**COMMITTEE F44 on GENERAL AVIATION AIRCRAFT**

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**MEMBERSHIP SECRETARY:** David J Oord, Aircraft Owners & Pilots Association, Suite 750, 50 F Street NW, Washington, DC 20001, United States (202) 609-719, e-mail: david.oord@aopa.org

**STAFF MANAGER:** Joe Koury, (610) 832-9804, Fax: (610) 832-7033, e-mail: jkoury@astm.org

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**eVTOL International Standards Workshop**

**Tuesday 23 April 2019, 10:00 – 17:30**

Hotel NH Brussels Bloom, Brussels, Belgium

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### OPENING WELCOME AND OPENING REMARKS

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:00</td>
<td>Welcome</td>
<td>Kyle Martin, GAMA</td>
</tr>
</tbody>
</table>

### SESSION I REGULATORY FRAMEWORK AND MARKET REVIEW

Session will focus on the current Part 21 market as well as updates on the European regulatory framework. This will address technology, airworthiness and operational considerations.

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:15</td>
<td>Implementing Basic Regulation for GA</td>
<td>Boudewijn Deuss, EASA</td>
</tr>
<tr>
<td></td>
<td>- Part 21 Light</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Part M Light</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Speaker</th>
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</thead>
<tbody>
<tr>
<td>12:00</td>
<td>LUNCH</td>
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</tr>
</tbody>
</table>

### SESSION II VERTICAL TAKE OFF AND LANDING: MARKET OVERVIEW

Session presentations will cover an overview of the market, changes in technology, regulatory considerations and its impact on the transportation infrastructure globally.

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>13:00</td>
<td>Market Overview: Innovations and Considerations</td>
<td>Christine DeJong, GAMA</td>
</tr>
<tr>
<td>13:30</td>
<td>EASA SC VTOL</td>
<td>Kyle Martin, GAMA EU</td>
</tr>
<tr>
<td>14:00</td>
<td>Operational Capabilities and Considerations</td>
<td>Ryan Naru, Uber</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:30</td>
<td>BREAK</td>
<td></td>
</tr>
</tbody>
</table>

### SESSION III MEANS OF COMPLIANCE: GAPS & PRIORITIES

Session will discuss standardization efforts underway. These areas are gaining consensus with the goal of beginning standards work in the near future. Some needs and gaps under consideration will be highlighted.

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:50</td>
<td>Energy Storage Devices</td>
<td>Tom Gunnarson, Kitty Hawk</td>
</tr>
<tr>
<td>15:10</td>
<td>Integration of Energy Storage Systems</td>
<td>Tom Gunnarson, Kitty Hawk</td>
</tr>
<tr>
<td>15:30</td>
<td>Inadvertent Icing Protection</td>
<td>Greg Bowles, GAMA</td>
</tr>
<tr>
<td>15:50</td>
<td>Crashworthiness</td>
<td>Nick Borer, NASA</td>
</tr>
<tr>
<td>16:20</td>
<td>UAM/eVTOL Emergency Systems Certification Credit</td>
<td>Ryan Naru, Uber</td>
</tr>
<tr>
<td>16:50</td>
<td>Design of Indirect Flight Controls (WK61549)</td>
<td>Dave Stevens, Terrafugia</td>
</tr>
</tbody>
</table>

### CLOSING CLOSING REMARKS

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>17:30</td>
<td>Strategic Planning &amp; Execution</td>
<td>Greg Bowles, F44 Chairman</td>
</tr>
</tbody>
</table>
Part 21 Light: Simple and proportionate rules for small aircraft manufacturers
Topics of Discussion

- Introduction to the Regulation (EU) No 2018/1139 (new basic Regulation)
- Overview of the proposed concept
- Explanation of Light Certified process
- Explanation of Light Declared process
- Next Steps
- Interactive discussion
On 11 September 2018 the new basic Act on common rules in the field of aviation entered into force

Regulation (EU) 2018/1139

repealing Regulation (EC) 216/2008

referred to currently as “new basic Regulation” (NBR)
Part-21 requirements are not always scaled to the risk of products designed/produced ...

... the new BR offers new tools and regulatory concepts and objectives, which will allow to make it more scalable

new RMT.0727 will look into this

The new BR introduces new and amends existing airworthiness concepts ..... 

... Part-21 needs to be reviewed in view of these changes introduced in the new BR
The NBR allows greater proportionality for Initial Airworthiness:

- Requirements shall be proportionate to the risk (operation open to public, 3rd party on ground, complexity of aircraft, persons affected ability to assess risks)

- An organisational approval is not always necessarily required if the risk is low and an organisation is able to declare its capability

- Compliance with the essential requirements for airworthiness (new Annex II) can be demonstrated without the issuance of a certificate and a declaration is possible

EASA has decided to develop a Part 21 Light with dedicated rules next to the current Part 21
Principal cornerstones of the concept

- No change in EASA or NAAs responsibilities
- A cooperative spirit between stakeholders:
  - Make Information available <-> Coordination between EASA & NAA
- Certification process corresponding with nature and risk of the product/activity
- A regulatory systems for GA that allows progressive engagement with EASA
- Possibility to choose between two different processes to certify aircraft. Either:
  - Type Cert + CoFA; or
  - RCoFA without Type Cert
- Possibility of using a declaration (subject to oversight) to demonstrate:
  - Organisational Capabilities (Design & Production)
  - Compliance of the design (with the cert basis or industry standards)
- Product oriented, using coordination between design and production
GA Aircraft Applicant
(possibly similar scope to Part M light Aeroplane < 2730 kg Rotorcraft < 1200 kg)

Risk evaluation and eligibility check

- **Current Part 21**
  - Standard Type Certificate process
    - Type Certificate
    - Certificate of Airworthiness
  - Light certified process
    - Type Certificate
    - Certificate of Airworthiness

- **New Part 21-Light**
  - Light declared process
    - No Type Certificate
    - Restricted Certificate of Airworthiness

Proposed proportionate regulatory system for GA
EASA proposed **Light Certified** process

- Applicable for conventional designs (non-novel, using acceptable standards + widely used SCs)
- Possibility for organisation to declare “DO” & “PO” capabilities, with oversight system
- Joined-up process for Design (EASA) and Production (NAA)
- Points of “engagement” with applicant:
  - Compliance Demonstration Plan & Cert. basis **approval**
  - On-site check before first prototype flight
  - On-site check and test flight before first production aircraft release
- Result: Type Certificate + Certificate of Airworthiness
0010 - Organisation holds a DOA/POA or declares its Design and Production Capability

0020 - In case a declaration is used: EASA for DO) and NAA (for PO) check eligibility and registers the declarations

0030 - Applicant submits Type Certificate application to EASA

0040 - EASA acknowledges receipt of the Type Certificate application
0050 - Applicant submits Compliance Demonstration Plan (CDP) with proposed Certification Basis

