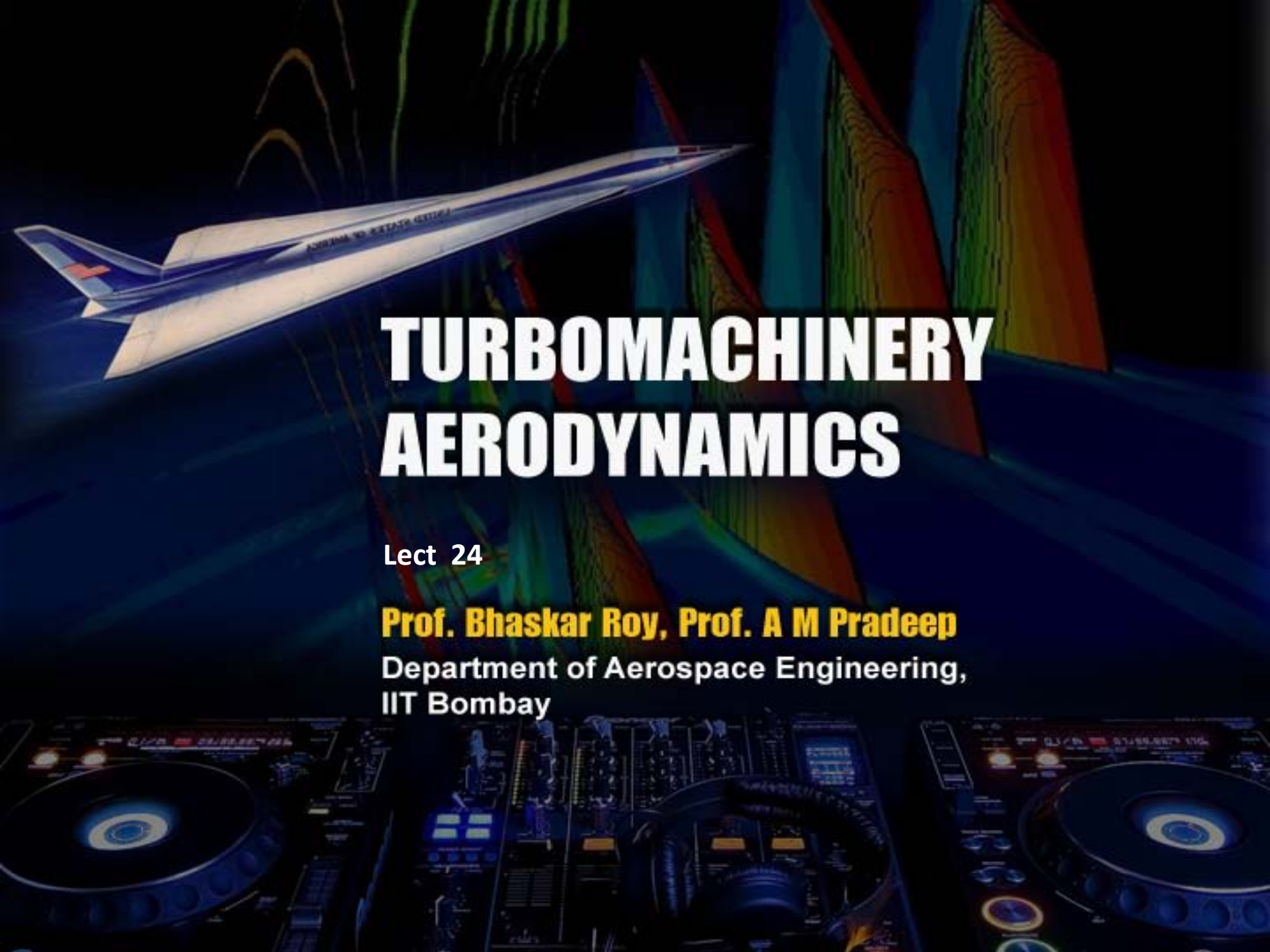

TURBOMACHINERY AERODYNAMICS

Lect 24

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Axial Flow Turbine

Multi-staging and Multi-spooling

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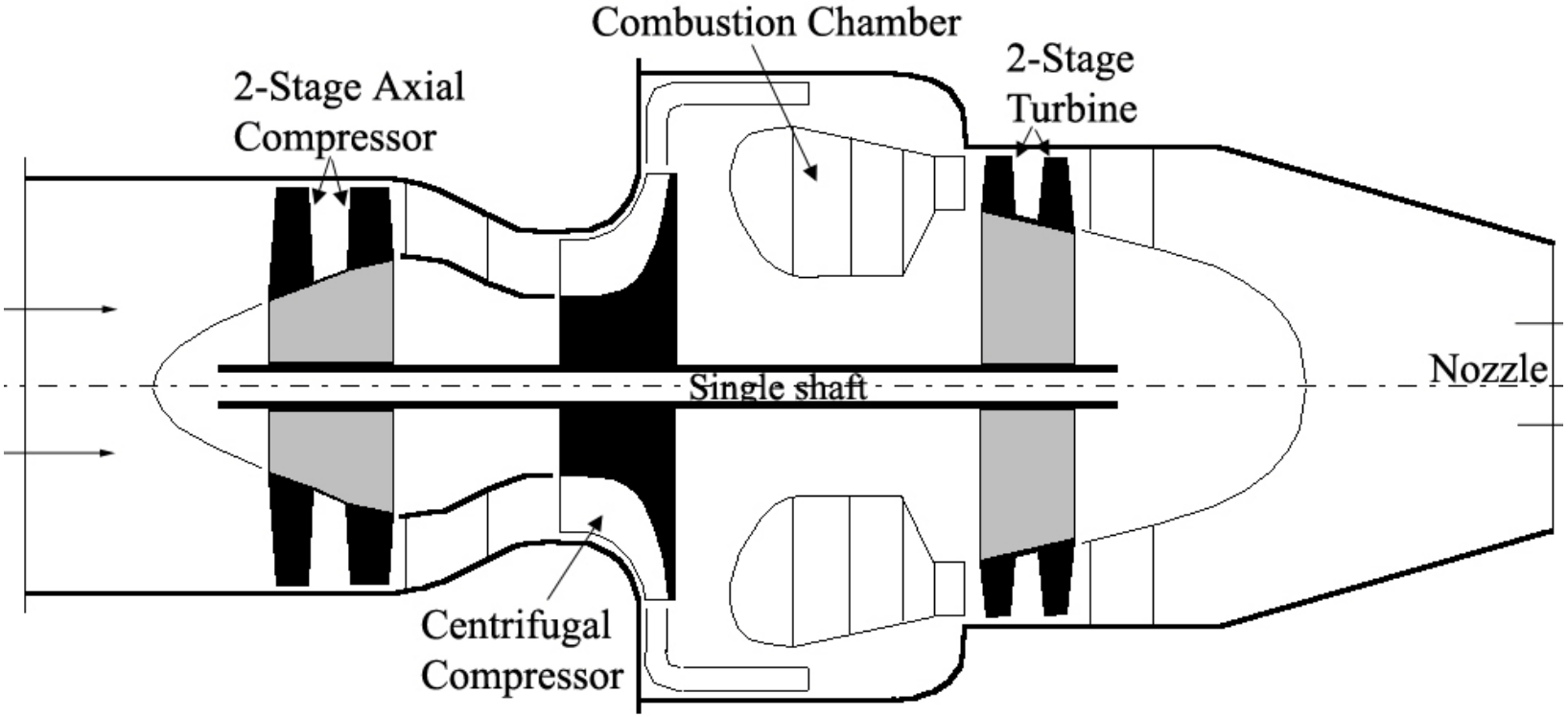
Multi-staging

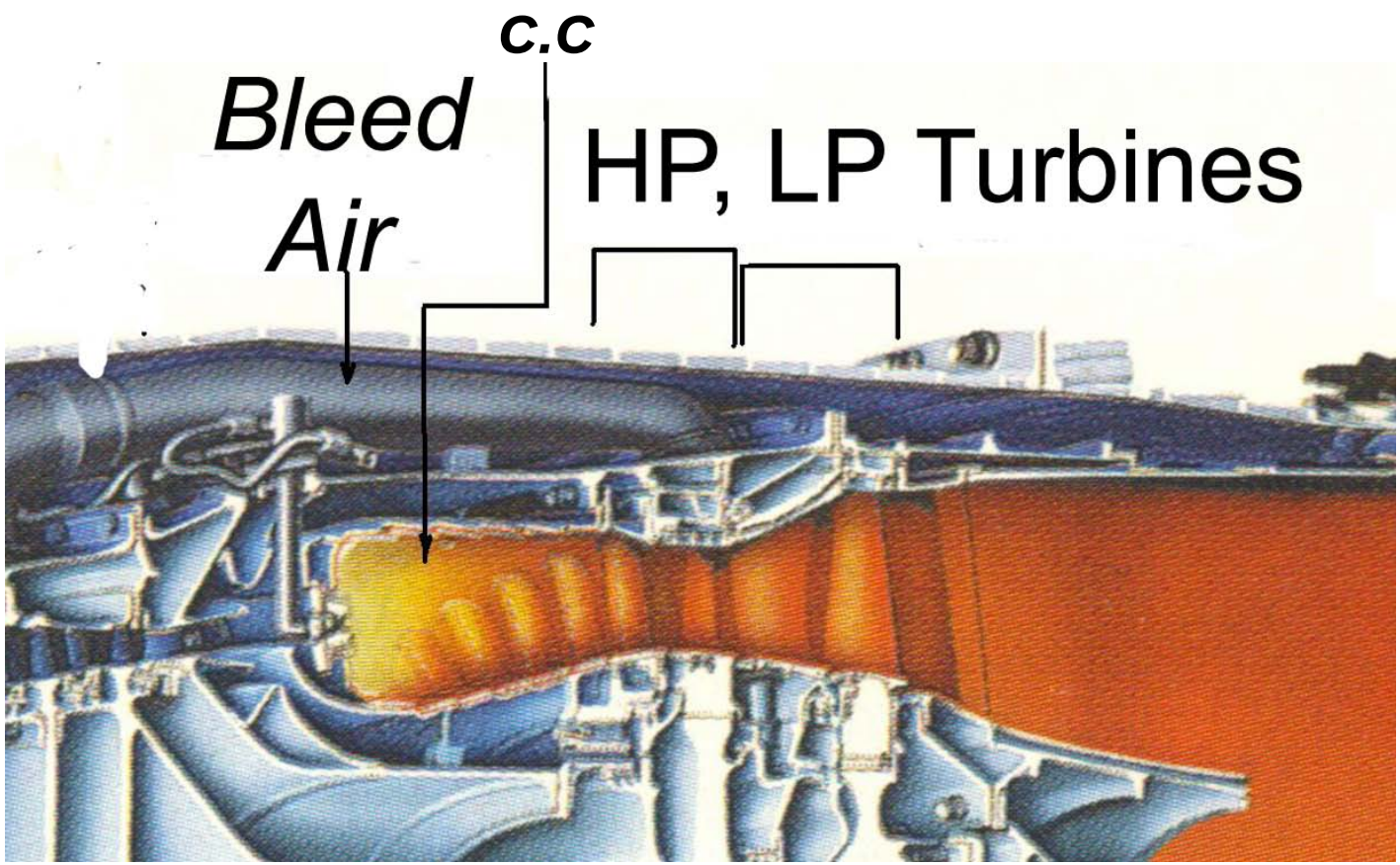
- Requirement for multi-staging of turbines comes from the aggregate of shaft work that needs to be produced .
- Typically if turbine pressure ratio requirement is more than 2.5 / 3.0 - multi-staging is required.
- As compression ratio over the years have kept on increasing, multi-staging has become inevitable in all aero-engines.
- Number of integer stages to be decided by the state of art of turbine design

