SOUTHEAST ASIA AVIATION
SAFETY CONFERENCE
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Power Management to Avoid Loss of Control due to Unintended Yaw

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- Latest flight physical insights – the nerd part…
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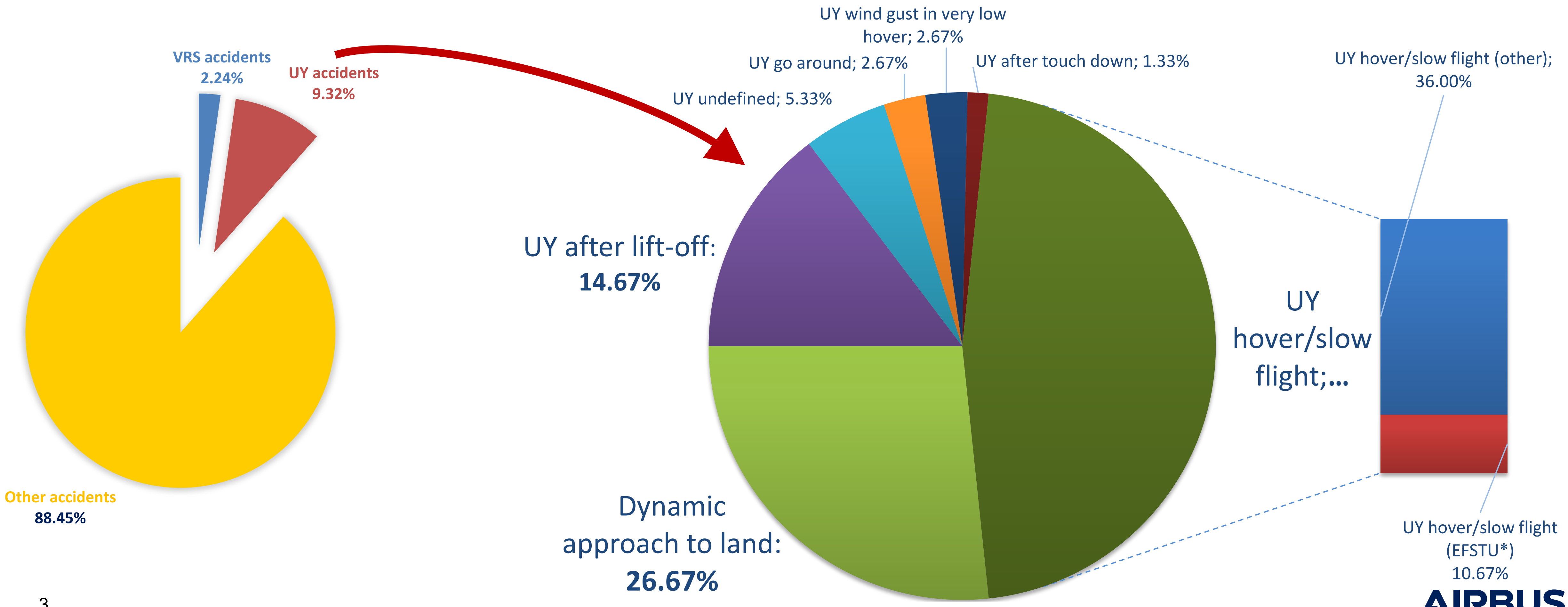
AIRBUS

Motivation – why resume a decade old discussion with vigor?

VRS & UY Airbus Helicopters‘ fleet accidents 2013-2023



Motivation – why resume a decade old discussion with vigor?

Loss of yaw control accidents

- Loss of anti-torque due to technical reasons/failures

  0.8 % of accidents*

- Insufficient anti-torque due to operation outside of the performance envelope

  1 % of all accidents*

- Loss of yaw control due to flight physical effects, not countered by the pilot

  (= Unintended Yaw UY)

  9.3 % of all accidents *

Motivation – why resume a decade old discussion with vigor?

- Unintended (unanticipated) yaw is a prime reason for helicopter accidents
- It needs to be put into focus to clarify prevention and recovery barriers
- *Many misconceptions, misnomers and bad assumptions still exist*

➢ Issue became in the focus of VAST Technology Team
and ESPN-R in 2022

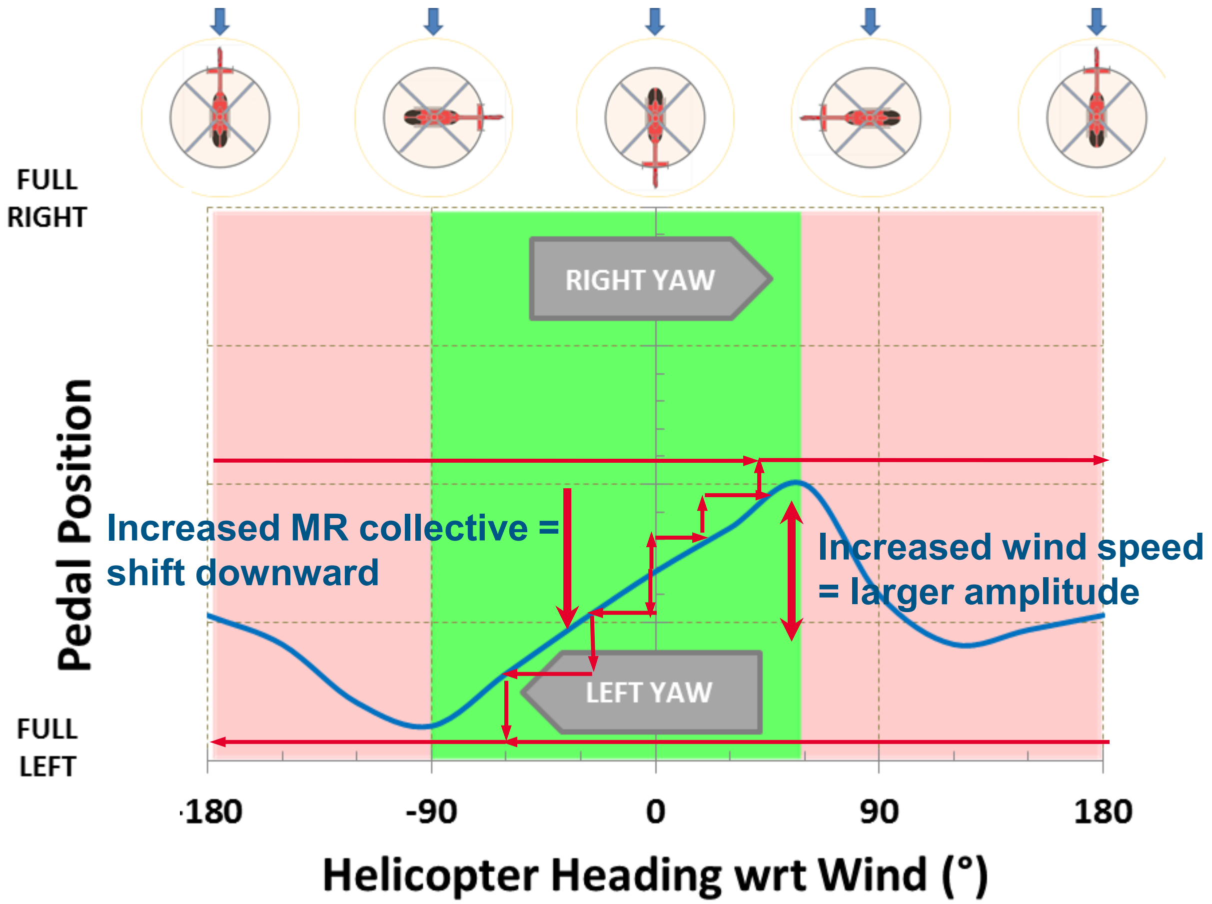
Latest flight physical insights – the nerd part…

Part 1:

The yaw-trim curve – pedal position needed

to maintain a specific heading in a wind field

Performing slow yaw turns in a wind field:
(Counter-clockwise turning main rotor)



- **Steady Trim curve** stable part in green area, trim curve unstable part (‚weathervaning‘) in red area
- Starting from a heading into the wind: a series of small pedal step inputs results in self-stabilizing heading
- A third step input leads above the maximum of the Pedal Curve. This makes the helicopter enter an endless spin – **stoppable with immediate, decisive (full) opposite pedal** – an **unanticipated yaw**, **not self self-subsiding**
- The same maneuver may be done on the other side, with the same result, but with an opposite yaw rate. **Effect name: Entry from stable into unstable control domain, control effect**

See also:
- AH SIN 3298-S-00
- EASA Rotorcraft & VTOL symposium 2021, *Flight investigations of the Unanticipated Yaw Phenomenon, Episode II*, David Ferullo
- Try it out with the AH Flight Physics simulator, SPN 3821-P-00, https://www.airbus.com/en/safety/safety-in-operations/helicopters-safety-in-operations/safety-multimedia-e-learning

Accident related to the phenomenon

Hover/low speed yaw turn in strong/gusty winds

Latest flight physical insights – the nerd part…

Part 2:

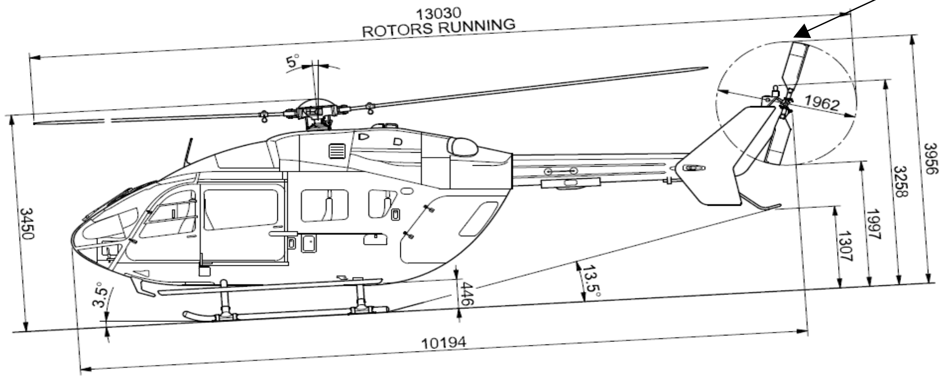
Deeper analysis of additional flight physical and aerodynamic effect for helicopter with a *conventional tail rotor* to be superimposed on the yaw trim curves

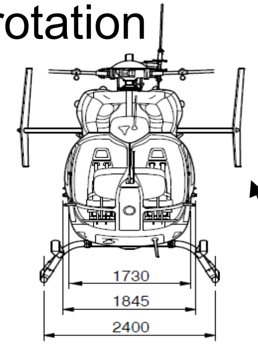
- Analysis done with a Bachelor Thesis and a Master Thesis
- both done under the VAST umbrella, with co-supervision from a FAA expert

BK117-C2 used for simulation

Counter-clockwise MR rotation

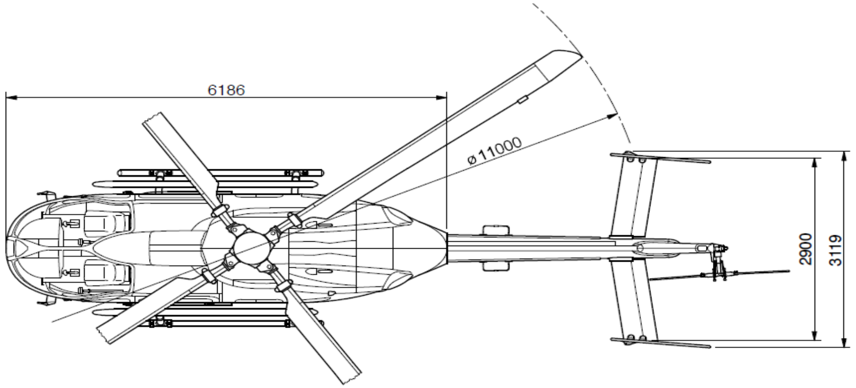
High tail rotor with top aft rotation





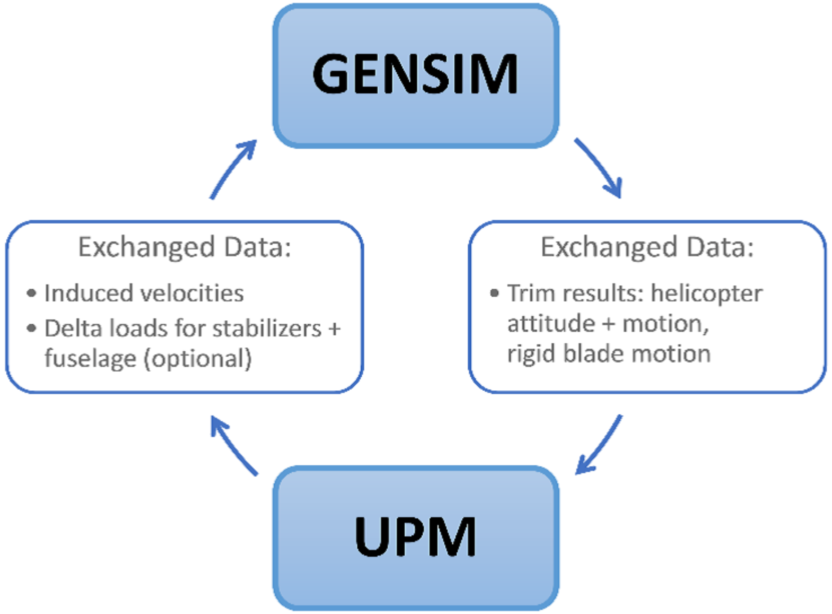
Flight condition:
Pressure Altitude: 2134 m (7 000 ft) Density Altitude: 8706,6 ft
Critical weight MTOM: 3585kg
Critical centre of gravity: most aft