0060 - Applicant submits Design and Production expositions

0070 - EASA approves the CDP and determines the Certification Basis

0080 - EASA and NAA acknowledge receipt of the Expositions

0090 - Applicant prepares and submits compliance demonstration reports
0100 - EASA and NAA conduct Critical Design and Production Review (before first flight of prototype)

0110 - Potential findings addressed by applicant

0120 - Application for Flight Condition (FC) and Permit to Fly (PtF)

0130 - Flight Conditions established by EASA and Permit to Fly and issued by NAA
EASA proposed **Light Certified** process (4 of 5)

- **0140** - Demonstration of compliance with Certification Basis completed and reports uploaded to EASA repository
- **0150** - Applicant declares compliance with the Certification Basis
- **0160** - EASA reviews compliance demonstration
**0170** - Applicant provides declaration of conformity of first article with design data

**0180** - EASA and NAA conduct first article inspection and organisation oversight visit

**0190** - EASA issues Type Certificate and Competent Authority issues Certificate of Airworthiness
EASA proposed **Light Declared** process

- Applicable for conservative designs (non-novel, using acceptable standards)
- Possibility for organisation to declare “DO” & “PO” capabilities, with oversight system
- Joined-up Design (EASA) and Production (NAA) process
- Points of “engagement” with manufacturer:
  - Eligibility check for the declared process
  - First oversight visit before first prototype flight
  - Second oversight visit and test flight before first production aircraft release
- Result: No Type Certificate, only Restricted Certificate of Airworthiness

**EASA PART 21-Light: The Declarative Process**

<table>
<thead>
<tr>
<th>Task</th>
<th>EASA</th>
<th>“Applicant”</th>
<th>NAA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Declare Design &amp; Production capability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eligibility check &amp; Registration (start of oversight cycle)</td>
<td></td>
<td></td>
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<tr>
<td>Start product development</td>
<td></td>
<td></td>
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<tr>
<td>Compliance Demonstration Plan (CDP) (with Standard basis) submitted</td>
<td></td>
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</tr>
<tr>
<td>Design and Production exposition submitted</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prepare and upload Compliance demonstration reports to SEPIAC</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Declare Flight Conditions and flight prototype ready for flight</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>First oversight visit (NAA and EASA)</td>
<td></td>
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<tr>
<td>“Findings” addressed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Application for Permit to Fly (PTF)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Issue PTF</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Compliance demonstration completed and uploaded</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Declaration of compliance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Declare conformity of first article (with standard basis)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second oversight visit (NAA and EASA)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>When product conforms to design data, issue ECOEA</td>
<td></td>
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</tr>
</tbody>
</table>
EASA proposed **Light Declared** process (1 of 5)

- **0010** - Organisation holds DOA / POA or declares its Design and Production Capability
- **0020** - EASA and NAA check eligibility and registers the declarations (oversight cycle starts)
- **0030** - Product development begins
- **0040** - Compliance Demonstration Plan prepared and submitted along with proposed certification basis or Standards to be used
EASA proposed **Light Declared** process (2 of 5)

- **0050** - Design and Production exposition submitted to EASA and NAA
- **0060** - Compliance demonstration reports prepared and uploaded to EASA repository
- **0070** - Applicant declares Flight Conditions and safety of prototype for first flight

<table>
<thead>
<tr>
<th>EASA</th>
<th>“Applicant”</th>
<th>NAA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Product</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Organisation (Design &amp; Production)</td>
<td></td>
</tr>
</tbody>
</table>
- **0080** - First oversight visit by EASA and NAA prior to first flight
- **0090** - Potential findings addressed
- **0100** - Application for Permit to Fly (PtF) submitted
- **0110** - NAA issues Permit to Fly

### Table: EASA Proposed Light Declared Process

<table>
<thead>
<tr>
<th></th>
<th>EASA</th>
<th>“Applicant”</th>
<th>NAA</th>
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<tr>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organisation (Design &amp; Production)</td>
<td></td>
</tr>
</tbody>
</table>

- ![Diagram](image-url)
0120 - Compliance demonstration completed and supporting documentation uploaded to EASA repository

0130 - Declaration of Design Compliance (with certification basis or standard) provided and registered by EASA

0140 - Applicant submits Declaration of conformity of the first article (with standards basis)
EASA proposed **Light Declared** process (5 of 5)

- **0150** - EASA and NAA conduct the 2nd oversight visit
- **0160** - NAA issues Restricted Certificate of Airworthiness issued when conformity of the 1st article with design data is confirmed
Terms of Reference (ToRs) for Rulemaking Task (RMT.0727) which also includes other elements of implementing the NBR that affect Part 21

- Draft will be shared for consultation with EASA Advisory Bodies in the coming days
- Final ToR will be published approx. in June/July 2019

EASA has elected to utilise a direct stakeholder consultation approach for the GA proportionality elements

- First public stakeholder consultation today at AERO
- Further consultation with GA stakeholders at future dedicated events
- If you are interested in attending these events or if you have any comments please send an e-mail to:

GA-Roadmap@easa.Europa.eu
Questions?
EVTOL MARKET OVERVIEW

INNOVATION & CONSIDERATIONS

CHRISTINE DEJONG, GAMA
OBJECTIVES

- TECHNOLOGY & PREDICTIONS
- AUTOMATION: SIMPLIFIED VEHICLE OPERATIONS
- ELECTRIC PROPULSION
- INFRASTRUCTURE
- SOLUTIONS BEFORE REGULATION: STANDARDS GAPS
TECHNOLOGY & PREDICTIONS
UAM: WHAT ARE PEOPLE SAYING?

- Drone
- Last-mile parcel delivery
- On-Demand Air Mobility
- Air Metro
- Air Taxi
- Simplified Vehicle Operations
- Not piloted, operated
- Autonomous, automated
WHERE WILL IT OPERATE?
Are Flying Cars Preparing for Takeoff?

In a new BluePaper, Morgan Stanley Research says autonomous urban aircraft may no longer be the stuff of comic books. Accelerating tech advances and investment could create a $1.5 trillion market by 2040.
**AIR METRO**

- Resembles current public transit options
- Pre-determined routes, regular schedules, and set stops in high traffic areas throughout the city
- Autonomously operated

