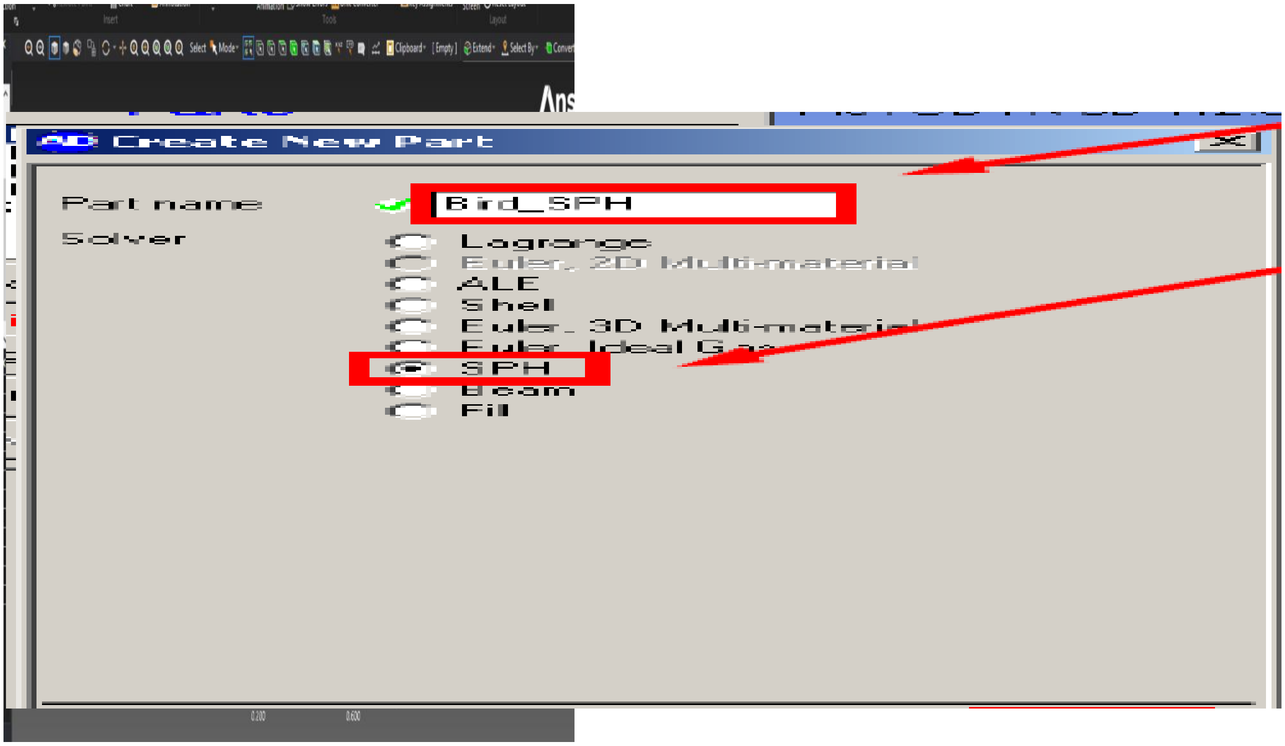
1. Geometry creation (SpaceClaim)
2. Mesh / Particle discretization
3. Material assignment
4. Contact definition
5. Initial velocity setup
6. Solution control
7. Post-processing

9. BOUNDARY CONDITIONS

- Bird initial velocity: 150–200 m/s
- Leading edge fixed at root
- Contact: SPH to surface contact

