DTU

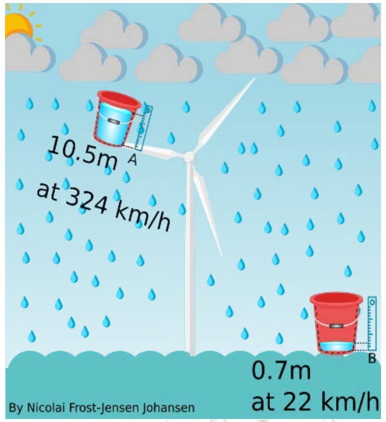
Public webinar IEA task 46 WP4 erosion testing

The abbreviated history of erosion testing

The abbreviated history of erosion testing

A USAF North American F-86D

AH-1W SuperCobra fra United States Marine Corps letter fra et landgangsfartøj.



First wave: 50's to 70's

- The Jet age
  - Radar domes
  - Turbine components

Second wave: 80's to 90's

- Helicopter blades

Third wave: 2010's to ??:

- Wind turbines

First wave: The jet age

- In 18 years planes more than doubled in speed
- New technological developments
  - Radar
    - Rad Domes to protect the sensitive antenna
    - Materials Transparent to RF
      - PMMA
      - GF
      - Other polymers

P-51 Mustang

P-51D of 375th Fighter Squadron, with underwing drop tanks

- 1940
  - Machine gun only
  - 630 km/h

F-86D/K/L Sabre

A USAF North American F-86D

- 1952
  - Guns and radar guided missiles
- 1,124.1 km/h

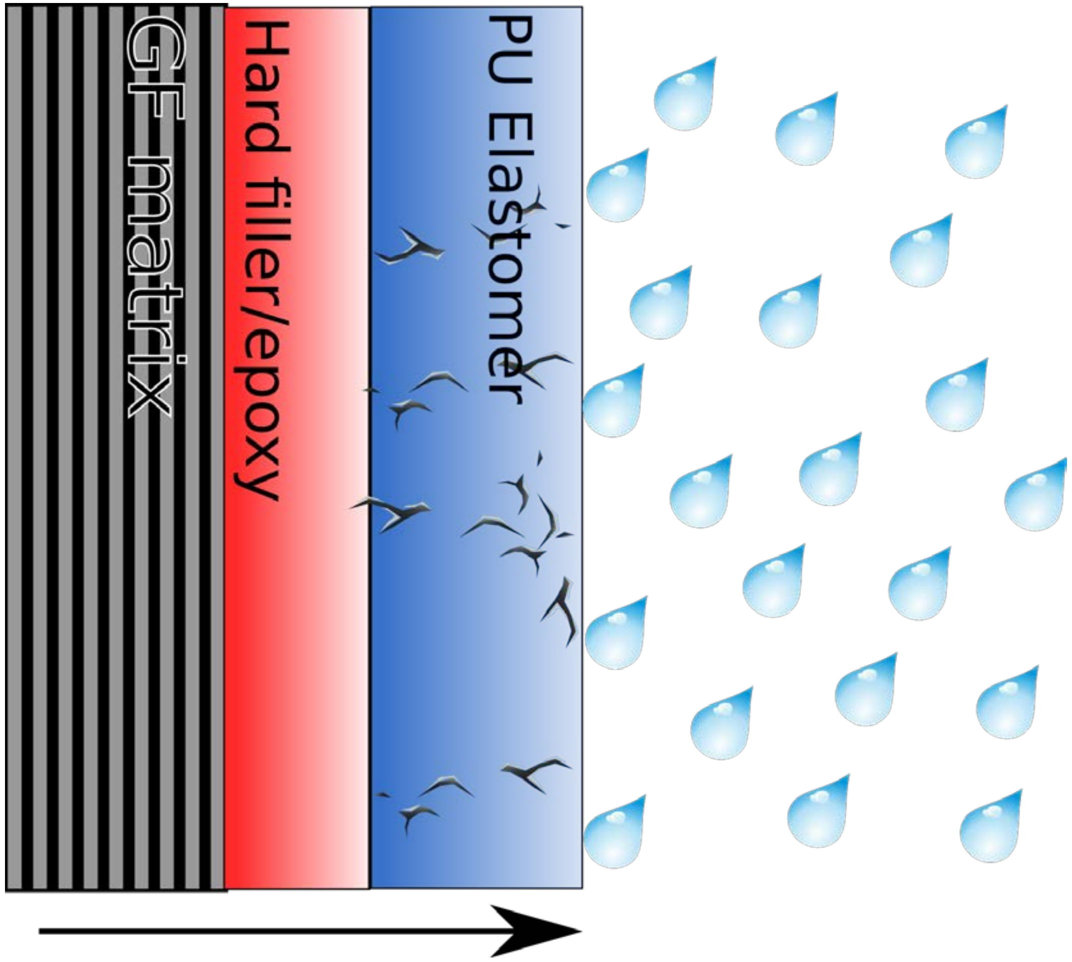
F-4 Phantom II

- 1958
  - Only missiles*
- 2,432 km/h

What are we simulating?

- Repeated droplet impacts on a surface
- Multiple impacts leading to fatigue resulting in loss of Material
- How do we simulate this in controlled conditions?

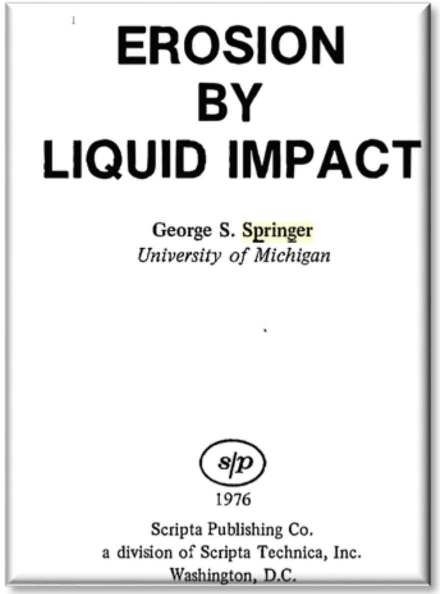
Option 1: Have Unlimited military budget!



Rockets!!!

Rocket sleds

- Samples to be tested was mounted on rocket sleds
  - Send along long linear rails
  - Stationary rain fields along the track.
- The work cumulated in 1976 with springers book
  - The famous springer model


EROSION BY LIQUID IMPACT

George S. Springer
University of Michigan

s/p
1976
Scripta Publishing Co.
a division of Scripta Technica, Inc.
Washington, D.C.

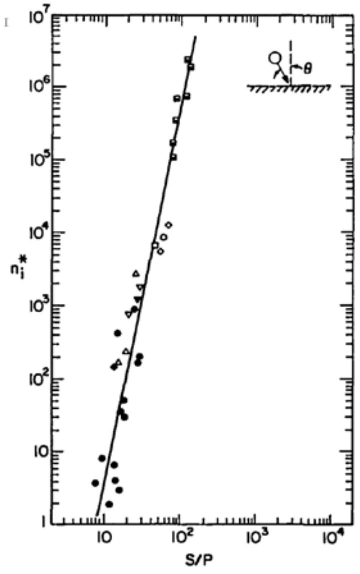


Fig. 2-5 Incubation period versus S/P. Symbols for data defined in Table 2-1. Solid line: Best fit to data (Springer & Baxi, [1]).

$$n_i^* = 7 \times 10^{-6} \left(\frac{S}{P}\right)^{5.7}$$

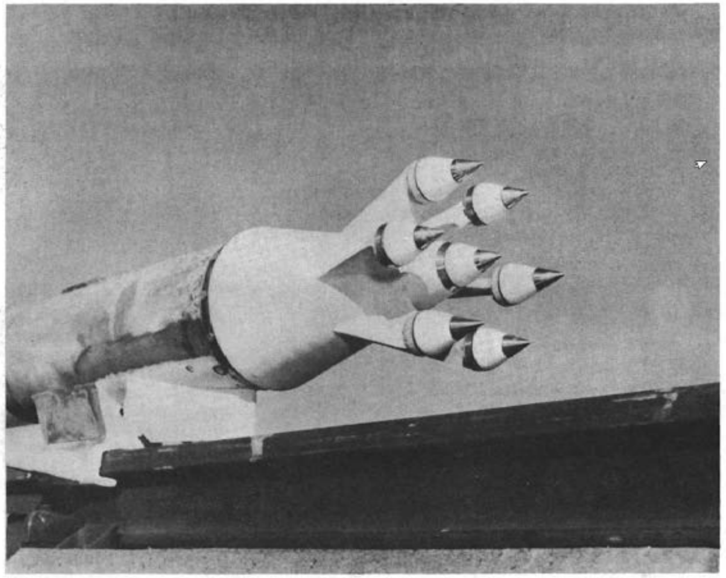


Figure 12. Samples assembled for test 5.

