The "Explo-Drone" project: toward a one-liter MAV for exploring confined environments

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Explo-Drone project

- Joint research project between ISAE and ONERA
- As part of the MAV Research Center

Objectif:
Developing a **compact micro air vehicle** capable of autonomously flying through **highly confined environments**.

Work packages

Automatics

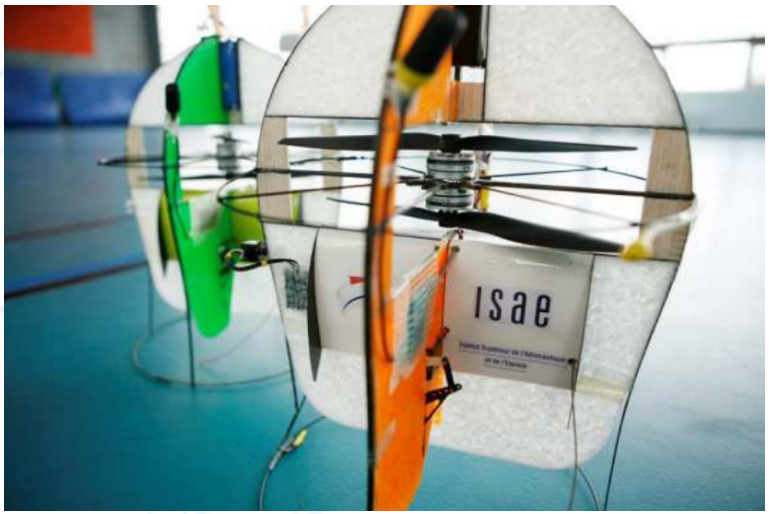
- **Work package 1** : Guidance and control through vision

Aerodynamics

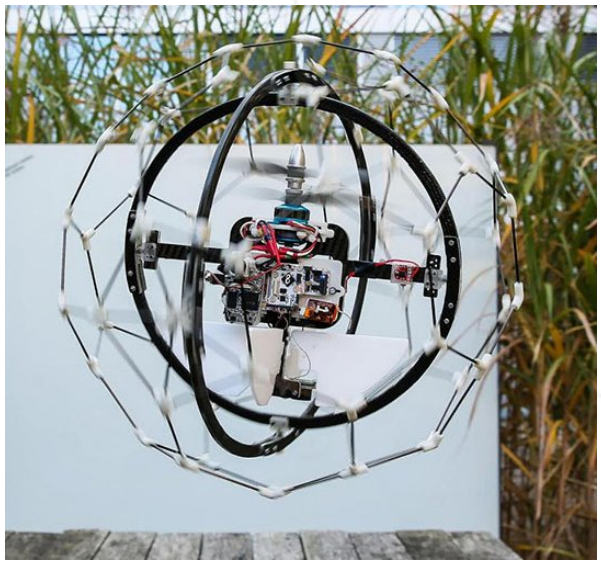
- **Work package 2** : Innovative blade design for compact, long-endurance micro air vehicles
- **Work package 3** : Aerodynamic interaction of micro rotors in confined environments
- **Work package 4** : The concept of "aerodynamic covertness" for indoor MAV exploration

Prototype

Project goal : Design of a compact (1L) ducted coaxial rotor MAV with a low aerodynamic footprint



VisionAir by ISAE



Gimball by Flyability
(EPFL Spin-off)

ONERA

THE FRENCH AEROSPACE LAB

Work package 1

Project constraints:

- Low power embedded system
- Low sensor payload

ONERA
THE FRENCH AEROSPACE LAB

Work package 1

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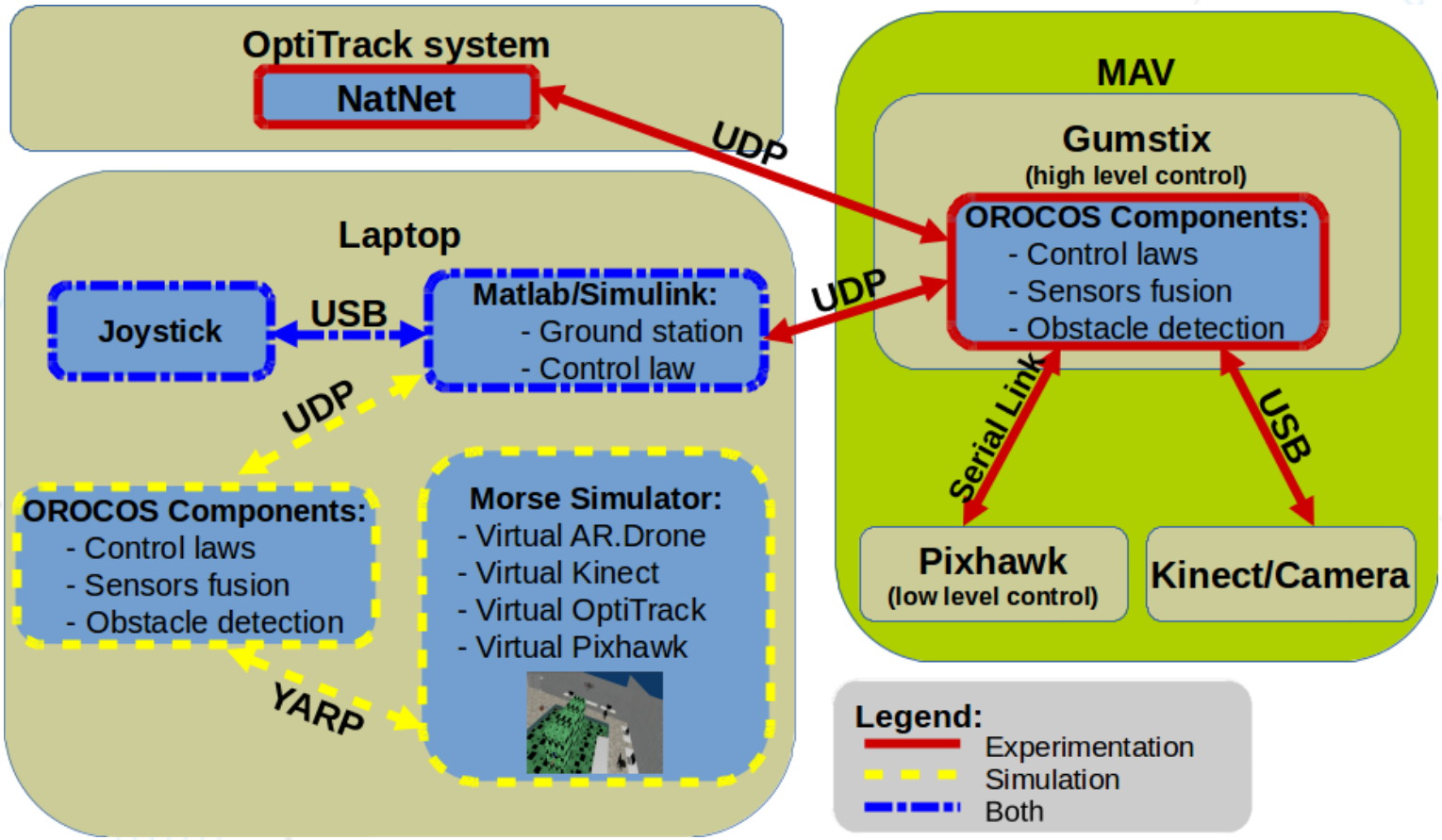
Proposed approach:

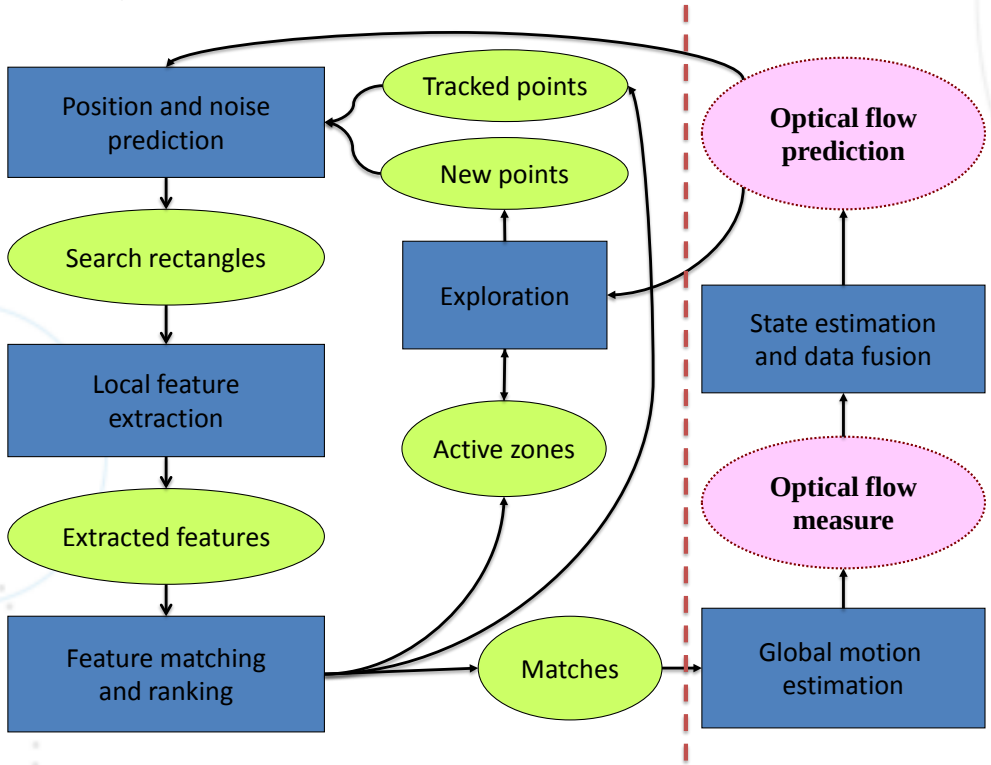
- Onboard reactive obstacle avoidance
- Offboard localization at a low frequency

Development framework



First approach for obstacles avoidance

Extend an existing optical flow algorithm design for low computing power embedded system:



Limitations of this approach on embedded processor

Following 60 features per frame of 320x240

Feature detector	Harris	Min-Eigen	FAST
I7 PC (ms)	3.2	2.7	0.41
Gumstix (ms)	405	504	4.3

We need more features to detect obstacles.