Multi-spooling of Turbines

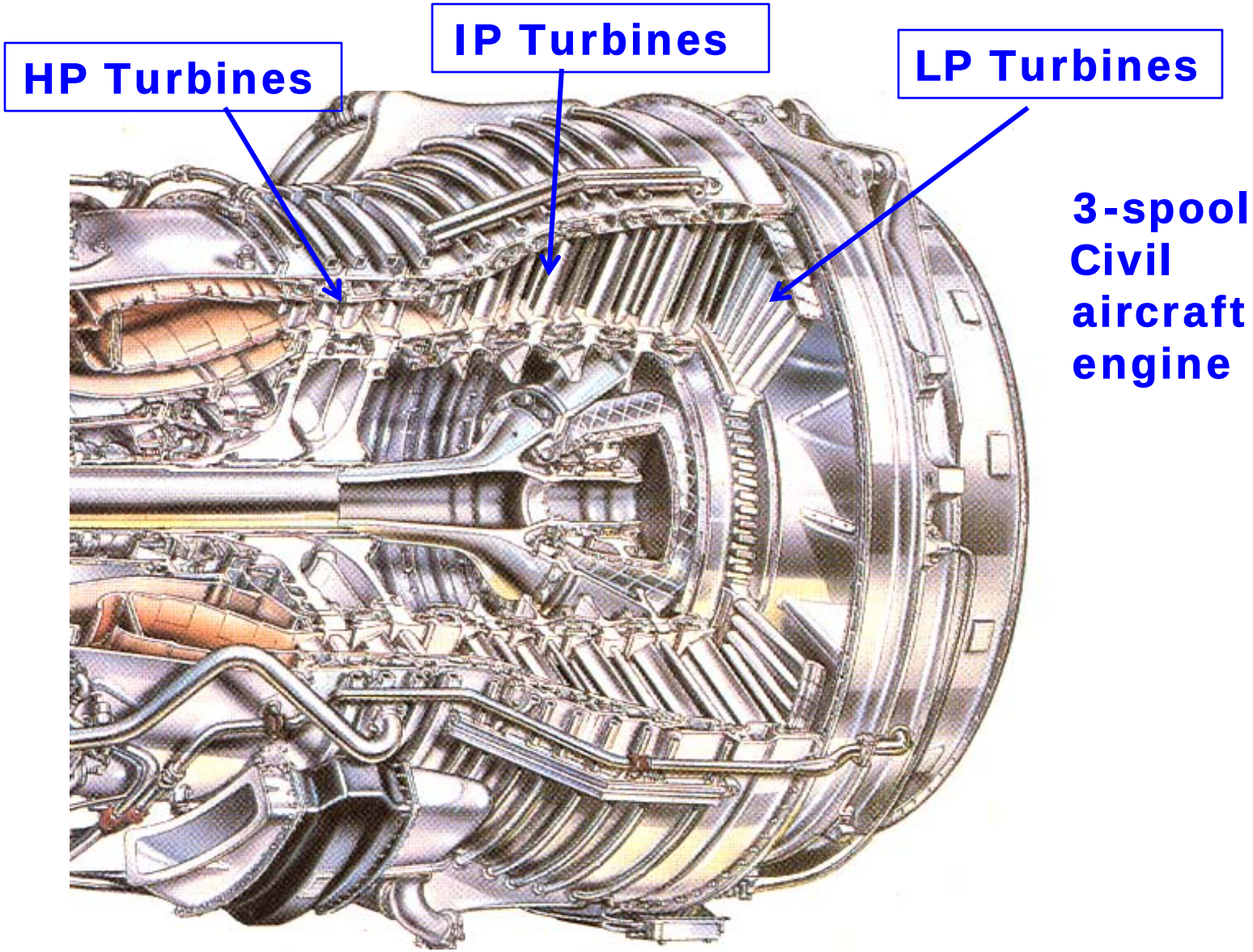
- Multi-spooling of turbines is necessary if the compressors have been split in more than one spool
- Multi-spooling is necessary in a turbo-prop engine if the propeller is needed to be run separately (with a gear box)
- Most modern aero-engines are 2-spool engines and there are few with 3-spool arrangements