Representative mid-weight helicopter model



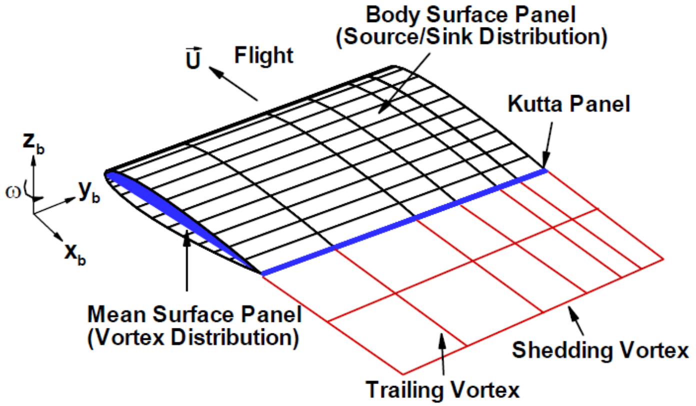
Relative large end-plates

Numerical tools used



AH flight mechanic, 6 DOF code

(can also be run stand-alone with a included basic aerodynamic modelling)



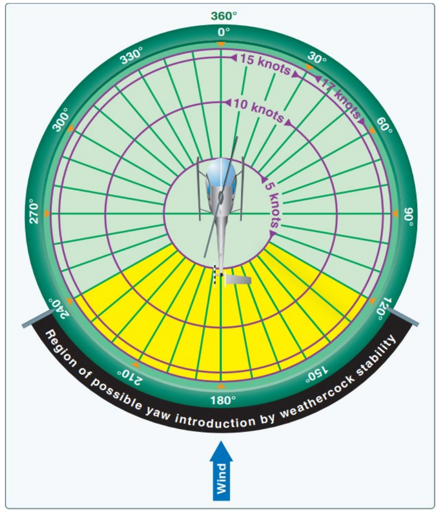
DLR unsteady panel method,

with **inclusion of vortex interaction**

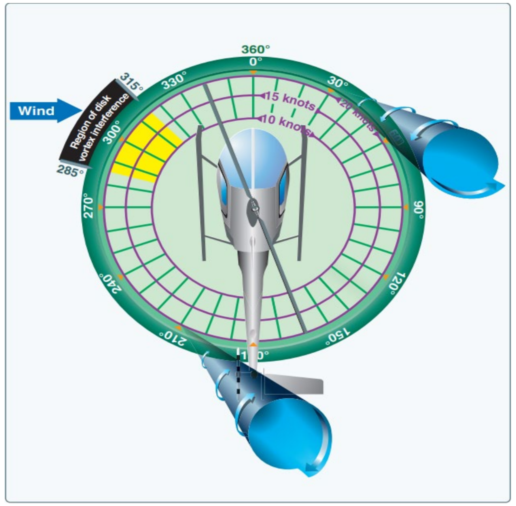
for sophisitcated flow simulation

Further Effects to be studied

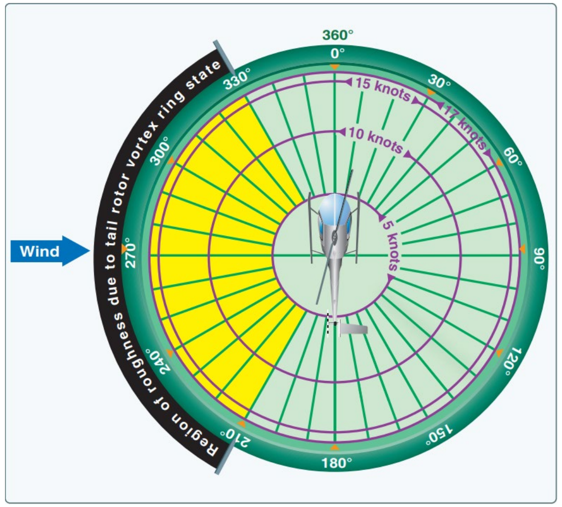
Weathervaning
(=unstable area in the trim curve), already covered by trim curve



Forward-left relative wind, MR vortex interaction with TR

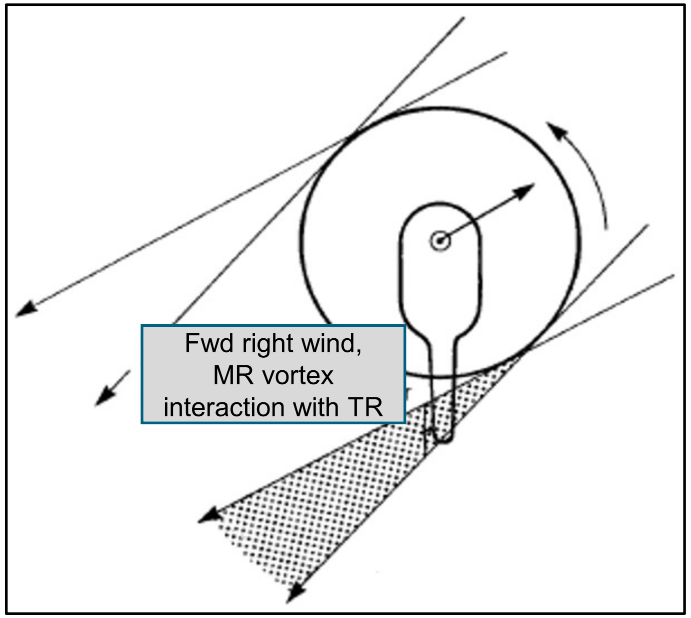


Tail Rotor VRS



Running-out-of-pedal for trim, 2 cases:

1. Wind straight from the right, reducing yaw control margin
2. Wind from fwd right, MR vortex interaction with TR (see below)

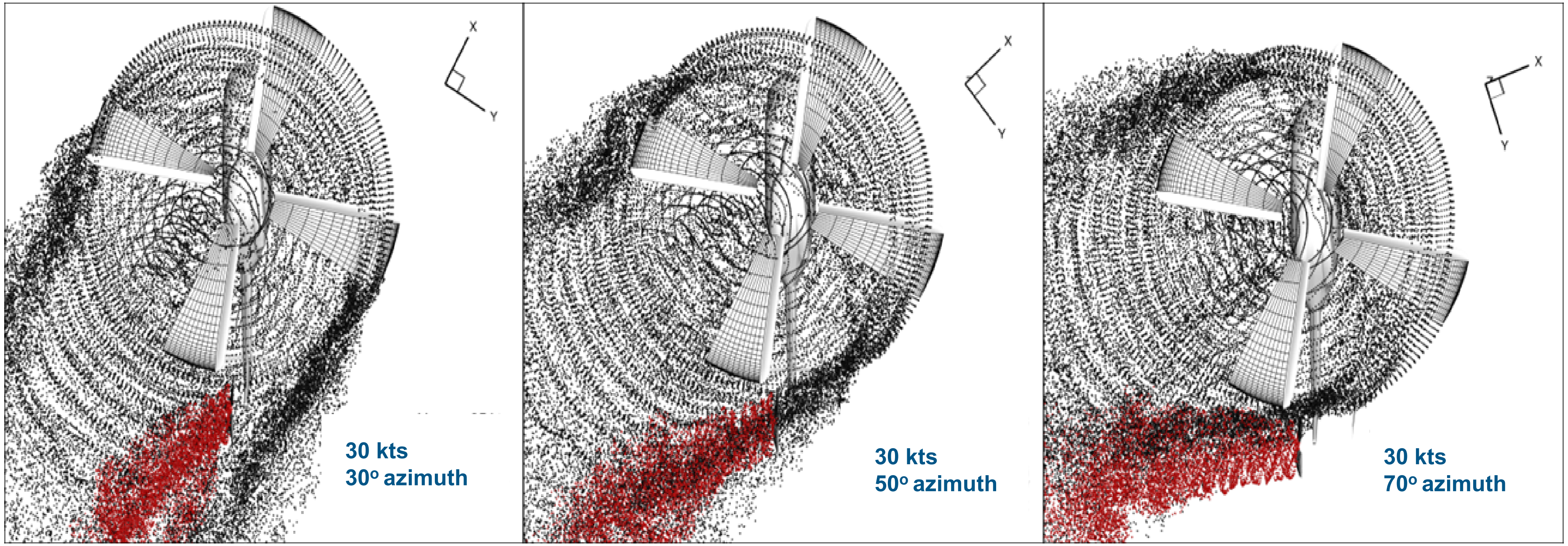


Pictures: Federal Aviation Administration: Helicopter Flying Handbook (FAA-H-8083-21B2019).

Task: establish ranking of these effects according to their criticality for UY

	Cause of the effect	Direction of inadvertent yaw (Counterclockwise rotating MR)	Yaw rate potentially self subsiding	Yaw rate stoppable by opposite pedal input
Entry from Stable into Unstable Control Domain	Pilot action	Left/ Right	No	Yes
TR VRS	Aerodynamical effect		To be examined	To be examined
Weathervaning	Stability		To be examined	To be examined
Running out of Pedal for Trim with wake interference	Aerodynamical effect		To be examined	To be examined
Running out of Pedal for Trim w/o wake interference	Stability		To be examined	To be examined

Running-out-of-pedal-for-trim (wind from fwd right)



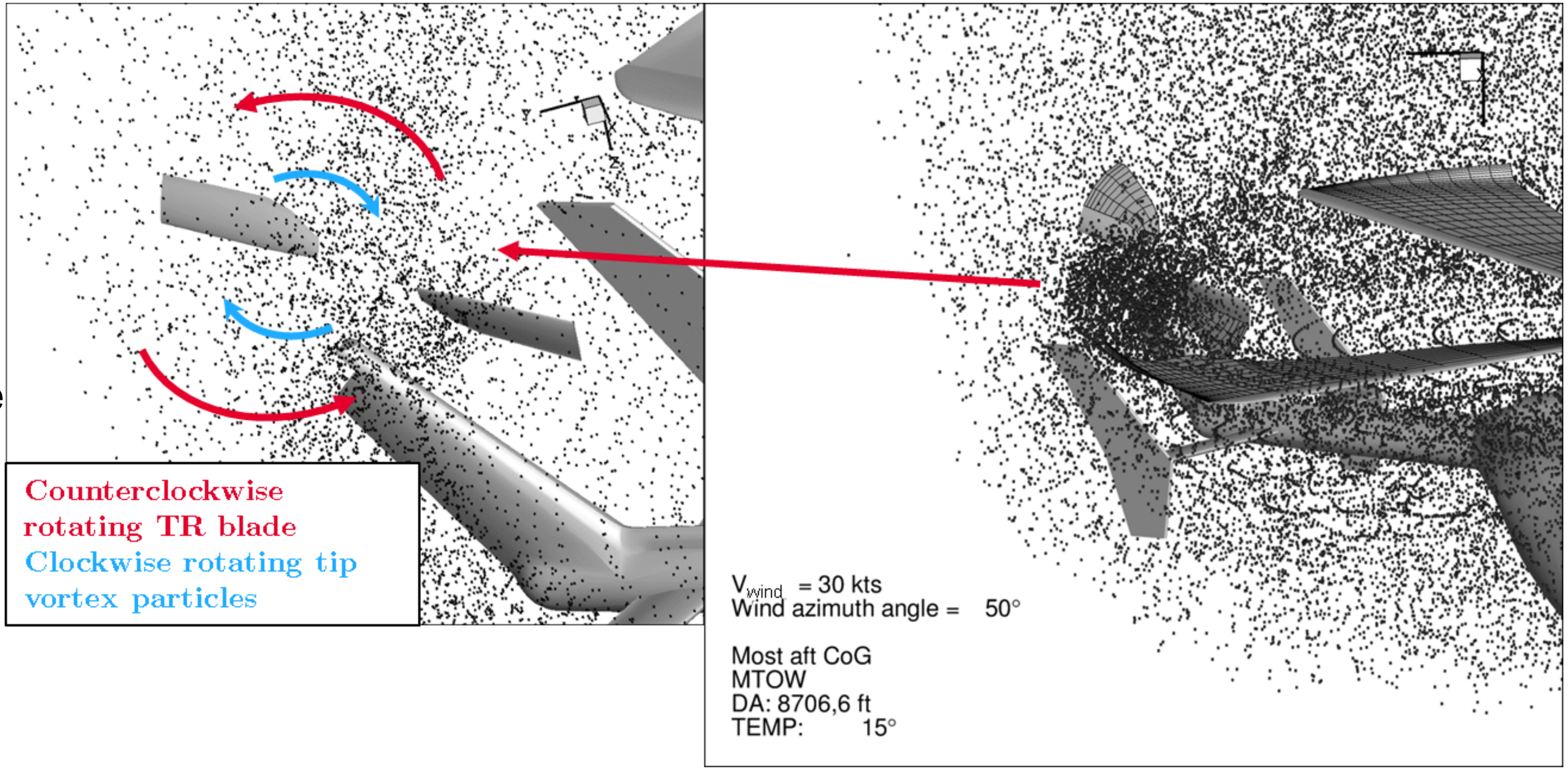
Findings:

For Tail Rotors with top blade moving aft – slight **gain** in thrust !
For Tail Rotors with top blade moving forward – *slight* **decrease** in thrust
High amount of control margin remains in any case
High degree of fluctuation/frequency caused by MR wake

Running-out-of-pedal-for-trim (wind from fwd right)

Explanation for thrust increase for *top blade moving aft* thrust increase:

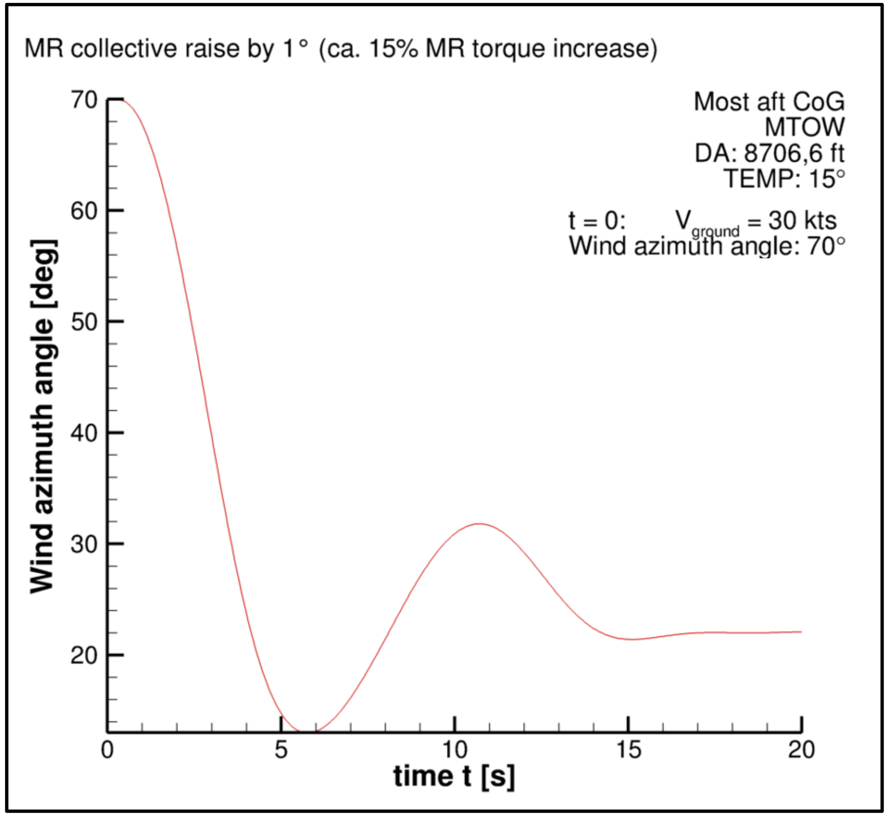
1. MR Tip vortex hits the TR system
2. MR tip vortex rotates in the opposite direction of the TR blades
3. This results in a thrust increase at the TR

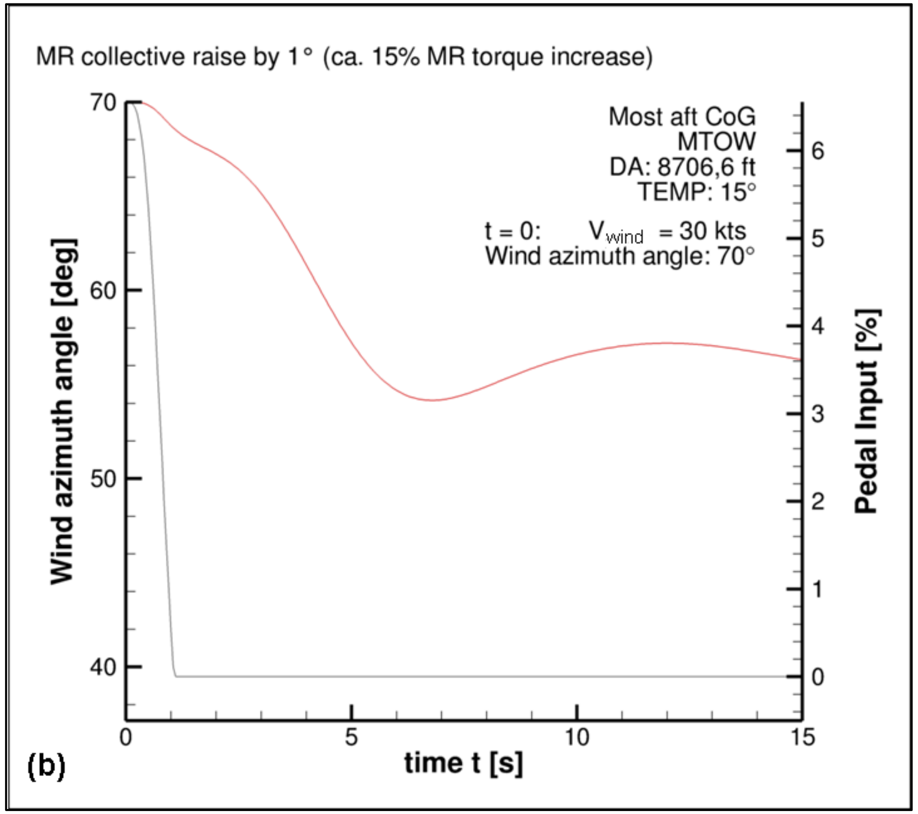


Running-out-of-pedal-for-trim (wind from 70⁰ azimuth at 30 kts)

Trim condition: 4% of left pedal input still remaining

Dynamic simulation: simulated load-pick up by raising collective pitch by 1° over 0.5 s





Case 1: dynamic response, pedal frozen

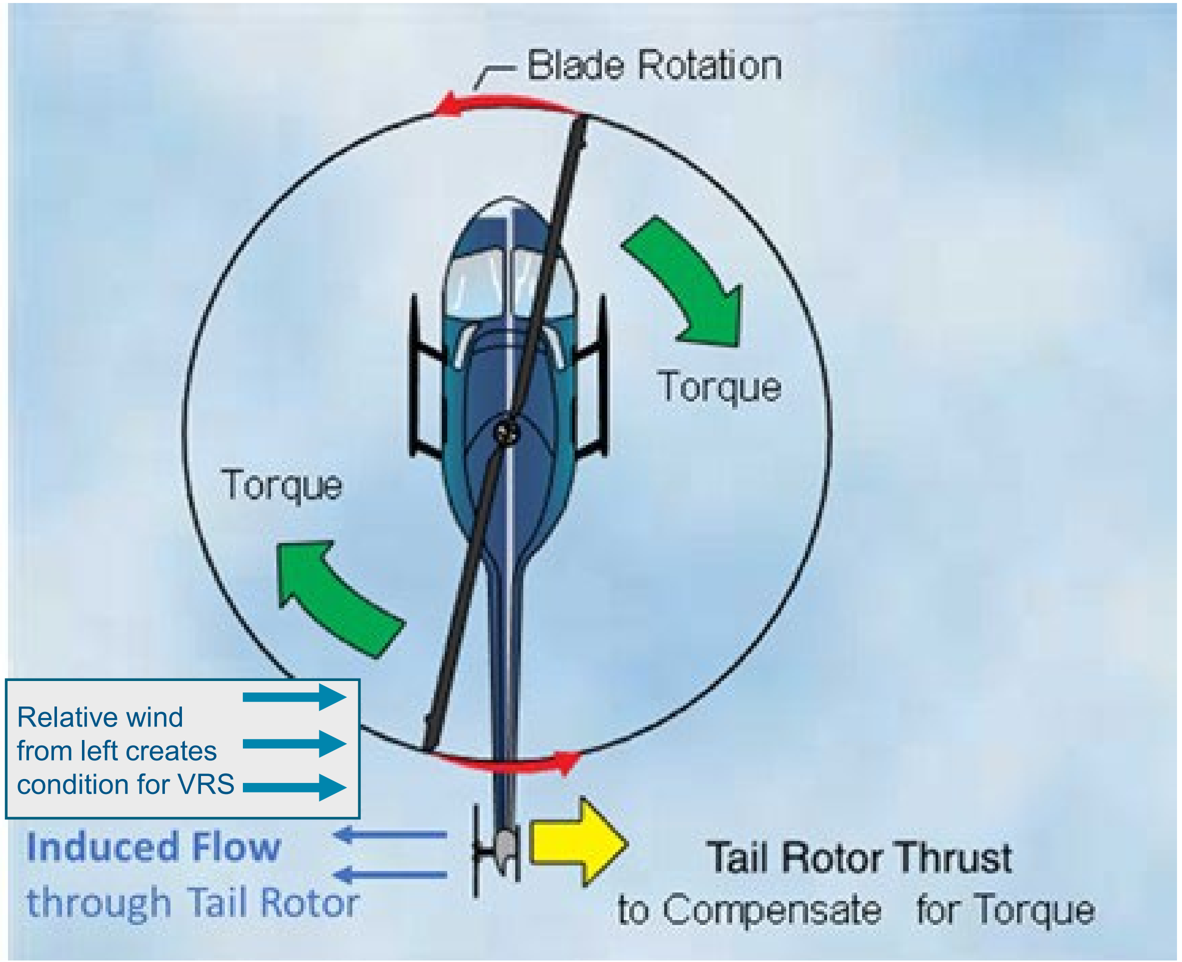
➢ **Self subsiding**

Case 2: dynamic response, pedal input to full left over 1s

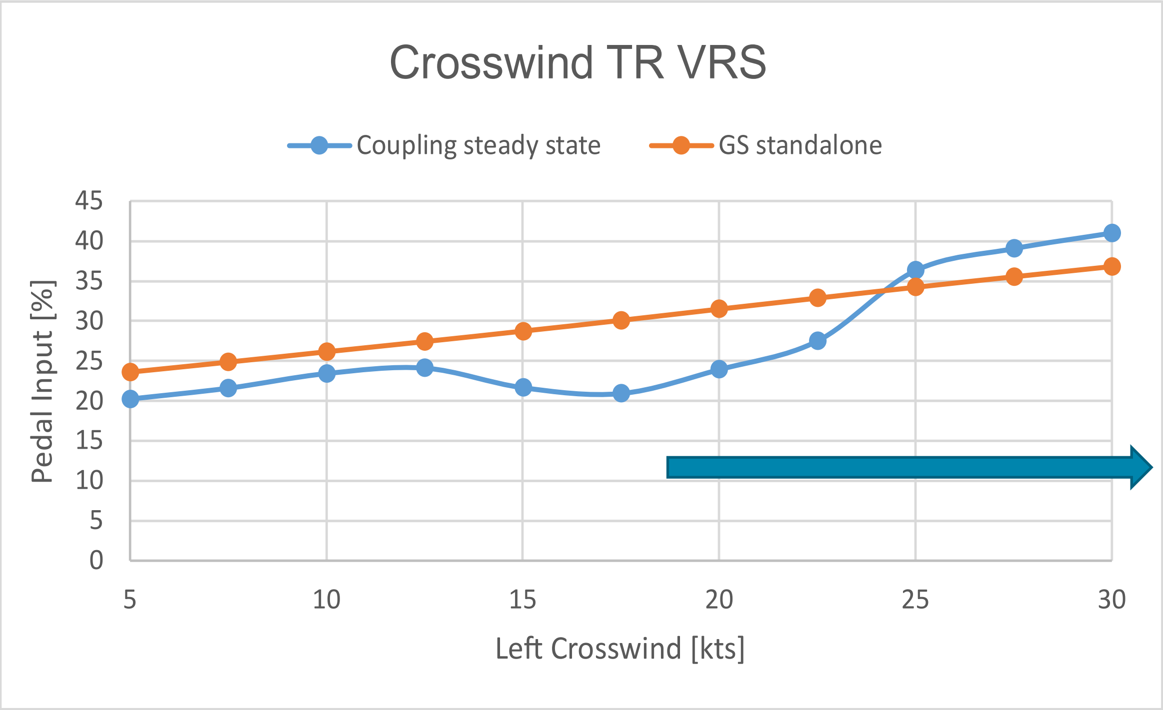
➢ **Remaining pedal margin should always be used**

Vortex Ring state of the tail rotor

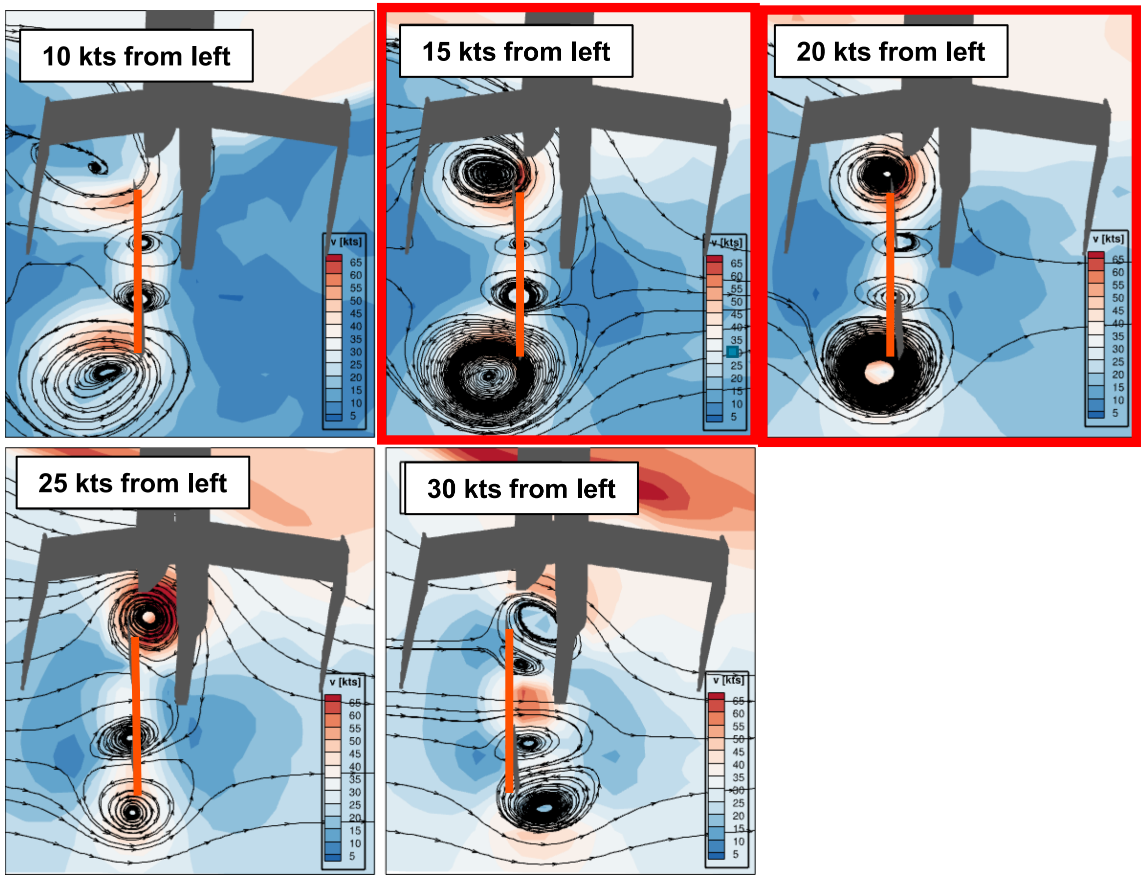
- Yaw trim condition is maintained by TR thrust, caused by induced flow field through the TR disk
- When flying in a left cross wind, conditions for TR-VRS are given
- VRS would result in loss of thrust, causing UY….