**AIR TAXI**

- Door-to-door ridesharing operation
- Customer specify desired pickup locations and drop-off destinations at rooftops
- Rides are unscheduled and on demand like ridesharing applications today.
- Autonomously operated
<table>
<thead>
<tr>
<th>Use case attribute</th>
<th>Description at end state</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle</td>
<td>2-5-passenger autonomous (unpiloted) VTOLs¹</td>
</tr>
<tr>
<td>Payload</td>
<td>~1,000 pounds</td>
</tr>
<tr>
<td>Distance</td>
<td>~10-70 miles per trip</td>
</tr>
<tr>
<td>Scheduling and routes</td>
<td>Routes are predetermined and scheduled well in advance of flight time</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>~100-300 vertiports per MSA located in high-traffic areas capable and of handling ~3-6 VTOLs at once (on average); charging stations; service stations; UTM</td>
</tr>
<tr>
<td>Technology</td>
<td>Improvements in battery technology, autonomous flight technology, detect-and-avoid (e.g., LiDAR, camera vision), electric propulsion, GPS-denied technology</td>
</tr>
<tr>
<td>Potential regulatory</td>
<td>Development of air worthiness standards, UTM, flight above people, weight and altitude restrictions, BVLOS, operator certification, identification, environmental restrictions</td>
</tr>
<tr>
<td>requirements²</td>
<td></td>
</tr>
<tr>
<td>Competing technology</td>
<td>Subway, bus, bike, rideshare, driverless cars (personal vehicle, ride-hail, or rideshare)</td>
</tr>
</tbody>
</table>
## Air Taxi

<table>
<thead>
<tr>
<th>Use case attribute</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle</td>
<td>2- to 5-passenger autonomous (unpiloted) VTOLs¹</td>
</tr>
<tr>
<td>Payload</td>
<td>~1,000 pounds</td>
</tr>
<tr>
<td>Distance</td>
<td>~10-70 miles per trip</td>
</tr>
<tr>
<td>Scheduling and routes</td>
<td>Routes are unscheduled and unplanned and are likely different each time</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Very large density of vertistops on or near buildings to create a “door-to-door” service; charging stations; service stations; UTM (unmanned traffic management)</td>
</tr>
<tr>
<td>Technology</td>
<td>Requires improved battery technology, autonomous flight, detect-and-avoid (e.g., LiDAR, camera vision), electric propulsion, and GPS-denied technology</td>
</tr>
<tr>
<td>Potential regulatory requirements²</td>
<td>Significant OEM requirements for air worthiness, BVLOS, UTM, flight above people, weight and altitude restrictions, operator certification, identification, environmental restrictions</td>
</tr>
<tr>
<td>Competing technology</td>
<td>Human-driven cars (personal vehicle, ride-hail/taxi, rideshare), driverless cars (personal vehicle, ride-hail, rideshare), commuter rail, subway, bus</td>
</tr>
</tbody>
</table>
CRAWL, WALK, RUN

Vehicle Certification, Air Metro Concepts

Vehicle Certification, Air Taxi Concepts

Air Taxi, Air Metro - ODAM Viability
KEY CHALLENGES

ADDRESS TECHNICAL, PHYSICAL, OPERATIONAL AND INTEGRATION OF HIGHLY INTERDEPENDENT SYSTEM OF SYSTEMS

- SAFETY AND SECURITY
- ECONOMICS
- TRANSPORTATION DEMAND
- REGULATION (CS23 / PART 23 OR PART 135)
- MARKET SUBSTITUTES (E.G., AUTONOMOUS DELIVERY AND TRANSPORTATION)
- PUBLIC ACCEPTANCE
AUTOMATION
LEVELS OF AUTOMATION

• AC377 Technical report: Framework for automation
• What systems are needed to automate specific pilot tasks?
• What validation and verification standards are needed for automating said tasks?
• What innovation to pilot licensing can be done with increased automation?
ELECTRIC PROPULSION

ELECTRICAL AIRCRAFT PROPULSION
THINKING OUTSIDE THE “BOX”

- Battery Safety
- Alternative Testing
- Integration of EPU into Aircraft
• Charging of Aircraft
• Storage of Energy
• Environmental Considerations (Noise)
• Impact On The Grid
• “Skyport” / “Vertiport” Design & Access
• Maintenance
SOLUTIONS
INDUSTRY CONSENSUS STANDARDS:
THE SOLUTIONS IN LIEU OF PRESCRIPTIVE REGULATION

- SVO - Unified Flight Controls F44.50
- Batteries - ESS & EPU work in F39 and F44
- Maintenance - F46 Ground Crew Personnel
- Charging/Storage - SAE E40
- Vertiports - F38.03
- Operational Considerations - F44
ADDITIONAL CONSIDERATIONS

Certification and Operations

13:30  EASA SC VTOL  Kyle Martin, GAMA
14:00  Operational Capabilities and Considerations  Ryan Naru, Uber

Technology

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QUESTIONS?

- Christine DeJong
- cdejong@gama.aero
- +1-202-236-7580
EASA SC-VTOL

Kyle Martin
Director, European Regulatory Affairs, GAMA

ASTM EVTOL Workshop, Brussels

23 April 2019
Operational

- Flights like Small Airplane / Small Rotorcraft; leisure, flight path ensuring emergency landings
- Flights into/over densely populated / congested areas
- Flights for revenue
- OPS not yet fully defined

Technical

- Multiple lift/thrust units providing distributed lift and/or thrust
- Probably limited endurance
- New common modes
Requirement phrasing

- SC objective-based, clean sheet,
- equal treatment
- High-level objectives, re-use suitable elements
  - Re-using CS-23 Amdt. 5,
  - complemented by transposed CS-27,
  - complemented by new elements as suitable.
- Concentrating on initial projects while generic as possible.
- Proportionate as possible / strict as required
Safety Objectives

- Survivability / protection of
  - crews and passengers
  - paying passengers
  - 3rd Parties (also on ground), including rescue services, maintenance, ...
- Proportionality for 'General Aviation'
  - Category BASIC
- Safety of paying passengers @ level of Commercial Air Transport
  - Category ENHANCED
- Gather experience, proceed to next level „autonomy“
EASA CONSULTATION ON DRAFT SC-VTOL

Public consultation

- 1000+ comments
- 50+ commenters

- research/academia
- associations/trade groups
- aviation authorities
- individuals
- industry – non TC holder
- industry – TC holder

- Workshop held on 27 February 2019
- EASA still processing comments
- SC Publication now expected in June 2019
KEY ELEMENTS OF THE SPECIAL CONDITION

VTOL SC construction

- VTOL safety
  - numerical objectives / DAL
  - controlled emergency landing
  - critical malfunction of thrust/lift
  - continued safe flight and landing
  - single failure
  - thrust lift unit
  - weight / pax limits
  - link to operations
Applicability – VTOL

- Aircraft
  - Lighter than air?
    - Yes
      - CS-31
    - No
      - Vertical take-off and landing capability?
        - No
          - CS-VLA
        - Yes
          - >2 lift units in VTOL?
            - No
              - CS-VLR
            - Yes
              - CS-27
              - CS-29
SC-VTOL applicability now expected to align with CS-27 (<9pax and <3175kg)
EASA will raise the bar for manned commercial operations of eVTOL to one just above CS-29 CAT ‘A’ but this will not apply to cargo variants which are not over populated areas. Significant issues include:

- ‘catastrophic’ being anytime the aircraft doesn’t reach a vertiport for landing (proposed as ‘operating cite’ previously)
- $10^{-9}$/DAL A
- Common Mode Failures
- Any single failure cannot lead to catastrophic despite reliability
The aircraft must be certified in one or both of the following categories:

1. Category Enhanced: the aircraft is capable of continued safe flight and landing after critical malfunction of thrust/lift. Aircraft intended for operations over congested areas or for Commercial Air Transport (CAT) operations of passengers must be certified in this category;

‘continued safe flight and landing’ means an aircraft is capable of continued controlled flight and landing at an operating site, possibly using emergency procedures, without requiring exceptional piloting skill or strength;

Define/remove/keep “operating site”?

| ‘Operating Site’ not defined sufficiently to provide acceptable basis for certification | Clarify definition. |
### At system level

<table>
<thead>
<tr>
<th>Maximum Passenger Seating Configuration</th>
<th>Failure Condition Classifications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minor</td>
</tr>
<tr>
<td>Category Enhanced</td>
<td>≤ 10^{-3} FDAL D</td>
</tr>
<tr>
<td>Category Basic</td>
<td></td>
</tr>
<tr>
<td>7 to 9 passengers</td>
<td>≤ 10^{-3} FDAL D</td>
</tr>
<tr>
<td>2 to 6 passengers</td>
<td>≤ 10^{-3} FDAL D</td>
</tr>
<tr>
<td>0 to 1 passenger</td>
<td>≤ 10^{-3} FDAL D</td>
</tr>
</tbody>
</table>

[Quantitative safety objectives are expressed per flight hour]
## Or, at aircraft level

<table>
<thead>
<tr>
<th>Category Enhanced</th>
<th>Minimum</th>
<th>Major</th>
<th>Hazardous</th>
<th>Catastrophic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \leq 10^{-2} )</td>
<td>( \leq 10^{-4} )</td>
<td>( \leq 10^{-6} )</td>
<td>( \leq 10^{-8} )</td>
</tr>
<tr>
<td></td>
<td>FDAL D</td>
<td>FDAL C</td>
<td>FDAL B</td>
<td>FDAL A</td>
</tr>
<tr>
<td>Category Basic</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>7 to 9 passengers</td>
<td>( \leq 10^{-2} )</td>
<td>( \leq 10^{-4} )</td>
<td>( \leq 10^{-6} )</td>
<td>( \leq 10^{-8} )</td>
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<tr>
<td></td>
<td>FDAL D</td>
<td>FDAL C</td>
<td>FDAL B</td>
<td>FDAL A</td>
</tr>
<tr>
<td>2 to 6 passengers</td>
<td>( \leq 10^{-2} )</td>
<td>( \leq 10^{-4} )</td>
<td>( \leq 10^{-6} )</td>
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<td></td>
<td>FDAL D</td>
<td>FDAL C</td>
<td>FDAL B</td>
<td>FDAL A</td>
</tr>
<tr>
<td>0 to 1 passenger</td>
<td>( \leq 10^{-2} )</td>
<td>( \leq 10^{-4} )</td>
<td>( \leq 10^{-5} )</td>
<td>( \leq 10^{-6} )</td>
</tr>
<tr>
<td></td>
<td>FDAL D</td>
<td>FDAL C</td>
<td>FDAL C</td>
<td>FDAL B</td>
</tr>
</tbody>
</table>

[Quantitative safety objectives are expressed per flight hour]
Elevate Product Timeline

2019
- May: Initial operation of proxy Uber Air service with rotorcraft, including first test of multi-modal product integrations
- June: Initial deployment of unmanned aerial vehicles (UAVs) to airspace
- Dec: Initial Skyport infrastructure locations in launch markets
  
  Elevate Summit 2019

2020
- H1: Development of Uber Air interface control documents (ICDs) and initial concept of operations (ConOps)

2021
- H2: Urban test flights in initial urban test markets

2022
- H1: Test flights in urban markets with ECS integrations

2023
- H2: Initial deployments of commercial service in 5 node networks

Uber Elevate
Scale of Operations: 2023

3 Cities

20-50 Aircraft

VFR/VMC 5-7

Flight Rules / Wx  Skyports per Market

Uber Elevate
Scale of Operations: 2024-2028

3-25
Cities

100+
Aircraft

VFR/VMC
Flight Rules / Wx

7-50
Skyports per Market
Scale of Operations: 2028+

25+ Cities

500+ Aircraft per Market

UTM/IMC

50+ Flight Rules / Wx

50+ Skyports per Market

Uber Elevate
## Network strategy to realize economic case

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Quiet</td>
<td>-15 dB</td>
<td>Noise improvement over helicopters</td>
</tr>
<tr>
<td>Fast</td>
<td>150-200 Miles per hour at cruise</td>
<td>Miles per hour at cruise</td>
</tr>
<tr>
<td>Pooled</td>
<td>4.00 / 2.67 Passenger seats / Avg. load</td>
<td>Passenger seats / Avg. load</td>
</tr>
<tr>
<td>High reliability</td>
<td>2000+ Flyable supply hours per year</td>
<td>Flyable supply hours per year</td>
</tr>
<tr>
<td>All-electric</td>
<td>~35% System cost improvement over hybrid-electric tilted duct rotor</td>
<td>System cost improvement over hybrid-electric tilted duct rotor</td>
</tr>
<tr>
<td>Autonomous</td>
<td>~20% Direct operating cost savings</td>
<td>Direct operating cost savings</td>
</tr>
<tr>
<td>At scale</td>
<td>20,000+ Vehicles deployed per year by 2032</td>
<td>Vehicles deployed per year by 2032</td>
</tr>
</tbody>
</table>

*UBER CONFIDENTIAL & PROPRIETARY*
Airspace Systems

Elevate Cloud Services
The Airspace Systems team is developing the Elevate Cloud Services (ECS) which will power all Uber aviation programs. ECS will ultimately facilitate real-time operations across aviation programs. Core responsibilities of ECS include fleet management, constraint management, airspace separation and deconfliction with other Unmanned Aircraft System Service Suppliers (USS), conformance monitoring etc.

Multimodal App Integration
Our Airspace Systems team is also leading the charge behind the multimodal trip integration for Uber Prime to facilitate Project Razor and ultimately Uber Air trips and Uber Eats deliveries. The integration will provide a seamless experience for stitching multiple modes of transportation together to move riders and things from A to B.

Skylanes and Airspace Algorithms
Our airspace team is developing algorithms for optimal separation of aircraft on ECS, dynamic skylanes which can scale and redistribute to optimally serve trip demand, and resource scheduling which can efficiently schedule aircraft based on the available resources like takeoff/landing/parking pads etc.

Communications & Navigation Infrastructure
We are also defining communication & navigation interfaces necessary for Uber Air vehicles and Uber Eats drones. This includes the development of airspace requirements for our aircraft OEM partners and the comm & nav architecture to facilitate safe nominal and off-nominal operations.
Urban air operations will be conducted in the low altitude airspace between the surface and a few thousand feet above ground level in or near densely populated urban areas. Uber assumes these operations will be conducted in all airspaces classes with the exception of A and the upper limits of E.