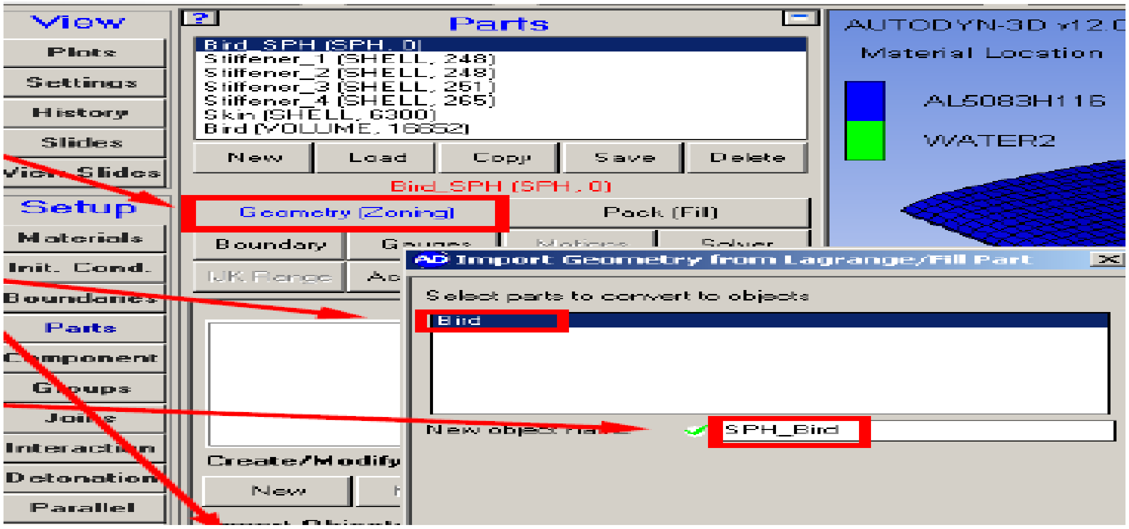
- Erosion criteria enabled

Mesh in Explicit Dynamics


Create New Part

Part name ✓ Bird_SPH

Solver
○ Lagrange
○ Euler, 2D Multi-material
○ ALE
○ Shell
○ Euler, 3D Multi-material
○ Euler, Ideal Gas
● SPH
○ Beam
○ Fill



Bird_SPH (SPH, 0)
Stiffener_1 (SHELL, 248)
Stiffener_2 (SHELL, 248)
Stiffener_3 (SHELL, 251)
Stiffener_4 (SHELL, 265)
Skin (SHELL, 6300)
Bird (VOLUME, 16552)

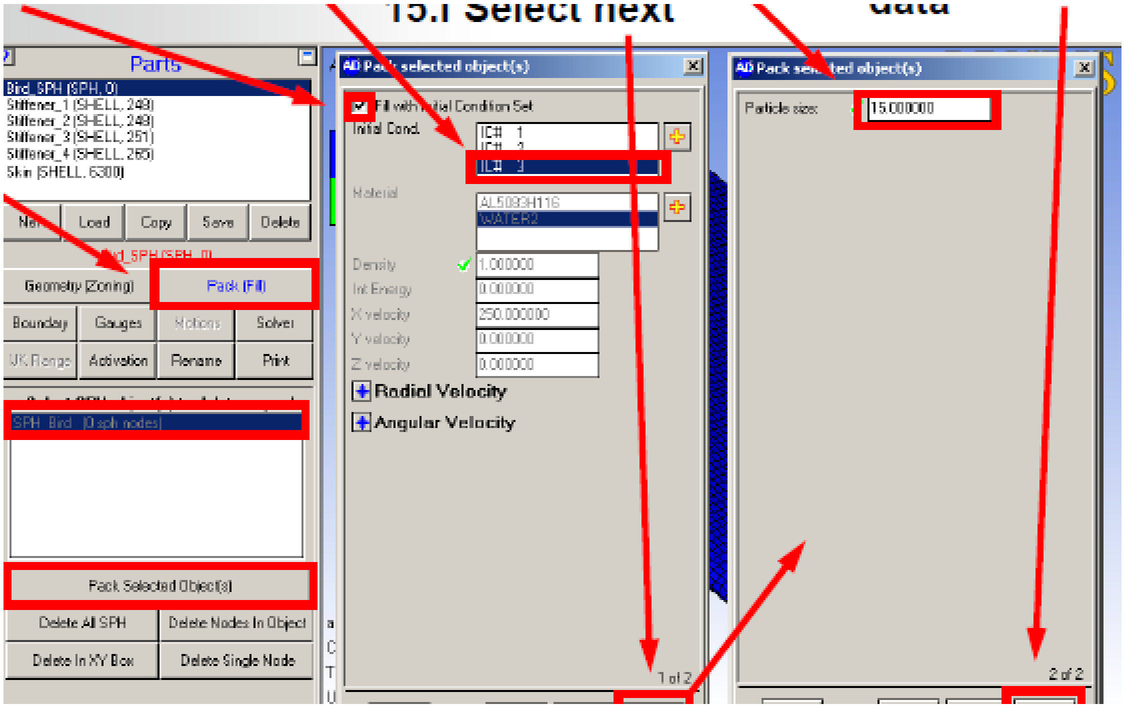
Bird_SPH (SPH, 0)

