SORA
Risk Assessment for unmanned airborne Mobility

Markus Farner, Manager Innovation and Advanced Technologies

Workshop Intelligent and Autonomous Technologies in Aeronautics
Winterthur, 12. September 2017
Content

• Development in Switzerland

• Safety in Aviation

• New Approach for new emerging Challenges
  ❖ Risk based Approach
  ❖ Change in Culture
  ❖ Tool for Risk Assessment
History,
24. April 2010
Any aircraft is normally not a danger by itself. It is the operation in which the aircraft takes part, which can create a risk.

- Risk for passengers on board the aircraft
- Risk for people on ground or in other aircrafts in case a collision
- Risk for critical infrastructure
- A crash can be acceptable as long no people are on board
Basics - Safety of an Operation in Aviation
Traditional Safety in manned Aviation

An Operation is sufficiently safe to accept the risk when:

✓ The Organisation behind the Operation is approved to accepted standards
✓ They use a crew, which is approved to accepted standards
✓ They use aircrafts which design, production & maintenance as well as the organisations behind are approved to accepted standards

The Operation is not sufficiently safe and therefore to prohibit
Safety in non-traditional Aviation

1. Operation is **sufficiently safe** to accept the risk.
   - All is approved to accepted standards
   - Within a legal framework which provides sufficient safety

2. Operation is **not sufficiently safe** and therefore to prohibit

3. Operation is **not sufficiently safe** and additional safety barriers are required to accept the risk.
Where we are?
And where we go?

PATS
Personal Airborn
Transportation System
Traditionally open Questions

• Which are the rules to fly? And where to fly?
• What are the rules for the design?
• What about the production?
• Design, Production, Maintenance people? License?
• Certification?
• Certificates?
New Approach

Drones/PATS
### Categories of harm – likelihood estimation

<table>
<thead>
<tr>
<th>Likelihood of Fatal injuries to third parties on ground</th>
<th>=</th>
<th>Likelihood of having UAS operation out-of-control</th>
<th>X</th>
<th>Likelihood of person struck by the UA if the operation is out of control</th>
<th>X</th>
<th>Likelihood that, if struck, person is killed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Likelihood of Fatal injuries to third parties in the air</td>
<td>=</td>
<td>Likelihood of having UAS operation out-of-control</td>
<td>X</td>
<td>Likelihood of other A/C struck by the UA if the operation is out of control</td>
<td>X</td>
<td>Likelihood that, if struck, the other A/C cannot continue a safe flight and landing</td>
</tr>
<tr>
<td>Likelihood of Damage to critical infrastructure</td>
<td>=</td>
<td>Likelihood of having UAS operation out-of-control</td>
<td>X</td>
<td>Likelihood of critical infrastructure struck by the UA if the operation is out of control</td>
<td>X</td>
<td>Likelihood that, if struck, the critical infrastructure is damaged</td>
</tr>
<tr>
<td>Likelihood of Fatal injuries to passenger</td>
<td>=</td>
<td>Likelihood of having PATS operation out-of-control</td>
<td>X</td>
<td>Likelihood of a crash of the PATS after operation is out-of-control</td>
<td>X</td>
<td>Likelihood that, if crashed, passenger(s) are killed</td>
</tr>
</tbody>
</table>
Responsibility?
Who to protect?

• Protection of the people on ground is included in the protection of the people on-board the aircraft.

• Protection of the people on-bord the PATS is included in the protection of 3d parties on ground and in the air.
One size fits all?
Holistic Risk Model (HRM)

UAS Operation out of Control

10^{-6} = \text{Likelihood of having UAS operation out-of-control} \times \text{Likelihood of person struck by the UAS} \times \text{Likelihood that, if struck, person is killed}
Harm Barriers Principles

Reduce the likelihood of fatalities or injuries

- Reduce the effects of the impact

- Reduction of the number of persons exposed to the risk
Harm & Harm Barriers

JARUS WG-6 - UAS operation

UAS operation is out of control

Contingency procedures are defined, validated and adhered to

Crew training is adequate to cope with the situation

UAS design features mitigate the severity of mid-air collision (e.g. frangible, very light)

UAS is equipped with capability to avoid collisions

The UAS is equipped with design features that aid visual acquisition and/or detection by other A/C

Specific operation profile designed with consideration to critical infrastructure

Damage to critical infrastructure

UAS equipped with obstacle avoidance capability

Effects of ground impact are reduced

Containment in place and effective (tether, geo-fencing, etc.)

