Large multistage axial turbines

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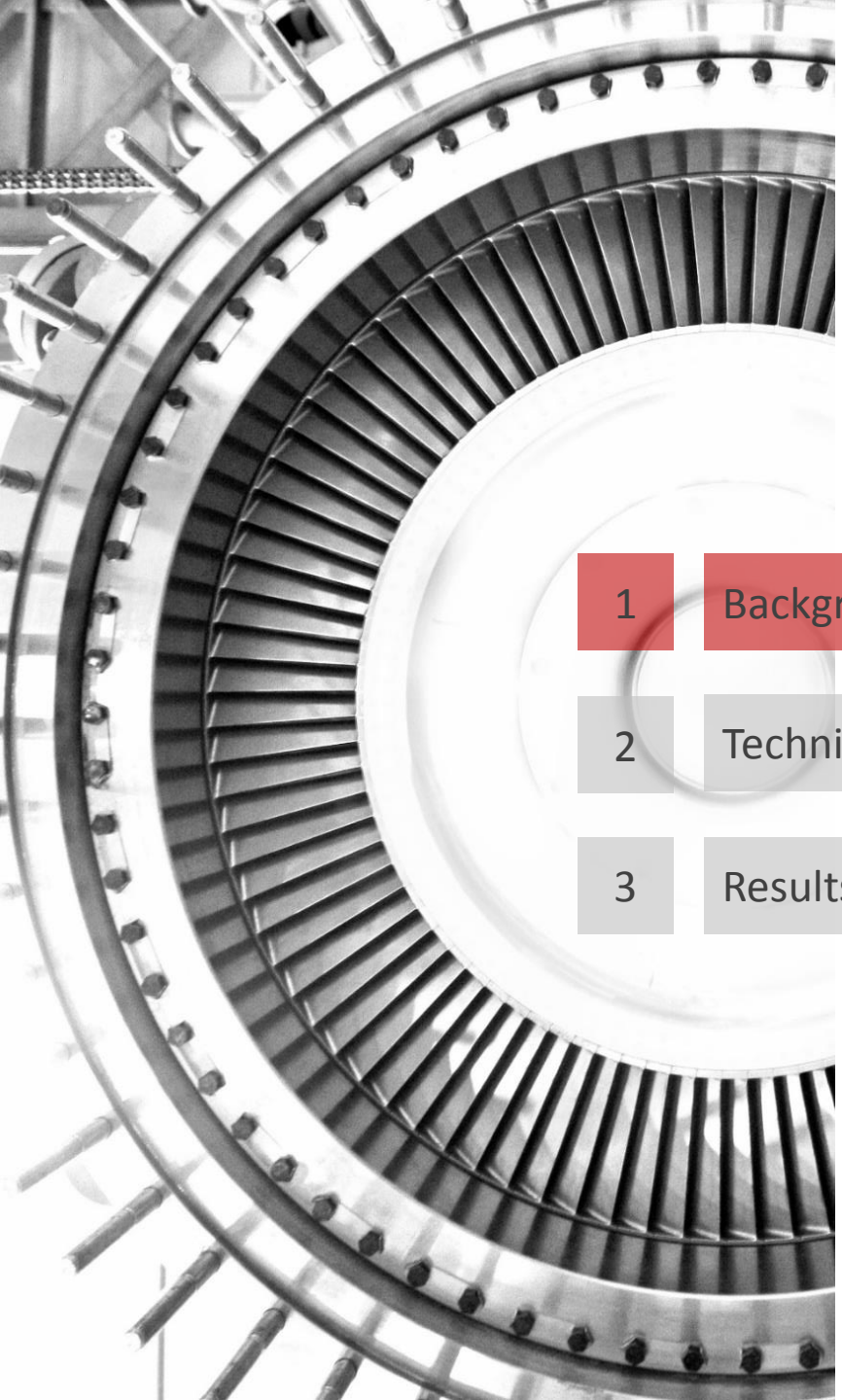

