

What Is Unintended Yaw? The Science Behind the Words

Flight-Physical Insights to Help Preventing of Loss-of-Yaw Control Accidents

European Rotors
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HELICOPTERS

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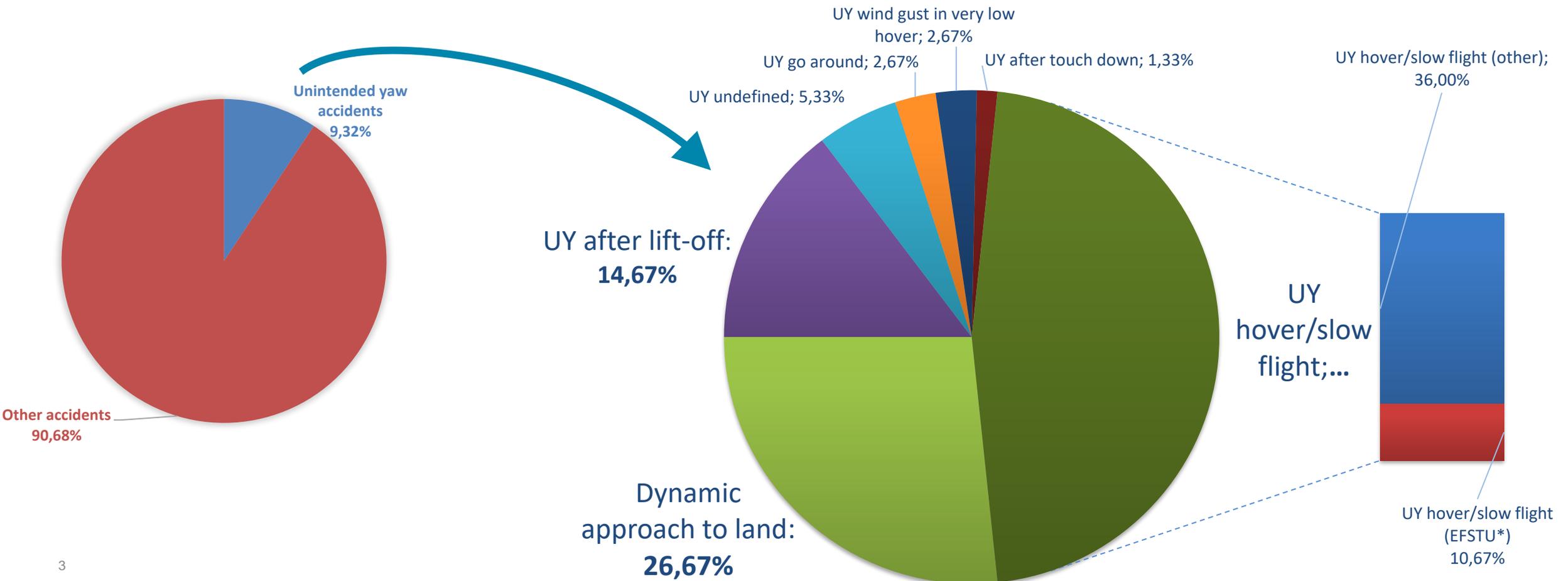
AIRBUS

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- Latest flight physical insights – the nerd part...
- Link to the real world: Implications for flight operations – bring the knowledge into the cockpit
- Conclusion

Motivation – why resume a decade old discussion with vigor?

UY Airbus Helicopters' fleet accidents 2013-2023



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 misconception, misnomers and bad assumptions still exist
- Issue became in the focus of VAST Technology Team
and ESPN-R in 2022

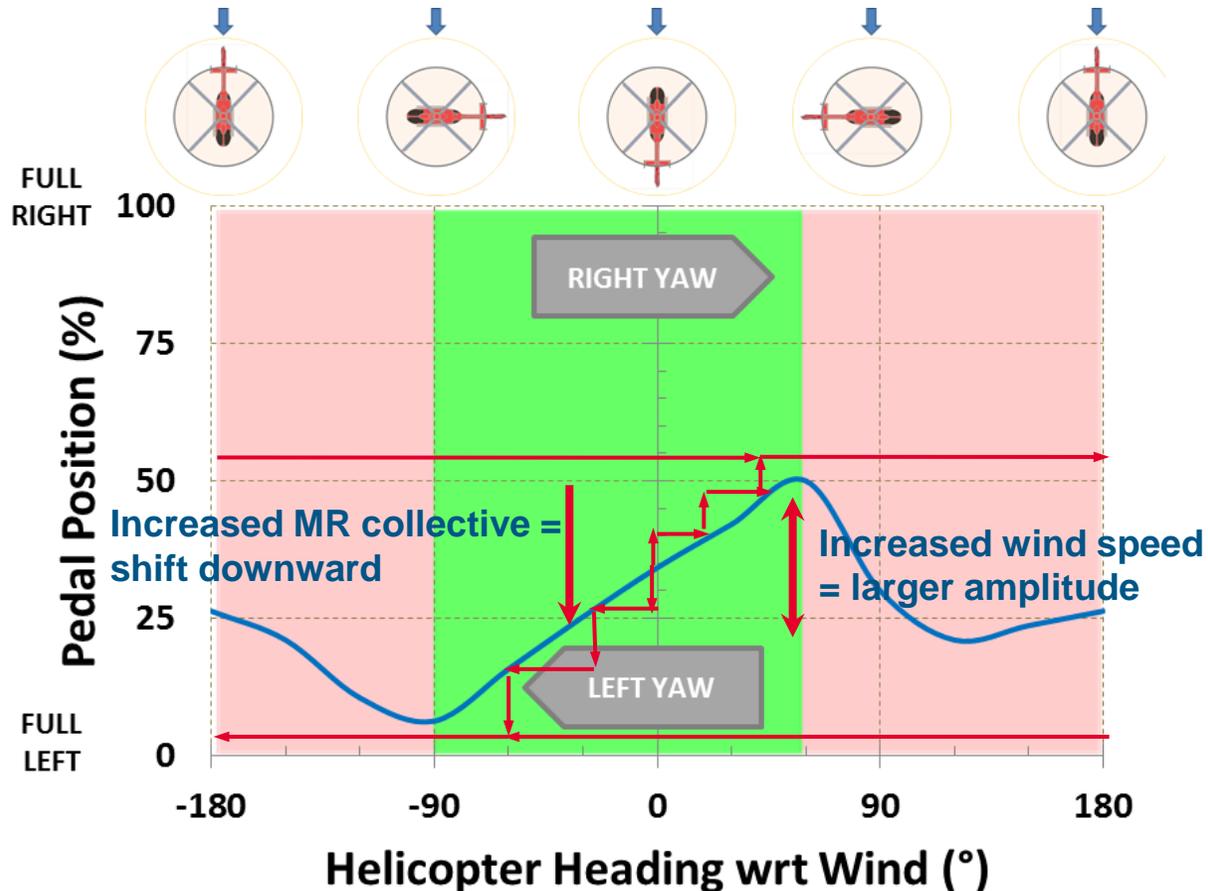
Latest flight physical insights – the nerd part...

Part 1:

The yaw-trim curve – pedal position needed to maintain a specific heading in a wind field

Latest flight physical insights – the nerd part...

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



- Trim curve stabel 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 stabel 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>

Latest flight physical insights – the nerd part...



Accident related to the phenomenon:

Hover/low speed yaw turn in strong/gusty winds

Latest flight physical insights – the nerd part...

Part 2:

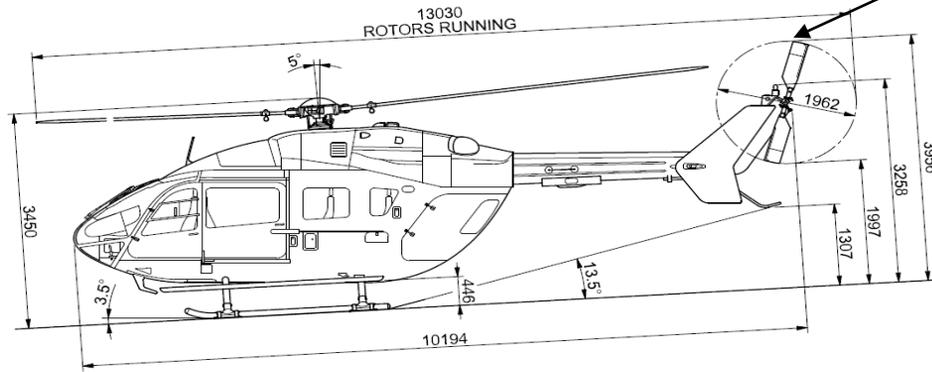
Deeper analysis of additional flight physical and aerodynamic effect for helicopter with a conventional tail rotor to be superimposed on the yaw trim curves

- Analysis done with a Bachelor Thesis (concluded)
- and a Master Thesis for finalization (ongoing)
- both done under the  umbrella, with co-supervision from a FAA expert

Latest flight physical insights – the nerd part...

