



Challenges for Vehicle Safety in Autonomous electric Vertical Take-off and Landing (eVTOL) Vehicles

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The UAM eVTOL Vehicle Problem



- There will be many types, makes, models and brands of eVTOL vehicles in -
- The size range of General Aviation aircraft, helicopters, and/or Light Sport Aircraft -
- Which will carry lots of occupants and operate in -
- Environments with many obstacles
- *With no discernable safety features* to adequately protect the occupant in the event of a mishap or crash (Part 1)*
- *And no regulations in place to cover the vehicle or how the vehicle operates (Part 2)*
- **Ok, there is one*

Introduction - why is this important?



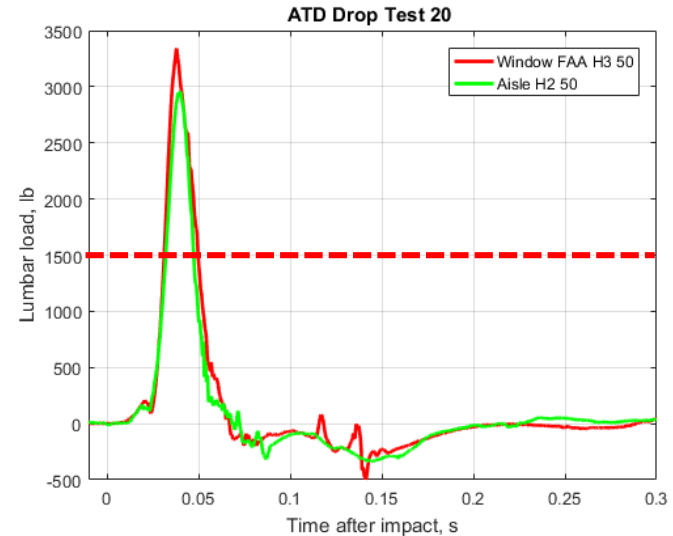
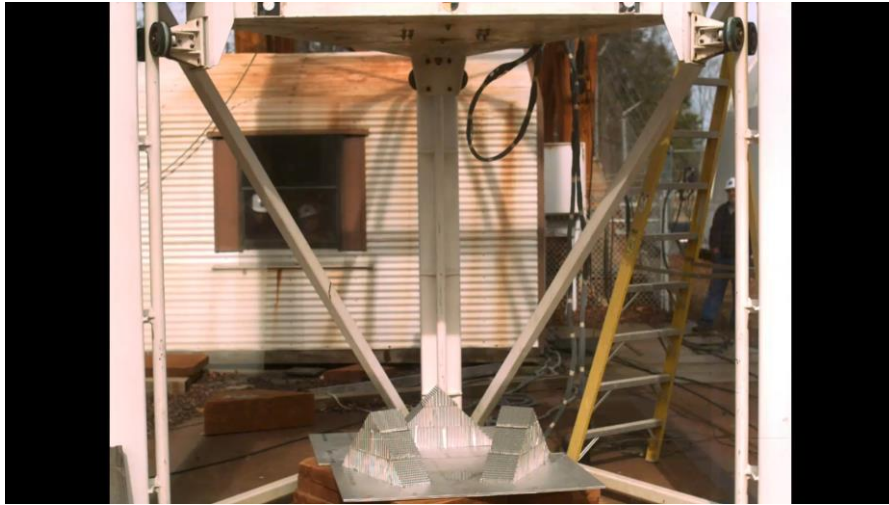
- Case study: A fall from only 14 feet (30 ft/s) has the capability of causing occupant injury if not protected
 - Impact shape from the below test is a current 14 CFR § 27.562 Regulation (*Emergency Landing Dynamic Conditions* for a helicopter)



Introduction - why is this important? (cont.)



- FAA regulations call for 1,500 lb. limit in lumbar region (for aircraft and helicopters)
 - Represents a 9% chance of detectable spinal injury and established through extensive testing
- Seats will fail qualification tests if this limit is exceeded during qualification testing
- Not directly comparable to UAM seats or conditions, but the basic premise holds



Littell, J.D. and M.S. Annett. "The Evaluation of Anthropomorphic Test Device Response under Vertical Loading." Proceedings from the American Helicopter Society International Annual Forum 74, Phoenix, AZ, May 14-17, 2018.