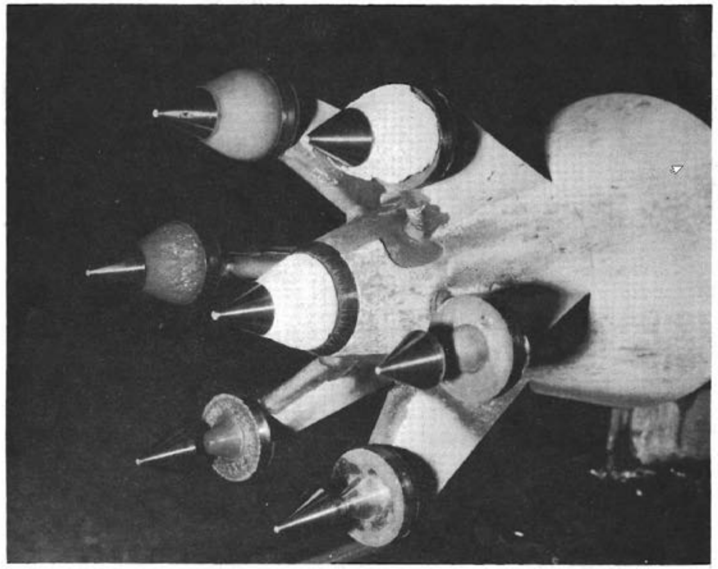


Figure 11. Test vehicle and samples after test 4.

The model works! But there are limits

Chapter 3. Introduction to rain erosion

Material	Density ρ	Speed of sound C	Dynamic Impedance Z	Max velocity V_{max}	$h_s > 2d\frac{C_s}{C_L}$ $d = 2mm$
	g/m^2	m/s	MPa/m^2s	m/s	m
Acrylic plastic[28]	1.22	1943	2.33	1137	5.3E-3
Aluminum[28]	2.7	5200	17.75	4650	14.2E-3
Epoxy[28]	1.77	3531	6.25	2318	9.7E-3
Neoprene[28]	1.55	135	0.21	502	369.1E-6
Nikel[28]	8.1	5055	40.95	12749	13.8E-3
Polyester[28]	1.82	3200	5.82	2188	8.7E-3
Polyurethane[28]	0.99	274	0.271	520	749.1E-6
Steel[28]	7.6	5182	39.38	12277	14.2E-3
Water[28]	1	1463	1.46		
Elastomers And rubbers					
Natural rubber[31]	0.92	165	0.15	55	451.1E-6
Styrene-butadiene rubber[31]	0.91	574	0.52	234	1.6E-3
Neoprene (chloroprene)[31]	1.24	180	0.22	62	492.1E-6
Polyurethane (low)[31]	1.15	93	0.11	30	254.3E-6
Polyurethane[31]	1.15	255	0.29	92	697.2E-6
Polyurethane (high)[31]	1.15	511	0.59	215	1.4E-3

Table 3.1: *The table shows maximum impact speeds V_{max} that Springer recommends using the straight line approximation of the Rankine-Hugoniot curve. The first set of data in the table is from Gorge Springer's book[28] material data for rubbers and elastomer is from Slot[31]*

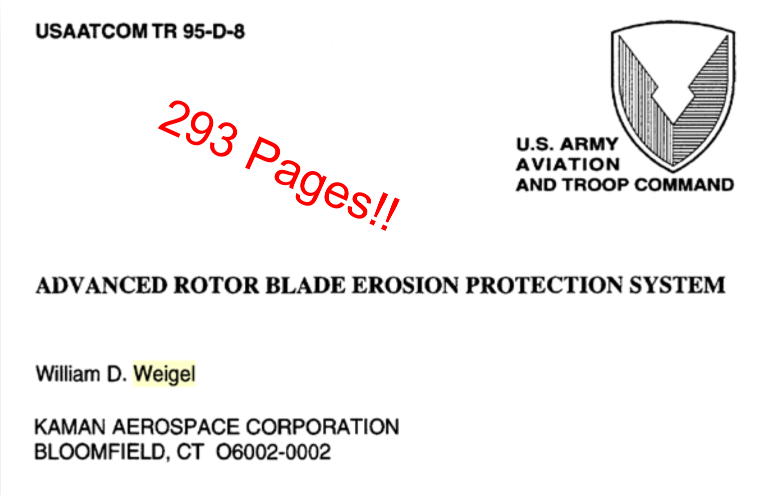
Second wave: Helicopters 80-90's

- Helicopter blades
  - 180 to 270 meters per second (m/s) or approximately 648 to 972 kilometers per hour (km/h)
  - Slower than jets but potentially more time in the rain.
  - Lots of work was conducted much in the, behind closed doors
  - Several independent and unique rotating arm facilities where made

Bell AH-1 Cobra

AH-1W SuperCobra fra United States Marine Corps letter fra et landgangsfartøj.

Option 1: Have Unlimited military budget!



USAATCOM TR 95-D-8

293 Pages!!

U.S. ARMY
AVIATION
AND TROOP COMMAND

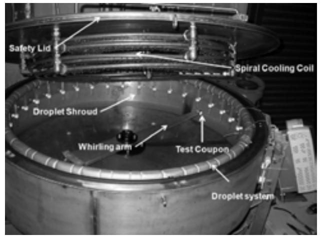
ADVANCED ROTOR BLADE EROSION PROTECTION SYSTEM

William D. Weigel

KAMAN AEROSPACE CORPORATION
BLOOMFIELD, CT O6002-0002

Table 1
Rain erosion test facilities.

Test method	Examples	Maximum test speed (ms^{-1})
Whirling arm	Royal Aircraft Establishment whirling arm rig [4,5]	~270
	Wright-Patterson AFB rotating arm apparatus, UDRI [6]	290
	SAAB-SCANIA whirling arm rig [7]	335
	Dornier rotating arm apparatus [7,8]	700
	AS&T rain erosion rig [9]	250



Tobin, E. F., Young, T. M., Raps, D., & Rohr, O. (2011). Comparison of liquid impingement results from whirling arm and water-jet rain erosion test facilities. *Wear*, *271*(9–10), 2625–2631. https://doi.org/10.1016/J.WEAR.2011.02.023

