Analysis of Crash Test of a Composite General Aviation Airplane

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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

$V_{SO} = 57 \text{ kts (96.2 ft / sec)}$

$Wt = 3200 \text{ lb.}$

Hard Surface and Soft Soil
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

Crashworthy Seats and Restraint Systems (not shown)

- EA Subfloor
- Strengthened Forward Fuselage
- Ramped (Non-Scooping) Belly Skin
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
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 - $\lambda = 9.045$

$$P_{cr} = \lambda^* \, P$$
Stiffener Design

- ± 45° Ply
- 3 x 0° Plies
- Foam Core

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

Revised Longeron Design

$\lambda = 3.50$

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

$\lambda = 14.83$

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

Stress-Strain Curve
BJB TC-300B Rigid Polyurethane Foam (12 lb/ft³)
EA Subfloor Fabrication

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

Approx. 11 in.

Flanges

Fiberglass rib

Fill gaps between lower spar caps and belly skin
Impact Dynamic Test Facility

On-Board Data Acquisition System
4 Hybrid II Atd’s
28 Airframe Accelerometers
Drop Test

$V = 94.7$ ft/sec, $\theta = 30^\circ$ (nose down)
Post-Test Photos

Impact Point
Post-test Photos
Cabin Accelerations

Vertical Acceleration

Longitudinal Acceleration
Rear Seat ATD Response

Lumbar Load

Bottom Cushion Effectively Attenuated Multiple (2-3) Impacts

Upper Torso Restraint Load

Lumbar Load, Upper Torso Restraint, & HIC OK
Vertical Pulse and Lumbar Load

Vertical Acceleration

Lumbar Load

![Graphs showing vertical acceleration and lumbar load over time](image)
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

\[ \int_{t_1}^{t_2} R \, dt = m V_2 - m V_1 \]
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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.