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A New Turbine Cascade for Aeromechanical Testing

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Background & Outline

- **Development of a new turbo-machine test facility at KTH**
  - *Annular cascade*
  - *Axial turbine or compressor blade rows*
  - *Controlled investigation of different phenomena of interest*
    - Flutter
    - Forced response
    - Unsteady tip clearance

- **The presentation focuses on the flutter capabilities of the facility elucidating**
  - *The facility itself*
  - *Techniques for achieving controlled flutter*
  - *Measurement techniques*

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Objective

- **Create a test bed for investigating flow phenomena of interest**
  - *To assess flow physics*
  - *To generate high-quality validation test cases for CFD*

- **Requirements**
  - *Realistic 3D flow at relevant flow parameters*
  - *Well-defined and controllable boundary conditions*
  - *Controlled simulation of respective phenomena of interest (flutter)*
  - *Extensive experimental capabilities*

Method of Attack

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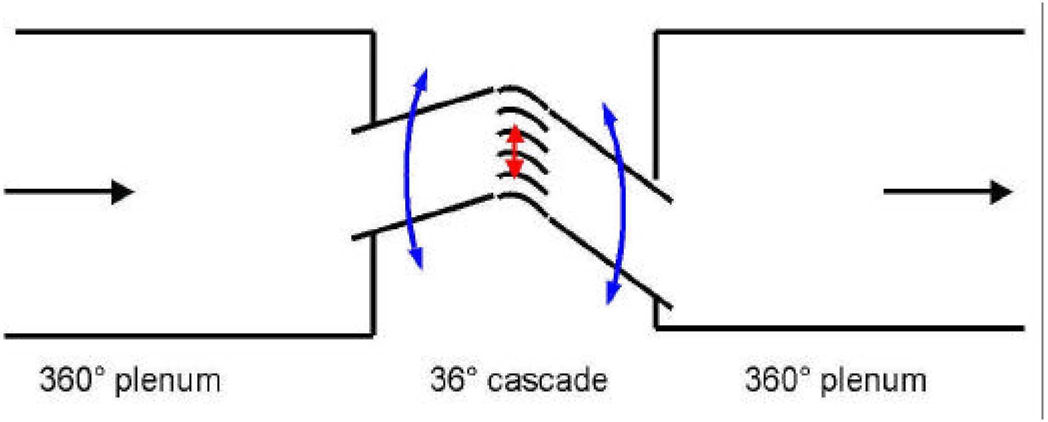
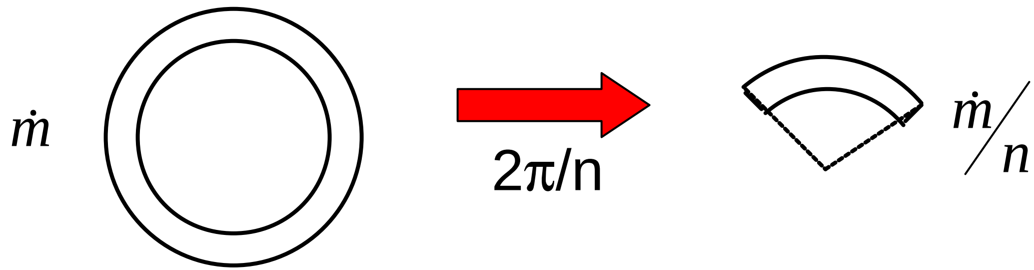
- **Continuous working mode facility**
  - *Integrated into existing air supply system*
- **Non-rotating annular cascade**
  - *Reduced to a sector in order to*
    - Maximize the size of the test object
    - Adapt it to the available mass flow
    - Still achieving transonic flow conditions

