Full-Scale Crash Testing of Transport Rotorcraft

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Outline

- Motivation
- Landing and Impact Research Facility
- NASA Rotary Wing Crashworthiness Research
- Transport Rotorcraft Airframe Crash Testbed (TRACT)
- Summary

Motivation- Recent Studies

Study 1: DOD-sponsored Study on Rotorcraft Survivability, sent to Congress Oct 2009. Reference: Couch, M. and Lindell, D., “Study on Rotorcraft Safety and Survivability,”AHS Forum 66, Phoenix, AZ, May 10-13, 2010.

Conclusions

- For cargo and utility helicopters, Combat hostile action loss rate nearly six times lower, and fatality rate four times lower, for OEF/OIF vs. Vietnam.

- A high percentage of helicopter losses are survivable

- “To reduce personnel injuries and fatalities for combat threat losses and mishaps, improve airframe crashworthiness and crash protection for passengers. DoD crashworthiness standards have not been updated since the 1970s and need to be expanded in scope to cover a wider set of aircraft and environmental conditions.”

Motivation- Recent Studies

Study 2: US Army AATD sponsored accident study under the Full Spectrum Crashworthiness (FSC) Program. Reference: Labun, L., “A Study of Rotary-Wing Crashes to Support New Crashworthiness Criteria,” AHS Forum 66, Phoenix, AZ, May 10-13, 2010

Conclusions

- Crashworthy fuel systems have virtually eliminated fatalities and severe injures due to post-crash fire.

- Onboard systems such as lap belts, shoulder restraints, inertia reels, and load limiting seats are effective in improving crash performance.

- The 90th-percentile survivable impact ground speeds and vertical speeds for aircraft *designed to crashworthy criteria* were generally higher than those for the previous generation of aircraft. The AH-64 exceeded the AH-1 in both ground speed and vertical speed for both direct-to-terrain crashes and post-obstacle crashes. Likewise, the UH-60 exceeded the comparable speeds for the UH-1

Motivation- Recent Studies

Study 3. US Navy sponsored study of Navy and Marine Corps helicopter accidents from 1985 to 2005. Reference: Kent, R., "Injury and Fatality Patterns in US Navy Rotary Wing Mishaps: A Descriptive Review of Class A and B Mishaps From 1985 to 2005," AHS Forum 65, Grapevine, TX, May 27-29, 2009.

Conclusions

- '85-'94 vs. '95-'05: DoN fatality rate (per 100,000 flight hours) reduced from 5.8 to 3.15, and injury rate (per 100,000 flight hours) reduced from 3.92 to 2.14
- Decadal differences attributed to improved policies, guidelines, training procedures and equipment for overseas operations
- Head injuries are an important cause of morbidity in helicopter mishaps.
- Non-pilot personnel appear to be at greater risk for injury.

Motivation- Full Spectrum Crashworthiness Criteria

- **AATD sponsored effort to develop comprehensive crash design requirements for a wide range of rotorcraft classes, types, configurations, and operating conditions that continue over the life cycle of the rotorcraft system.**
- **Identify the key components that contribute to a system's crashworthiness**
- **Crashworthiness Index (CI) proposed as new design standard to replace ADS-11B current specification, with a higher score contribution due to basic airframe crashworthiness**

	Basic Airframe Crashworthiness Rating Summary	Optimum Score	Accessed Score
1	**Crushing of Occupied Areas**		
1a	Crushing of Cockpit	15	16.52
1b	Crushing of Cabin	15	18.53
2	Absence of "Plowing" Tendency	10	10
3	Resistance to Longitudinal Impact Loads	10	10
4	**Resistance to Vertical Loads**		
4a	Vertical Impact, Gear Extended	80	61.5
4b	High Mass Retention	20	20
5	**Resistance to Lateral and Rollover Impact Loads**		
5a	Lateral Impact	15	13.5
5b	Static Rollover	15	15
6	**Landing Gear Vertical Force Attenuation**		
6a	Vertical Impact, Gear Retracted	40	38.8
6b	High Angle Vertical Impact	20	6.9
6c	Low Angle Vertical Impact	20	18.3
6d	Tail Boom Protection	5	5
7	Landing Gear Location	5	5
8	Effects of Blade Strike	20	20
9	Effect of Fuselage Separation	5	5
	TOTAL	**295**	**264.0**

Example from RDECOM TR 12-D-12

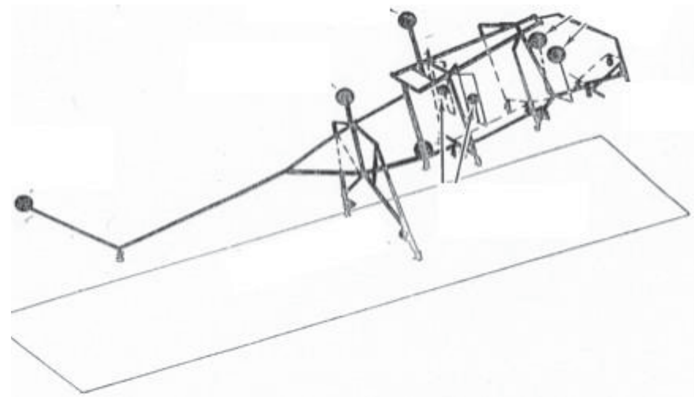
Motivation- System Integrated Approach

- Many conditions not currently modeled and evaluated accurately for occupant casualty response
  - Post-obstacle vs. direct-to-terrain
  - Multi-terrain impact (water, soft soil, prepared surface)
  - Crushing of subfloor/ landing gear stroke
  - Crashworthy seats / troops benches
  - Restraints
- These factors will alter the magnitude and duration of the acceleration pulses imparted into the occupant
- A comprehensive method is required to associate impact velocities, attitudes and terrains to seat interface and occupant G-loads

