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A revised Tesla Turbine Concept for ORC applications

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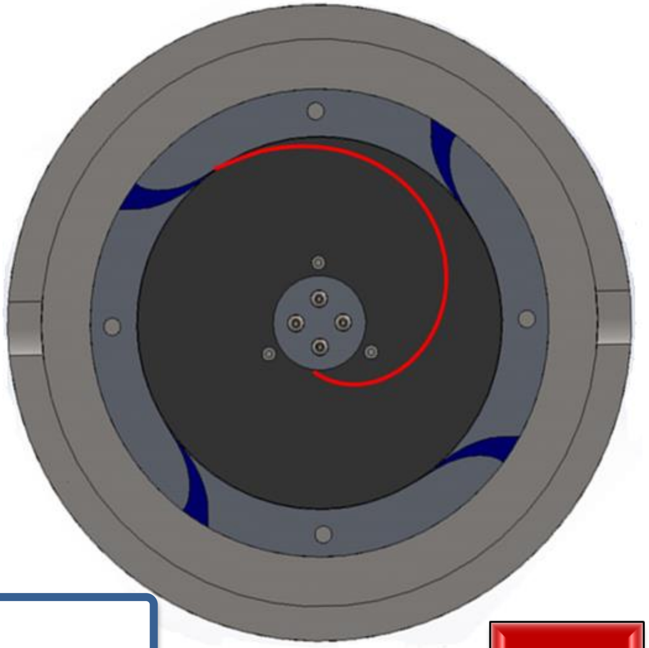
Introduction

One of the main issues with micro Organic Rankine Cycles is linked to the expander, as this component often involves **high manufacturing costs** and offers **low reliability**



Tesla turbine main features

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- Simple Structure
- Reliable
- Low cost expander

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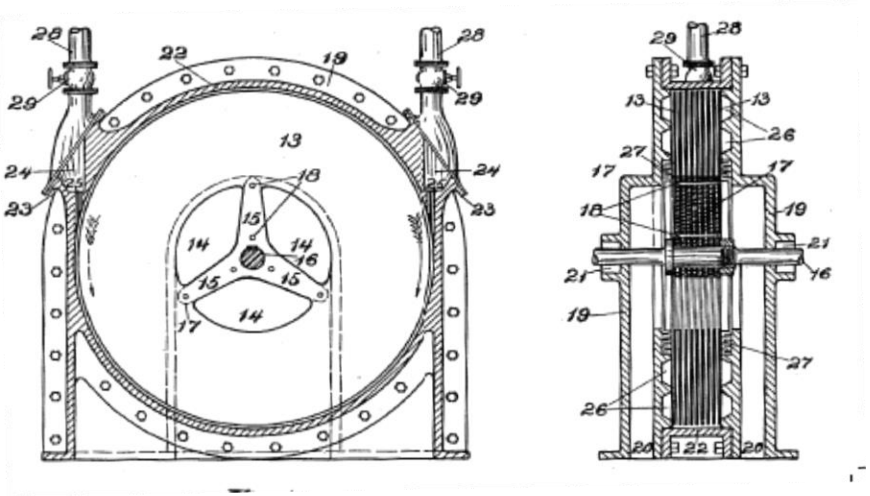
- At present, low experimental efficiency documented

Power range 0.5 - 5 kW

Flow modeling

- Multiple parallel flat rigid disks arranged co-axially in order to maintain a **very small gap** between them.
- The working fluid moves from the inlet to the outlet radius due to the difference in pressure determined by **friction** and by the exchange of momentum