Introduction of features descriptors for nearby features matching:

Feature descriptor	SURF	SIFT
I7 PC (ms)	12.4	7.2

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$\Rightarrow$ **new sensor needed**

Comparison of environment sensors

	Laser scanner	Asus Xtion (structured light)	Kinect V2 (Time-of-Fligh)	Stereo vision	Mono vision
Range (m)	0.1-40	0.3-4	0.5-4	0.2-5	Movement needed
On Sensor depth computation	Yes	Yes	No	No	No
Weight	High	Medium	High	Medium	Low
In the dark	Yes	Yes	Yes	Not directly	Not directly
Textures needed	No	No	No	Yes	Yes
Connectivity	USB2	USB2	USB3	2 USB2	USB2
Field of view	Very Large	Medium	Medium	Medium	Medium
Planar	Yes	No	No	No	No
Resolution	Very High	High	High	Low/High	Low/High
Cost	High	Low	Low	Low	Low

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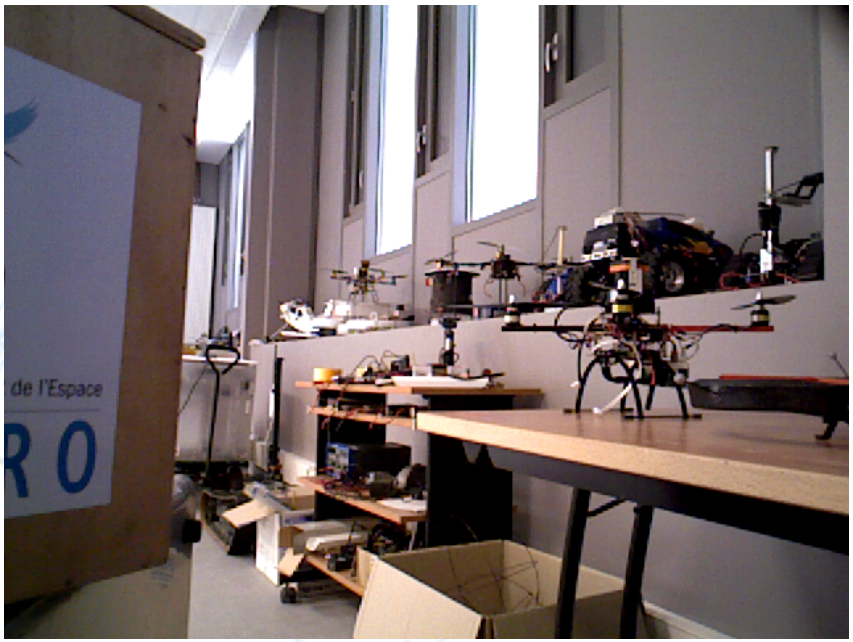
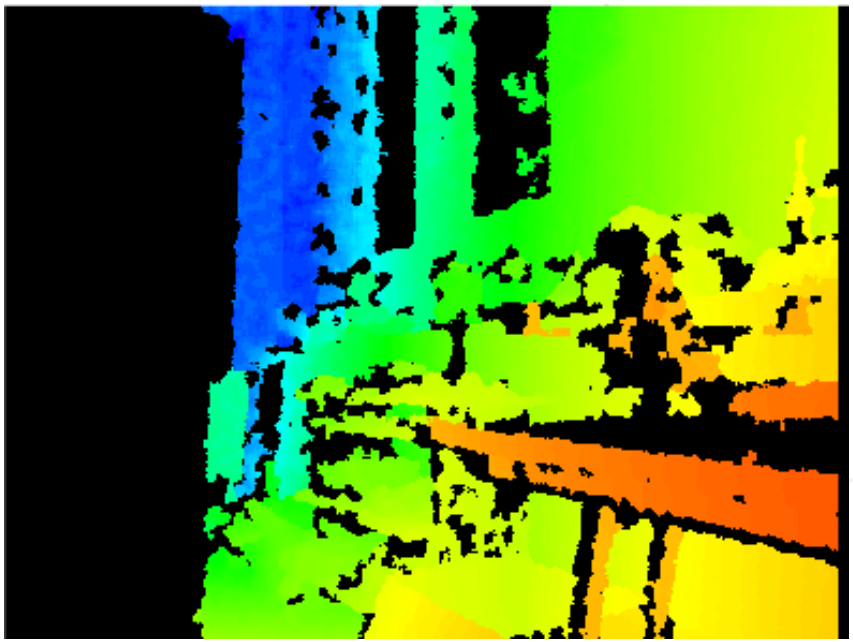
Weight	High	**Medium**	High	Medium	Low
In the dark	Yes	**Yes**	Yes	Not directly	Not directly
Textures needed	No	**No**	No	Yes	Yes
Connectivity	USB2	**USB2**	USB3	2 USB2	USB2
Field of view	Very Large	**Medium**	Medium	Medium	Medium
Planar	Yes	**No**	No	No	No
Resolution	Very High	**High**	High	Low/High	Low/High
Cost	High	**Low**	Low	Low	Low

