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DYNAMIC POSITIONING CONFERENCE
October 14-15, 2014

POWER/THRUSTERS

DP Thrusters – Dynamic Loads and Mechanical Damages

Dr. Ir Jie Dang

MARIN

DP THRUSTER

DYNAMIC LOADS & MECHANICAL DAMAGES

Dr. Ir. Jie Dang

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INTRODUCTION

- More than 50 years of industry applications
- Diesel-electric drive
- Increase power and size
- Wide range applications
- Gear damages
  - Surface pitting
  - Sub-surface fatigue
  - Tooth root damage
  - ……
  - Tooth Interior Fatigue Fracture (TIFF)

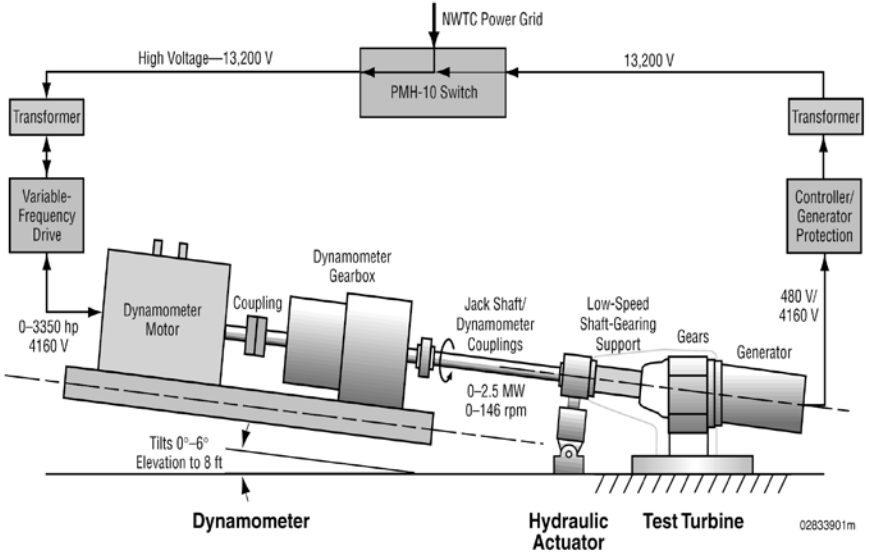
Classification statistics of mechanical damages

Components	Percentage of damages
Propellers	24%
Gears	12%
Bearings	11%
Ducts	3%
Steering gears	0%

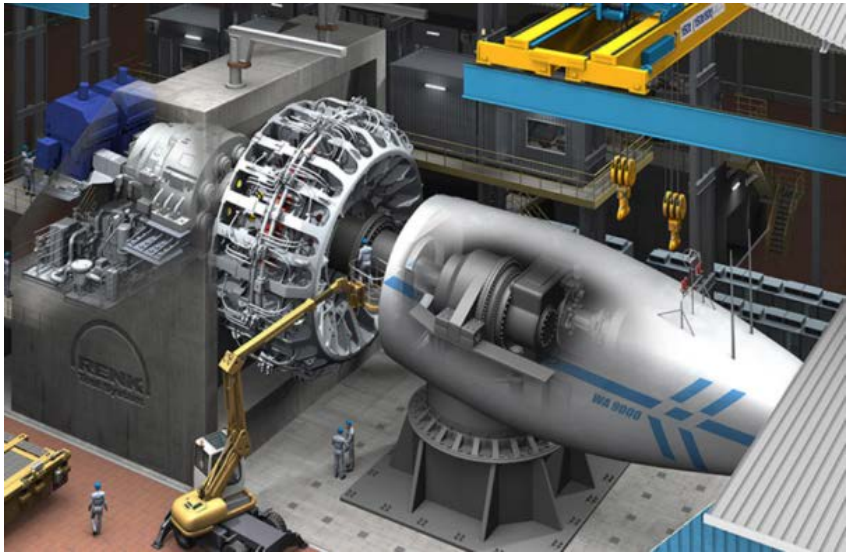
TIFF damage to a tooth of a bevel gear

INTRODUCITON

- Lack of understanding, lack of workshop testing
  - What the wind mill industry is doing:



NREL's 2.5 MW Dynamometer Test Bed



CURI's 15MW RENK LABECO Test Systems

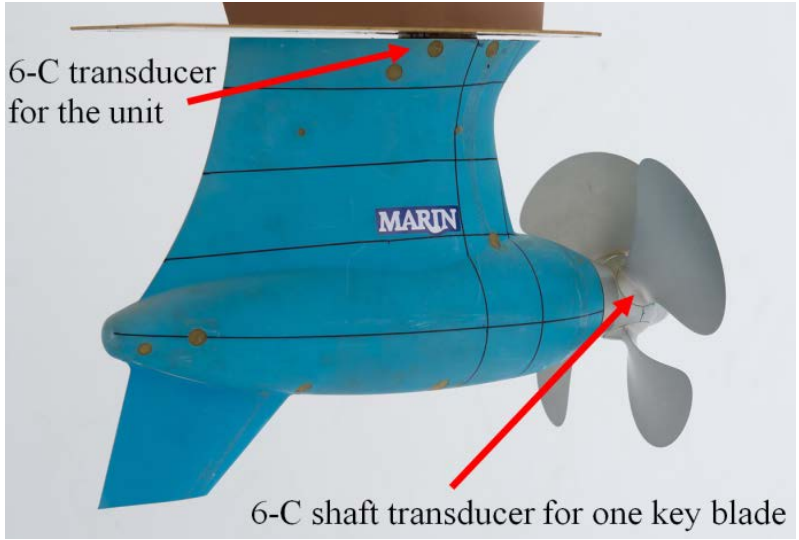
INTRODUCTION

- What marine industry is catching up:

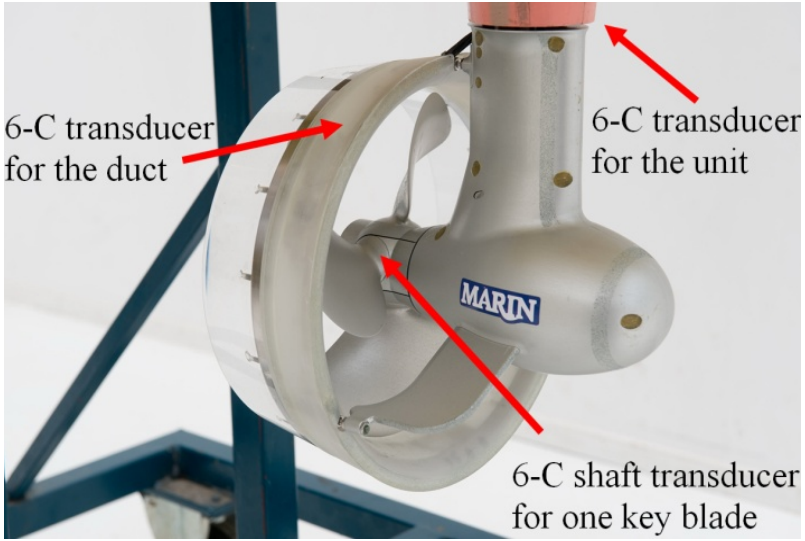
WPTC's 2MW Thruster Test Centre in Helsinki

TEST SET-UPS FOR HYDRODYNAMIC LOADS

- Typical thrusters for DP applications
  - Generic pulling thruster with open propeller, electric motor
  - Generic pushing thruster with ducted propeller, gear drive



generic pulling thruster with C4-70 propellers (2X6-C)



generic pushing thruster with D4-70 in 19A (3X6-C)

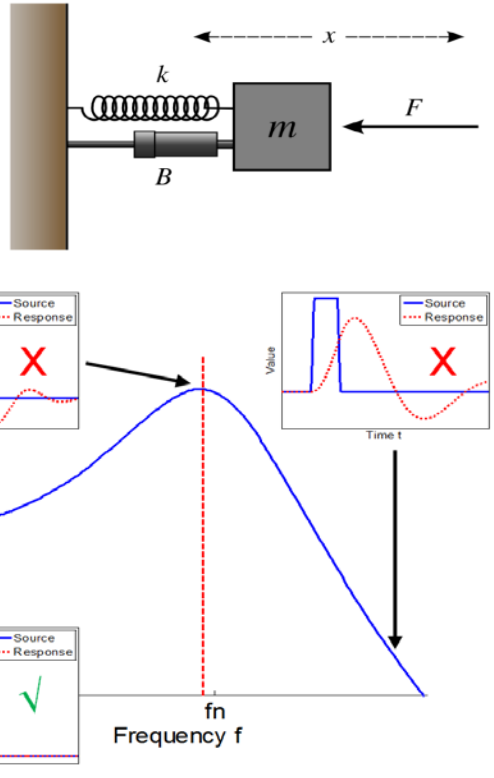
TEST SET-UPS FOR HYDRODYNAMIC LOADS

- The Depressurized Wave Basin (DWB) at MARIN

MARIN's Depressurized Wave Basin (DWB) with wave generators

TEST SET-UPS FOR HYDRODYNAMIC LOADS

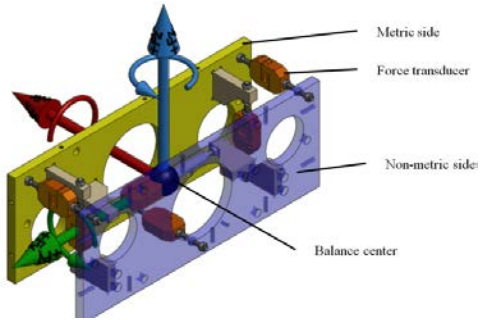
- How to measure dynamic loads?
  - Sensitivity of transducer ⇔ response frequency
  - Mass-spring-damper system
  - Increase natural frequency of the system
    - Increase the stiffness of transducers k
    - Reduce mass on metric side - m
    - Increase mass on non-metric side

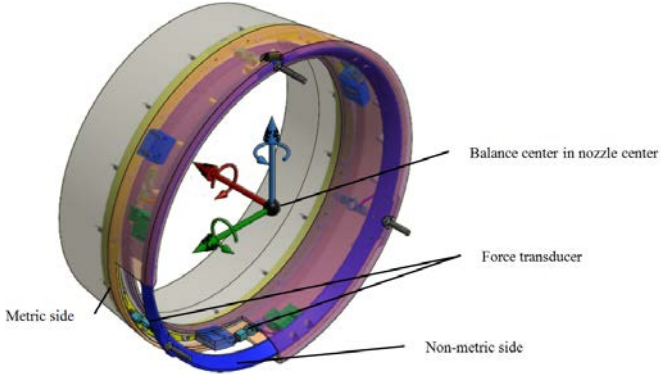


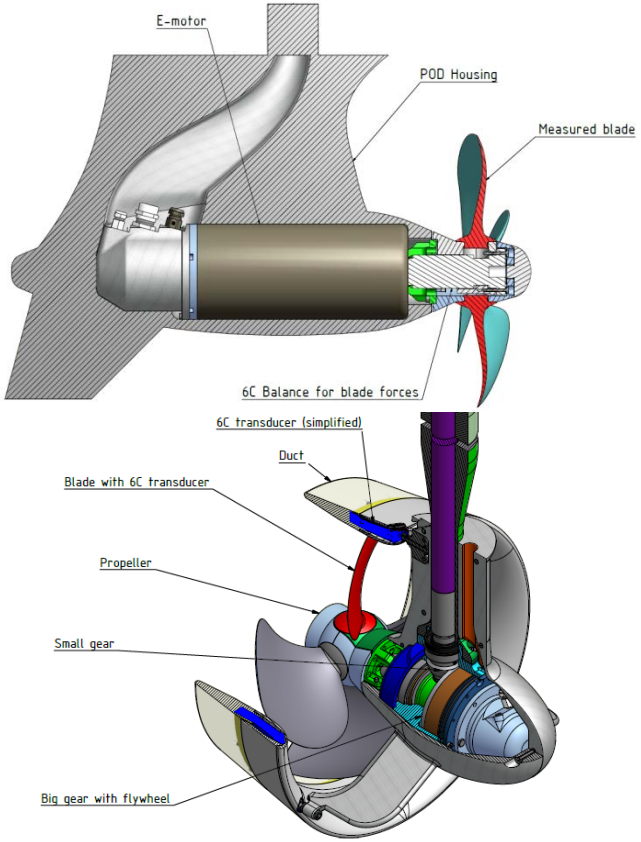
mass-spring-damper system and its dynamic response