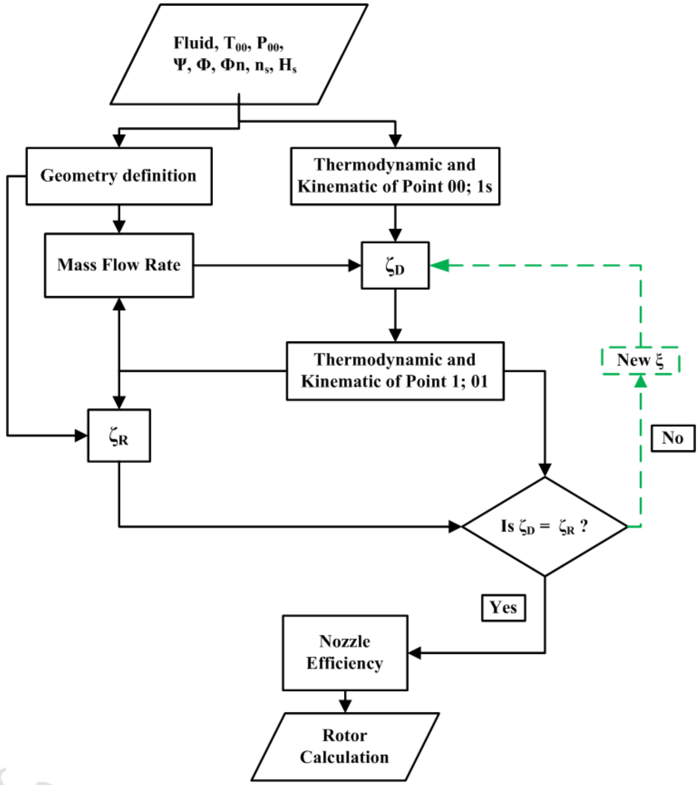
Figures from Tesla's Patent, 1913

Viscous turbine

The position of the Tesla turbine on the Balje diagram is in the same location of drag turbines and volumetric expanders (very low specific speed, relatively high specific diameter).

Stator flow model

Parameter	Unit	Parameter	Unit
Inlet Total Pressure	[Pa]	Nozzle Throat Mach number	[-]
Inlet Total Temperature	[K]	Specific speed $n_s = \frac{rpm}{60\pi} \frac{\sqrt{\dot{V}_2}}{\Delta h_{0s}}$	[-]



Rotor flow model

From Continuity:

➔ Absolute radial velocity

$$\frac{1}{r}\frac{\partial(r\rho v_r)}{\partial r} = 0$$

From momentum, r-direction:

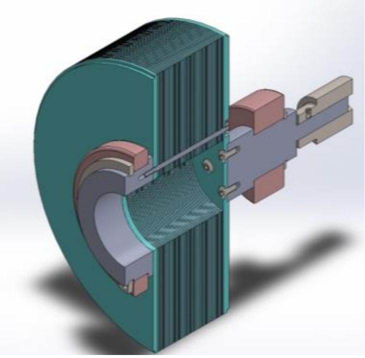
➔ Pressure gradient in radial direction

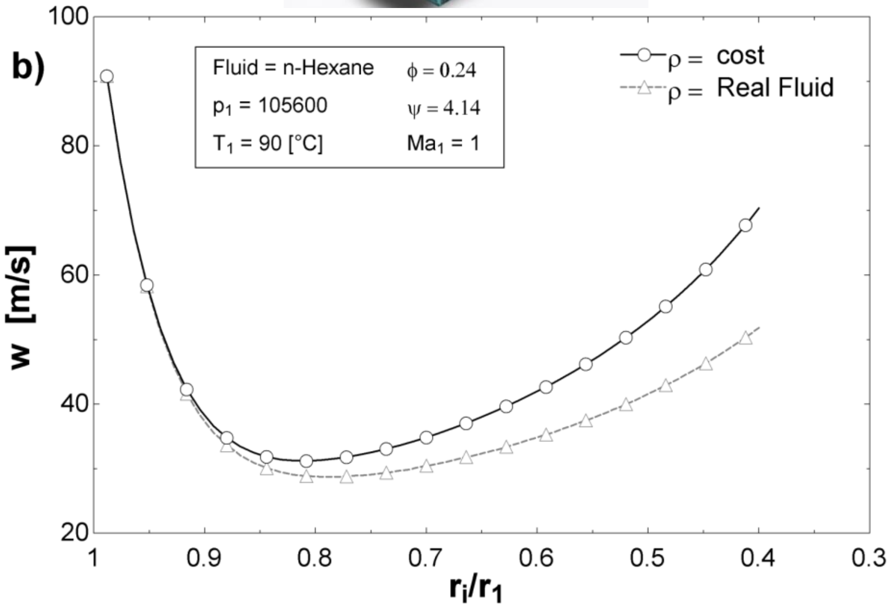
$$\left(\frac{\partial p}{\partial r}\right) = -\frac{12\mu}{b^2}\left(\frac{\dot{m}}{2\pi r b \rho}\right) + \frac{\rho}{r}\left(\frac{\dot{m}}{2\pi r b \rho}\right)^2 + \frac{\rho}{r} v_\theta{}^2$$

