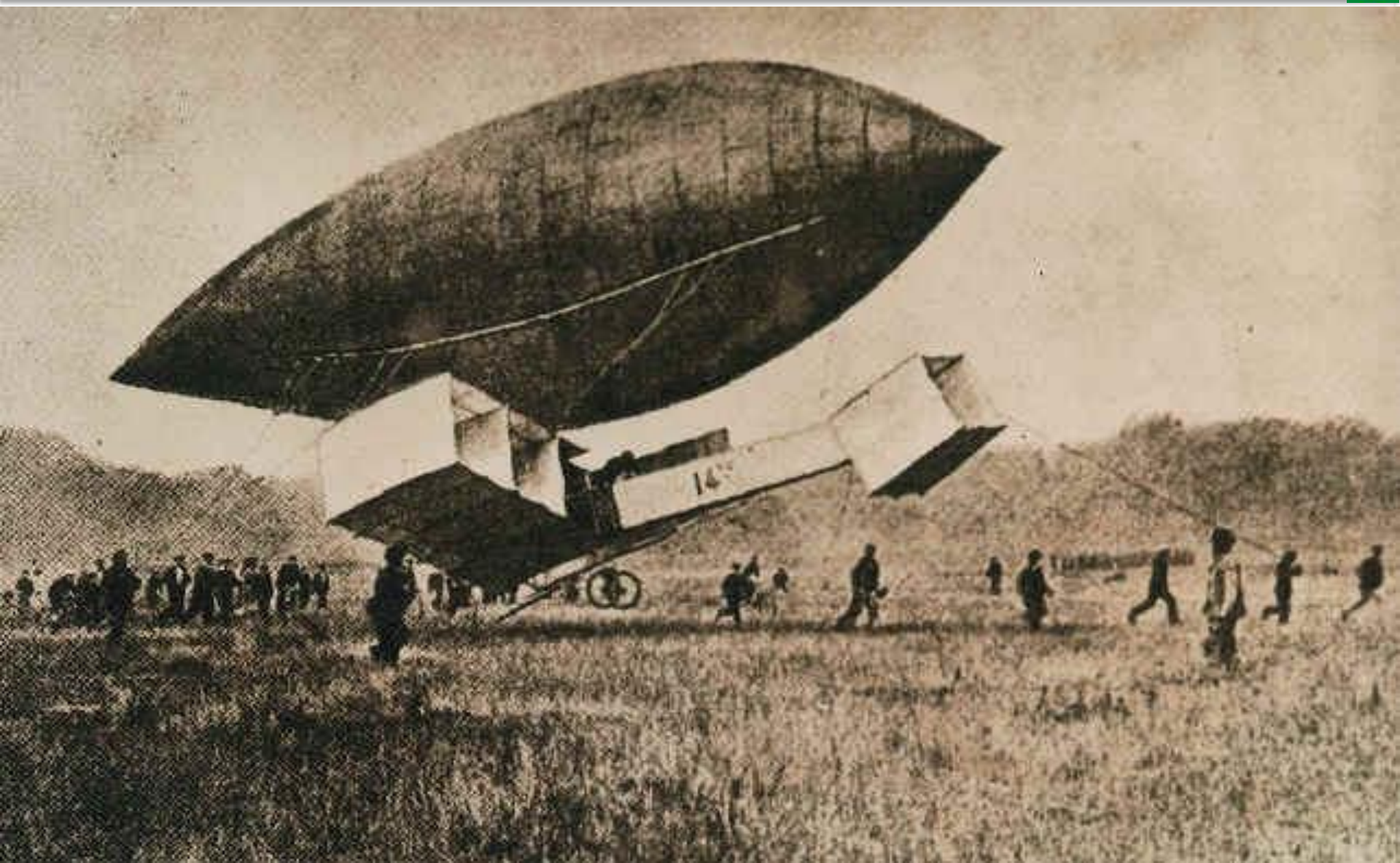
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FUNCATE