New approach: Xtion depth sensor

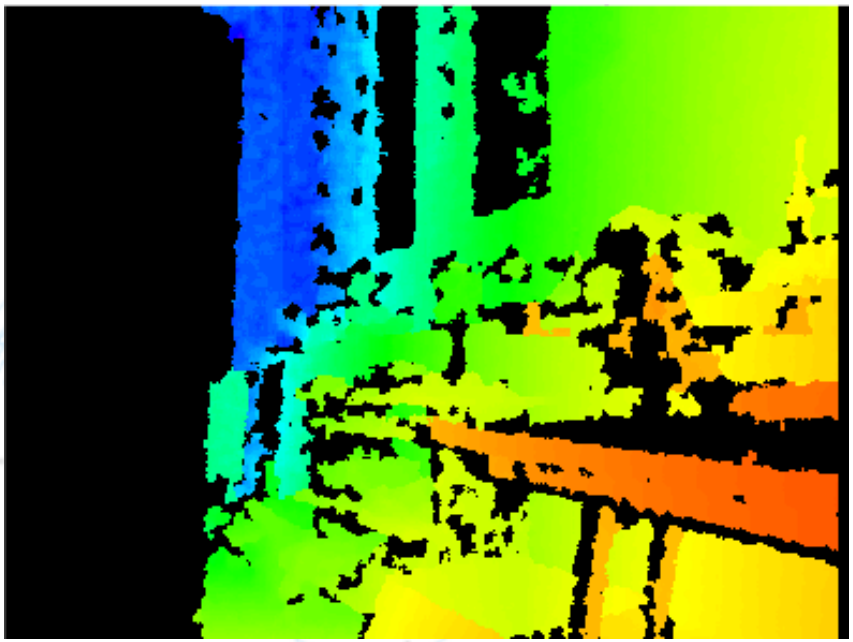
Default results

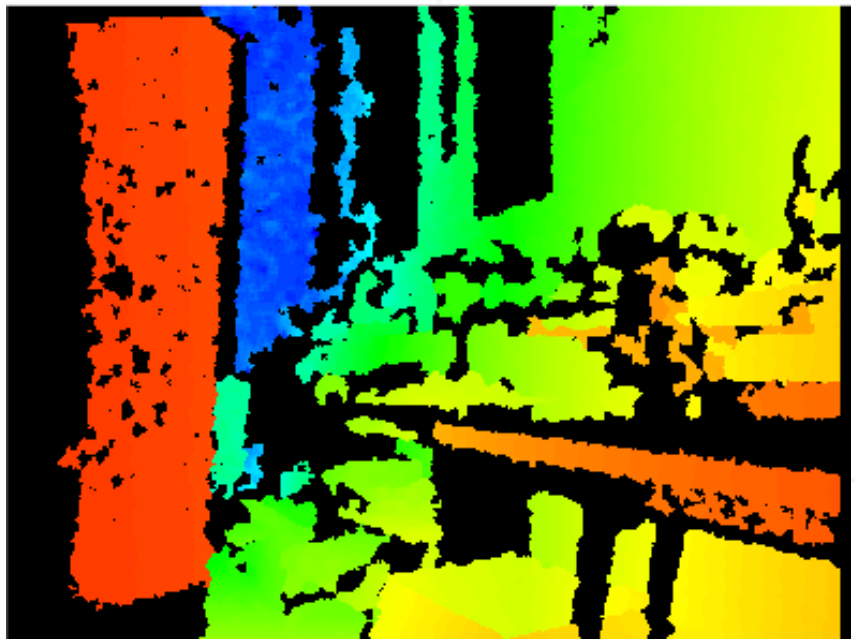




New approach: Xtion depth sensor

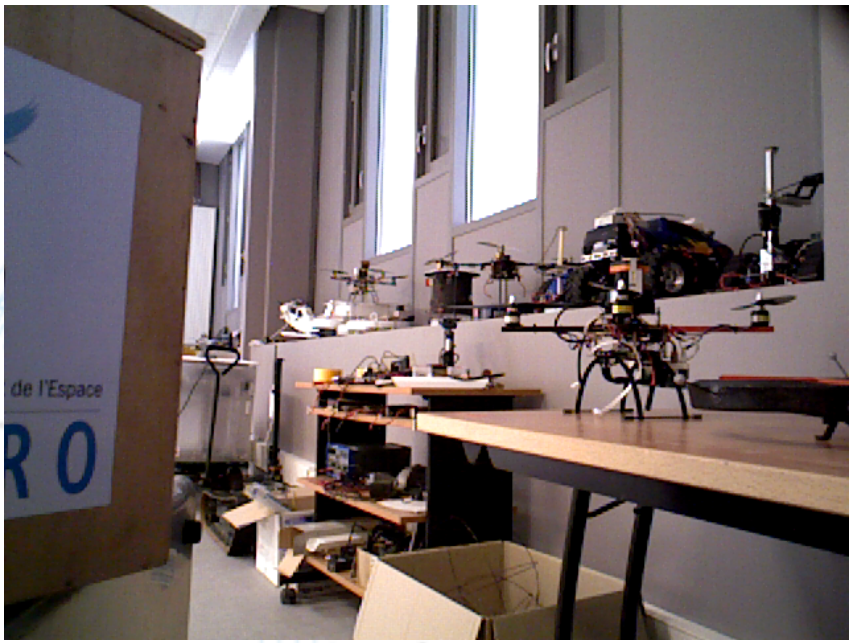
with an IR filter





New approach: Xtion depth sensor

with fisheye lenses



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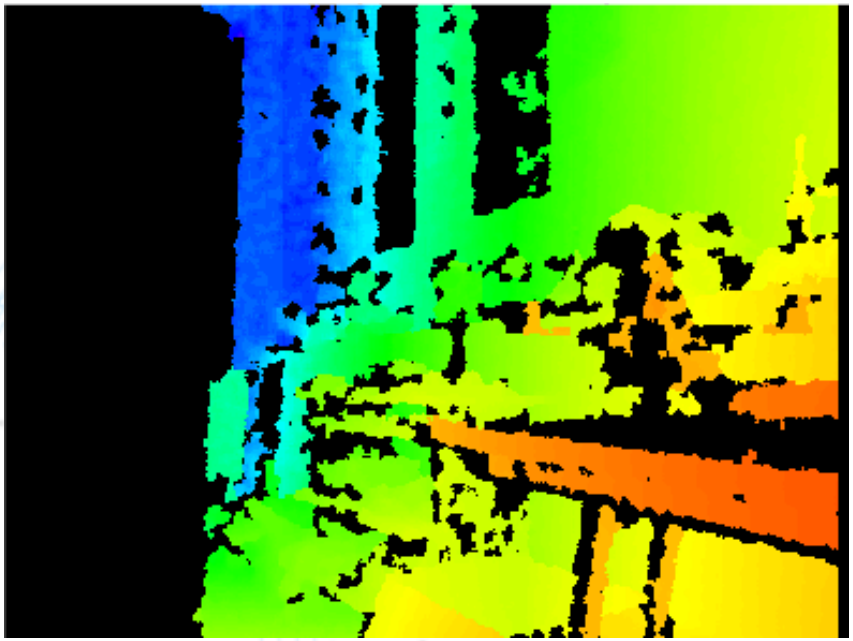
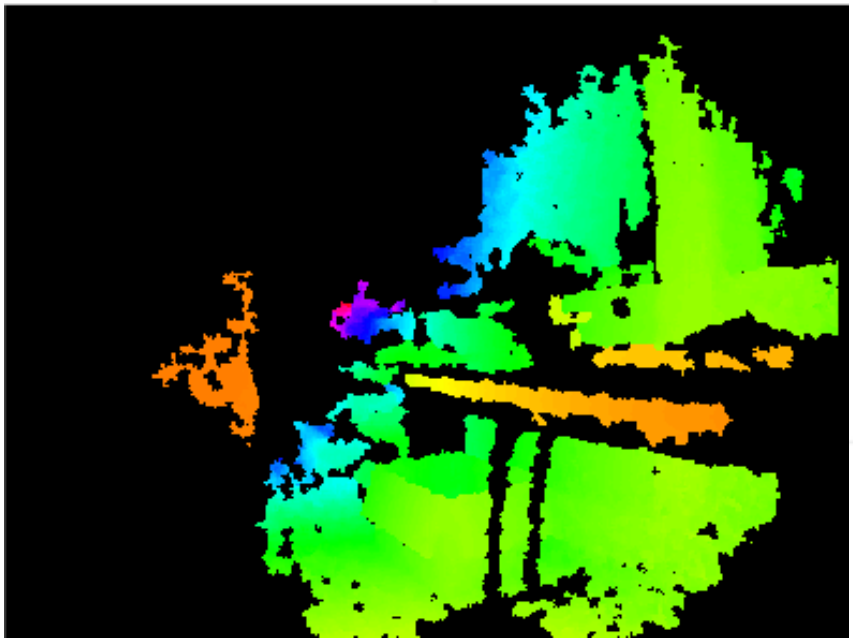




Future work

- New approach with an Asus Xtion
- Development of a reactive control law
- Integrate the aerodynamic disturbances model into the control law

Aerodynamics

Compact and efficient

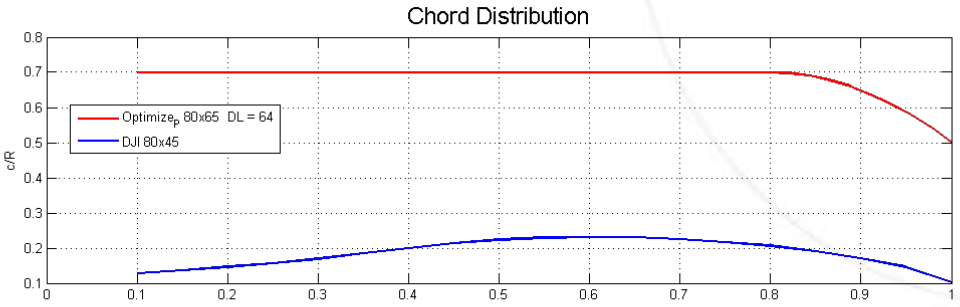
Robust to wall proximity

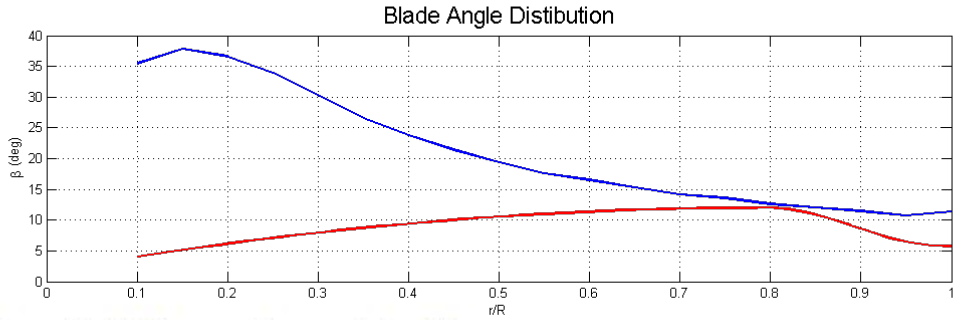
Low aerodynamic footprint

Architecture : counter-rotating rotors

Issue : commercial rotors not appropriate for hovering flight

Solution : optimize rotor blade twist and chord laws using aerodynamic theories, taking into account upper-to-lower rotor interactions





Preliminary results :

13 % gain in aerodynamic efficiency (Power Loading) on a single rotor with respect to the best commercial rotor for a 200 gr equivalent Thrust.

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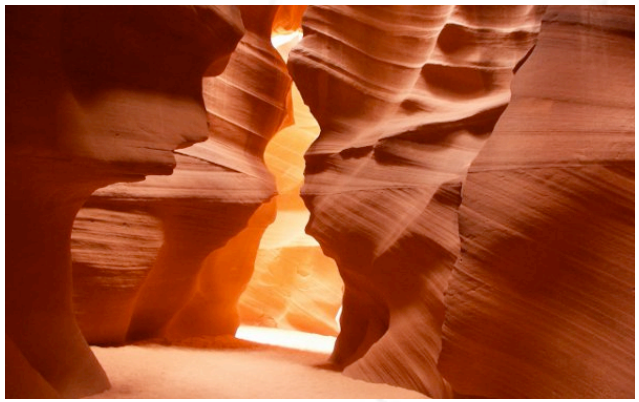
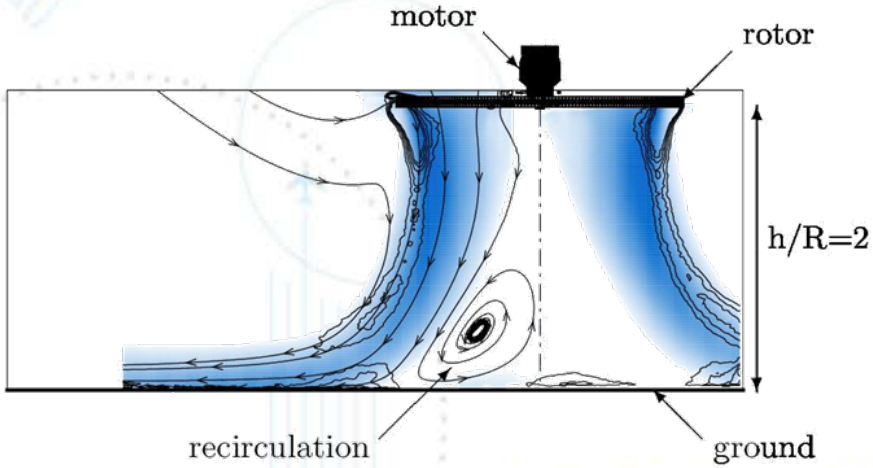
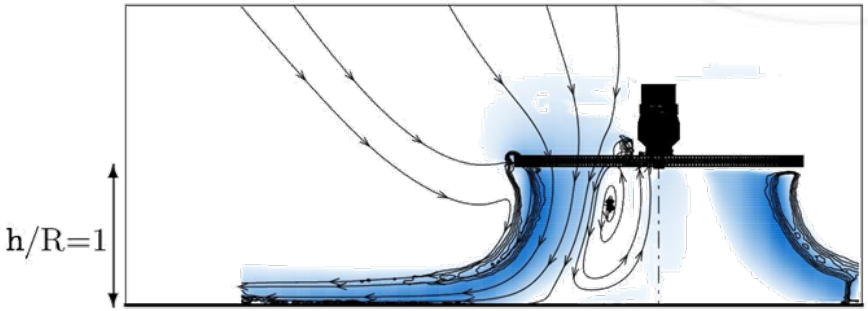
Issue : wall proximity affects aerodynamics