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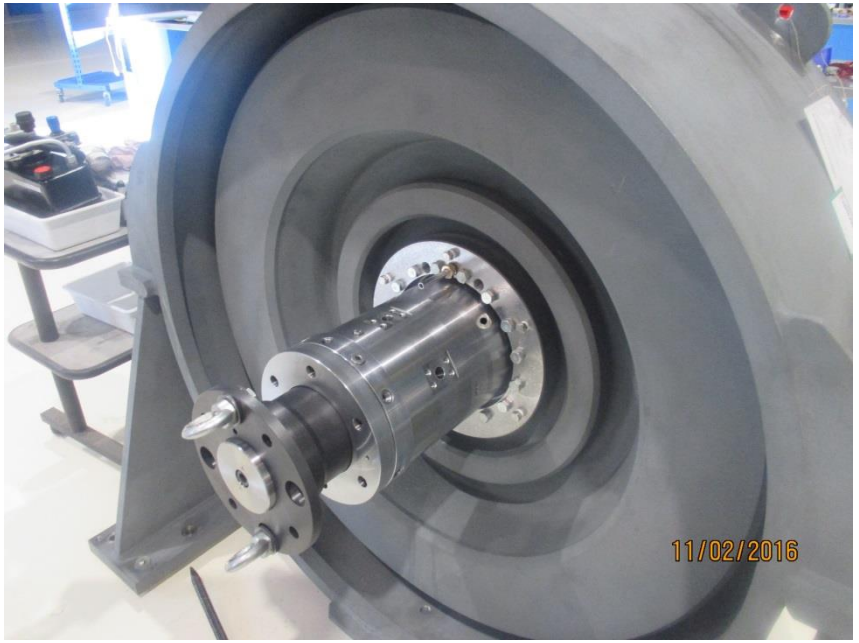
1 Background:

Most industrial scale ORC axial turbines are designed with a cantilever (alternatively called “overhung”) arrangement, where the turbine shaft is entirely supported on one side and the turbine rotors are attached on the other side of the expander.



Large multistage axial turbines

1 Background:

The cantilever design offers a number of advantages such as:

Simple shaft bearings design, being the shaft supported by one side only.

Single rotating seal system in contact with the working fluid.

Light and compact turbine casing. Typically not a split casing.

Efficient diffuser design and simple discharge piping.

Easiness of access for ordinary and extraordinary maintenance.

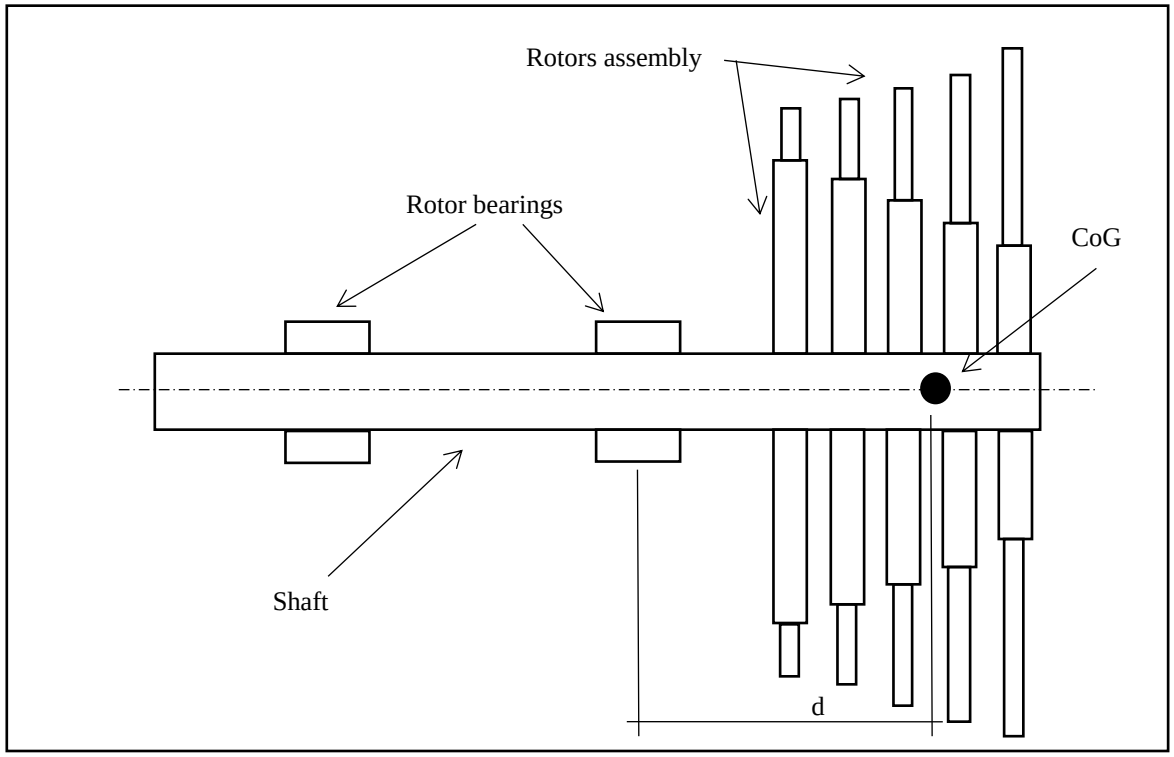
Cantilever arrangement definitely involves lower turbine costs, both in terms of Capex and Opex and it is practically the most commonly adopted solution by the industrial ORC manufacturers.