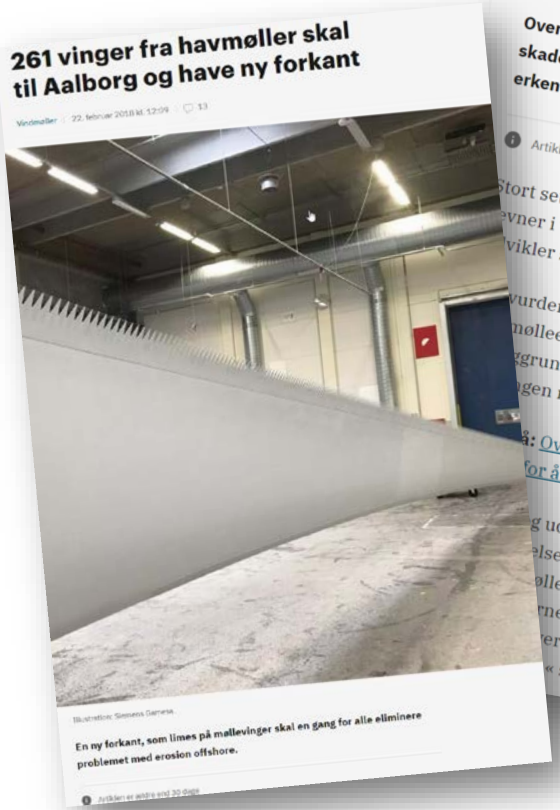
Third wave: Wind Turbines

- In the 2010’s the problem of erosion start to rear it s face on wind turbines
  - Infamously the Anholt park had 261 blades recoated after only 5 years op operation

~~Option 1: Have Unlimited military budget!~~

Option 2: do the Hard ting and Collaborate

BICEPS - testing of leading edge erosion protection systems



261 vinger fra havmøller skal til Aalborg og have ny forkant

Vindmøller | 22. februar 2018 kl. 12:09 | 13

Illustration: Siemens Gamesa.

En ny forkant, som limes på møllevinger skal en gang for alle eliminere problemet med erosion offshore.

Artiklen er ældre end 30 dage

Vindmølleejere må regne med dyre reparationer af møllevinger

Vindmøller | 11. november 2013 kl. 05:07 | 7

Overfladen på næsten alle vindmøllevinger skæmmes af smårevner og skader, der med tiden gør dyre reparationer uundgåelige. Fabrikanter erkender problemet.

Artiklen er ældre end 30 dage

Stort set alle vinger på danske vindmøller på land har småhuller og -evner i vingeoverfladen, som nedsætter møllens effektivitet og vikler sig mere og mere, hvis skaderne ikke repareres.

vurderer Strange Skriver, der er teknisk konsulent hos nølleejernes interesseorganisation Danmarks Vindmølleforening, grund af mølle-inspektioner rundt om i landet. Derfor prøver gen nu at råbe ejerne af de 4.600 vindmøller på land op.

å: Overrasket branche: Gamle vindmøller producerer mindre for år

g udbedring af vingerne har aldrig før været en del af elsesplanen for en vindmølle. Men med de mange skader, vi øllevinger i dag, må vi opfordre vores medlemmer til at få rne på deres møller regelmæssigt og forberede sig på ert fald 100.000 kroner til reparationer gennem « siger han.

Why is a turbine different than a helicopter?

- Time, speed and money
  - A helicopter gets 1h of maintenance per 10h I air
  - Turbine 1 h of maintenance per 10’000h in the “air”
  - Speeds 60-100m/s vs 180-270m/s

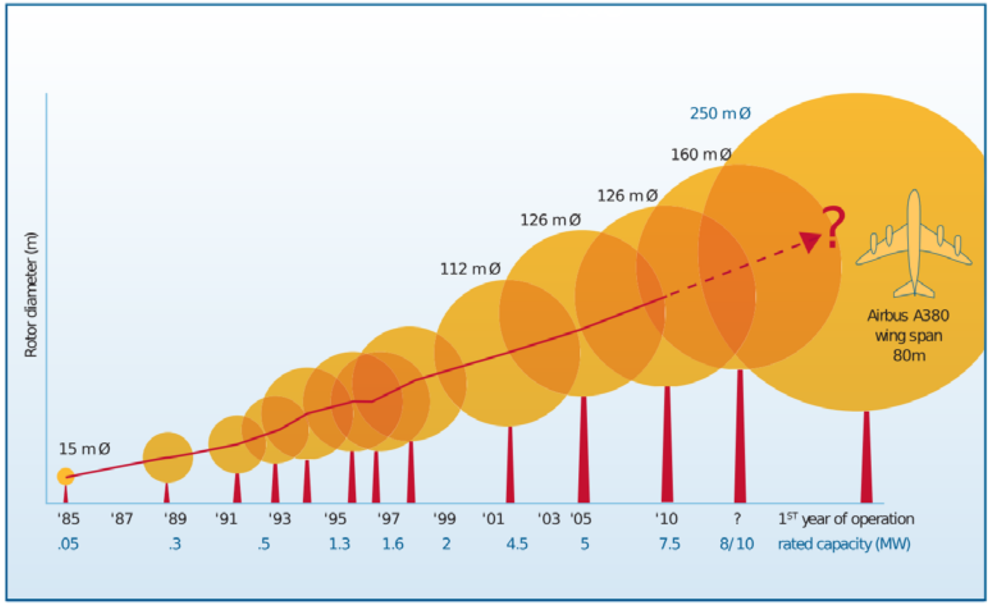


Figure 3.6: *Illustration showing how blade size has increased over the last 30+ years. The figure is from[14]*

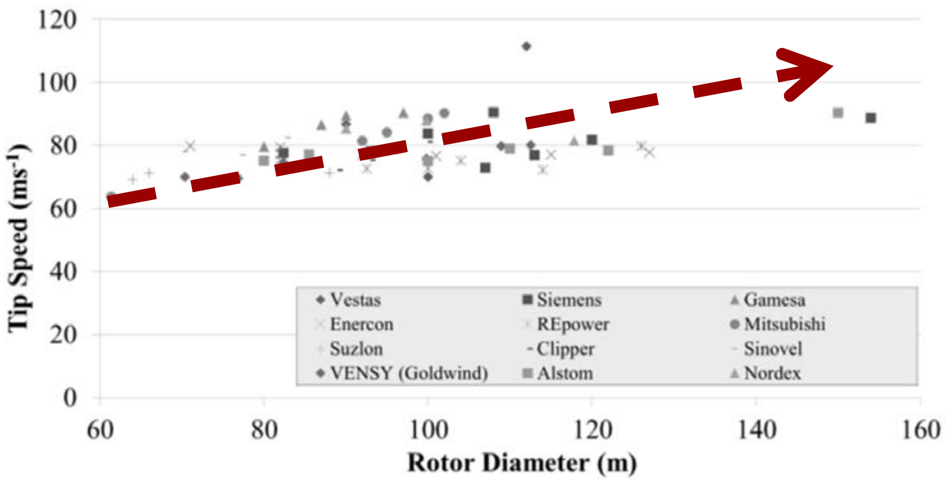


Figure 3.7: *The graph shows data collated[16] from different turbines where the tip speed of the turbines is plotted versus the rotor diameter. It can be seen, that the tip-speed tends to increase with rotor diameter*

The industry needed to standardize

- The BICEPS consortion
  - SRGE, VESTAS and LM
  - DVL-GL RP 0171
    - 2018
  - The new standard for erosion testing for wind energy


