Computational Forensics for Airplane Bombing

with a Case Study of Daallo Airlines Flight 159 in February, 2016

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Mathematical modeling and computer simulation for the study of aircraft bombing and the associated forensics.

Characteristics of bombing are illustrated in photographs. How well these characteristics can be captured by computational mechanics?

Laptop-bombing case of Daallo Airlines Flight 159 is used as a case-study to demonstrate that event reconstruction can be done for the purpose of forensic investigation.

The dynamic effects and phenomena of explosions and the associated event reconstruction are visualized by many video animations.

Introduction

Our objectives:

- the effectiveness of computational mechanics in capturing blast phenomena;
- the destructive effects to airframes by detonation according to the varying amounts of explosives;
- the damage to the aircraft in the specific incident of Daallo Airlines Flight 159 referred to earlier.

Outline

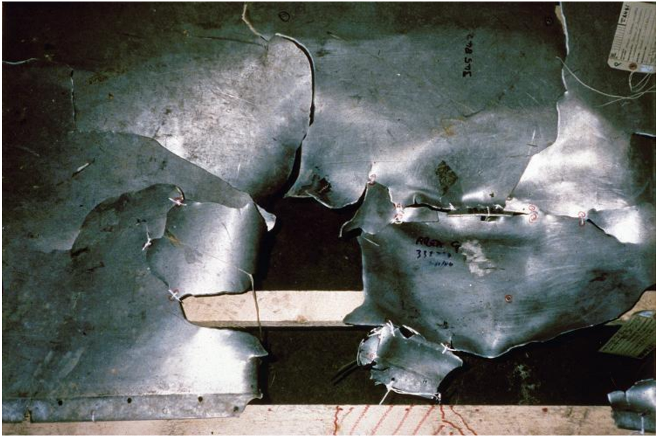
1. Phenomenology of Bombing
   - we display a photo set manifesting major characteristics of blast phenomena intended as goals to be reached and matched by computational work.
2. Computer Modeling of Airplane Bombing
   - we will describe the essential modeling aspects, tabulating the fundamental physical and empirical laws and numerical methods that constitute the basis for computer modeling based on the software tool LS-DYNA. Validation is also given.
3. Aircraft Blast Simulations and Phenomena
   - we will compute and then visualize general explosive and demolishing effects of bombings on an airplane or a metal plate and compare results with those in Section 1.
4. Case Study of the Daallo Airlines Flight 159 Bombing
   - we will address the modeling, computation and simulation of the laptop bombing case of the Daallo Airlines Flight 159 case.
5. Concluding Remarks
   - some final comments and forward-looking statements.

Phenomenology of Bombing

Postblast footprints are characterized by the following:

- The bending and rolling of metal onto/under itself;
- The jaggedness along the edges;
- Small cratering and micro-pitting on the surface;
- The thinning and feathering on the edge;
- The blackening on the damage-surface.

"Bending and rolling". The many pieces of bent metal are indicative of the direction of explosion and thereby can point to the placement of the explosives and the epicenter of explosion.



"Jaggedness". A distinctive pattern has emerged. Notice in the center (explosion epicenter) of the photo that all of the severed ends of the skin metal fragments are jagged, not smooth.

Recovered remains of a suitcase from Pan Am Flight 103. Note the varying fragment sizes and the *jaggedness* of the edges.

"Pitting and cratering". This is characteristic of being in close contact with the detonation of a high energy high explosive.

"Thinning and feathering", due to the excessive forces and the stretching from the explosion.

"Gas washing" from the combustion (detonation) of the explosive onto the material.

Mathematical model for bombing based on LS-DYNA

Software
LS-DYNA

Spatial domain
A region in $\mathbb{R}^3$ with high explosive (HE) within a metal confinement (such as airplane).