Motivation-Crashworthiness Analytical Capabilities

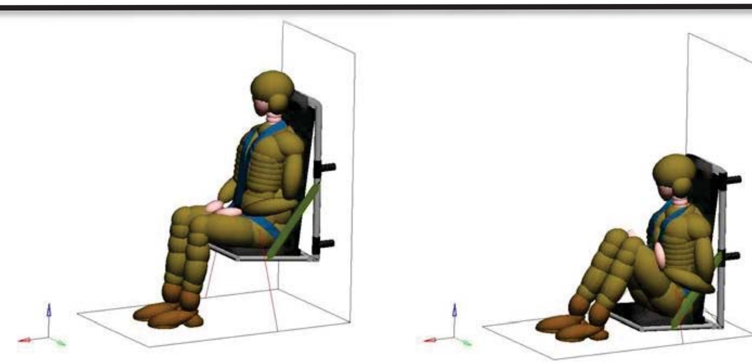
KRASH

- Lumped parameter modeling of fixed and rotary wing
- Vehicle kinematics captured, minimal computational time
- Hybrid approach with finite element models (FEM)
- Limited support for further development



MADYMO

- Detailed representations of Anthropomorphic Test Devices (ATD) and whole-body models, heritage within automotive crashworthiness
- Highly integrated multi-body/FE capability that can be coupled with other explicit codes



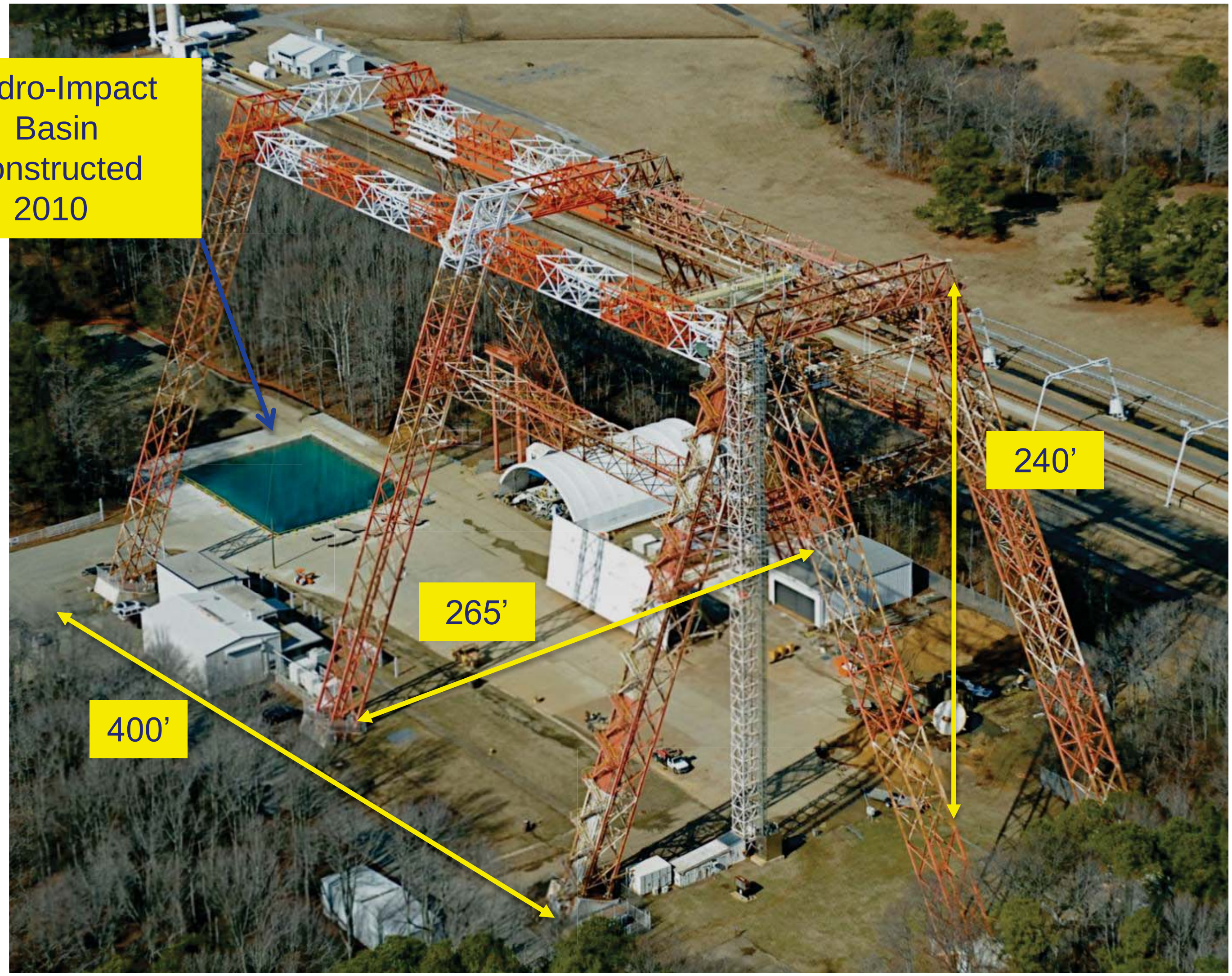
LS-DYNA/ PAM-CRASH/ Radioss/ ABAQUS-Explicit