DNV·GL

RECOMMENDED PRACTICE

DNVGL-RP-0171

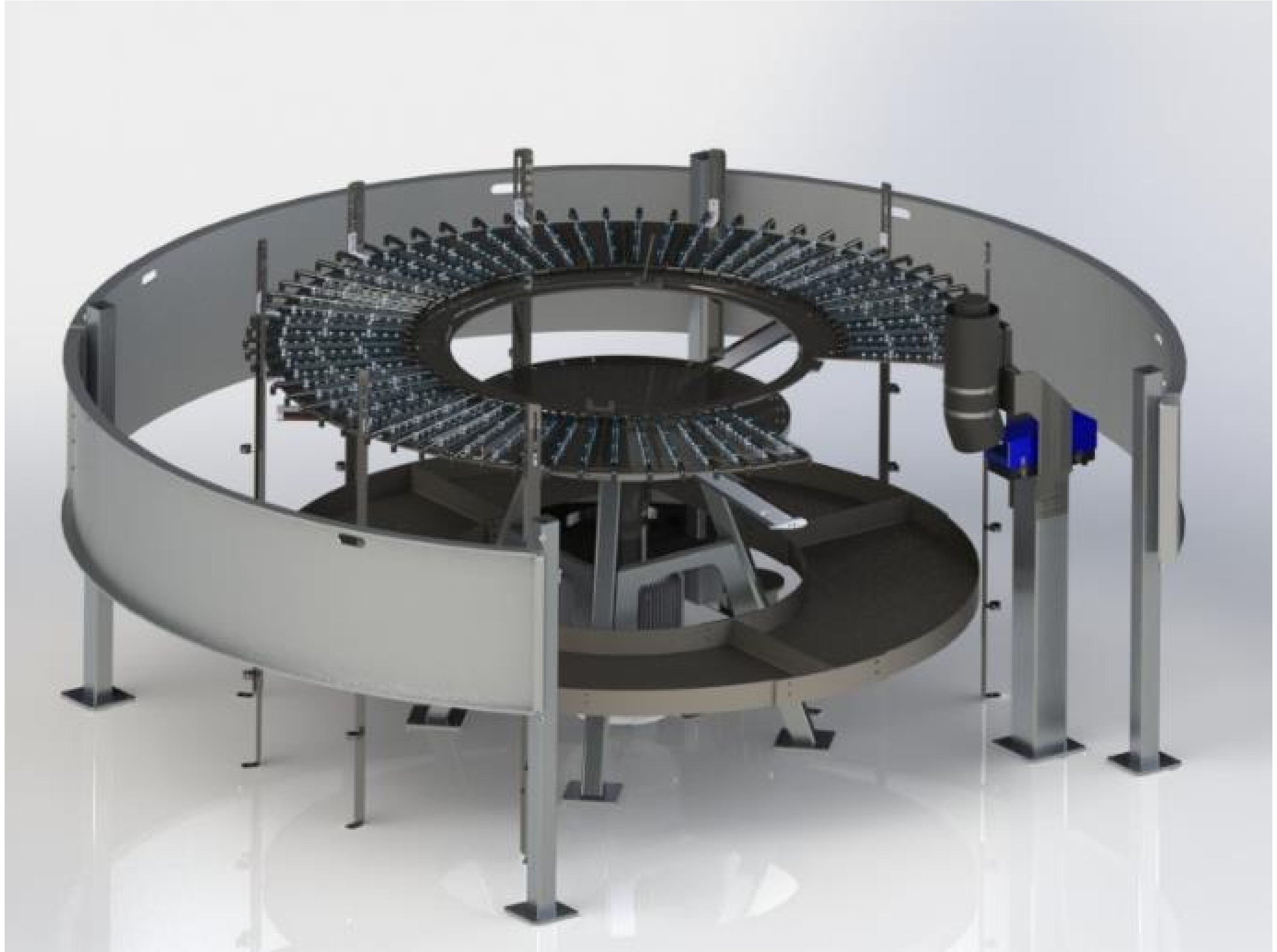
Edition February 2018

Testing of rotor blade erosion protection systems

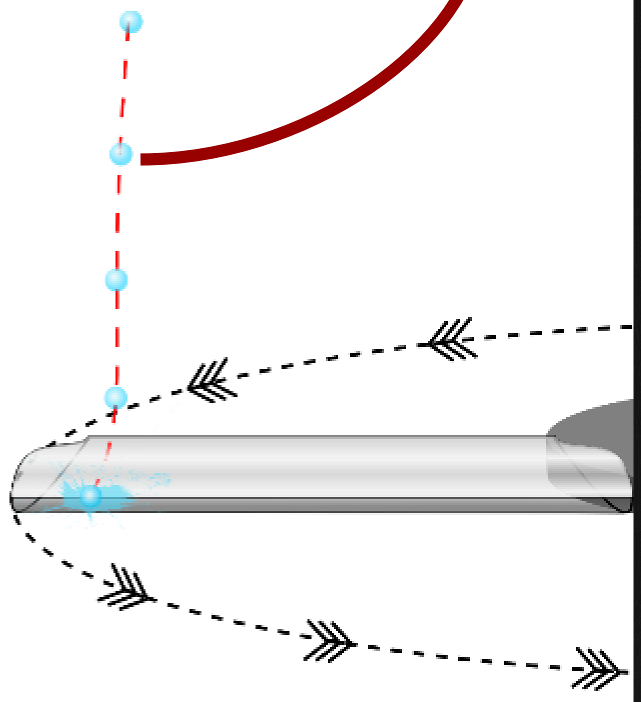
DNV GL AS

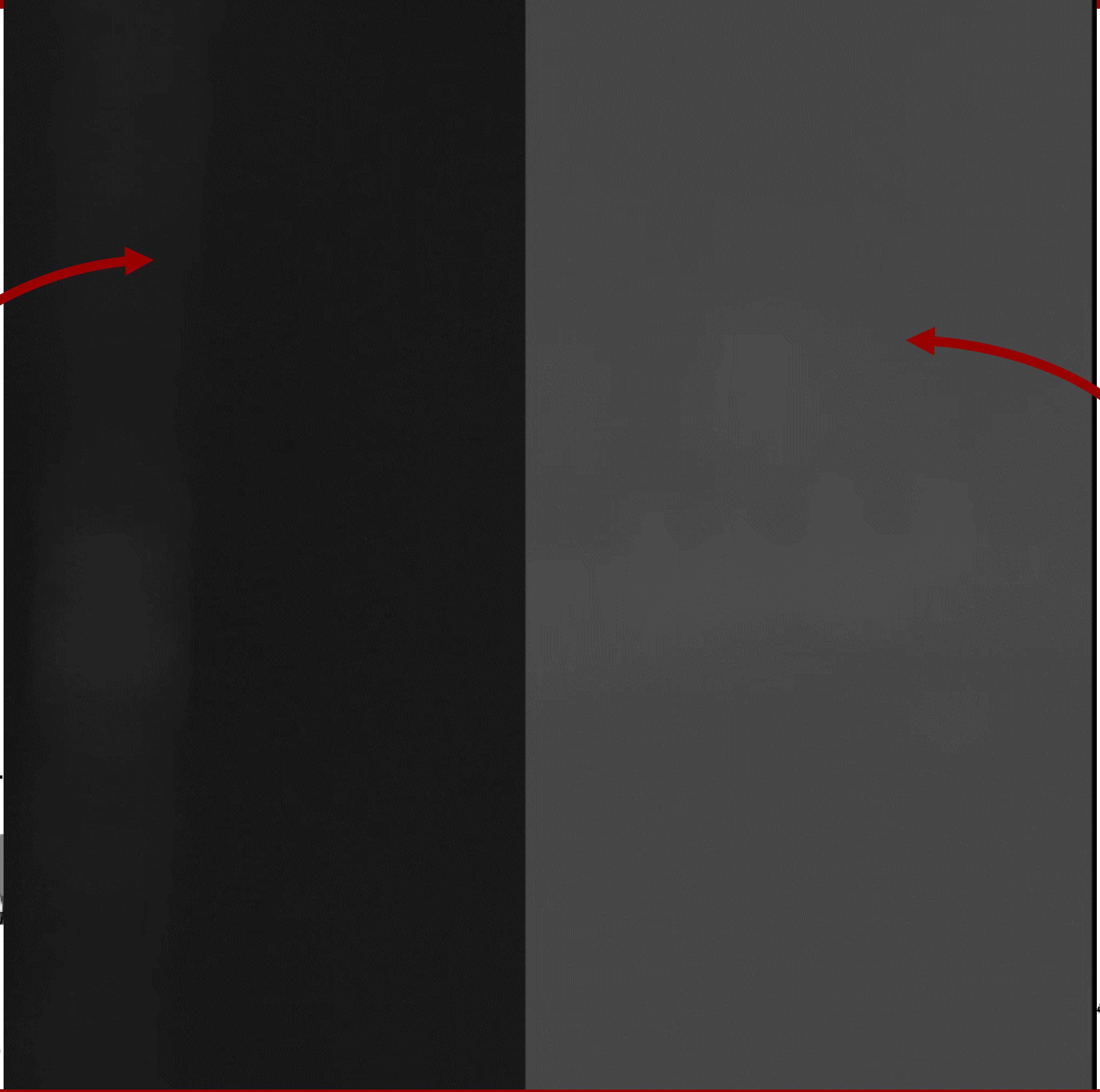
Whirling arm Rain Erosion Tester(RET) short introduction