From momentum, θ-direction:

➔ Absolute tangential velocity

$$\frac{\partial v_\theta}{\partial r} = \frac{24\,\mu\,\pi\,r\,w_\theta}{b\,\dot{m}_c} - \frac{v_\theta}{r}$$

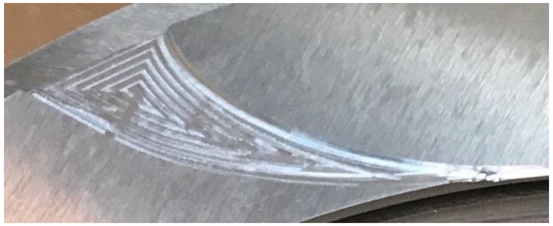




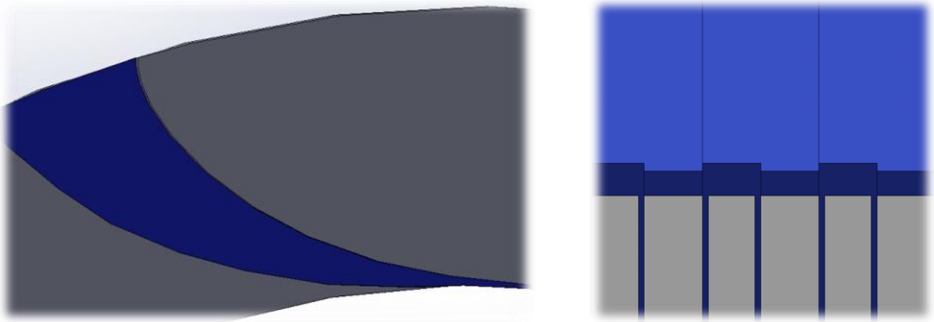
Effect of Variable Density

Stator/Rotor Coupling

A total pressure loss - accounting for enlargement at stator exit and contraction at rotor inlet, was introduced:



$$\Delta p = \Delta p_e + \Delta p_i = \frac{1}{2} k_e \rho v_1^2 + \frac{1}{2} k_i \rho w_1^2$$