- Finite element analysis tools
- Detailed representations of ATD's and airframes
- Accurate modeling of terrain (less than 20% of all mishaps occur on prepared surfaces)

Landing and Impact Research Facility (LandIR)

Constructed in early 1960's as a lunar landing simulator

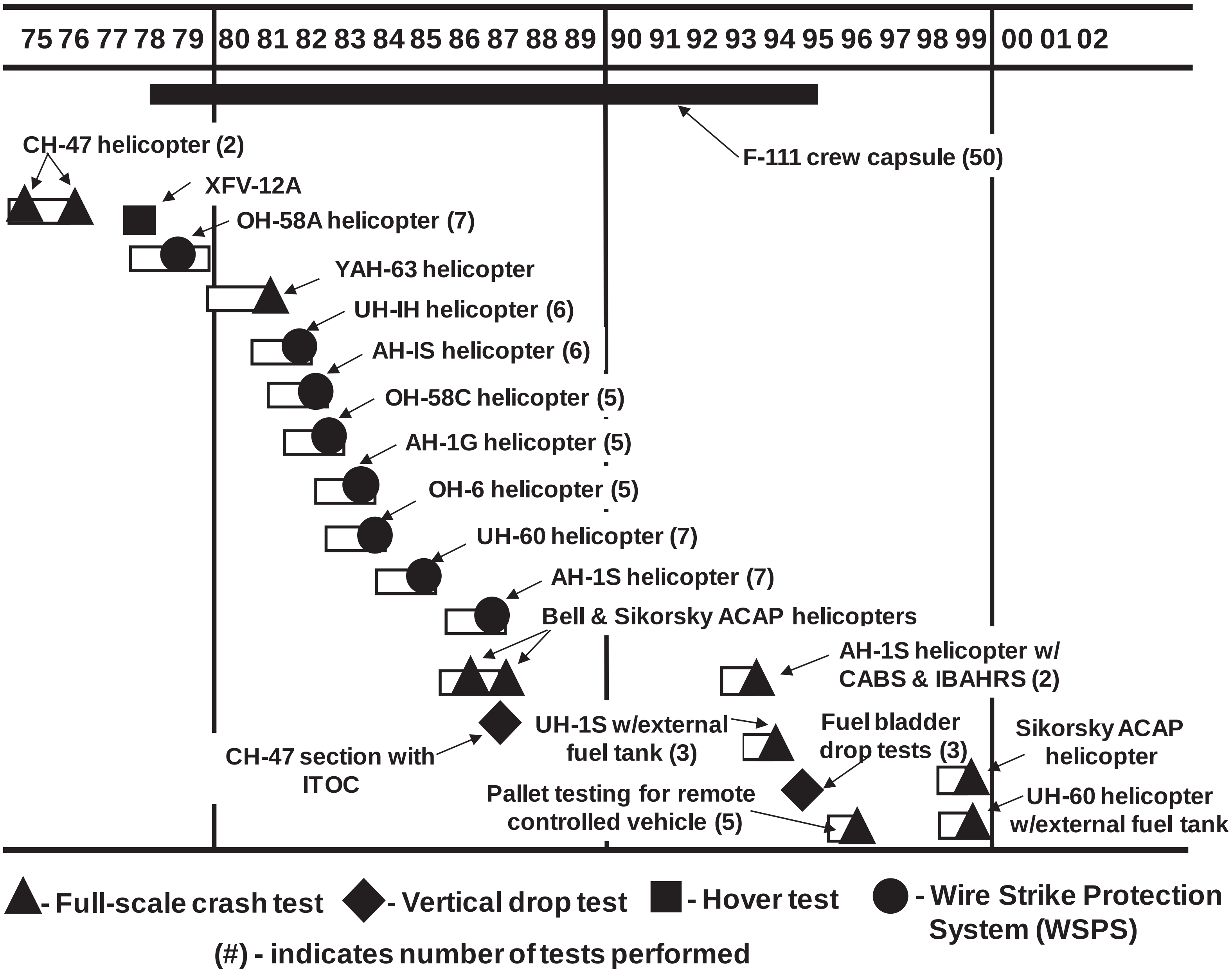
70-foot Drop Tower



Landing and Impact Research Facility (LandIR)