Vortex Ring state of the tail rotor



Is this a VRS?



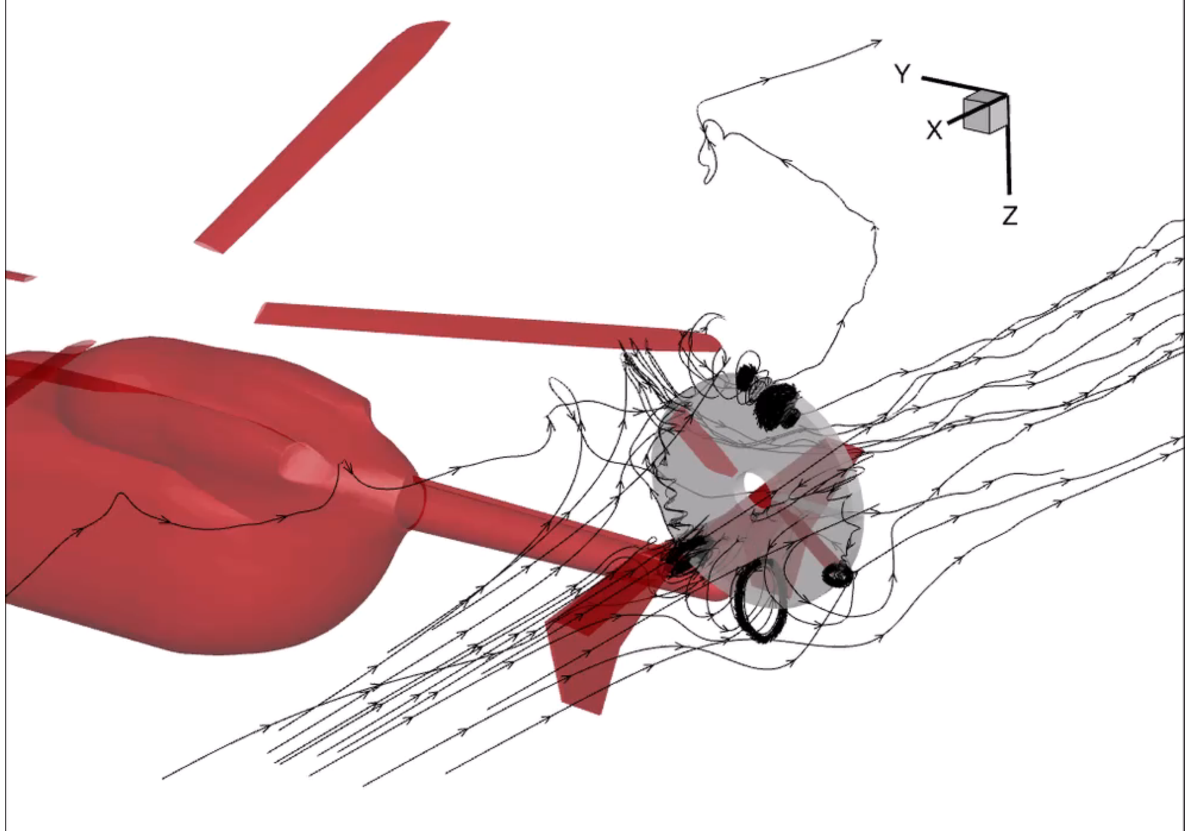
Result for yaw trim condition for full left crosswinds:

- At 17.5 kts cross wind maximum left pedal – indication for a ‚loss of thrust'
- **High control margin/controllability remains**
- High degree of fluctuation/frequency on pedals needed to maintain heading– **potential overcontrol by pilots, resulting in UY motion**

- VRS formation is strongly disturbed by MR wake interference
- VRS stays in the incipient stage, **can not fully develop**
- Loss-of-thrust remains low, as depicted
- Signicant amount of turbulence/fluctuation in the VRS phase

Vortex Ring state of the tail rotor

Effect of the main rotor wake



Wind velocity = 20 knots
Wind azimuth = -90 deg

The main rotor wake effectivley interrupts the build-up of the tail rotor VRS:

- VRS remains in the incipent stage
- Reduction in the loss-of-thrust as compared to full VRS
- The detrimental effect of full VRS is reduced
- VRS reduction is strongest for high tail rotors, with less reduction for low tail rotors

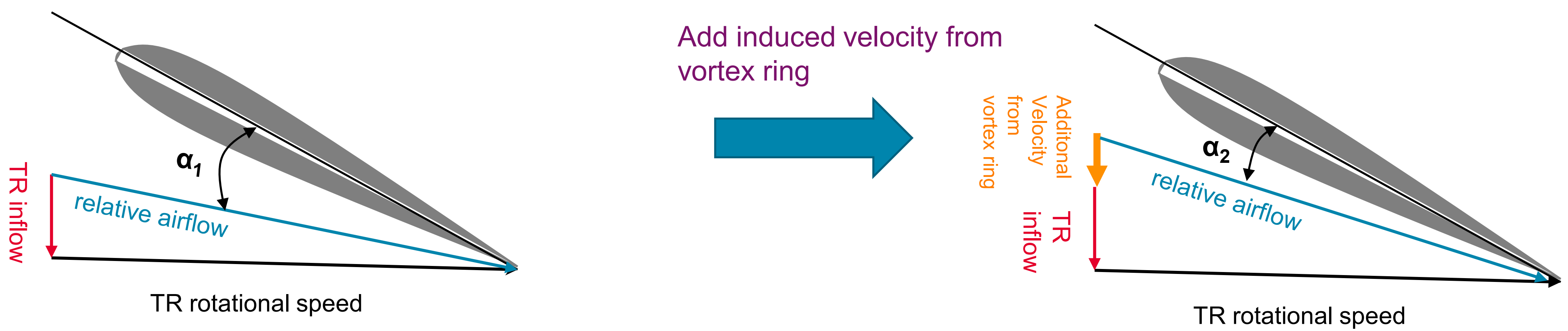
Airbus Amber

Vortex Ring state of the tail rotor - Effect of TR VRS on angle of attack

Schematic depiction, cross-sectional view of a TR blade

Angle of Attack **α_1**

Reduced Angle of Attack **α_2**



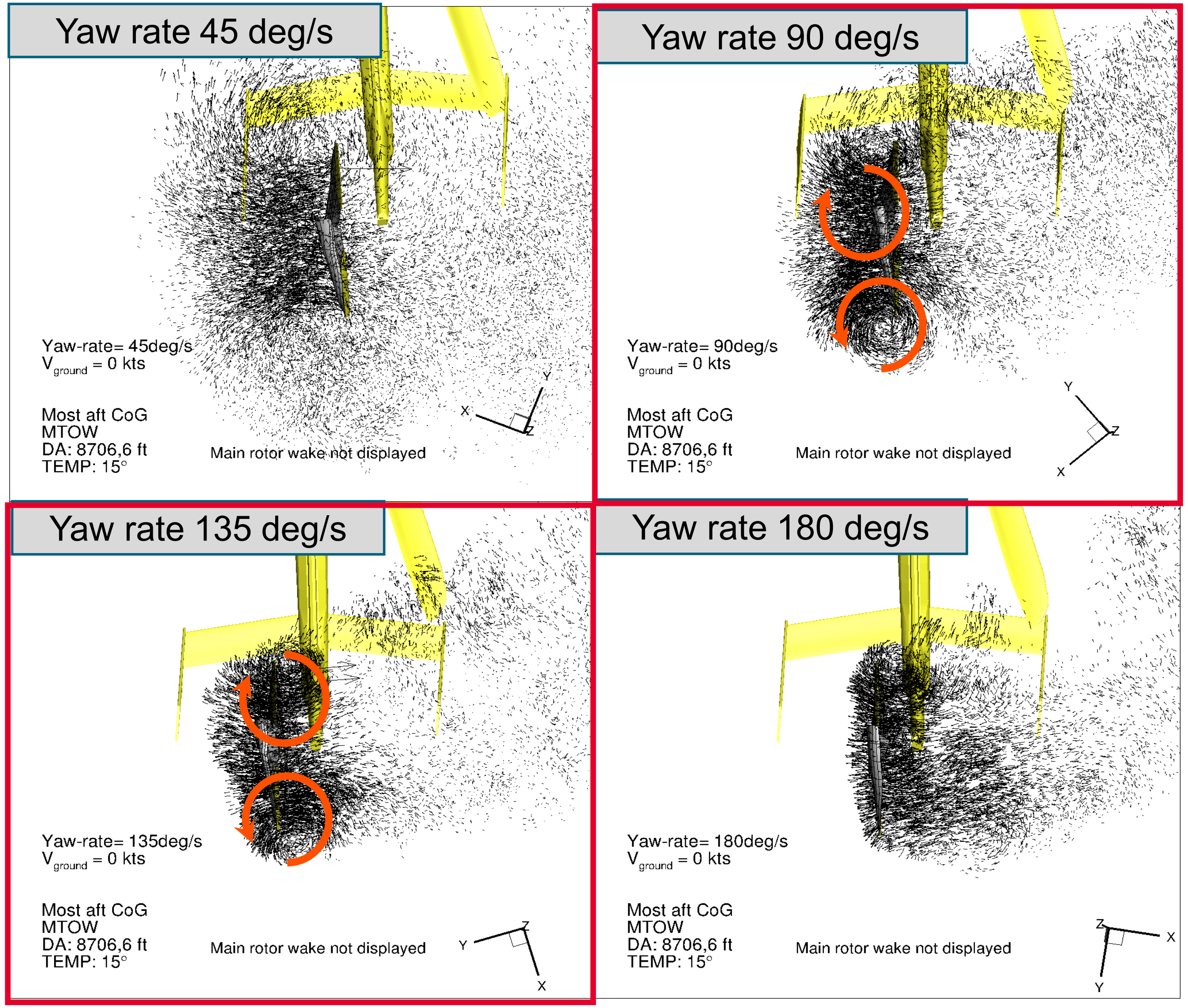
Cross-sectional view of a TR blade

$\alpha_2 < \alpha_1$

Less thrust for same collective pitch

Vortex Ring state of the tail rotor - a bad case…

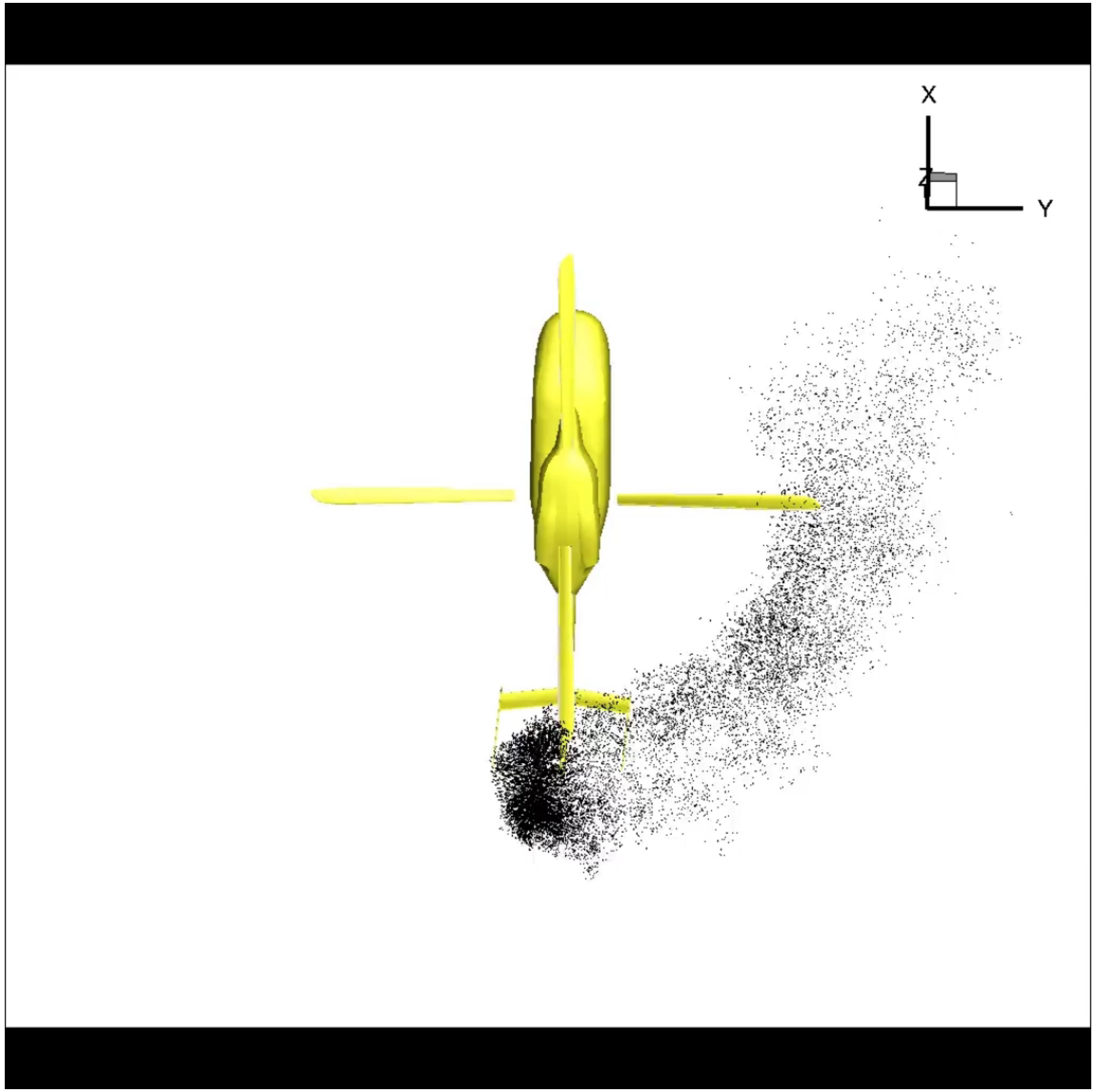
Yaw rotation in hover to the right results in left relative wind on the TR, conditions for the incipient VRS:



- Best incipient VRS seen between 90°/s and 135°/s
- Main rotor wake interference is again clearly visible in the simulation
- **For the dynamic simulation, 101.25 °/s chosen as ‚worst case scenario‘ with lowest TR thrust**

Vortex Ring state of the tail rotor - a bad case…

Unsteady time simulation:
Helicopter with inital yaw rate of 101.25 deg/s



→ **Yaw rate can be stopped by full opposite pedal Input in less than one revolution**

→ **Yaw rate induced TR VRS does not subside on its own**

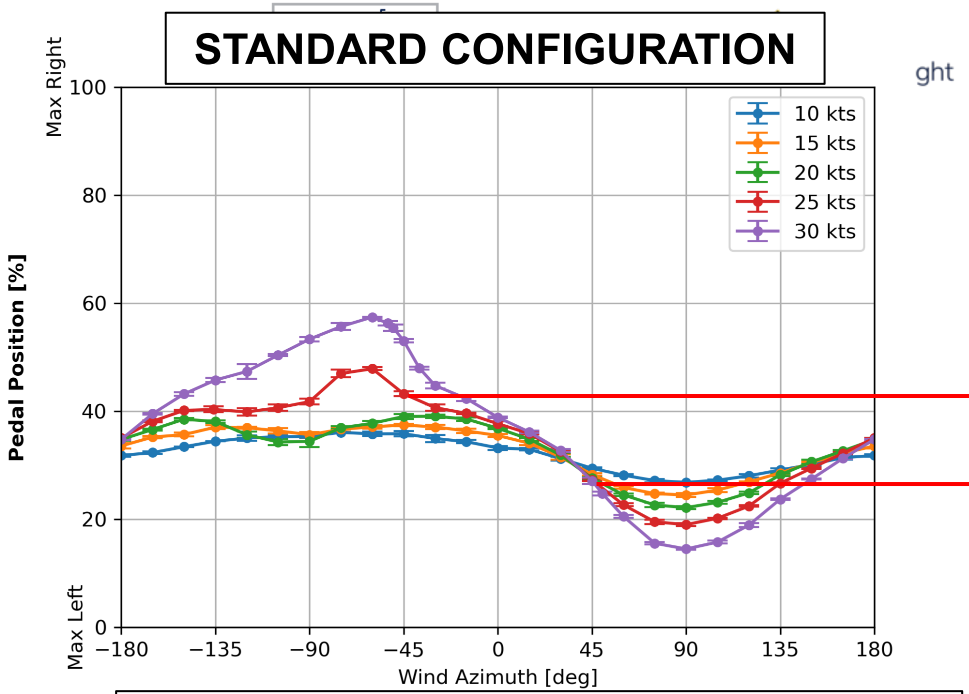
Task: establish the ranking of these effects according to their criticality for UY (finalized…)

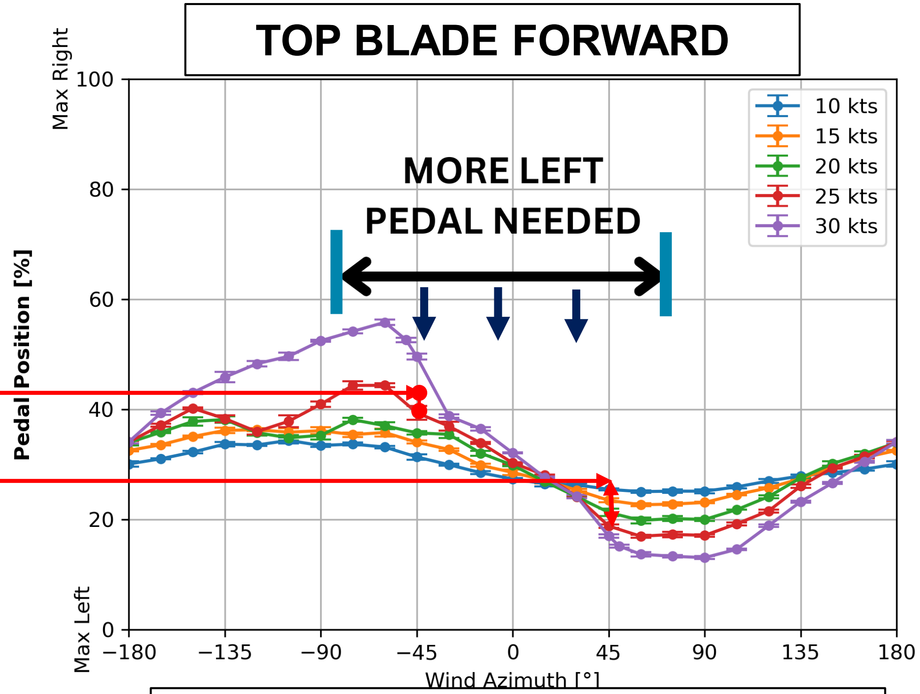
	Cause of the effect	Direction of inadvertent yaw (Counterclockwise rotating MR)	Yaw rate potentially self subsiding	Yaw rate potentially stoppable by opposite pedal input
Entry from Stable into Unstable Control Domain	Pilot action	Left/ Right	No	Yes
TR VRS	Aerodynamical effect	Right	No	Yes
Weathervaning	Stability	Left/ Right	Yes	Yes
Running out of Pedal for Trim with wake interference	Aerodynamical effect	Left for top aft blades Right for top fwd blades	Yes	Yes
Running out of Pedal for Trim w/o wake interference	Stability	Right	Yes	Yes

Configuration study for yaw trim including all effects

- Simulations covering wind speeds from 10kts to 30 kts, covering the 360° azimuth
- All aerodynamical effects considered during the simulation
- Performed for different helicopter configuration (BK117-C2 numerical model altered accordingly):

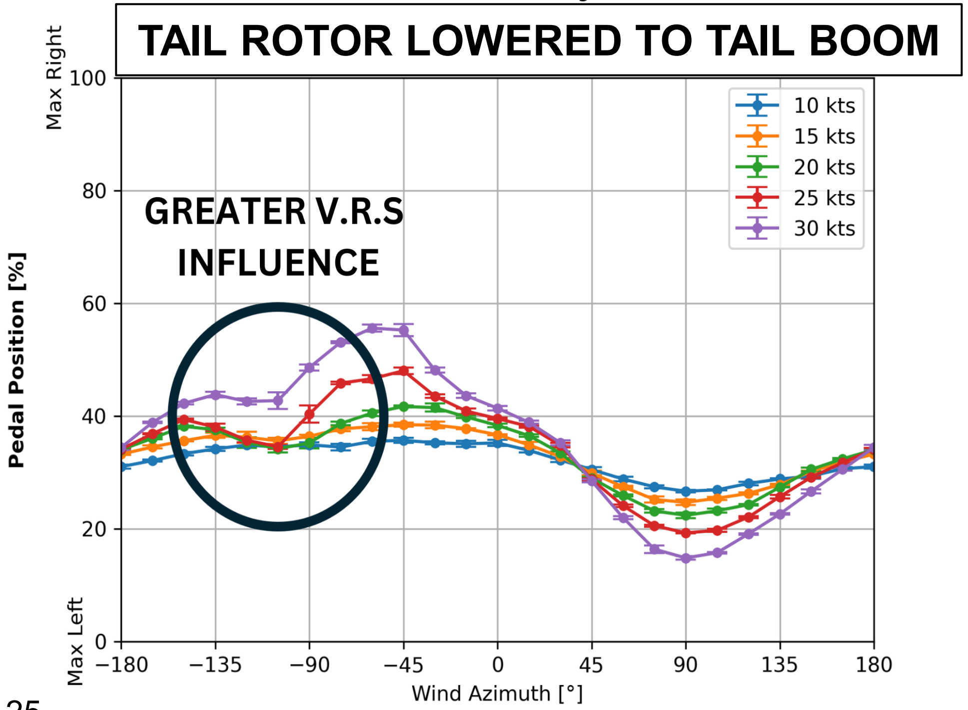
1. Tail rotor mounted on vertical fin, top blade rotating aft *(standard configuration)*
2. Tail rotor mounted on *vertical fin, top blade rotating forward*
3. Tail rotor mounted on the *tail boom, top blade rotating aft*
4. Standard configuration at lower weight – *reduced disc loading of MR*

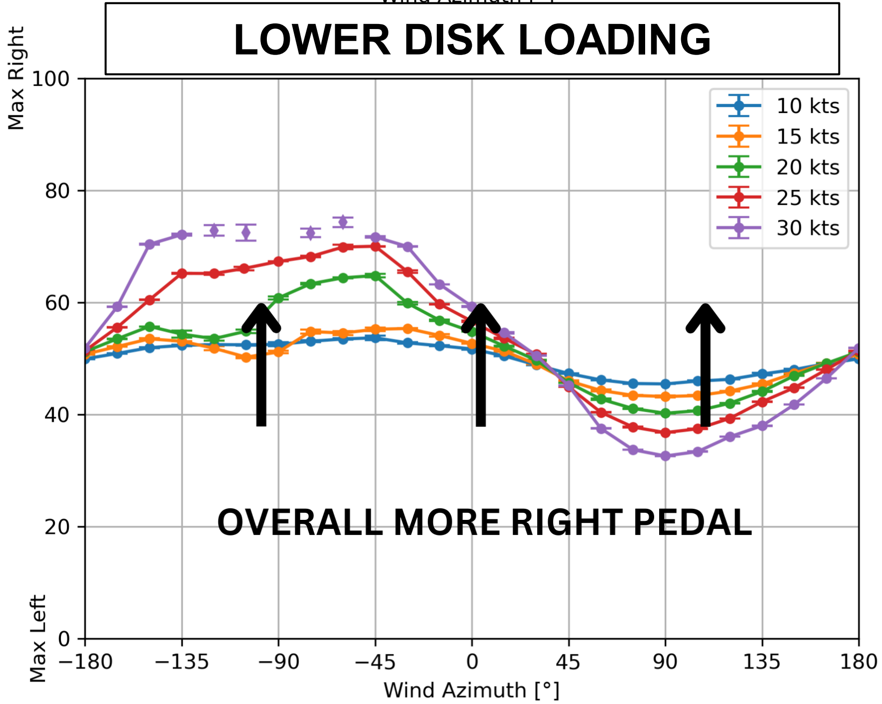




Pedal positions for different helicopter configurations

- Pedal position for trim still remains within the available range and sufficient control for all configurations



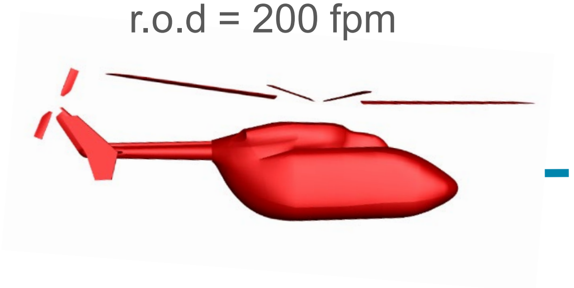


Time domain simulation based on accident data – the accident

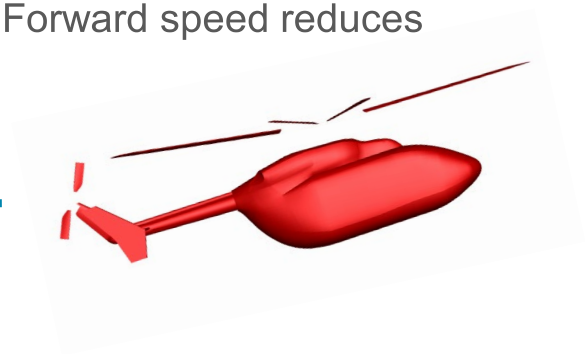
Time domain simulation based on accident data