On the other hand, it can be difficult if not even impossible to fit a large (>5MW) cantilever ORC turbine with a number of expansion stages bigger than 3 or 4, which may be beneficial to the expander efficiency, for a number of reason.

Large multistage axial turbines

1 Background:

Normally, in a cantilever axial flow turbine, each subsequent expansion stage is attached to the shaft after the previous one and so the rotating mass is increased and also its Center of Gravity (CoG) becomes further and further distant from the shaft bearings and the polar moment of inertia is increasing as well



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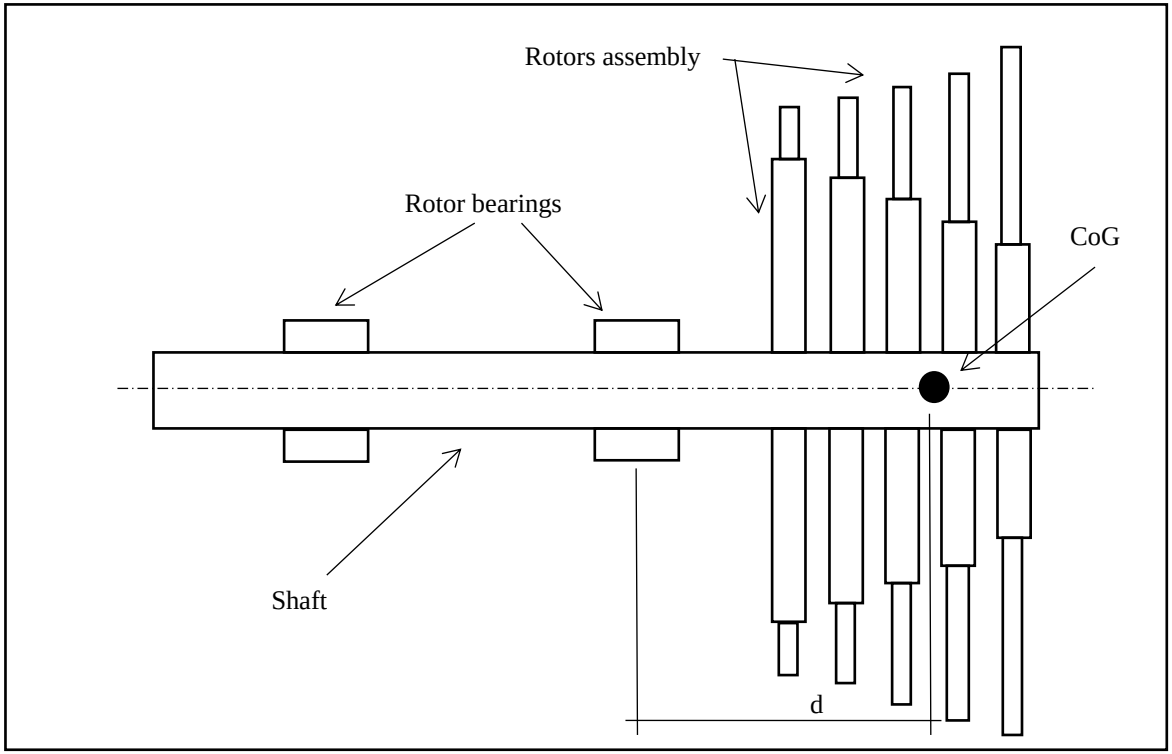
1 Background:

Clearly, such a trend results in a progressive reduction of the flexional and torsional frequencies of the shaft with the evident and well known risk of system resonance with high vibration operation and, possibly, mechanical failures.

Even a proper selection of the shaft/bearings system, which indeed plays a crucial role in the design, most of the time can not avoid to face resonance phenomena.



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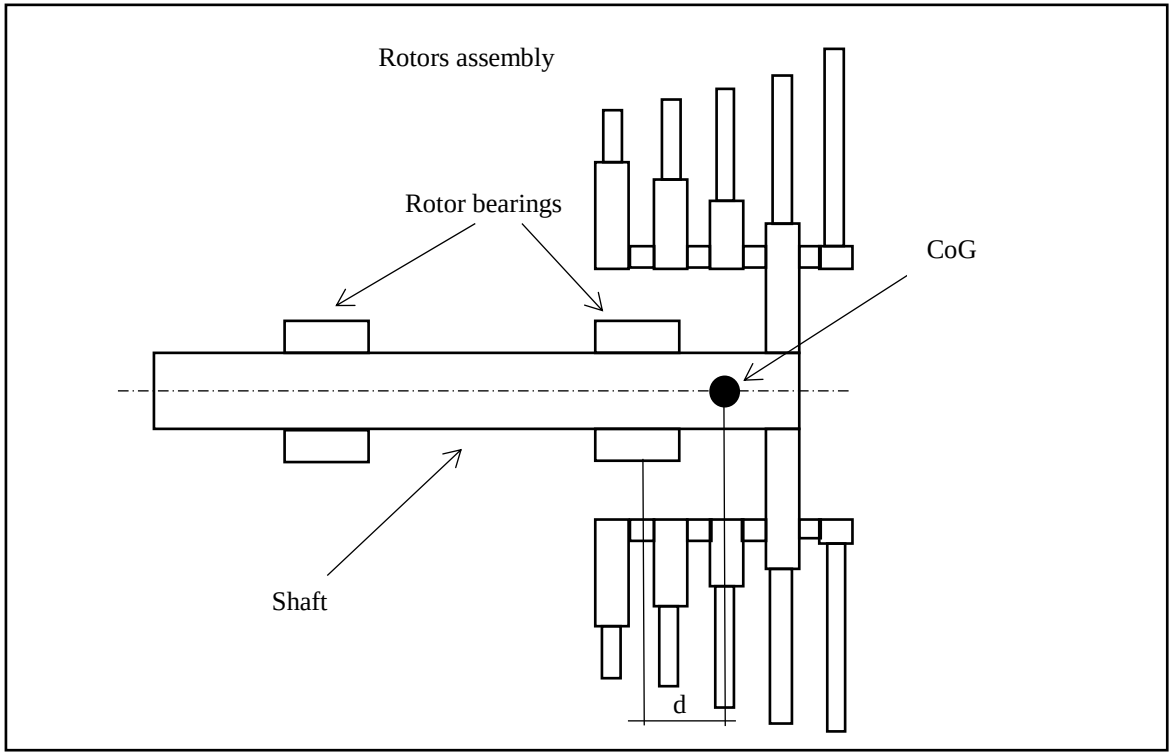
2 Technical Innovation:

Turboden developed and patented a new approach to the cantilever design, where the rotor assembly is attached only once to the shaft, typically at the last or at the second-last stage level and the rotor discs are connected each other at a large diameter. The amount of rotating mass can be reduced by almost 50% compared to a traditional design with great benefit for the dynamic behavior of the system.