Military Aircraft Crashworthiness Research

LandIR Military Rotorcraft Crashworthiness Research



Develop and Validate Tools, Technologies and Concepts to Overcome Key Barriers for Rotary Wing Vehicles

Vision

- Improve capabilities, performance and acceptance of existing and future rotorcraft configurations for civil and dual-use military missions
- Explore and develop new capabilities for rotorcraft use as commercial transportation in national airspace

Scope

- Conventional and non-conventional light, medium, heavy and ultraheavy rotorcraft
- Technologies that address performance, noise, efficiency, safety, passenger acceptance and affordability

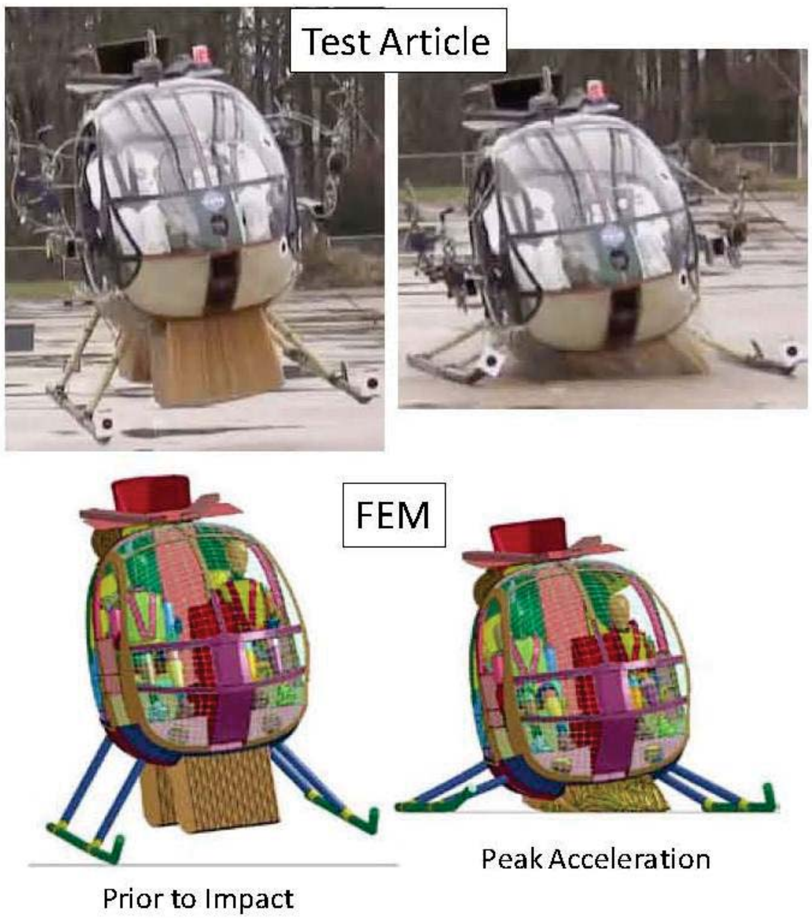
Rotary Wing Crashworthiness Research

Full-Scale Crash Testing of MD-500

- Evaluate a novel, externally-deployable energy absorber (DEA)
- Two tests conducted, with and without the DEA
- Developed a system-integrated FEM of the test article that included skid gears, airframe, seats, occupants, restraints, DEA, ballast and the impact surface
- Model calibrated using conventional and multi-dimensional calibration methods
- Evaluated the impact response of a biofidelic dummy torso from the Johns Hopkins University Applied Physics Laboratory

Rotary Wing Crashworthiness Research

System-Integrated Model Calibration



Updated model based on improvements in spatial and temporal response of FEM against measured test accelerations and velocities

Rotary Wing Crashworthiness Research

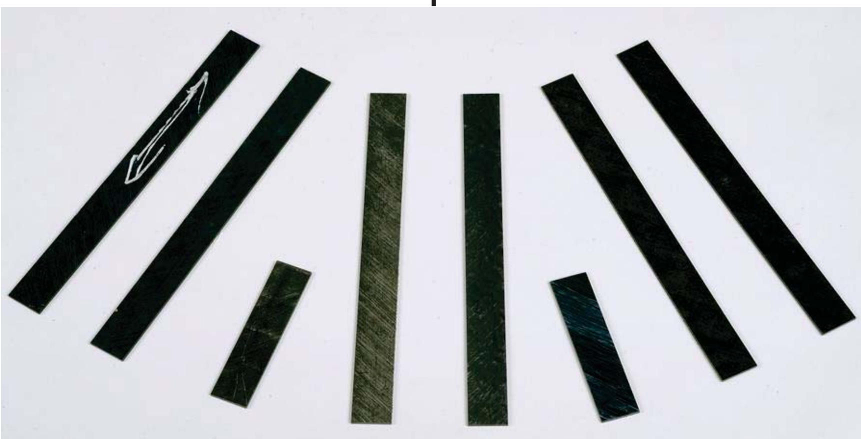
Composite Airframe Impact Testing and Simulation