Governing equations
For air: the standard system of conservation equations of mass, momentum, and energy. These lead to the compressible Navier-Stokes and the associated energy equations for the gaseous fluid (air).
For solid (metallic) confinement: viscoplasticity model of solid MAT_PLASTIC_KINEMATIC is selected in LS-DYNA [6, Manual Vol II, p.2-95]
For HE: the material model MAT_HIGH_ EXPLOSIVE_BURN in chosen from LS-DYNA [6, Manual Vol II, p.2-110]

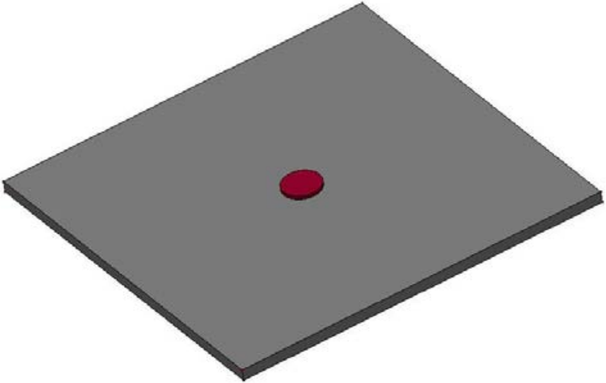
Empirical relations
The Jones-Wilkins-Lee equation of state (EOS_JWL in LS-DYNA [6, Manual Vol II, p.1-18])

$$p = A\left(1 - \frac{\omega}{R_1 V}\right) e^{-R_1 V} + B\left(1 - \frac{\omega}{R_2 V}\right) e^{-R_2 V} + \frac{\omega E}{V},$$

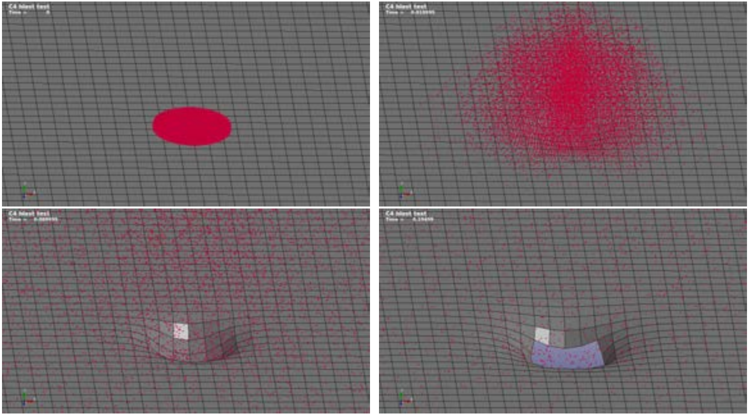
Computer modeling procedures:

- **Preprocessing** & model selections, choice of proper physical and computational parameters, grid generations;
- **Computing/ supercomputing** & code development, algorithm designs, implementation on a supercomputer;
- **Postprocessing** & representation of numerical output data in terms of graphics, tables or animation videos;
- **Validation**& comparison and confirmation between computed data and experimental data.

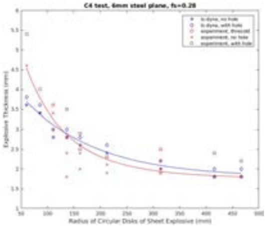
Explosive set-up geometry for Shirey's explosion test.



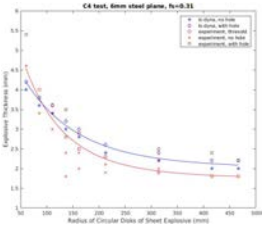
Snapshots of simulation for Shirey's explosion test.



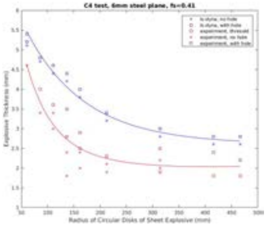
Threshold curves for 6 mm steel plate with three different value of failure strains. The curves in (a) show a good qualitative match with the value 0.28 for the failure strain.



(a)



(b)



(c)

Relationship between explosive charge weight and hole diameter for reinforced concrete explosive test; from Jasak, et al's book.

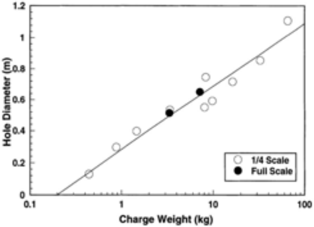


Figure 10.18. Experimental results from contact charges [data from Forsen (1990)].