A key element of this concept is that UAM aircraft primarily operate under UAS Traffic Management (UTM) rules and regulations in airspace that supports UTM.

FAA will authorize those operations through performance authorizations similar to those specified for BVLOS operations in the UTM Conops.

UAM Operations within the authorized area of operation for UTM are managed by one or more UAS Service Suppliers (USS) under the FAA’s regulatory authority, operations outside are managed by the FAA.
Within the UTM airspace Uber (and possibly others) use the Dynamic Skylane Networks to organize the flow of traffic.

Aircraft on the Uber network will be operating within the dynamic skylane network unless required for safety or during certain off-nominal operations. In order to optimize throughput Uber requires a highly precise navigation performance in all dimensions from our vehicles with cross track errors and flight path errors of less than 20 ft.

Each aircraft will be assigned a detailed 4D trajectory from the departure charging pad to the landing charging pad before it moves from the departure pad.

Aircraft state will be constantly monitored against the planned trajectory by the ECS and necessary adjustments will be made.

ECS will update the trajectories accordingly or resequence as needed to keep the multi-modal plan up to date.
The Elevate Cloud Services (ECS) encompass the core of the system capabilities. They are responsible for managing the aircraft on the Uber network, providing situation awareness and interfaces for the people in the system and coordinating with all external airspace entities and non-airspace related Uber functions.

ECS is designed as highly automated system connecting operations in the global network operations center, local operations control centers, skyport terminals and in the vehicles themselves.

Aircraft that operate under UTM and ATM rules must be equipped for both types of operations and need to follow the respective procedures for each operating paradigm. Even if there is no intent to operate under ATM rules, aircraft will still be dual equipped to deal with blunders or other reasons for entering ATM controlled airspace.
Airspace Integration

- Uber will initially operate under visual flight rules (VFR) and the pilot will monitor the airspace close to the aircraft for other traffic.

- ECS will monitor for potential traffic conflicts on a strategic (volume or trajectory-based level) as well as on a tactical level as much as possible and initiate maneuver actions and pilot alerts. ECS will also provide situation awareness to the pilots, feeding relevant information into a pilot app designed to support the pilot during operations and to relay information between ECS and the aircraft.

- Eventually, more automated onboard separation systems will be adapted from detect and avoid (DAA) systems. On-board automation will support the pilot in tactical traffic avoidance and play an increasing role once proven reliable and trustworthy.
Multimodal Operations

Uber Air will seamlessly string a ground transportation segment to a Skyport, to a pooled flight with three other passengers, and finally a just-in-time ground transportation leg to a rider’s final destination.

These operations merge tested pooling and just-in-time services from existing Uber services with system-wide safety management frameworks characteristic of aviation operations today.
Variable Fidelity Aircraft Design Tools
The Vehicles team is developing variable fidelity aircraft design tools to enable rapid analysis of electric vertical takeoff and landing aircraft. Variable fidelity aerodynamics and aeroacoustics is at the heart of the challenge of designing Uber Air aircraft and a discriminator for market viability.

eVTOL Concept Development
eVTOL common reference models (eCRMs) are being developed using the design tools developed by the vehicles team to showcase how eVTOL may be designed to meet Elevate requirements and utilize enabling eVTOL technologies.

Technology Investment
Uber is developing enabling technologies like stacked co-rotating prop-rotors together with UT Austin and the Army Research Lab in support of low noise, high thrust propulsion. This technology may enable lift+cruise concepts to size properly for the Elevate network.

Comparative Assessment
Comparative assessments of eVTOL are critical to understanding how the industry is looking at the market and can validate the tools we are standing up. This allows us to look critically at our business case to provide the best possible product for our Uber Air riders.
Basic Operational Requirements

- Operations will be conducted with a pilot in command that hold at least a commercial pilot certificate with appropriate category and class ratings and, if required, an appropriate type rating or endorsement for the aircraft.

- Skyports will be designed to serve <7,000 pound aircraft with a 50’ foot controlling dimension and satisfy airspace, sizing and separation requirements defined in AC 150/5390-2C. Efforts within ASTM and NFPA will further define unique requirements and additions/exceptions to existing guidance to support the employment and charging operations of eVTOL aircraft.

- The physical location of skyports will be selected based on consumer demand, levels of existing ambient noise, and will work to complement existing transportation systems, and take into account operational impact on the community.
Basic Operational Requirements

- Operations will be conducted on all days of the week, during day and night hours, under VMC conditions, and will be constrained by local operating restrictions related to noise and environmental impact.

- All ground operations, aircraft and passenger handling will be covered by the SMS and all operations will be conducted in accordance with ICAO SARPS and satisfy IS-BAH and IS-BAO standards.

- Security systems at the skyport will ensure that all riders are properly identified and screened against Flight Secure.

- Operations are expected to be conducted under Part 135, requiring a series of exemptions, deviations and additions to the existing ruleset to effectively manage on-demand urban aviation with eVTOL aircraft.
Consensus Standards Development

Update of Current Activity

Batteries (ESS)  
Motors (EPU)

Tom Gunnarson  
Kitty Hawk Corp

eVTOL International Standards Workshop  
January 30, 2018
Consensus standards –

Serve as a means of compliance for a design’s approval/certification

- Overview of ASTM F39.05 standard for “Energy Storage Systems” used for propulsion (includes Li-Ion batteries)

- Update on ASTM F39.05 standard for design of “Electric Propulsion Units”
Why create another “battery” standard?

- RTCA DO-311A doesn’t work
  - Stuck on “coffin” box for containment leading to unsafe tests and unacceptable weight penalty
- Use performance-based requirement language
- Incorporate safety concepts from other industries
ESS - Referenced Documents

- **RTCA DO-311A** “Minimum Operational Performance Standards for Rechargeable Lithium Battery Systems.”


- **RTCA DO-160** “Environmental Conditions and Test Procedures for Airborne Equipment.”

- **SAE J1739** “Potential Failure Mode and Effects Analysis in Design (Design FMEA), Potential Failure Mode and Effects Analysis in Manufacturing and Assembly Processes (Process FMEA).”

This standard addresses ESS used to power aircraft propulsion which are typically of high capacity in contrast to batteries for secondary systems or auxiliary power.

This standard adjusts requirements based on ESS integration location to maintain an equivalent level of safety while affording the option of lighter weight containment for lower risk installations.
This ASTM Standard should assure that the safe installation of an ESS such that any single failure will not result in fire, explosion, or a high voltage hazard.

This Standard includes tests that simulate “normal” conditions and “off-normal” conditions that, although infrequent, may occur during service life.

Pass/ fail criteria are assigned to each test.
Categories of ESS integration

Three categories of ESS are defined based on airframe integration; the minimum safety criteria vary according to category:

- **ESS located within the primary pressure vessel**, or, for an unpressurized aircraft, within, or immediately adjacent to the cabin such that gases vented by the ESS could enter the passenger compartment.