- Does the design building block test sequence for material characterization & analysis methods validation encapsulate all critical modes of failure for composites, primarily Carbon Fiber Reinforced Plastics (CFRP)?
- Current models are phenomenological models and parameters in the simulation are determined by curve fitting or calibration.
- Goal: Conduct impact tests and simulations of composite airframe structures to assess feasibility for crash load attenuation, and to evaluate analytical capabilities to predict failure initiation, damage progression, and energy absorption

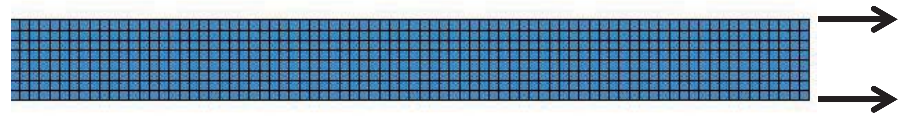
Rotary Wing Crashworthiness Research

Composite Airframe Impact Testing and Simulation

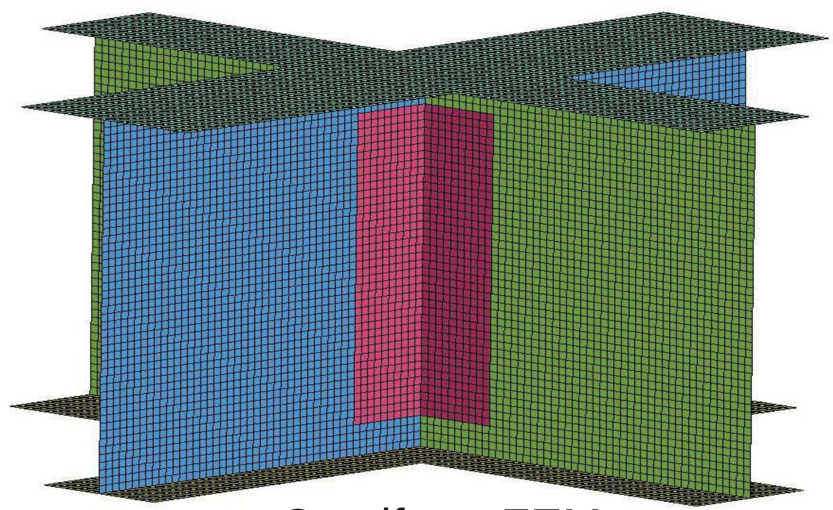
Coupons



Tensile Coupon FEM



Subfloor Cruciform

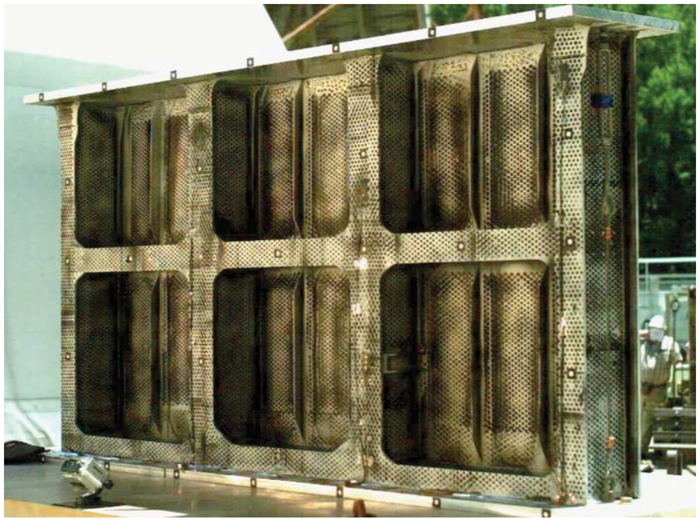


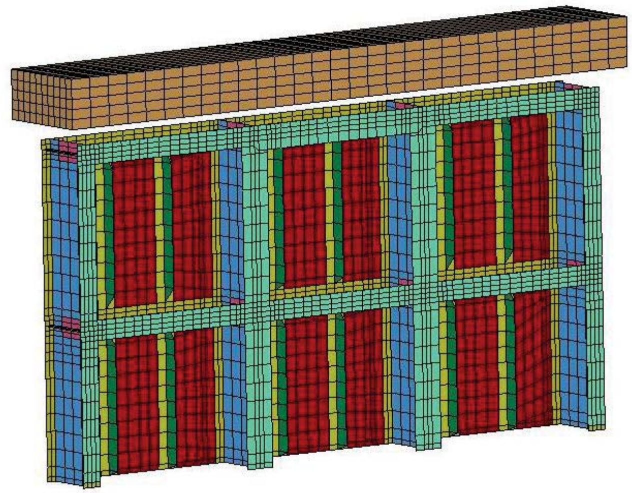
Cruciform FEM

Rotary Wing Crashworthiness Research

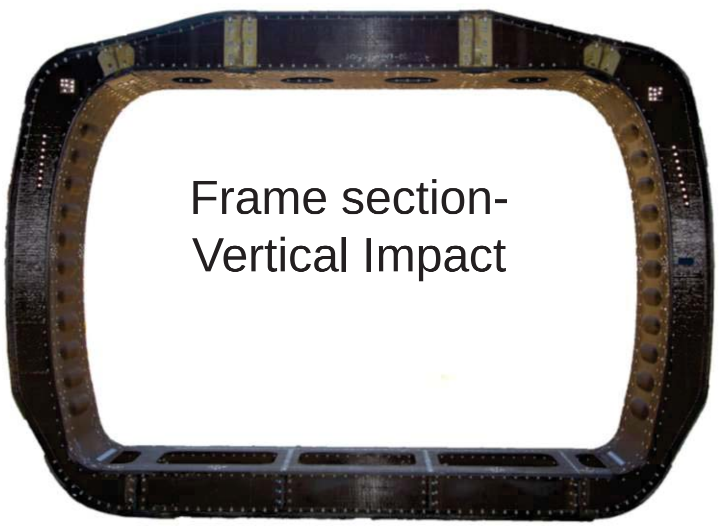
Composite Airframe Impact Testing and Simulation

Subfloor-Longitudinal Impact





Subfloor FEM

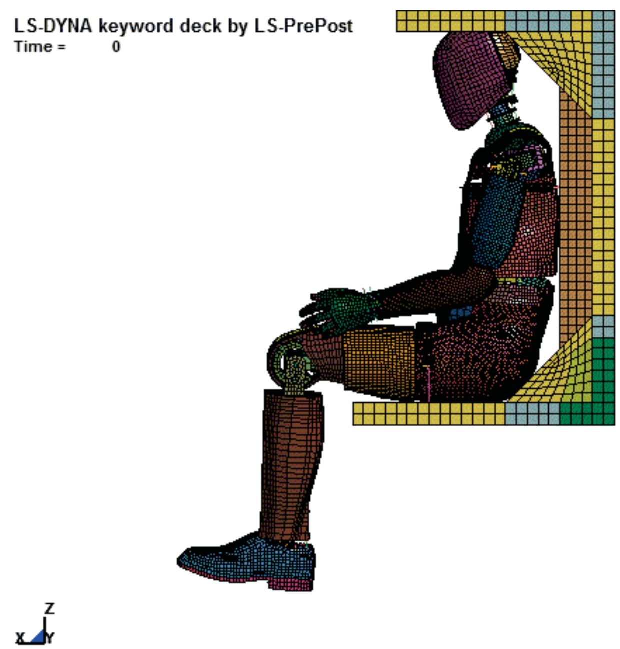


Frame section-
Vertical Impact

Frame section
FEM

Rotary Wing Crashworthiness Research

- How do we predict occupant injuries for aircraft crash and spacecraft landing conditions?
- Do we have the correct tools to predict injury?
- Evaluate adequacy of human occupant models under vertical loading
- Hybrid II, Hybrid III, THOR/NT



Transport Rotorcraft Airframe Crash Testbed (TRACT)