AL5083H116
WATER2

Import Geometry from Lagrange/Fill Part

Select parts to convert to objects
Bird

New object name ✓ SPH_Bird



Bird_SPH (SPH, 0)
Stiffener_1 (SHELL, 248)
Stiffener_2 (SHELL, 248)
Stiffener_3 (SHELL, 251)
Stiffener_4 (SHELL, 265)
Skin (SHELL, 6300)

SPH_Bird (0 sph nodes)

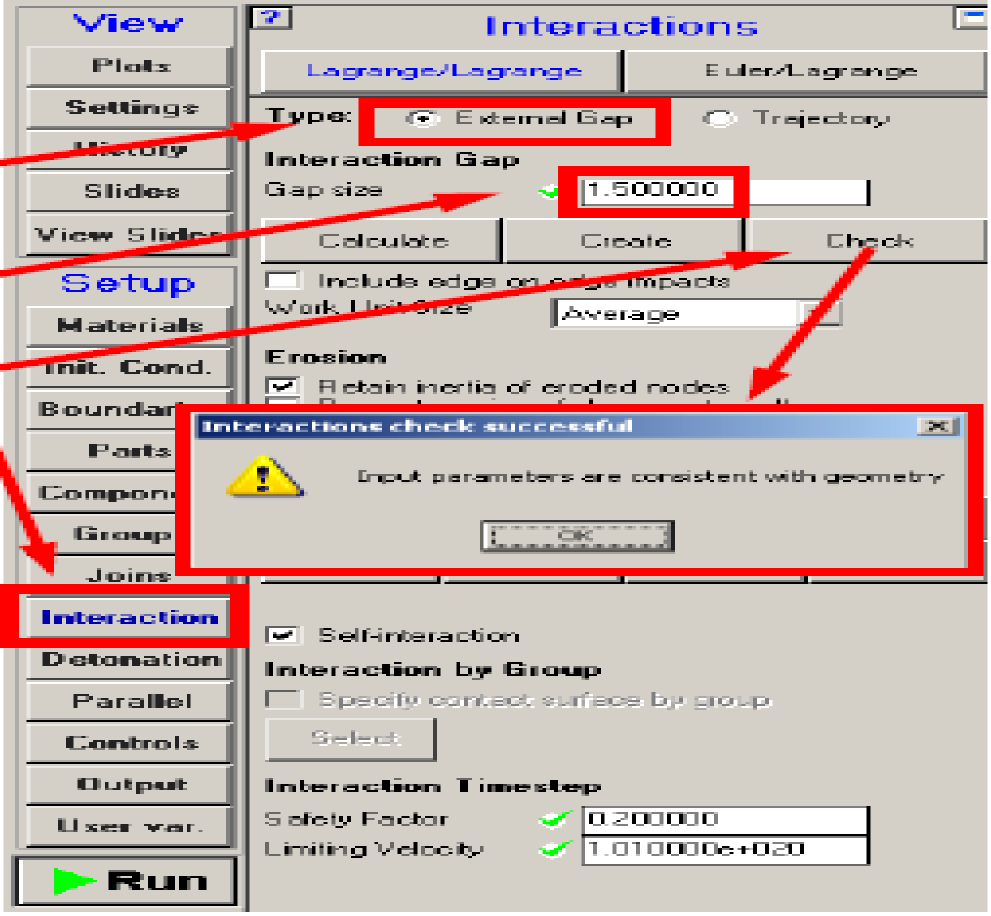
☑ Fill with Initial Condition Set

Initial Cond.: IC# 1, IC# 2, IC# 3

Material: AL5083H116, WATER2

Density: 1.000000
Int Energy: 0.000000
X velocity: 250.000000
Y velocity: 0.000000
Z velocity: 0.000000