BK117 C2 used for simulation

Counter-clockwise MR rotation



High tail rotor with top aft rotation



Flight condition:

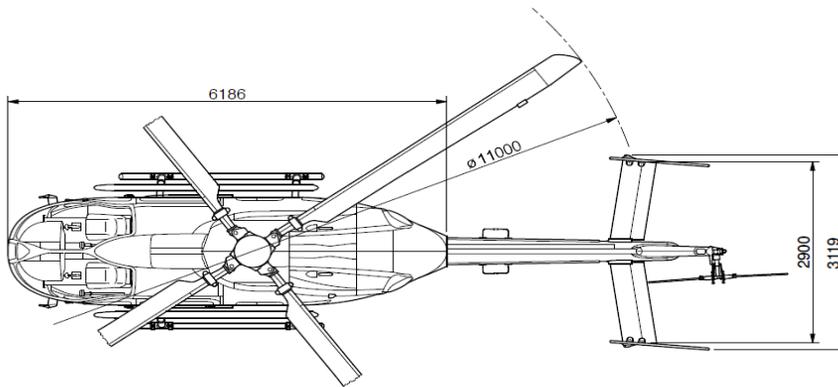
Pressure Altitude: 2134 m (7 000 ft)

Density Altitude: 8706,6 ft

Critical weight MTOM: 3585kg

Critical centre of gravity: most aft

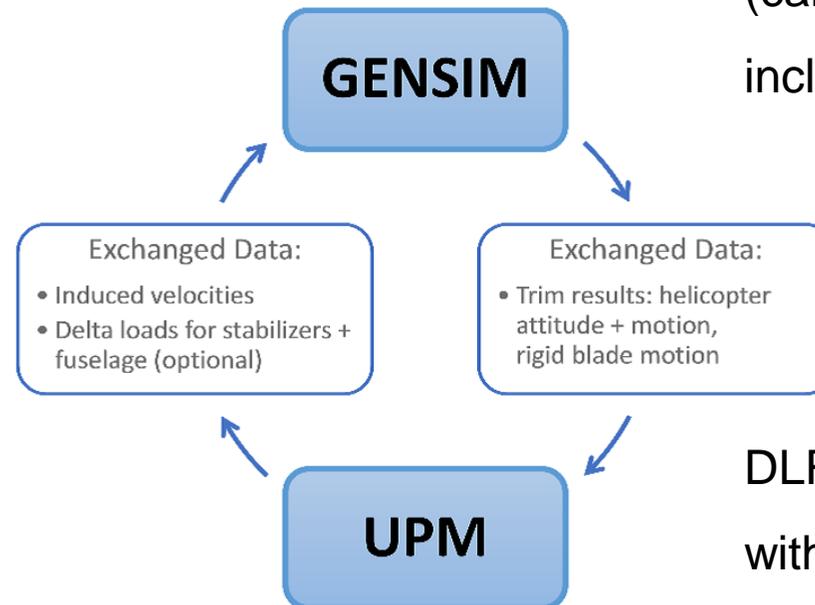
Representative mid-weight helicopter model



Relative large end-plates

Latest flight physical insights – the nerd part...

Numerical tools used:



AH flight mechanic, 6 DOF code
(can also be run stand-alone with a
included basic aerodynamic modelling)

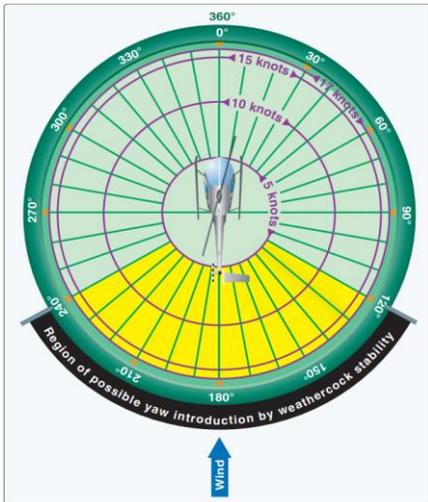
DLR unsteady panel method,
with **inclusion of vortex interaction**
for sophisticated flow simulation

Latest flight physical insights – the nerd part...

Further effects to be considered:

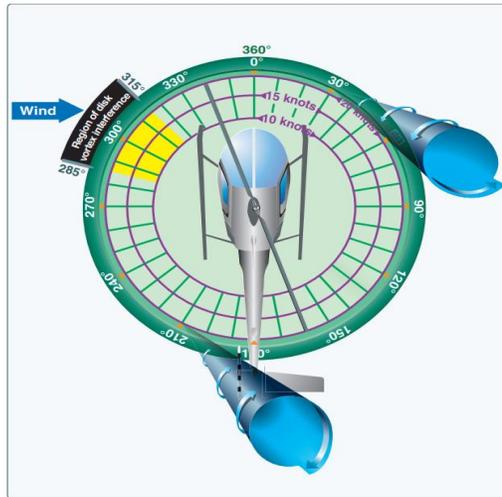
Weather vanig

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



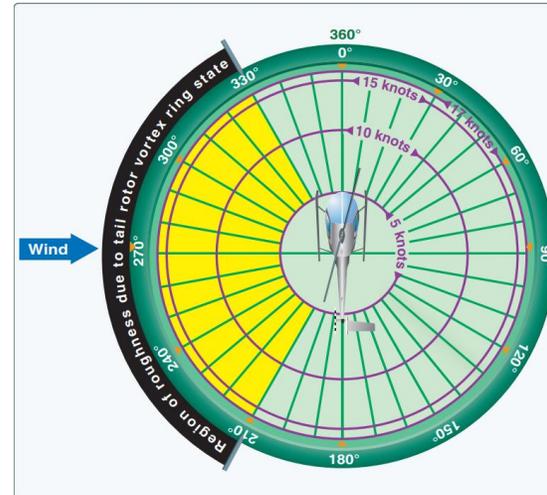
Forward-left relative wind, MR vortex interaction with TR

-not yet investigated, case with a high control margin



Tail Rotor VRS

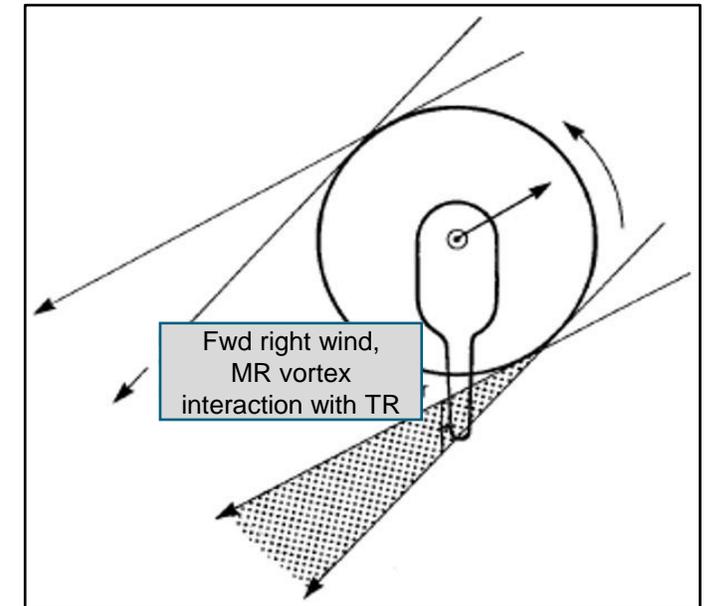
investigated



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)

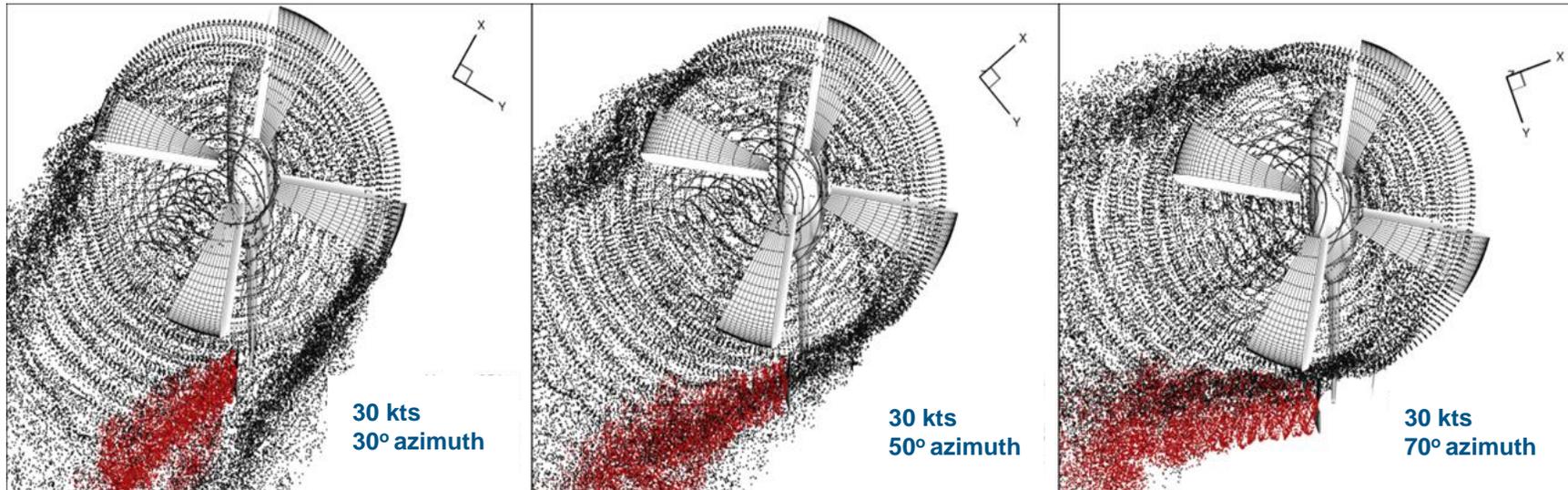
investigated



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

Latest flight physical insights – the nerd part...