- **ESS isolated from occupants but in proximity to aircraft primary structure**, for example in a wing bay similar to a conventional fuel tank.

- **ESS isolated from occupants and primary structure**, e.g. behind a firewall or in an external pod.
Sec 10 - Testing and qualification requirements (CS 23.2430, CS 23.2515)

- Maximum sustained discharge rate at high temperature
- Short circuit test with protection enabled
- Single point over-discharge protection failure; charge test with protection enabled
- Overcharge test with protection enabled
Sec 10 Testing and qualification requirements (CS 23.2430, CS 23.2515)

- Single Point Overcharge Protection System Failure
- Single point thermal control system failure
- Protection against high voltage exposure
- Vibration
- Single cell abuse testing with pack installation
ESS-Related Standards

- ASTM F3235 - Standard Specification for Electrical Storage Batteries in Small Aircraft
  - WK65629 Post-Impact Conditions
  - WK66028 Applicability to airplanes with distributed propulsion
Current Status & Challenges

- Currently on Draft No 7
- Looking to publish standard by middle of 2019
- Solving the “Coffin Box”
- Not very many aviation propulsion ESS designers/manufacturers
- Little operational data
Current Status & Challenges

• New areas to consider:
  • New Protection Technologies
  • Temperature Testing Envelope
  • Battery Fire Testing – Multiple Cells vs Entire Battery
  • Drop Testing
  • Over/Undercharging Stringency
  • Recognition of New Cell Types & Mfg. Controls
  • Dendrite Considerations
  • Plating Considerations
Development of a standard for the design of “Electric Propulsion Units” under ASTM WK47374

Scope

• Minimum requirements for the design of Electric Propulsion Units (EPU) for General Aviation aircraft.

• Distributed propulsion is not excluded. This standard is designed around an EPU. The number of EPUs does not matter unless a common control/inverter is used.

• This standard does not apply to combustion motors, gearboxes, variable pitch propellers, liquid cooling aspects or fuel cell power sources.
WK47374 - EPU

- **Motor**—A machine that converts electrical power via direct or alternating current into rotational mechanical power.

- **Motor Controller**—A device or devices that serves to govern the operation of an electric motor. It could include a manual or automatic means for powering on or stopping the motor, selecting direction of rotation, selecting and regulating motor speeds, regulating or limiting the torque and protecting against overloads and faults.

- **Electric Propulsion Unit (EPU)**—The EPU shall as a minimum consist of the electric motor, associated electronic controllers, disconnects and wiring and monitoring gauges and meters.

- **Thruster**—A device such as propeller, rotor or fan for translating mechanical energy to thrust.
Other EPU MoC Sources

- EASA Special Conditions
- ASTM F2840 (LSA)
- SAE
- JARUS
Current Status & Challenges

- F3338-18 *Standard Specification for Design of Electric Propulsion Units for General Aviation Aircraft* published late 2018

- Starting new tasks –
  - WK67455 Regulatory content extraction and incorporation of suggested improvements
  - WK66523 Addition of liquid cooling means of compliance

- Little to no directly applicable service history
INADVERTENT ICING ENCOUNTER

- **Flight into Known Icing**
- **IFR Inadvertent**
- **VFR Inadvertent**
PROPULSION

- **Electric Motors**
  - Airflow for Cooling Systems
  - Conducting Paths
  - Ice-Lock

- **Props**
  - Balance
  - Thrust/Lift
  - Low RPM Shed
  - Ingestion
SENSORS

- Pitot/Static
- AoA
- Visual Systems
- Temp Sensors
- Detect & Avoid?
- Other?
FLIGHT/THRUST CONTROL

• Control Margins/Rates
• Deteriorated Performance
• Abnormal Responses
METHODS

• Heating
• Fluids
• Surfaces/Coatings
• Impulse
• Hybrids
FUTURE REVISIONS

• eVTOL Icing Environment
  • Normal Icing
  • Extreme Icing
• FIKI for eVTOL
Challenges for Vehicle Safety in Autonomous electric Vertical Take-off and Landing (eVTOL) Vehicles

ASTM F44 Workshop on Means of Compliance for VTOL Certification
April 23, 2019
Nicholas Borer
Aeronautic Systems Analysis Branch
NASA Langley Research Center

Presenting on behalf of
Justin Littell Ph.D.
Structural Dynamics Branch
NASA Langley Research Center
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)
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

• Unfortunately, it is inevitable that a crash will happen. When it does, there needs to be mitigation available. Currently, it’s only a parachute (called a Ballistic Recovery System).
Accidents by phases of flight

- General Aviation
- Uber mission profile

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” – CAPS
  - 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
Uber mission profile detail

- 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?
Current Vehicles (not a complete list)

A3 Vahana
- Aluminum skid gear
  - Image from https://vahana.aero

Terrafugia
- Road legal and LSA certified (but not a VTOL vehicle)
  - Image from Terrafugia

Ehang 184
- Rigid seat and rigid gear
  - Image from www.ehang.com

AirspaceX MOBi
- Can these be crushable?
  - Image from airspacex.com
Crash Mitigation Features Available on Current Aircraft

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

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

2 – Energy Absorbing Subfloor Results
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

---


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.)

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)


5 – NASA Developed DEA

- 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
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)
• 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

- 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 ?
Vehicle Certification – The “how”

- Performance based standards – Part 23 (amendment 64) – commonly called the “Part 23 rewrite”
  - High level requirements, no technical solutions prescribed
  - Technical solutions that can 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
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

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


*https://www.ntsb.gov/investigations/data/Pages/AviationDataStats2014.aspx
AnnualReview_2014_Public_2_Part121_20160902.xls
Current Committee / Working Groups

• Uber Elevate (2nd year)
  – Attendees:
    • Uber, OEMs, Policymakers (incl. NASA), Suppliers, Venture Capitalists (VCs)
  – Subject matter:
    • 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

• 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
UAM eVTOL
Emergency Systems Certification Credit

April 23, 2019

Uber Elevate
Uber strongly believes there should be equivalency between Part 23 safety standards and those applicable to VTOLs.

- Part 23 TLS and FDAL targets are appropriate relative to pilot error rates and intended for urban, commercial ops
- eVTOLs have additional safety features that reduce common loss of control, disorientation, and weather related emergencies

JARUS AMC RPAS.1309 Group’s logic asserts that higher aircraft complexity require additional certification rigor.

