Analysis of Crash Test of a Composite General Aviation Airplane

Presented at the
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AGATE

The AGATE Consortium

70 Members
$200 Billion Sales
10 Universities
9 Avionics Co.
7 Airframe Co.
6 Trade Associations
3 Engine Co.
1 Retrofit Co.
> $100 Million Budget

36 States
38 Princ. Members
25 Supp. Members
4 Assoc. Members
3 Gov't Partners
7 Technical Work Packages
2 Management Work Packages

General Aviation Safety

- GA aircraft accidents cause two fatalities every day
  - Produces public perception that GA aircraft are not safe
- Public expects integrated occupant safety features to be incorporated in vehicle design
  - Safety Education is a Significant Component of Automotive Marketing

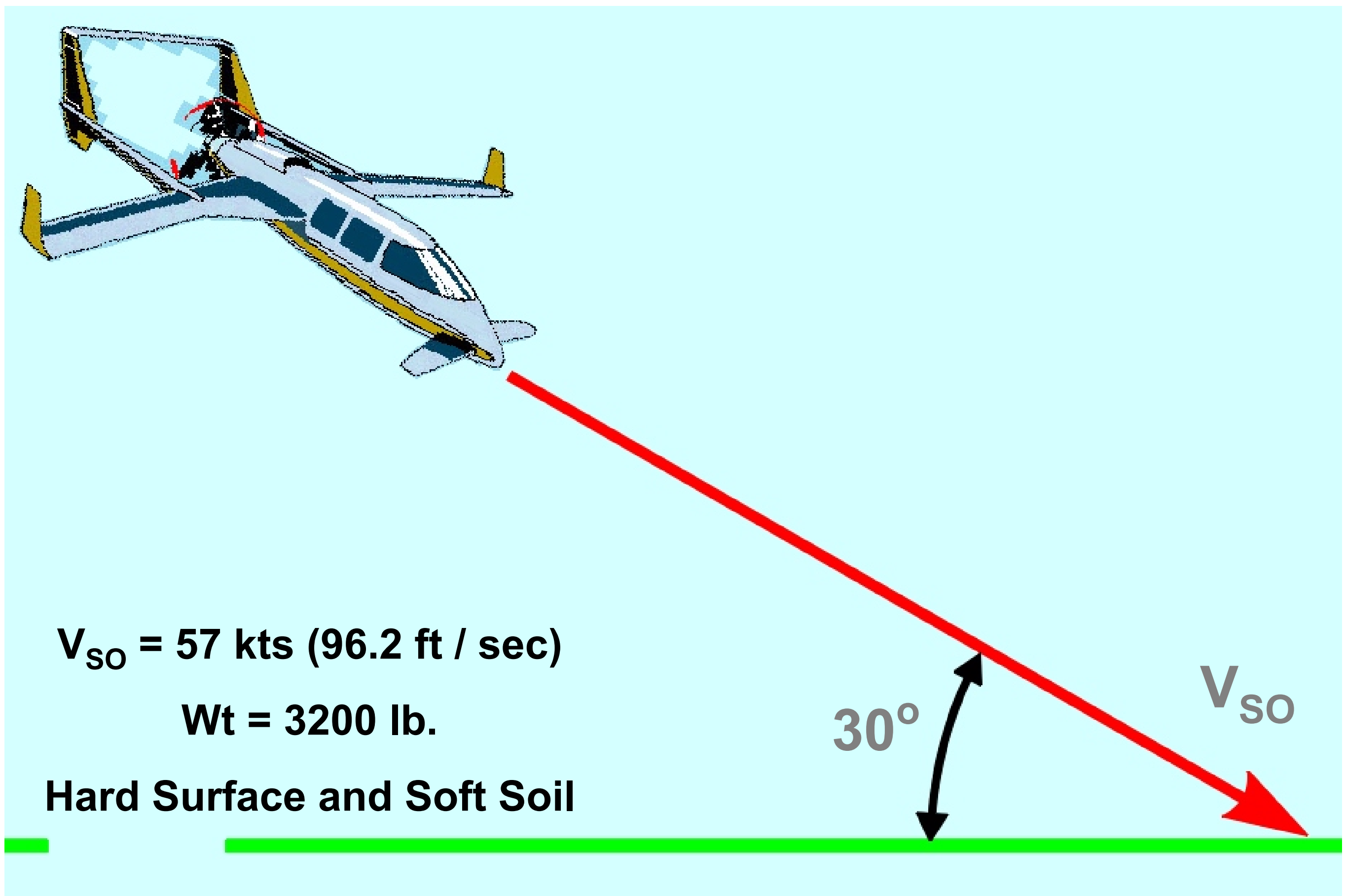
Advanced Crashworthiness Research Objectives

- Develop and validate advanced crashworthiness concepts and design methods
  - Improve safety
    - With minimal cost and weight increases
    - Well-defined certification process
- Enhanced Level of Safety
  - Increased survivability
    - Energy absorbing structural design concepts
    - Advanced restraint and occupant protection systems
- AGATE Team Members
  - NASA AvSP
  - Lancair
  - Simula
  - Wichita State University
  - Mod Works
  - FAA NRS / FAA CAMI

AGATE Research Milestones

- Define Survivable Crash Conditions
- Develop Systems Approach to Crashworthiness Design
- AGATE Aircraft Drop Test
  - Utilize Baseline AGATE Aircraft
    - Lancair Columbia 300
  - Incorporate Additional Crashworthiness Features
  - Perform Drop Test at NASA Langley Research Center
  - Analyze Results
- Develop Certification Methodology