Particle size: 15.000000



Type: ● External Gap ○ Trajectory

Interaction Gap
Gap size: 1.500000

☐ Include edge on edge impacts
Work Unit Size: Average

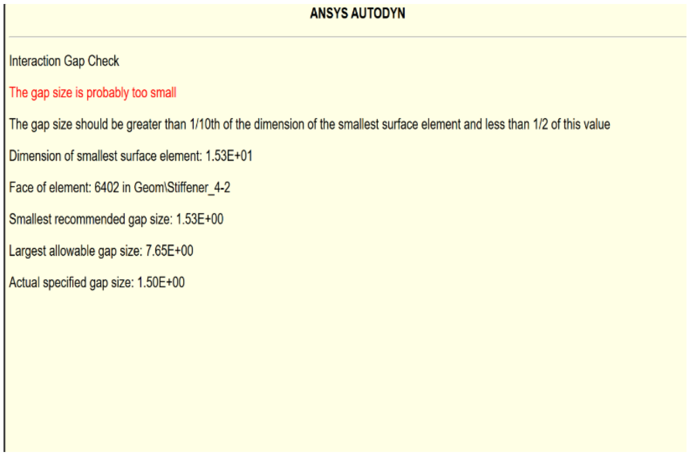
Erosion
☑ Retain inertia of eroded nodes

Interactions check successful
Input parameters are consistent with geometry

☑ Self-interaction

Interaction by Group
☐ Specify contact surface by group

Interaction Timestep
Safety Factor: 0.200000
Limiting Velocity: 1.010000e+020



ANSYS AUTODYN

Interaction Gap Check

The gap size is probably too small

The gap size should be greater than 1/10th of the dimension of the smallest surface element and less than 1/2 of this value

Dimension of smallest surface element: 1.53E+01

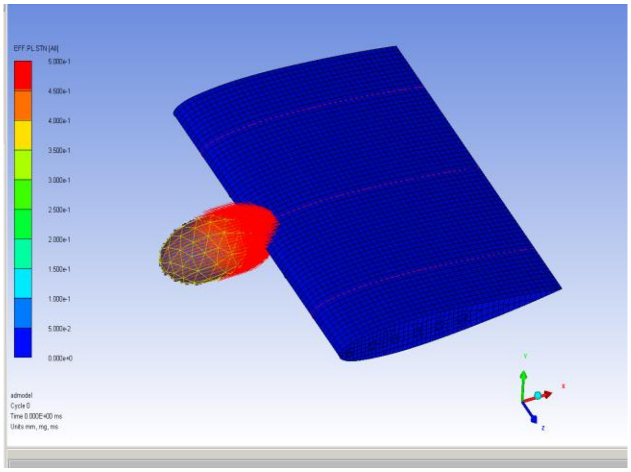
Face of element: 6402 in Geom\Stiffener_4-2

Smallest recommended gap size: 1.53E+00

Largest allowable gap size: 7.65E+00

Actual specified gap size: 1.50E+00

Checking the data for solution run



Deck Preparation carbon fiber

10. MESH AND SPH DISCRETIZATION

- Bird: SPH particles
- Leading edge: Shell / solid elements
- Refined mesh at impact region

SPH avoids:

- Mesh tangling
- Hourglass modes
- Negative volumes

11. RESULTS

11.1 Deformation Pattern

- Bird spreads fluid-like
- Large local indentation
- No rebound

11.2 Energy Distribution

Energy summary:

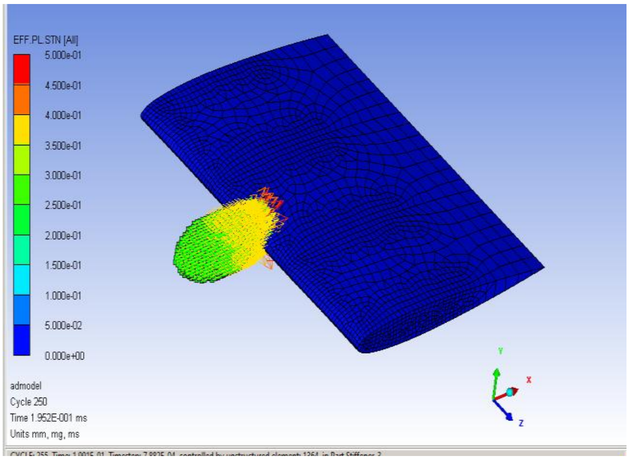
- Initial kinetic energy
- Internal energy increase
- Contact energy
- Structural strain energy