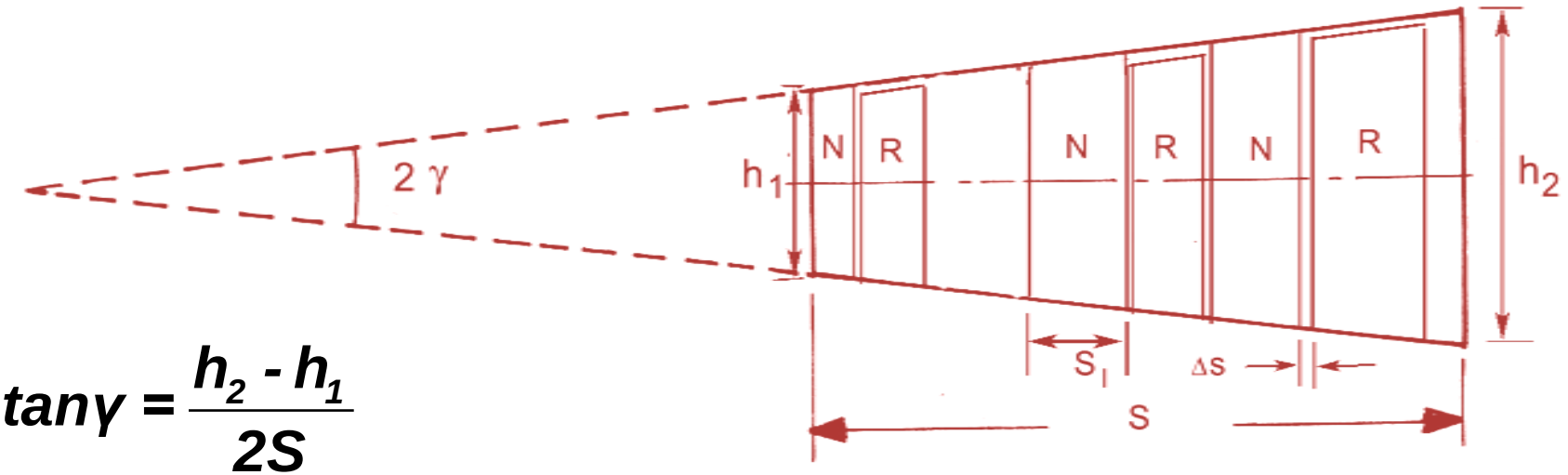
A single spool engine with multi-staged turbine