- Recreating an unintended yaw accident during an approach for landing

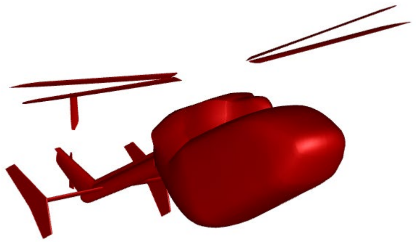
Level flight descending
t = 0 s
vx = 40 knots
r.o.d = 200 fpm



Increased pitch attitude 10 degrees in 3 seconds
t = 3 s
Forward speed reduces



Freeze of pedal position
t = 9 s
vx = 26.67 knots
r.o.d = 128 fpm



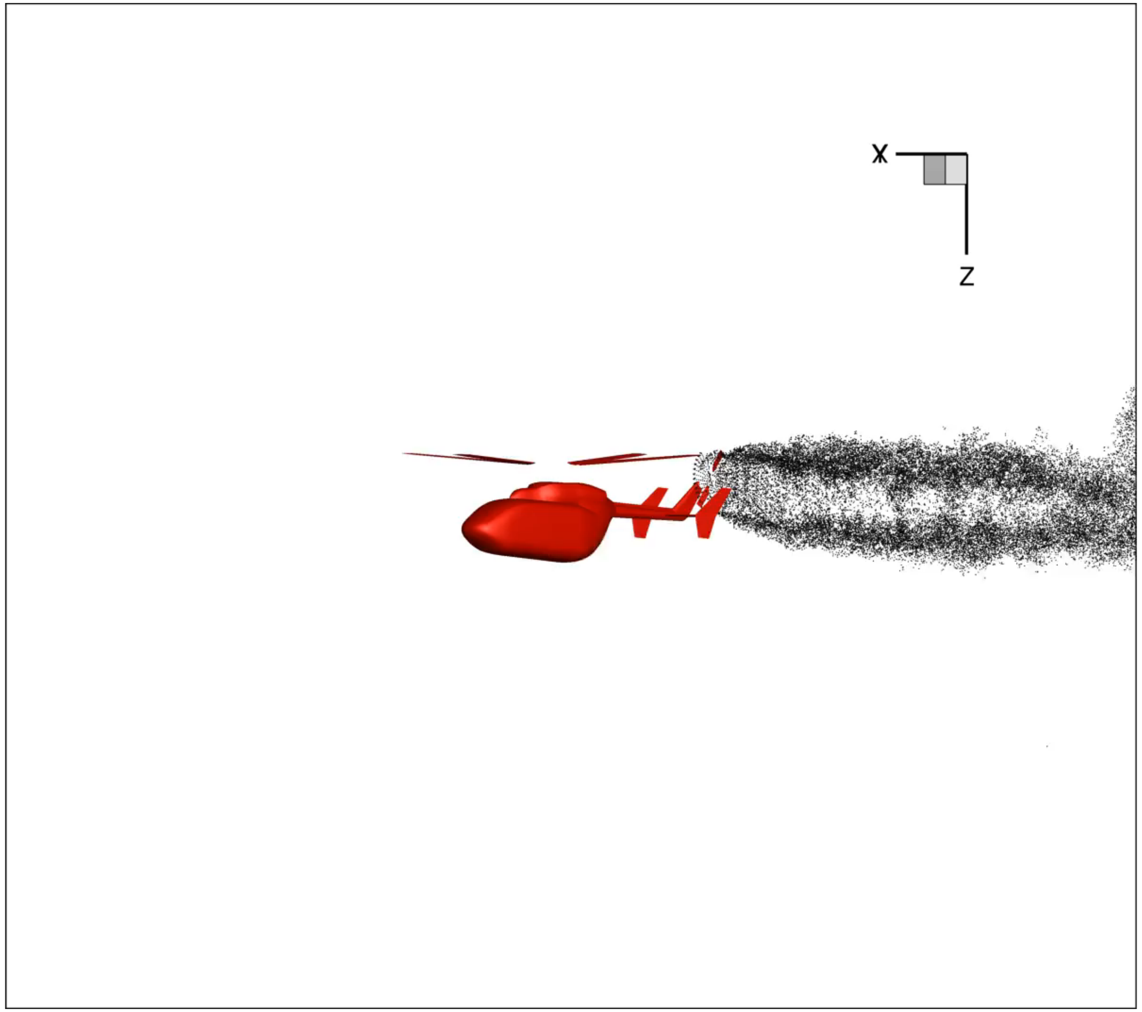
Increase collective stick 20% in 6 seconds
t = 15.12 s

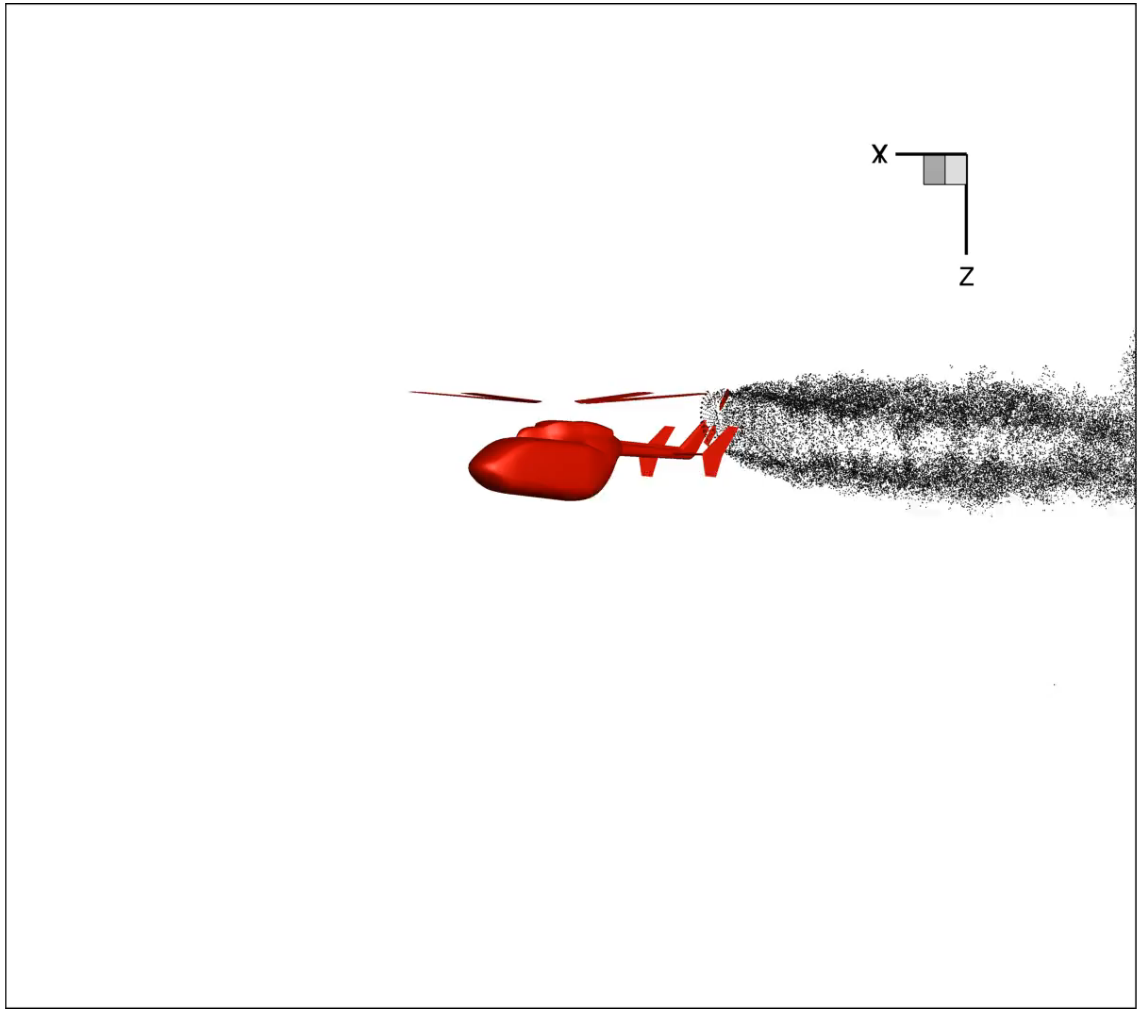
→ Yaw rate reaches > 100 deg/s

→ Apply different left pedal deflections (10%, 50%, 100% of remaining stroke)
t = 21.12 s

Remark:
If yaw rate = 0 deg/s
Level flight

RESULTS – Recovery Methods



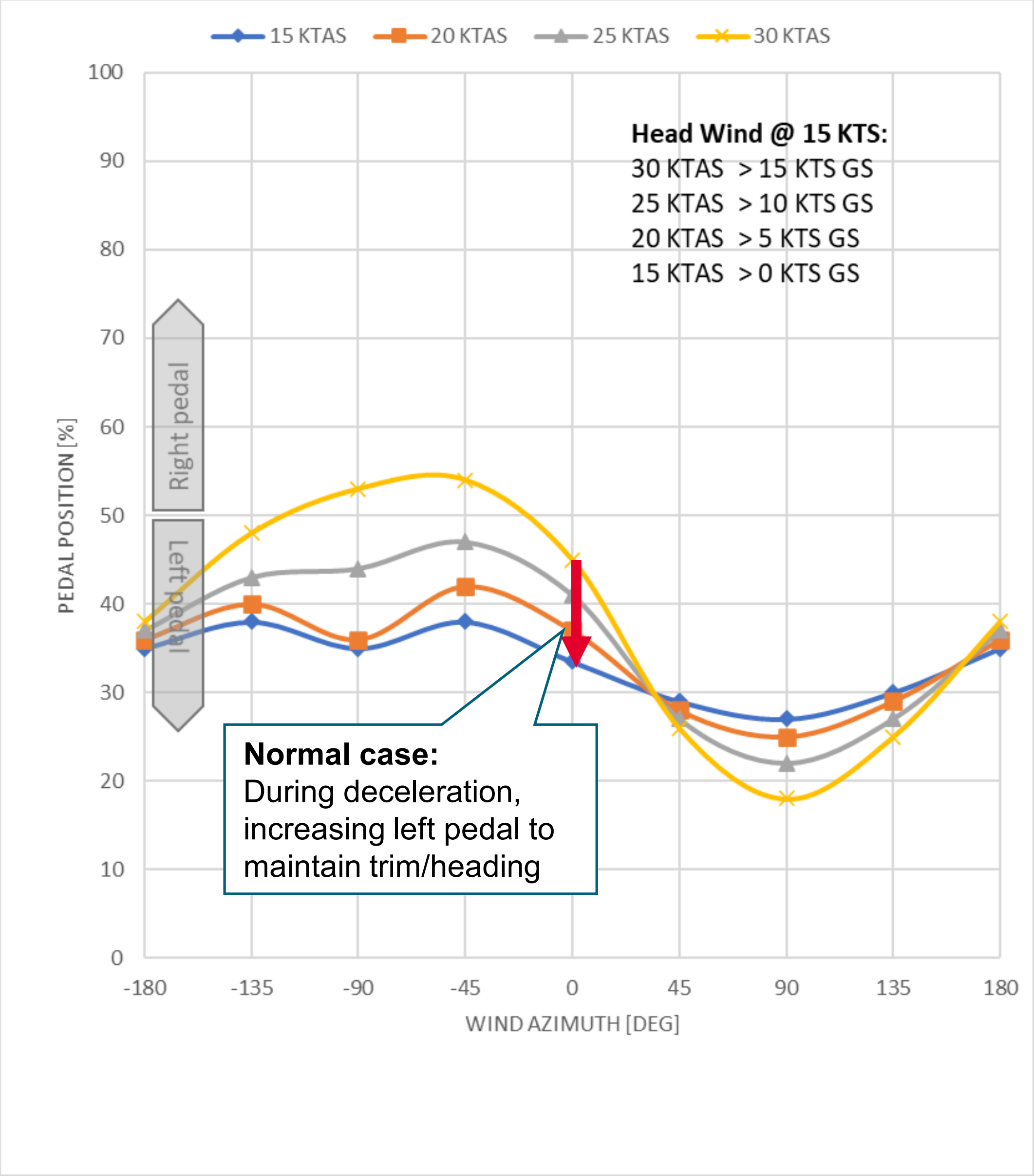


Conclusion: use a decisive and full opposite pedal input for recovery, it will work…