STPA Hazard Analysis for Light Aircraft Crosswind Takeoffs

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March 2015 – Boston

Agenda

1. Why study crosswinds?
2. Flight Testing Campaign
3. STPA
4. Discussion

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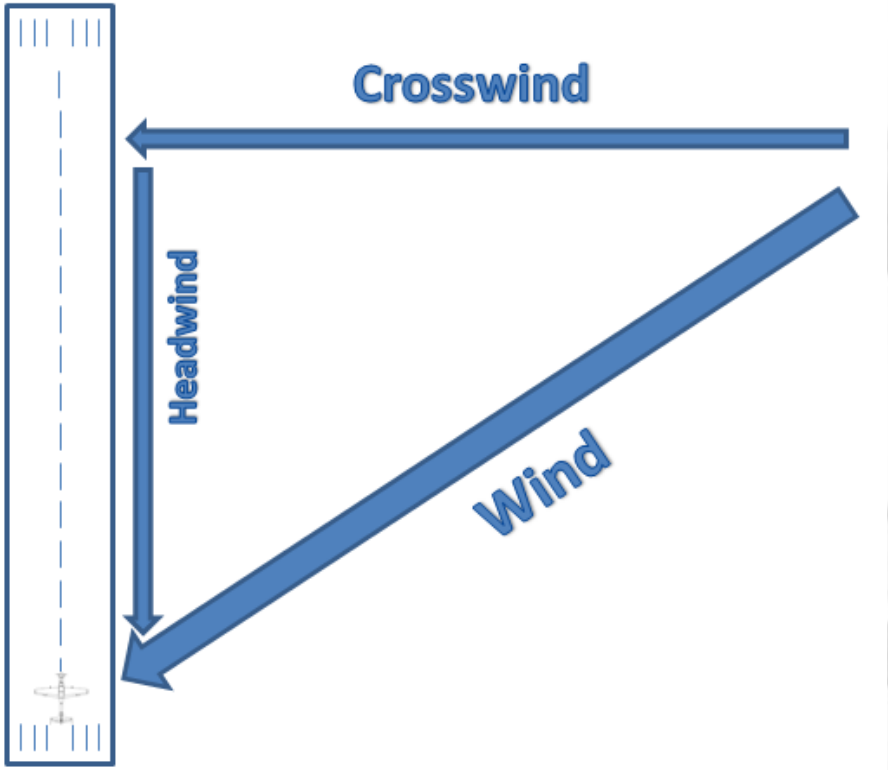
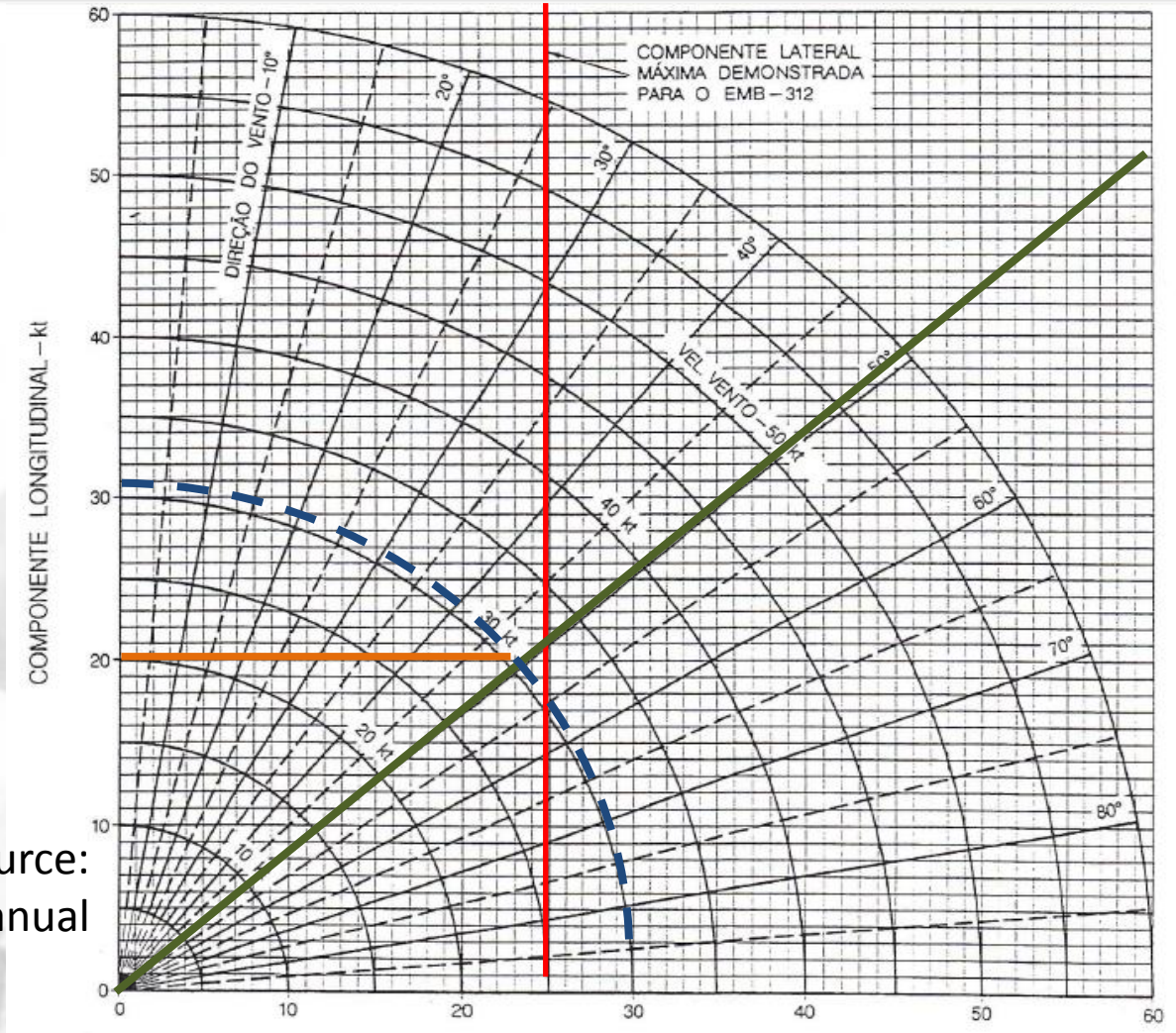
Definition





Source:
T-27 Flight Manual

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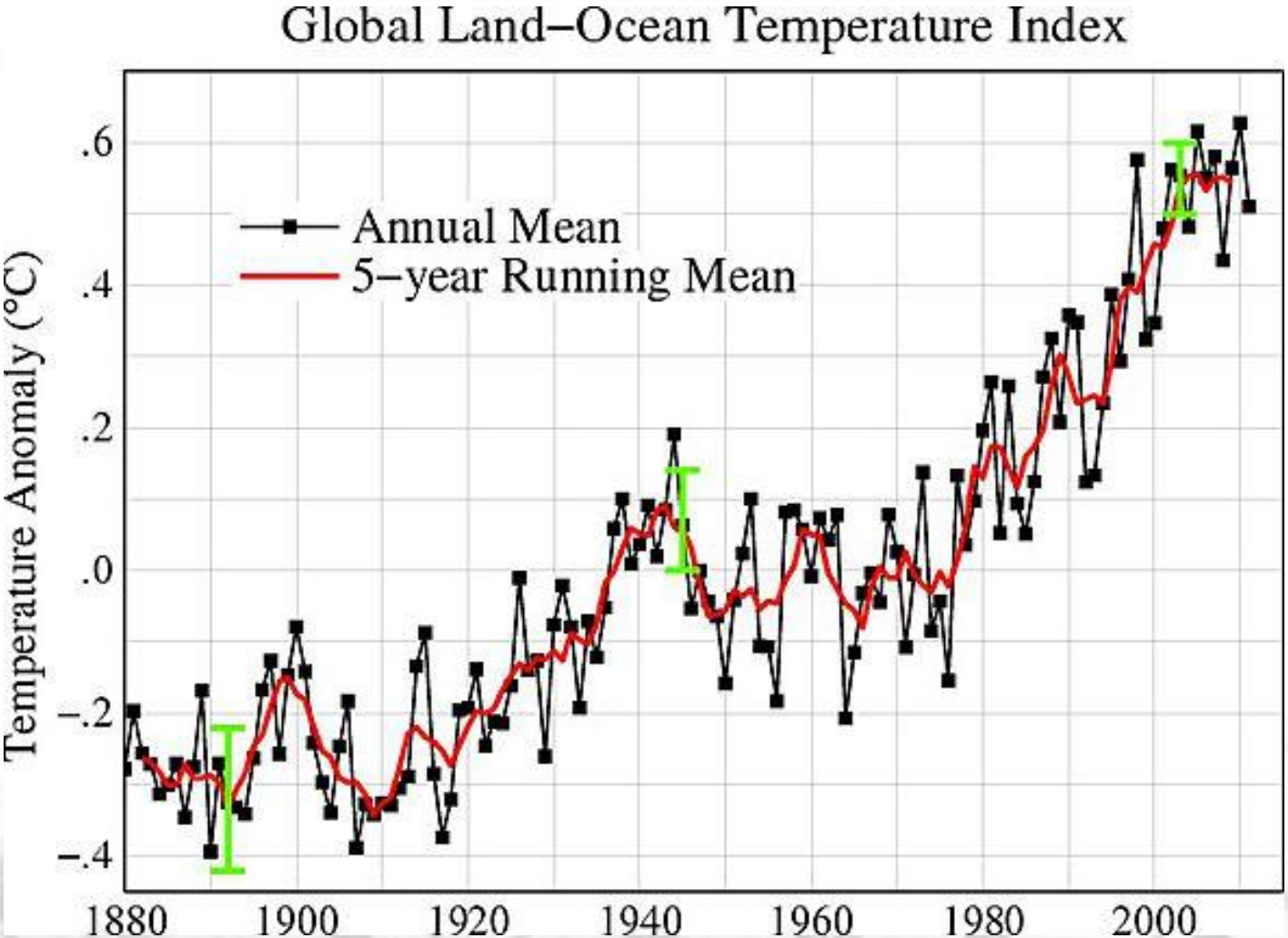