TEST SET-UPS FOR HYDRODYNAMIC LOADS

- Six component transducers or frames



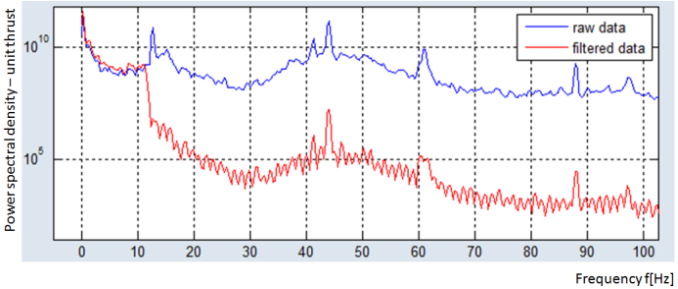




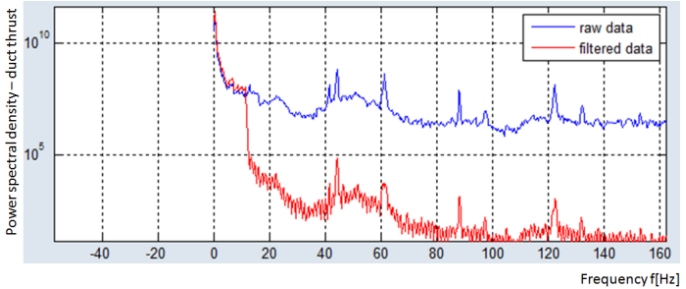
Unit **Duct** **Shaft**

TEST SET-UPS FOR HYDRODYNAMIC LOADS

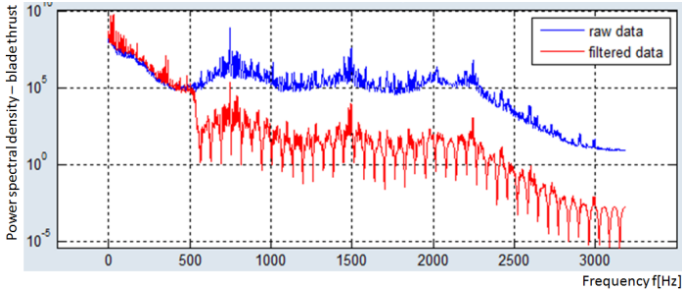
- Natural frequency of transducers



Unit



Duct



Shaft

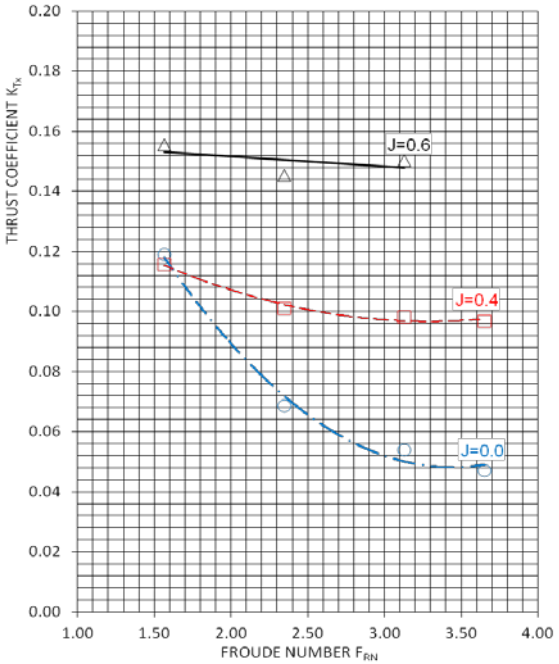
TEST SET-UPS FOR HYDRODYNAMIC LOADS

- Scaling laws and similarities
  - Reynolds Number
  - Froude law of ship
  - Cavitation number of propeller $F_{RN} = \sqrt{\frac{D}{g}}n$
  - Weber number $We = \frac{\rho V^2 \mathrm{D}}{\gamma} = \frac{\rho n^2 D^3}{\gamma}$
  - Air cushion effect
  - Cauchy scaling for ice-propeller interactions

$$\rho_{ice} U/S$$

- Synchronized high-speed video recordings

$$\sigma_n = \frac{p_a + \rho g h - p_c}{0.5\rho D^2 n^2} = \frac{p_a - p_c}{0.5\rho D^2 n^2} + \frac{h/R}{F_{RN}^2}$$



Propeller Froude number effect

TEST PROCEDURES

- Type of tests – dynamic loads
  - During extreme maneuvering
  - During thruster-thruster interaction
  - Ventilation
  - Ice-thruster interaction

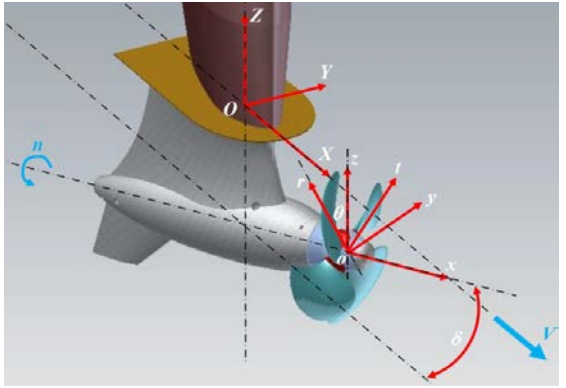
  - Open water and also in behind conditions