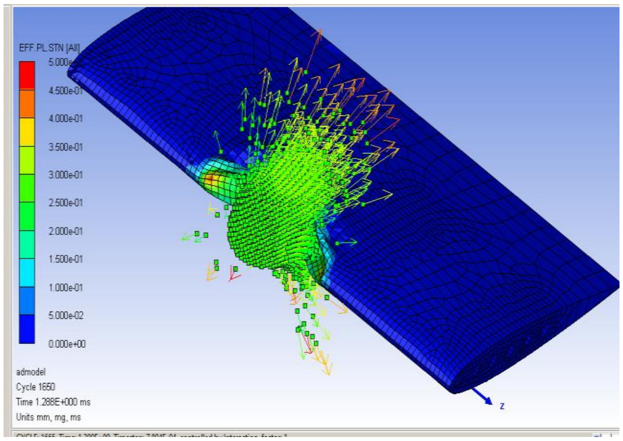
Carbon fiber absorbs significant energy before failure.

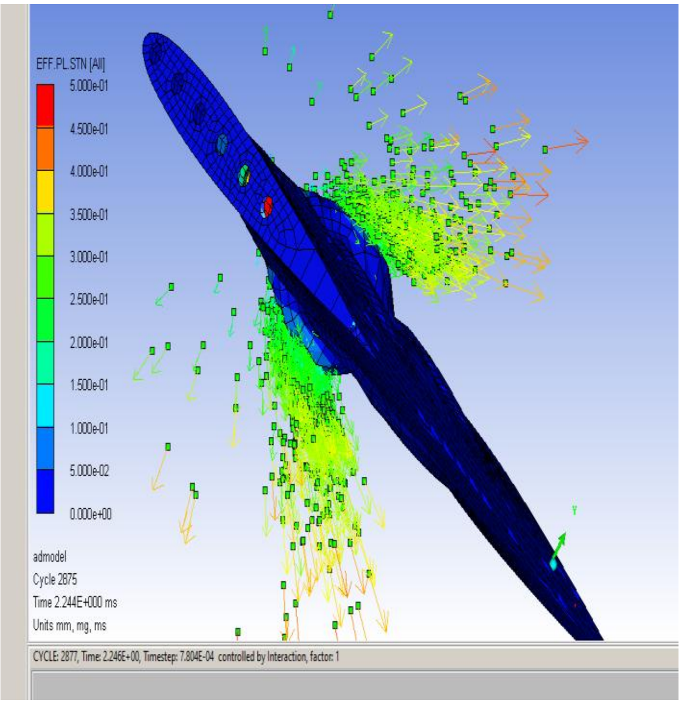
11.3 Time Step Evolution

Four stages observed:

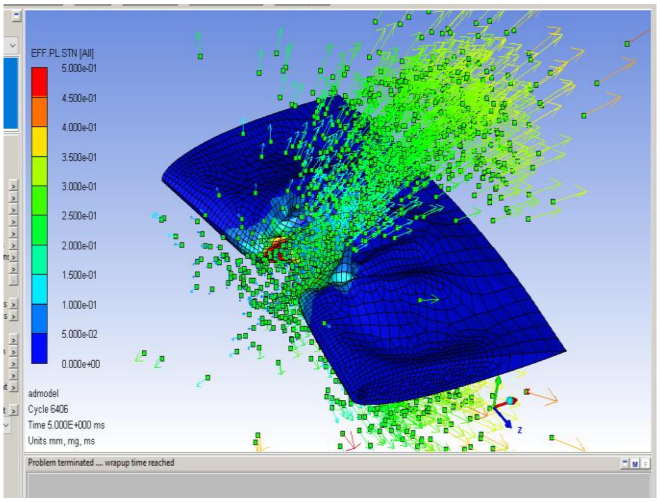
1. Initial contact (shock peak)
2. Maximum deformation
3. Bird spreading
4. Structural vibration decay



