Probabilistic Risk Analysis
Procedure for Aircraft Overruns

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Runway Excursion: when the aircraft departs from the runway limits during the operation.

Three possible scenarios:
- Landing Overrun,
- Takeoff Overrun
- Landing Undershoot
Runway-related accidents represent a relevant fraction of the total number of recorded accidents in airport operations.

[Flight Safety Foundation, 2009]
Overrun Probability Models: a comparison

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th># of factors in the model</th>
<th>Input/Output variables</th>
<th>Based on international data (accident / NOD)</th>
<th>NOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eddowes et al.</td>
<td>2001</td>
<td>1</td>
<td>Deterministic</td>
<td>No</td>
<td>No</td>
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<tr>
<td>Kirkland et al.</td>
<td>2004</td>
<td>1</td>
<td>Deterministic</td>
<td>No</td>
<td>No</td>
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<tr>
<td>Wong et al.</td>
<td>2008</td>
<td>17</td>
<td>Deterministic</td>
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<td>Yes</td>
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<td>Hall et al.</td>
<td>2008</td>
<td>14</td>
<td>Deterministic</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

FAA - Airport Cooperative Research Program (ACRP) - Report 3
“Analysis of Aircraft Overruns and Undershoots for Runway Safety Areas”
Objective

Development of a Probabilistic Risk Analysis Procedure to design a topological “risk map” of overrun events based on the statistical characterisation of airport operations and context conditions.

Methodology

- State of the art review and model selection
  - ACRP Model

- Event probability and location model
  - Ops statistical characterisation
  - Monte Carlo

- Event-Consequence model
  - Kinetic Energy as Severity index

- Topological model “Risk Map”

- Test case application
The ACRP Model (Hall, 2008)

- Made of three modules:
  - **Accident Probability Model**: returns the overrun probability value for a given operation
  - **Longitudinal Location Model**: returns the conditional probability that the longitudinal excursion is greater than a certain value starting from the runway end
  - **Lateral Location Model**: returns the conditional probability that the lateral excursion is greater than a certain value starting from the runway centre axis

- Based on international accident data and NOD in countries with accident rates similar to US.
- Input data are normalised by means of a deceleration model developed by Kirkland et al. (2003)
ACRP Accident Probability Model

**INPUT:**
Categorical variables of relevant factors

\[ b(\text{Landing Overrun}) = -15.456 + 0.551(\text{Heavy aircraft}) - 2.113(\text{Commuter Aircraft}) - 1.064(\text{Medium Aircraft}) - 0.876(\text{Small Aircraft}) + 0.445(\text{Turboprop Aircraft}) - 0.856(\text{Foreign Origin}) + 1.832(\text{Ceiling Height}<1000 \text{ ft}) + 1.639(\text{Ceiling Height} 1001-1500 \text{ ft}) + 2.428(\text{Visibility}<2 \text{ SM}) + 1.186(\text{Visibility} 2-4 \text{ SM}) + 1.741(\text{Visibility} 4-6 \text{ SM}) + 0.322(\text{Visibility} 6-8 \text{ SM}) - 0.532(\text{Crosswind} 2-5 \text{ kt}) + 1.566(\text{Crosswind} 5-12 \text{ kt}) + 1.518(\text{Crosswind}>12 \text{ kt}) + 0.986(\text{Electrical Storm}) + 1.926(\text{Icing Conditions}) + 1.499(\text{Snow}) - 1.009(\text{Temperature}<5^\circ \text{C}) - 0.631(\text{Temperature} 5-5^\circ \text{C}) + 0.265(\text{Temperature}>25^\circ \text{C}) + 1.006(\text{Non Hub Airport}) + 0.924(\text{Significant Terrain}) \]

**OUTPUT:**
Overrun Probability for a single movement

\[ P = \frac{1}{1 + e^{b}} \]

**Limitation:** available excess runway is not considered among the relevant factors
ACRP Longitudinal Location Model

- Regression model: \[ P(\text{Location} > x) = e^{-ax^n} \]
- Separate models for Landing and Takeoff Overruns
- **Lateral Location Model is very similar** (over variable \( y \))
Deceleration Model (Kirkland et al. 2003)