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



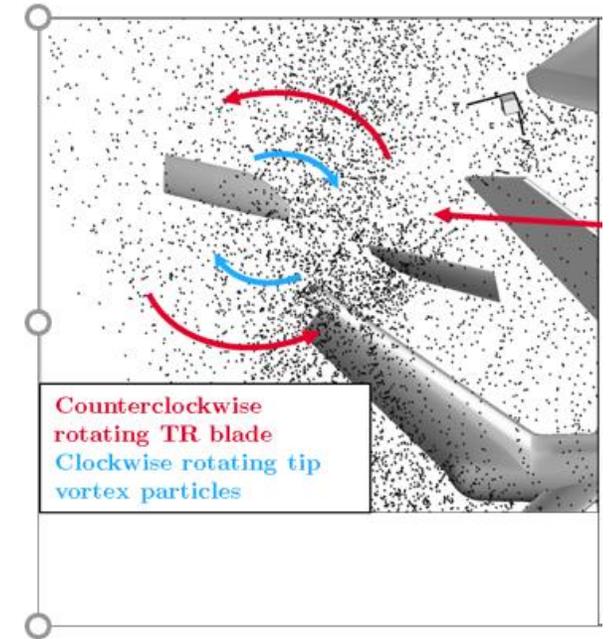
Findings:

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



Explanation for thrust increas for top blad moving aft thrust increase:

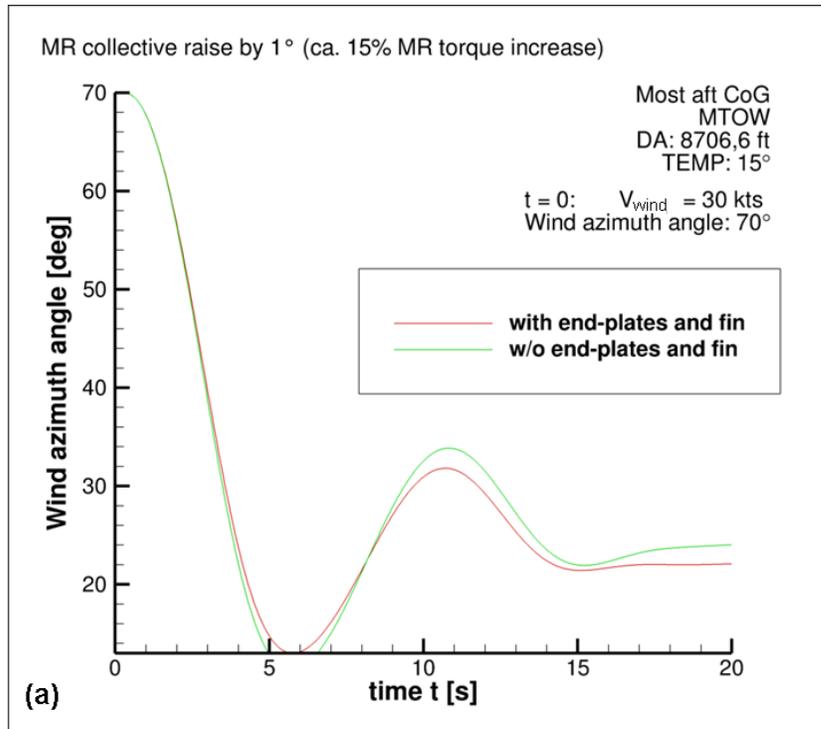
MR vortex sheet rotates in opposite direction to TR blade rotation, higher velocity on blade results in increase thrust

Latest flight physical insights – the nerd part...

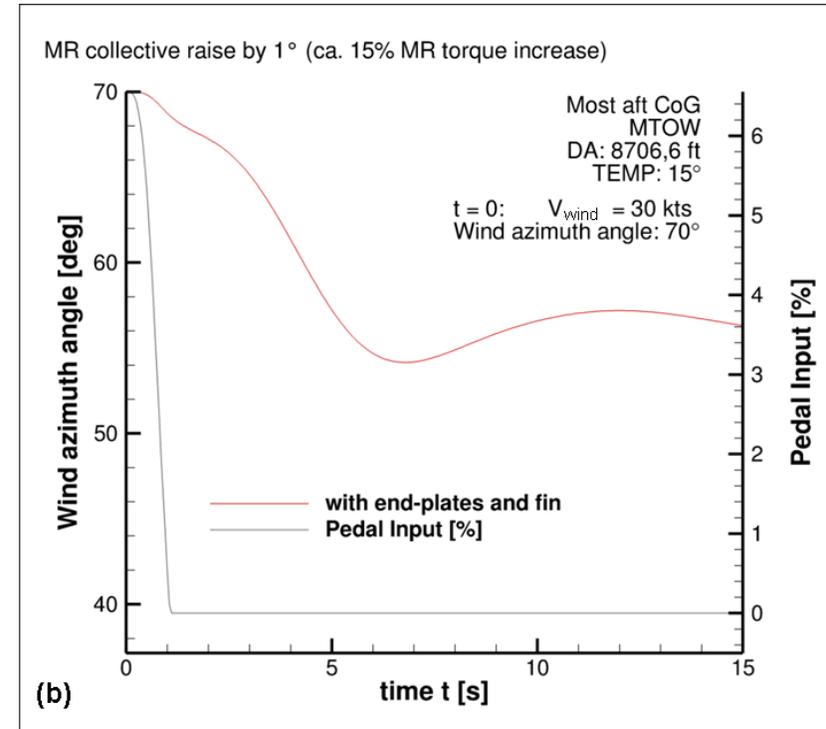
Runnig-out-of-pedal-for-trim (wind from 70° azimuth at 30 kts)

Trim condition: 4% of left pedal input still left

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



Case 1: dynamical response, pedal frozen
➤ **Potentially self subsiding**

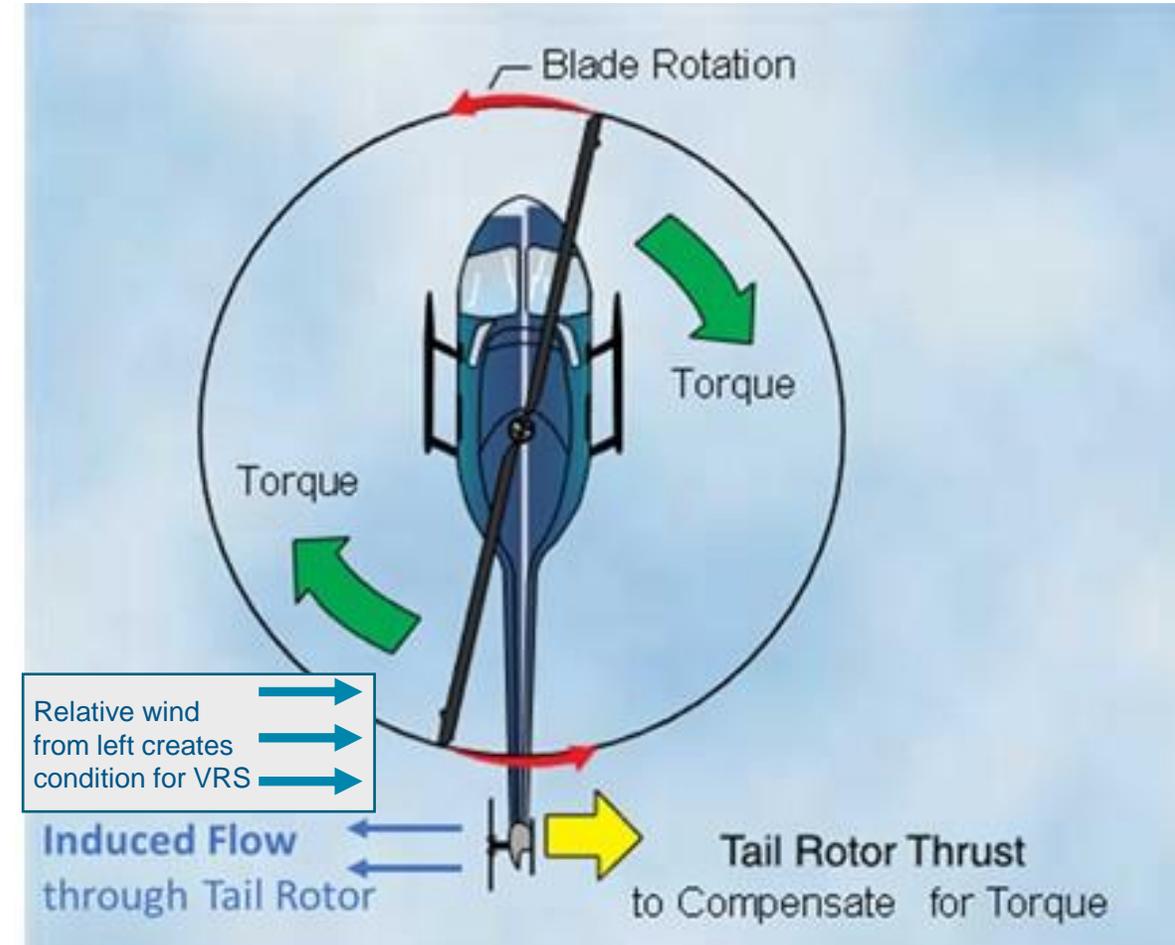


Case 2: dynamical response, pedal input to full left over 1s
➤ **Remaining pedal margin should always be used**

Latest flight physical insights – the nerd part...