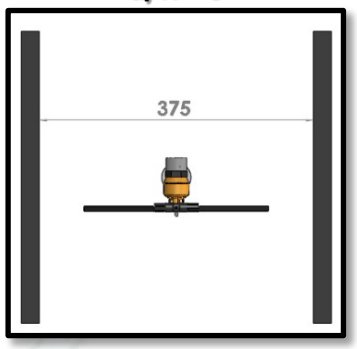




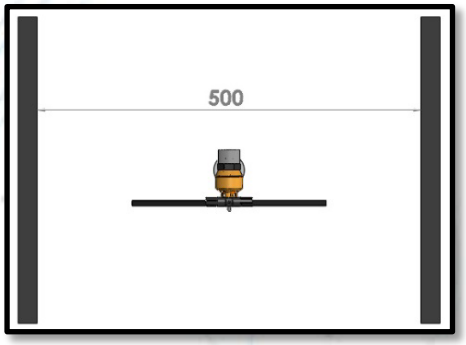


CONFINEMENT CASES (Multiple Wall)

d/R = 3



d/R = 4



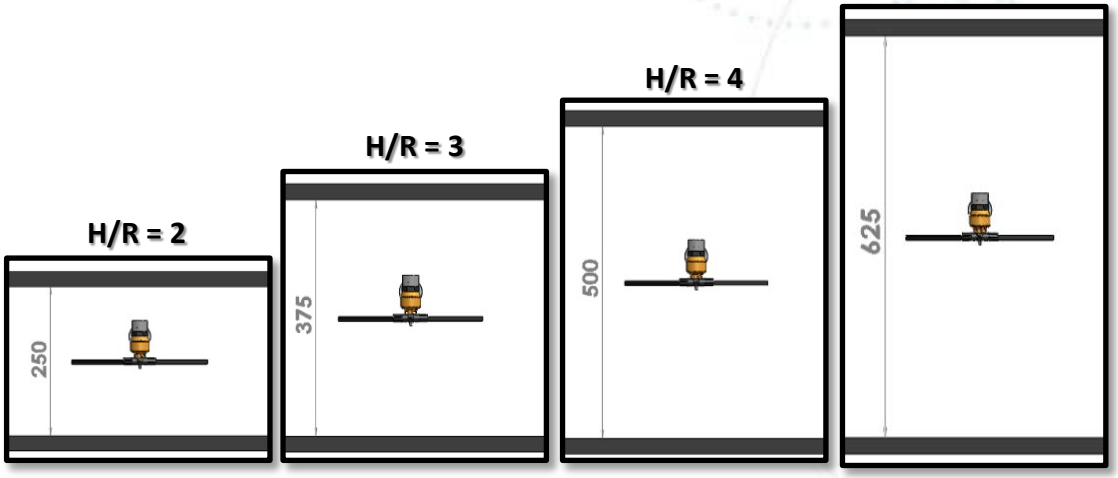
Two-Wall Duct Effect (ITwDE)

H/R = 2

H/R = 3

H/R = 4

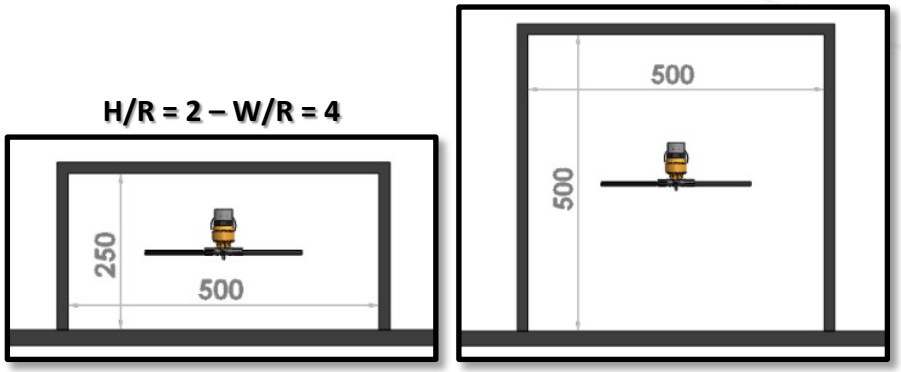
H/R = 5



Channel Effect (IChE)

H/R = 2 – W/R = 4

H/R = 4 – W/R = 4



Square Duct Effect (ISDE)

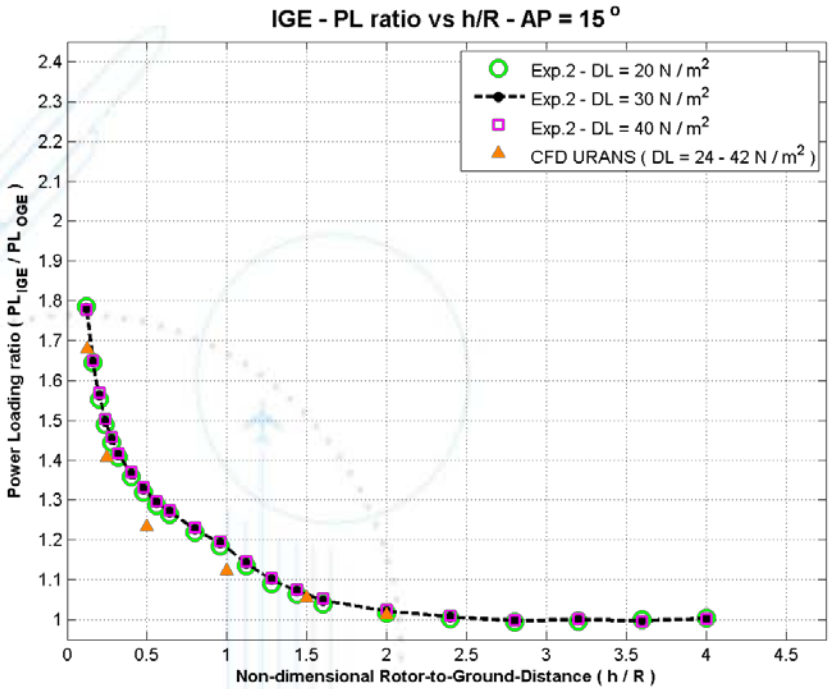
Aerodynamics

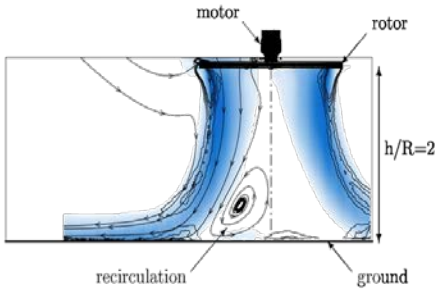
Compact and efficient

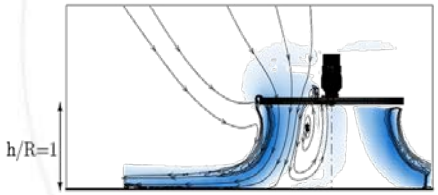
Robust to wall proximity

Low aerodynamic footprint

Issue : wall proximity affects aerodynamics







Results :

Modelling of aerodynamic coefficients with wall distance

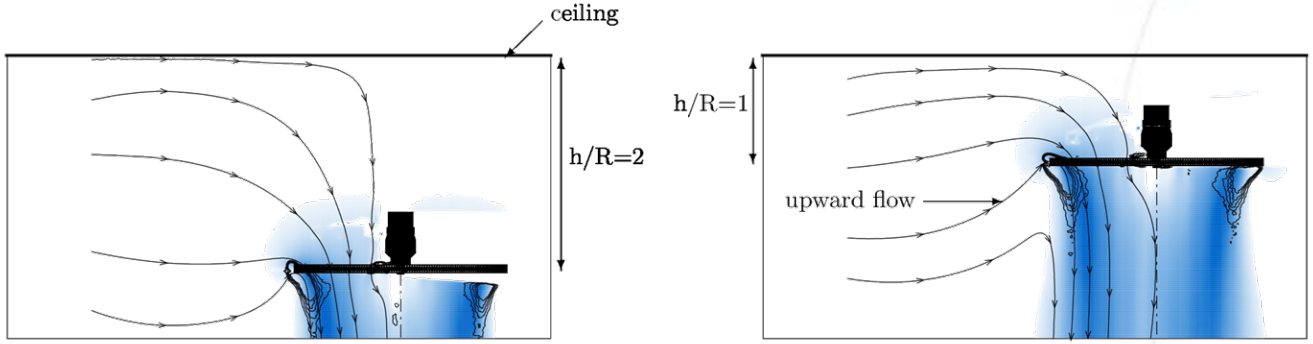
Flying near ground enhances aerodynamic efficiency