AGATE Test Condition



General Aviation Crashworthiness

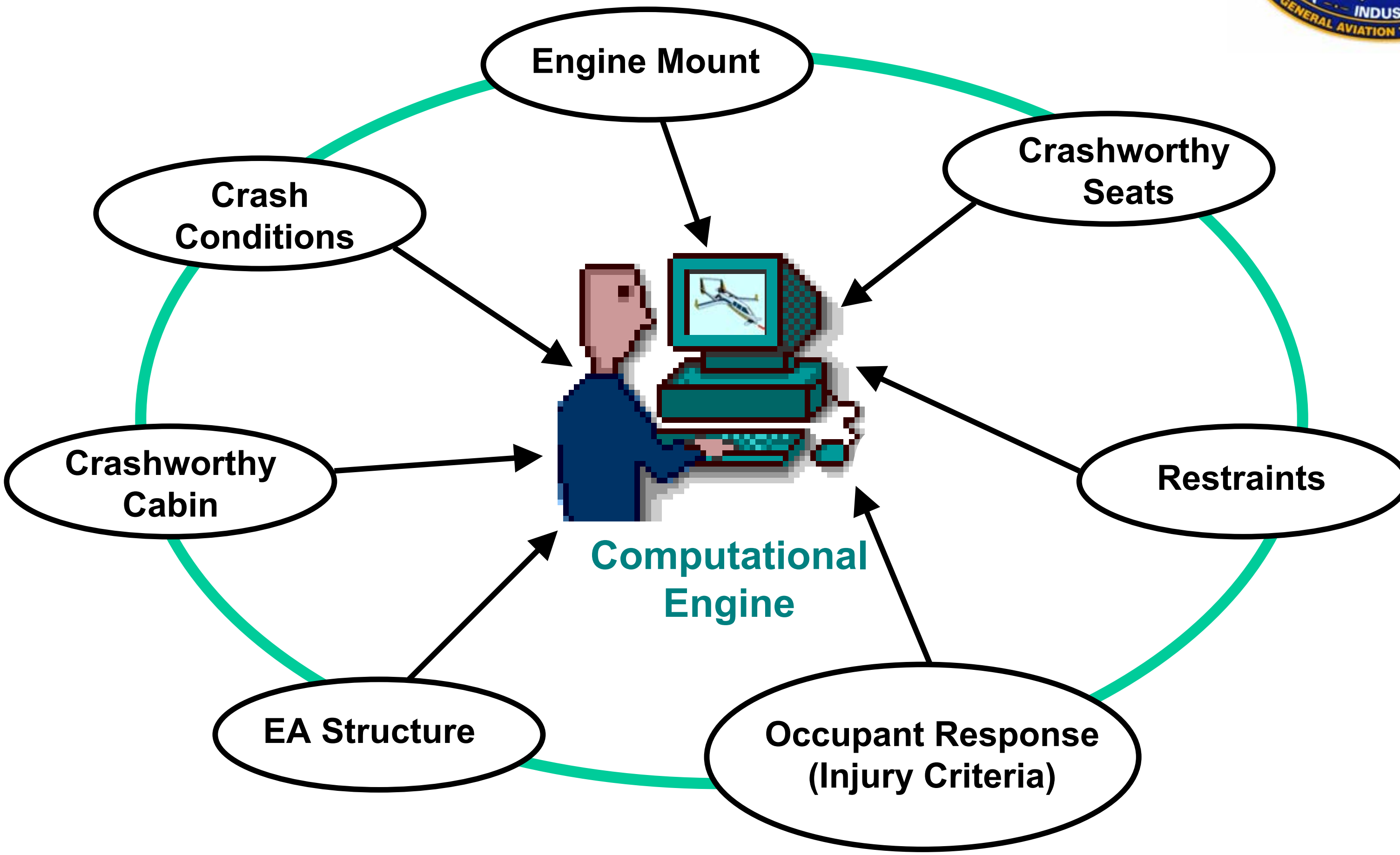
AGATE Aircraft

- **2 – 6 seats**
- **Composite Airframe**
- **Crashworthiness Study Considered**
  - **Low Wing**
  - **Tractor Propulsion System**

Fundamentals of Crashworthiness Design

- **Maintain a survivable volume for the occupants**
- **Restrain the occupants within that volume**
- **Limit the occupant decelerations to tolerable levels**
- **Provide rapid egress**
- **Minimize post-crash hazards**

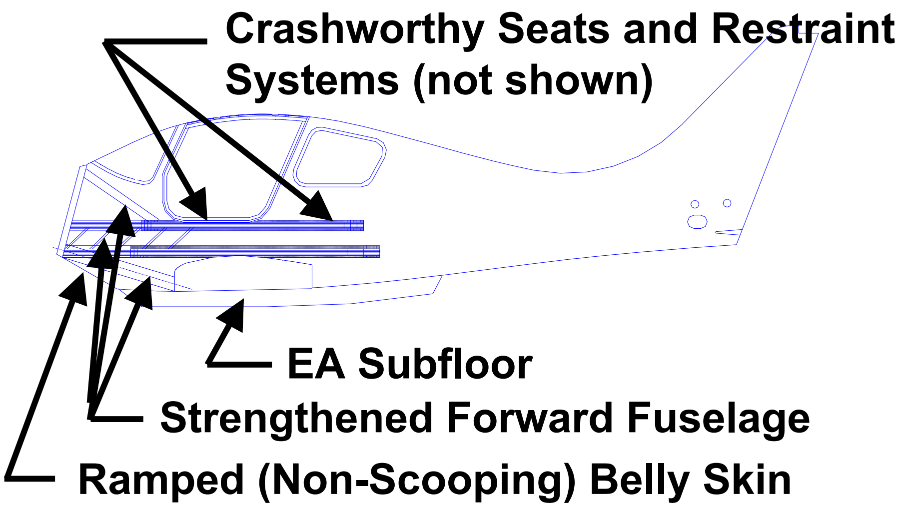
Systems Integration



Consider the Interactions between the System Components

Airframe Design

- The Essential Cabin Crashworthiness Structure
  - Required to maintain survivable volume
  - The forward fuselage between the two longerons and fwd of the "saddle structure"
- Energy Absorbing Structure was Considered to be the
  - Fuselage structure below the lower longerons
  - This includes the energy-absorbing subfloor



Airframe Design (cont.)

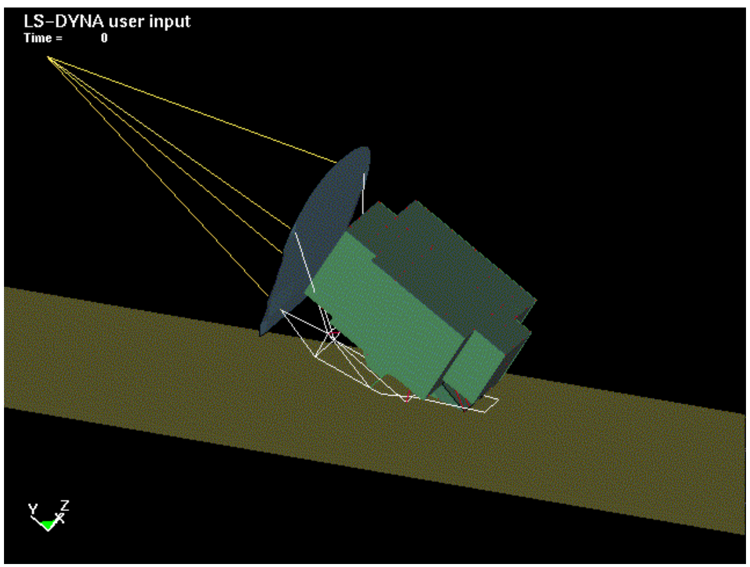
- **The following was considered to be frangible Structure**
  - **The windshield**
  - **The windshield frame and door frame**
    - **These structures are not expected to survive severe, but survivable, accidents and therefore were assumed to provide no resistance to the impact forces**