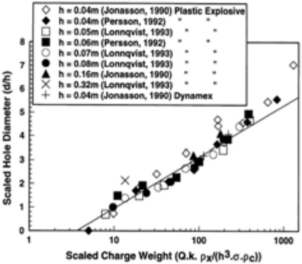
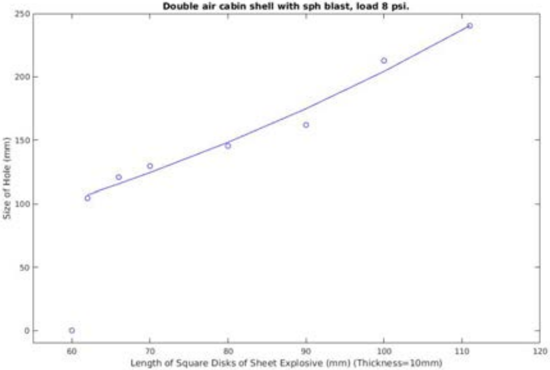


Figure 10.19. Dimensionless charge weight/hole diameter relationship [data from Lonnqvist (1993)].

Relationship between explosive charge weight and hole diameter in aircraft explosion

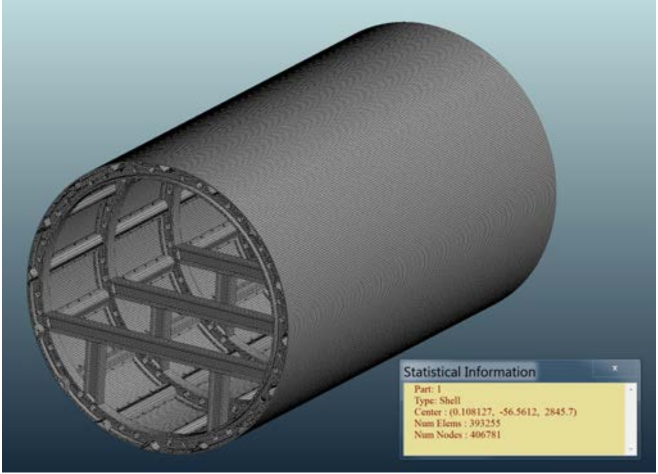


Aircraft Blast Simulations and Phenomena

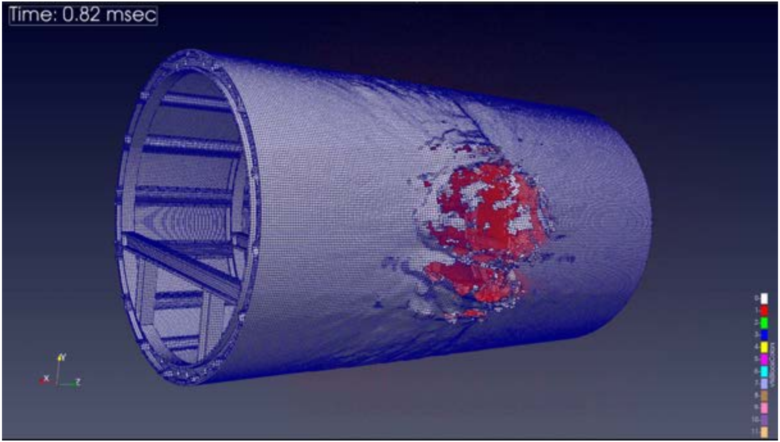
Two purposes:

- we want to see the dramatic effects of the dynamic display of demolition of an airframe by large amounts of explosives;
- we check how well computational mechanics can capture the major characteristics of blast phenomena.

The airframe configuration (made by "Simon"). We use LS-PREPOST to generate mesh as shown. The mesh has 406781 nodes and 393255 faces. The diameter is 4060, the length 7031, the center coordinates $(0, 0, 2841)$ (in units of mm).