Multi-stage HP + LP turbine layout: Military Engine



3-spool Civil aircraft engine



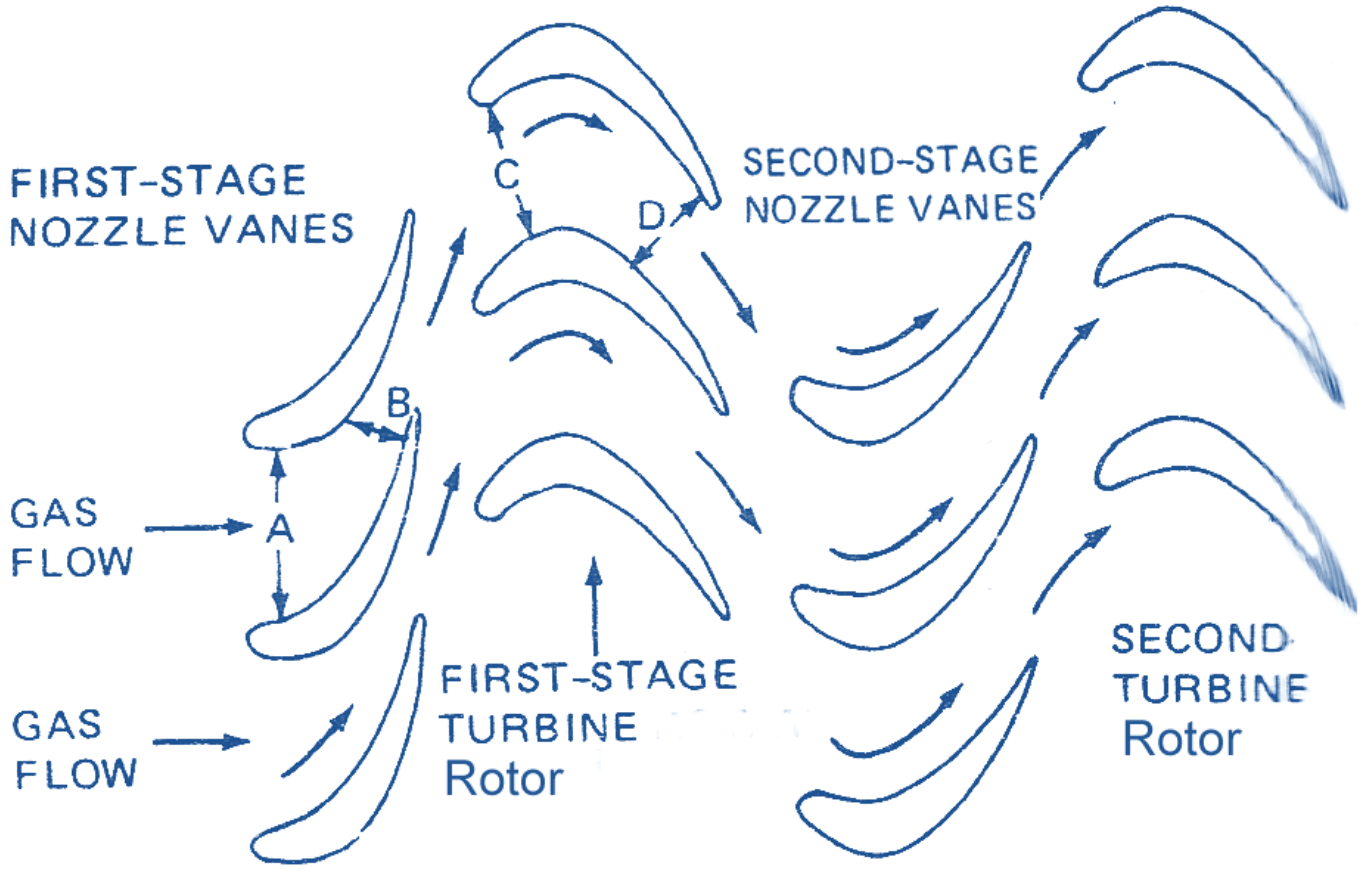
$$\tan\gamma = \frac{h_2 - h_1}{2S}$$

$$S = \Sigma\Delta S + \Sigma S_i = \Delta S.Z_p + S_i.Z$$

where Z is the number of stages, and $Z_p = 2.Z - 1$

$$\tan\gamma = \frac{h_2 - h_1}{2Z_p\left(\Delta S + S_i\right)} = \frac{S_i\left(\overline{h_2} - \overline{h_1}\right)}{2Z_p S_i\left(1 + \frac{\Delta S}{S_i}\right)} = \frac{\overline{h_2}\left(1 - \frac{\overline{h_1}}{\overline{h_2}}\right)}{2Z_p\left(1 + \frac{\Delta S}{S_i}\right)}$$

Flow through the blades is non-axial and varies from the root to the tip



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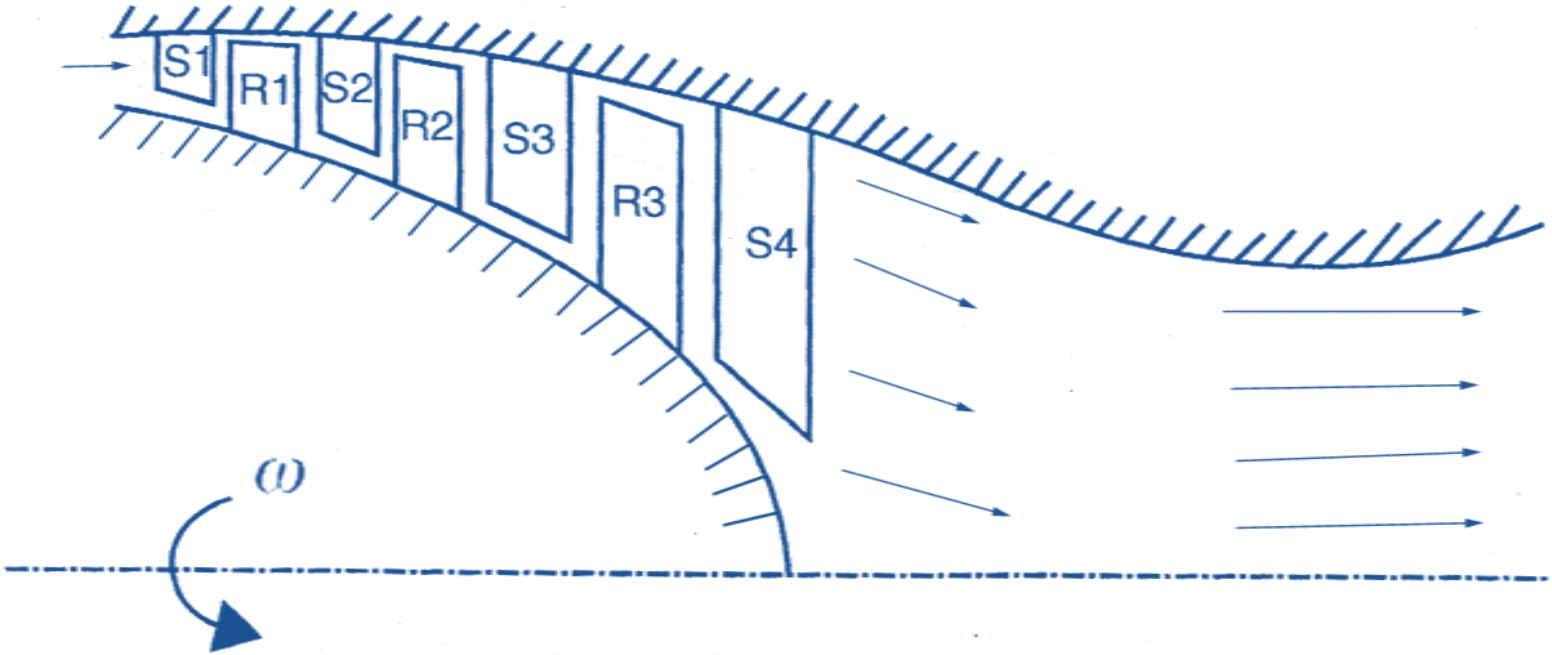
Axial Flow track in modern multi-stage turbines is often curved