Source: Jones et al. 1999

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

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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

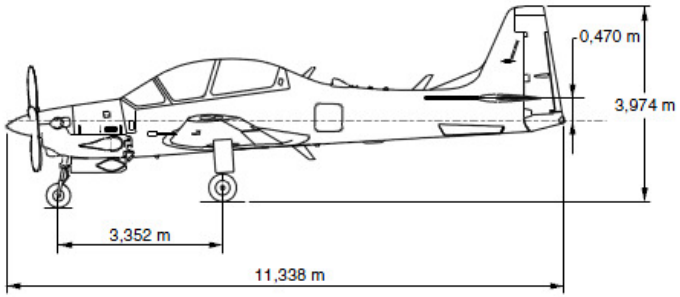
15,64% of the accidents

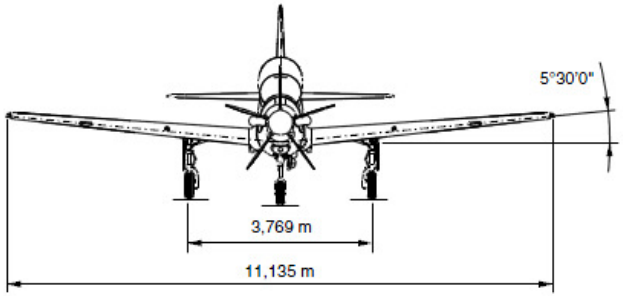
Source: CENIPA

Objective

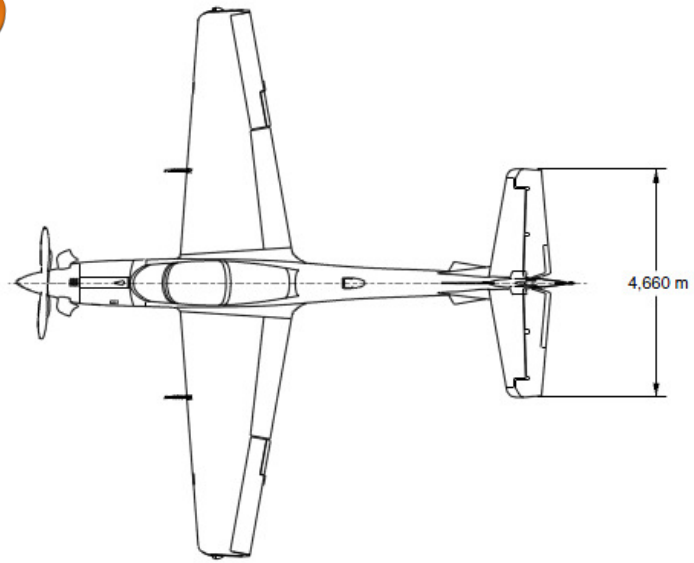
Identify mitigating actions that must be taken by light aircraft manufacturers, owners, operators and pilots to make crosswind takeoffs safer