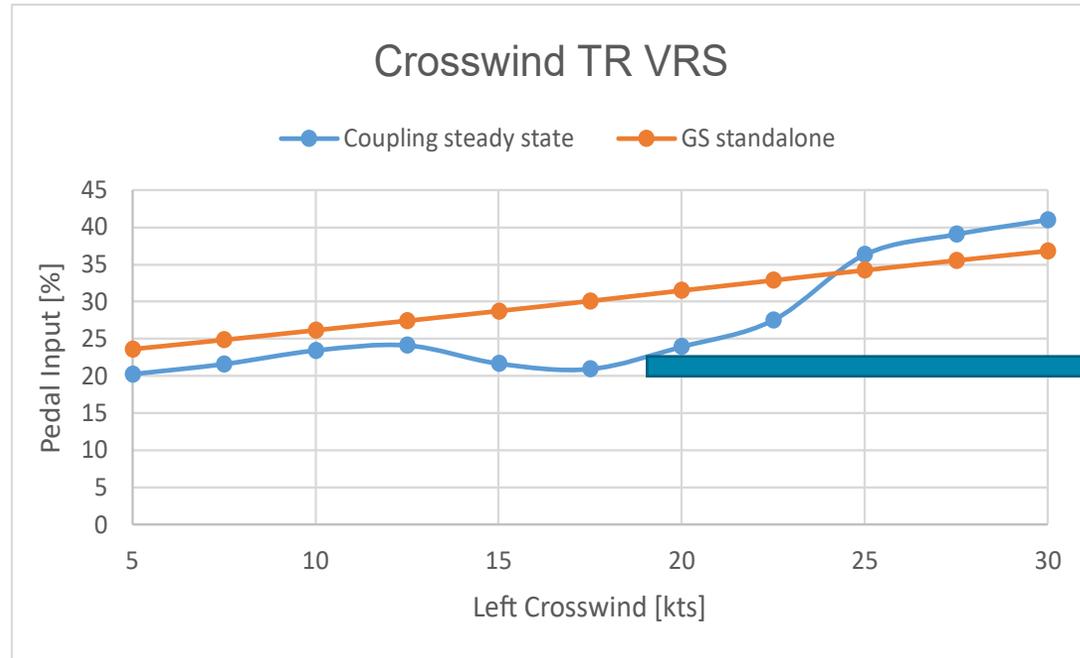
Vortex Ring state of the tail rotor

- 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....



Latest flight physical insights – the nerd part...

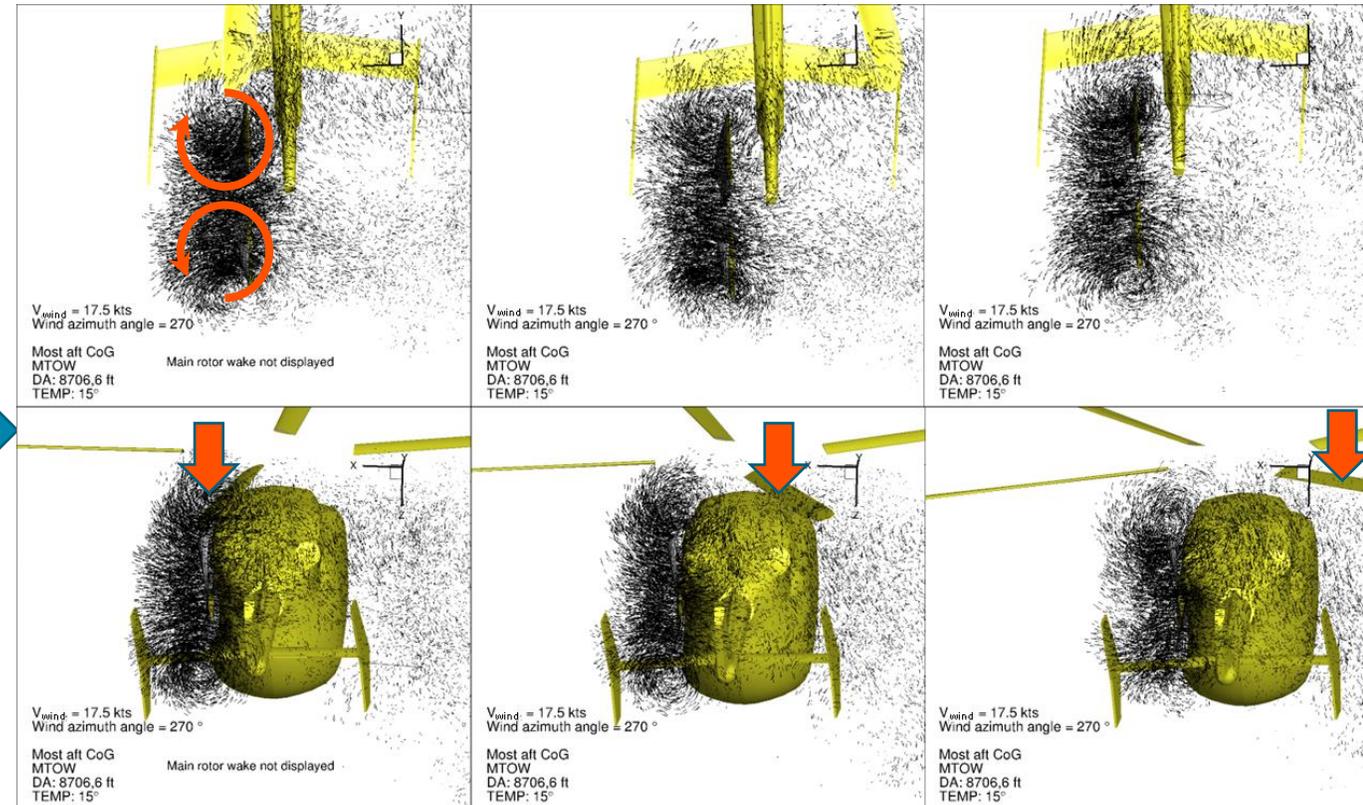
Vortex Ring state of the tail rotor



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**

Is this a VRS?