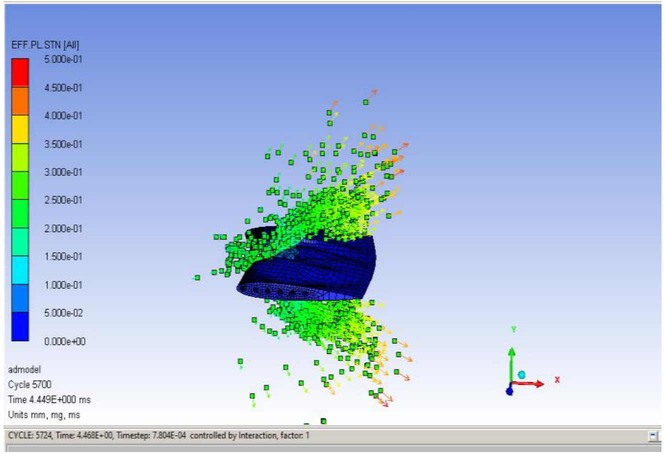




```
CYCLE: 2877, Time: 2.246E+00, Timestep: 7.804E-04 controlled by Interaction, factor: 1
```



```
Problem terminated .... wrapup time reached
```



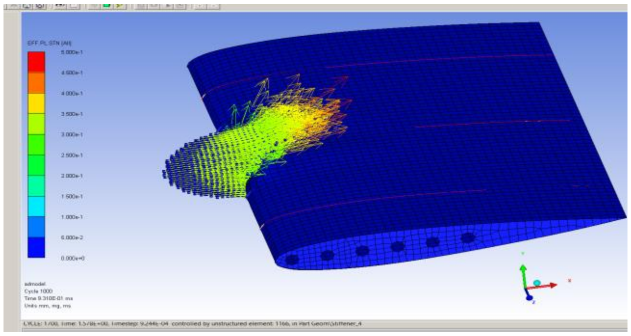
```
CYCLE: 5724, Time: 4.468E+00, Timestep: 7.804E-04 controlled by Interaction, factor: 1
```

12. MATERIAL RESPONSE – CARBON FIBER

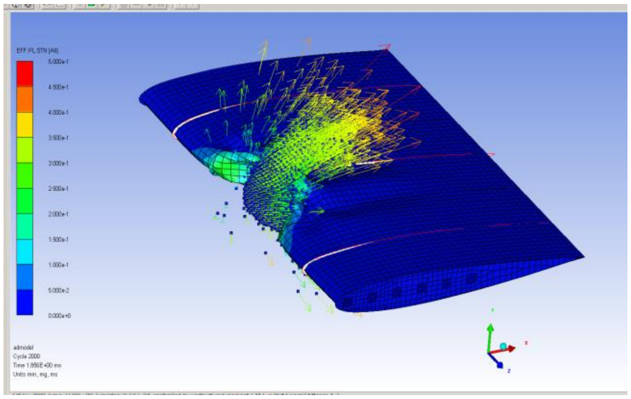
Material summary shows:

- High stress resistance
- Progressive damage
- Delamination initiation
- No catastrophic failure

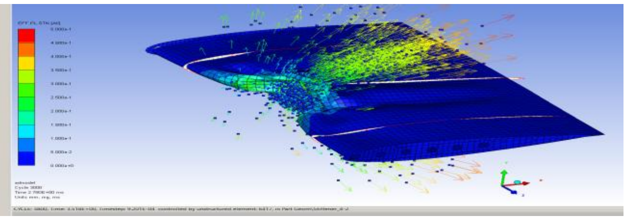
Energy absorption confirmed by total energy plots.