Arrow Campaign





Super Tucano
EMB-314
A-29

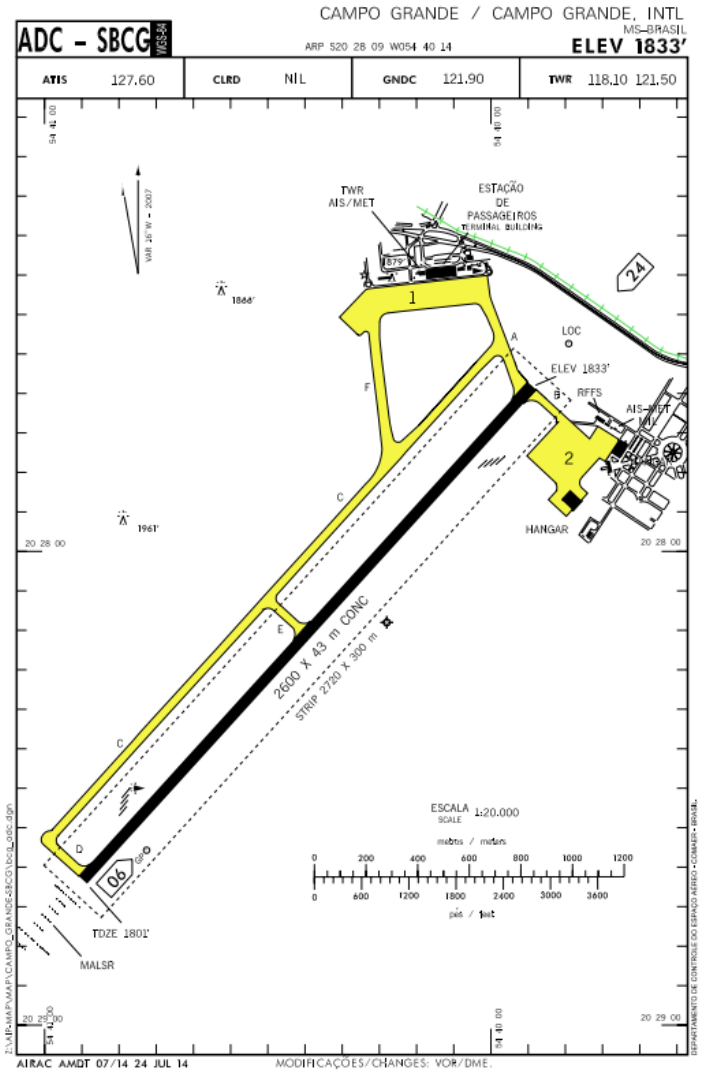


Source: Flight Manual

Campo Grande Air Base

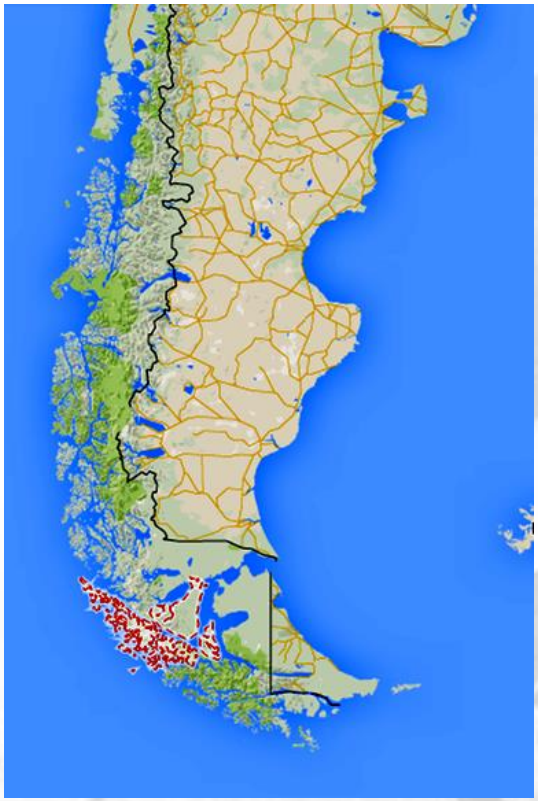
94 aborted sorties (6%)