- | Crash Prevention | Crash Mitigation |
|---|------------------------------|
| Distributed Electric Power (DEP) | Ballistic Recovery Parachute |
| Redundant motors/propellers | |
| Lasers, LIDAR, RADAR, cameras, etc for object detection | |
| Reserve power | |
| Secure communications | |
| Weather avoidance | |
| Landing pad security | |

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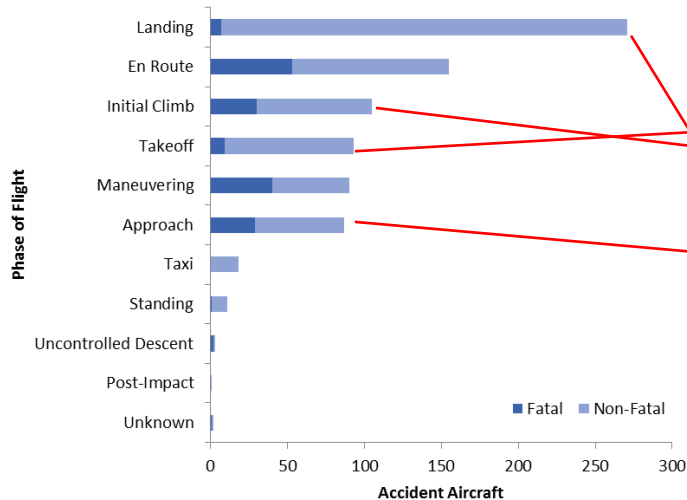
Accidents by phases of flight



- General Aviation
- Uber mission profile

<https://www.nts.gov/investigations/data/Pages/AviationDataStats2015.aspx#>

Phase of Flight for Personal Flying Accidents, 2015



	Segment	Time (min)	Distance (mi)	Vertical Speed (ft/min)	Horizontal Speed (mph)	AGL Ending Altitude (ft)
A	Ground Taxi		No Distance Credit	0	3	0
B	Hover Climb			0 to 500	0	40
C	Transition + Climb		Sizing Nominal 60 25	500	0 to 1.2*V _{stall}	300
D	Departure Terminal Procedures			0	1.2*V _{stall}	300
E	Accel + Climb			500	1.2*V _{stall} to 150	1000
F	Cruise			0	0	1000
G	Decel + Descend			500	1.2*V _{stall}	300
H	Arrival Terminal Procedures			500	1.2*V _{stall}	300
I	Transition + Descend		No Distance Credit	500 to 300	1.2*V _{stall} to 0	40
J	Hover Descend			300 to 0	0	0
K	Ground Taxi			0	3	0
L	Reserves		Balked Landing, 6 mi Cruise			

- Most phases occur below 300' AGL
- Not entirely analogous but trends are there

Crash Mitigation: Current safety feature – Ballistic Recovery System (BRS)



- <https://sbir.nasa.gov/SBIR/successes/ss/1-005text.html>
- Developed for Cirrus as the “Cirrus Airframe Parachute System” – CPAS
 - Allowed C20 and C22 to get certified for inadvertent spin entry and recovery
- No lower limit for deployment specified
 - “If CAPS is deployed too close to the ground, the chance of a successful deployment greatly decreases”
 - Cirrus claims demonstrated deployment at 400’ from straight and level flight
- There are cases where CAPS has been activated, but failed to deploy
- Uber recommends vehicles have BRS
- I would also recommend vehicles have BRS (but this cannot be the only safety feature in equipage)
 - Also BRS needs to be tailored (size, performance, deployment, etc.) to UAM vehicle environments



<https://cirrusaircraft.com/flight-training/caps-training/>

Cirrus Chute Deployment Fails Over Texas, Pilot Still Makes Safe Landing

A 2001 SR22, With A REPACKED CAPS Chute, Experiences Rocket Firing But NO Chute Deploy

You know you’re having a bad day when a flight goes so bad that you feel you must resort to using a parachute to see you safely through the flight... but the day is TRULY bad when that chute fails and leaves you to battle the emergency that you thought you had escaped from.