- Objective: Evaluate transport category rotorcraft crash response under combined horizontal and vertical loading
- Two CH-46 airframes provided by PMA-226
- Likely impact conditions
  - 20-30 ft/sec vertical
  - 20-30 ft/sec horizontal
  - 2-4 degree pitch up attitude
  - Soft soil impact

TRACT

- Collaborators
  - NAVAIR
  - AATD
  - FAA
- Discussions for supplementary experiments
  - Crashworthy side-facing troop seats?
  - Floor mounted and side mounted seats?
  - New seat energy absorber concepts?
  - Pre-tensioning/active retraction systems for inertia reel?
  - Advanced cargo restraints?
  - Available ATD's (Hybrid II, Hybrid III Aerospace, THOR, SID, ES-2)?

TRACT-Instrumentation Options

- LandIR capability: > 600 channels of data
  - Ruggedized onboard data acquisition system
  - Accelerometers
  - Strain gages
  - Strap load cells (restraint loads)
  - ATD load cells (thoracic and lumbar spine)
  - Pressure gages (for hydrodynamic pressures due to ditching)
- Full-field photogrammetry (high speed)
  - Velocity, attitude, pitch rates
  - Panel Strains
- Interior cameras
  - Occupant flail and strike envelope

TRACT-Tentative Schedule

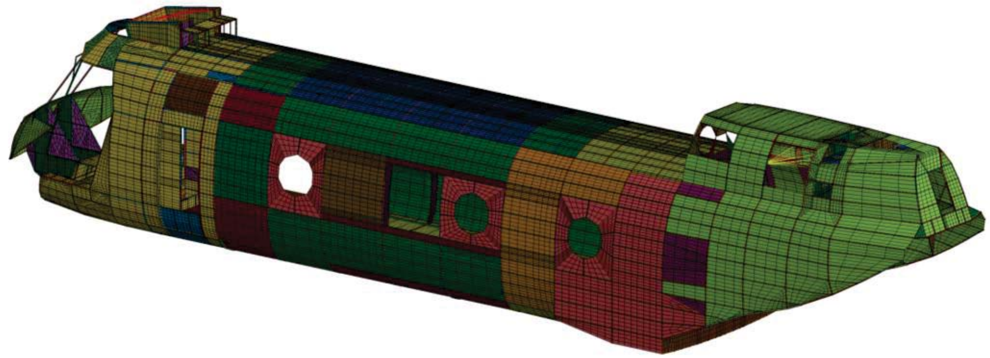
- First swing test scheduled for Summer 2013, considered “baseline” test
- Second swing test scheduled for FY14, evaluate energy absorbing subfloor concept
- Potential for fuselage frame section drop tests prior to swing test
- Potential for ditching test in Hydro Impact Basin following land tests