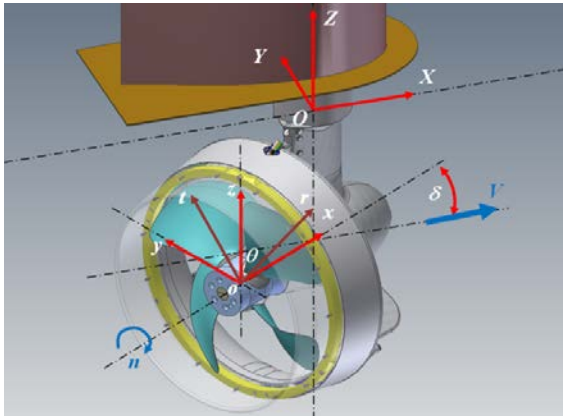
- Data analysis
  - Coordinate systems
    - Ship fixed O-XYZ
    - Thruster fixed o-xyz
    - Blade fixed o-xtr
  - Non-dimensionalized

$$K_{F,T} = \frac{F,T}{\rho n^2 D^4} \qquad K_{M,Q} = \frac{M,Q}{\rho n^2 D^5}$$

  - Fourier fitting

$$K = \sum_{k=0}^{N} \left[A_k \sin(k\delta) + B_k \cos(k\delta) \right]$$





The coordinate systems

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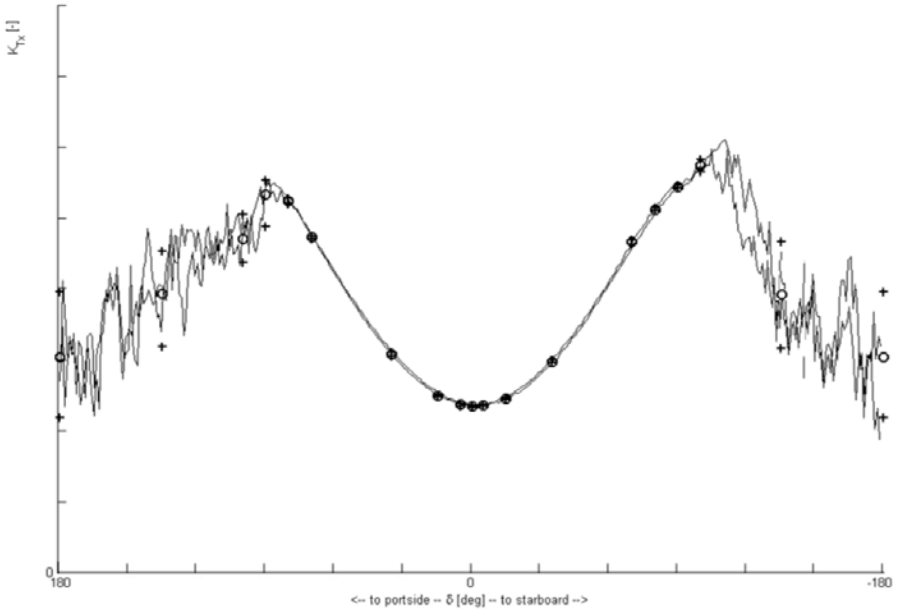
TEST PROCEDURES