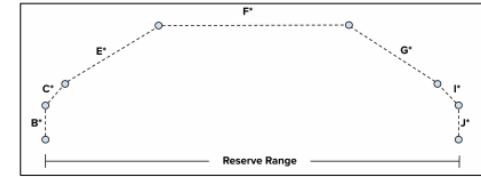
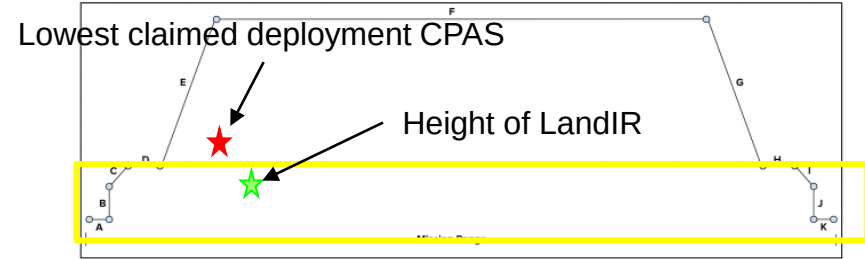


Earlier Thursday, Cirrus Pilot Tim Valentine, flying near Addison Texas aboard N715CD, experienced some mode of instrument failure while IFR in a 12 year old Cirrus SR22, serial number 16. According to Valentine, who spoke to ANN extensively Thursday within hours of the incident, he was IFR from Addison TX to Kansas at 7000 feet when he noticed the first signs of some instrumentation issues while avoiding the back side of a major thunderstorm cell. Later, Valentine experienced more serious issues when the HSI went down, the autopilot followed and he began to suspect problems with his Attitude Indicator. The trend was not encouraging.

Uber mission profile detail



- <https://s3.amazonaws.com/uber-static/elevate/Summary+Mission+and+Requirements.pdf>
- 9 out of 11 segments of Uber's mission profile are at 300' AGL or below (highlighted)
 - Lowest CPAS claimed deployment is 400' AGL
 - Correspond to noted segments in phases of flight
- Will a BRS function adequately at these heights?
- Will the BRS function at low altitudes?
- Will the BRS function at low speeds?
- Will the BRS function in urban environments?
- If BRS deploys, will that be perceived as a good thing or bad thing?

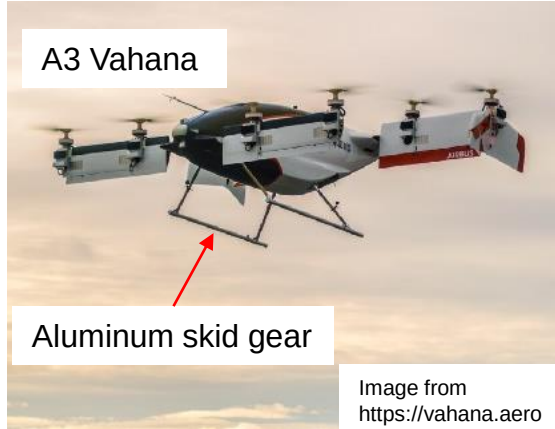


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D Departure Terminal Procedures			0	1.2*Vstall	300
E Accel + Climb		Sizing Nominal 60 25	500	1.2*Vstall to 150	1000
F Cruise			0	150	1000
G Decel + Descend		No Distance Credit	500	150 to 1.2*Vstall	300
H Arrival Terminal Procedures			500	1.2*Vstall	300
I Transition + Descend		No Distance Credit	500 to 300	1.2*Vstall to 0	40
J Hover Descend			300 to 0	0	0
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Current Vehicles (not a complete list)



A3 Vahana



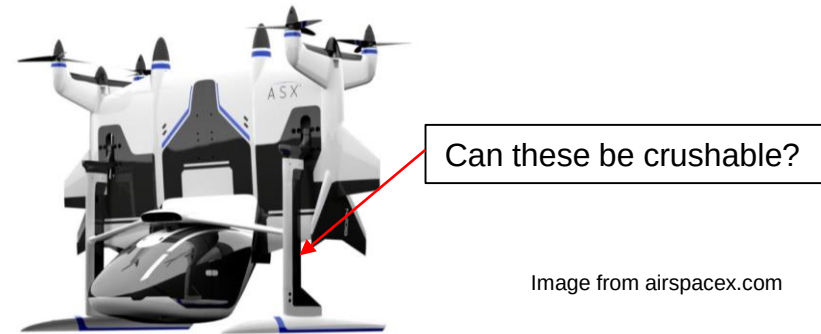
Ehang 184



Terrafugia



AirspaceX MOBi



Crash Mitigation Features Available on Current Aircraft



1. Energy Absorbing Materials
2. Energy Absorbing Subfloor
3. Energy Absorbing Seats
 1. Both Military and Civilian
4. Energy Absorbing Landing Gear
 1. UH-60
5. External Airbags
 1. Similarly – floatation bags
6. Internal Airbags
 1. CABS
7. Object strike prevention
 1. WSPS in helicopters
8. Head and neck restraints
 1. Mostly used in racing applications