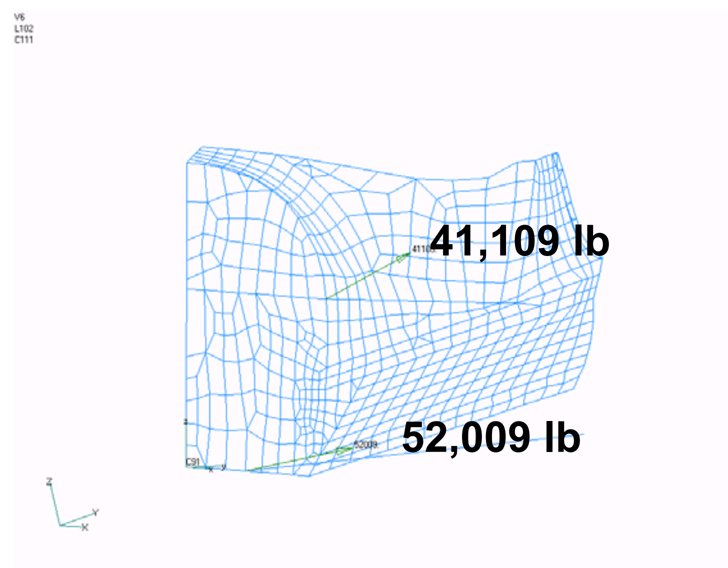
Crashworthiness Modeling Approach

- Focus on the load path between the contact surface and the occupants
- Consider the overall aircraft response
- Start the design process from the front of the airplane at the contact surface
  - Progressively work back along the load path
  - Increase the sophistication of the model as one designs successive crashworthiness features
  - Estimate impact loads using “simple” LS-Dyna model
  - Use Nastran to “size” the structure
    - Buckling and crippling were critical

Airframe Design

- **The firewall forces were estimated using the engine mount / rigid airplane model**
  - **Rigid airplane, rigid engine**
  - **These forces were doubled in view of the higher loads expected for soft soil impacts**





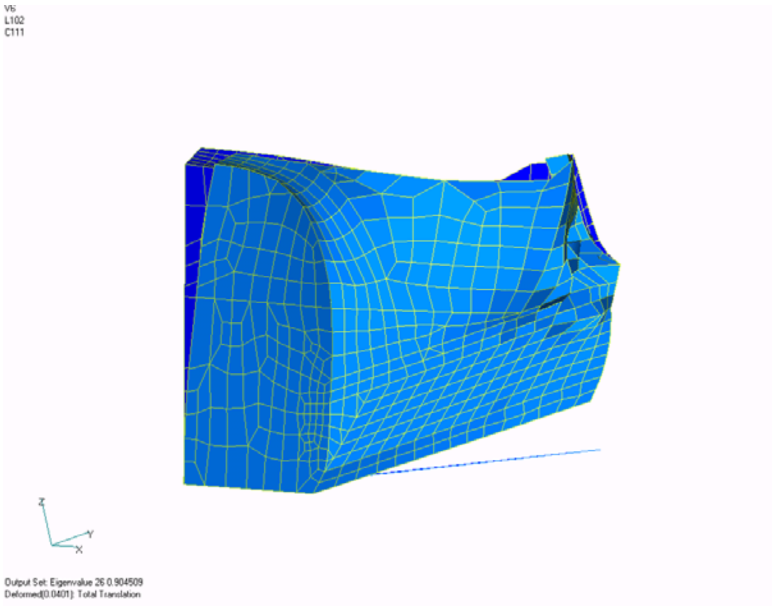
50 G Longitudinal Loads

Lower Engine Mount Supports

- The floor structure of the unmodified airplane was inadequate to resist the lower engine mount forces
- By comparison, the floor in Jim Terry's last two drop test articles was fiberglass reinforced plywood
  - The Terry test articles were significantly lighter
- The most convenient solution was to install reinforced steel tubes between the firewall and the front spar shear web at a location near the saddle structure
  - Note: saddle structure is approximately located at the a/c cg