- Quasi-steady model tests

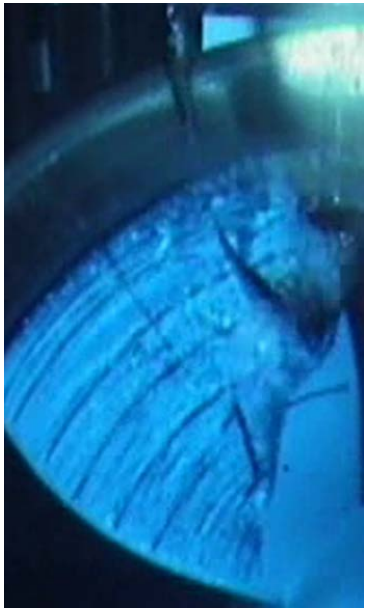


TEST RESULTS

- Ventilation inception – vortex induced

onset

developing

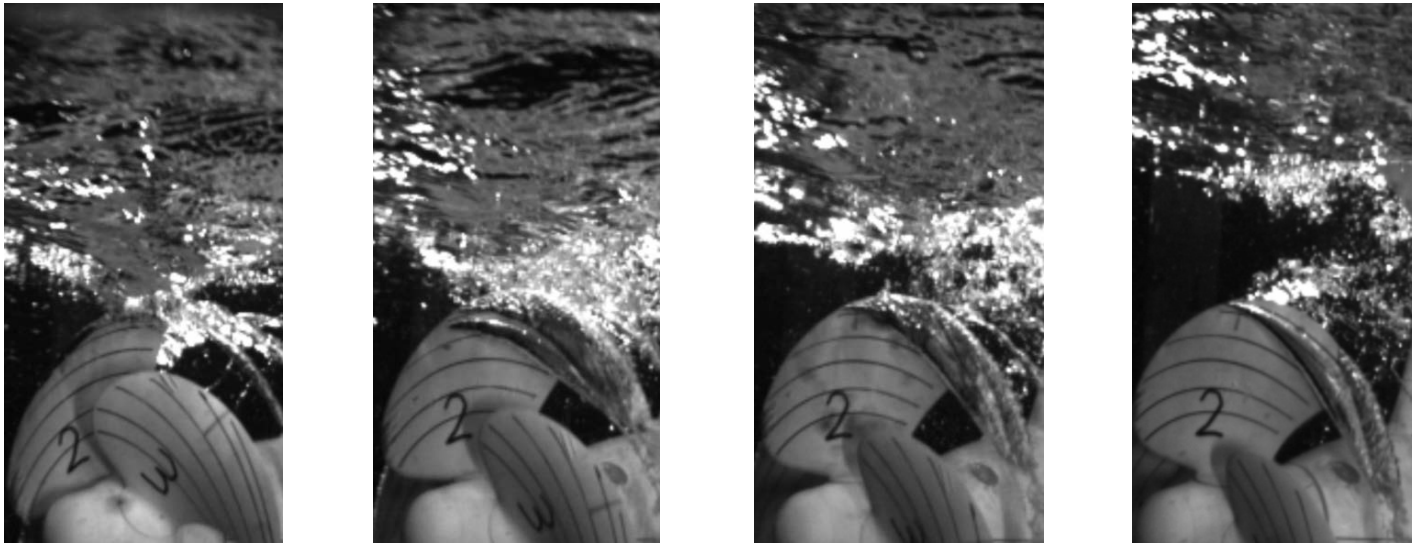


fully developed

An example of vortex induced ventilation in bollard pull condition, thruster with ducted propeller

TEST RESULTS

- Ventilation inception – blade low pressure induced



onset **fully developed** **retrieving** **finishing**

An example of blade ventilation in waves, pulling thruster with open propeller

TEST RESULTS

- Ventilation inception

onset

start duct L.E. ventilation

blade ventilated

fully ventilated

duct L.E. ventilation finishing

finishing

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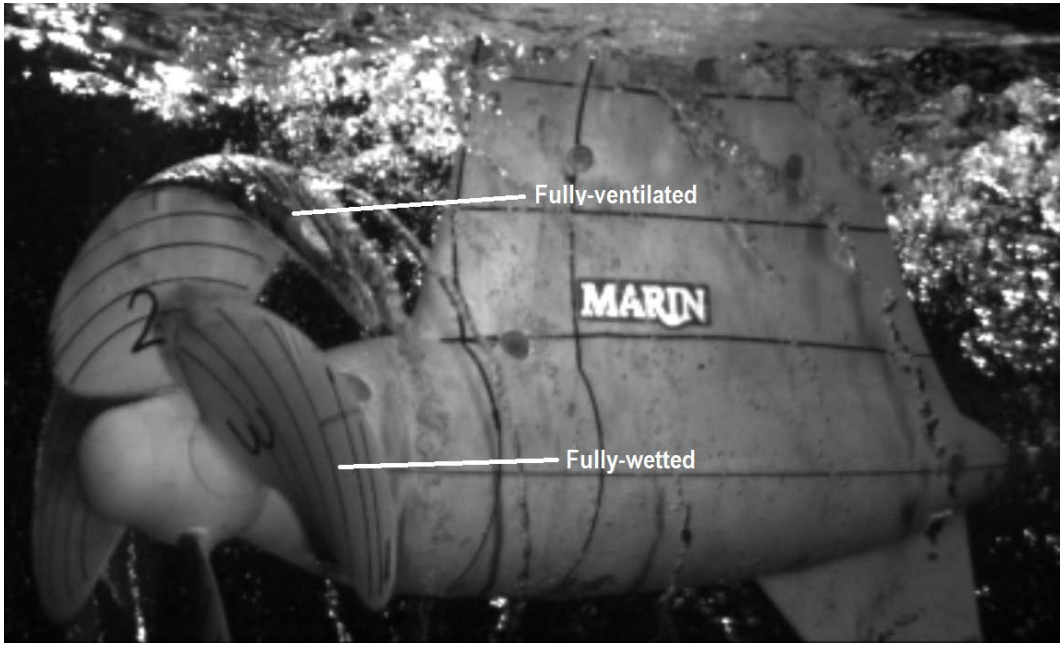
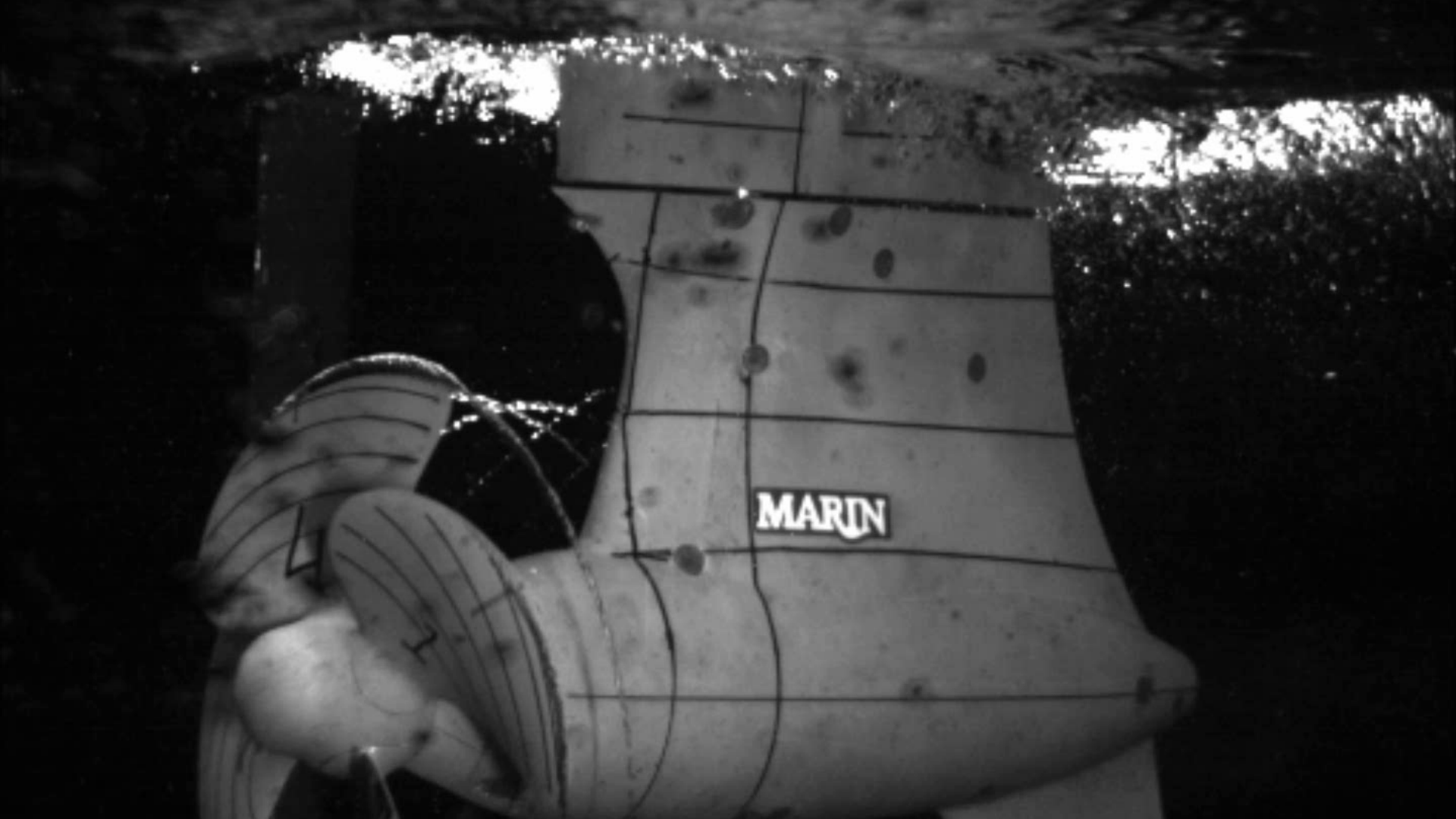
2

