STPA Hazard Analysis for Light Aircraft Crosswind Takeoffs

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Agenda

- Why study crosswinds?
- Flight Testing Campaign
- STPA
- Discussion
Definition

Crosswind

Headwind

Wind

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Global Land–Ocean Temperature Index

Source: Jones et al. 1999

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Why study crosswinds now?

Climate change:

- Intense thunderstorms
- Wind from different directions

Limited space for new runways
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Lighter aircraft

Personal aircraft growth
Why study crosswinds now?

Climate change:
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New pilots
Why study crosswinds now?

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Limited space for new runways

Lighter aircraft

Personal aircraft growth

New pilots

New manufacturers
Statistics

2013 Brazil (CENIPA)

Lost of control of the aircraft on ground:

22.15% of the incidents
12.5% of the accidents

Contributing factors: Pilot judgment

13.18% of the incidents
15.64% of the accidents

Source: CENIPA
Objective

Identify mitigating actions that must be taken by light aircraft manufacturers, owners, operators and pilots to make crosswind takeoffs safer
Arrow Campaign

Super Tucano
EMB-314
A-29

Source: Flight Manual
Campo Grande Air Base

94 aborted sorties (6%)

Test Requisition

Source: AisWeb
Chile
Punta Arenas

Source: Flight test report

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Three anemometric stations

Source: Flight test report

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Right crosswind takeoff

Brakes release

Rotation

Source: Flight test report
Takeoff sequence:

1. Brakes release
2. Yaw correction
3. Airspeed
4. Engine parameters
5. ARTU engagement
6. Rotation
7. Skid reduction
8. Retract landing gear
Roll Moment caused by Aerodynamics

\[ L = \frac{\rho}{2} V^2 S C_L \]
\[ f_{\text{friction}} = \mu \cdot N \]
Is that possible to predict which tire blows first?

Is that possible to predict when a tire will blow?

Does the pilot perceive?
Functional structure

- Legislations
- Air Force
- Squadron
- Pilot
- Reaction
- Flight Controls
- Aircraft
- Meteorology
- Environment
- Runway Conditions
- Instructor

- Safety Agency
- Control Tower

March 2015 – Boston
Human Factors:
- Will to proceed on mission
- Flight experience
- Crosswind experience

Responsibilities:
- Accomplish the mission
- Not hurting anyone
- Not damaging the aircraft

Control Loop:

Aircraft:
- Weight
- Tires conditions

Environment:
- Wind direction and intensity
- Gusts
- Wet or dry surface

Linear and Angular Accelerations

Throttle, Control Stick, Pedals and Brakes

Pilot

Auto Pilot

ARTU
### Relation between Accidents and Hazards

<table>
<thead>
<tr>
<th>Accident</th>
<th>Hazards</th>
</tr>
</thead>
</table>
| Loss of control on ground (A1)                   | - Severe braking (H1)  
- Late or no decision to abort (H2)  
- Flight controls misuse during takeoff run (H3)  
- Blown tire procedure not followed (H4)           |
| Loss of control in the air (A2)                  | - Mistaken flight controls use during rotation (H5)  
- PIO (Pilot Induced Oscillation) (H6)              |
| Next landing with some gear partially retracted (A3) | - Landing gear retraction with blown tire (H7)                           |

Source: the authors
<table>
<thead>
<tr>
<th>CONTROL ACTION</th>
<th>NOT PERFOMED</th>
<th>LEADS TO DANGER</th>
<th>TOO EARLY/SOON OR OUT OF SEQUENCY</th>
<th>TOO SHORT OR TOO LONG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce throttle</td>
<td>Not Applicable</td>
<td>Not Applicable</td>
<td>Late decision to abort (UCA 1)</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>Applying brakes</td>
<td>Not Applicable</td>
<td>Brake severely when aborting (UCA 2)</td>
<td>Not Applicable</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>Applying pedals at brakes release</td>
<td>Not Applicable</td>
<td>Aggressive directional corrections (UCA 3)</td>
<td>Delayed pedal application (UCA 4)</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>Applying lateral force on stick</td>
<td>Keep the stick in neutral during takeoff run (UCA 5)</td>
<td>Not Dangerous</td>
<td>Not Dangerous</td>
<td>Keep full lateral deflection on stick until rotation (UCA 6)</td>
</tr>
<tr>
<td>Applying controls simultaneously</td>
<td>Not Applicable</td>
<td>Not Dangerous</td>
<td>Allow banking while alignment with wind (UCA 7)</td>
<td>Induce PIO by wide controls input (UCA 8)</td>
</tr>
<tr>
<td>Retract the landing gear</td>
<td>Landing without following complete blown tire procedure (UCA 9)</td>
<td>Retract landing gear with blown tire (UCA 10)</td>
<td>Not Dangerous</td>
<td>Not Applicable</td>
</tr>
</tbody>
</table>
Safety Constraint or Requirements (SCR)