Accident evolution – Flight Physical Explanation

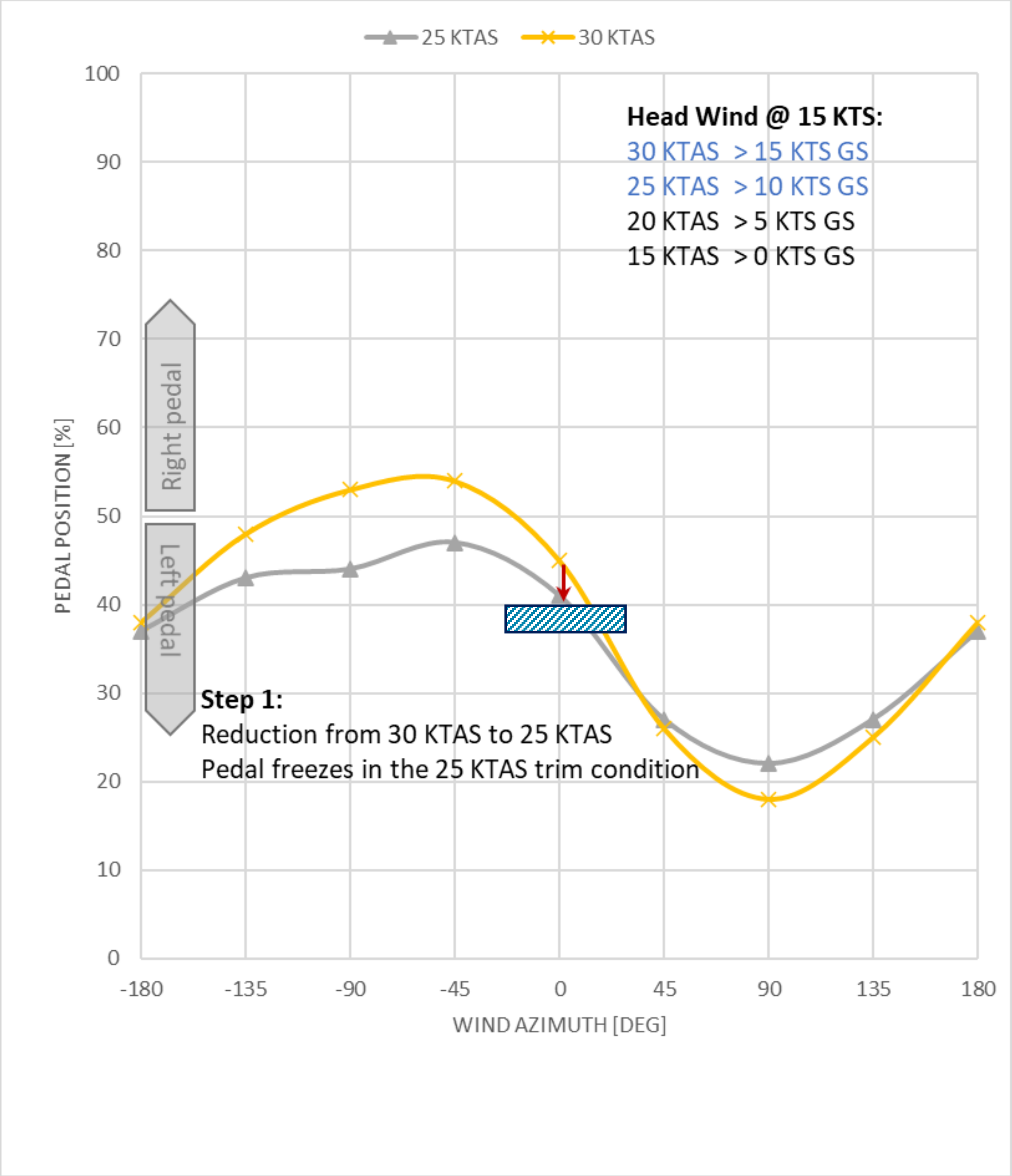
- Accident scenario applied to the computed trim data for BK117 C2
- Flight into a 15 knots head wind assumed

- First illustration:
  – Normal deceleration, full pedal stroke available



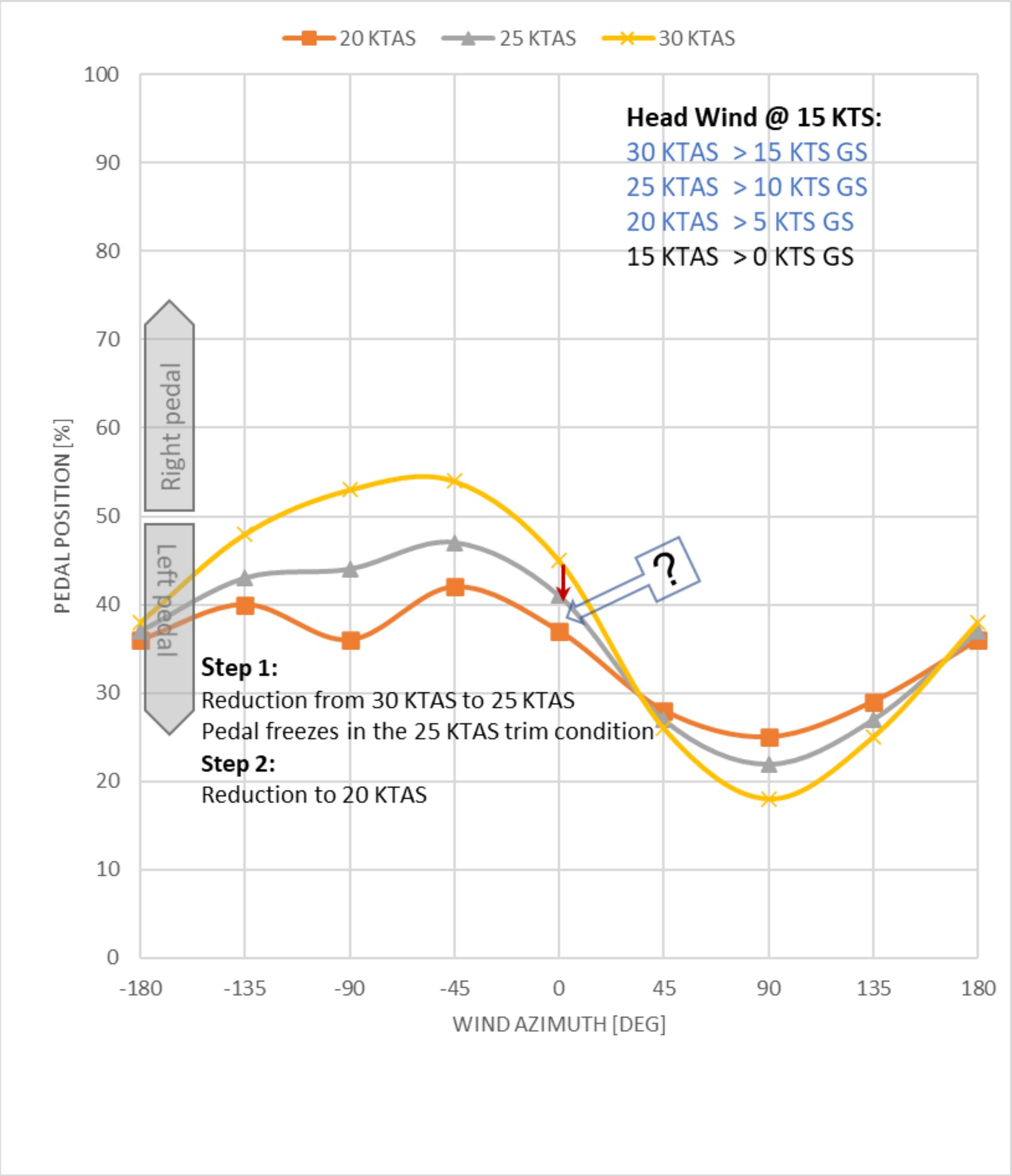
Accident Evolution – Flight Physical Explanation

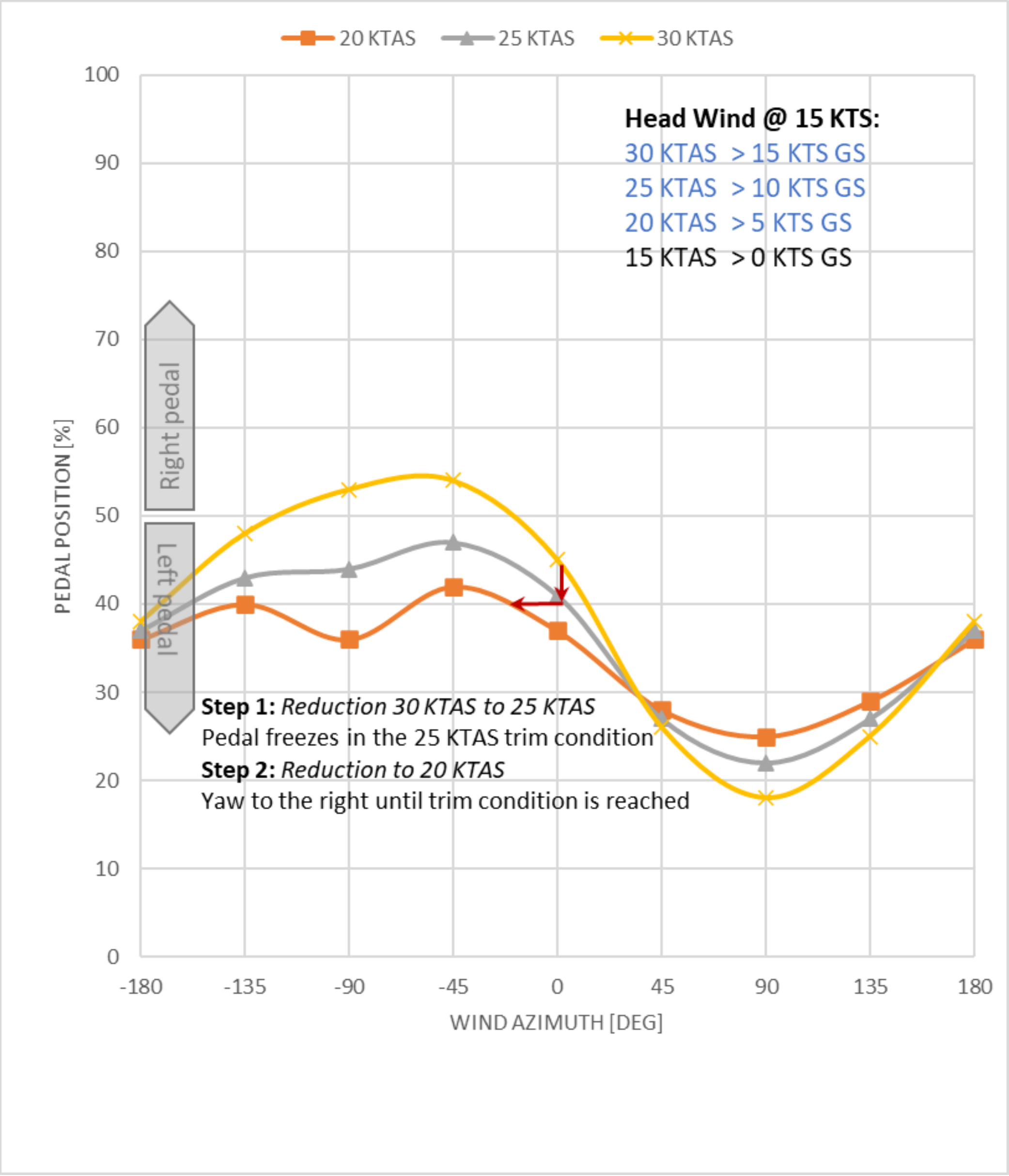
- Accident scenario applied to the computed trim data for BK117-C2
- Flight into a 15 knots headwind assumed
  - Normal deceleration from 30 KTAS to 25 KTAS
  - Pedal blocked/frozen at this condition



Accident Evolution – Flight Physical Explanation

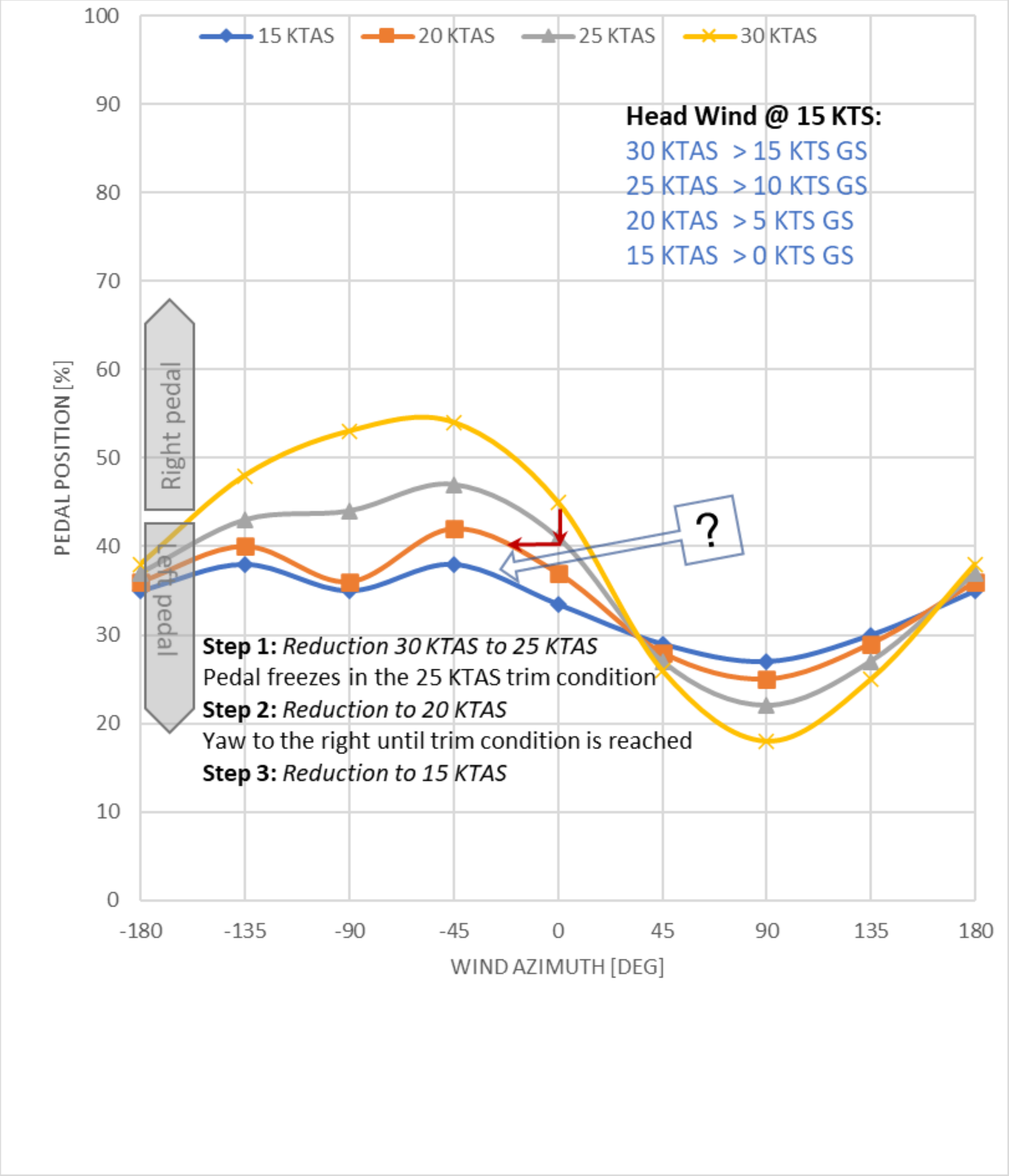
– further deceleration from 25 KTAS to 20 KTAS, pedal blocked