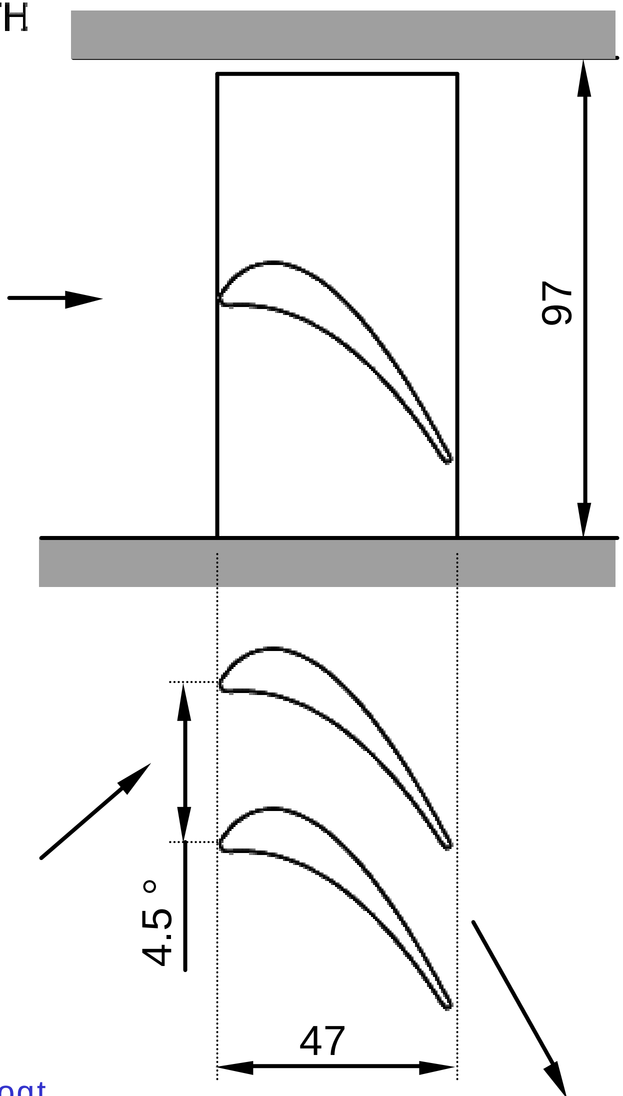


The Sector Cascade



- **Reduction of a full annulus to a sector**
- **Problem**
  - *Inherent flow periodicity of full annulus no longer present*
- **Thus**
  - *Need for achieving periodicity in controlled way*
  - *Similar to task in linear cascades*
    - Use of tailboards
- **In addition**
  - *Tailoring of inflow conditions*
    - Flow direction set by means of tailboards

Cascade Geometry



- **Base geometry**
  - *High-subsonic LPT rotor profile, 3D blading*

Parameter	Unit	Value	Range
Inflow agle	°	26	-60/+30
Outflow angle	°	-61	-8/+10
Inlet Mach number	-	0.31	-0.06/+0.13
Outlet Mach number	-	0.82	±0.15
Re_{cax}	-	4.2e5	±1e5
Total temperature	K	300	-0/+30