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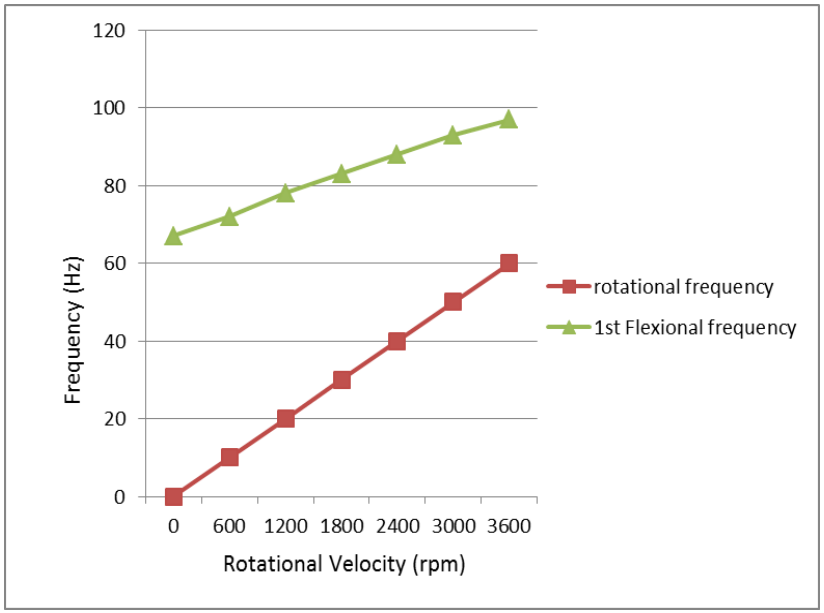
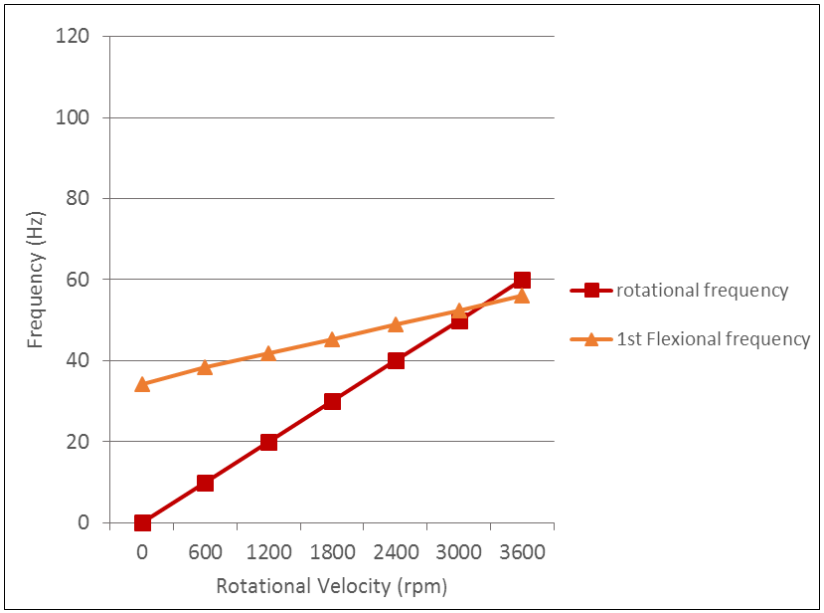
2 Technical Innovation:

Campbell diagram comparison



Campbell diagram of a 5 stages 9MW turbine adopting the new design. Resonance occurs well above 3600 rpm while the nominal operation speed is 3000 rpm



Campbell diagram of a 5 stages 9MW turbine adopting the traditional design. Resonance occurs around the nominal speed of 3000 rpm

