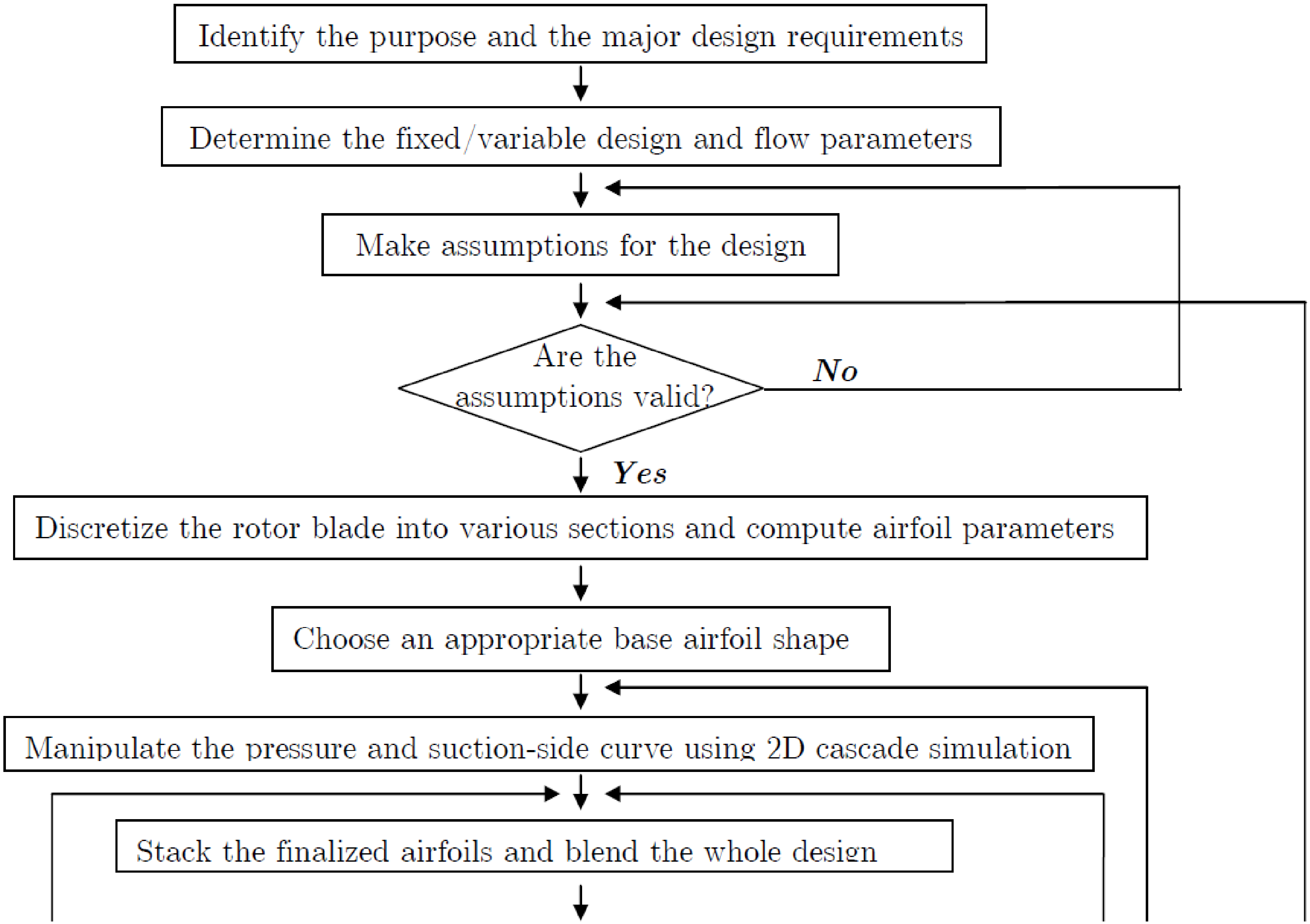
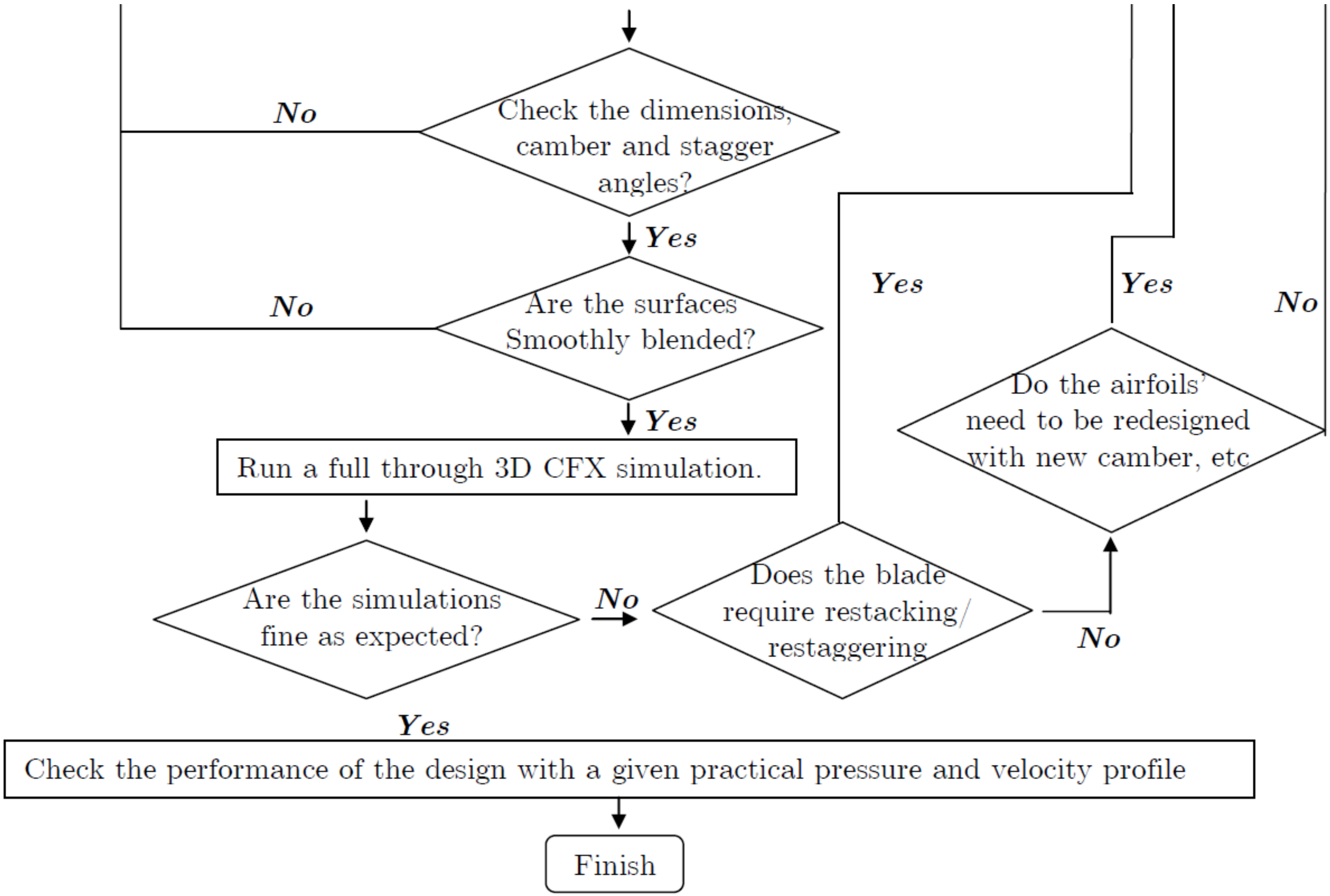
- Recap: Lecture 14: 15th September 2015, 1530-1655 hrs.
  - Design methodology for axial compressors