- Industry standard tester
- Developed by R&D A/S
- More than 15 tester have been commissioned around the world
- Testing a multiple velocities at once
- Automated
- Controlled diverging rain field
  – Equal n# impacts along blade
    - More even erosion

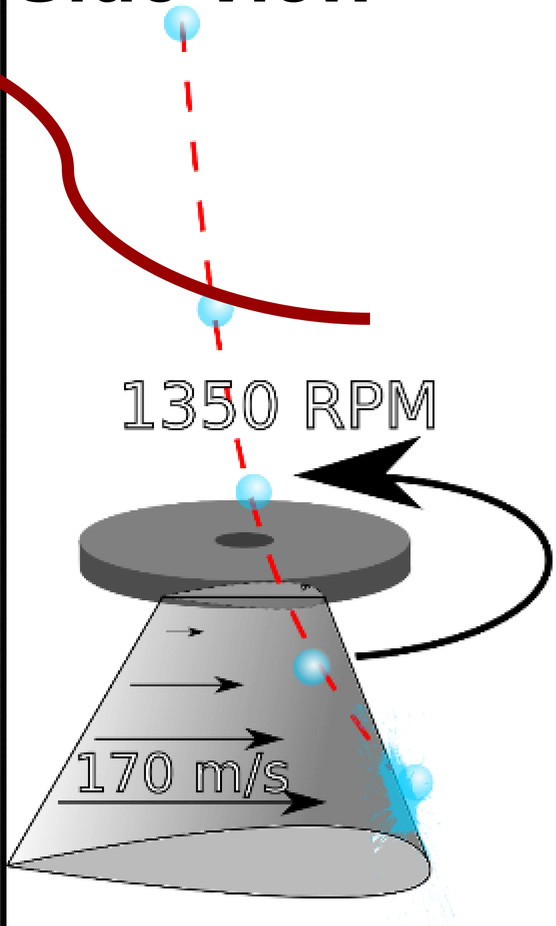


Front view



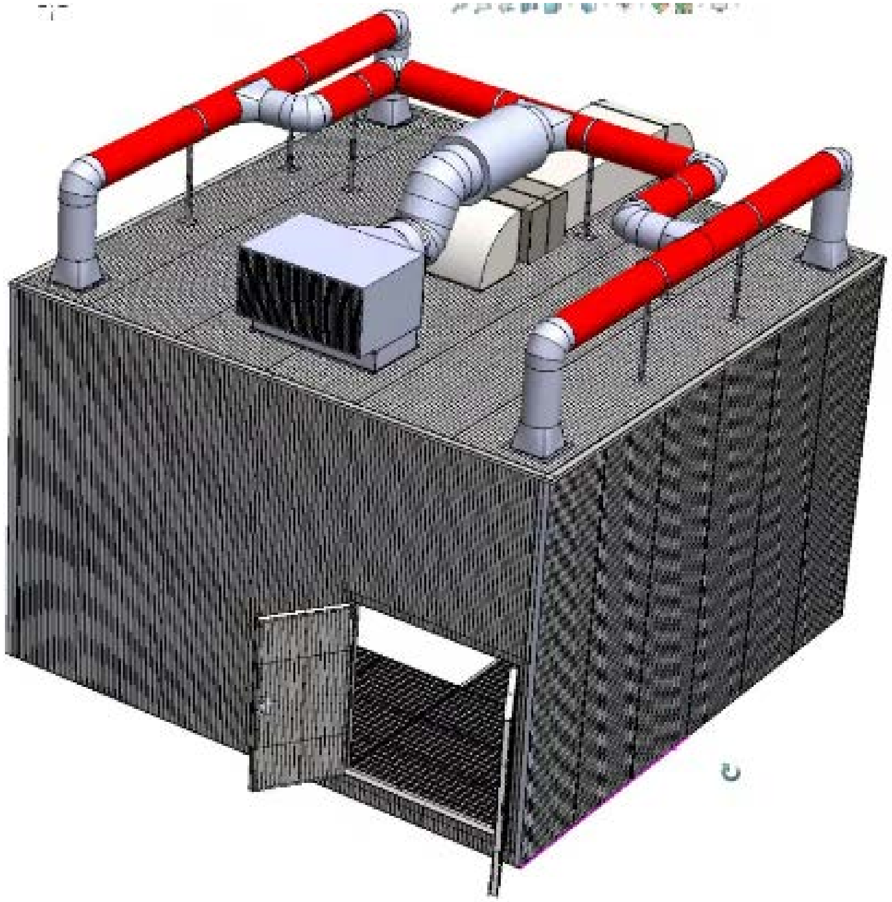


Side view



But we are not, done yet!!!

- Most machines are inside commercial environments
  - Exceptions, AIST Japan(university), ORE catapult (UK)
  - There is a need for a open platform
- Unique capabilities of the DTU RET
  - Full independent rain felid
    - One ring with 600 needles and one with 1200
    - Possibility of 6X the rain intensity compared to standard
  - Temperature control
    - Expected +-15degC temperature control compared to ambient
  - Extended chamber Height
    - Future possibility for changing drop height, or introducing hail generation system
  - Extra Large operator facility, allowing for teaching and training of small groups



Thank you for listening

To get in contact go to:

https://wind.dtu.dk/facilities/leading-edge-erosion-test-facility

And see our deliverables on:

https://iea-wind.org/task46/t46-results/

4.1 overwiev of testing methods

4.2 damage classification system

4.3 open tool for damage analysis and prediction (ongoing)

- Nicolai Frost-Jensen Johansen public CV

View Scopus Profile

Nicolai Frost-Jensen Johansen

- Development Engineer, Department of Wind and Energy Systems
- Composites Analysis and Mechanics
- Wind Energy Materials and Components Division

 https://orcid.org/0000-0001-9986-7162
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- Websitehttps://wind.dtu.dk

Extra slides on the open tool

- The following are slides about the current 4.3 deliverable. Where we are working on releasing a open python framework for using the methodologies in 0171 and 0573
- A focus is on how best to fit the observed erosion data from the RET, to get the most out of this expensive test.

A unified python-based rain-erosion lifetime calculation tool, using rain-erosion test data.

- Investigate the different lifetime models and compare the outputs (lifetime), using V & N dependency.