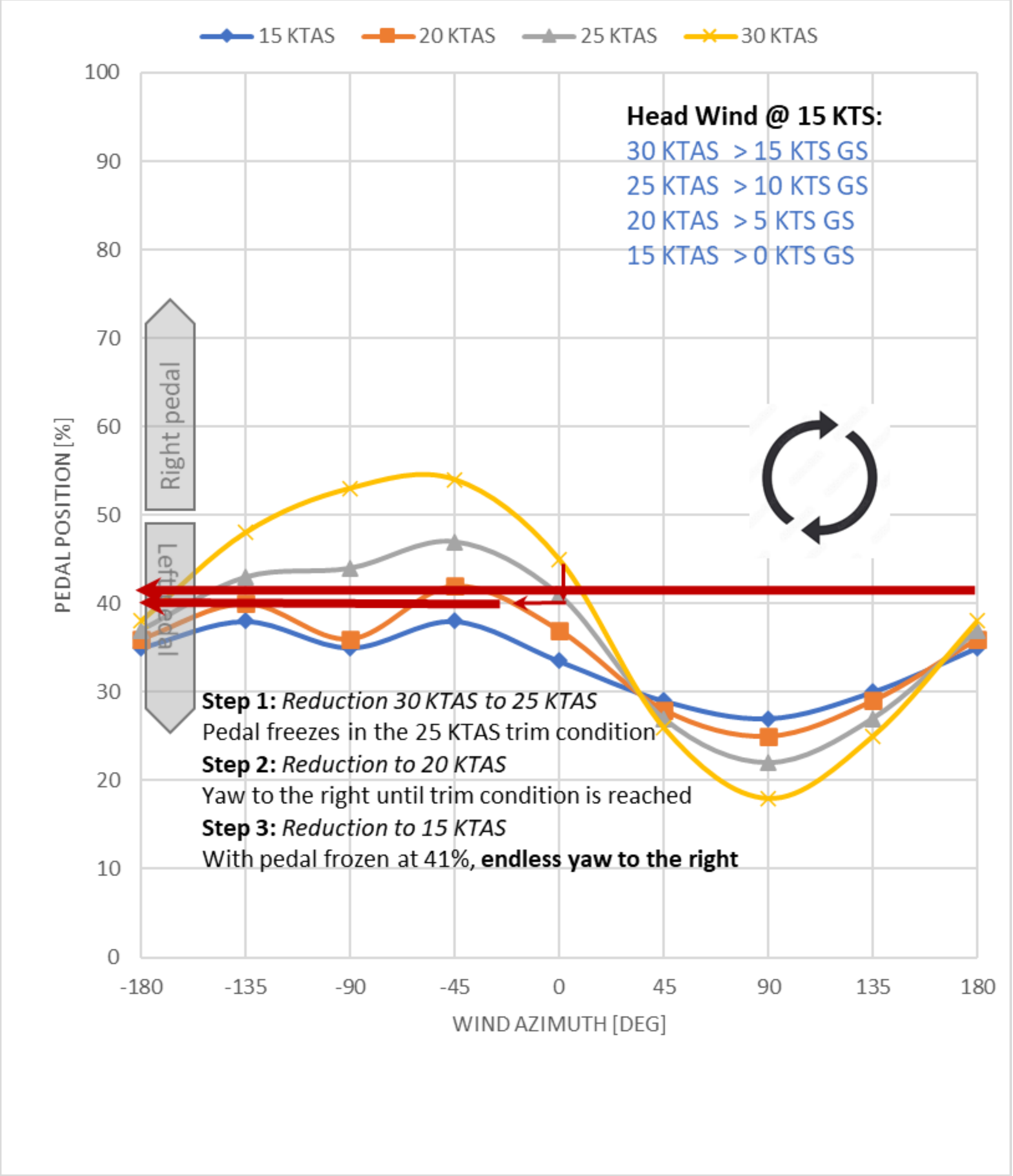




Accident Evolution – Flight Physical Explanation

– further deceleration from 20 KTAS to 15 KTAS, pedal blocked

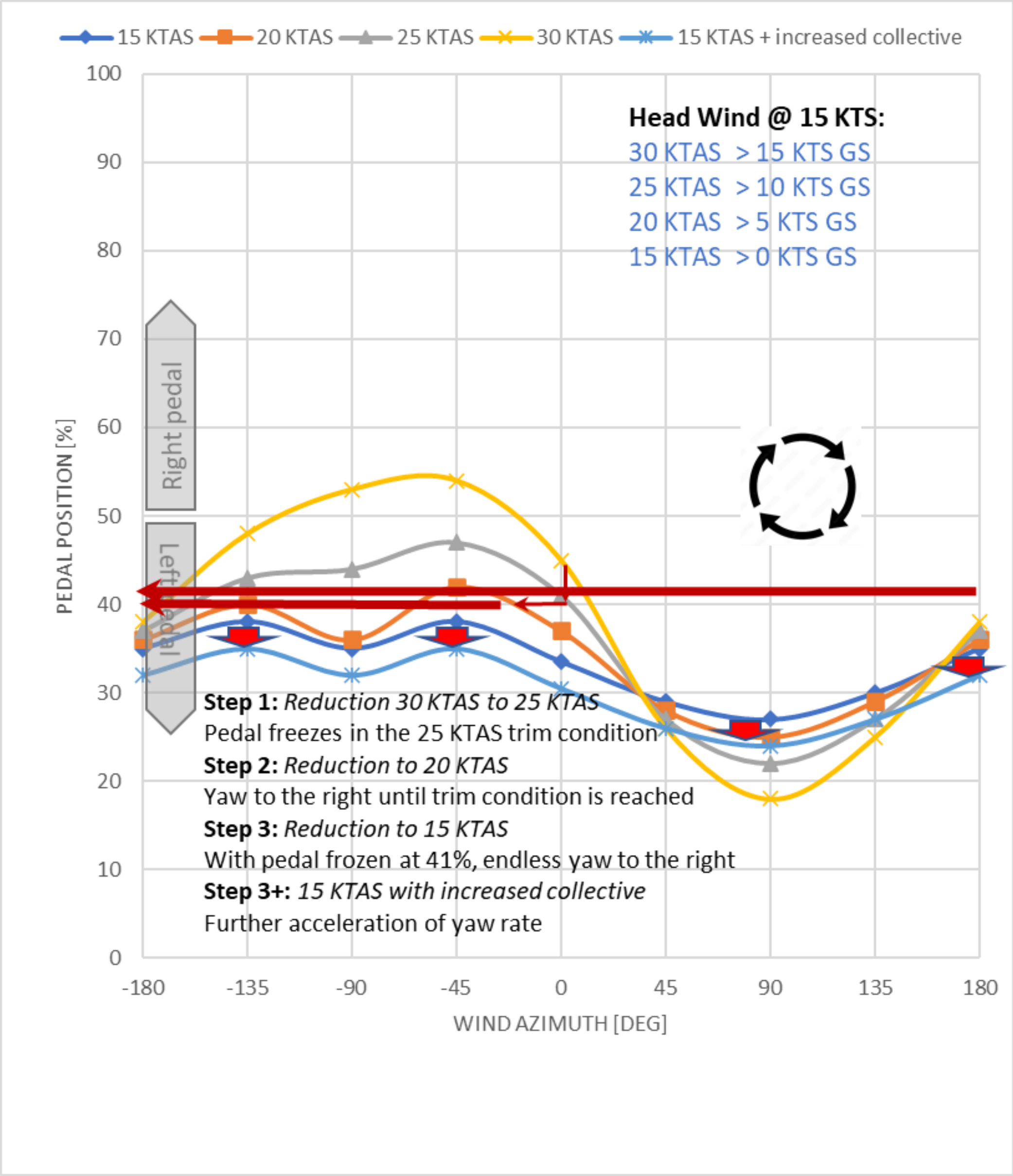




Accident Evolution – Flight Physical Explanation

– By reflex, the MR collective is increased

➢ **Acceleration of yaw rate**



Link to the real world: Implications for flight operations – bring the knowledge into the cockpit

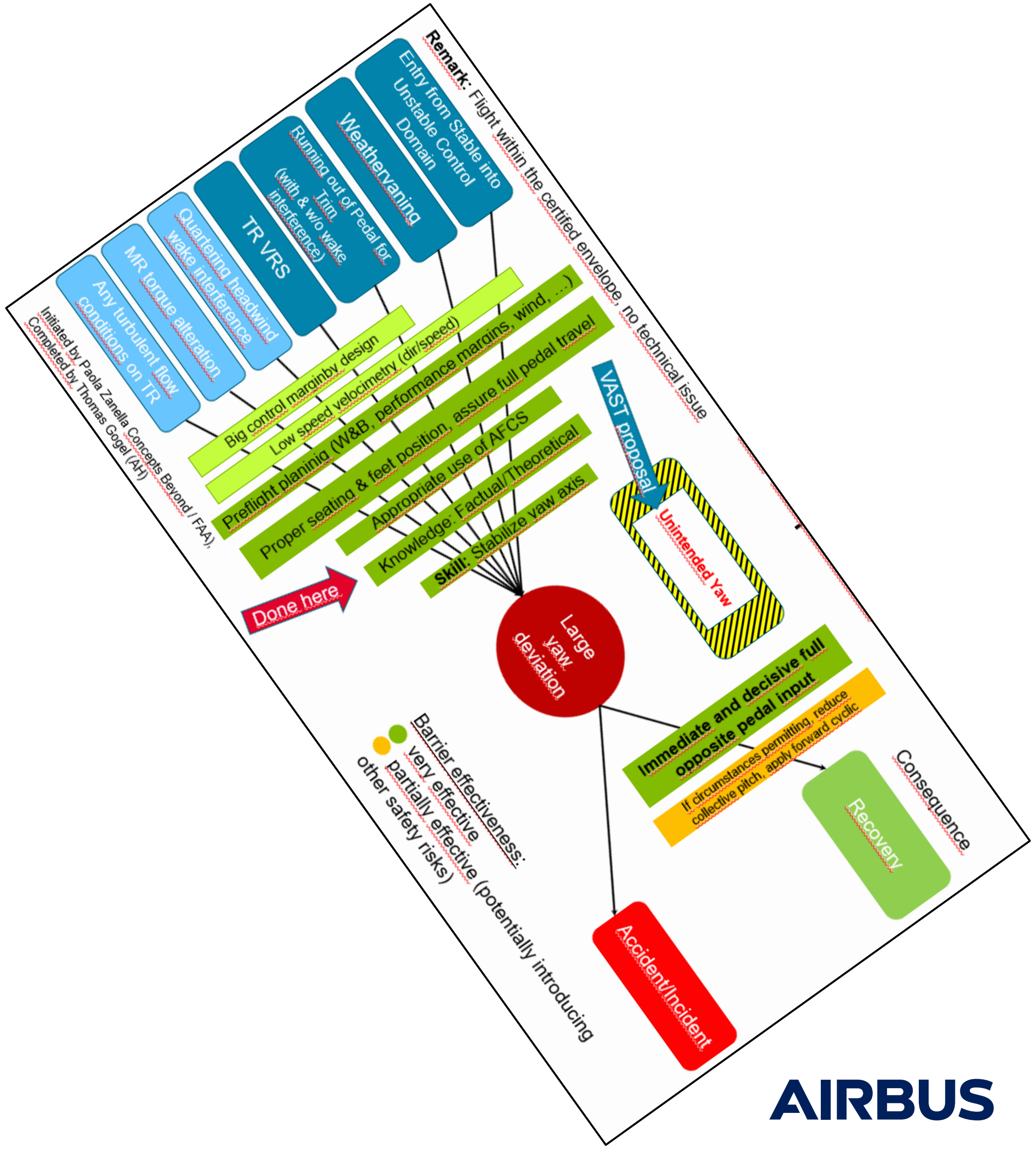
Take aways from the analysis:

1. <u>Preventive barriers:</u>

- Proper preflight planing and situational awareness (W&B, performance margins & FLM flight envelope, wind/gusts including obstruction/building turbulence, full pedal travel available etc.)
- Proper seating and feet position on the pedals and pedal adjustment, assure full travel
- Appropriate use of Automation
- **Factual and theoretical knowledge**
- Piloting skills to stabilize yaw deviations

2. <u>Corrective barriers:</u>

- **Immediate and decisive full opposite pedal input**
  -whatever the flight-physical cause, the same pilot reaction is needed…




The End
Thank you for listening!