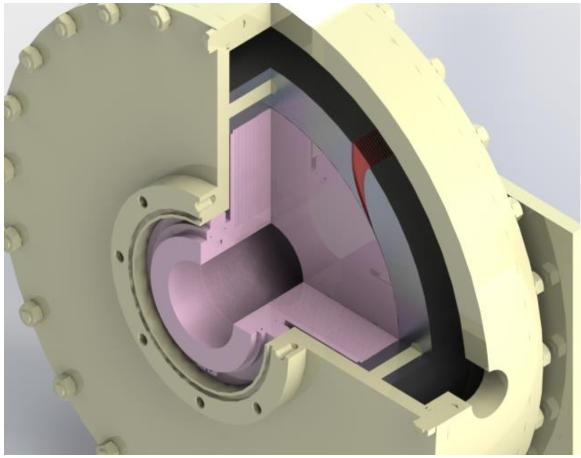


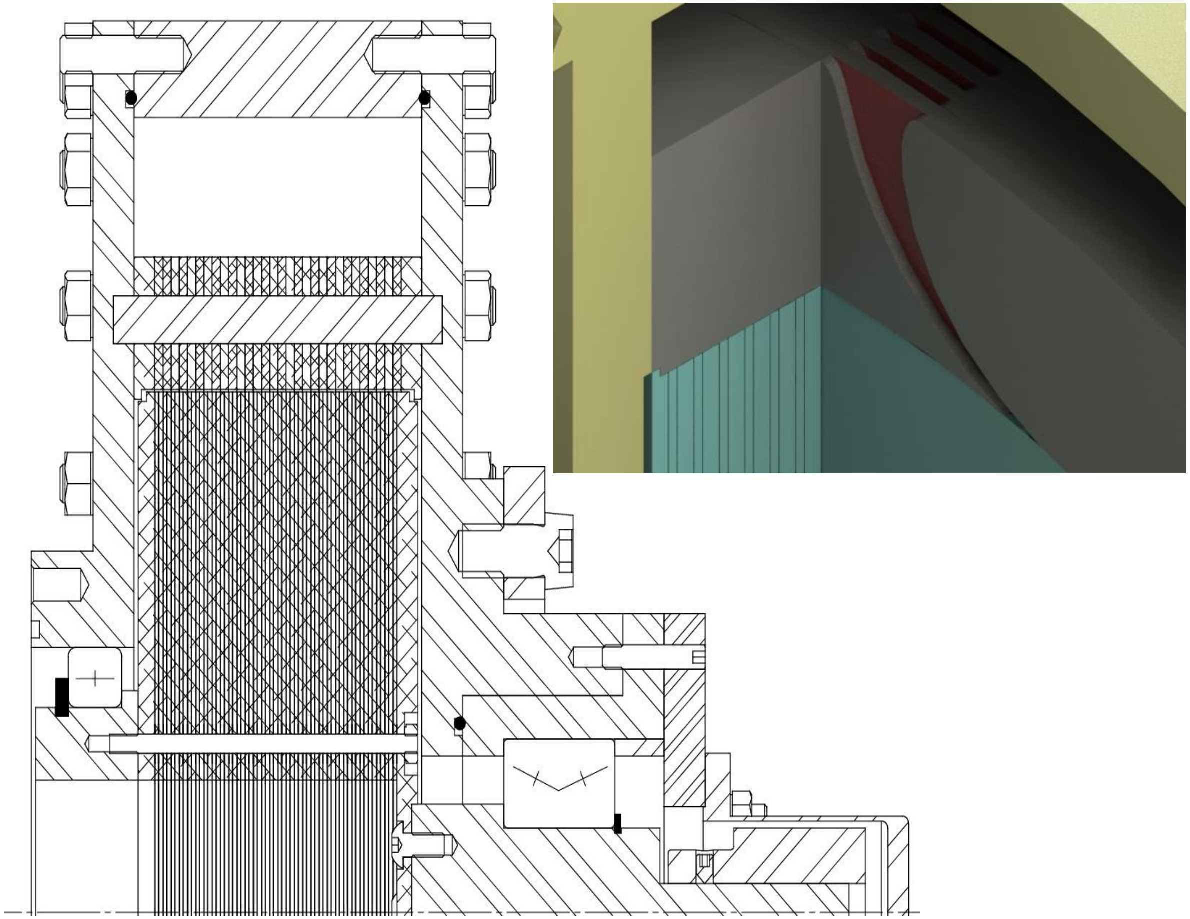
Abrupt enlargement at stator exit	**Contraction at rotor inlet**

- Iterative process in order to determine ρ

- The loss coefficient for abrupt enlargement (k_e) is modeled as an incompressible Borda-Carnot coefficient using the velocity immediately before the enlargement.
- The loss coefficient for contraction (k_i) is obtained through a polynomial fitting of empirical data using the velocity immediately after the contraction.

Conceptual Design





- Plenum chamber
- Radial nozzle inlet
- Modular design (stackable in axial direction)
- Improved hollow shaft discharge
- Sealed machine design with magnetic generator coupling

Working fluid assessment

Tesla turbine Geometry

Parameter	Section	Unit
Stator inlet diameter	0.25	[m]
Stator outlet/Rotor inlet diameters	0.2	[m]
Effective stator channels	8	[-]
Inlet Stator angle (radial direction)	0	[°]
Outlet Stator angle (radial direction)	85	[°]
Stator Vane Height	0.001	[m]
Rotor outlet diameter	0.08	[m]
Channel Height	0.00012	[m]

Analyzed fluids:

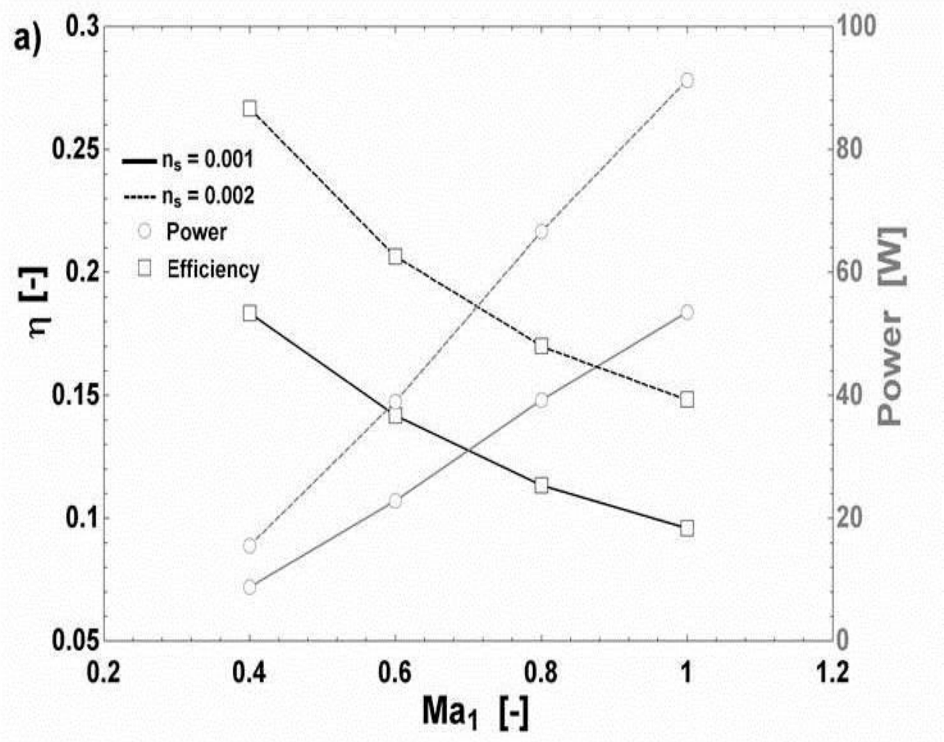
- R245fa
- n-hexane

- Reference total temperature $T_{00} = 100°C$
- Total pressure is different for the two fluids and it was selected in order to have superheated vapor 10°C above saturation temperature

R245fa

Total inlet temperature of 100 [°C] and Inlet Total pressure of 1.009 [MPA]

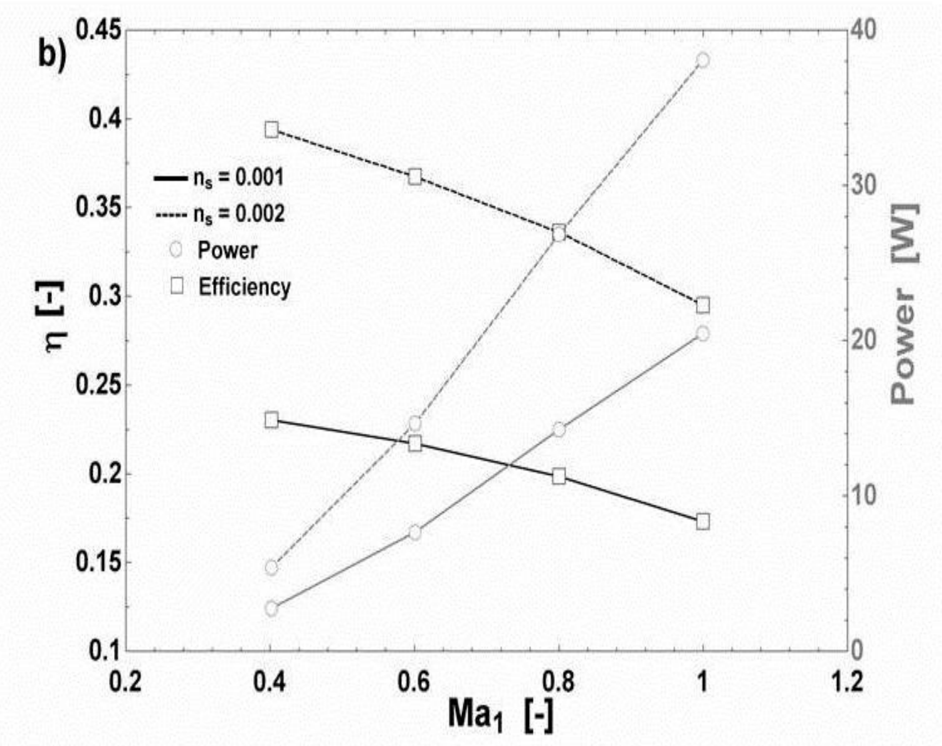
$n_s = 0.001$				
Parameter	$Ma_1 = 0.4$	$Ma_1 = 0.6$	$Ma_1 = 0.8$	$Ma_1 = 1$
Ma_2	0.20	0.40	0.60	0.78
Ψ	5.65	5.69	6.31	7.58
ϕ	0.26	0.31	0.40	0.54
D_s	85.5	77.8	67.9	57.9
RPM	1455	2010	2330	2455
p_2/p_0	0.83	0.63	0.42	0.26
$n_s = 0.002$				
Ma_2	0.31	0.54	0.75	0.94
Ψ	2.33	2.49	2.92	3.68
ϕ	0.12	0.16	0.21	0.29
D_s	85.2	75.5	64.5	54.2
RPM	3010	3970	4466	4597
p_2/p_0	0.80	0.58	0.38	0.23