- Alternate blade ventilation



An example of alternate blade ventilation on the propeller of a thruster with even-numbered blades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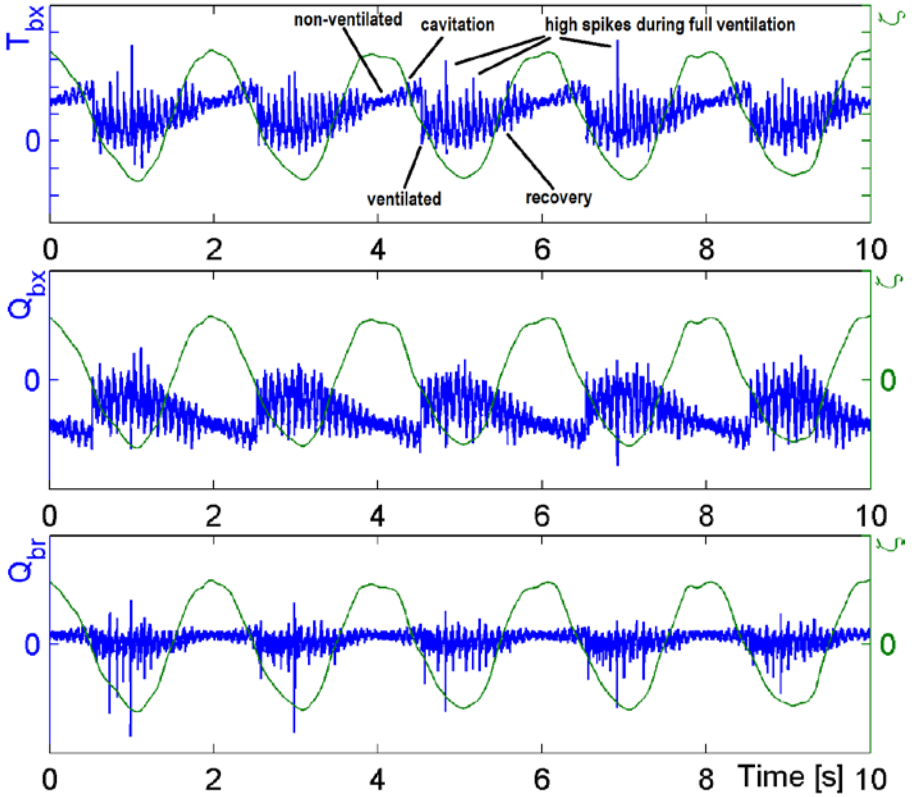
TEST RESULTS