- Relates the travelled distance \( (s) \) during an excursion to the initial speed of the aircraft \( (u) \)

\[
u = -qs + \sqrt{(qs)^2 - 2ps}
\]

\( q = \text{constant [ms]} \)
\( s = \text{travelled distance [m]} \)
\( p = \text{coefficient dependent on ground type:} \)

<table>
<thead>
<tr>
<th>Ground Type</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet Grass/Dry Grass/Pavement</td>
<td>-0.0185</td>
</tr>
<tr>
<td>Mud/Gravel</td>
<td>-2.8065</td>
</tr>
<tr>
<td>Obstacles/Water</td>
<td>-8.5365</td>
</tr>
</tbody>
</table>
Probabilistic topology of the event occurrence:
Probability distribution of each single area to be involved in an overrun event [event/movement]
Probabilistic topology of the event severity:

**Iso Kinetic Energy Areas [KJ/movement]**

Expected speed at a certain point beyond the runway end

![Graph showing expected speed vs distance from runway end](image)
Probabilistic topology of the event severity:

Iso Kinetic Energy Areas

[\text{KJ/movement}]

MONTE CARLO SIMULATION

Expected kinetic energy at a certain point beyond the runway end

![Expected Kinetic Energy vs Distance from runway end](image-url)
Probabilistic topology of the event severity:

Iso Kinetic Energy Areas

[KJ/movement]
Linate Airport (LIN) – Milan, Italy

Meteorological Data
- Source: ENAV
- Format: METAR
- Large sample (sampling frequency of 30 min)
- Strong seasonality
- Information on Icing conditions is lacking
- Large uncertainties due to unstable factors (e.g. wind direction)

Traffic Data
- Source: Airport Operator
- Format: records from database Business Objects
  - about 40,000 movements/year
- Landing and takeoff weight information is lacking;
  - substituted with Maximum Takeoff Weight of Aircraft (MTOW)
Linate Airport (LIN) – Milan, Italy

• Seasonality of meteorological data
  ▫ Chi-square and Friedman tests on single parameters
  ▫ Four separated models have been developed for each season

• Sensitivity Analysis
  ▫ To determine the most relevant factors under different seasons (tornado plot)

• Correlations
  ▫ Linear approximation - Pearson’s coefficient
Sensitivity Analysis

- Major influencing factors: **Icing, Snow, Crosswind**

- Major differences between landing and takeoff critical conditions

- Relevant traffic conditions: Equipment Class and User Class
Expected Probability for each single area to be involved in an overrun event [event/movement]
Event probability - Expected return time [years/event]
IKEA (Iso Kinetic Energy Areas): expected kinetic energy distribution [kJ/movement] beyond runway end
Advantages of the proposed approach

- **First attempt to characterise an airport overrun risk**
  - Probabilistic approach
  - Topological representation
  - Based on NOD on traffic and meteorological information

- **Easy way of reporting results, understandable by non technical people**
  (e.g. policy makers and population)

- **Can be easily combined with structural vulnerability analyses** of buildings and infrastructures to arrive at a full risk assessment of the airport area

- **IKEA information can be directly used to design protection measures** and physical barriers
Opportunities for future developments

On the side of the Probability and Location Models:
  ▫ to include Available Excess Runway among the factors included in the ACRP model

On the side of the Deceleration Model
  ▫ to enhance the model proposed by Kirkland et al. (2003), to take into consideration a larger variety of ground types and also the contribution of specific protective installations

On the side of the Consequence Model
  ▫ Standardisation of basic structural analysis and characterisation of different airport facilities
  ▫ Modelling more complex scenarios (e.g. overrun + fire/explosion)
Thank you!
Overrun Event Probability

- Fall and Winter are the most critical seasons:
  - Due to adverse meteorological conditions

- Differences between Landing and Takeoff:
  - Means differ of about an order of magnitude:
    - $P_{\text{Landing}} = 1.19 \times 10^{-6}$
    - $P_{\text{Takeoff}} = 2.81 \times 10^{-7}$
  - Variances differ of about one order of magnitude