TRACT- Pre-test Analysis

H-46 NASTRAN Model
Provided by
PMA 226

Increased refinement around stub-wings for Nonlinear Static Analysis

TRACT LS-DYNA Finite Element Model (FEM)



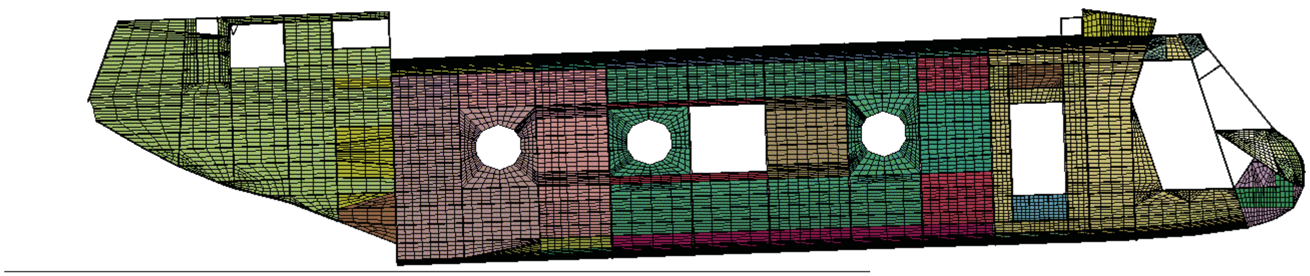
- ~50,000 nodes, ~60,000 elements
- Combination of mass, bar, and shell elements
- Elastic-plastic aluminum properties
- Current weight ~ 10,000 lb
- Overhead mass = 3,250 lb (750 fwd, 2,500 aft)
- Cockpit mass = 1,400 lb
- Cargo Floor Mass = 2,000 lb

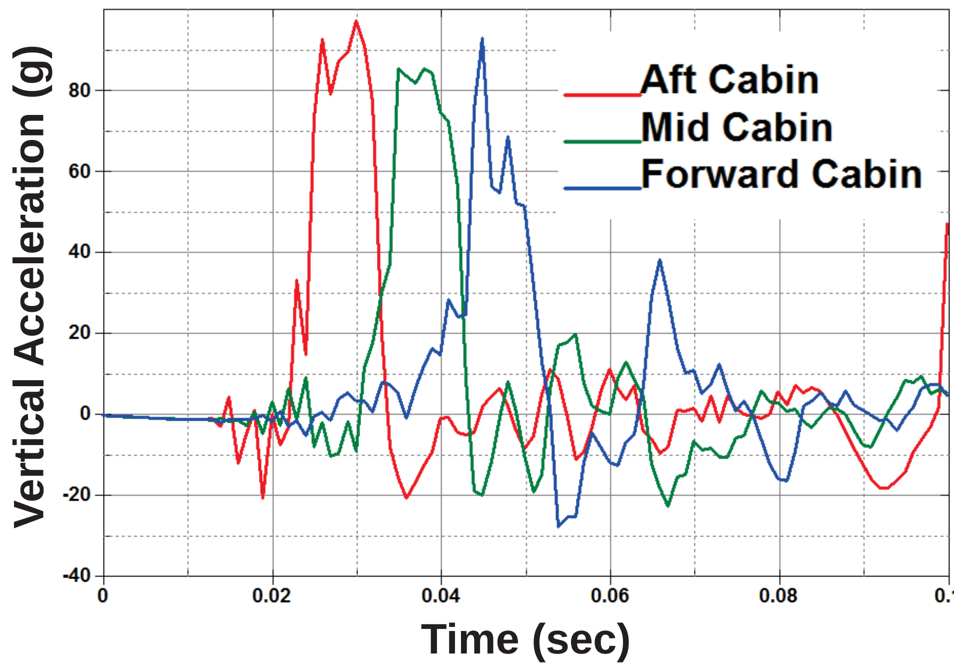
Model Converted to LS-DYNA for Explicit FEA Crash Simulation

TRACT-Pre-test Analysis

Impact Conditions:

24 ft/sec vertical, 24 ft/sec horizontal, 2 Degree Pitch-Up attitude





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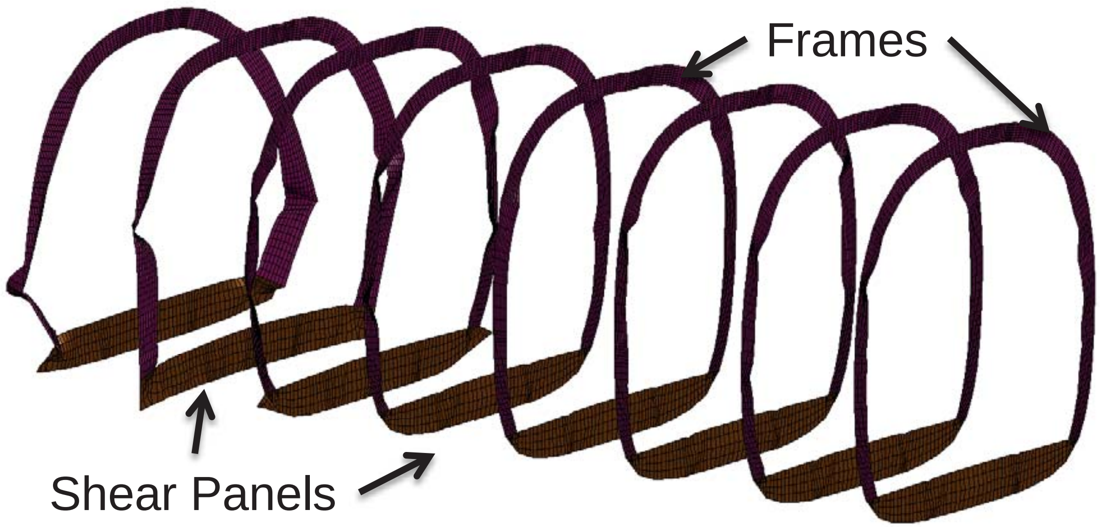
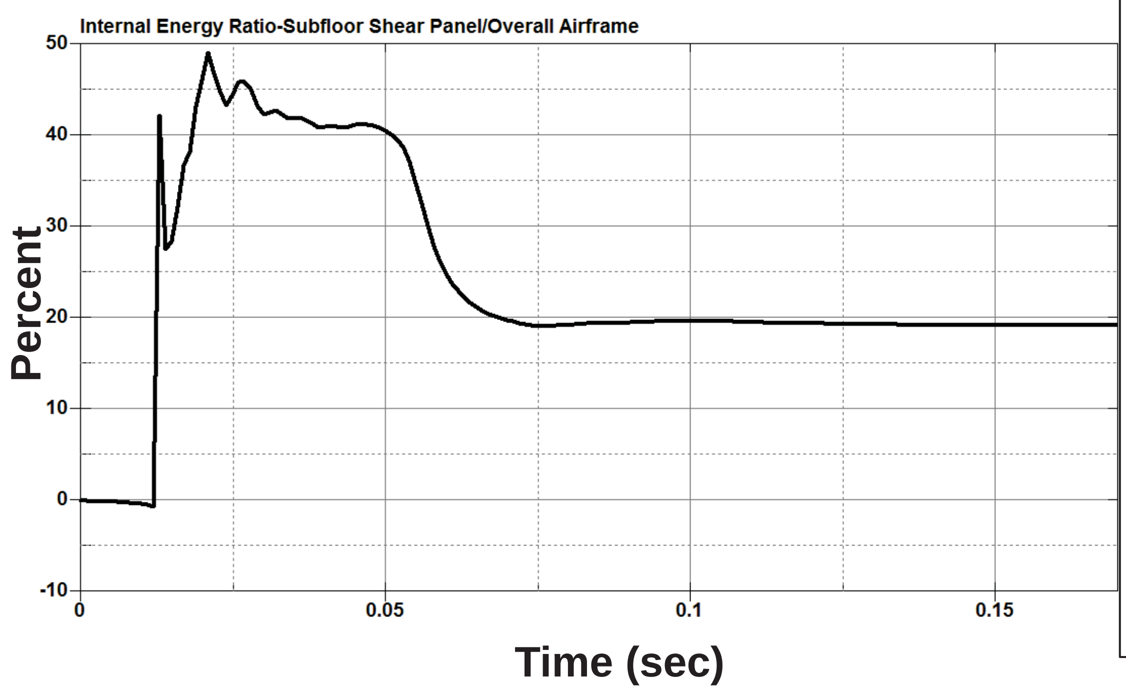
TRACT-Pre-test Analysis





- The shear panels in the subfloor contribute 30-40% to the overall internal energy absorption (plastic deformation)
- Can advanced composite concepts implemented in the subfloor reduce overall floor loads?
  - Maintain stiffness and strength performance while increasing specific energy absorption capability
  - Sandwich composite (honeycomb, Rohacell)
  - Hybrid materials laminates (Kevlar, Zylon, Glass, Carbon)
- Can this behavior be predicted analytically?

Summary

- Combined test and analysis capabilities at NASA Langley Research Center provide an integral, effective, and unique approach to studying crashworthiness
  - Full-scale testing with combined loading
  - Improved prediction of system-level vehicle response
  - Improved prediction of hydrodynamic loads due to water impact
  - Biofidelic dummy models and injury assessment
  - Structurally efficient composite concepts for improved crash performance
- Full-scale transport category crash tests planned for 2013-2014 with the goals of:
  - Characterizing complex interaction of airframe/seat/restraints/occupant under multi-terrain impact
  - Assessing both crew and troop dynamics assessed
  - Evaluating new crashworthy technologies

Ultimate Objective is Improved Crashworthiness and Crash Certification by Analysis