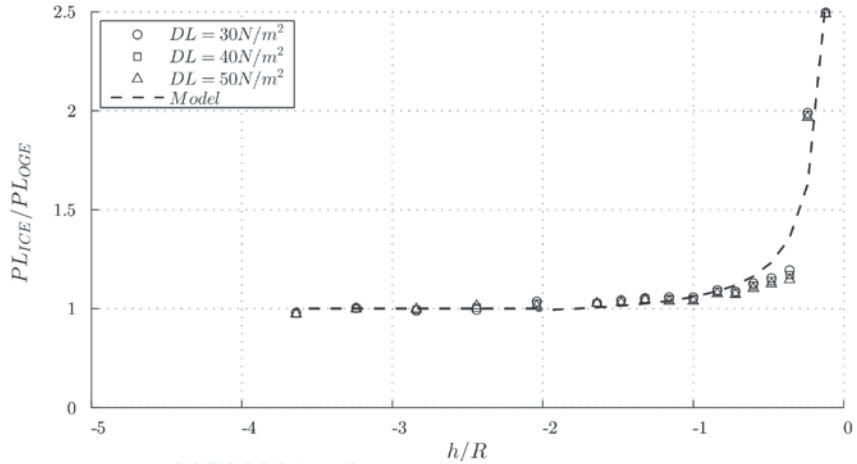
Aerodynamics

Compact and efficient

Robust to wall proximity

Low aerodynamic footprint

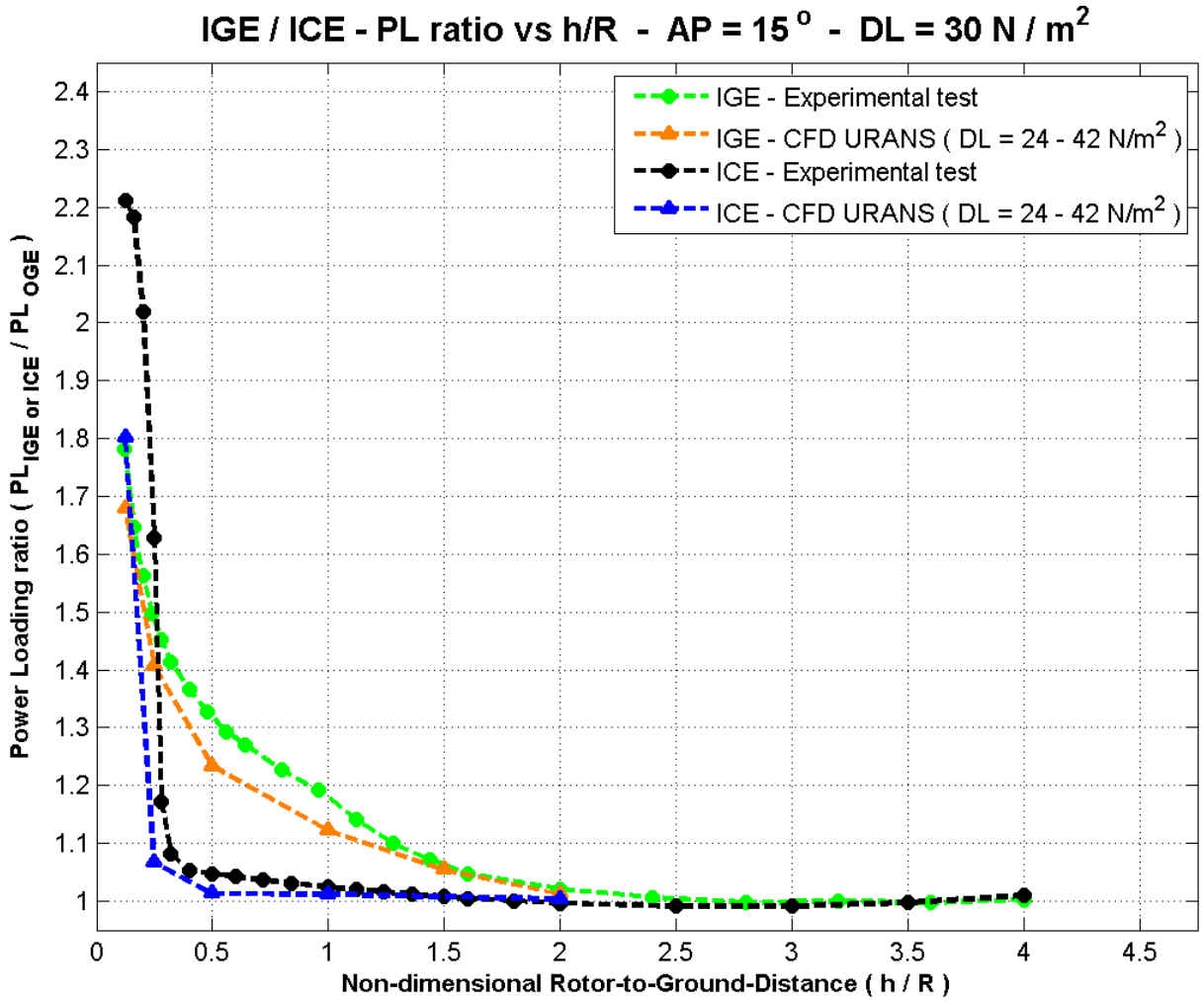




Results :

Modelling of aerodynamic coefficients with wall distance

Flying near ceiling enhances aerodynamic efficiency


IGE / ICE - PL ratio vs h/R - AP = 15 o - DL = 30 N / m2
IGE - Experimental test
IGE - CFD URANS (DL = 24 - 42 N/m2)
ICE - Experimental test
ICE - CFD URANS (DL = 24 - 42 N/m2)
Power Loading ratio (PL IGE or ICE / PL OGE)
Non-dimensional Rotor-to-Ground-Distance (h / R)
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

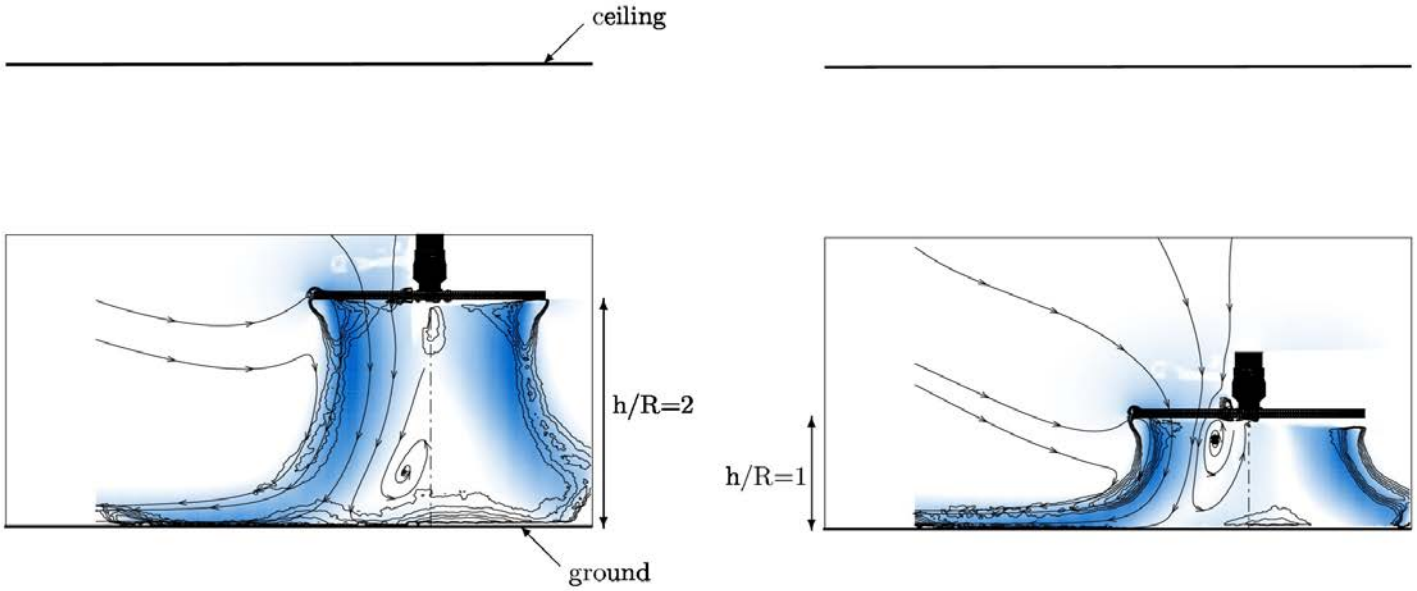
Aerodynamics

Compact and efficient

Robust to wall proximity

Low aerodynamic footprint

Issue : wall proximity affects aerodynamics



Results : Channel effects result from the linear combination of ground and ceiling effects

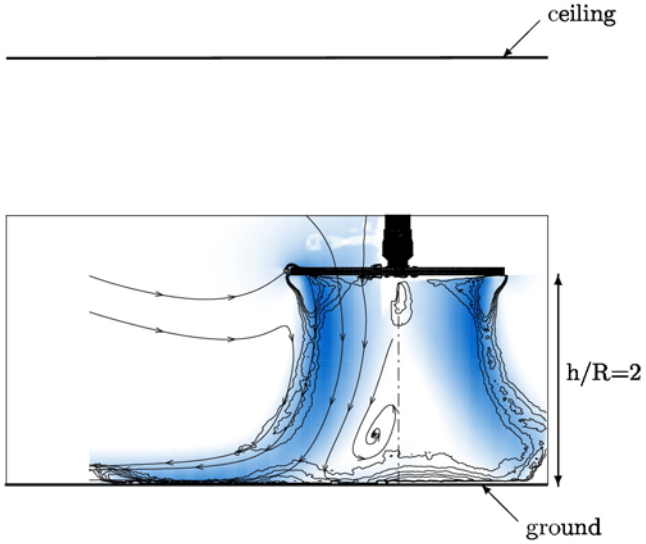
Aerodynamics

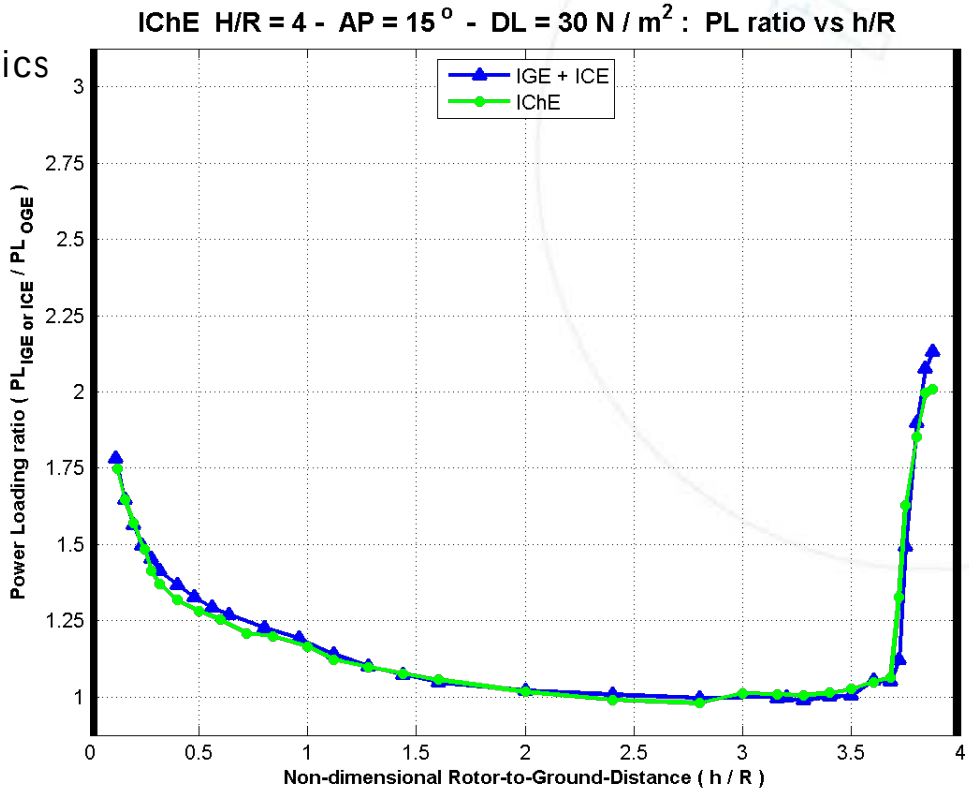
Compact and efficient

Robust to wall proximity

Low aerodynamic footprint

Issue : wall proximity affects aerodynamics





Results : Channel effects result from the linear combination of ground and ceiling effects