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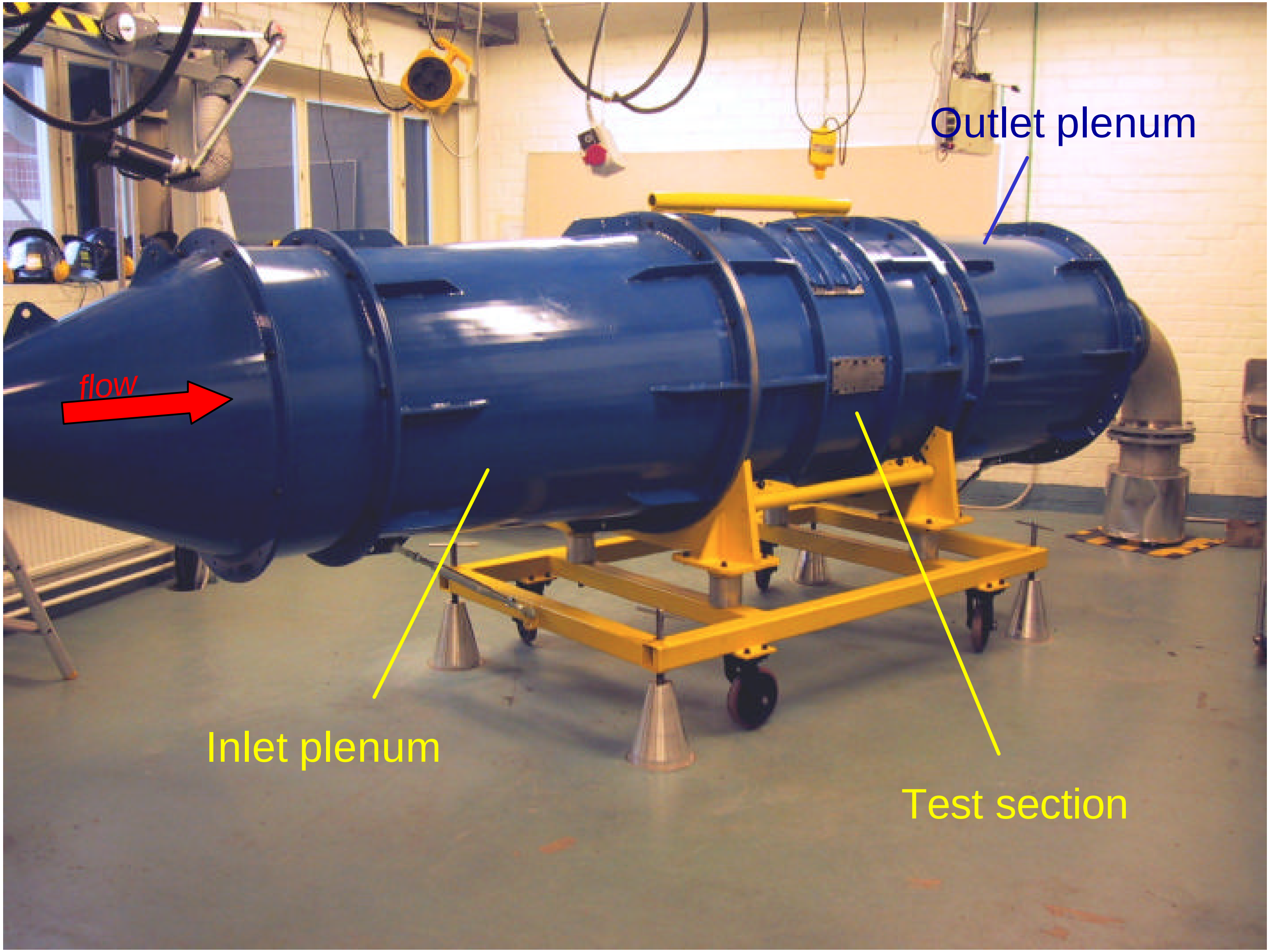
Test Facility