Forward Fuselage Analysis

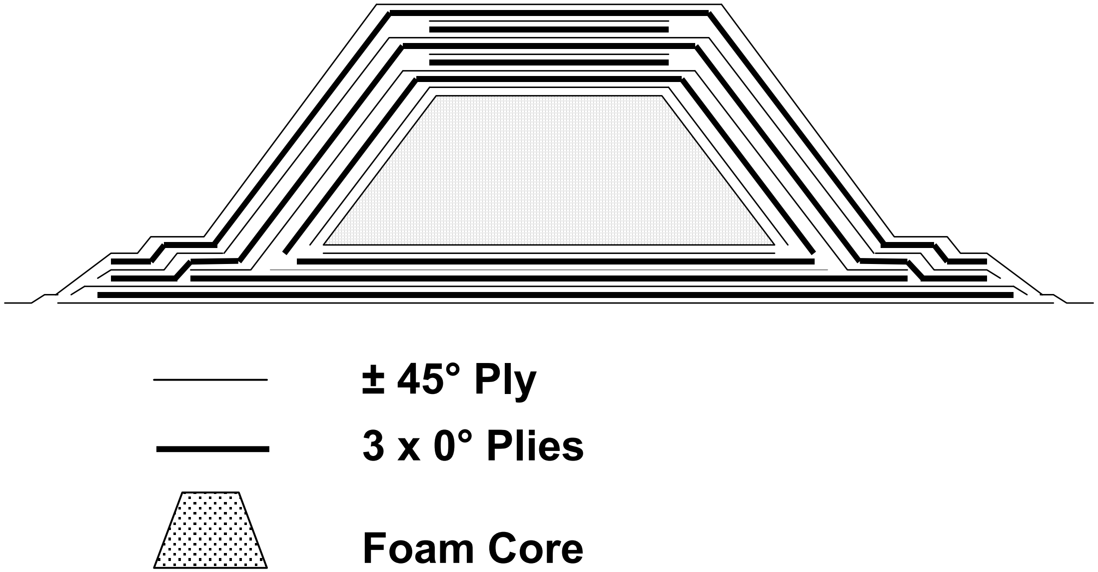
Linear Nastran Model



Buckling Solution - λ = 9.045

$$P_{cr} = \lambda \ P^{*}$$

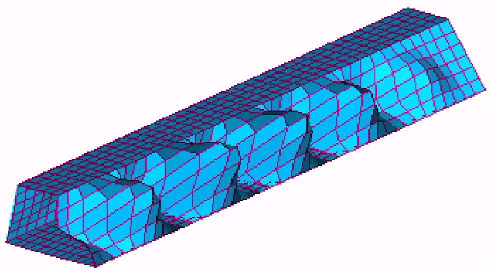
Stiffener Design

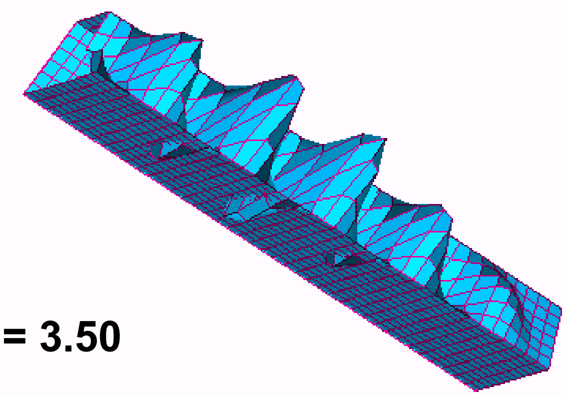


Wet layup resin: L 285 Resin & L 285 Hardener
Martin G. Sheufler GmbH (MGS)
Material: Newport NB321/13K70P Carbon Cloth

Crippling Analysis

Original Longeron Design

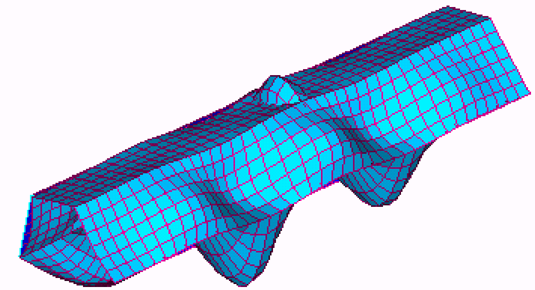


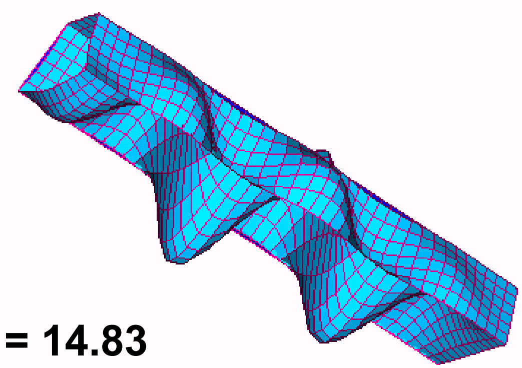


$\lambda = 3.50$

$P_{cr} = 8{,}955$ lb.

Revised Longeron Design

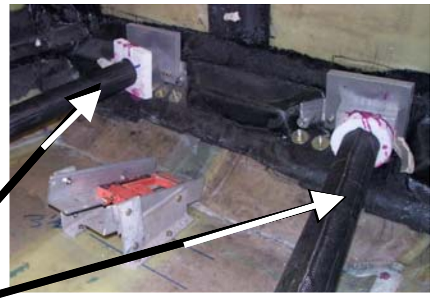




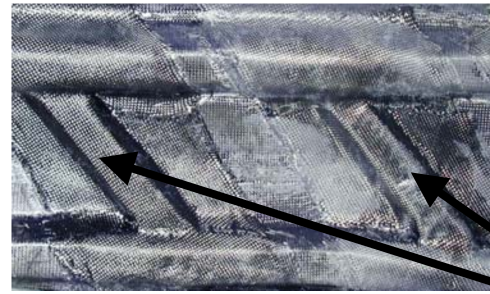
$\lambda = 14.83$

$P_{cr} = 70{,}172$ lb.