Aerodynamics

Compact and efficient

Robust to wall proximity

Low aerodynamic footprint

Issue : wall proximity causes « brown-out » phenomenon

- **Archaeology**
- **Civil Rescue**
- **Confined environment**

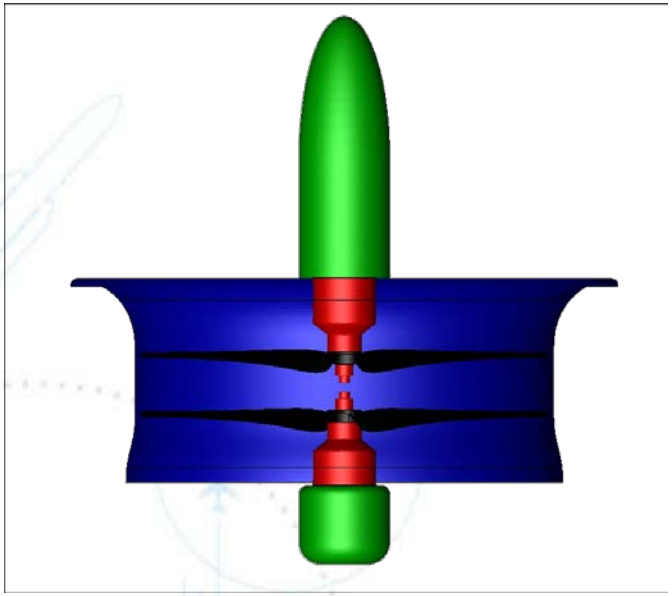
Aerodynamics

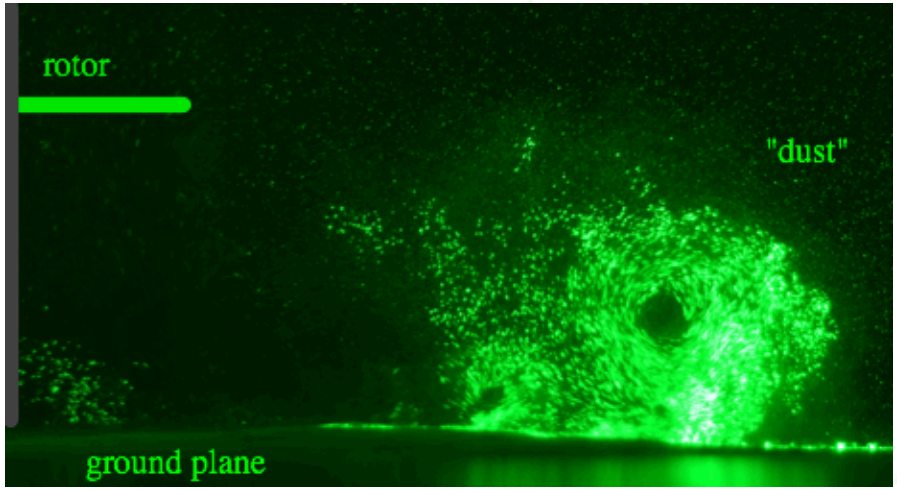
Compact and efficient

Robust to wall proximity

Low aerodynamic footprint

Issue : wall proximity causes « brown-out » phenomenon





Solution : shrouded rotors

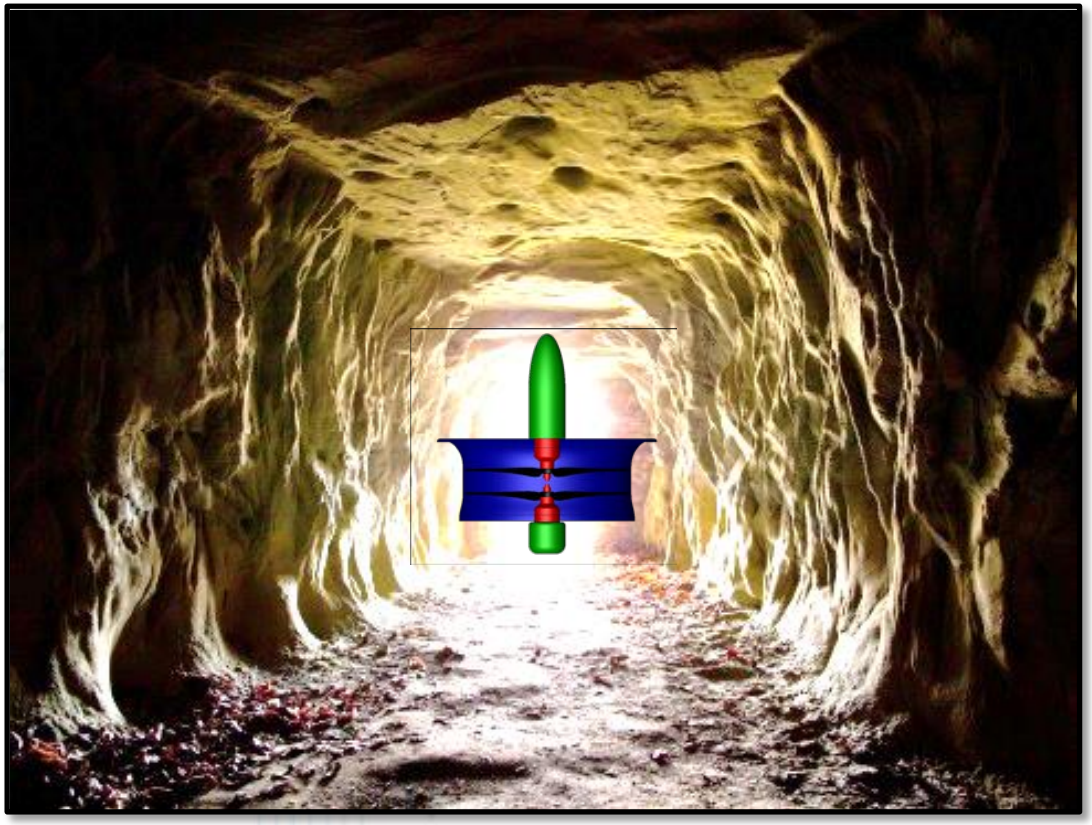
Aerodynamics

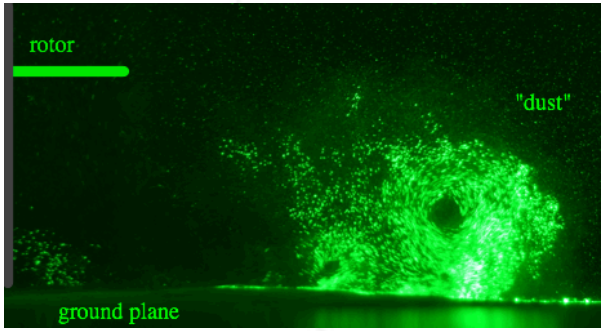
Compact and efficient

Robust to wall proximity

Low aerodynamic footprint

Issue : wall proximity causes « brown-out » phenomenon





Solution : shrouded rotors

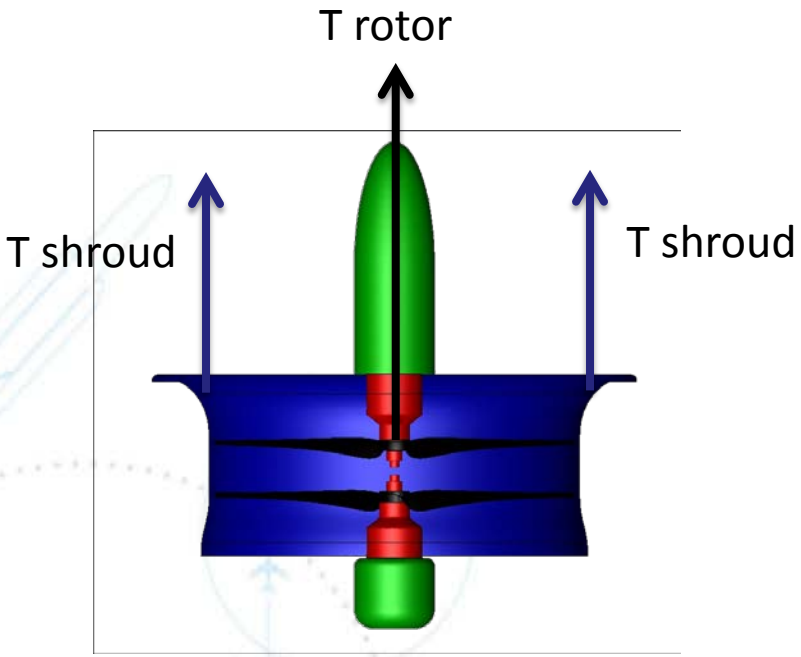
+ Inherent safety

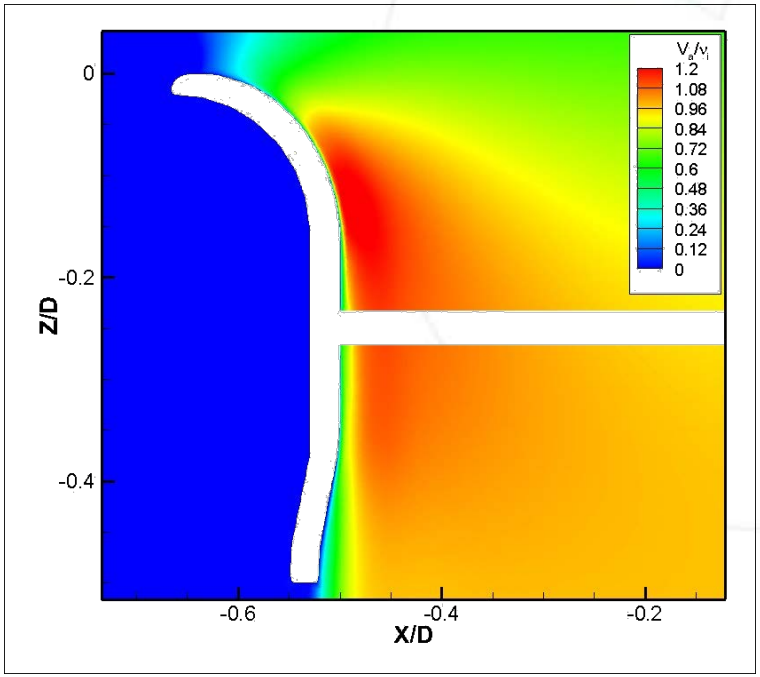
Aerodynamics

Compact and efficient

Robust to wall proximity

Low aerodynamic footprint





Solution : shrouded rotors

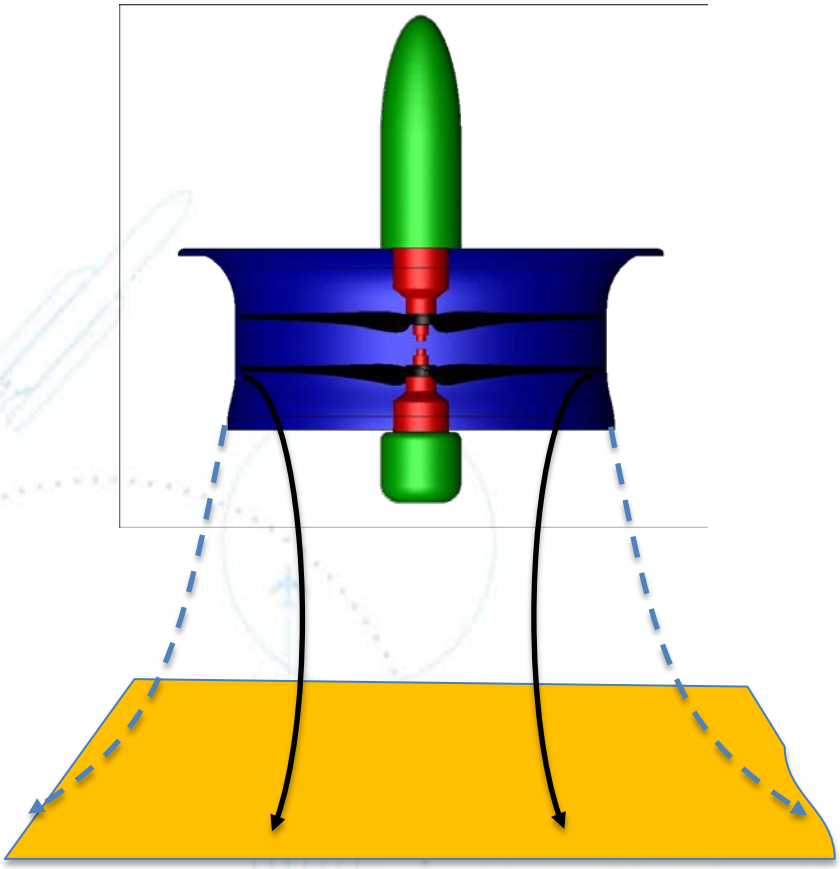
+ Inherent safety
+ Contributes to thrust