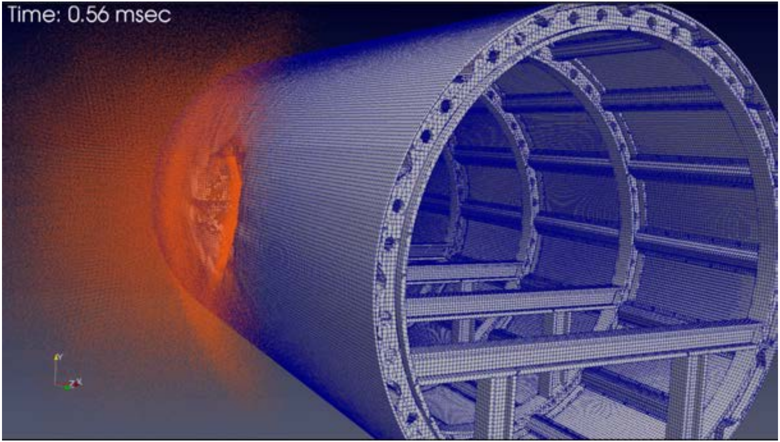


A ball-shaped explosive charge of diameter 495 mm with center at $(-1550, 160, 2450)$ is placed in the interior of the airframe. The amount of TNT is 106.76 kg. The separation between the airframe and the charge is 223 mm. play pause resume stop

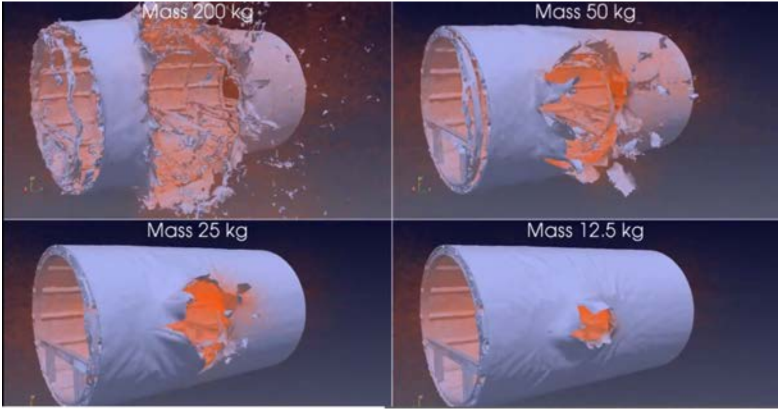


A ball-shaped explosive charge with center at $(-2300, 160, 2450)$ is placed in the exterior point close to the airframe. The amount of TNT is 106.76 kg. The separation between the airframe and the charge is 20 mm. play

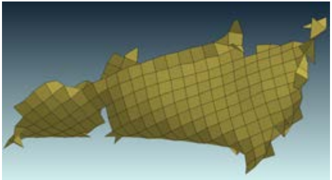
pause resume stop

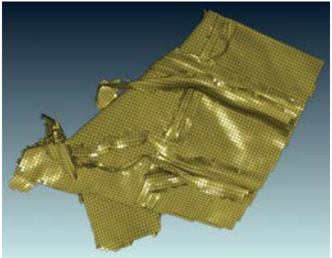


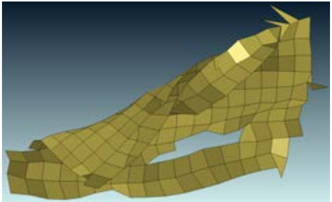
A panel of four explosions, using explosive amounts of 200kg, 50kg, 25kg and 12.5kg, is displayed side-by-side in order to view and compare the effects of damage. play pause resume stop

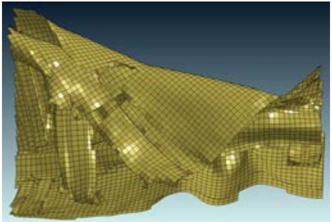


Samples of fragments and bent parts of debris from the computed explosions. One can see that with large explosions, metal can bend $\pm$ 180 degrees.

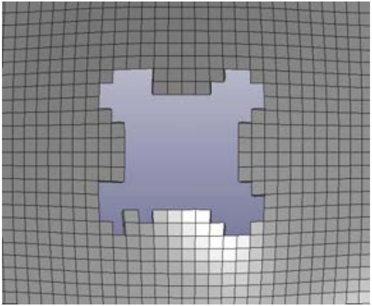




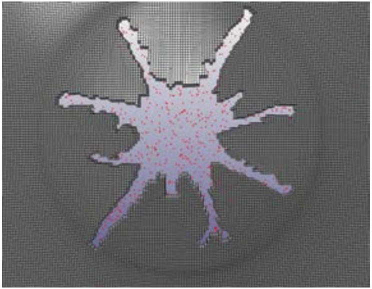




In this blast test, the amount of explosive charge C-4 used is 0.56 kg (cylinder with radius 136.52 mm and thickness 6mm), on a 6mm steel plate. Panel (a) has a crude mesh, with cell size 10 mm $\times$ 10 mm, and the resulting hole shows essentially no pattern of jaggedness. Panel (b) has a much finer resolution (cell size 2.5 mm $\times$ 2.5 mm) near the crater hole, and the jaggedness along the rim of the hole is conspicuous.