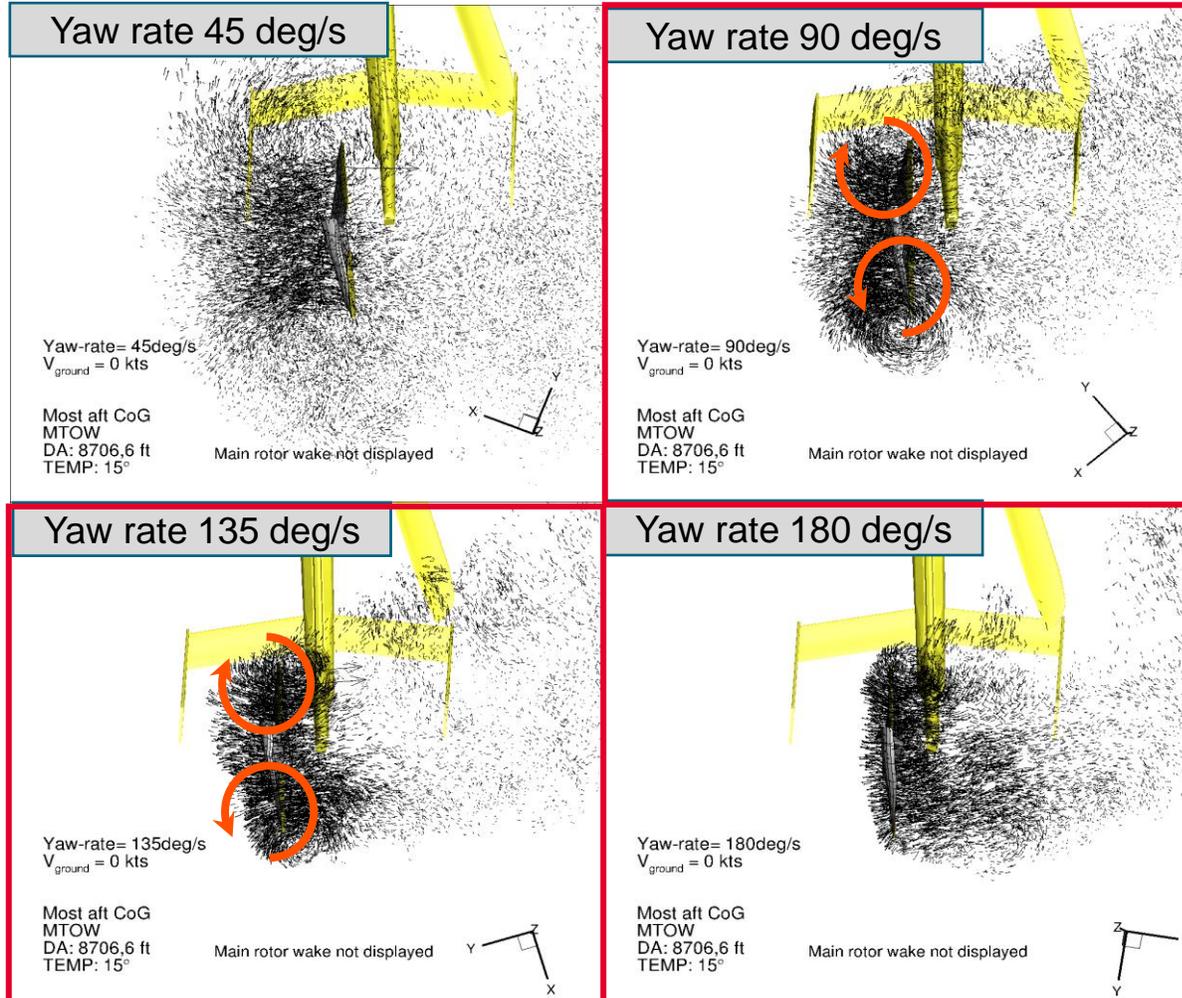


- VRS formation is strongly disturbed by MR wake interference
- VRS stays in the incipient stage, **can not fully develop**
- Loss-of-thrust remains low, as depicted
- Significant amount of turbulence/fluctuation in the VRS phase

Latest flight physical insights – the nerd part...

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

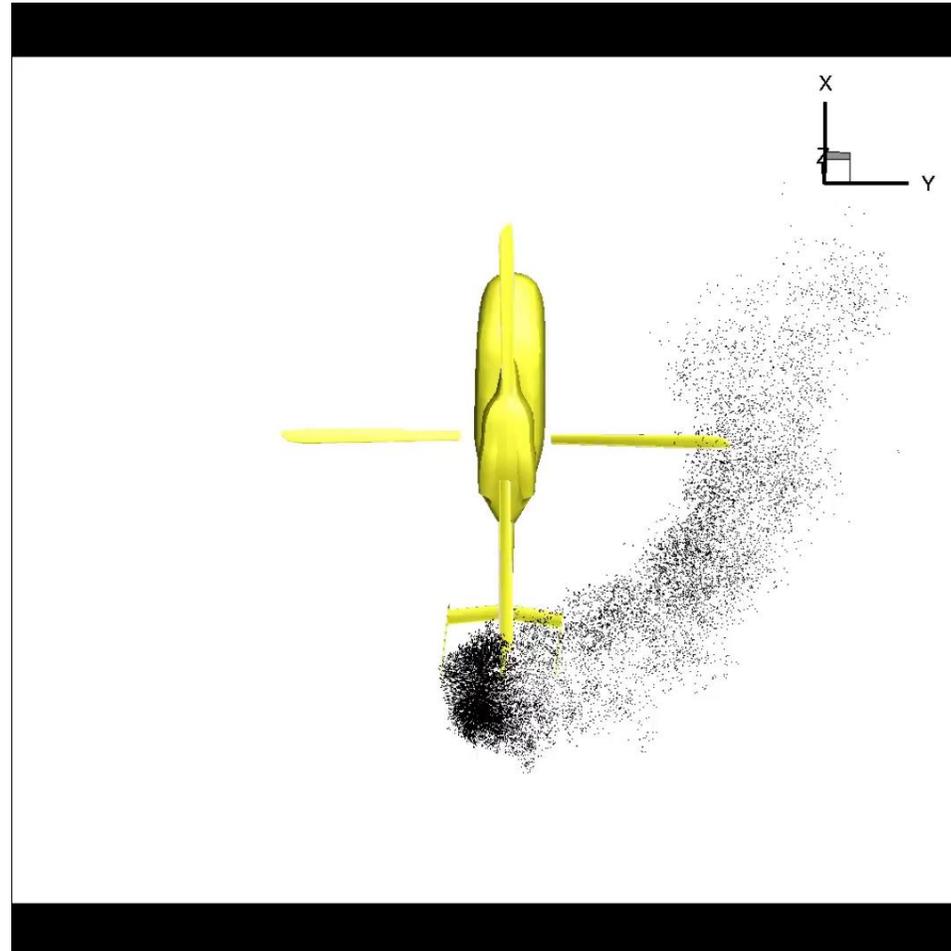
Yaw rotation to the right results in left relative wind on the TR, conditions for the incipient VRS:



- 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

Latest flight physical insights – the nerd part...

Unsteady time simulation: Helicopter with 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

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

Take aways from the analysis:

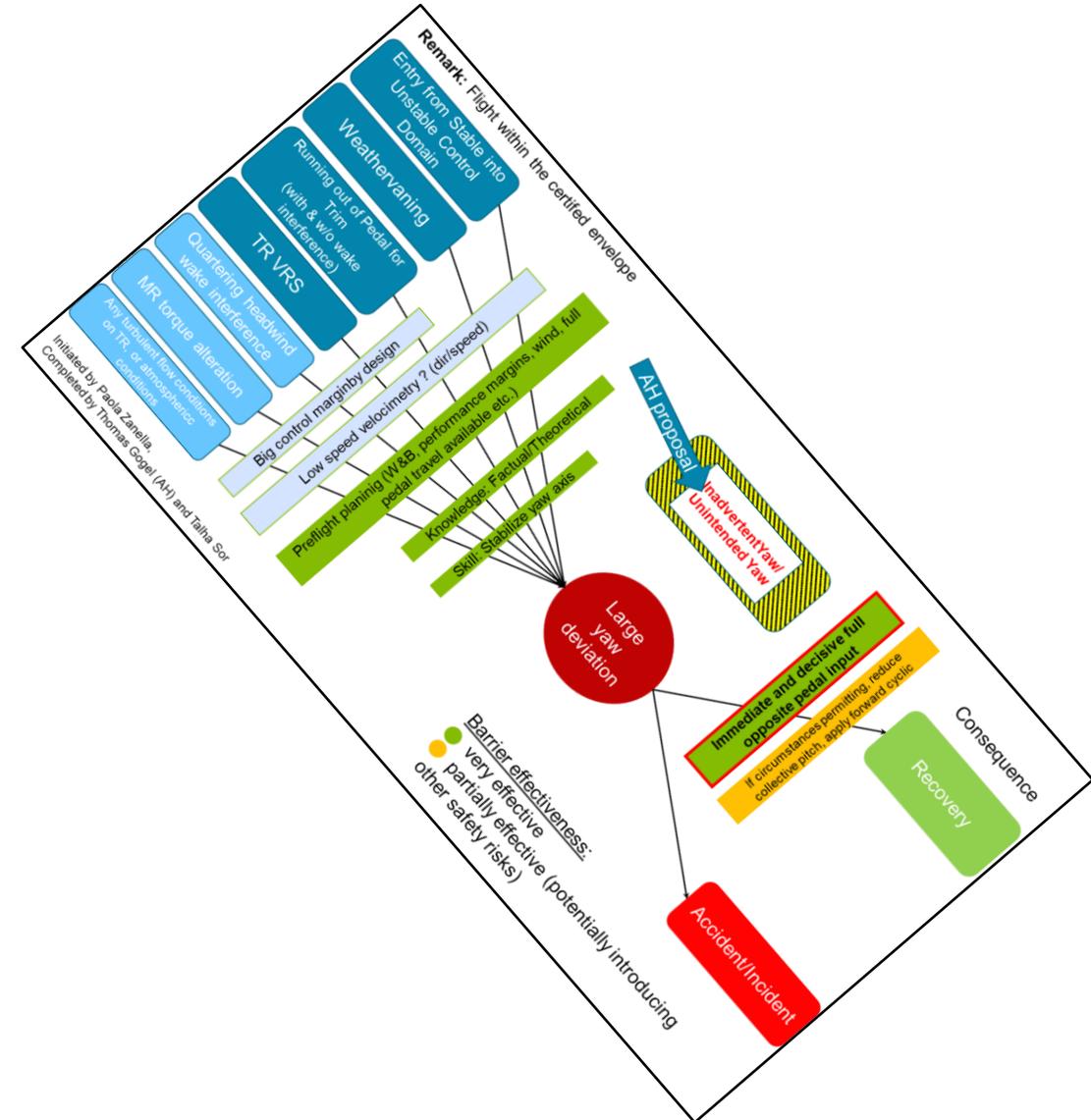
Take-aways from the analysis:

1. Preventive barriers:

- **Awareness, knowledge** and skills
- Proper preflight planning and situational awareness (W&B, performance margins & FLM flight envelope, wind/gusts including obstruction/building turbulence, full pedal travel available etc.)