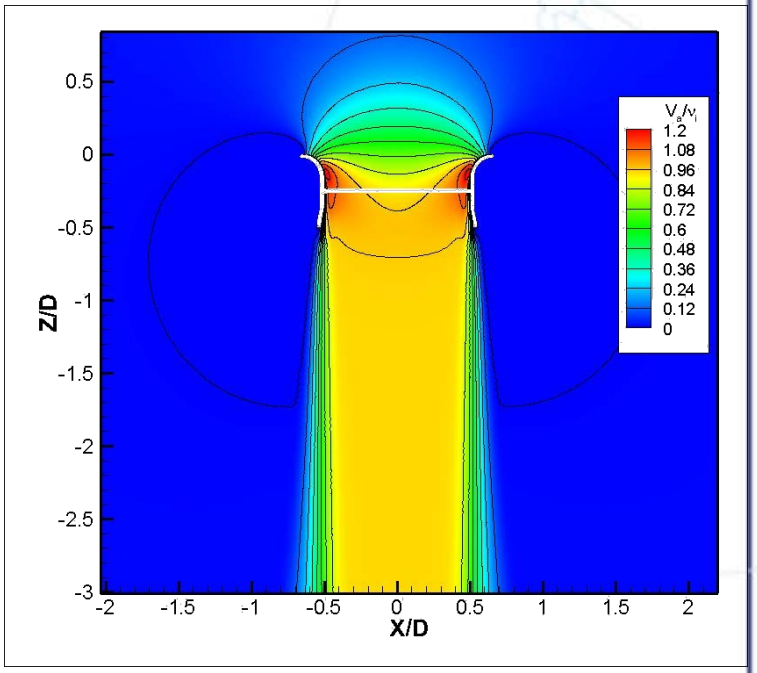
Aerodynamics

Compact and efficient

Robust to wall proximity

Low aerodynamic footprint





Solution : shrouded rotors

+ Inherent safety
+ Contributes to thrust
• Promote rotor jet divergence

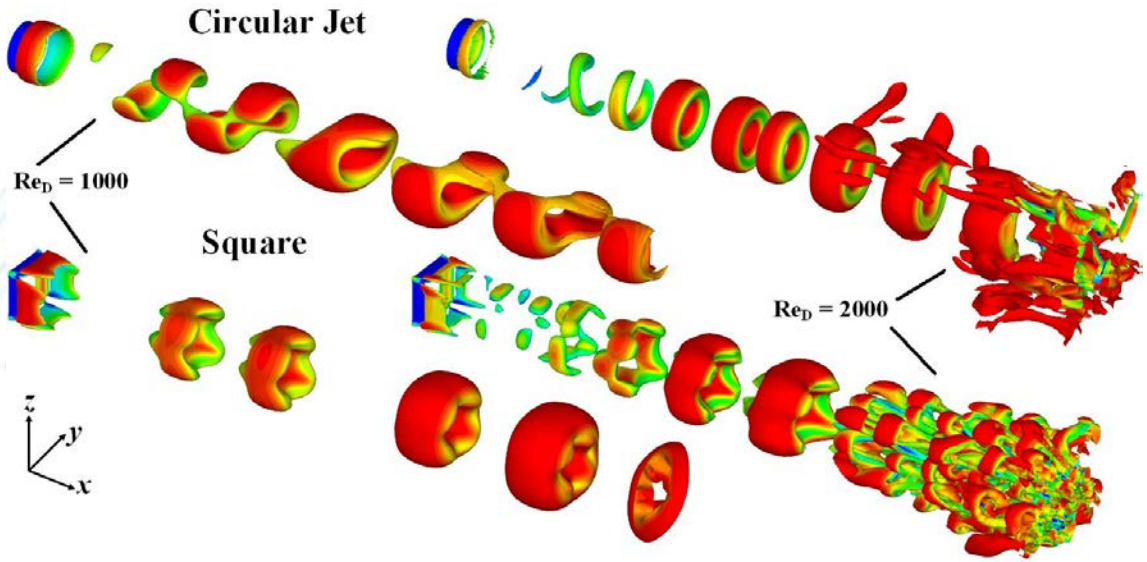
Aerodynamics

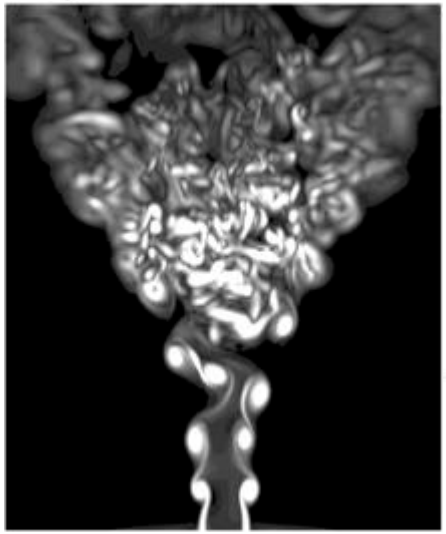
Compact and efficient

Robust to wall proximity

Low aerodynamic footprint

Energy Dissipation





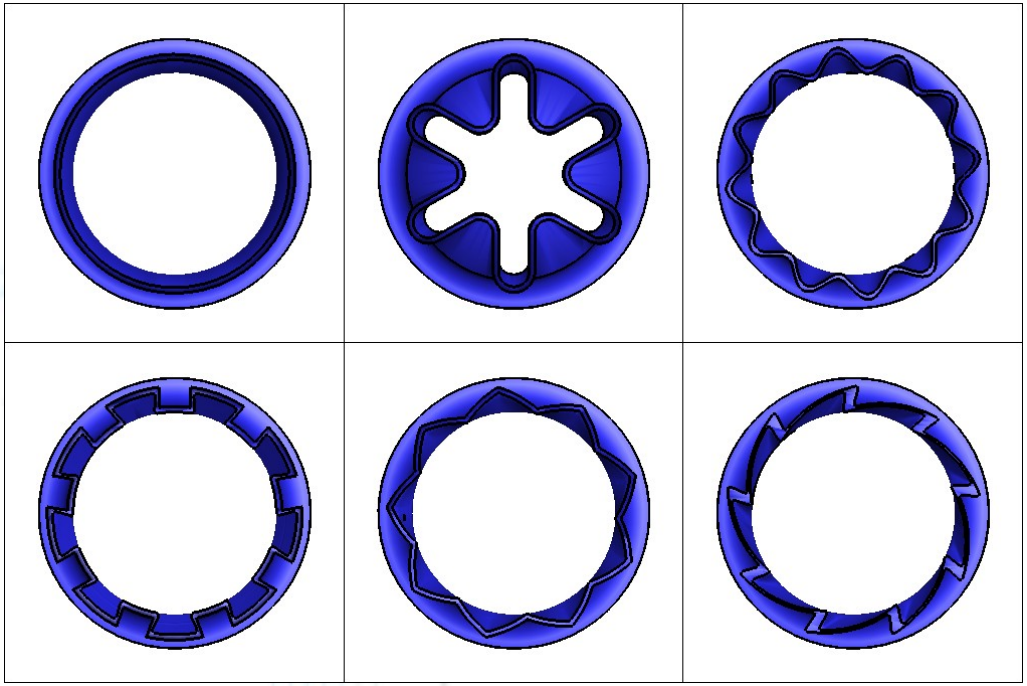
Aerodynamics

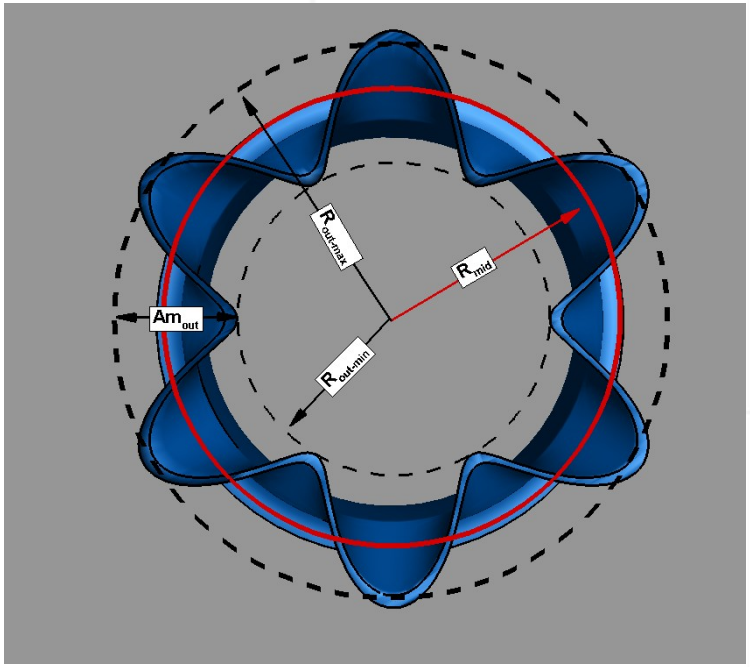
Compact and efficient

Robust to wall proximity

Low aerodynamic footprint

Shroud Nozzle Geometry





Aerodynamics

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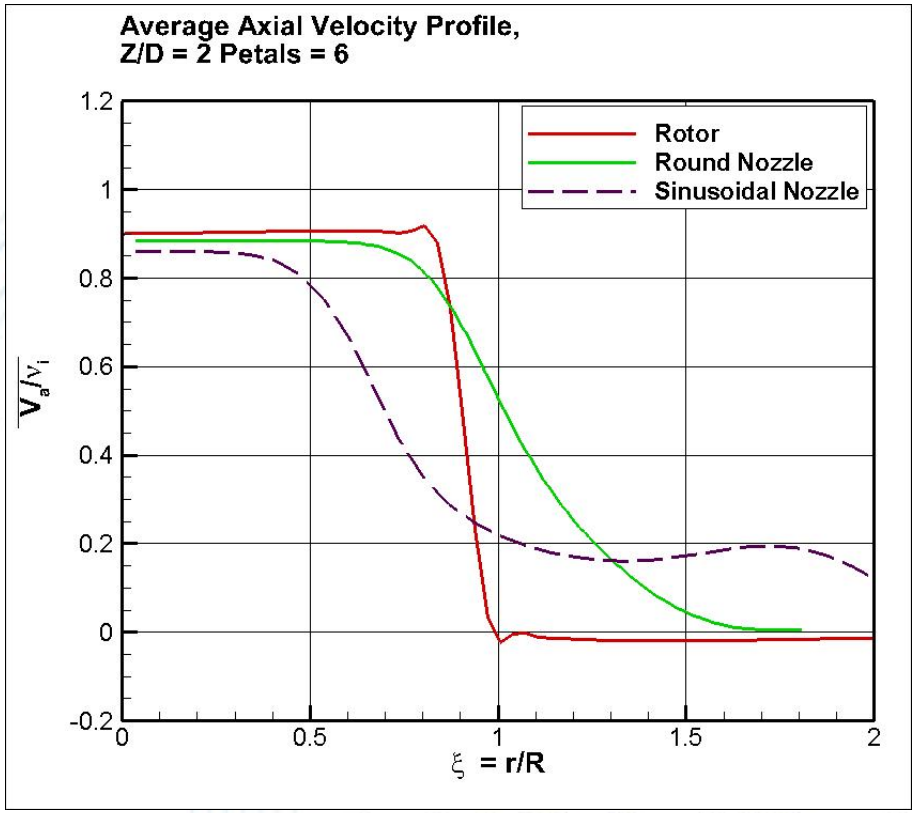