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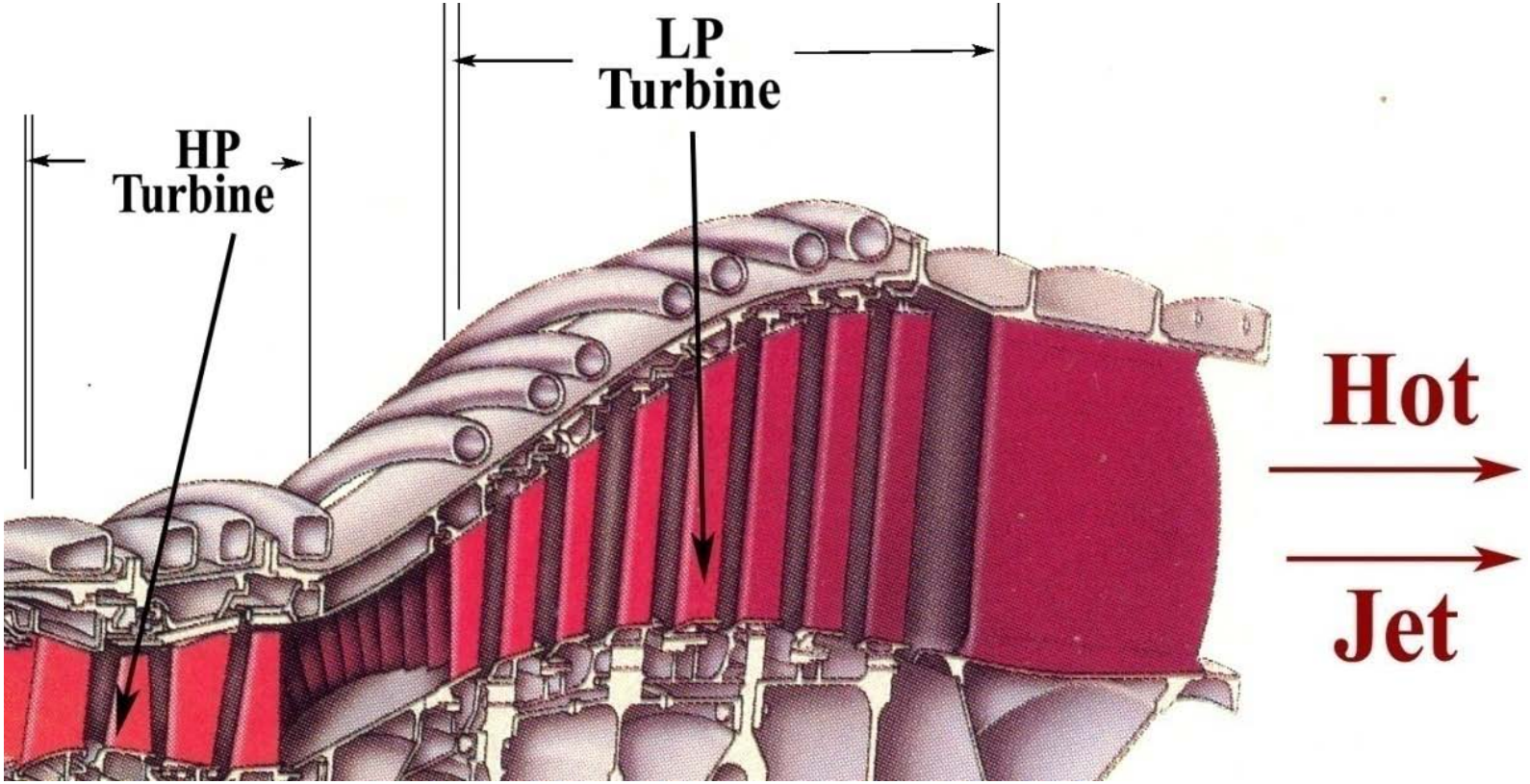
Multi-stage flow analysis

- Flow track design decision comes from continuous application of continuity condition
- The track is diverging in axial direction
- Flow paths through the blades are generally in curved converging passages.
- This, thus, requires application of 3-D flow analysis to get accurate notion of the flow
- Most modern turbines are analyzed using 3-D CFD analytical techniques