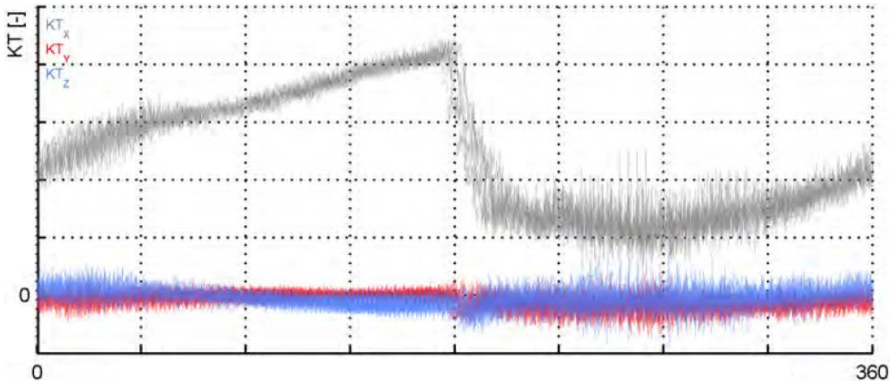
- Blade dynamic loads

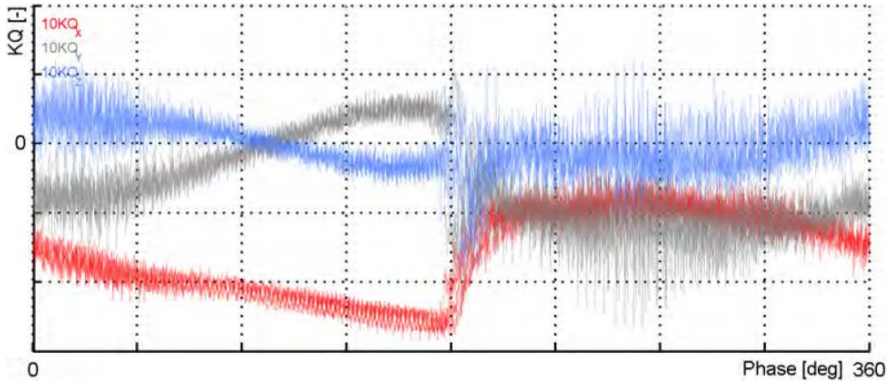


Blade dynamic loads in 5 wave periods, open propeller P/D= 0.8, thruster steering angle 0 degrees, advance ratio 0, shaft immersion 1.5R, cavitation number σ_n=2.0, wave amplitude 1R, period 2 seconds

TEST RESULTS

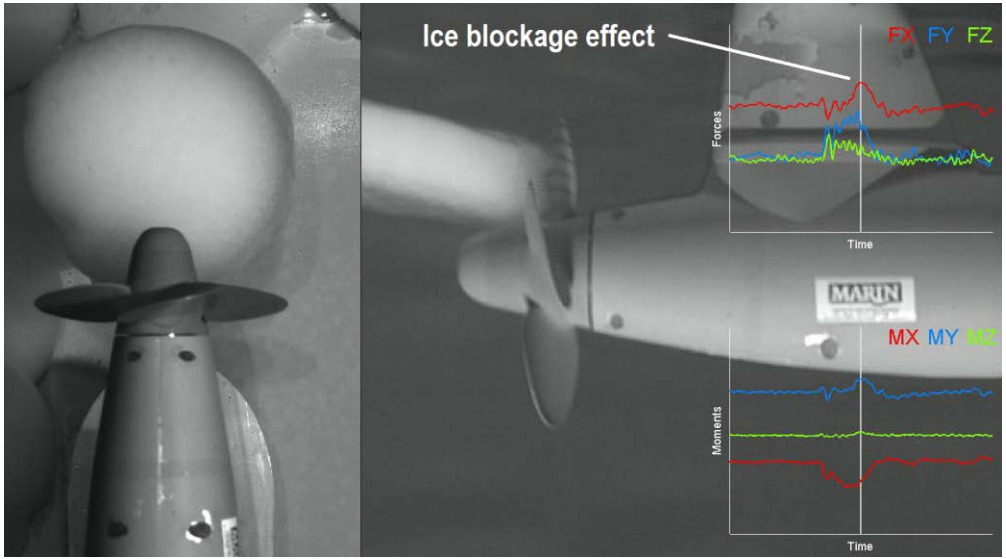
- Shaft dynamic loads





Non-dimensionalized shaft loads in one wave period, propeller pitch ratio 0.8, thruster steering angle 0 degrees, advance ratio 0.0, shaft immersion 1.5R, cavitation number σ_n=2.0, wave height 1R, wave period 2 seconds

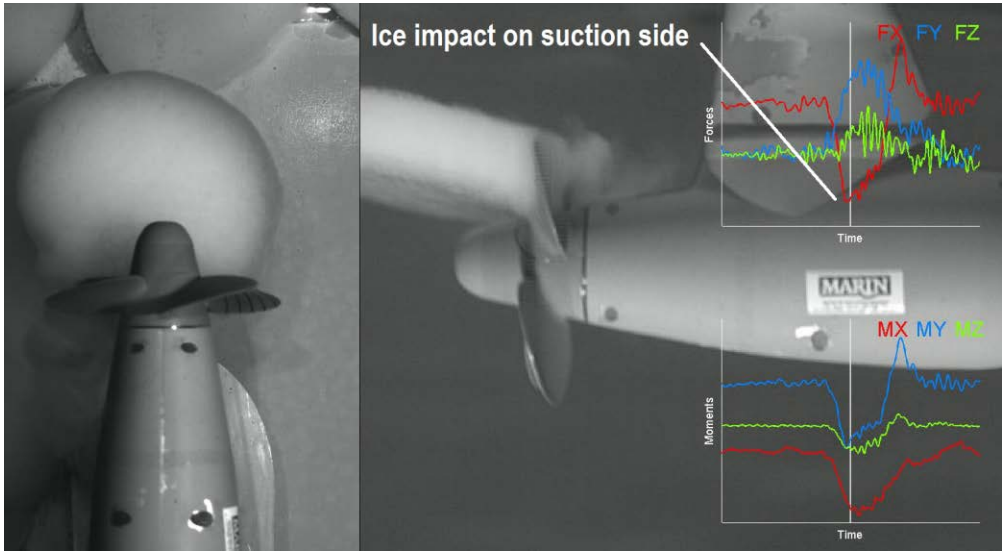
- Ice-propeller impact loads



An example of propeller flow blocked (but not touched) by an ice floe, resulting in sudden increase in blade thrust F_X and torque M_X, minor influence on blade spindle torque M_Z, synchronized results