Forward Fuselage Reinforcement



Floor Stiffeners

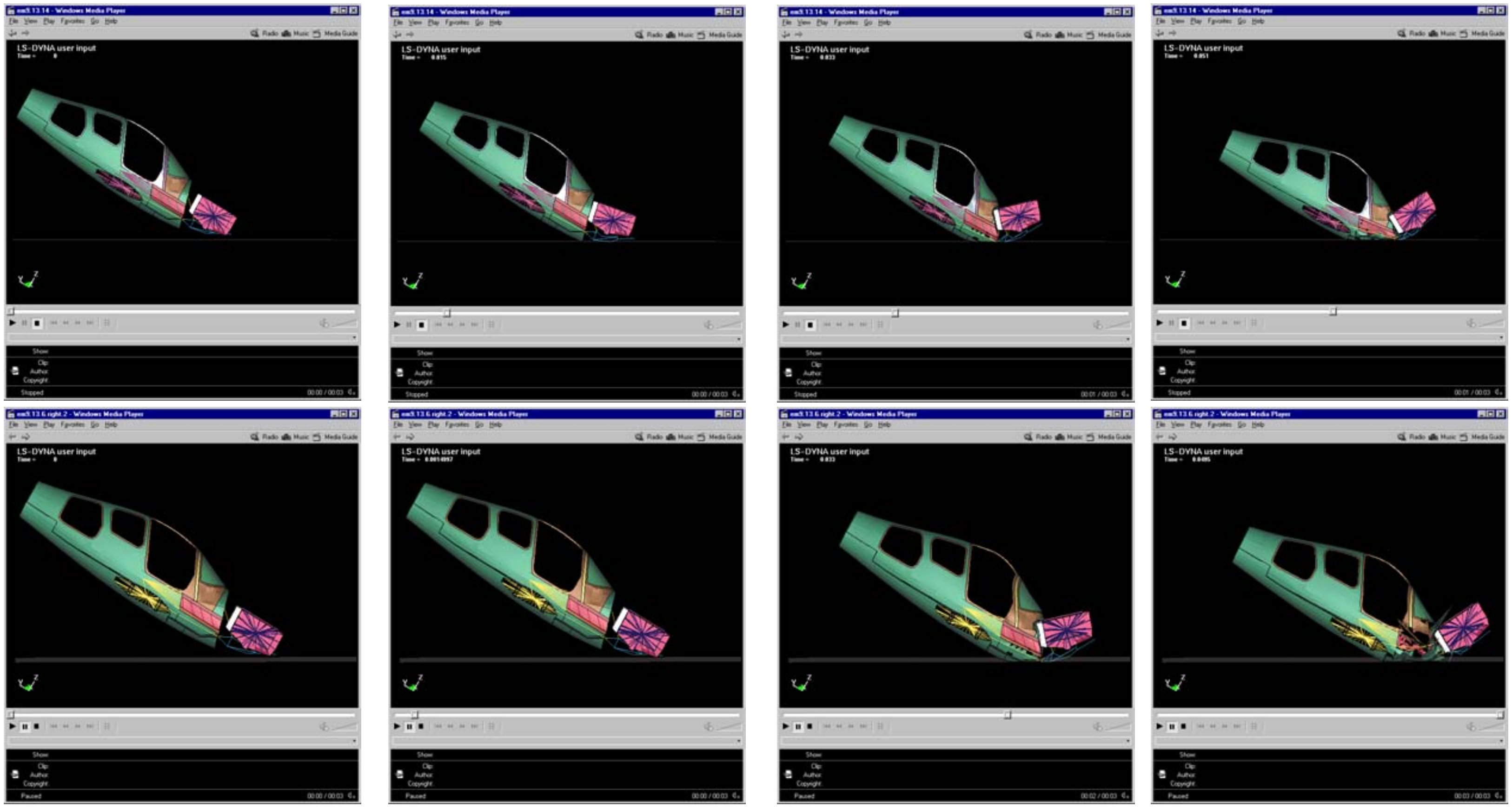


Shear Web Stiffeners

Longeron

Firewall & Fwd Fuselage

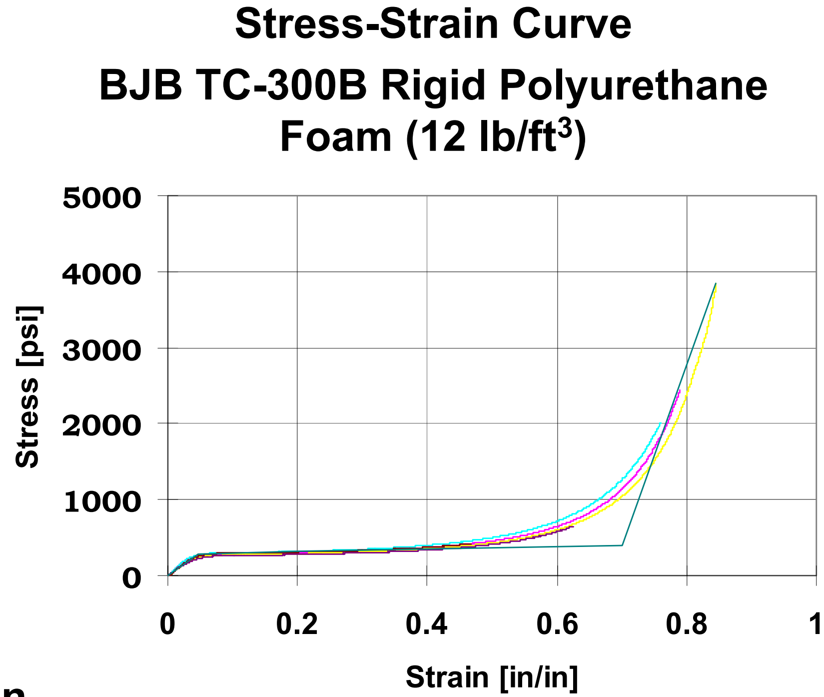
LS-Dyna Simulations



t = 0.000 t = 0.015 t = 0.033 t = 0.050

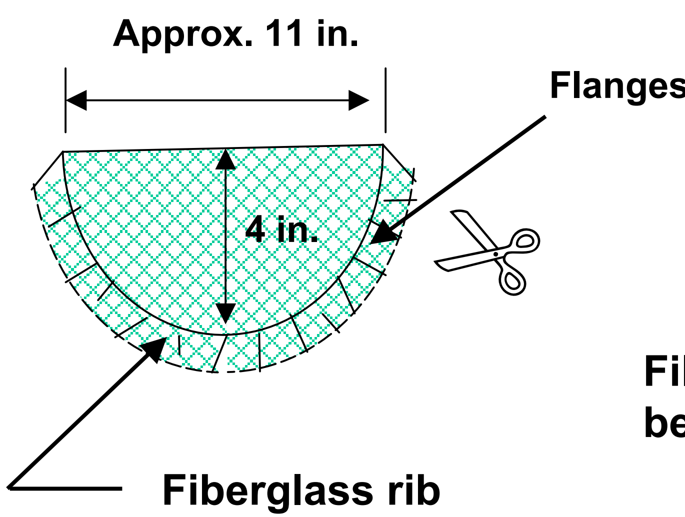
Em9.13.14.avi (top) em9.13.6.right.2.avi (bottom)

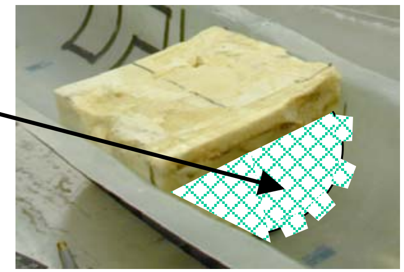
Energy Absorbing Subfloor

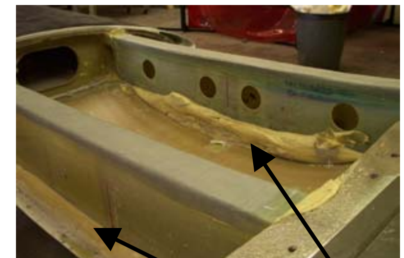


- Foam blocks (each strake)
  - Under the front spar - 11 in. x 10 in.
  - Under the rear spar - 11 in. x 15 in.
  - Behind Baggage Compartment – 11 in. x 20 in.

EA Subfloor Fabrication







Fill gaps between lower spar caps and belly skin

- **EA strakes bonded to belly skin using HYSOL EA 9309.3 two-part adhesive**
  - **High Peel Strength**