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Test Facility - Internal

Cascade

LPT rotor blades

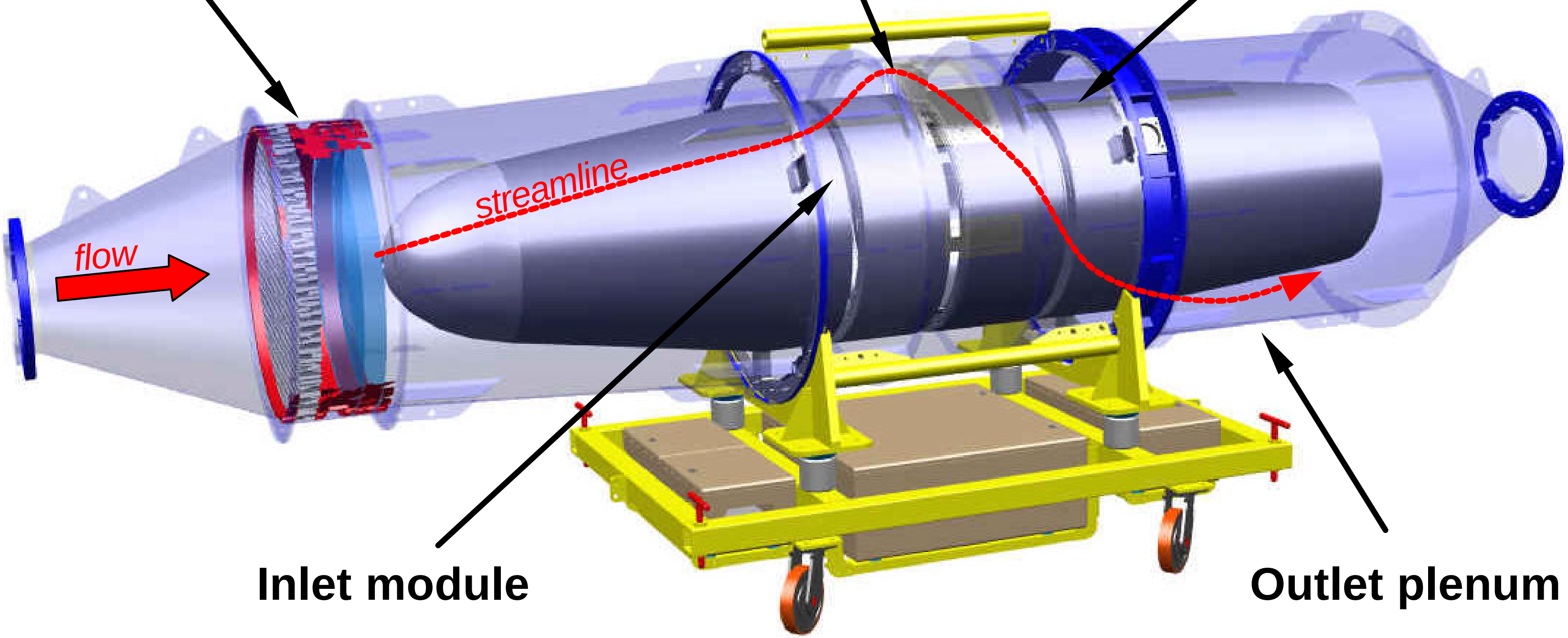
8 passages

Flow conditioner

Straightens and equalizes the flow

Outlet module

Control of flow periodicity



Inlet module

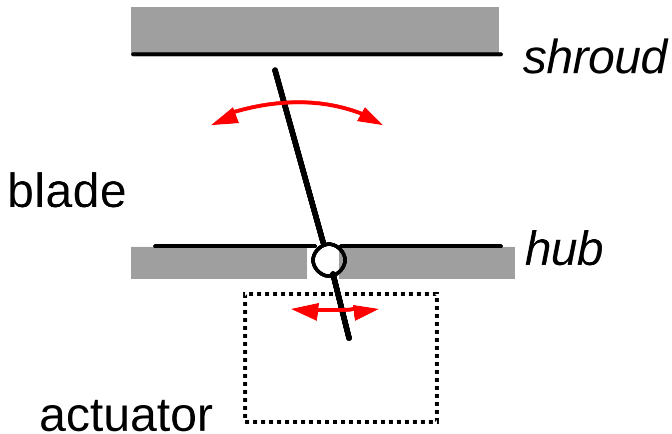
Design / off-design flow conditions

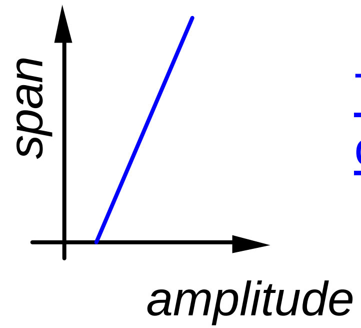
Outlet plenum

Controlled Blade Oscillation

- **Simulating state of flutter**
  - *One blade oscillated*
  - *Aerodynamic response measured on oscillating and neighbor blades*
- **Controlled oscillation of blade**
  - *Different "generic" low order modes*
    - Bending
    - Torsion
    - Combined bending & torsion
- **Relevant Parameters**
  - *Reduced frequency* $k = \frac{2pf \cdot c_{ax}/2}{u_{ax}} = 0...0.5...(1.0)$
  - *Oscillation angle*
  - *"3D" shape: amplitude at tip larger than near hub*