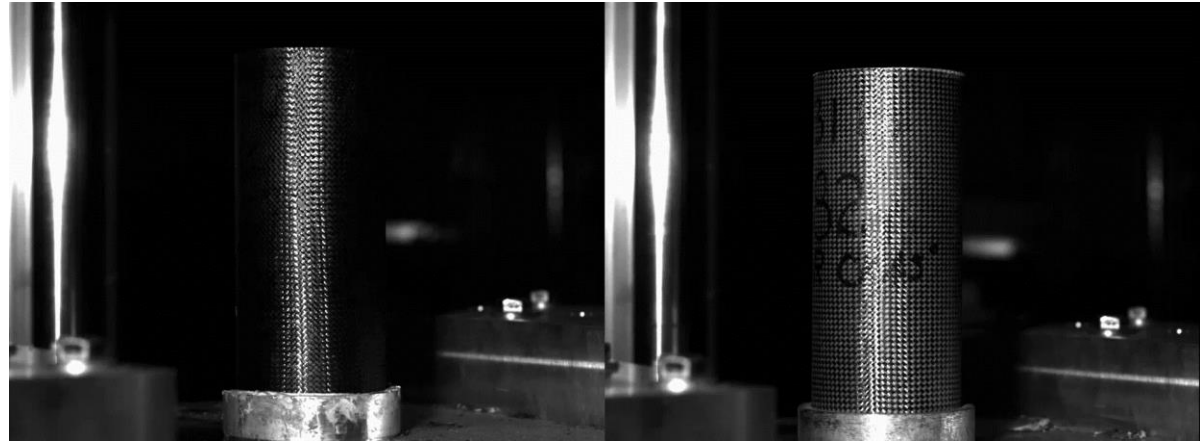
1 - Energy Absorbing Materials



- Carbon is very strong and stiff, however it is very brittle, and failures by splaying and exhibiting pulverization
- UAM OEMs are heavily investing in letting the public know that they will be using carbon composite materials
 - I call this the “wow factor”
- Aramid fiber such as Kevlar is ductile
- Crash mitigation needs ductile materials such that impact energy turns into strain energy at levels suitable for occupant survivability
 - Why are all aircraft made out of aluminum now? b/c lightweight and ductile (and cheap)
- Carbon and Kevlar are about the same price, about the same weight, and are easily available for use



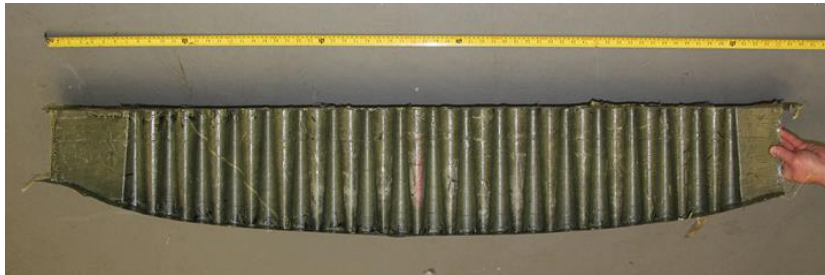
Carbon vs Carbon/Kevlar



Carbon vs Carbon/Kevlar

2 – Energy Absorbing Subfloor

- Conical beam “Conusoid” developed for a retrofit into a CH-46 helicopter
- Energy Absorbing Beam Member”. US Patent # 9,616,988. Issued April 11 2017
- Carbon/Kevlar shaped into interlocking conical shape
- 50% weight savings over aluminum



