16.50 Propulsion Systems
HWK#9

In **HWK#6**, you designed the major cycle parameters for a small turbojet engine. We will here re-visit this engine and do the mean-line design of its compressor. For the given data, check back on the HWK#6 statement; some of the relevant results of that exercise are listed below:

$$\tau_c = 2.0003 \quad T_{t2} = 279.8K \quad T_{t3} = 559.7K \quad P_{t3} = 7.017 \times 10^5 \, Pa$$
$$M_2 = 0.4 \quad \dot{m} = 12.078 \, kg/s \quad A_2 = 0.1385 \, m^2$$

For the design of the repeating-stage compressor we additionally prescribe a constant mean radius $\bar{r} = (r_T + r_H)/2$ and axial velocity w (to be determined), a mean blade speed $\omega\bar{r} = 300 \, m/s$, a first-stage hub-to-tip ratio $(r_H / r_T)_2 = 0.4$ and a mean-line solidity $\bar{\sigma} = 1.5$. The stages are all similar (same angles), and this implies there is a set of inlet guide vanes to provide the required non-zero azimuthal velocity to the flow entering the compressor. Each stage will be of a 50% reaction design, meaning the flow turning and deceleration will be identical in the rotor (in rotor frame) and in the stator. Finally, the diffusion factor D shall be 0.5 or less in the rotor and stator of each of the stages.

(a) Calculate the hub and tip radii and the mean radius at compressor inlet (station 2). For this purpose, ignore the inlet guide vanes.
(b) Calculate the axial velocity w, and from flow continuity, calculate the flow area A_3, and the blade radii (hub and tip) at compressor exit (station 3).
(c) The choice of number of stages N is crucial. Show that for the conditions chosen here, each stage will provide the same increase $\Delta T_{t,s}$ in total temperature. A small N is favorable for weight, but may force too much work per stage and result in excessive losses (D too high). Try N values from 7 to 10; for each N, calculate from the Euler equation the flow turning $|v_2 - v_1|$, and then, from the velocity triangles, each of the important velocities (V_1=V'$_2$, V_2=V'$_1$) and the corresponding D value. Select the best N.
(d) Sketch to approximate scale a meridional section of the compressor, as well as the shapes of the blades for one of the stages.

Concept questions:

(1) Are the stage pressure ratios uniform? If not, which provide more pressure ratio?
(2) At 50% design flow, we found in HWK#6 that the compressor pressure ratio was reduced to 4. Describe what problems would occur with your design at this flow if the rotors of all stages were mounted on the same shaft.

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