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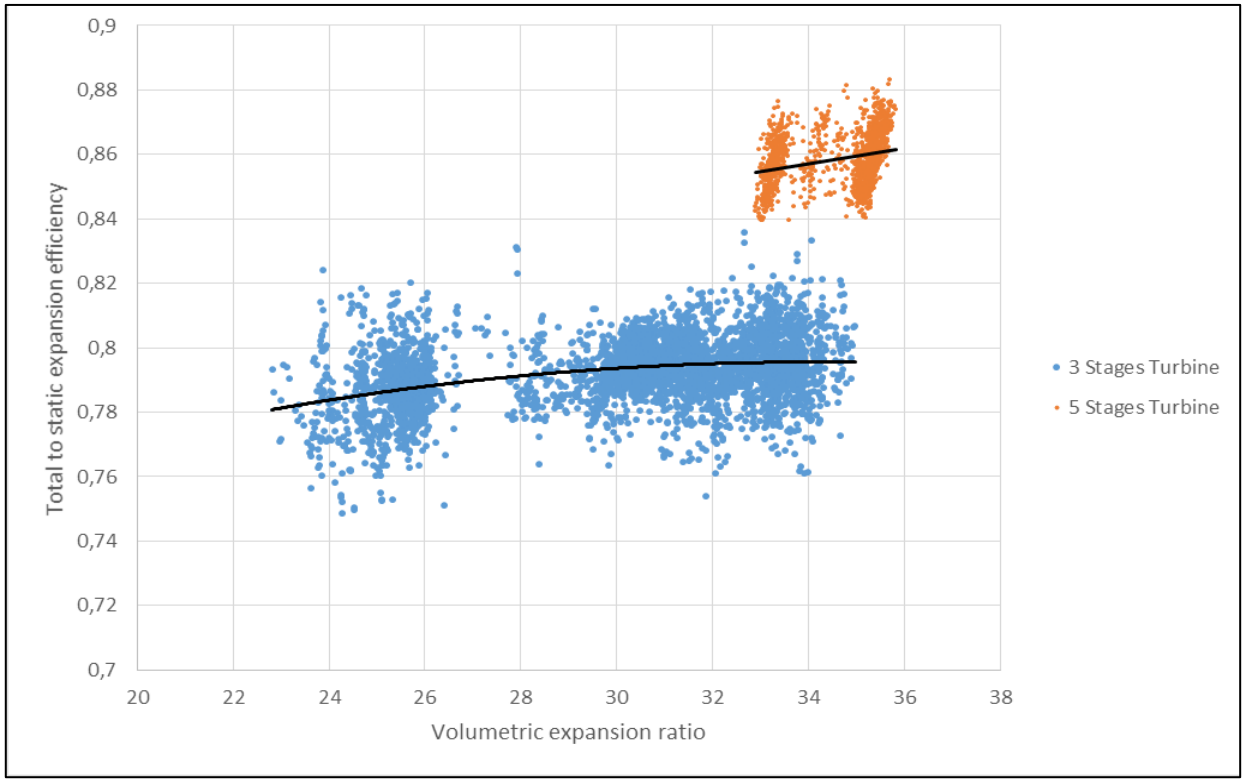
3 Results:

At comparable expansion ratios, the measured efficiency of a 5 stages turbine has been increased by more than 5 percentage points compared to the efficiency of a 3 stages expander with the same fluid, same mean diameter and same rpm.



Total to static efficiency vs. Volumetric expansion ratio of a 3 stages turbine (blue dots) and a 5 stages turbine (orange dots) expanding the same fluid. The black lines represents the average efficiency over the considered time period (2 month).

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3 Results:

Five stage rotor during machining

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3 Results:

This technology can be effectively applied also to geothermal ORC expanders. Although geothermal sources are typically characterized by lower temperatures compared to heat recovery applications, by employing more than four stages it is sometimes possible to achieve a better fluid dynamic design of the turbine, especially when 1,500 rpm direct drive configuration is adopted

Five stage 16MW geothermal turbine adopting the new Turboden rotor design

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Conclusion:

Classic cantilever layout is a convenient and effective turbine design widely adopted in ORC powerplants, representing the vast majority of the installed units worldwide.