Full Size Specimen

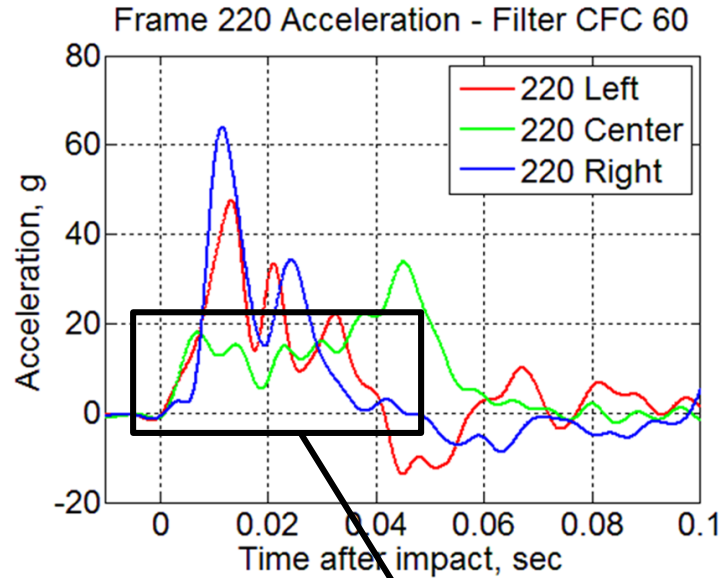


Original Subfloor in CH-46



Conusoid retrofit into CH-46

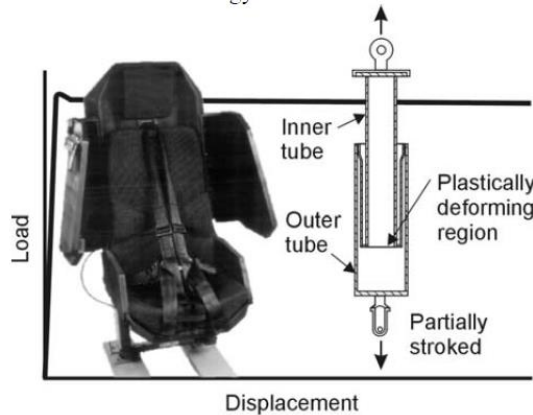
2 – Energy Absorbing Subfloor Results



3 – Energy Absorbing Seats



- Almost all military helicopters and civilian transport aircraft contain energy absorbing seats
 - Conform to 25.562 civilian and military guidelines
- General Aviation seats, while potentially not energy absorbing, must still pass 14 CFR § 23.562



Bell Air Taxi Prototype

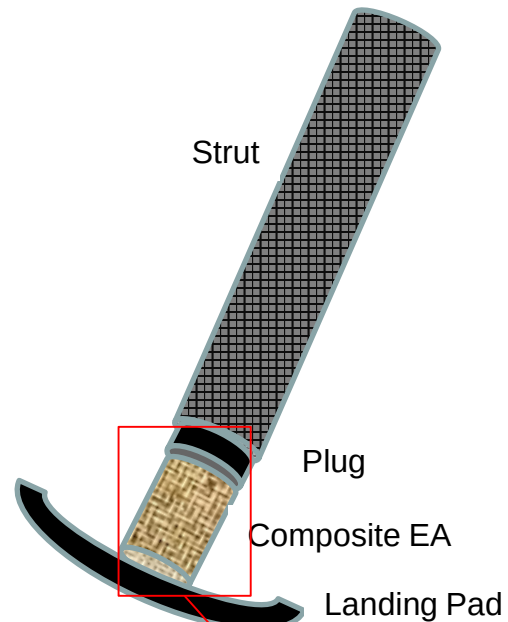
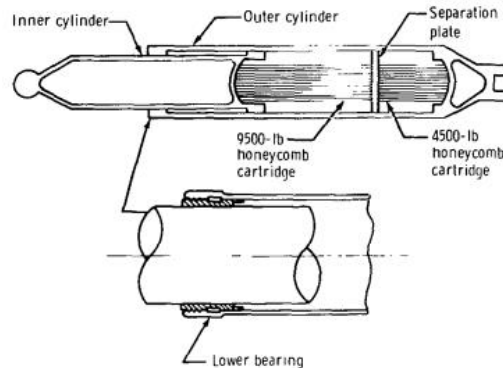


Part 25.562 - Test #1

4 – Energy Absorbing Landing Gear

- Oleo struts are common on all aircraft to attenuate landing and shock loads
 - But not typically used to mitigate crash loads
 - UH-60
- Crush tubes would be a viable solution
 - NASA and other researchers
- Apollo LEM used crushable honeycomb
- Materials are readily available (honeycombs, foams, etc.)