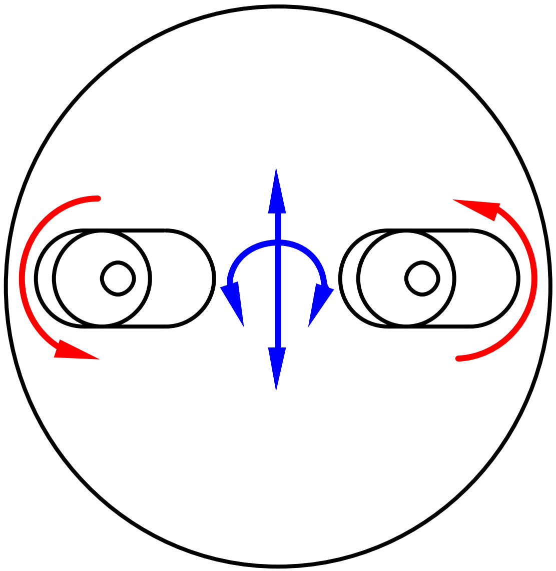
Actuator Principle



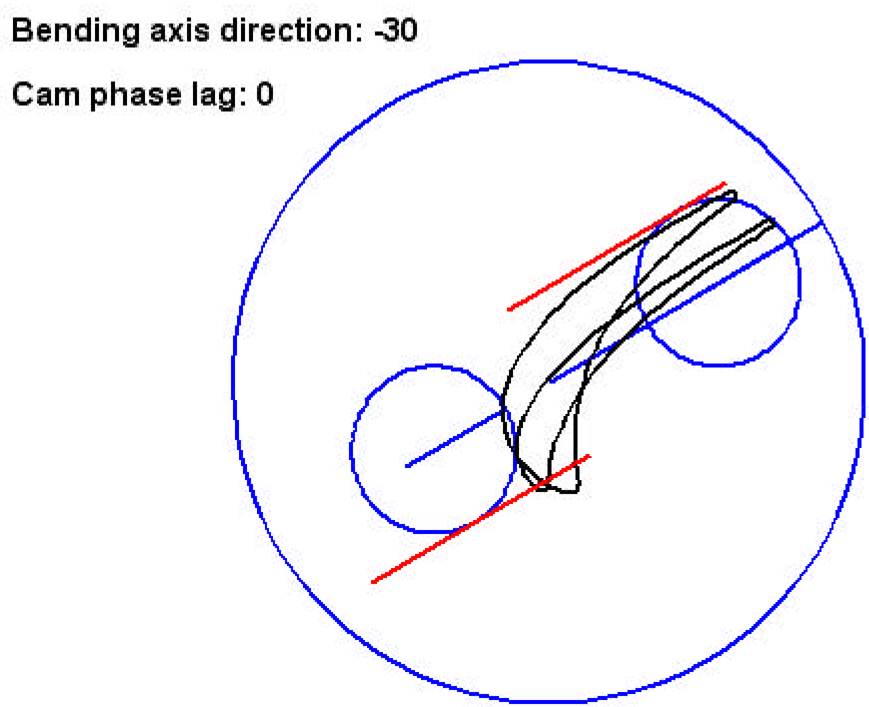


Truly 3D oscillation

Parameter	*Controlled by*
Oscillation frequency	Rotational speed of cams
Oscillation amplitude	Eccentricity of cams
Oscillation mode	Phase lag between cams



Actuator Animation - Bending



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Actuator Animation - Torsion

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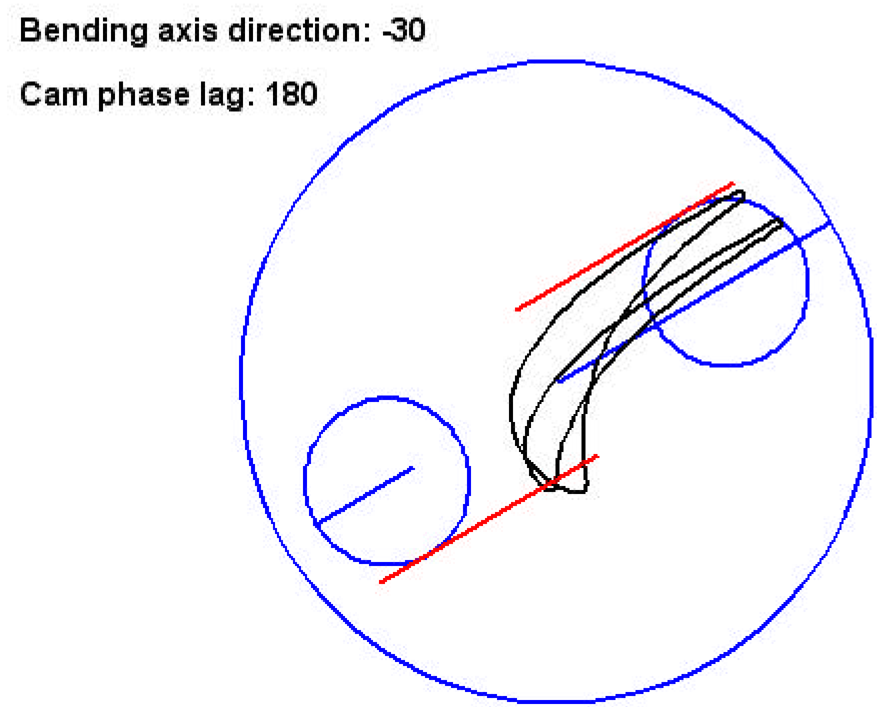