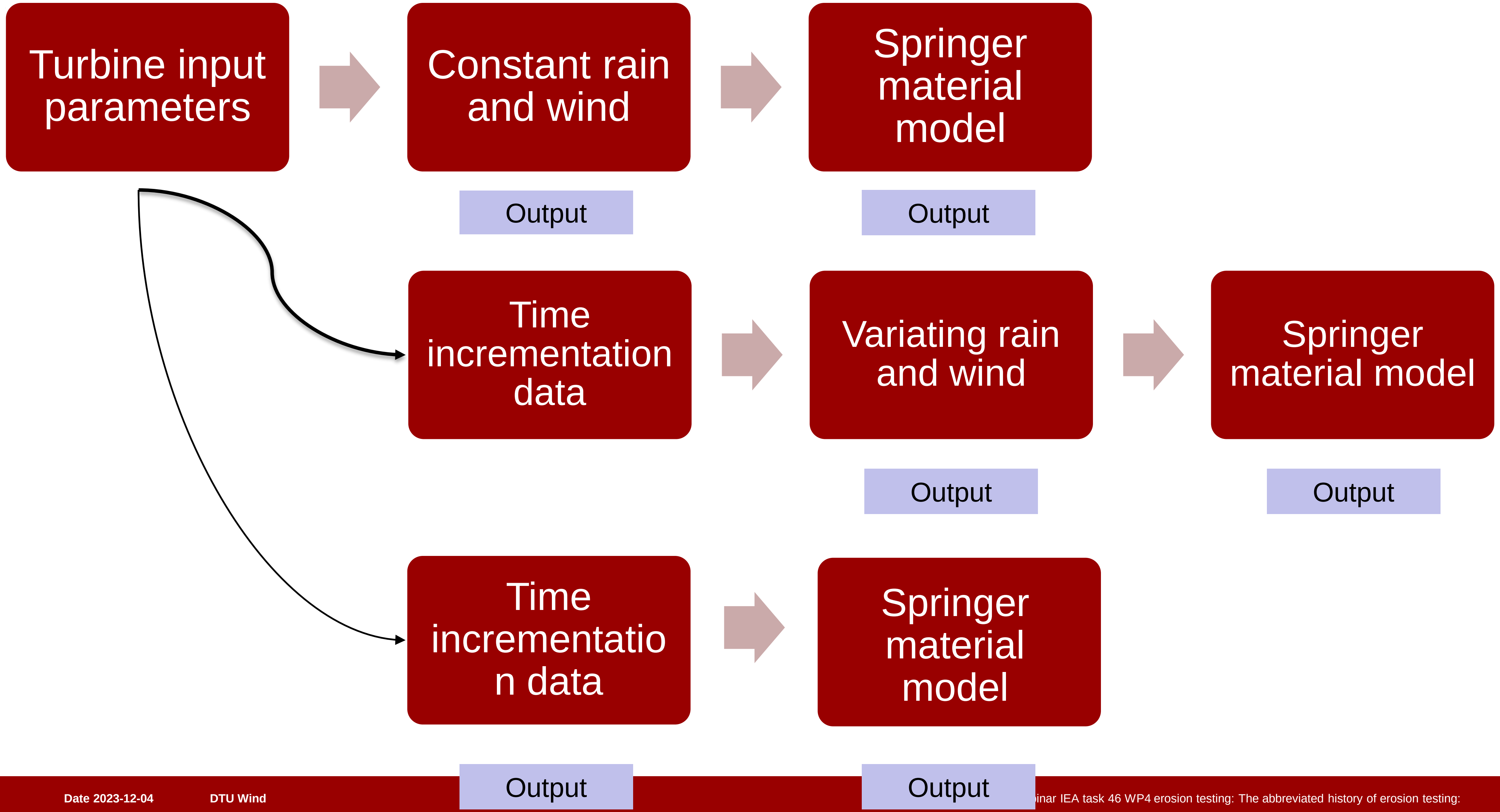
1. Constant rain and tip-speed √
2. Constant rain and tip-speed (springer) √
3. Variating rain and variating tip speed √
4. Variating rain and variating tip speed (springer) √
5. Time-series incrementation -
6. Time-series incrementation (springer) -
7. **Also have the Cobra-code implemented in python**

- Compare the V & N dependent results

- Investigate the uncertainty and influence of drop size & falling height on rain, number of specific impacts and impingement. Propagate mentioned through to lifetime estimate.

- Create a bar-plot illustrating lifetime-uncertainty for each method.

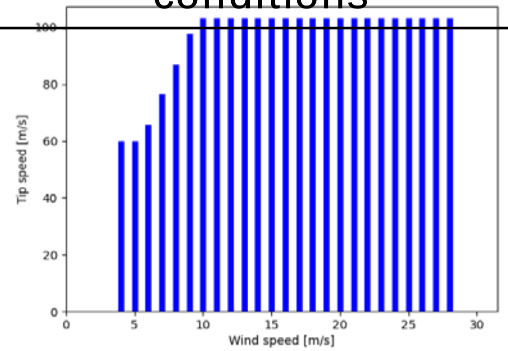
The models & their complexity levels.



Turbine input parameters

$r_{hub}, L_{blade}, L_{coverage}$

Variating turbine conditions



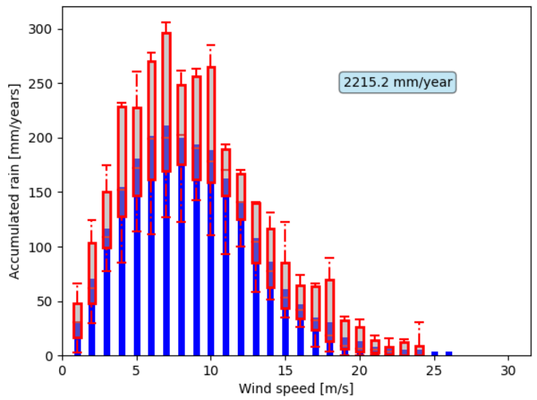
$u_{wind,i}$
$\omega_{rpm,i}$

Constant turbine condition

ω_{rpm}, v_{tip}

Time-series data

u_i, I_i



Constant rain & wind

u_{wind}, I_{mm}

1

Springer material data

$V_{impact}, \theta_{impact}, h_{thickness}$
$\rho_{liquid}, \rho_{substrate}, \rho_{coating}$
$C_{liquid}, C_{substrate}, C_{coating}$

Springer material data

$V_{impact}, \theta_{impact}, h_{thickness}$
$\rho_{liquid}, \rho_{substrate}, \rho_{coating}$
$C_{liquid}, C_{substrate}, C_{coating}$

Springer material data

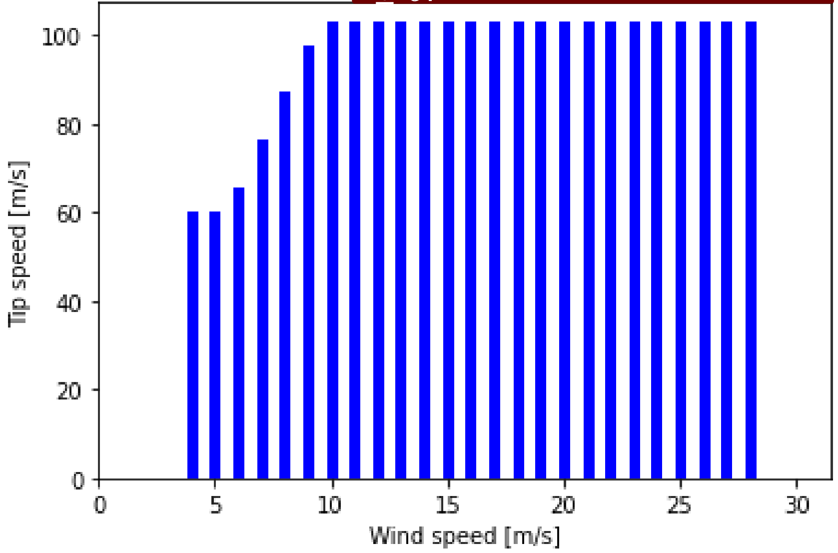
$V_{impact}, \theta_{impact}, h_{thickness}$
$\rho_{liquid}, \rho_{substrate}, \rho_{coating}$
$C_{liquid}, C_{substrate}, C_{coating}$