Impact Dynamic Test Facility

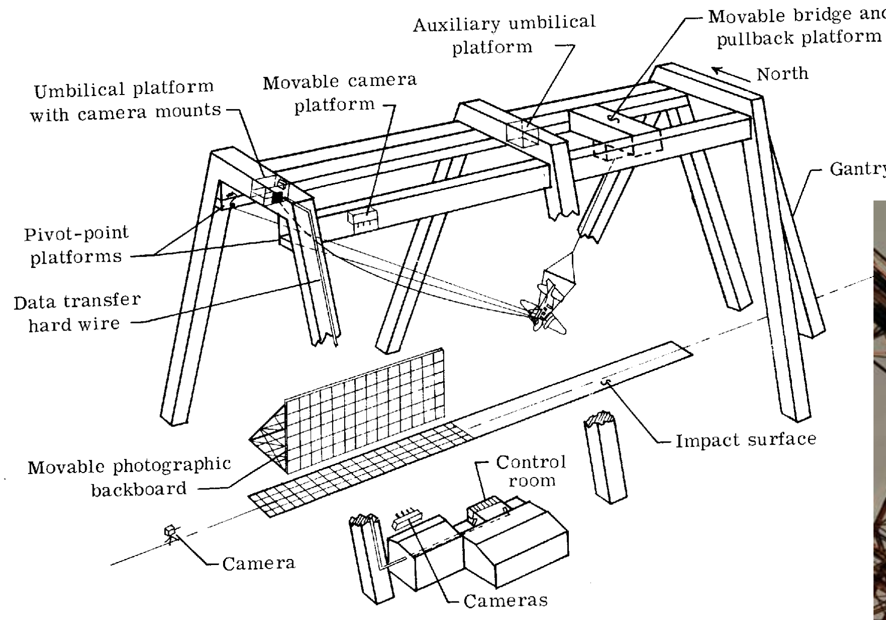


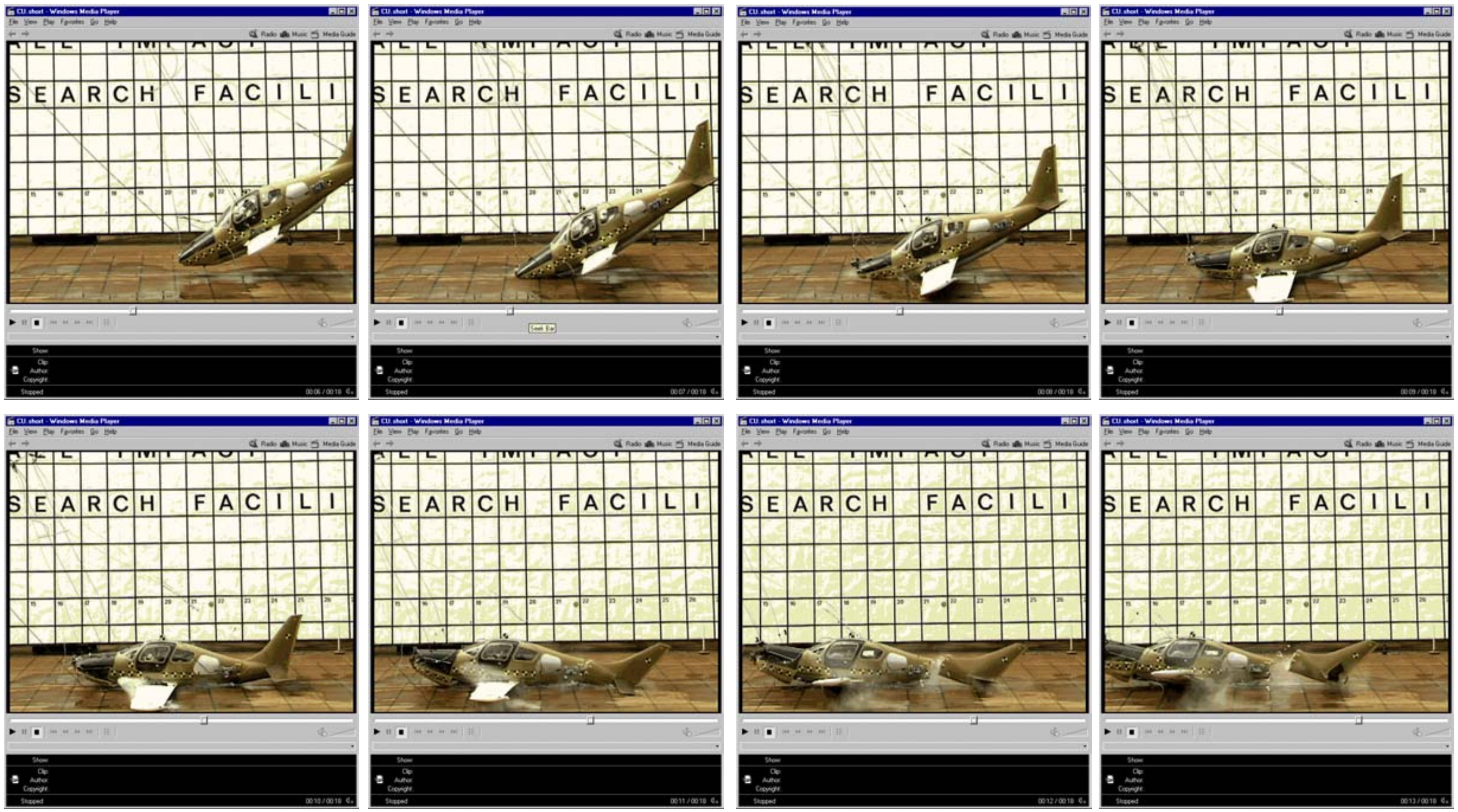
Diagram of impact dynamics research facility.

On-Board Data Acquisition System

4 Hybrid II Atd's

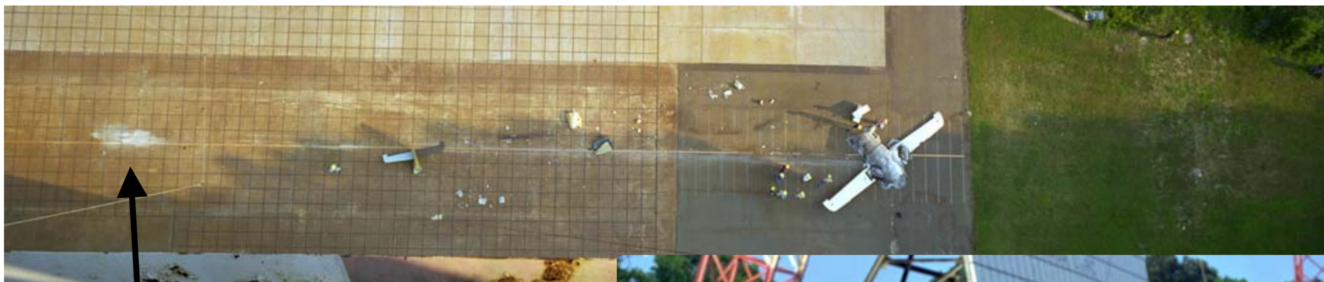
28 Airframe Accelerometers

Drop Test



$V = 94.7$ ft/sec, $\theta = 30^{o}$ (nose down)