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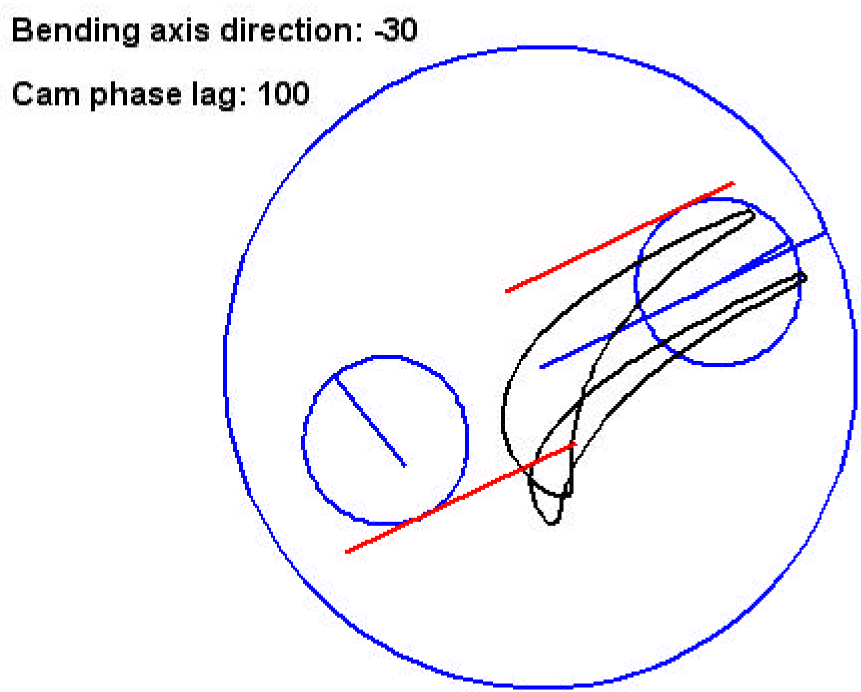
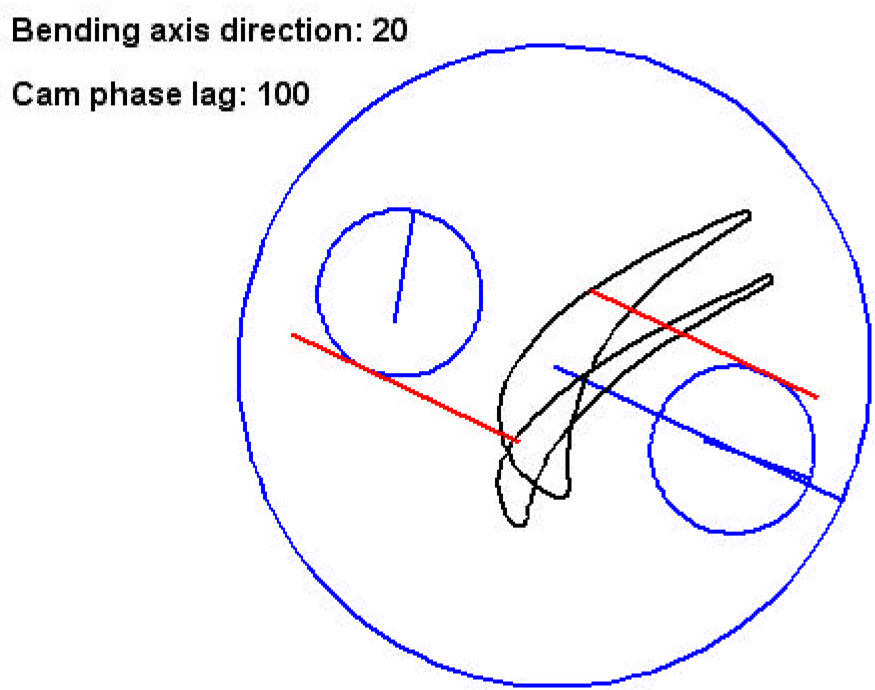
Actuator Animation - Combined