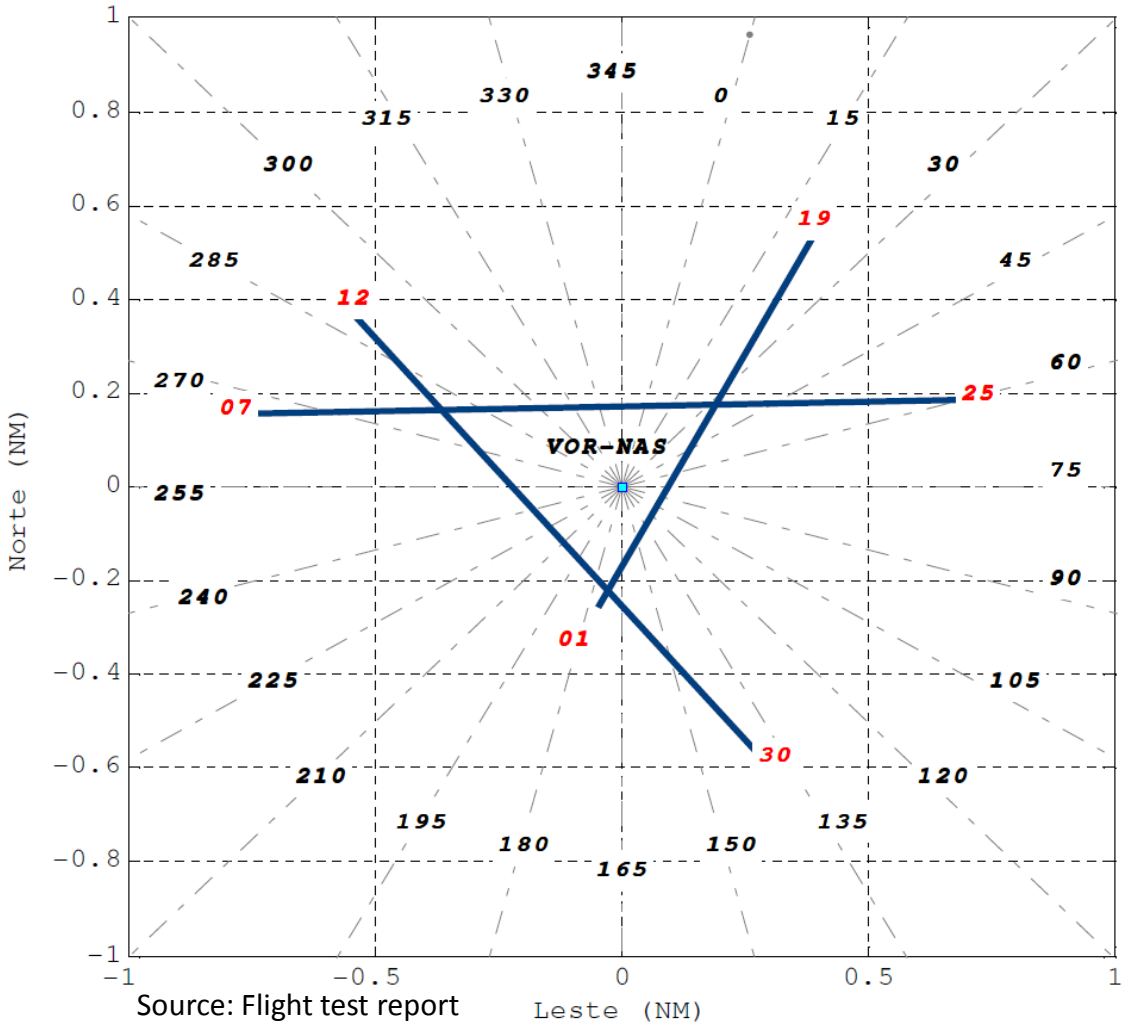
Test Requisition



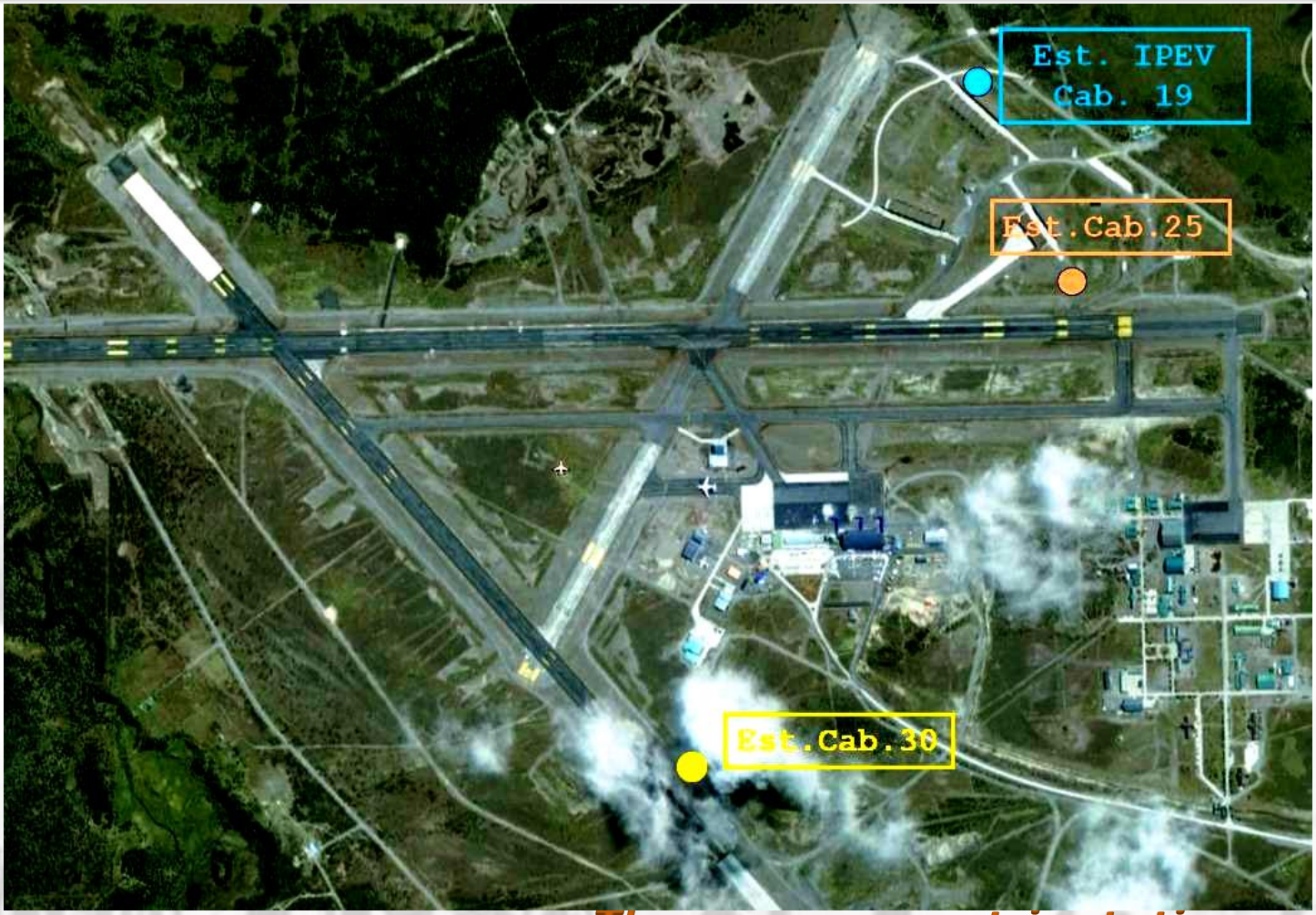
Source: AisWeb

Chile
Punta Arenas





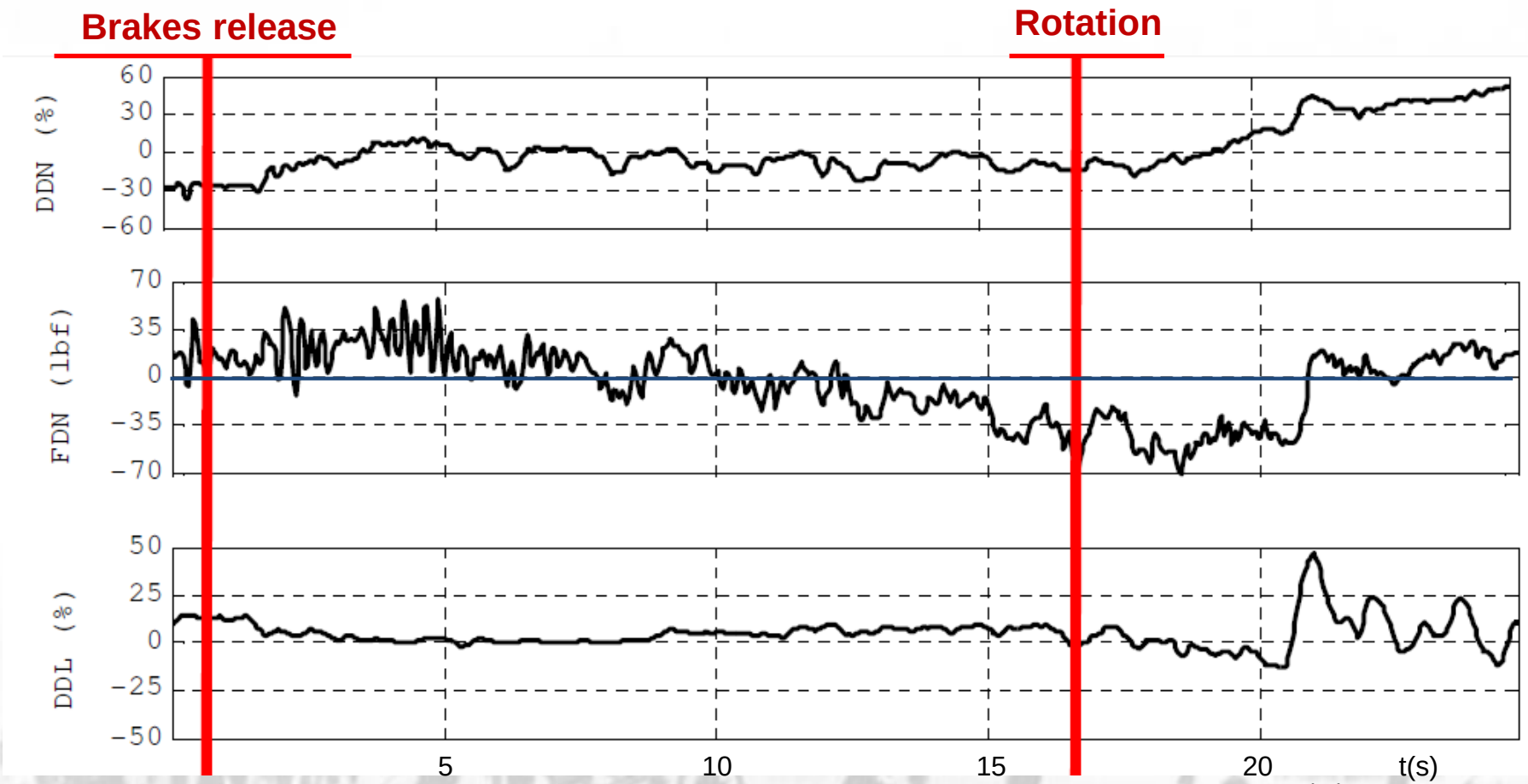
Source: Flight test report