n-Hexane

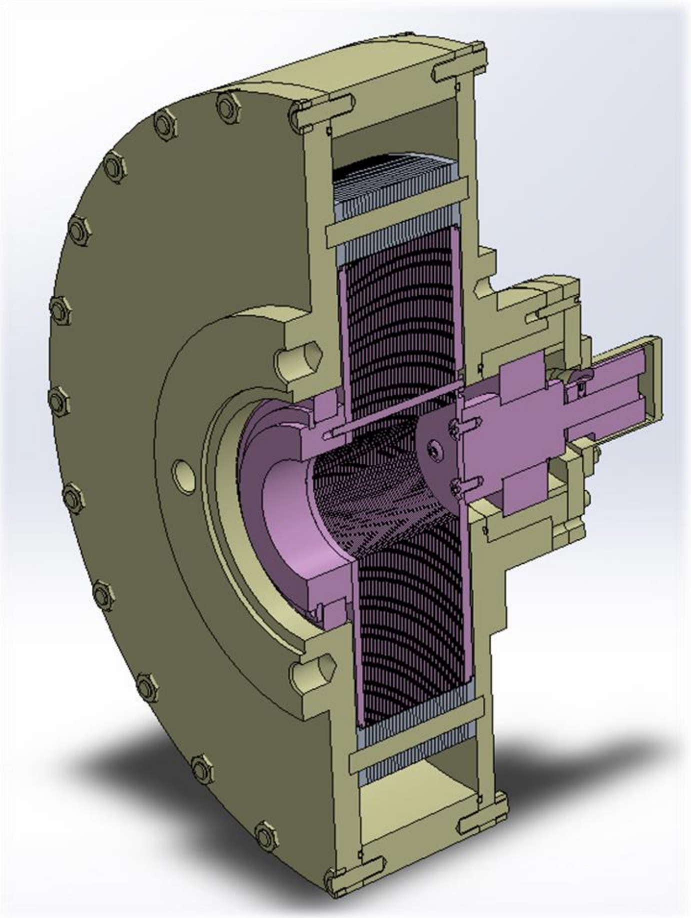
Total inlet temperature of 100 [°C] and Inlet Total pressure of 0.185 [MPA]

$n_s = 0.001$				
Parameter	$Ma_1 = 0.4$	$Ma_1 = 0.6$	$Ma_1 = 0.8$	$Ma_1 = 1$
Ma_2	0.10	0.16	0.24	0.35
Ψ	6.48	7.02	7.73	8.77
ϕ	0.26	0.30	0.37	0.47
D_s	34.42	32.18	29.44	26.01
RPM	2020	2790	3395	3770
p_2/p_0	0.83	0.66	0.48	0.31
$n_s = 0.002$				
Ma_2	0.16	0.25	0.34	0.46
Ψ	2.81	3.11	3.53	4.14
ϕ	0.12	0.15	0.18	0.24
D_s	34.81	32.05	28.85	25.08
RPM	4285	5795	6885	7475
p_2/p_0	0.81	0.63	0.44	0.28



Conclusions

- The Tesla turbine rotor performs well with **low mass flow rates**. These conditions, for a fixed geometry of the nozzle and fixed velocity at the throat, are obtained for **low density at nozzle exit**.
- The results indicate that:
    - **Tesla turbine appears potentially competitive** with other expanders for low **n_s (0.001-0.01)** and high **D_s (20-80)** (typical range for **volumetric expanders or drag turbines**).
    - The right range of the **flow coefficient** for optimal rotor efficiency is very low (**Φ = 0.01-0.1**). Higher flow coefficients are attractive to increase power output (Φ = 0.05-0.3) at the expense of efficiency.
    - The W**ork coefficient Ψ can be very high (over 2)**.
    - **Rotational speed** has a strong influence the expander power and efficiency, but generally, the **turbine can be sized to work properly within 4000-6000 rpm**.



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