Post-Test Photos

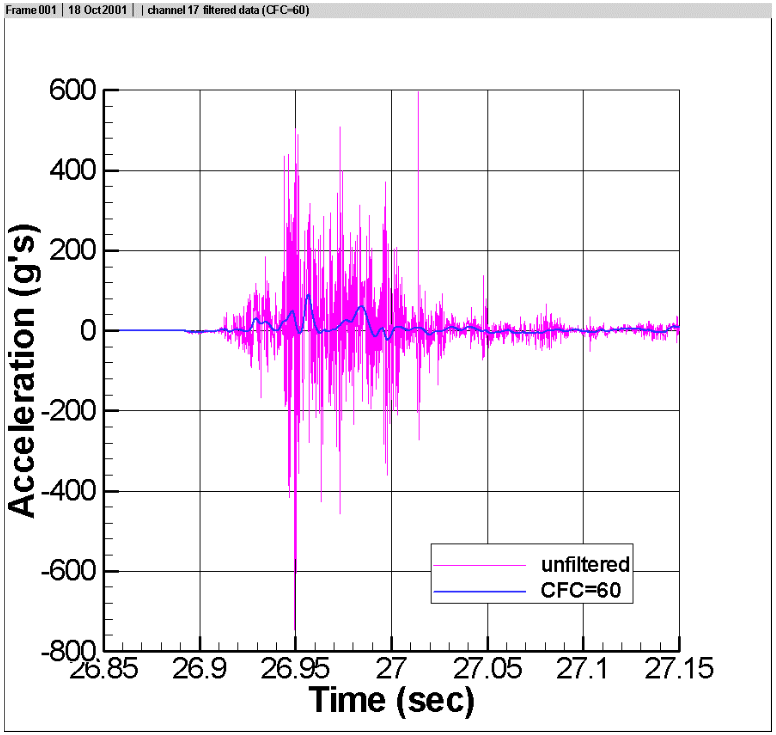


Impact Point

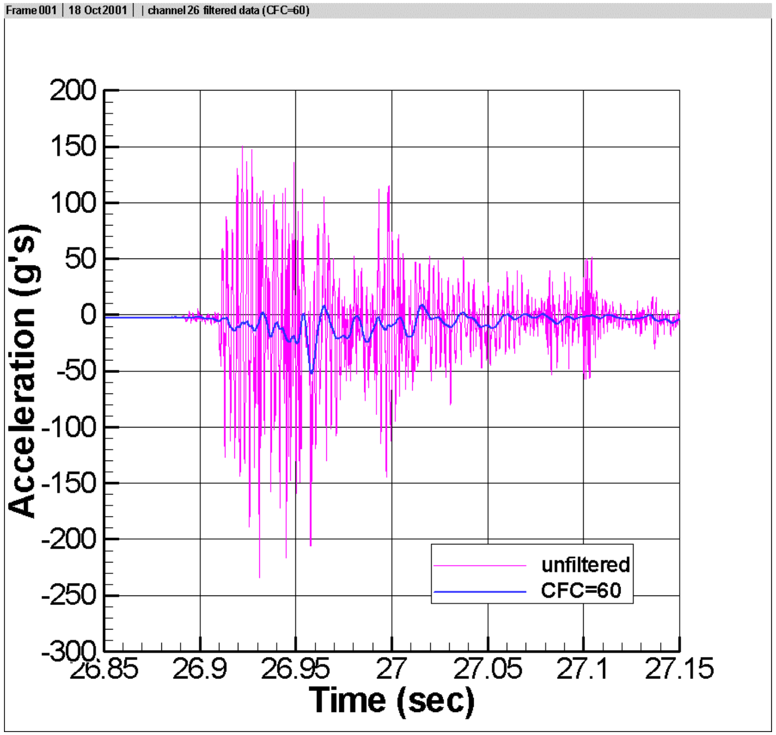
Post-test Photos

Cabin Accelerations

Vertical Acceleration

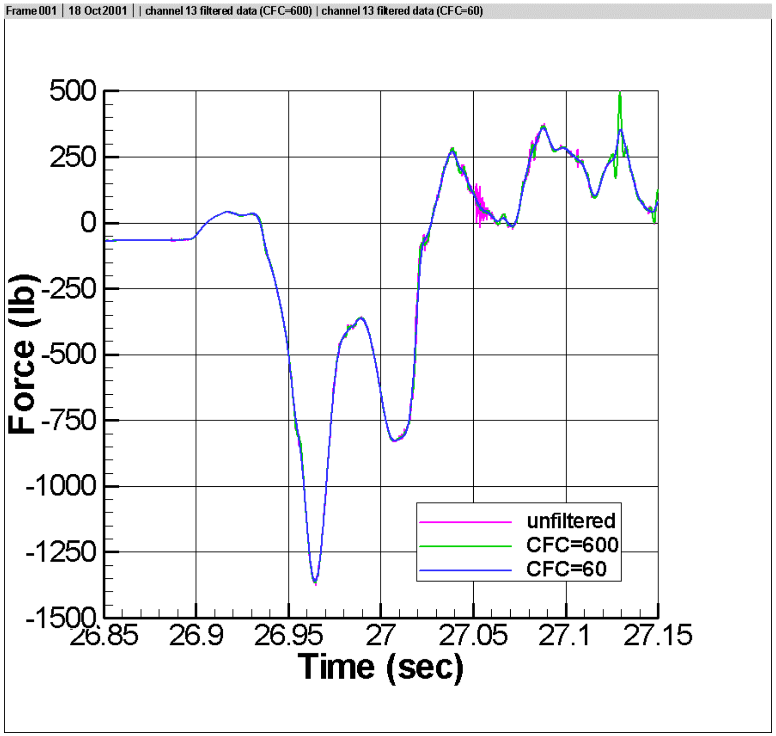


Longitudinal Acceleration

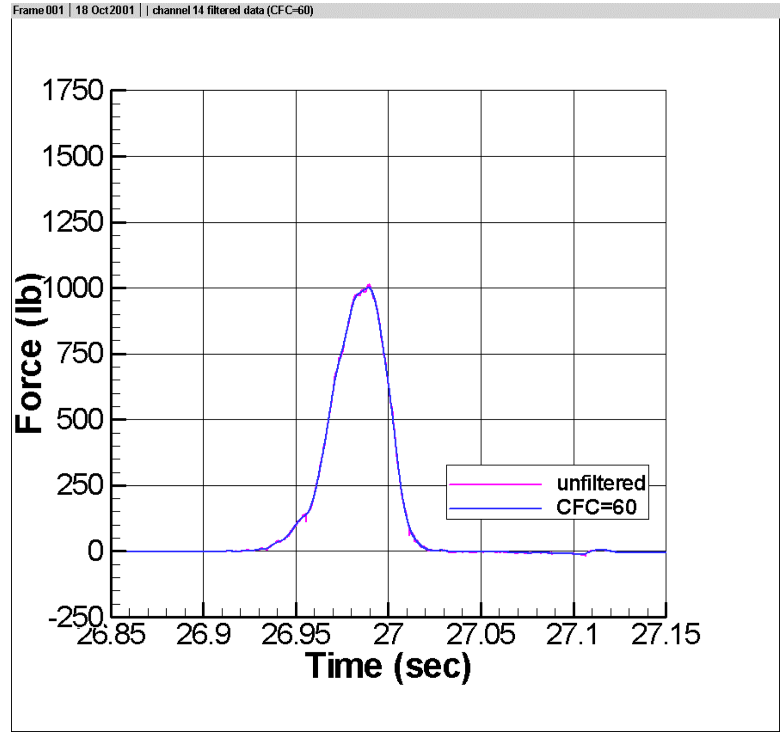


Rear Seat ATD Response

Lumbar Load



Upper Torso Restraint Load

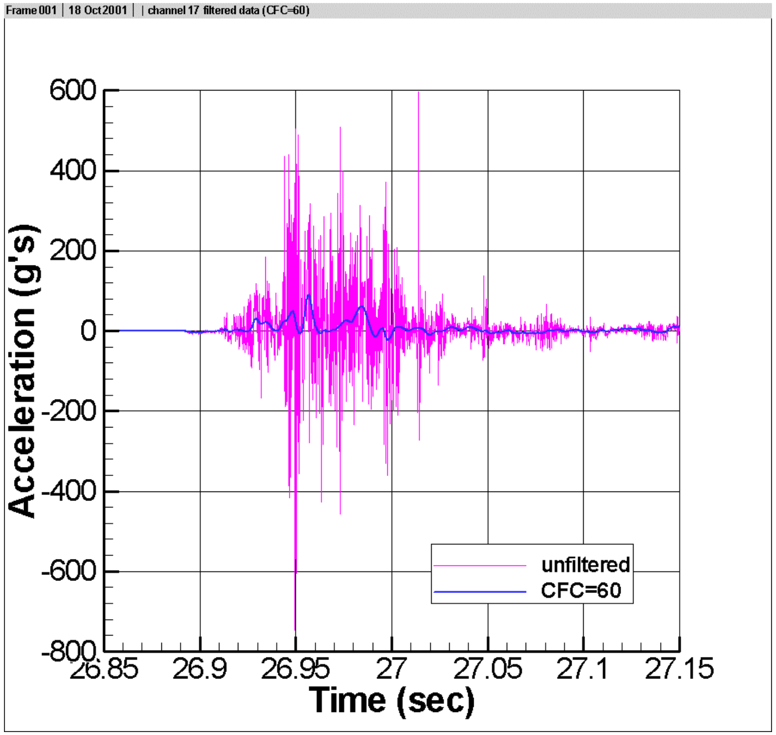


Bottom Cushion Effectively Attenuated Multiple (2-3) Impacts

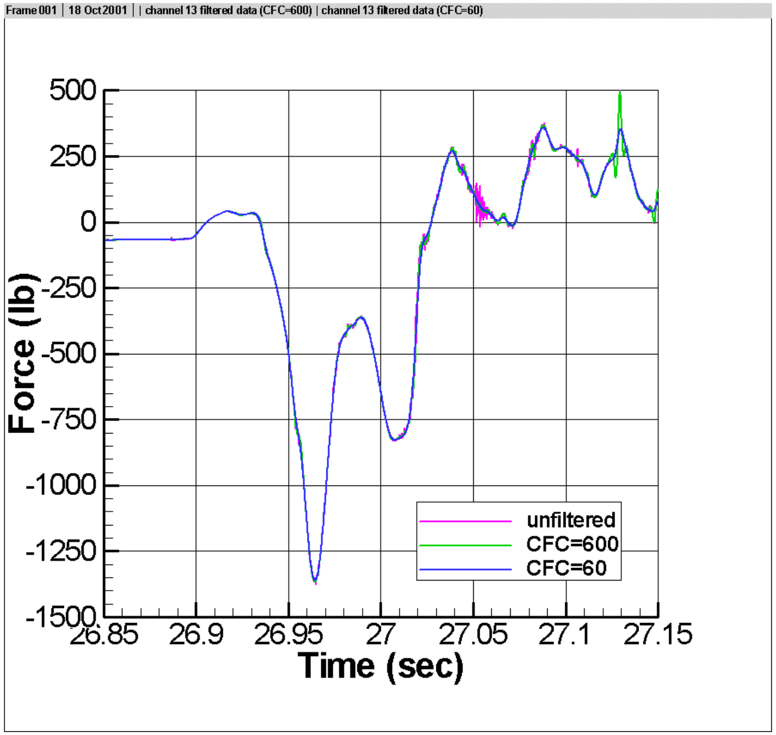
Lumbar Load, Upper Torso Restraint, & HIC OK

Vertical Pulse and Lumbar Load

Vertical Acceleration



Lumbar Load



Left-Rear Bottom Cushion

Forward

Outboard

Drop Test Observations

- Secondary Bonds Performed Well
  - No Failures
  - Engineers who have tested a lot of composites know things that designers don’t
- Airframe strength was adequate for the hard-surface impact
  - May or may not be adequate for soft-soil impact
- Energy Management thru application of the Impulse / Momentum Equation may be a more effective crashworthiness strategy than Energy Absorption for applications with limited space

$$\int_{t_1}^{t_2} \mathrm{R}\, dt = m\mathrm{V}_2 - m\mathrm{V}_1$$

Acknowledgments

- This program was supported by
  - NASA AvSP
  - NASA AGATE (including a number of industry members)
- The Contributions of Lancair and Simula are noteworthy
- The Advanced Composites Laboratory at the WSU’s National Institute for Aviation Research
- Steve Soltis – FAA Crashworthiness NRS
- Rick DeWeese – FAA CAMI
- Bill Shipman – Photometrics
- Nelson Seabolt – NASA IDRF Technician

Conclusions

- The cabins of GA aircraft can be designed to maintain a survivable volume using traditional aerospace design techniques
  - Analysis and design start at initial point of contact and follow load path to aircraft cg
- Linear-elastic techniques are useful in crashworthy design studies
- Nonlinear finite element computer programs are effective analyses techniques, but
  - They have not matured in terms of their ability to predict the effect of local details
  - Their failure models are inadequate for composite and sandwich structures
  - Their use in modern design cycles is expensive and time consuming

Conclusions (cont.)

- **Seat / Restraint systems designed to the requirements of 14 CFR 23.562 performed well in the full-scale AGATE drop test**
  - **Successfully mitigated two-three successive impulses**
- **Accident mitigation strategies should consider technologies designed to exploit impulse-momentum mechanisms in addition to energy absorbing mechanisms**
  - **e.g. ramped firewalls, load-limiting engine mounts, etc.**