- Majority of eVTOLs require fly-by-wire solutions and fall under JARUS Complexity Level II - increases TLS and FDAL by one magnitude. This is based on eVTOL’s extensive use of software and Airborne Electronic Hardware

### Part 23 Amdt. 64, ASTM F3230-17

<table>
<thead>
<tr>
<th>Assessment Level</th>
<th>Persons</th>
<th>Catastrophic failure rate [FH]</th>
<th>Complexity Level II (FBW) [Cat events/FH]</th>
<th>Complexity Level III (Autonomy) [Cat events/FH]</th>
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<tbody>
<tr>
<td>Assessment Level I</td>
<td>1 reciprocating</td>
<td>2-6 +crew</td>
<td>$1 \times 10^{-6}$ FDAL C</td>
<td>$1 \times 10^{-7}$ FDAL B</td>
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<tr>
<td>Assessment Level II</td>
<td>&gt;=2 reciprocating or turbine</td>
<td>2-6 +crew</td>
<td>$1 \times 10^{-7}$ FDAL C</td>
<td>$1 \times 10^{-8}$ FDAL B</td>
</tr>
<tr>
<td>Assessment Level III</td>
<td>&gt;=1 reciprocating or turbine</td>
<td>7-9 +crew</td>
<td>$1 \times 10^{-8}$ FDAL B</td>
<td>$1 \times 10^{-9}$ FDAL A</td>
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<tr>
<td>Assessment Levels IV</td>
<td>&gt;=1 reciprocating or turbine</td>
<td>10-19 +crew</td>
<td>$1 \times 10^{-9}$ FDAL A</td>
<td>$1 \times 10^{-9}$ FDAL A</td>
</tr>
</tbody>
</table>

Sources:
- FAA 14 CFR 23.2005 (Amdt. 64)
- AC 23.1309-1E - System Safety Analysis and Assessment for Part 23 Airplanes
- ASTM F3230-17 Standard Practice for Safety Assessment of Systems and Equipment in Small Aircraft
- JARUS Working Group 6 - Safety & Risk Assessment Scoping Paper to AMC RPAS.1309 Issue 2 Safety Assessment of Remotely Piloted Aircraft Systems
- Uber eVTOLs
Lack of Safety Incentives

Problem Statement

- Existing airworthiness regulations encourage certifying to minimum safety standards and de-incentivize use of non-traditional emergency mitigation systems.
- Aircraft certification process is very cost intensive and does not do a good job at addressing human errors that result in emergencies.
- No “magic bullet” safety system exists that prevents all possible risks. Operators prefer a “safety layer” approach that allows for independent systems that mitigate accident consequences.

Recommendation

Industry and regulatory bodies explore incentivizing use of the following emergency mitigation systems:

- Airframe Emergency Parachutes (AEPs)
- Retrorocket Soft Landing Systems
- Smart Energy Absorbing Seats
- Additional Energy Absorbing Structure

Impact Velocity Reduction
Impact Energy Absorption

Uber Elevate
VTOL Certification Strategy

Majority of VTOL OEMs are designing aircraft for redundancy where no single component failure is permitted to result in catastrophic. In practice, this means any rotor, tilting or energy providing function can fail and allow VTOL landing.

eVTOL autorotative capability is decreased relative to rotorcraft, however, there are no critical components required for maintaining control. In addition, VTOLs can use glide capability as emergency mitigation strategy.
Airframe Emergency Parachutes

Description

Whole aircraft parachute systems designed with active, rapid inflation mechanisms. AEPs have potential to greatly reduce bystander risk due to low ground impact velocity.

Required features:
- Capable of controlling opening to open rapidly at low speed but open slowly at high speed
- Must be integrated with flight control system
- Require separation mechanism at touchdown to prevent dragging
- Must sound alarm to minimize bystander injury

Parachute Types

Round
- Simplest design, extraction system
- Existing GA applications, highest tech maturity
- Not easily steerable

Parafoil
- Forward velocity inflates airfoil-shaped canopy
- Smaller surface area allows rapid inflation
- Easily Steerable

Cluster Parachutes
- Multiple smaller parachutes allow for lower dynamic pressure, rapid opening
- Performance improves for heavier aircraft
- Most complex opening system

Use Cases

AEPs are design for minimum reliance on other systems
- Pilot loss of control
- Pilot disorientation
- Pilot incapacitation
- Mechanical failures that overcome redundancy
- Mid-air collision
- Icing
- Energy exhaustion
AEP Sizing Assumptions

Parachute descent rate likely between 25-30 ft/s (similar to Part 23, ASTM F3083, and Part 27.562 impact velocities)

Part 23 and 27 seat certification differences are primarily measured G loads (static and dynamic)

If Part 27 seat G loads are required, stroking seats will be required alongside parachutes

Sources:
ASTM F3083 Standard Specification for Emergency Conditions, Occupant Safety and Accommodations
AEP Performance

Parachutes will work above 250’ AGL at zero initial forward speed using rapid opening systems.

This is defined as the minimum altitude aircraft will deploy parachute and be arrested to design sink rate. Based on expected rapid extraction and a nominal Uber Air aircraft weight, parachutes will be effective during operations will be approximately 200’ AGL during transition at forward speed.

Emergencies after transition will result in a ground impact will be below 20mph

Uber Elevate

AEPs will provide catastrophic mitigation for >90% of average ODM mission
Future Focus: Retrorocket Soft Landing

Use of solid propulsion to slow aircraft before ground impact. Potentially can become a true zero-zero solution similar to Mars Spirit lander, Soyuz capsule systems.

- Requires integration with ground sensing altimeters and flight control system
- Likely will require smaller parachute to decrease amount energy needed to slow from cruise speed and altitude
- Possible to use thermally stable flammable solids currently approved for AEP systems.
- High reliability of systems can be achieved with redundant igniters
- Can be designed to minimize risk of burning area around aircraft
- Low TRL state, likely will not be available for initial launch of urban mobility aircraft

Source: Cruz, Juan R., “Parachutes for Planetary Entry Systems,” NASA Langley Research Center, Sep 2005
Energy Absorption

Seats
Current seat designs are optimized for reduced system weight and 170lbs Anthropomorphic Test Dummy. Additional safety features increase certification risk under current regulatory structure.

Suggest that there is incentive to adding safety features:
- Automatic detecting and adjustment of stroking mechanism for different weights
- Airbags added to seat or surrounding cabin
- Inertia-reels and pretensioners
- Load limiters into belt path
- Improved methods for seat belt release

Seats design safety philosophy should embrace wide passenger demographic, minimize blunt force trauma, and allow egress in case of fire

Structure
Suggest that there is incentive to adding safety features:
- Increased crushable volume in aircraft floor
- Credit given for energy absorbing landing gear that exceeds Part 23 or Part 27 requirements
- Deployable energy absorbing structure similar to NASA Langley MD-500 tests

Sources:
Point System Recommendation

Because additional emergency mitigation systems increase aircraft cost, certification risk, and empty weight, they are unlikely to find their way on aircraft. Aircraft OEMs are not incentivized with current airworthiness regulation to exceed minimum safety standards.

Recommend that regulatory agencies create a point system that allow for aircraft to meet existing Part 23 TLS and FDAL rather than JARUS recommendation. Mitigation systems should not be double-counted to calculate FTA analyses but should be considered as supplemental systems.