2. Corrective barriers:

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



Conclusion

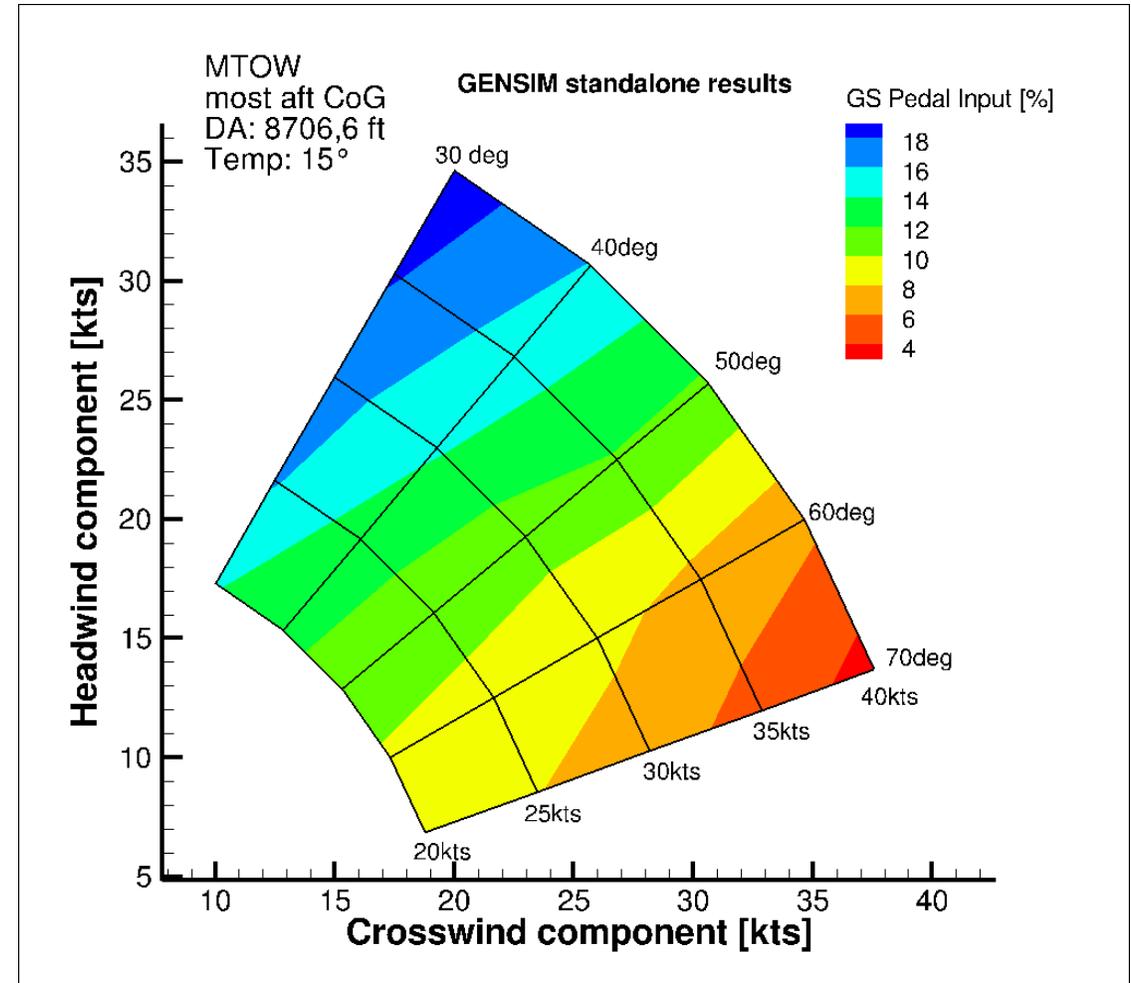
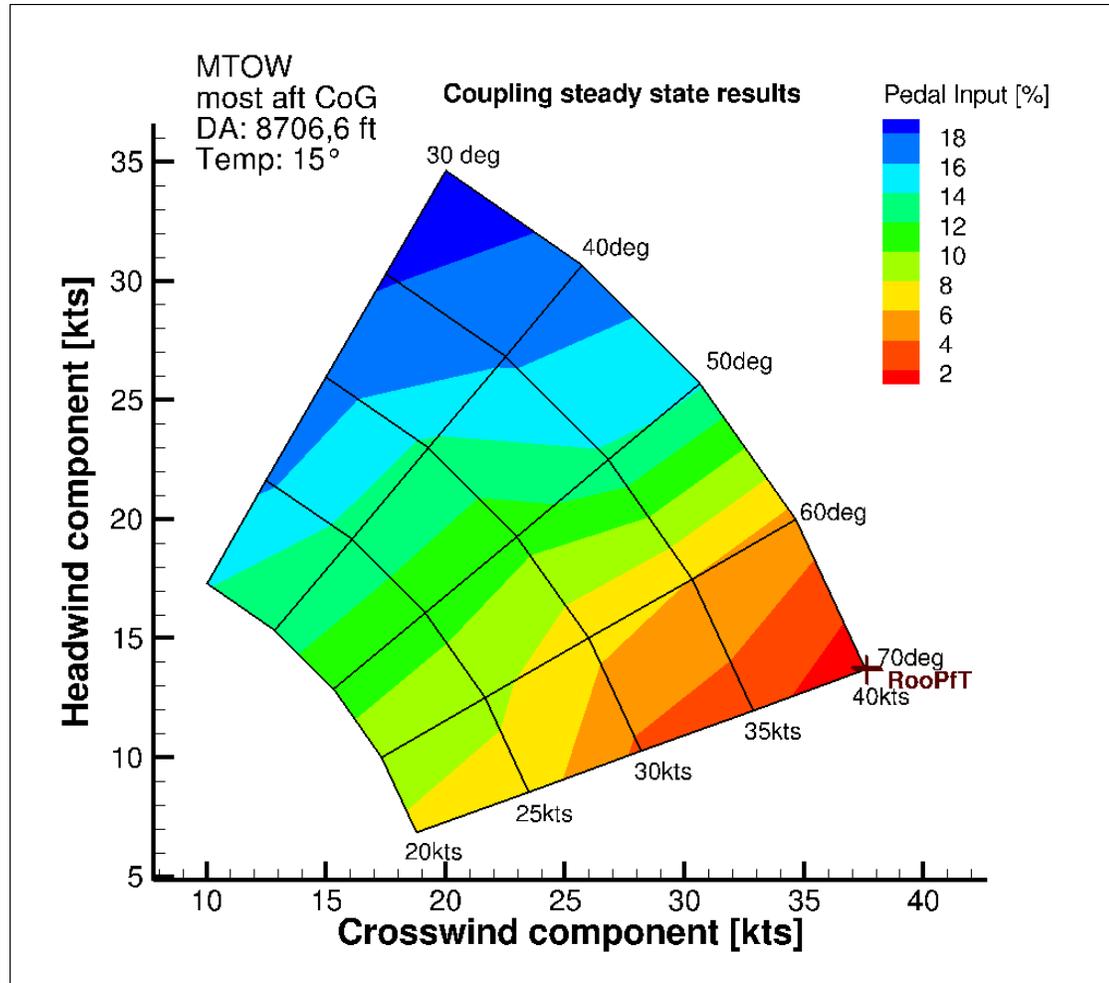
Decades-old discussion on UY/LTE (whatever the term...), lots of gossip:

- Recent effort launched under  to properly analyse, examine and classify the underlying flight physical phenomena, targeting avoidance and recovery actions
- Awareness initiative (Safety Promotion) launched via ESPN – R and various manufacturers
- When analysis completed, collaborative approach for common definition, description, training etc., transported via strong safety promotion initiative into the cockpits
- Analysis results to be used to improve Flight simulators (Enabling better UY training)



