EVTOL Crashworthiness

Moving Forward

Presented to: eVTOL Crashworthiness Workshop #2
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Date: October 9, 2020
EVTOL Certification

- Safety continuum-
  - primarily tied to occupancy
  - Operations over large populations;
  - beginning to look at protecting people on the ground
  - In some cases, UAS have higher expectations
  - Operations over transportation centers
  - Fit into safety continuum based upon initial model

- When operation/utilization model changes....level of safety can change
- Safety is tied to the initial assumptions and crashworthiness should be buried deep in the design and adequate to accommodate change
EVTOL Certification-First Steps

- Define the aircraft configuration
- Define the aircraft utilization
- Is it more 23 or 27?
- EVTOL aircraft don’t typically fit into the normal certification holes and require coordination for cert basis
- The wide design variations also result in big variations in performance(diverging from 23/27)
Current Path
-Proceed With the Known

- Part 23/27 static and dynamic crashworthiness loads derived from how vehicle flies/lands in emergency
- Currently applying some sort of 23/27 crashworthiness
- Part 27 fuel tank requirements are possibility
- Encourage incorporating crashworthiness best practices
  - Survivable volume
  - Occupant restraint/interior protection
  - Airframe load attenuation
  - Anti-plowing
  - Post crash fire protection
  - Good egress
## EVTOL Certification - Current Example Static Loads

- Conventional wisdom and current state of the art for a s/vtol plane with wingborne cruise

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<tbody>
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<td><strong>Static Occupant</strong></td>
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<tr>
<td>Forward</td>
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<td>16g</td>
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<td>Rearward</td>
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<tr>
<td>Upward</td>
<td>3.0g</td>
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<td>4g</td>
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<tr>
<td>Downward</td>
<td>6.0g</td>
<td>6.0g</td>
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<td>20g after intended displacement of seat device</td>
<td>20g after intended displacement of seat device</td>
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<td>Sideward</td>
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<td>8g</td>
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<tr>
<td>Occupant weight</td>
<td>190 pounds</td>
<td>190 pounds</td>
<td>170 pounds*</td>
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<td><strong>Static items of Mass</strong></td>
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<td>Forward</td>
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<td>Upward</td>
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<tr>
<td>Sideward</td>
<td>4.5g</td>
<td>4.5g</td>
<td>4.5g</td>
<td>6g</td>
<td>6g</td>
<td>6g</td>
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<tr>
<td>Retractable Gear</td>
<td>3g</td>
<td>3g</td>
<td>3g</td>
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<tr>
<td>Ultimate inertia force</td>
<td>3g</td>
<td>3g</td>
<td>3g</td>
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</table>

*170 pounds is used as 190 pounds is traditionally used to accommodate parachute on utility and acrobat aircraft.*
**EVTOL Certification - Current Example Dynamic Loads**

- Conventional wisdom and current state of the art for a s/vtol plane with wingborne cruise

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<tbody>
<tr>
<td>1st test (combined fwd/down) 1st row</td>
<td>19g, Δ velocity = 31 ft/sec, 0.05 sec rise time</td>
<td>19g, Δ velocity = 31 ft/sec, 0.05 sec rise time</td>
<td>30g, Δ velocity = 30 ft/sec, 0.031 sec rise time</td>
<td>30g, Δ velocity = 30 ft/sec, 0.031 sec rise time</td>
</tr>
<tr>
<td>1st test (combined fwd/down) Other rows</td>
<td>15g, Δ velocity = 31 ft/sec, 0.06 sec rise time</td>
<td>15g, Δ velocity = 31 ft/sec, 0.06 sec rise time</td>
<td>30g, Δ velocity = 30 ft/sec, 0.031 sec rise time</td>
<td>30g, Δ velocity = 30 ft/sec, 0.031 sec rise time</td>
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<tr>
<td>2nd test (FWD) with floor warpage 1st row</td>
<td>26g, Δ velocity = 42 ft/sec, 0.05 sec rise time</td>
<td>26g, Δ velocity = 42 ft/sec, 0.05 sec rise time</td>
<td>18.4g, Δ velocity = 42 ft/sec, 0.071 sec rise time</td>
<td>26g, Δ velocity = 42 ft/sec, 0.05 sec rise time</td>
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<tr>
<td>2nd test (FWD) with floor warpage Other rows</td>
<td>21g, Δ velocity = 42 ft/sec, 0.06 sec rise time</td>
<td>21g, Δ velocity = 42 ft/sec, 0.06 sec rise time</td>
<td>18.4g, Δ velocity = 42 ft/sec, 0.071 sec rise time</td>
<td>21g, Δ velocity = 42 ft/sec, 0.06 sec rise time</td>
</tr>
<tr>
<td>ATD weight</td>
<td>170 pounds</td>
<td>170 pounds</td>
<td>170 pounds</td>
<td>170 pounds</td>
</tr>
</tbody>
</table>

*170 pounds is used as 190 pounds is traditionally used to accommodate parachute on utility and acrobat aircraft.*
Disclaimer:

• To this point as described, is where we are right now with current applicants and adapted requirements

• From this point on, this presentation mixes the known and suggests a plan forward into a better predicted solution for future EVTOL crashworthiness

• This is not FAA policy and is not data that is directly suitable for certification
What is an Emergency Landing?