Source: Flight test report

Three anemometric stations

Right crosswind takeoff

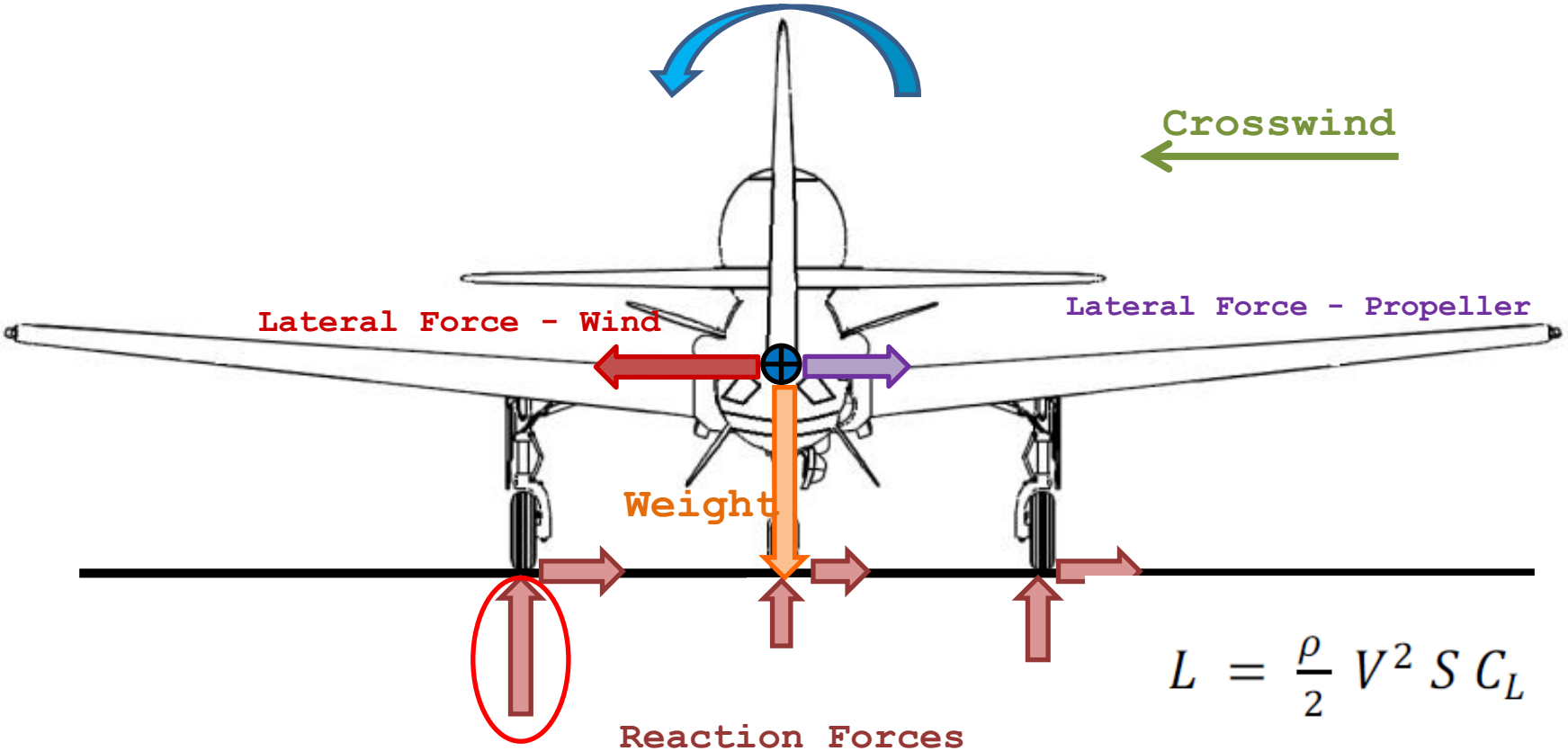


Source: Flight test report

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



$$L = \frac{\rho}{2} V^2 S C_L$$