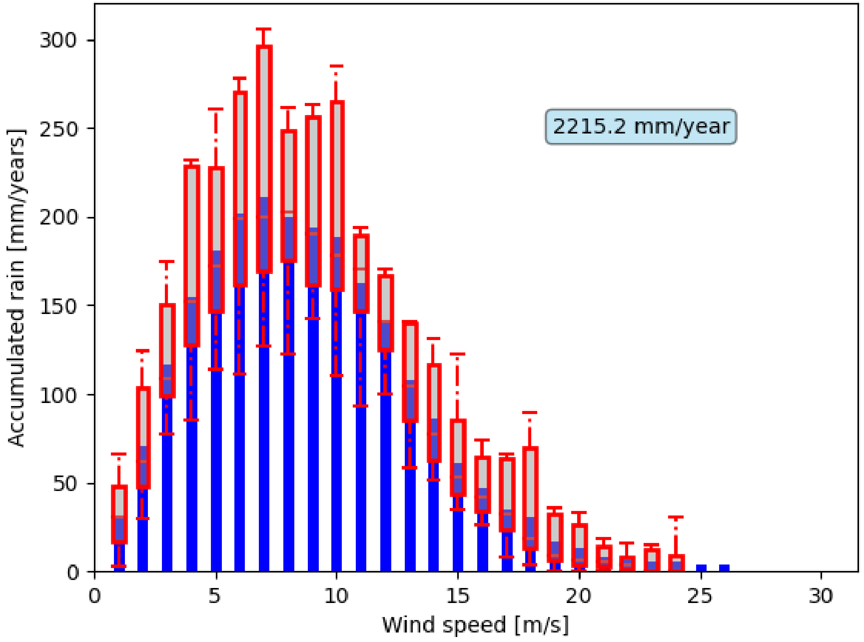
Constant and variating rain and wind

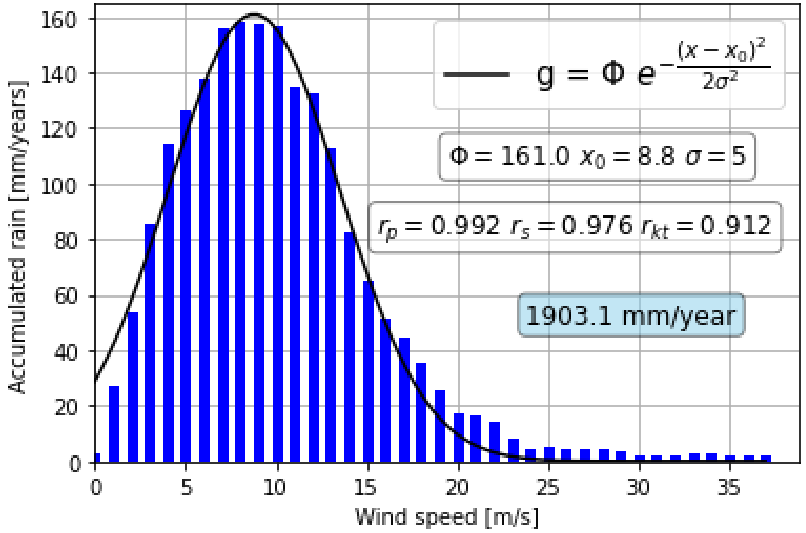
Note !!! Requires:
RET data SN curve fitting parameters
Turbine operating conditions

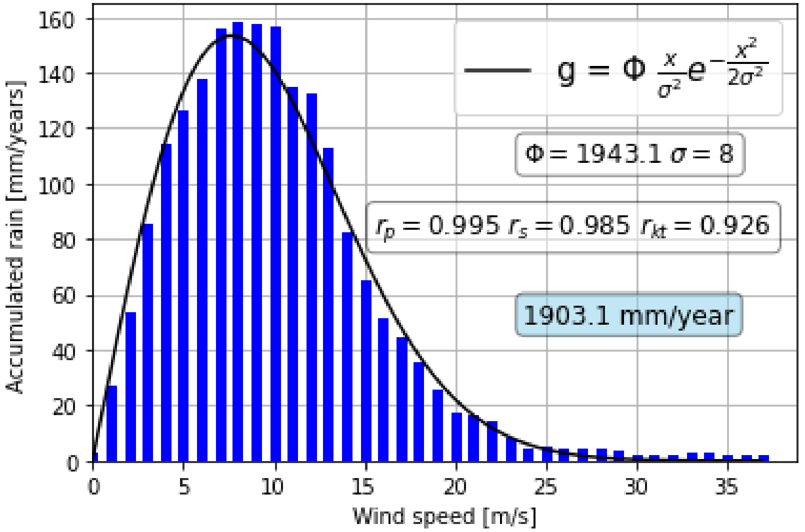
Site data

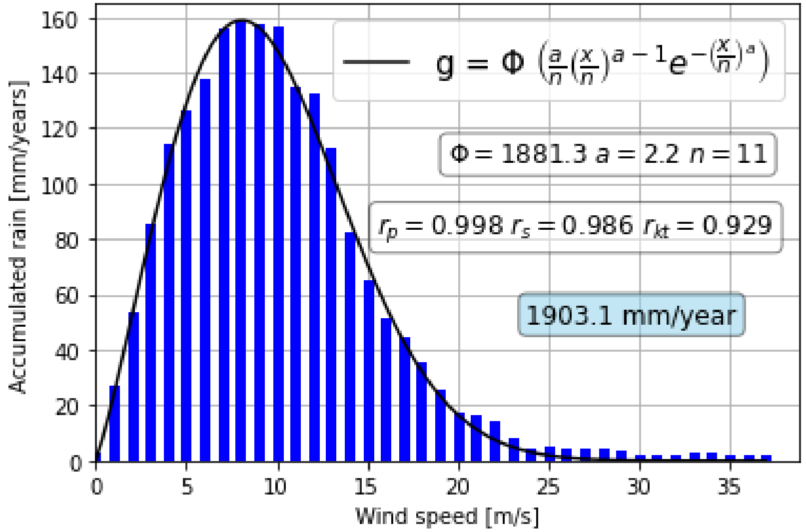
Note !!! There is also a variation in the tip speed curve, a small variation can be implemented $\pm\ \sigma$.