Limiting factors:
- VTOL TLS/FDAL is never below equivalent part 23 aircraft
- Mitigation system reliability standards must be created and performance must be validated
- Mitigation system effectiveness must be verified
- Must be aligned with VTOL loss of thrust standards

Example Case

- Existing P23 II +FBW
- JARUS-based complexity factor
- +AEP, Smart seats, better energy absorption

Reducing costs related TLS/FDAL certification and maintenance offsets emergency mitigation system cost and additional weight
6(c) At the time of writing no manned Part-23 aircraft has been certificated with complex fly-by-wire flight control systems. If such an application were to be made it would be reasonable for the authorities to raise the number of potential catastrophic failure conditions by 1 order of magnitude. While it is accepted that Complexity Level I RPAS will have less complex systems, this cannot be said for Complexity Level II RPAS. It is therefore reasonable to assume that Complexity Level II RPAS containing complex airborne electronic hardware and software may have an order of magnitude of one hundred potential failure conditions regardless of the category of RPAS.
Indirect Control Systems Specification Development

WK61549
Indirect Control Systems – Why?

• The option to install and certify Indirect Control Systems (aka “fly-by-wire” systems) onto Part 23 aircraft has recently become of great interest to the GA community

• The evolution to the next level of GA aircraft relies on the development of this capability
  • Simplified Training Requirements
  • Improved Operational Safety
    • Envelope Protection Capabilities
    • Enhanced Autopilot/Autonav Capabilities
  • Simplified Vehicle Operations
    • Auto-T/O and Auto-Land Capabilities
    • Semi-autonomous Flight Path Execution
    • Full Point-to-Point Autonomy (one day...)
Current State

• Indirect Control Systems in Part 23 aircraft are all but unheard of
  • No regulatory basis for their acceptance
  • Systems are quite common in Part 25, but primarily enacted through Special Conditions

• Our approach in developing the specification thus far has been to glean information from many different sources of possible requirements (existing industry standards, Special Conditions, white papers, etc.) and combine them into a specification specifically tailored for Part 23 aircraft
Assessment of Need (Write or Revise?)

- To determine a path forward, we started by reviewing MIL-DTL-9490E
  - This is a public-access military standard
  - It is currently inactive, but continues to serve as a good reference

- The currently active descendant of MIL-DTL-9490E is SAE-AS94900
  - SAE-AS94900 was created by essentially copying MIL-DTL-9490E as a starting point
  - SAE provided me a perusal-copy of AS94900 so I could understand its contents and potential usability for Part 23, rather than creating “yet another” standard
    - The original source-document content has been modified over time to address new concerns
    - SAE-AS94900 is currently the “go-to” standard for Part 25 and military aircraft; however, it needed to be evaluated for applicability to Part 23
Results

• After assessing the “concatenated” contents of MIL-DTL-9490E and AS94900, we found:
  • Of the 494 sections, there were 445 sections that actually contained “technical” information
  • Of those 445 sections, 265 (63%) contained information that would not be relevant to a standard for Part 23 aircraft
    • Redundant to existing information
      • 10 definitions
      • 230 general design guidelines
      • 16 system safety considerations
    • Not applicable to Part 23 aircraft
      • 7 military-specific
      • 2 rotor-craft specific
New Document Initiation

• ASTM decided to have F44.50 move forward with compiling a new document specifically tailored to Part 23
  • The existing standards were simply too “heavy” to modify for our needs
    • Existing focus is primarily Big Iron and/or military usage
    • Over 60% of the information is redundant or not applicable to Part 23

• We started by culling through MIL-DTL-9490E, removing the redundant and non-applicable sections
  • MIL-DTL-9490E seems to originally have been written as a stand-alone document, covering many aspects (general design practices, system safety approaches, etc.) that are redundant to the existing Part 23 library
  • The remaining content provided a basis for focusing conversations on additional development needs

• As we started refining the remaining content, we rapidly discovered additional redundancies, additional holes, and additional needs for clarity
Lessons Learned (to date)

• As we started refining the remaining content, we rapidly discovered additional opportunities to improve redundancies, holes, and clarity.

• The first question was one of scope – what should be included in the new document and (perhaps more importantly) what should not:
  • Remember, the source-document was an “all things to everyone” document, and that is explicitly not our goal.
  • We determined that we are focused on the “output” aspects of the control system, to the exclusion of the “input”:
    • Autopilots, human pilots, stability augmentation systems – these are all systems that deal with determining “input” to the aircraft.
    • They exist today, interfacing with traditional mechanically-linked “output” systems.
  • The new ICS standard deals with that portion of the aircraft system(s) responsible for the “post-processing” of the commands provided by these “input” systems:
    • The ICS essentially determines how to affect the aircraft configuration to safely achieve the desired state called for the input commands.
  • We also dropped the word “Flight”, to recognize that other systems (e.g. ground steering) can also be indirectly controlled and therefore covered by this standard.
Lessons Learned (to date)

• The second challenge was determining a method of describing the requirements and limitations for an ICS that was agnostic of the particular design approach taken – and therefore of its capabilities, vulnerabilities, architecture, failure modes, etc.
  • Traditional Part 23 systems use cables and pulleys – which are boringly predictable
  • The ICS designs of tomorrow are not as predictable and well-behaved... and may have different “operational modes”, none of which truly classify as “failure conditions”
• We have therefore retained the approach of the previous documents, defining a spectrum of operational performance rather than discrete failure modes or events
  • The Operational States are quantized in order in order of “operational degradation” to align with the current concepts of Minor, Major, etc.
  • The likelihood of entering an operational quanta (which is completely design-agnostic) can then be mapped into our existing systems for evaluating failure conditions
Lessons Learned (to date)

• The third (and ongoing) question was (and is) one of content – what topics should be covered in the new document and what should not
  • We have landed on an approach whereby a key assessment of whether to retain content involves whether it is already adequately covered by other existing language in the Part 23 library
    • If the content is largely redundant to the intent of existing language, it is removed
    • If the content is unique to ICS considerations, or if it is clarifying of the existing language in an ICS context, then it is retained
  • We have also been incorporating the content of related Special Conditions as they have been identified as relevant during discussions
Next Steps

• We are currently working through our first set of ballot-collected responses.
  • This is proving invaluable to help us further focus and refine the document content
  • The result of this will be a thoroughly-scrubbed “base document” upon which to build

• Once our “base document” is stabilized, the plan is to then review other sources that may provide information to fully flesh-out the document.
  • One key piece of anticipated information is a set of “MTE--esque” maneuvers (being developed under the Grand Challenge initiative) that could possibly be used to demonstrate aircraft control abilities
  • The idea is that these maneuvers would be agnostic of the system executing them
    • If a human pilot in a traditionally-controlled aircraft can perform them, WIN!
    • If a fully-automated synthetic pilot in an indirectly-controlled aircraft can perform them, WIN!
  • This concept is still under development, but we are very interested in building upon that initiative
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  • 8.4 – Indirect Control System Software Documentation
Discussion / Actions

• If you are interested in being involved in the effort, please contact me for an invitation to the collaboration area.
  • dave@terrafugia.com