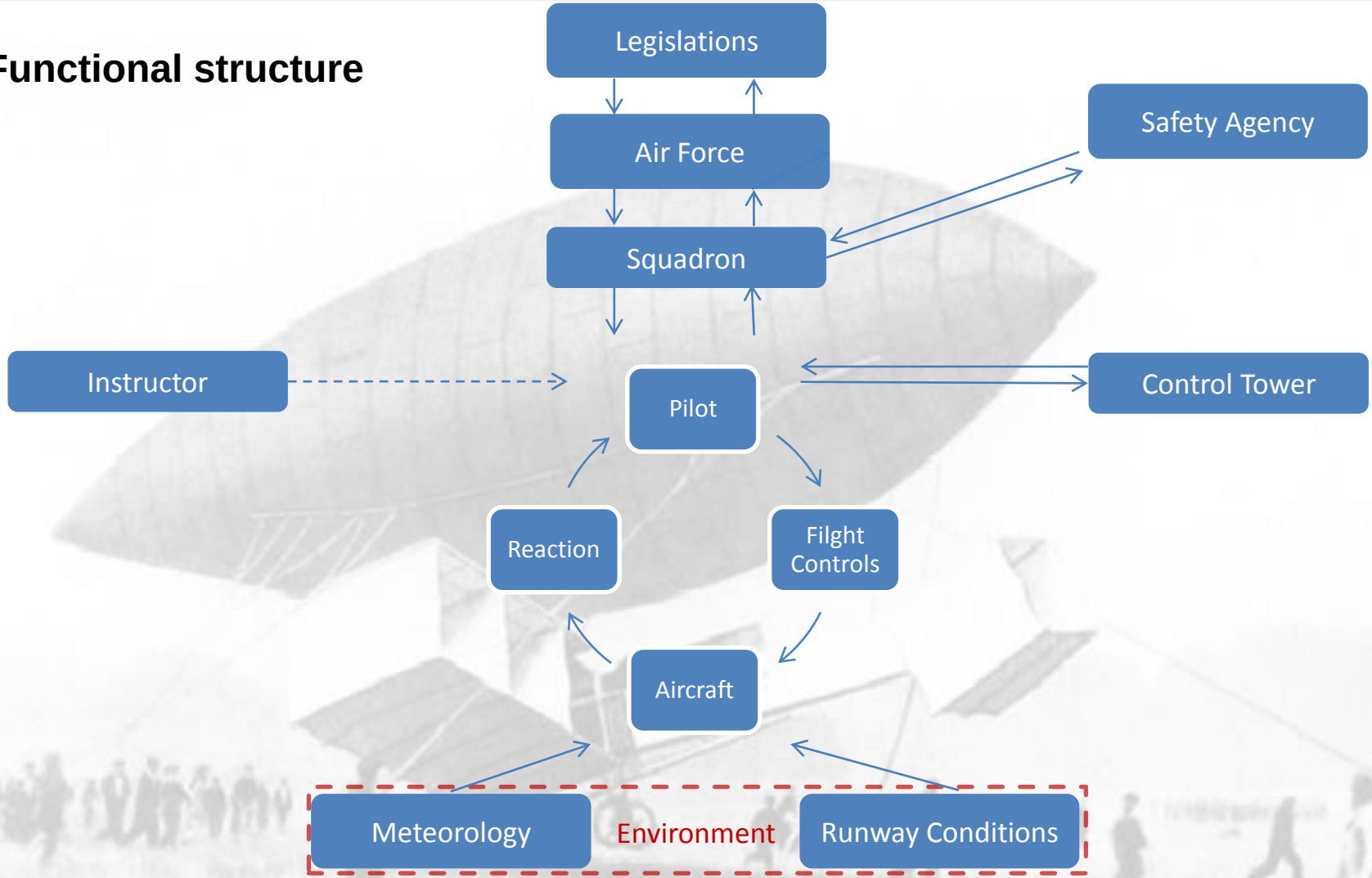
$$f_{friction} = \mu \cdot N$$

Is that possible to predict which tire blows first?

Is that possible to predict when a tire will blow?

Does the pilot perceive?