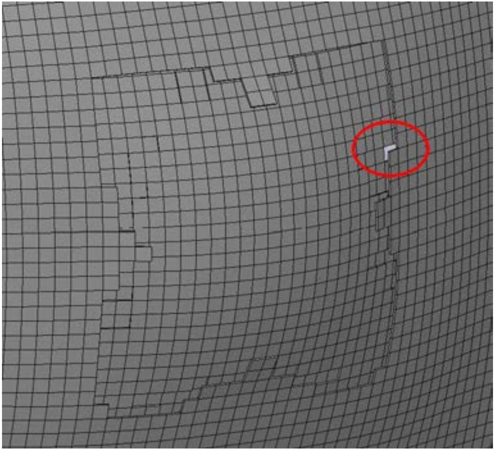


(a)

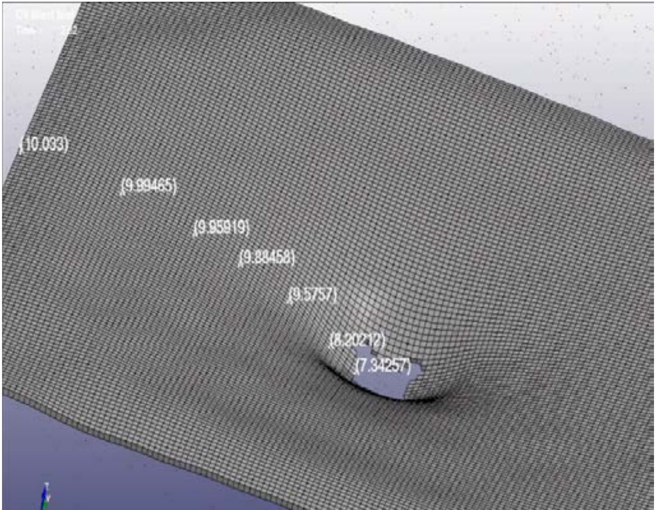


(b)

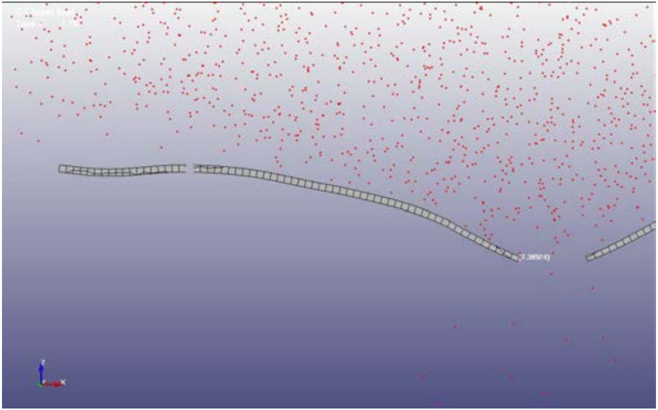
Some small-scale cratering as indicated on the steel plate in the process of being breached.



Testing the thinning and feathering along the edges of blast breaching of a steel metal plate, with thickness 10mm. As cratering is in progress, the plate is stretched and this causes the reduction of thickness as indicated by the percentage in the figure.

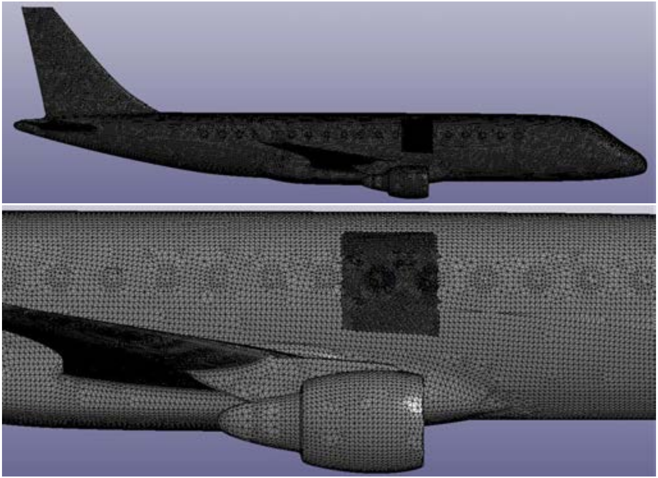


At the end of the blast, nevertheless, we do not see the emergence of a sharp edge.