SCR 1: The takeoff must be aborted at the first sign of loss of directional control.
SCR 2: Brakes cannot be applied severely when aborting with strong crosswind. Pilots are conditioned to apply severely and immediately the brakes when aborting because performance manuals are calculated considering braking that way. The pilot should plan not to perform takeoffs with strong crosswinds on short runways. The severe application of brakes at high speed, when the tires are already near their lateral grip limit may cause the wheels to lock and reduce braking efficiency or burst its tire.
SCR 3: Directional deviations must be corrected smoothly and continuously.
SCR 4: Yawing at brakes release must be counteracted quickly.
SCR 5: Side stick command should be applied to the side of the wind after releasing the brakes.
SCR 6: Side stick command must be gradually reduced as the aircraft gains speed.
The SCR5 aims to equalize the weight among the main gear. To keep the wings leveled and prevent the rotation with stick fully applied to one side, SCR6 must be followed. The optimal implementation depends on the pilot sensibility because, even assuming a constant acceleration, the rolling effectiveness is not linear.
SCR 7: After rotation, the skid angle must be reduced to keep wings leveled.
SCR 8: The transition of primary flight controls in the rotation should be performed smoothly and continuously. To avoid PIO the pilot must establish a constant attitude in the rotation and apply other primary controls (aileron and rudder) smoothly and continuously. SCR 7 and 8 are synthesized in a single operation that is improved by experience for every pilot.
SCR 9: The procedure for landing with a blown tire must be completely followed.
SCR 10: When the bursting of a tire at high speed is suspected and the pilot decides to continue, the landing gear must not be retracted.
STPA step 2

Pilot

Linear and Angular Accelerations

Aircraft

Throttle, Control Stick, Pedals and Brakes

ARTU

Process Model
- Pedals position
- Control Stick position
- Throttle:  - Idle
  - Maximum power
- Brakes:  - Free
  - Softly applied
  - Severely applied

Process Model
- Switch:  - Engaged
  - Disengaged
### Controls to avoid UCA 2

#### BRAKE SEVERELY WHEN REJECTING A TAKEOFF

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Associated Causal Factor</th>
<th>Rationale/Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rejecting a takeoff at high speed, pilots reduce the throttle and press</td>
<td>Takeoff abort is trained only in simulator.</td>
<td>Loss of control gets even more dangerous when runway is wet.</td>
</tr>
<tr>
<td>brakes severely because the acceleration and stopping calculations</td>
<td>There is no training of rejected takeoff with crosswinds.</td>
<td></td>
</tr>
<tr>
<td>consider this.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Recommendation

**Manufacturer:** Develop calculations with a multiplication factor for accelerate-stop distances with crosswinds.

**Operator (only military):** Promote the installation of stop barriers at the end of short runways.

**Operator:** Standardize conservative procedures about accelerate-stop distances for each location.

<table>
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<tr>
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</thead>
<tbody>
<tr>
<td>Pilot does not analyze takeoff charts when preparing for a crosswind</td>
<td>No manual provides guidance on techniques or braking restrictions in cases of crosswind.</td>
<td>The decision to abort is a pilot judgment that is questionable by the operator, owner or customer.</td>
</tr>
<tr>
<td>takeoff.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Recommendation

**Pilot:** Mentalize the set of actions that would be needed to reject a takeoff at high speed.

**Source:** the authors
Controls to avoid UCA 3

### AGRESSIVE DIRECTIONAL CORRECTIONS

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Associated Causal Factor</th>
<th>Rationale/Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gusts make the aircraft to yaw, requiring corrections with greater magnitude.</td>
<td>Pilot applies significant input on pedals as an overreaction to gusts, skidding the aircraft.</td>
<td>Wingman takeoffs require the pilot to maintain half the width of the track. A tire burst in this condition may cause a collision between aircraft.</td>
</tr>
</tbody>
</table>

**Recommendation**

**Operator (only military):** Prohibit the Wingman takeoffs when wind exceeds a limit set by the operator, depending on the aircraft characteristics.

**Pilot:** React smoothly and continuously to yawing.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Associated Causal Factor</th>
<th>Rationale/Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is not possible to predict that there will be strong crosswinds. So it is impossible to use a procedure for changing worn tires before limit.</td>
<td>The limit for changing tires is the same regardless of the operating conditions.</td>
<td>A worn tire can be released for the flight and reach the condition for changing during the takeoff run.</td>
</tr>
</tbody>
</table>

**Recommendation**

**Operator:** Guide maintenance personnel about the careful inspection of tires in the pre-flight and recommend its early replacement in crosswinds conditions.

**Pilot:** When preparing for crosswind takeoff, perform careful inspection of tires, asking for new ones if necessary.

Source: the authors

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## Controls to avoid UCA 10

### RETRACT LANDING GEAR WITH BLOWN TIRE

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Associated Causal Factor</th>
<th>Rationale/Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot retracts the landing gear with a burst tire by conditioned behavior or because did not realized the burst of one or more tires.</td>
<td>The landing gear is retracted with one or more blown tires causing damage to the aircraft and compromising the next lowering of the landing gear.</td>
<td>At high speed with gusts, it is natural that a pilot does not notice the bursting of a tire.</td>
</tr>
</tbody>
</table>

**Recommendation**

**Manufacturer:** Develop a landing gear system that will not be damaged if the gear retracts with a tire burst.  
**Manufacturer:** Develop a pressure sensor that warns the pilot when the tire looses pressure.  
**Operator:** Check the possibility of installing a certified system of tire pressure monitoring.  
**Pilot:** Consider the tire burst as critical emergency in the takeoff briefing.

Source: the authors
Discussion

- STPA as a toll for continuous variables

- Expliciting the tacit knowledge

- Mitigating Action - Updating doctrinal manuals and operational procedures to pilots and maintenance staff to maintain constraints effectiveness
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Future work

- High wing aircraft
- Twins in single engine situations
- Standards change
Experimental Test Flight

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