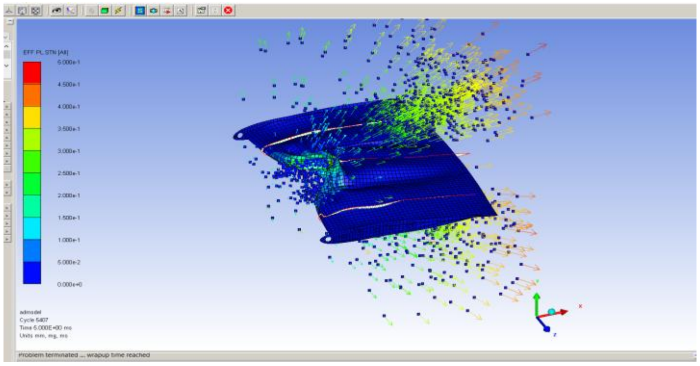
Carbon fiber 1st step run time



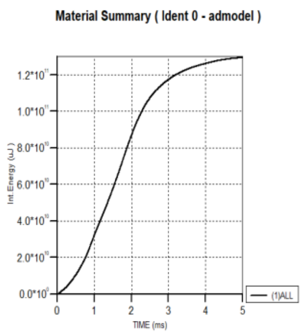
Carbon fiber 2nd step run time

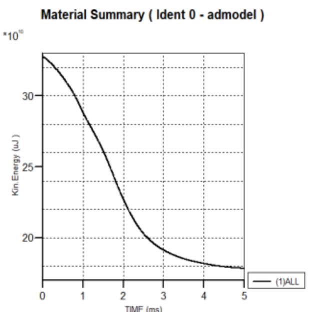


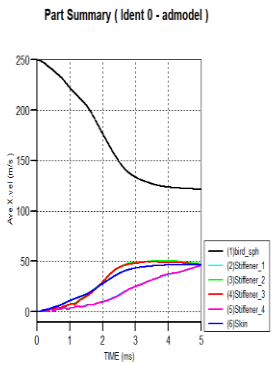
Carbon fiber 3rd step run time



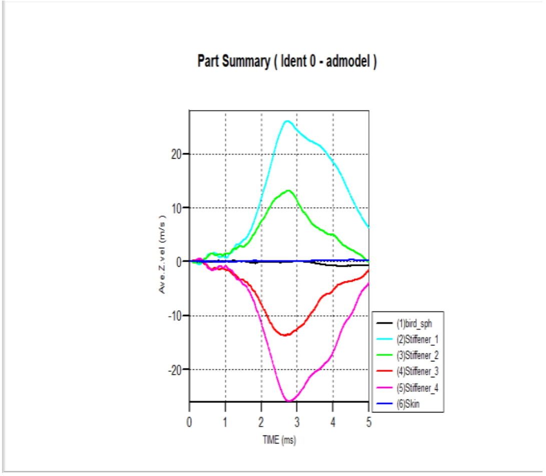
Carbon fiber last run time

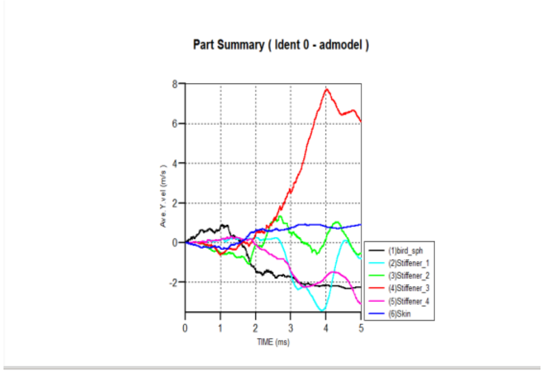


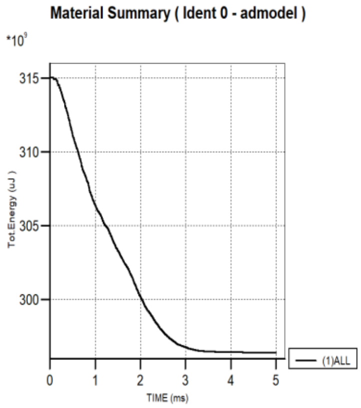




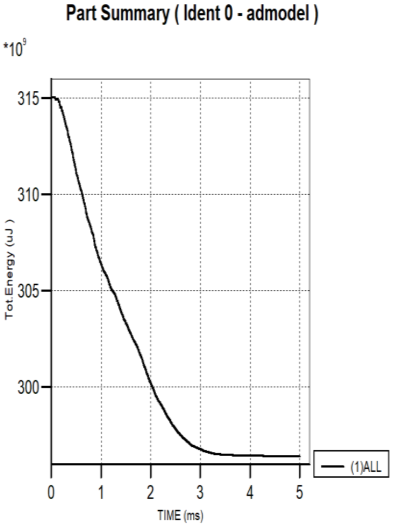
blem terminated ... wrapup time reached



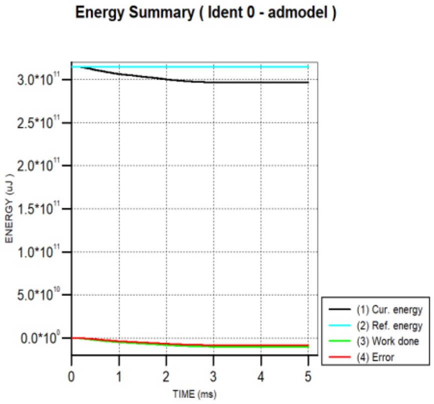




Material summary carbon fiber



Part total energy carbon fiber



Energy summary carbon fiber

13. COMPARISON: LAGRANGIAN VS SPH

Method	Stability	Accuracy	Deformation Handling
Lagrangian	Low	Moderate	Poor at high strain
ALE	Good	High	Good
SPH	Excellent	High	Excellent

SPH provides best balance.