Back Up

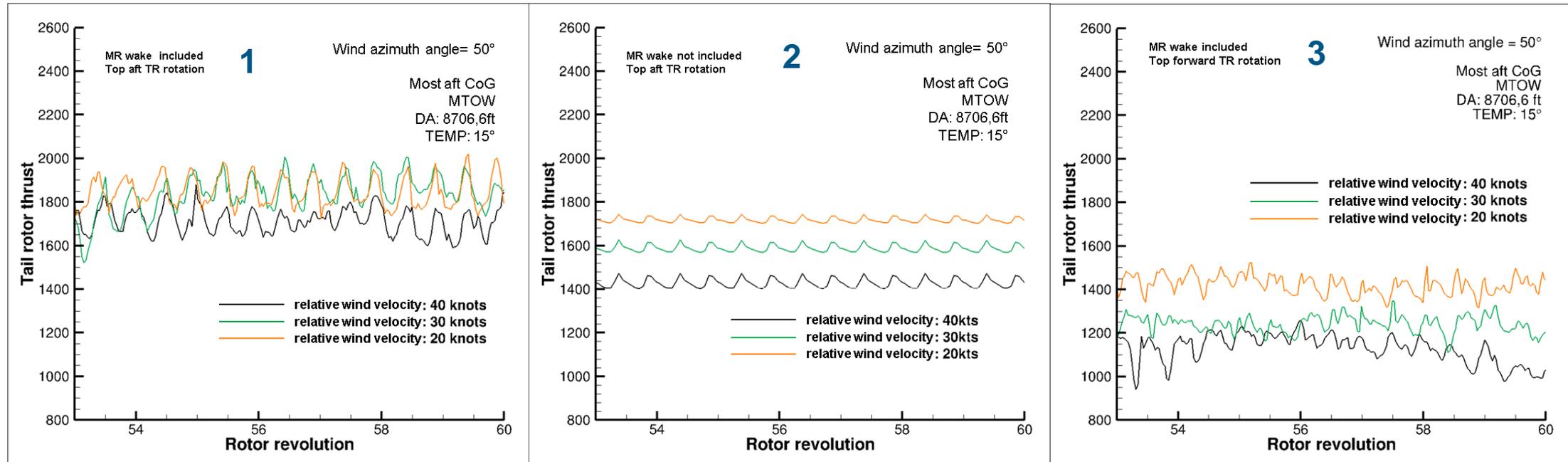
Running out of Pedal for Trim – yaw trim sweep



=> Less TR collective is needed between 40 to 55 degrees to generate sufficient TR thrust compared to GENSIM standalone results

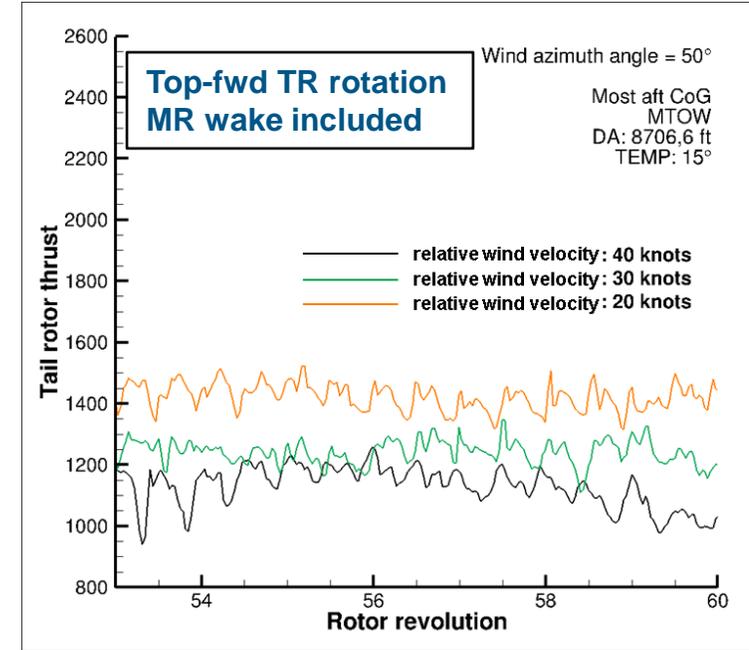
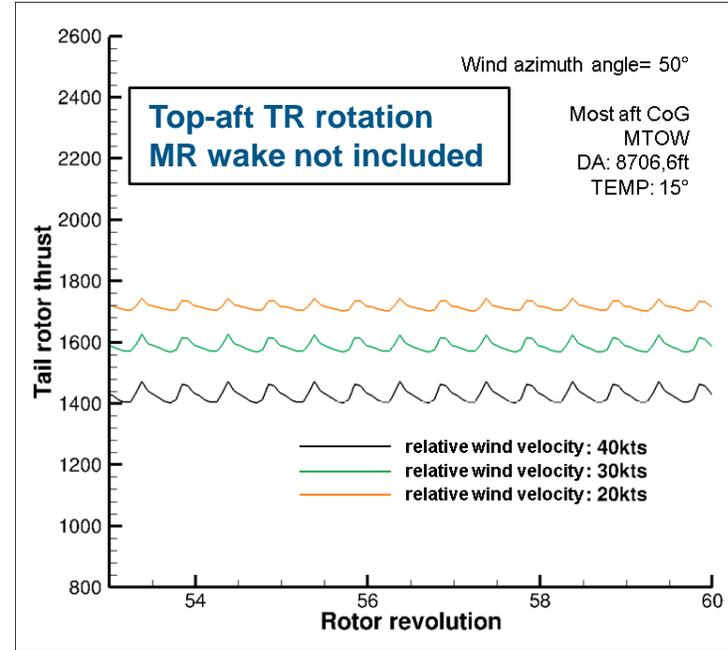
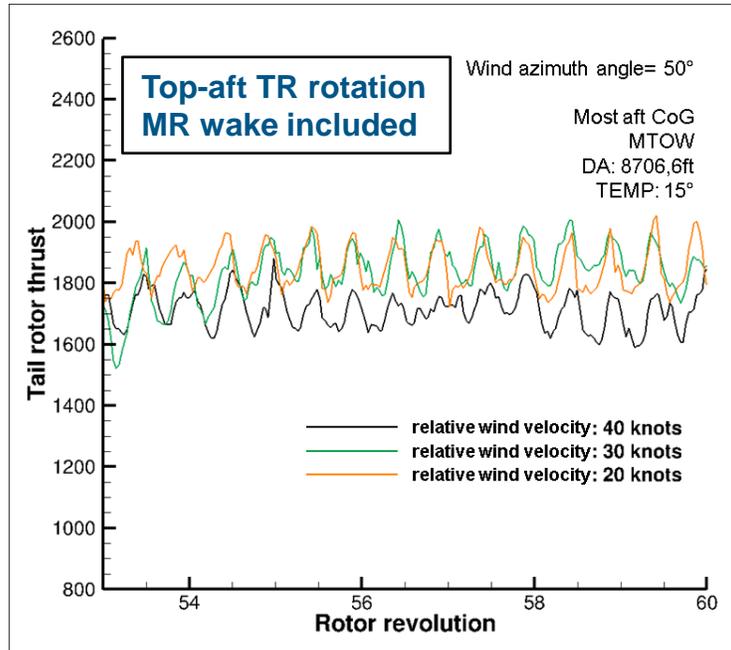
Running out of Pedal for Trim – MR wake interaction case study

1. thrust increase, turbulence for top-blade-aft
2. frozen pedal input: no wake interaction, lower thrust
3. frozen pedal input , top-blade-fwd: decrease in thrust, turbulence



Latest flight physical insights – the nerd part...

Runnig-out-of-pedal-for-trim (wind from fwd right) - contnd.

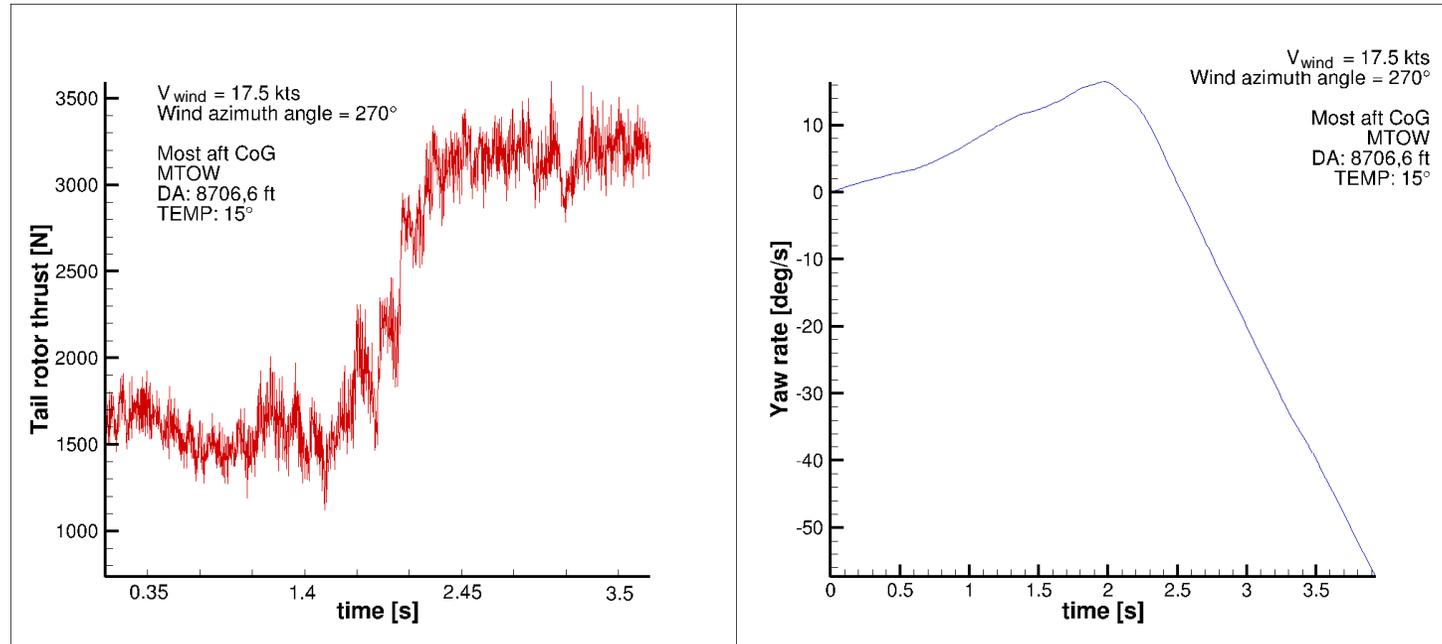


- High level turbulence

- Smooth airflow, regular alterations during each MR rotation
- Lower thrust level as for case with MR wake inclusion