Cessna 172 Nose gear test



5 – External Energy Absorbing Mechanisms



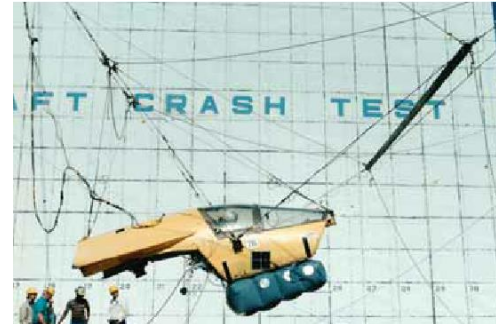
- NASA investigated external airbags to attenuate Orion capsule land-landing
 - Now in use by Boeing CST-100
- NASA also examined F-111 cockpit ejection with airbag attenuation
 - Still concerned about pilot injury even with parachutes
 - ~60 tests
- Current helicopter skid gear airbags are primarily for floatation and not impact attenuation
- NASA developed DEA (detail next slides)



https://www.nasa.gov/mission_pages/constellation/orion/2nd-gen-airbag-test.html



<https://www.cnn.com/2018/03/26/us/nyc-helicopter-crash-ntsb-preliminary-report/index.html>



Jackson, K.E. et al. "A History of Full-Scale Aircraft and Rotorcraft Crash Testing and Simulation At NASA Langley Research Center." 4th Triennial International Aircraft and Cabin Safety Research Conference. Nov. 15-18, 2004. Lisbon, Portugal.

5 – NASA Developed DEA



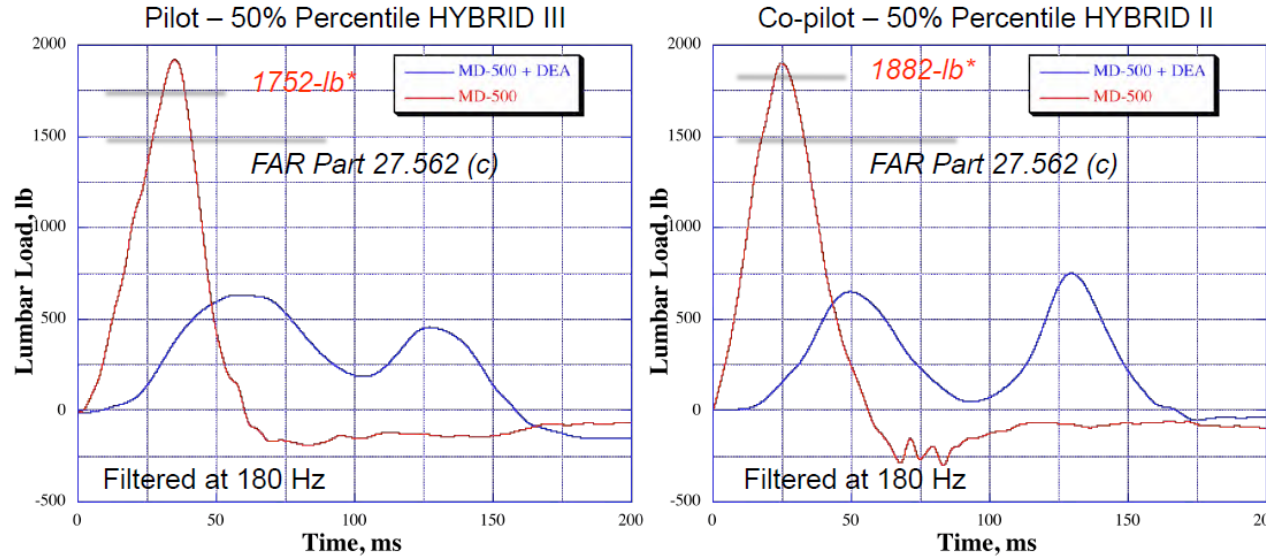
- Kellas S., “Deployable Rigid System for Crash Energy Management,” US Patents 6,755,453, June 29, 2004, 6,976,729 December 20, 2005, and 7,040,658 May 9 2006
- Developed by NASA as either a forward-fit (Orion capsule) or retrofit on existing small aircraft
- One example of crash energy management developed by NASA
- Kevlar honeycomb which can be folded and stowed