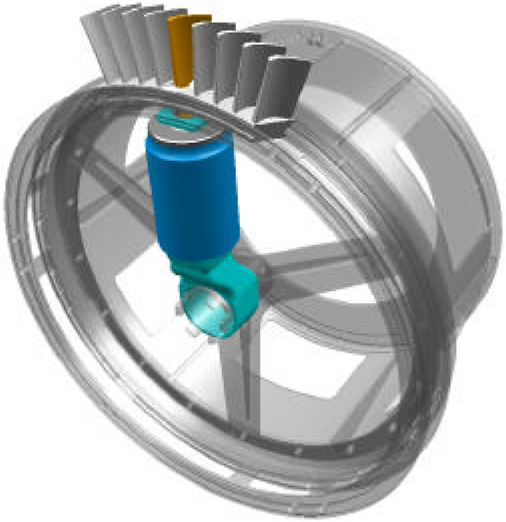


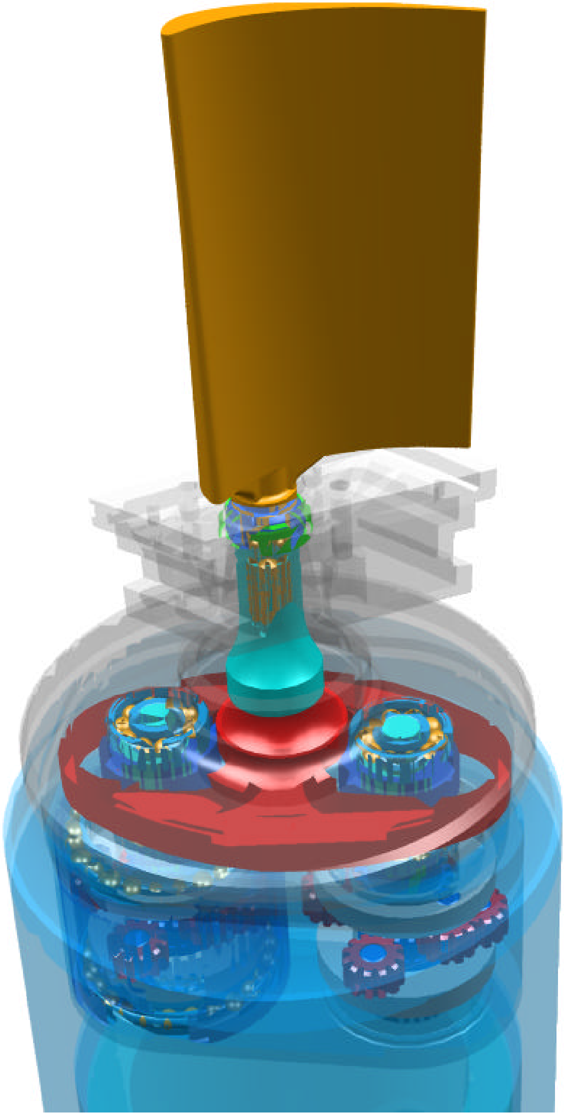
Actuator Animation – Combined II



Actuator Design

- **Fully mechanical solution**
- **Applicable to any blade index**
- **Achievable parameters**
  - *Reduced frequency: 0…0.6*
  - *Bending angle: 0…6.5deg*
  - *Torsion angle: 0…11.0deg*





Instrumentation

- **Casing and hub**
  - *Line of static and dynamic pressure tappings*
  - *Cascade is "swept by" (traverse measurement)*
- **Blades**
  - *Static pressure*
    - 100 static taps distributed on several blades
    - Identical reference tap on each blade for recombination
  - *Dynamic pressure*
    - Recessed-mounted KULITES (XCQ-062, LQ-080)
    - Only on oscillating-type blades, on-blade calibrated
  - *Static and oscillating blades can be combined arbitrarily*
- **Assisting**
  - *Aero probes, optical techniques*

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Summary & Conclusions

- **Introduction of a new test facility for aeromechanical testing**
  - *Annular sector cascade, 3D blading*
  - *Fully controllable flow conditions and flutter parameters*

- **Strengths**
  - *Achievement of controlled truly 3D flutter modes in 3D flow*
  - *Experimental versatility and comparatively low effort for re-blading*

- **Limitations**
  - *Ducted flow*
    - <u>Periodicity has to be achieved artificially</u>
    - <u>Inflow to cascade not truly sheared</u>
  - *Achievable oscillation modes are still generic*