This kind of design was limiting the number of expansion stages up to 3 or 4, mainly due to the rotor-dynamic stability of the system that is adversely affected by the overhung mass proportionally increased by the number of the stages.

Large sized heat recovery ORCs and possibly geothermal ORCs would benefit by a larger number of expansion stages in the turbine (i.e. 5 or 6), improving their efficiency.

The new Turboden rotor design overcomes this limitation, introducing a new 5 stages axial expanders family targeting both the heat recovery and the high efficiency geothermal ORC applications.

The first unit of this kind is operation since 2016 showing an efficiency improvement of 5 and more percentage points compared to similar size previous generation units

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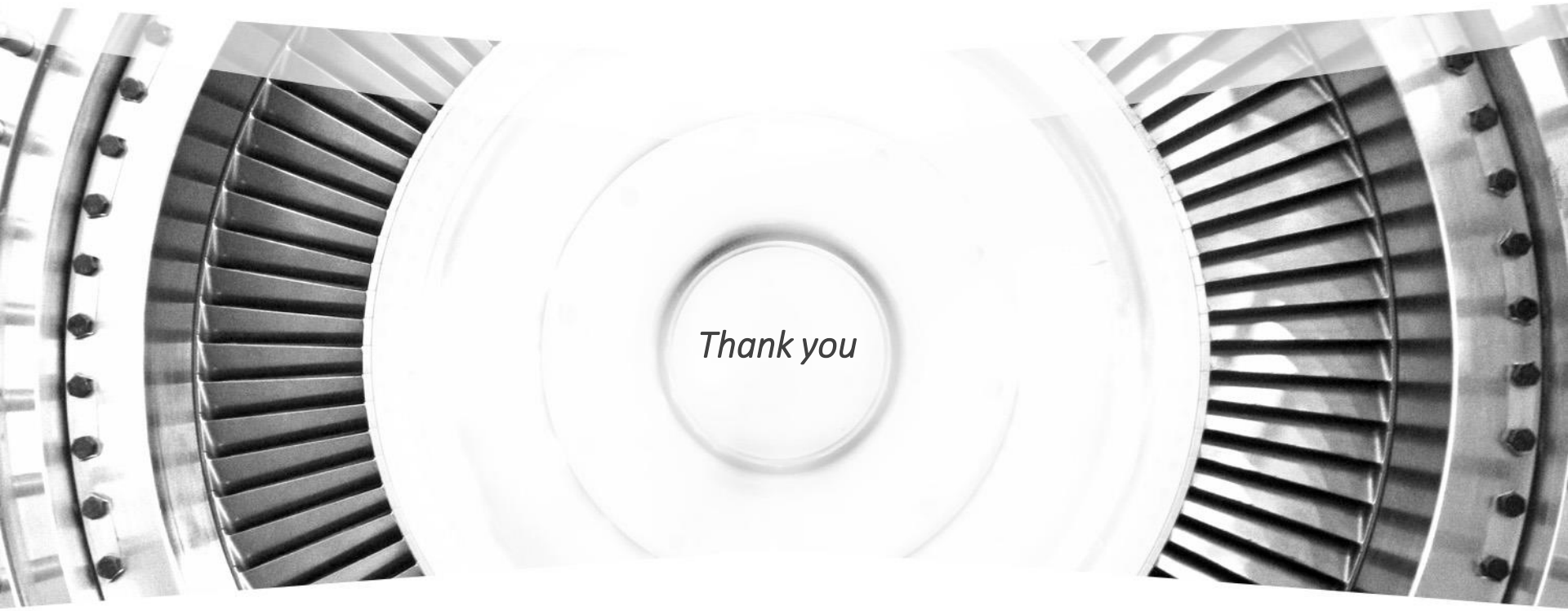

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