5 – NASA Developed DEA Video Comparison



- Two identical tests conducted, one with and one without DEA
- Nominal impact conditions: 40 ft/s horizontal, 26 ft/s vertical
- DEA test conducted first, presented in reverse order here

5 – NASA Developed DEA Test Results



- 67% and 60% Peak lumbar load attenuation for pilot and co-pilot respectively when using the DEA

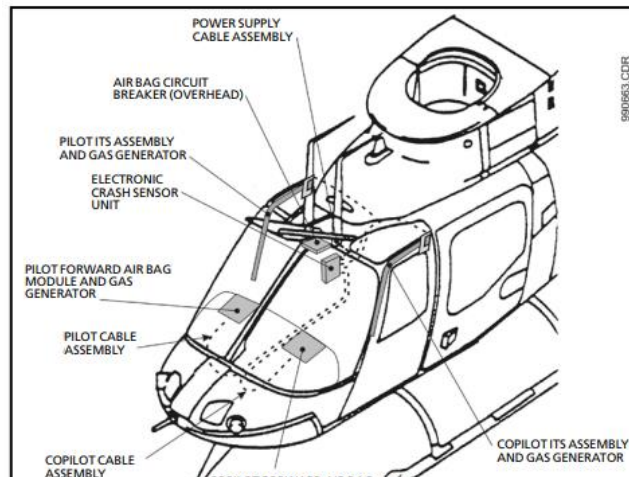
6 – Internal Cockpit Airbags

- NASA AH-1S tests led to the development of the CABS systems for the UH-60 and OH-58 helicopters
 - Currently sold by BAE Systems
- Currently on civilian aircraft there is only seatbelt airbags (coming slide)
- Some pushback on GA side for implementation (cost, functionality)



Jackson, K.E. et al. "A History of Full-Scale Aircraft and Rotorcraft Crash Testing and Simulation At NASA Langley Research Center." 4th Triennial International Aircraft and Cabin Safety Research Conference. Nov. 15-18, 2004. Lisbon, Portugal.

CABS FOR OH-58: SYSTEM OVERVIEW



BAE systems. Cockpit Airbag system
baes_ds_Cockpit Air Bag System - CABS_redesign_digital (4).pdf

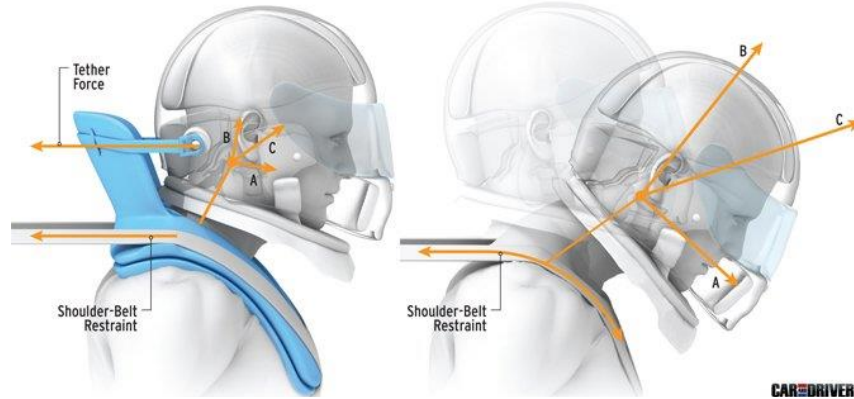
7 – Object Strike Prevention



- Collision avoidance is fine for buildings and large structures but will it “see” birds, wires, antennas and other smaller structure?
- Wire cutter (high mass)
- Canopy protection (low mass)
 - My idea, with absolutely no research behind it (yet), is to envelope the canopy with a flexible cable/rope to deflect foreign object wires
 - This will not protect against birds, rocks or other “solid” objects
 - Separate research into materials/canopy shapes are needed to protect and deflect against these objects



8 – Restraints



<https://www.caranddriver.com/features/the-physics-of-how-the-hans-device-saves-lives-feature>

http://www.aviationconsumer.com/issues/49_6/safety/Airbag-Seatbelts-Pricey-But-Effective_7067-1.html

- Part 121 aircraft have lap belt only for passengers
 - Jump seats are typically 4 point harnesses
- Part 23 aircraft certified after 1986 must have lap belt + shoulder harness
- Since 2003 restraint airbags have been certified for use
- NASCAR has the HANS device
- What needs to be on UAM vehicles?