14. DISCUSSION

Key findings:

- Shock pressure dominates initial damage
- SPH captures fluid spreading accurately
- Carbon fiber reduces localized failure
- Mesh distortion eliminated
- Energy absorption behavior validated

15. ENGINEERING IMPLICATIONS

Simulation enables:

- Weight optimization
- Structural reinforcement design
- Reduced experimental iterations
- Certification pre-analysis

16. LIMITATIONS

- Bird treated homogeneous
- No detailed bone structure
- Simplified EOS
- No aerodynamic pre-stress included

Future work:

- Multi-material bird model
- Oblique impact
- Composite failure refinement

17. CONCLUSION

This study successfully performed high-velocity bird strike simulation on aircraft leading edge using SPH method.

Major conclusions:

1. Bird behaves hydrodynamically at high velocity.
2. Shock (Hugoniot) pressure governs initial structural response.
3. SPH effectively models extreme deformation.
4. Carbon fiber shows strong energy absorption capability.
5. Numerical simulation reduces experimental cost.
6. SPH is superior to pure Lagrangian modeling for bird strike problems.

The developed methodology provides a reliable framework for bird strike structural assessment and aerospace certification analysis.

REFERENCES

Allan, J. R., and Orosz, A. P., “The Costs of Bird strikes to Commercial Aviation”, Bird Strike Committee Proceedings, Bird Strike Committee-USA/Canada, Third Joint Annual Meeting, Calgary, AB, 2001.

Anghileri, M., Castelletti, L-M L, and Mazza, V., “Bird Strike: Approaches to the Analysis of Impacts with Penetration”, Impact Loading of Light Structures, WIT Transactions on Engineering Sciences, Vol

49, 2005. (International Conference on Impact Loading of Lightweight Structures, May 2004.)

Frischbier, J., Kraus, A., "Multiple Stage Turbofan Bird Ingestion Analysis with ALE and SPH Methods", AIAA Paper No. 2005-1016, 2005.

Rueda, F., Beltrán, F., Maderuelo, C., and Climent, H., "Bird strike Analysis of the Wing Slats of EF-2000," Structures under Shock and Impact VII, 2002 WIT Press.

Wilbeck, J. S., and Rand, J. L. "The Development of Substitute Bird Model", ASME Journal of Engineering for Power, 1981, Vol.103, pp 725-730.

McCallum, S. C. and Constantinou, C. "The Influence of Bird-Shape in Bird-Strike Analysis", 5th European LS-DYNA Users Conference, Birmingham, UK, May 2005.

Bin, K. A., 1993. Gas entrainment by plunging liquid jets. Chem. Eng. Sci., 48, 3585-3630.

Bonetto, F. et al, 1994. The analysis of a plunging liquid jet – the air entrainment process. Chem.

Eng. Comm., 130, 11-29

Bourne, N. K. et al, 1996. The impact and penetration of water surface by a liquid jet, Proc. R.

Soc. Lond. A, 452, 1497-1502.

Chanson, H., 1996. Air Bubble Entrainment in Free-Surface Turbulent Shear Flows, Academic

Press, San Diego, CA, USA.

Hirt, C. W. & Nichols, B. D., 1981, J. Computer. Phys., 39, 201.

Kunugi, T. et al. 1997. Proc. of 11th CFD Symposium, E2-4.

Benson, D., "Computational Methods in Lagrangian and Eulerian Hydrocodes", Computer Methods in Applied Mechanics and Engineering, 1992, No. 99, pp235-394.

Wilbeck, J. S., "Impact Behavior of Low Strength Projectiles", Ph. D. Dissertation, Texas A&M University, May 1977.