Effects of ground impact are reduced (e.g. Emergency Parachute)

Crew training is adequate to cope with the situation

Contingency procedures are defined, validated and adhered to

Fatal injuries to third parties on the ground

Fatal injuries to third parties in the air (Mid air collision with manned aircraft)

SORA • Risk Assessment for unmanned airborne Mobility
Markus Farner
# Ground Risk Assessment

<table>
<thead>
<tr>
<th>Intrinsic UAS Ground Risk Class</th>
<th>1 m / approx. 3 ft</th>
<th>3 m / approx. 10 ft</th>
<th>8 m / approx. 25 ft</th>
<th>&gt;8 m / approx. 25 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max UAS characteristics dimension</td>
<td>&lt; 700 J (approx. 529 Ft Lb)</td>
<td>&lt; 34 KJ (approx. 25000 Ft Lb)</td>
<td>&lt; 1084 KJ (approx. 800000 Ft Lb)</td>
<td>&gt; 1084 KJ (approx. 800000 Ft Lb)</td>
</tr>
<tr>
<td>Typical kinetic energy expected</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Operational scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>VLOS over controlled area, located inside a sparsely populated environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BVLOS over sparsely populated environment (over-flown areas uniformly inhabited)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VLOS over controlled area, located inside a populated environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VLOS over populated environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BVLOS over controlled area, located inside a populated environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BVLOS over populated environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VLOS over gathering of people</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BVLOS over gathering of people</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Harm barriers out of SORA

<table>
<thead>
<tr>
<th>Harm barriers for GRC adaptation</th>
<th>Robustness</th>
</tr>
</thead>
<tbody>
<tr>
<td>An Emergency Response Plan (ERP) is in place, operator validated and effective</td>
<td>1</td>
</tr>
<tr>
<td>Effects of ground impact are reduced(^d) (e.g. emergency parachute, shelter)</td>
<td>0</td>
</tr>
<tr>
<td>Technical containment in place and effective(^e) (e.g. tether)</td>
<td>0</td>
</tr>
</tbody>
</table>

\(^d\) Reduced

\(^e\) Effective
### Specific Assurance and Integrity Levels (SAIL)

<table>
<thead>
<tr>
<th>Lethality</th>
<th>SAIL</th>
<th>UAS Ground Risk Class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>HIGH</td>
<td>VI</td>
<td>VI</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>VI</td>
<td>V</td>
</tr>
<tr>
<td>LOW</td>
<td>V</td>
<td>IV</td>
</tr>
</tbody>
</table>

This table illustrates the specific assurance and integrity levels (SAIL) for UAS ground risk class, categorizing them into three levels: HIGH, AVERAGE, and LOW, each with different risk classes assigned.
Threat & Threat Barriers
## Threat barriers out of SORA

<table>
<thead>
<tr>
<th>Technical issue with the UAS</th>
<th>SAIL</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ensure the operator is competent and/or proven (e.g. ROC)</td>
<td>O</td>
<td>L</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>UAS manufactured by competent and/or proven entity (e.g. industry standards)</td>
<td>O</td>
<td>O</td>
<td>L</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>UAS maintained by competent and/or proven entity (e.g. industry standards)</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>UAS developed to authority recognized design standards (e.g. industry standards)</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>L</td>
<td>M</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>UAS is designed considering system safety and reliability</td>
<td>O</td>
<td>O</td>
<td>L</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>Inspection of the UAS (product inspection) to ensure consistency to the ConOps</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>Operational procedures are defined, validated and adhered to</td>
<td>L</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>Remote crew trained and current and able to control the abnormal situation</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>Safe recovery from technical issue</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td></td>
</tr>
</tbody>
</table>
Holistic Risk Model (HRM)

Level of Robustness

Why this happens?