Part 2 – What will the regulations look like? Two major areas



- **Operation Certification** (the rules you have to follow for operation)
 - Uber is using/assuming 14 CFR Part 135 (Air carrier service)
 - Uber wants accident rate incidents lower than Part 135
 - Note that commercial air travel is Part 121
 - Part 135 is typically for Biz Jet charters, helo sight seeing

- **Vehicle Certification** (rules on vehicle design)
 - Part 21.17(b) – Special class
 - Part 23 (GA) ?
 - Part 27 (helo)?
 - New ?



- Performance based standards – Part 23 (amendment 64) – commonly called the “Part 23 rewrite”
 - High level requirements, no technical solutions prescribed
 - Technical solutions that can be used are moved to Standards organizations
 - ASTM F44 - General Aviation
 - ASTM 2245 – Light Sport
 - Or other technical solutions can be used in order to meet the requirements
- Must demonstrate equivalent level of safety (similar to Part 25 ARAC) for new design via prescriptive requirements
 - New design must meet the safety standards of previously tested and proven aircraft
 - Example is FAA SCs 25-362 (Boeing 787)
 - Primarily through test or test/analysis
 - However, since no certified UAM aircraft exist yet, the equivalent level of safety would have to be tied to an aircraft of different “class”
- If new, then create a whole new set of regulations

Operation Certification - Part 121 vs. Part 135



- Part 135*
 - Non-Cargo On-Demand consists of
 - Air Taxi
 - Air Medical
 - Air Tour
 - 557 Operators, 10,655 aircraft
 - In 2010
 - 3.1 Million hours flown
 - Between 2004 and 2002
 - 472 total accidents, 111 fatal
 - 300 fatalities total
 - For 2002-2011 period, there was 1.5 fatal accidents per 100,000 flight hours
- Uber assumption
- Part 121* (2014 data)
 - Scheduled Air Carriers
 - 2014
 - 17 Million hours flown
 - 2014
 - 0 fatal accidents
 - 29 total accidents
 - 2014
 - 0.16 accidents per 100,000 flight hours
- Safer

Current Committee / Working Groups



- Uber Elevate (2nd year)
 - Attendees:
 - Uber, OEMs, Policymakers (incl. NASA), Suppliers, Venture Capitalists (VCs)
 - Subject matter:
 - Keynotes: Vehicle Concepts, Energy Storage, Policymakers, Airspace
 - Sessions: Airspace, Network Optimization, Battery Safety, Community Acceptance, Sky-ports, *Certification thru Part 23*, Lessons Learned, Affordability, Growth
 - There was no discussion on vehicle safety/crashworthiness/mitigation
 - *Certification thru Part 23* – would like to use the Part 23 rewrite as a basis for eVTOL vehicle certification, which includes crash conditions
 - But is Part 23 really the way forward?
 - The discussion on the operator is still Part 135? Not covered
 - <https://www.uber.com/info/elevate/summit/>

Current Committee / Working Groups (cont.)



- AHS Electric VTOL Symposium (now in 6th year)
 - Organizing members are Vertical Flight Society, AIAA, NASA, SAE
 - Attendees (general summarized for 5th year): NASA, Uber, OEMs, Academia, SAE, GAMA, Suppliers, VCs (I did not see FAA)
 - Subject Matter: Analysis Tools, Challenges of Airspace, User Experience, Challenges of Certification, Challenges of Acoustics, Challenges of Hybrid Electric, Prospective Markets
 - <https://vtol.org/news/5th-annual-transformative-vtol-workshop>
- Are there others?

Summary



- How are the vehicles going to be certified ?
 - Will dictate performance based vs. means of compliance
 - Feed into the amount and type of safety features integrated into vehicle design
 - Examples given
- How are the vehicle operations going to be certified?
 - Operational model of a air charter (Part 135)
 - Or more like commercial aviation (Part 121)
- Working groups such as ARACs or Advisory Committees with a mix of OEM, Government, Regulators, SMEs required for development