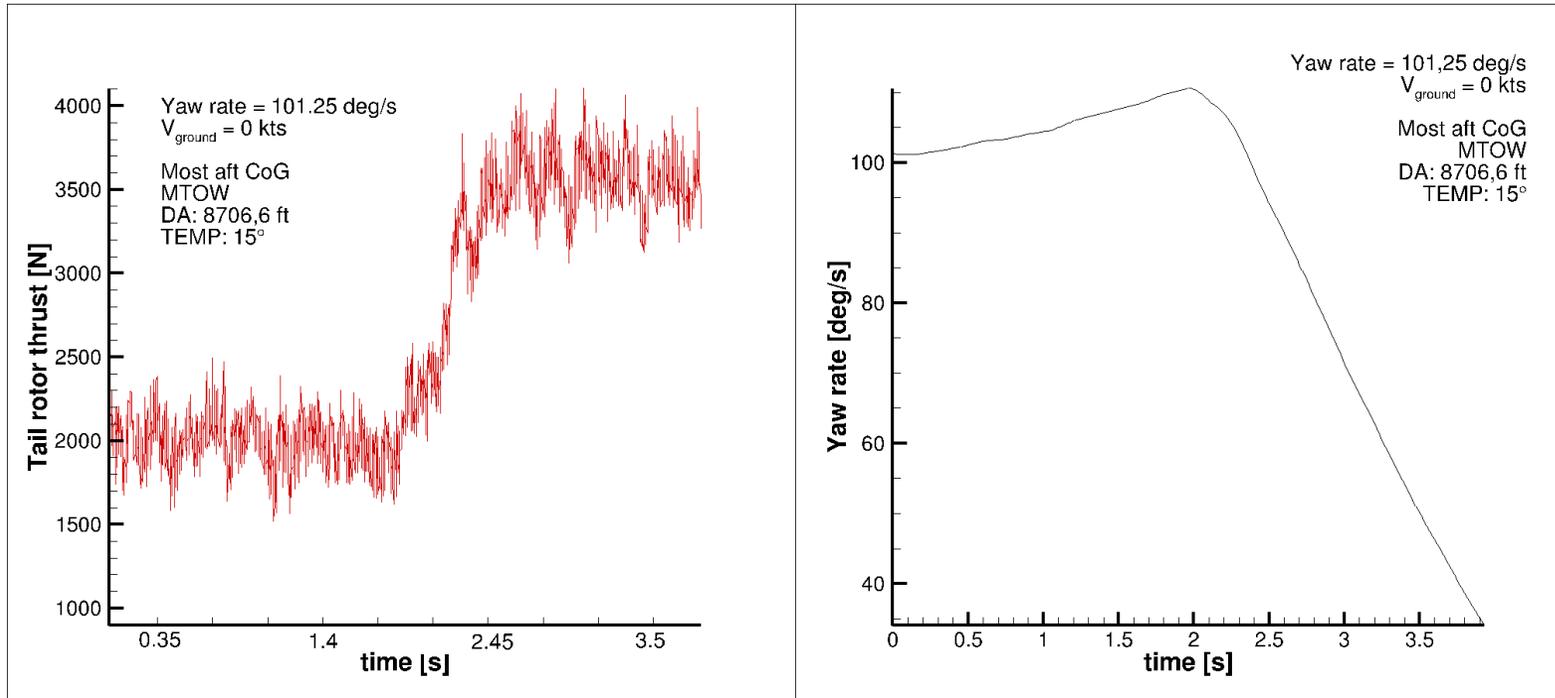
- Again high level of turbulence
- Even lower thrust level due to reduction of TR relative velocities by MR wake vortex moving in the same direction

Unsteady time simulation results of the TR VRS, left cross wind



- Airbus Amber

Unsteady time simulation results of the TR VRS, VRS yaw rate induced



=>Yaw rate due to UY can be stopped by a full Pedal Input

=>Yaw rate induced TR VRS does not subside on its own

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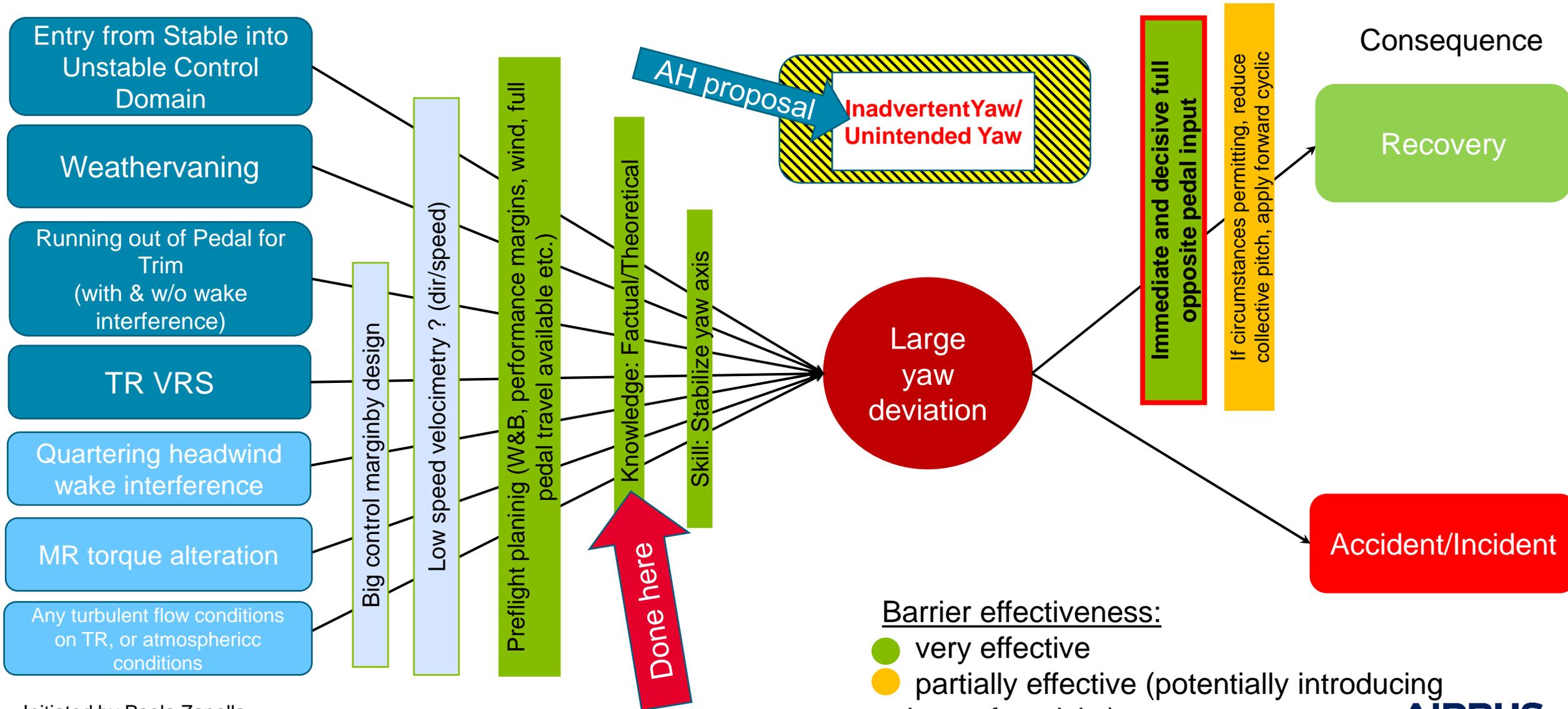
Link to the real world: Implications for flight operations – bring the knowledge into the cockpit

UY - Ranking of the contributing phenomena

	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	LTE (?)	Right	No	Yes
Weathervaning	Flightmechanical / Stability	Left/ Right	Yes	Yes
Running out of Pedal for Trim with wake interference	LTE (?)	Right	Yes	Yes
Running out of Pedal for Trim w/o wake interference	Stability	Right	Yes	Yes

UY/ IY– Bow-tie depiction

Remark: Flight within the certified envelope



Barrier effectiveness:

- very effective
- partially effective (potentially introducing other safety risks)