Multi-staging of Turbine

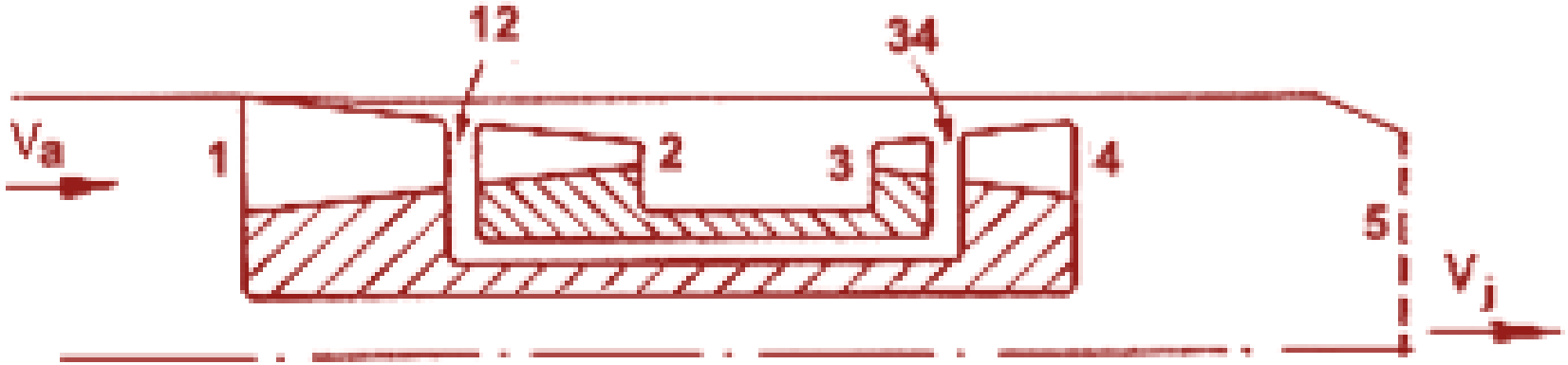


Multi-stage HP + LP turbine layout; Civil Engine

Compressor Turbine Matching

SINGLE SPOOL ENGINE

TWO-SPOOL TURBOJET



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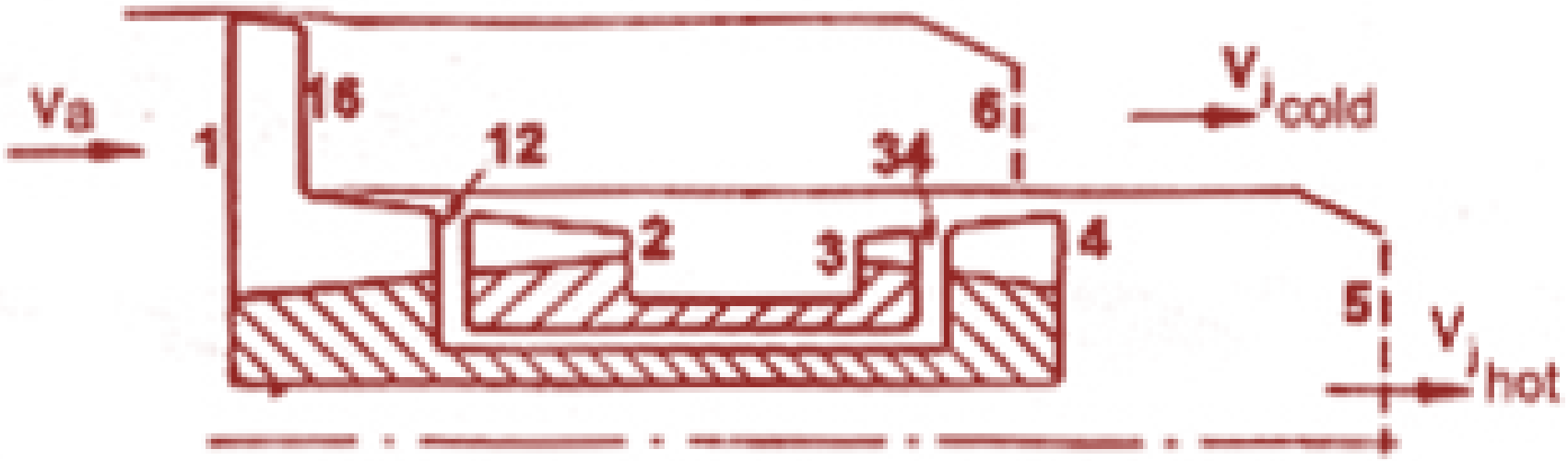
TWO-SPOOL HIGH BYPASS TURBOFAN ENGINE



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1. Single spool : power produced by turbine is equal to the power into the compressor (for matching).

$$C_p(T_{02}-T_{01}) = C_{p\text{-}gas}\, k_H\, T_{03}$$

2. Two – spool arrangement

HP turbine work :