- Technical issue with the UAS
- Human Error
- Adverse operating conditions
- Datalink deterioration
- Deterioration of external systems supporting UAS operation beyond the control of the UAS operator (e.g., GPS)

UAS operation is out of control

- JARUS WG-6 - UAS operation
- Mid-air collision with manned aircraft

What happens if?

- Fatal injuries to third parties on the ground
- Fatal injuries to third parties in the air (Mid-air collision with manned aircraft)
- Damage to critical infrastructure

Level of Robustness

SORA • Risk Assessment for unmanned airborne Mobility
Markus Farner
Air Risk Model

Air Risk

Nominal
- Ambient risk
- External mitigations
- DAA

Off-nominal (loss of control of operation)
- Ambient risk
- Likelihood of mishap
- Protection from mishap
Target Level of Safety

Internal Mitigations
Residual Risk

External Mitigations

Air-Risk Class
Airspace Threat
Qualitative Approach to Air Risk

<table>
<thead>
<tr>
<th>Risk Factors</th>
<th>Operational Factors</th>
<th>Air-Risk Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximity</td>
<td>Flight rules</td>
<td></td>
</tr>
<tr>
<td>Geometrics</td>
<td>Altitude</td>
<td></td>
</tr>
<tr>
<td>Dynamics</td>
<td>Airspace Type</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Underlying Population</td>
<td></td>
</tr>
</tbody>
</table>

\[ X \]
Proximity, Geometry, Dynamics
Proximity, Geometry, Dynamics
Proximity, Geometry, Dynamics
Proximity, Geometry, Dynamics
Qualitative Approach to Air Risk

1. **Proximity** - The more aircraft in the airspace, the higher the rate of proximity, the greater the risk of collision.

2. **Geometry** - An airspace which sets or allows aircraft on collision courses increases risk of collision.

3. **Dynamics** - The faster the speed of the aircraft in the airspace the higher the rate of proximity, the greater the risk of collision.
Where to expect Aircrafts
Airspace Encounter Categories (AEC)

• Close to an Airport
• Within a TMZ
• Over Urban Areas
• Over Rural Areas
• South pole / North pole
• Controlled Airspace
• Uncontrolled Airspace
• Above Minimum Flight Altitude
• Below Minimum Flight Altitude
• Stratosphere
Airspace Encounter Categories (AEC)

Very High Risk for Mid Air Collision

- **Close to an Airport**
  - Controlled Airspace
  - Above Minimum Flight Altitude
  - Below Minimum Flight Altitude

- **Within a TMZ**
  - Controlled Airspace
  - Above Minimum Flight Altitude

- **Non Airport Areas**
  - Controlled Airspace
Airspace Encounter Categories (AEC)

High Risk for Mid Air Collision

- **Over Urban Population**
  - Controlled Airspace
  - Above Minimum Flight Altitude
  - Below Minimum Flight Altitude

- **Over Rural Population**
  - Controlled Airspace
  - Above Minimum Flight Altitude

- **Within a TMZ**
  - Below Minimum Flight Altitude
Airspace Encounter Categories (AEC)

**Low Risk for Mid Air Collision**

- Over Rural Population
  - Controlled Airspace
  - Below Minimum Flight Altitude
- Stratosphere

**Very low Risk for Mid Air Collision**

- South pole / North pole / Sahara Dessert
Airspace Encounter Categories (AEC)

- Very High Risk for Mid Air Collision: Risk Class 4
- High Risk for Mid Air Collision: Risk Class 3
- Low Risk for Mid Air Collision: Risk Class 2
- Very low Risk for Mid Air Collision: Risk Class 1
## Airspace Encounter Categories (AEC) and Air Risk Class (ARC)