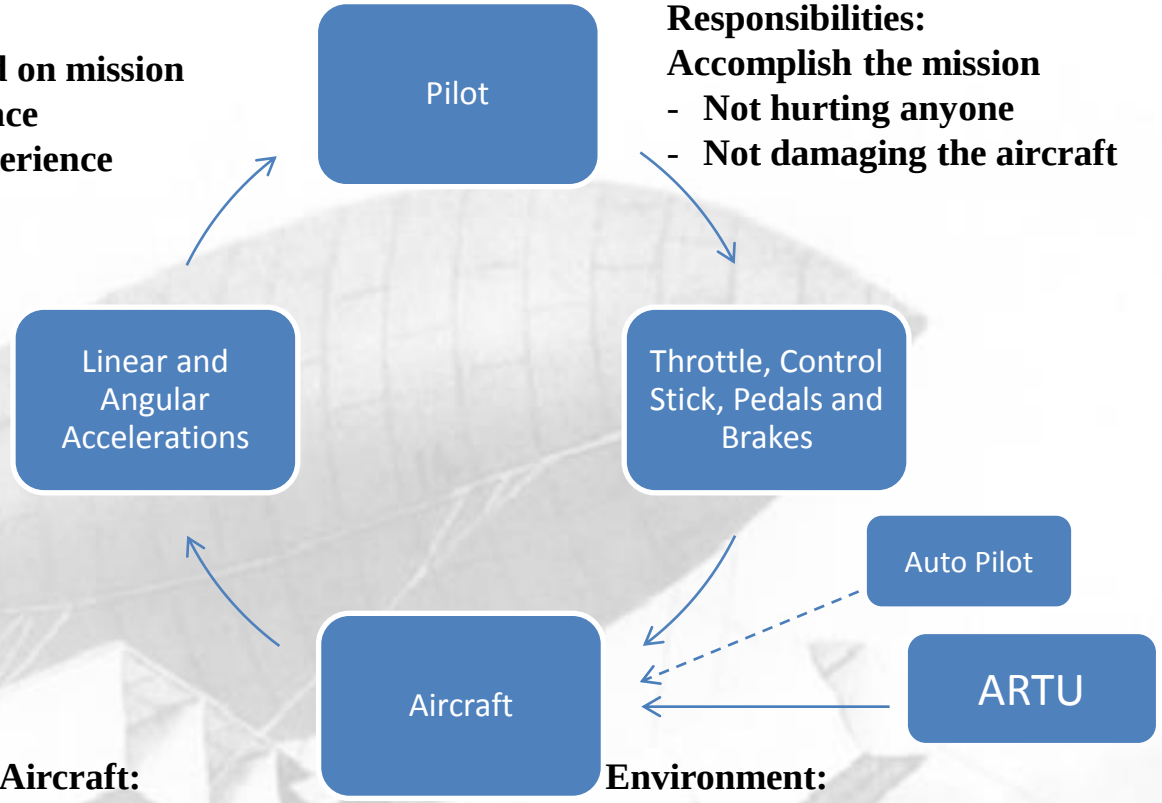
Functional structure



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**

Relation between Accidents and Hazards

Accident	Hazards
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)**

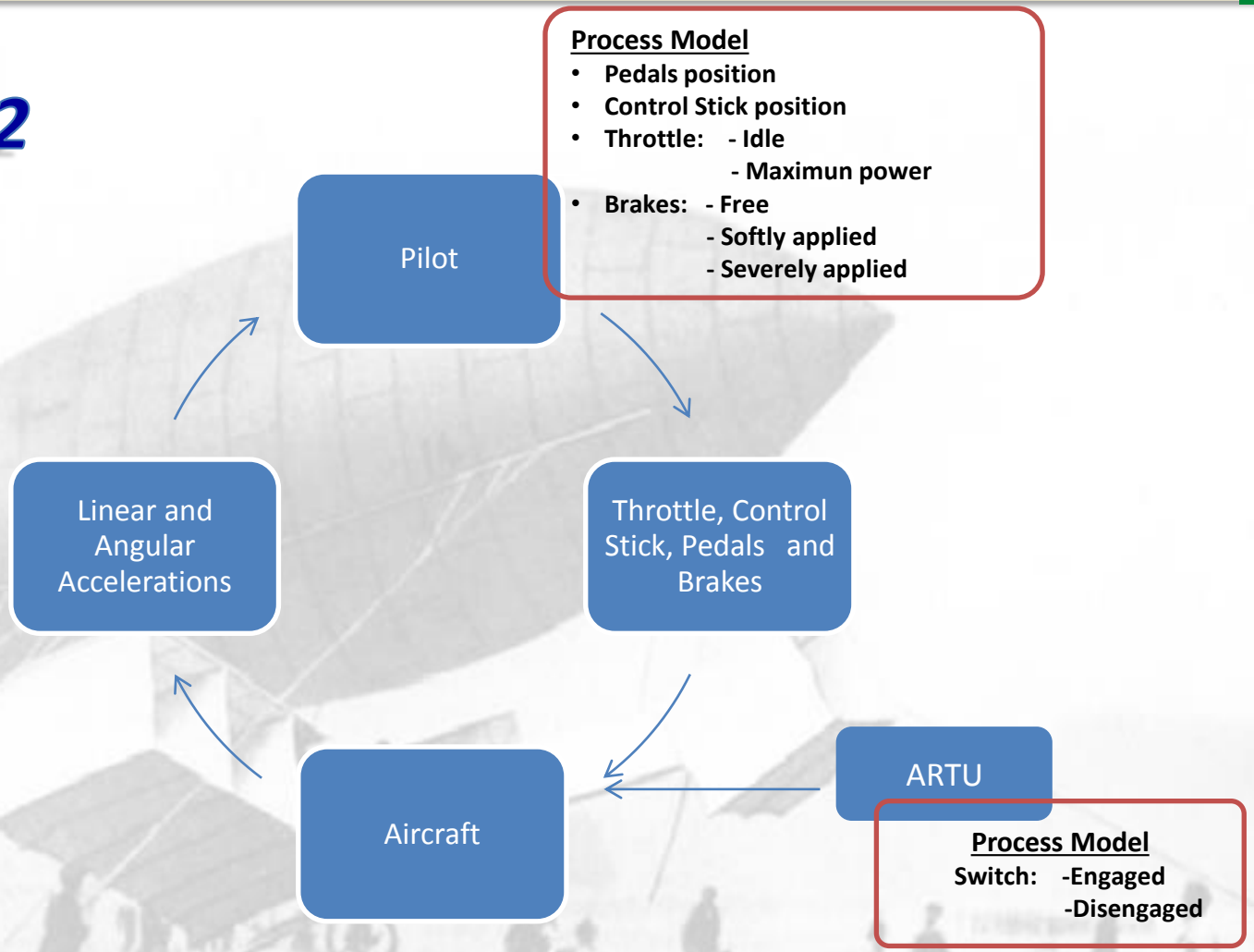
Source: the authors

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

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



Controls to avoid UCA 2

BRAKE SEVERELY WHEN REJECTING A TAKEOFF		
Scenario	**Associated Causal Factor**	**Rationale/Notes**
Rejecting a takeoff at high speed, pilots reduce the throttle and press brakes severely because the acceleration and stopping calculations consider this.	Takeoff abort is trained only in simulator. There is no training of rejected takeoff with crosswinds.	Loss of control gets even more dangerous when runway is wet.
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.		
Scenario	**Associated Causal Factor**	**Rationale/Notes**
Pilot does not analyze takeoff charts when preparing for a crosswind takeoff.	No manual provides guidance on techniques or braking restrictions in cases of crosswind.	The decision to abort is a pilot judgment that is questionable by the operator, owner or customer.
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		
Scenario	**Associated Causal Factor**	**Rationale/Notes**
Gusts make the aircraft to yaw, requiring corrections with greater magnitude.	Pilot applies significant input on pedals as an overreaction to gusts, skidding the aircraft.	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.
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.		
Scenario	**Associated Causal Factor**	**Rationale/Notes**
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.	The limit for changing tires is the same regardless of the operating conditions.	A worn tire can be released for the flight and reach the condition for changing during the takeoff run.
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

Fonte: o autor

Controls to avoid UCA 10

RETRACT LANDING GEAR WITH BLOWN TIRE		
Scenario	**Associated Causal Factor**	**Rationale/Notes**
Pilot retracts the landing gear with a burst tire by conditioned behavior or because did not realized the burst of one or more tires.	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.	At high speed with gusts, it is natural that a pilot does not notice the bursting of a tire.
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*

Future work

- *High wing aircraft*
- *Twins in single engine situations*
- *Standards change*

Experimental Test Flight

March 2015 – Boston

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