$$W_{HP}/\ m = C_{pg}.(T_{03} - T_{034})$$

$$= C_{pg}.T_{03}\ (1 - T_{034}\ /\ T_{03})$$

$$= C_{pg}.k_{HP}.T_{03}$$

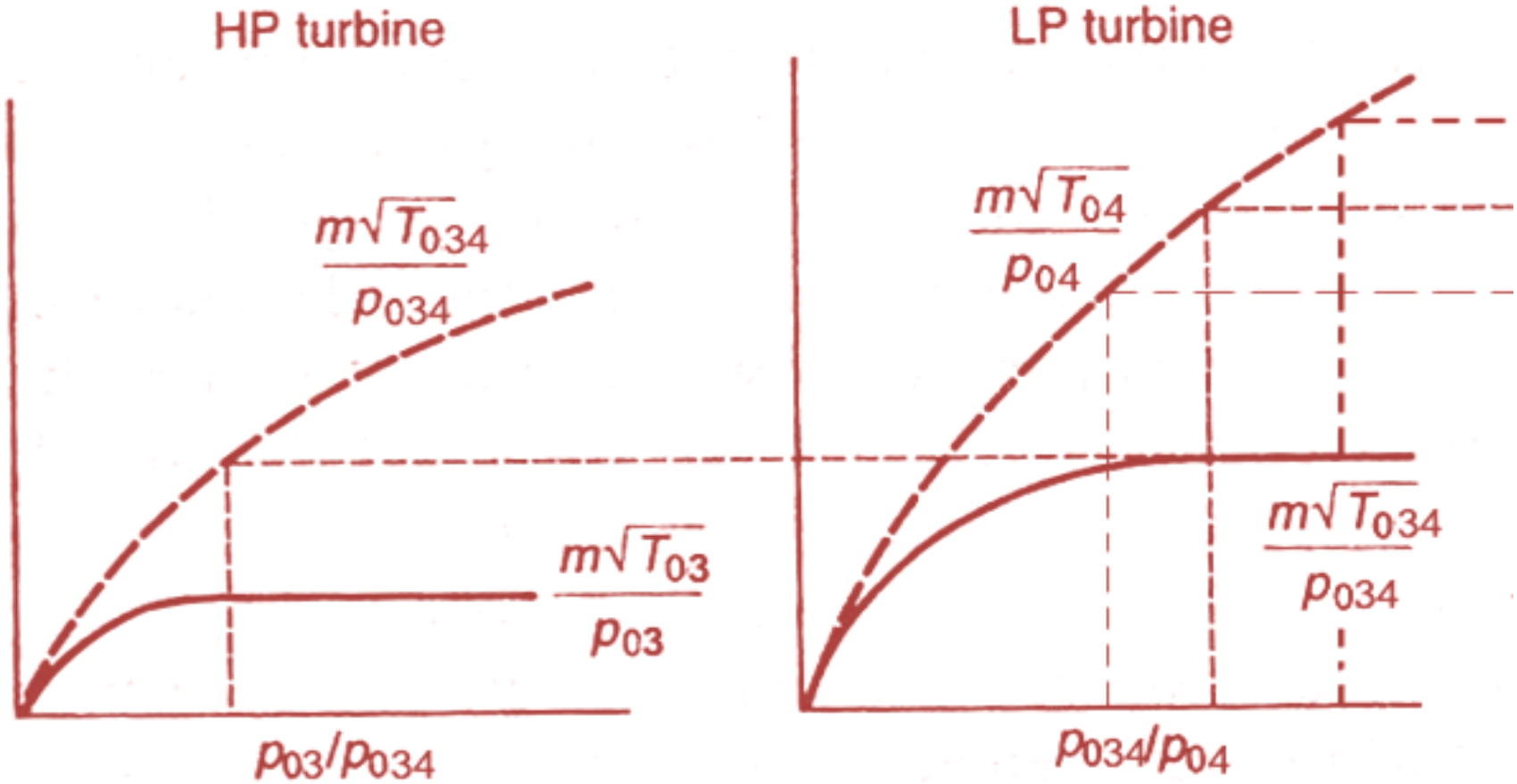
: LP turbine

$$W_{LP}/\ m = C_{p\text{-}gas}.(T_{034} - T_{04})$$

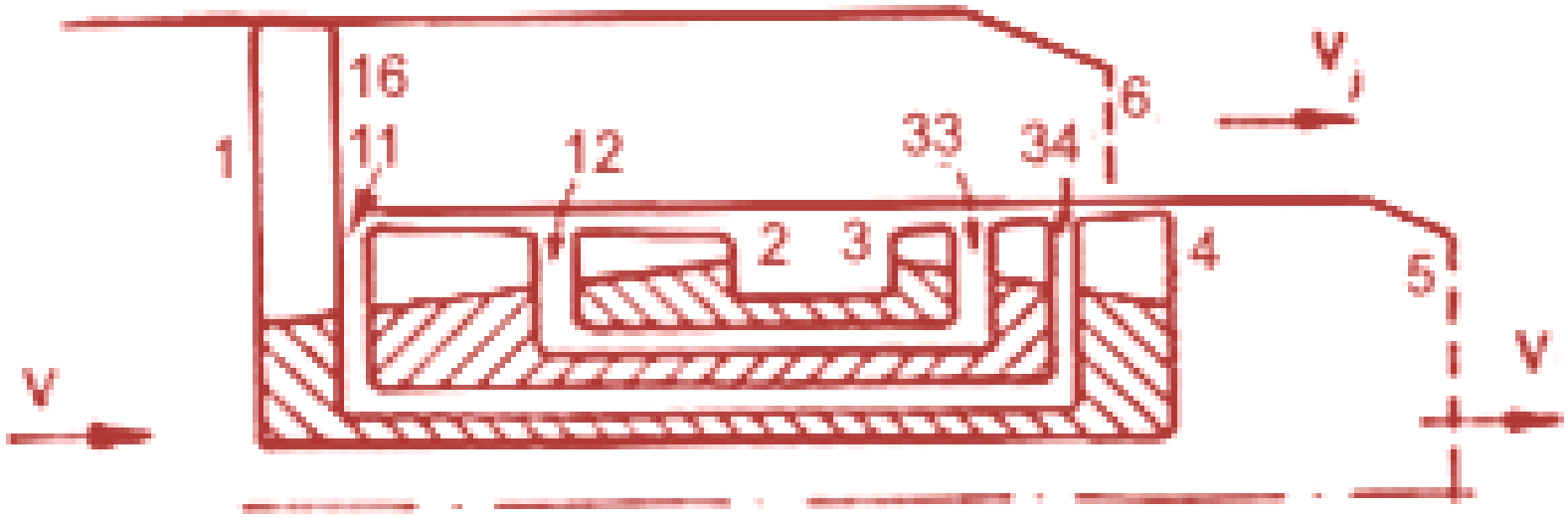
$$= C_{p\text{-}gas}.T_{034}\ (1 - T_{04}\ /\ T_{034})$$

$$= C_{p\text{-}gas}.k_{LP}.T_{03}$$

Turbine Spool Matching



THREE-SPOOL HIGH BYPASS TURBOFAN ENGINE



Three spool engine

Compressor-Turbine spool-by-spool matching needs to be augmented with various engine controls that facilitates better matching and safer operation at all operating conditions

Axial Turbine -----

3-D Flow theories for turbine blade design

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