<table>
<thead>
<tr>
<th>Airspace Encounter Categories (AEC)</th>
<th>Operational Airspace</th>
<th>Air Risk Class (ARC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Integrated Airspace Operations above 500 ft.</td>
<td>Operations within Class A, B, C, D, or E airspace above 500 ft. AGL</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Operations within an Airport Environment above 500 ft. AGL</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Operations within Class G airspace above 500 ft. AGL within Mode C Veil /TMZ</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Operations within Class G airspace above 500 ft. AGL over urban environment</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>Operations within Class G airspace above 500 ft. AGL over rural environment</td>
<td>3</td>
</tr>
<tr>
<td>6 Integrated Airspace Operations below 500 ft.</td>
<td>Operations within Class A, B, C, D, or E airspace below 500 ft. AGL</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>Operations within an Airport Environment below 500 ft. AGL</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>Operations within Class G airspace below 500 ft. AGL within Mode C Veil /TMZ</td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td>Operations within Class G airspace below 500 ft. AGL over urban environment</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>Operations within Class G airspace below 500 ft. AGL over rural environment</td>
<td>2</td>
</tr>
<tr>
<td>VLL Operations 500 ft.</td>
<td>Operations in airspace above FL600</td>
<td>2</td>
</tr>
<tr>
<td>VHL</td>
<td>Operations in Atypical Airspace</td>
<td>1</td>
</tr>
<tr>
<td>Any</td>
<td>Operations in Atypical Airspace</td>
<td>1</td>
</tr>
</tbody>
</table>
Reason mitigation model (Swiss Cheese)

UAS
Unmitigated
Collision Risk

Strategic
Conflict
Management

External
Mitigations

Internal
Mitigations

Providence

Target
Level of Safety

Mitigations

SORA • Risk Assessment for unmanned airborne Mobility
Markus Farner
Air-Risk Class and strategic mitigations

- Risk Class 1
- Risk Class 2
- SEP Level 1
- Risk Class 3
- SEP Level 2
- Risk Class 4
- SEP Level 3

SORA • Risk Assessment for unmanned airborne Mobility
Markus Farner
## Specific Assurance and Integrity Levels (SAIL)

<table>
<thead>
<tr>
<th>Air Risk Class</th>
<th>Specific Assurance and Integrity Level (SAIL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARC 4</td>
<td>SAIL VI</td>
</tr>
<tr>
<td>ARC 3</td>
<td>SAIL IV</td>
</tr>
<tr>
<td>ARC 2</td>
<td>SAIL II</td>
</tr>
<tr>
<td>ARC 1</td>
<td>SAIL I</td>
</tr>
</tbody>
</table>
### Specific Assurance and Integrity Levels (SAIL)

<table>
<thead>
<tr>
<th>Deterioration of external systems supporting UAS operation</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedures are in-place to handle the deterioration of external systems supporting UAS operation</td>
<td>L</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>The UAS is designed to manage the deterioration of external systems supporting UAS operation</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>External services supporting UAS operations are adequate to the operation</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>
Air-Risk Class and tactical mitigations

Risk Class 1
Tactical Mitigation

Risk Class 2
Tactical Mitigation

Risk Class 3
Tactical Mitigation

Risk Class 4
Tactical Mitigation

Internal Mitigations
TLS—Target Level of Safety
External Mitigations

Encounter Risk Rate
## Tactical Mitigation, Performance Levels

<table>
<thead>
<tr>
<th>Air Risk Class</th>
<th>Tactical Mitigation Performance Requirements (TMPR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARC 4</td>
<td>High Performance</td>
</tr>
<tr>
<td>ARC 3</td>
<td>Medium Performance</td>
</tr>
<tr>
<td>ARC 2</td>
<td>Low Performance</td>
</tr>
<tr>
<td>ARC 1</td>
<td>Optional - the operator/applicant may still need to show some form of mitigation as deemed necessary by the local authority/qualified entity</td>
</tr>
</tbody>
</table>
# Robustness Levels

<table>
<thead>
<tr>
<th>Low Integrity Level</th>
<th>Medium Integrity Level</th>
<th>High Integrity Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW</td>
<td>LOW</td>
<td>LOW</td>
</tr>
<tr>
<td>LOW</td>
<td>MEDIUM</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>LOW</td>
<td>MEDIUM</td>
<td>HIGH</td>
</tr>
</tbody>
</table>
3 Pillars of a new Risk Assessment

- Risk Based Approach. What are the real Risks of the Operation
- New Culture. Holistic not Atomistic
- A Total Hazard and Risk Assessment
QUESTIONS?