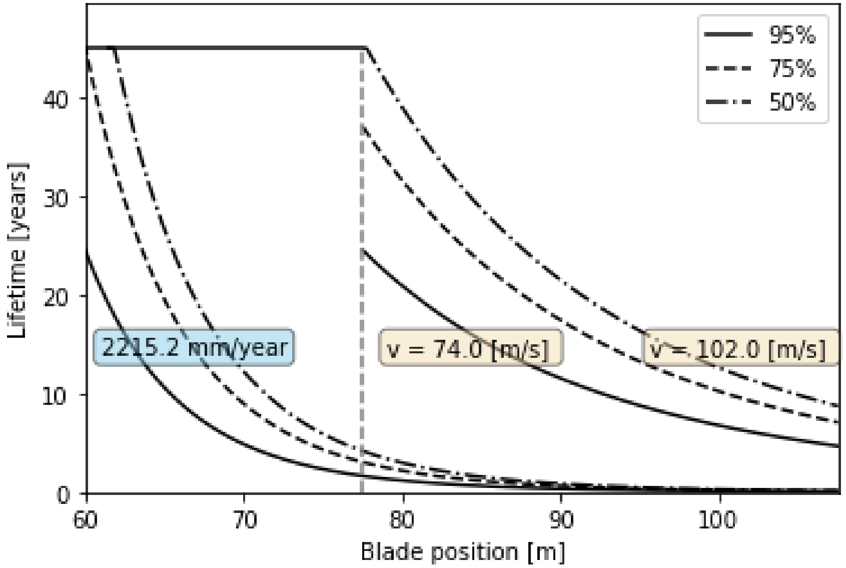


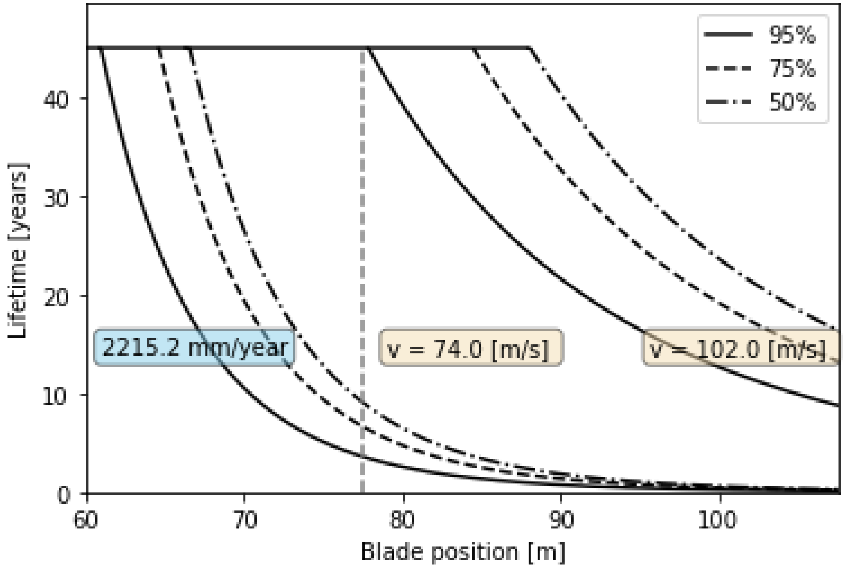


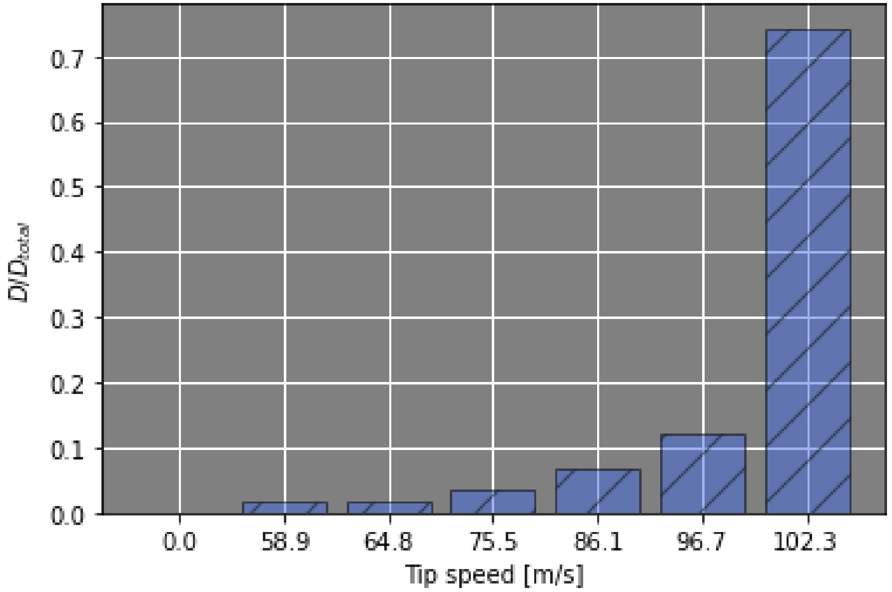


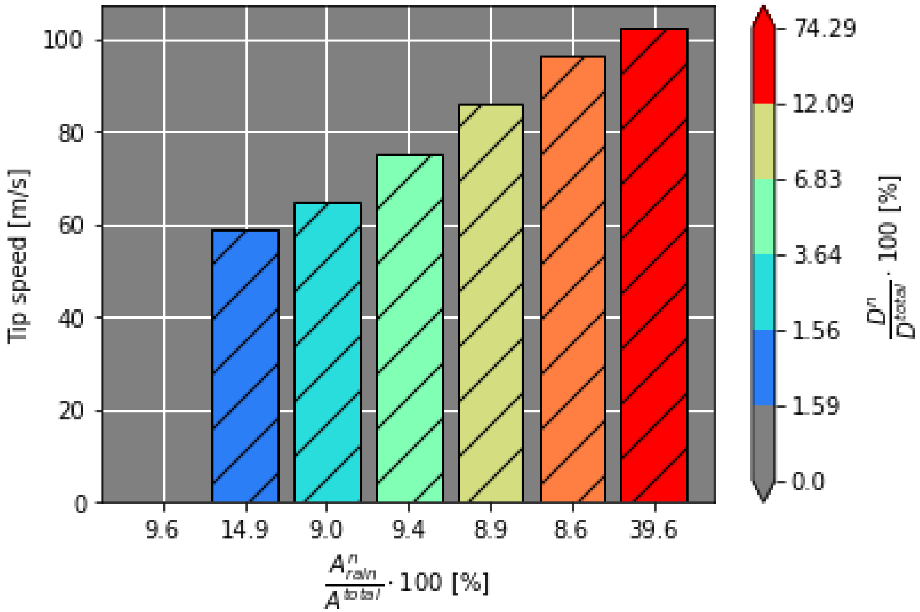


Constant variating rain and wind output



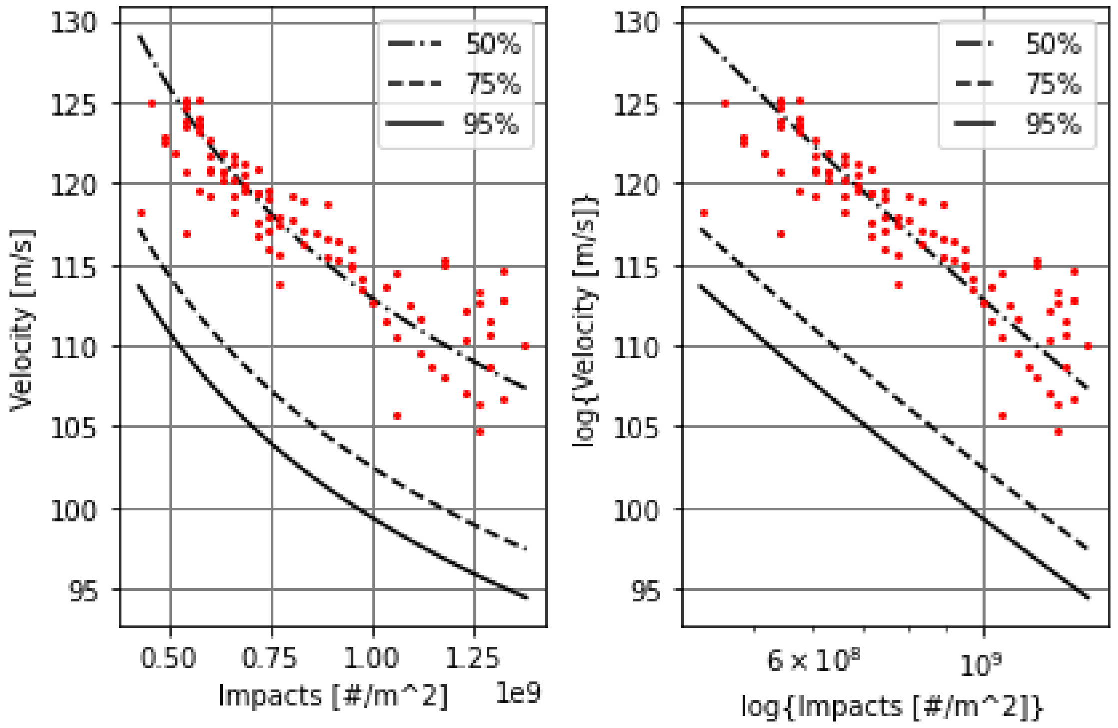






Working on the confidence intervals

- Some data seems to break the statistical 95/95% conf intervals
- We are looking at alternative methods
- Mean fit's are identical to our other tools
- Semilog plot implemented



What do we need to complete

- **Provide Sample Data for Testing:**
  - RET data that exemplifies typical outcomes.
  - Data that includes material properties speed of sound and density values for springer model
- **Submit Image Sets from the RET:**
  - High-quality image sets derived directly from the Rain Erosion Tester.
- **Contribute RET Test Reports:**
  - Comprehensive reports from past and recent tests.
- **Share Data that can be disseminated:**
  - Data sets that can be shared with the project team, and or published.
  - Anonymized data is acceptable. However, the more detailed and complete the data, the better it will serve the project's objectives.
- **Become a Beta Tester:**
  - Participants who can test early versions of the program and provide feedback.
- **Supply Turbine Site MET Data:**
  - Meteorological data from turbine sites.
  - Ideally, this data should come with blade inspection.