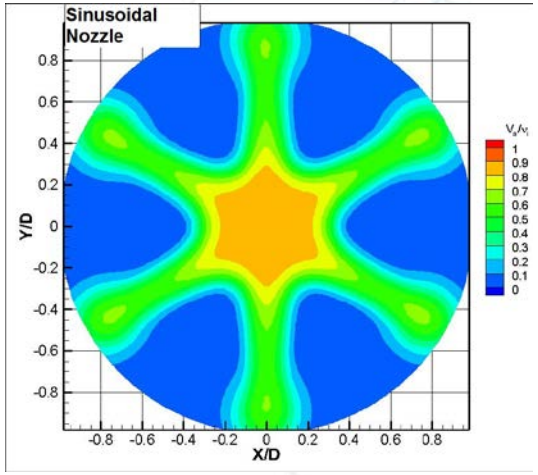
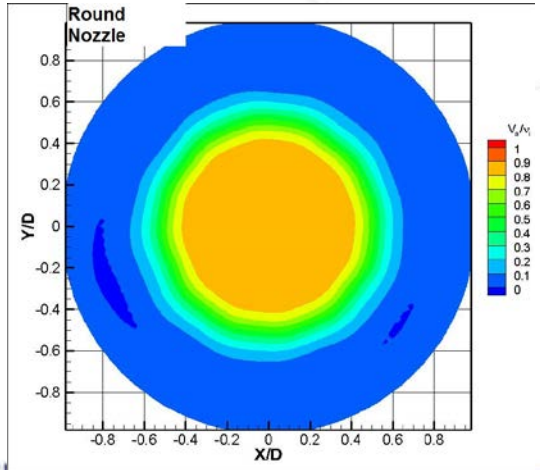
Shroud Nozzle Geometry Some Results



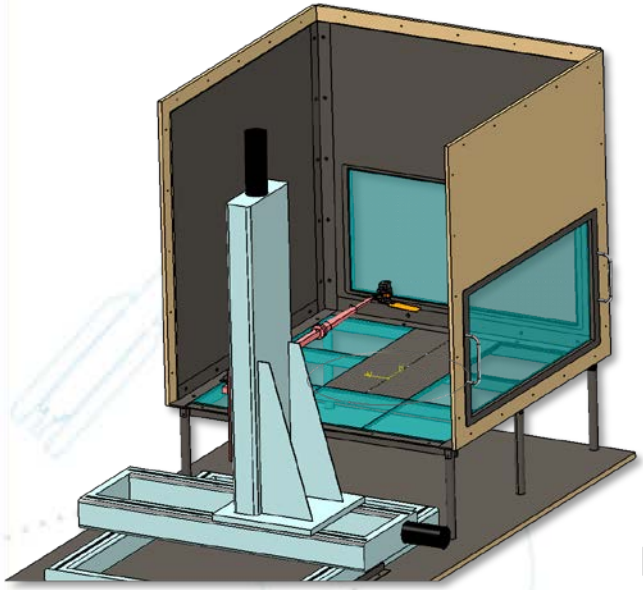


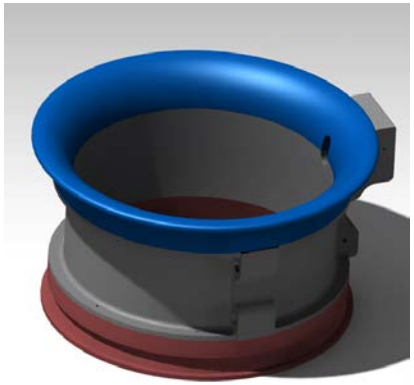


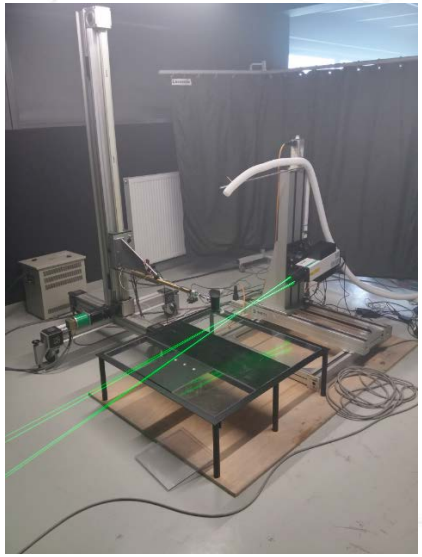
Future Work

Experimental

Numerical







Rotor-Shroud

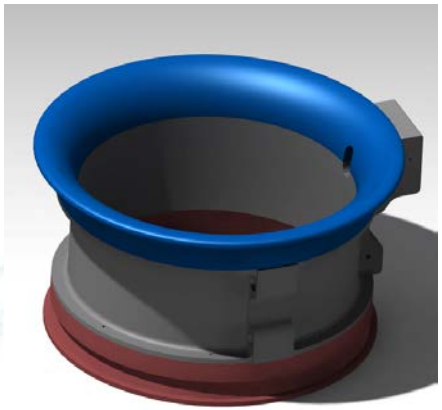
Ground effect measurements :

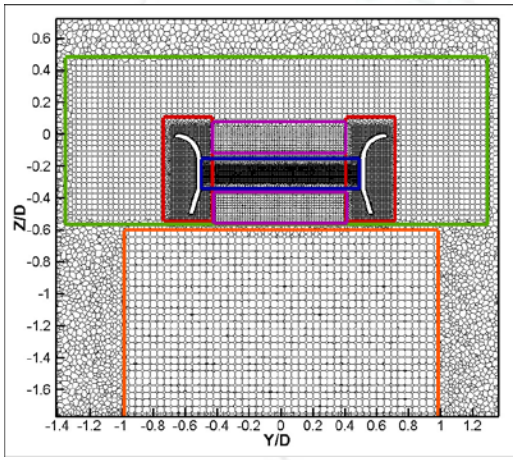
- Force and Moments
- Ground and Shroud Pressure Measurements
- LDV measurements of the wake

Future Work

Experimental

Numerical

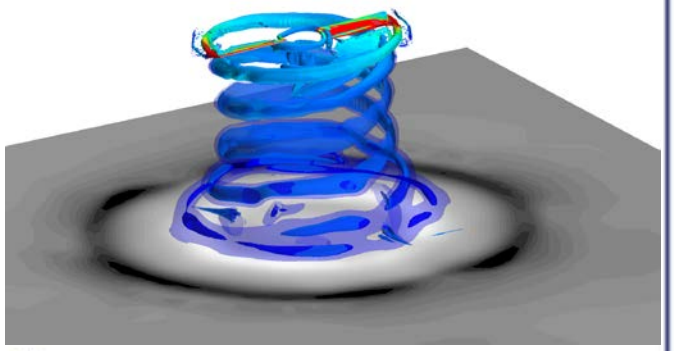




Rotor-Shroud
Ground effect Simulations

- RANS (VBM)
- URANS (Rotating blade)

Simulation of Vortex Generators in the Shroud Wall



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