- We bound an emergency landing as an impact where the aircraft is under control at impact or at least under control until just before impact.
- In this external impact condition, we can then evaluate protection/crashworthiness and have a line in the sand for suitable protection within human tolerance.
- Beyond this emergency condition, all bets are generally off on survivability.
EVTOL Emergency Landing

- Parts 23 and 27 emergency landings are based upon years of service data derived from relatively unchanged configurations/modes of flight.
- EVTOLs offer more variables and don’t have this crash history defining survivability vectors to pick a “survivable point” on a curve.
- EVTOLs need “another way down” to controlled emergency landing.

*Note that multiple charts like this have been historically compiled to define survivable impacts, this is not “The” chart to use.*
Know Your Emergency Landing

- We need to control our emergency landing
- EVTOL likely won’t look like 23/27 emergency landing
These EVTOL aircraft are not airplanes nor are they helicopters…..

- Part 23 aircraft assume some wing lift to emergency landing.
- Part 27 autorotate to emergency landing
- EVTOLs we are seeing are typically optimized for transition flight, if having wingborne lift, higher stall-speed wings limited flight controls
- Have little reason to believe right now that EVTOLs will have emergency landings with velocities and orientations that approximate 23/27
- EVTOLs need to consider “another way down” to controlled emergency landing within bounds of system failures
Another Way Down

• EVTOL aircraft crashworthiness process needs to consider aircraft system safety like never before

• Emergency landing parameters of external vehicle impact direction/magnitude limited to where vehicle crashworthiness can have a chance

• What system redundancy or features are available to control EVTOL emergency landing; if failed, what else can be utilized to maintain control
  – Not saying not possible, just that EVTOLs need to assess and utilize scenarios for redundancy/abilities to emergency landing for likely failures
  – Unique by aircraft
  – Specific concern for transition flight, low airspeed/altitude (coffin corners of envelope), operation over congested areas
  – Response time, recovery time

• Incumbent upon applicant to demonstrate overall aircraft ability to deliver aircraft to crashworthy emergency landing conditions
Controlling Descent

How can we control descent?
• Residual thrust for multiple rotors
• Residual thrust coupled with residual lift
• Control redundancy via thrust and/or flight controls
• FHA should drive design for solutions to achieve emergency landing
  ---use care in just relying on the small probabilities
• How does automation affect emergency landing?
• Ballistic parachute systems have limitations
  – Traditionally a supplemental safety system
  – Trading controllable situation with uncontrolled situation; maybe with better outcome
  – Established performance is an impact with fuel burn and reduced weight
  – Limited envelope, not likely to be useful at low AGL
  – Would become MEL/no dispatch item
EVTOL Certification -

Crashworthiness in the Future

• Define vehicle operation/flight/failures/emergency landing
• Define emergency landing, based upon how it flies considering loss of power, thrust, system failure
  – VTOL-has transient phase to horizontal or is purely vertical thrust-will drop like helo with little or no forward airspeed
  – Fixed wing/wingborne lift flight(can land horizontally)-will glide in like airplane with appropriate airspeed
  – Performance tied to unique design of aircraft
  – At this point we can discuss appropriate crashworthiness
Emergency Landing Vector

- If EVTOL emergency landing can be brought to within parameters of 23/27 then existing emergency landing may be able to leverage existing part 23/27 crashworthiness in an appropriate manner.
- If EVTOL emergency landing deviates from the known, then applicant would need to demonstrate equivalent occupant survivability.
- Emergency landing vectors are not identical and do not easily correlate to the XX.562/561 floor crashworthiness loads due to airframe attenuation.
EVTOL Certification-Best Practices

• Advantageous to build crashworthiness features early into airframe design and system architecture/operations
  – Crushable, energy absorbing airframe
  – More-rigid passenger cabin structure
  – Solid restraint/seat attachments to airframe, but can gimbal and stay attached in crash
  – Consider headstrike/flail envelope in cabin avoid rigid, sharp features
  – Restrain items of Mass/batteries/powerplants/cargo
  – Ensure egress capability features after crash/deformation
  – Minimize post crash fire hazards
  – All of which are bounded by a defined emergency landing condition
  – *First responder rescue features (NFPA alternate fuel vehicles safety training)
Final Thoughts

• Traditionally, Certification moves ahead incrementally and the level of safety is based upon the best knowledge we have now
• Currently, 23/27 requirements are applied with systems failure hazard analysis undergone independently—we have a good idea of how 23/27 aircraft hit the ground
• Don’t bet on eliminating crashworthiness if your FHA numbers are really small..... There will be a baseline crashworthiness level.
• New avenues will be more of a challenge as vehicle type/operations certification is not stable
• Other paths......Longer/More Advanced/Likely Safer/But...More Expensive Paths
  – Automotive approach-path of full vehicle crash response/seat/restraint/ATD
  – Potentially extensive modelling that will likely require substantiation via large scale or component test
  – Crashworthiness will depend on robust systems safety
• Better, more data results in better understanding/crashworthiness performance
• But we can’t get there without bounding the emergency landing condition
Questions

Early experiments in transportation