TEST RESULTS

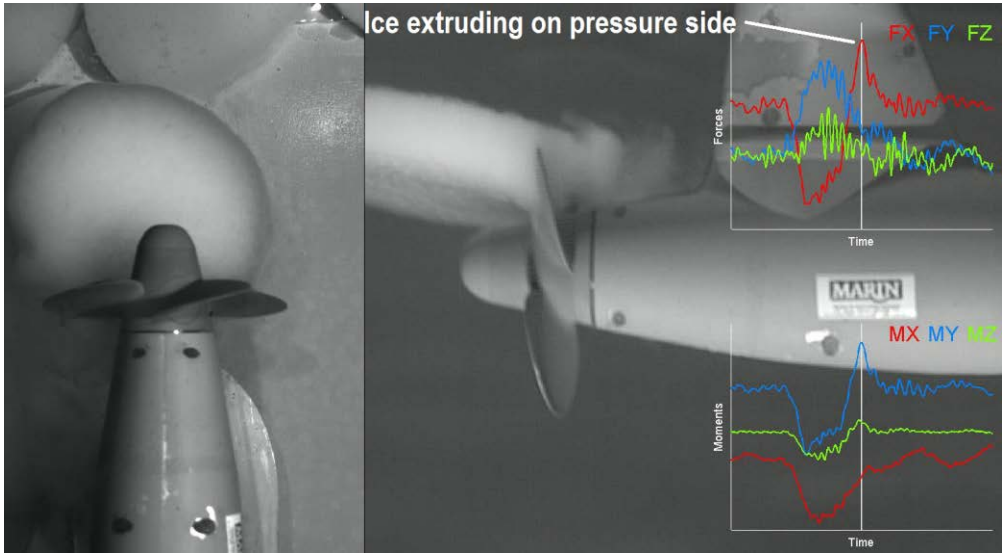
- Ice-propeller impact loads



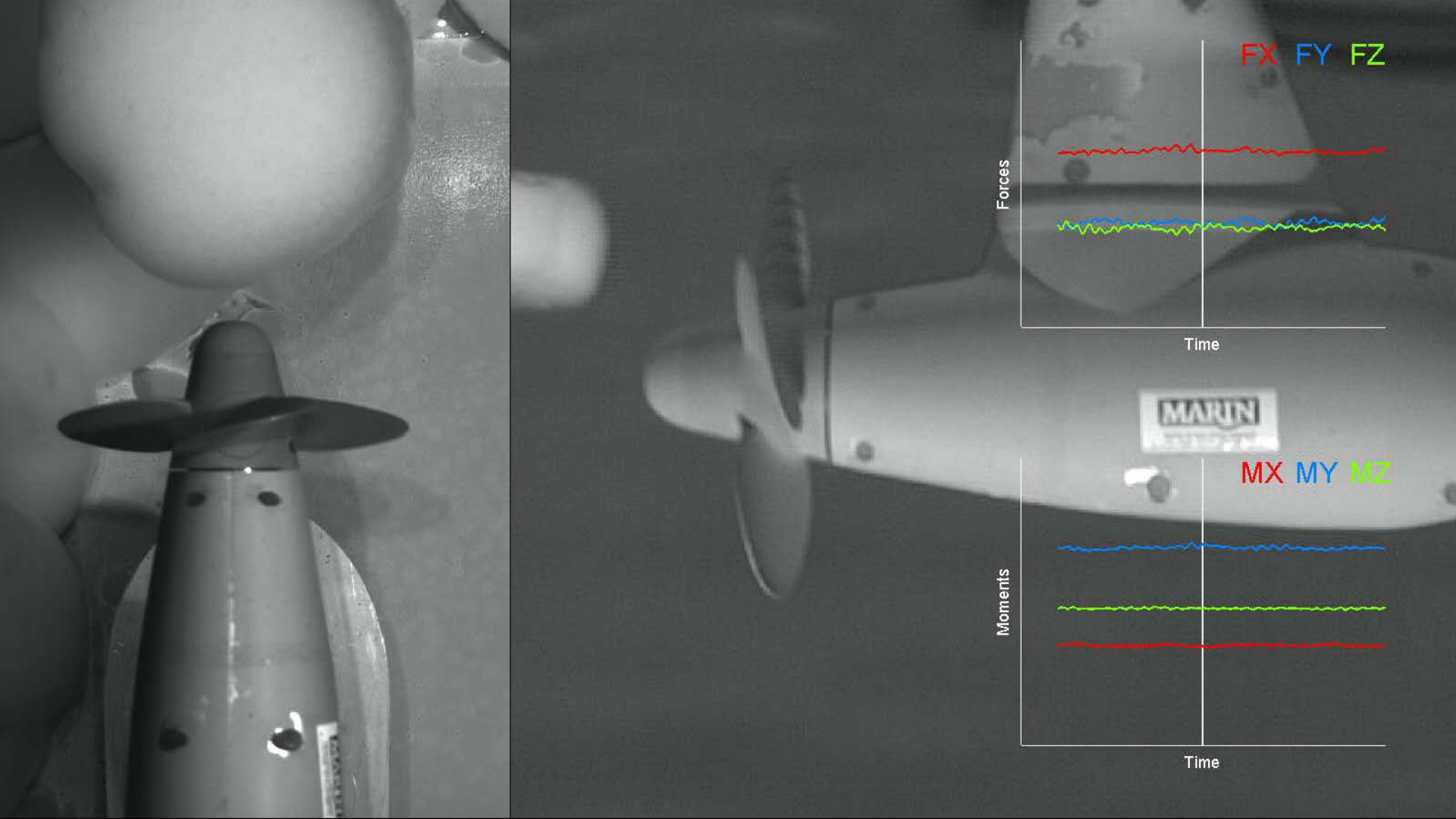
An example of ice impact on the suction side of a blade when the blade cuts into the ice, resulting in a strong negative peak of thrust F_X, torque M_X and blade spindle torque M_Z, synchronized results

TEST RESULTS

- Ice-propeller impact loads



An example of an ice floe being cut-off and extruded from the pressure side of a blade, resulting in a high positive peak of blade thrust F_X and torque M_X, and fluctuations of blade spindle torque M_Z, synchronized results


FX FY FZ
Forces
Time
MARIN
MX MY MZ
Moments
Time

CONCLUDING REMARKS

- Transducers with high accuracy and high response frequency are essential.
- Test conditions and scaling laws are very important – DWB
- Quasi-steady test technique to reduce cost
- Dynamic loads are synchronized with high speed video recordings – understanding the physics

Important for thruster designers, manufacturers, classification societies, and also for the operators to prevent damages to mechanical thrusters in service

THANK YOU!

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