

Selection of Turbine Type for S-CO₂ Applications

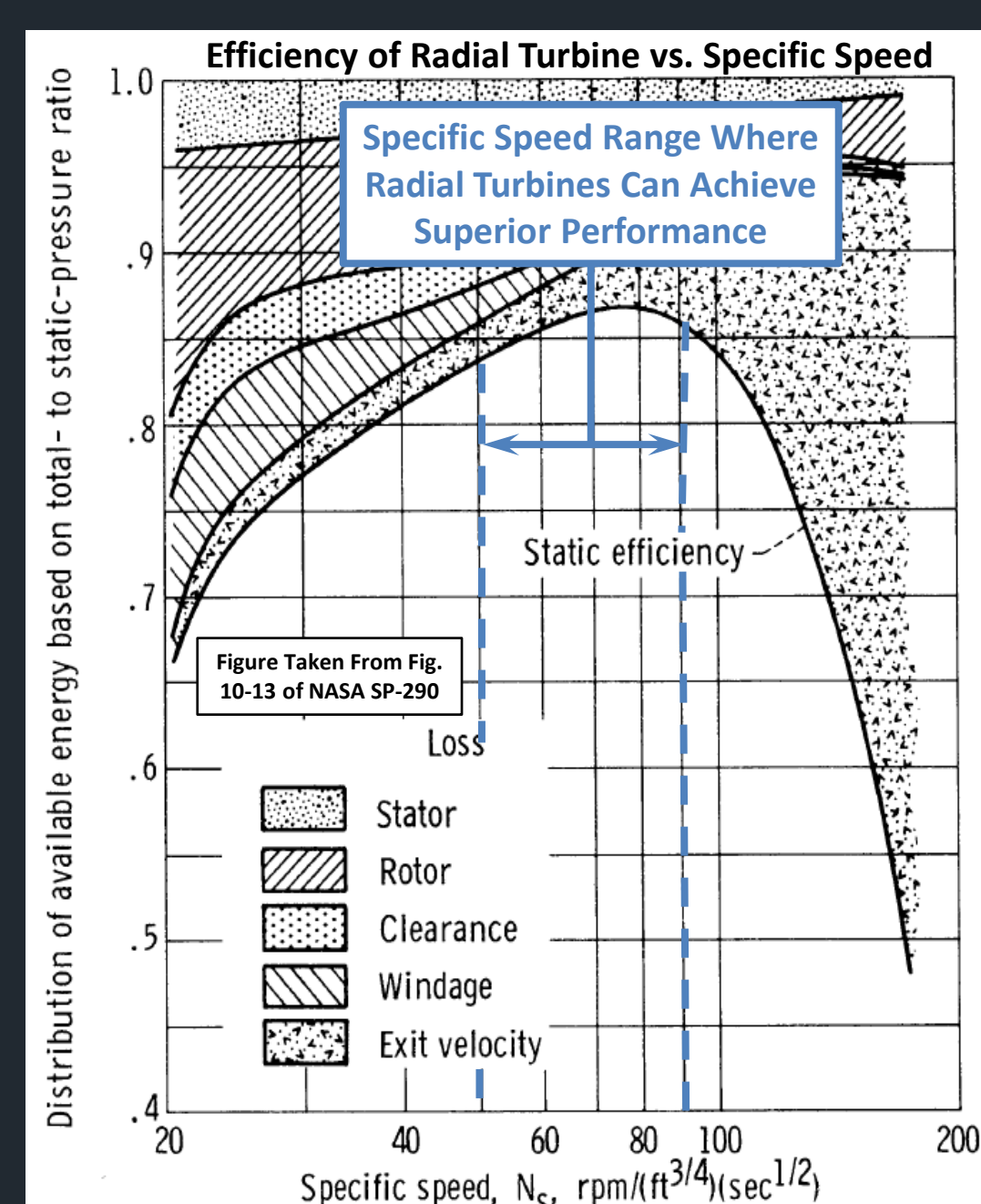
The selection of the appropriate turbine type for use in a super-critical CO₂ power cycle can be key to the success of the project. The two turbine types typically employed in these power systems are axial flow and radial inflow turbines. Consideration of the unique attributes of these two architectures often drives the selection process.

The high fluid densities of super-critical CO₂ tend to produce compact turbomachinery which favors high shaft speeds to achieve optimal aerodynamic performance. However, rotordynamic, seal and bearing requirements often impose limitations on allowable design speed, which lead to lower specific speed design requirements in the range where either axial or radial turbine types may be an appropriate choice.

Axial flow turbine stages can be successfully applied to a much wider range of specific speed applications, where the specific speed is defined as:

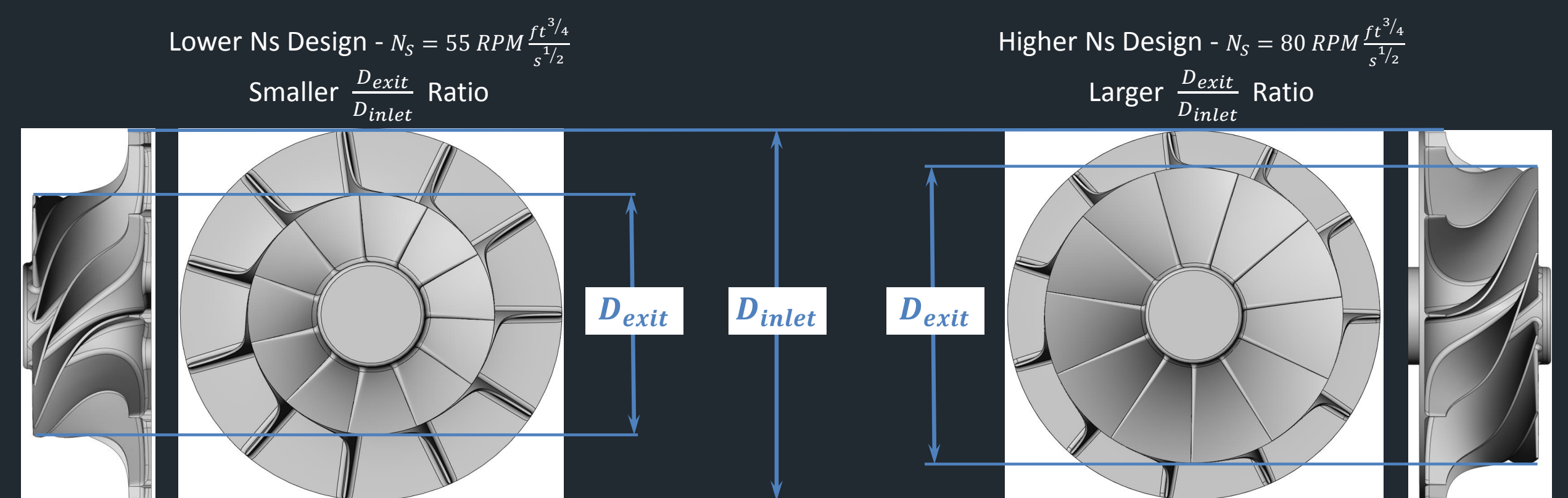
$$N_S = \frac{N\sqrt{Q}}{\Delta H^{.75}} \text{ with } N [=] \text{ RPM}, Q [=] \frac{\text{ft}^3}{\text{s}} \text{ \& } \Delta H [=] \text{ ft.}$$

However, radial inflow turbines can achieve higher efficiency than their axial counterparts over a narrow specific speed range of approximately 50 to 90 $\text{RPM} \frac{\text{ft}^{3/4}}{\text{s}^{1/2}}$.



At low specific speed conditions, the ratio of the exducer to inducer diameter ($\frac{D_{exit}}{D_{inlet}}$) for a radial inflow turbine becomes small where conservation of angular momentum will dictate higher levels of tangential velocity (swirl) at the exducer. The energy associated with this swirl velocity represents lost recovery and efficiency unless the swirl can be removed by the exducer blading, which requires high turning and solidity in the blade design. Structural and manufacturing considerations often constrain the exducer blade shapes, and this is especially true for high density S-CO₂ applications where blade gas loads are relatively higher than typical applications.

At high specific speed conditions, the exducer to inducer diameter ratio approaches unity causing the radial inward flow to negotiate a rapid transition to axial flow. The high levels of streamline curvature along the shroud lead to stronger secondary flows and reduced achievable blade loadings. The geometric conditions of radial inflow turbines at high and low specific speeds thus limit the range over which this turbine type can deliver superior performance.



Axial Turbine Designs

Advantages

- Generally higher efficiency at specific speeds below ~55 and above ~90 $\text{RPM} \frac{\text{ft}^{3/4}}{\text{s}^{1/2}}$.
- Better able to pass debris/two phase flow through axial blading than radial inflow. Less prone to nozzle erosion problems.
- Requires less axial space and generally less overhung mass for improved rotordynamics.
- More amenable to multi-stage configurations.
- Packaging of axial flow machines is often simpler than that of radial machines, particularly for multi-stage configurations.
- Less susceptible to blade vibratory stress than radial inflow rotors, especially if shrouded.

Disadvantages

- Not well suited to casting of entire rotor (blisk). Rotor either machined as blisk, or with cast blades using fir-tree type attachment to machined disk. Leads to higher manufacturing cost relative to cast radial inflow rotors.
- Fewer options exist to tune the axial thrust load through minor modifications to the wheel (e.g. adjusting scallop cut – See figures in radial turbine section).
- Exhaust diffuser design is typically more complex and costly than that required for radial inflow configurations.
- Requires greater stage count for applications with large pressure ratios if stages are constrained to be of subsonic design.

Radial Turbine Designs

Advantages

- Generally higher efficiency for applications with specific speeds in the range of 55 to 90 $\text{RPM} \frac{\text{ft}^{3/4}}{\text{s}^{1/2}}$.
- Axial thrust load is more tunable by adjustment of the depth of the scallop cut in the back shroud.
- Can handle higher pressure ratios per stage without the need for supersonic design which tends to produce greater noise and rotor-stator interaction.
- Can be designed without inlet nozzles, though nozzles are usually required for peak performance at the design point.
- More radially compact design. Exhaust diffuser is generally simple with no center body required.
- Rotor designs are amenable to casting for lower high volume production costs.

Disadvantages

- Does not handle ingestion of debris (i.e. pipe scale, etc.) or two phase flow well. Centrifugal effect of rotor tends to trap debris/liquid droplets in between nozzle exit and rotor inlet. This condition can lead to severe nozzle erosion. Excellent cleanliness/filtration is required.
- Can contribute to system startup/control difficulties where turbine rotor acts as an inefficient compressor due to centrifugal effect, until the flow direction in the system loop is properly established.
- Long, thin blade shapes are more susceptible to vibratory stress.

Examples of axial thrust tuning with scallop cuts