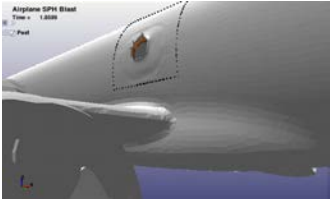
Case Study of the Daallo Airlines Flight 159 Bombing

Finite element mesh generation of an Airbus A321 model aircraft by LS-PREPOST.

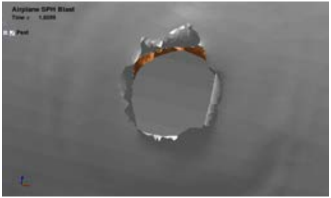


Comparison between the real airplane damage to Daallo Flight 159, part (a), and the simulation results, part (b) and (c), where $24 \times 1.5 \times 24\, cm^3$ TNT is used for a base model Airbus A321 aircraft.

(a)



(b)



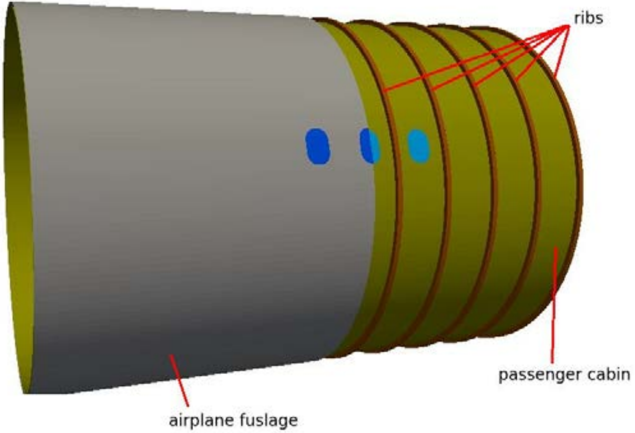
(c)

The photos show the interior damage of the Daallo airliner after the blast. It is noteworthy that the blown-up hole is essentially confined within the two ring-ribs and two stringers. Such ring-ribs and stringers provide a strong protective effect to the airframe, causing the damaged hole to take a nearly square shape.

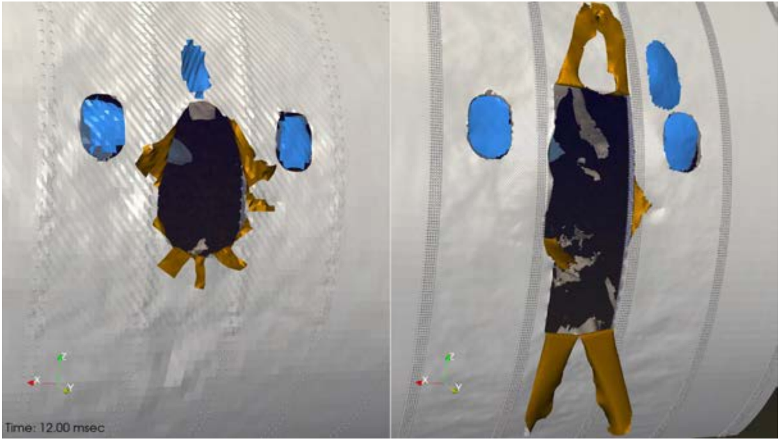
(a)

(b)

A refined model of the Airbus A321 aircraft. The ring-ribs and three acrylic windows have been added.



The left, part (a), is made of a cruder finite element mesh, while the right, part (b) contains a finer mesh. play pause resume stop



Concluding Remarks

Airliner bombings happen infrequently these days, however, their investigation forensics methodology needs to be researched and developed. Based on evidential bombing characteristics and mathematical/computational modeling and validation, we hope our work here has paved a sound foundation for this important field. Many issues, such as the construction of even more refined models for the aircraft, and to quantify and capture bombing phenomena with fine details, remain to be done. These will constitute interesting work and challenges for the future.