- Note: Lecture scheduled on Tuesday, 22nd September 2015 stands cancelled.
  - Make-up lecture planned on Saturday, 26th September 2015 between 1030-1200 hrs.

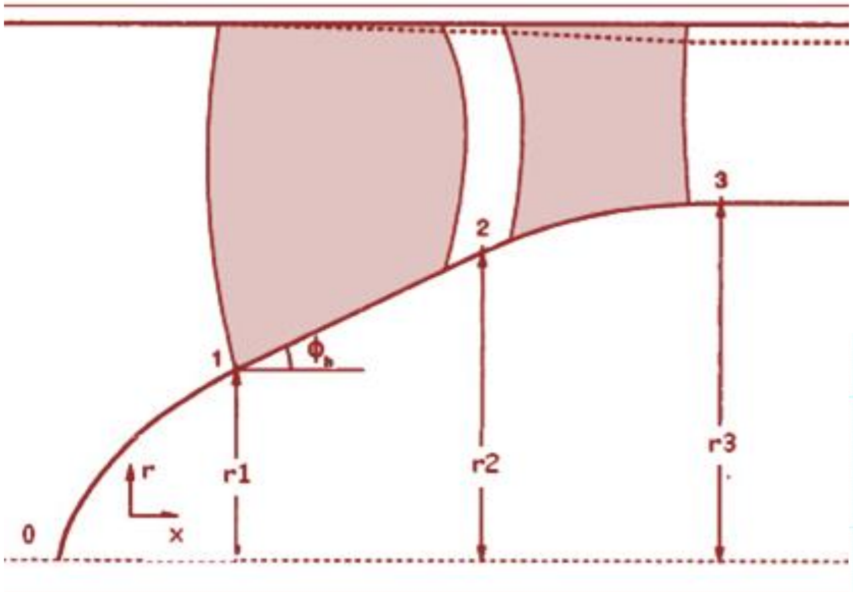
Design Procedure

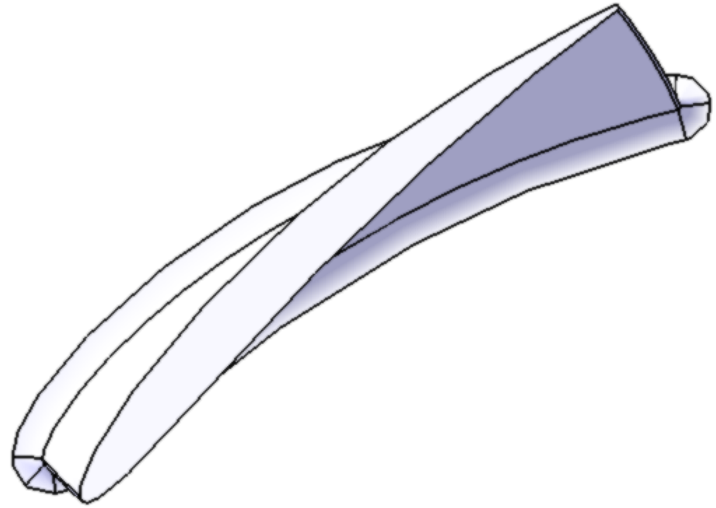


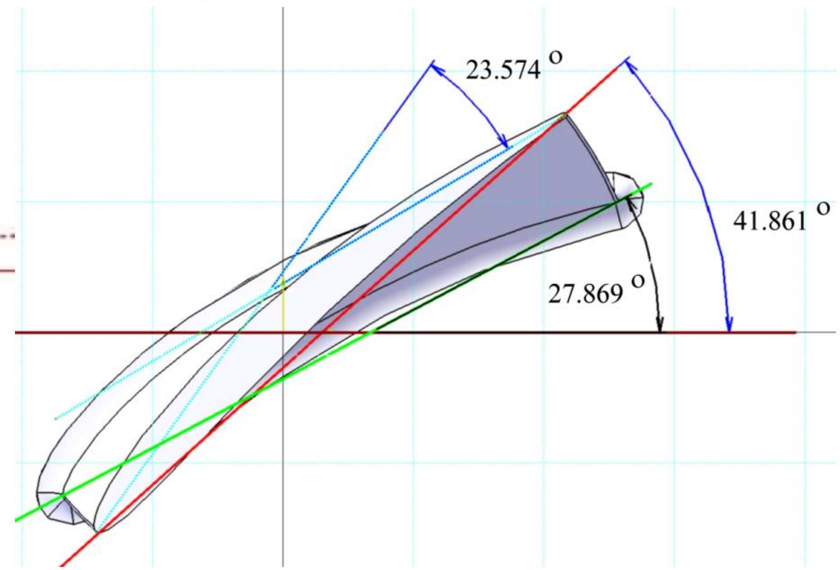
Design Procedure cont…



3-D Blade Shapes



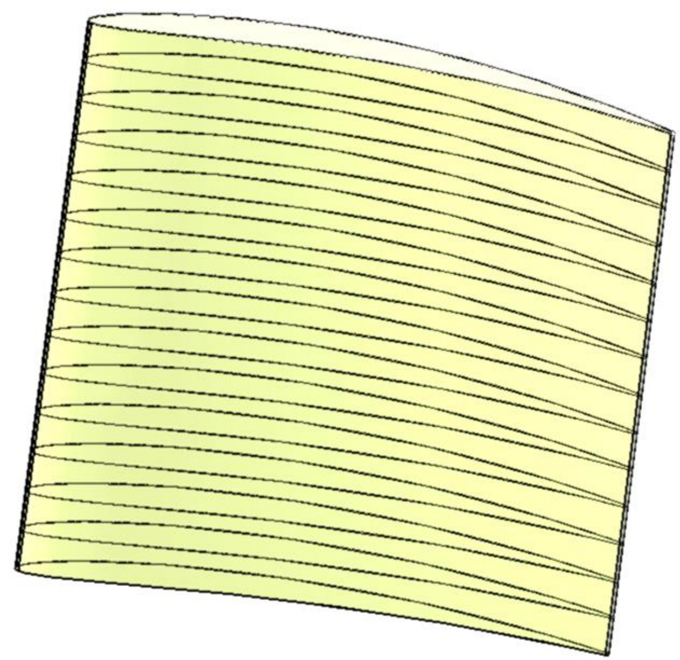




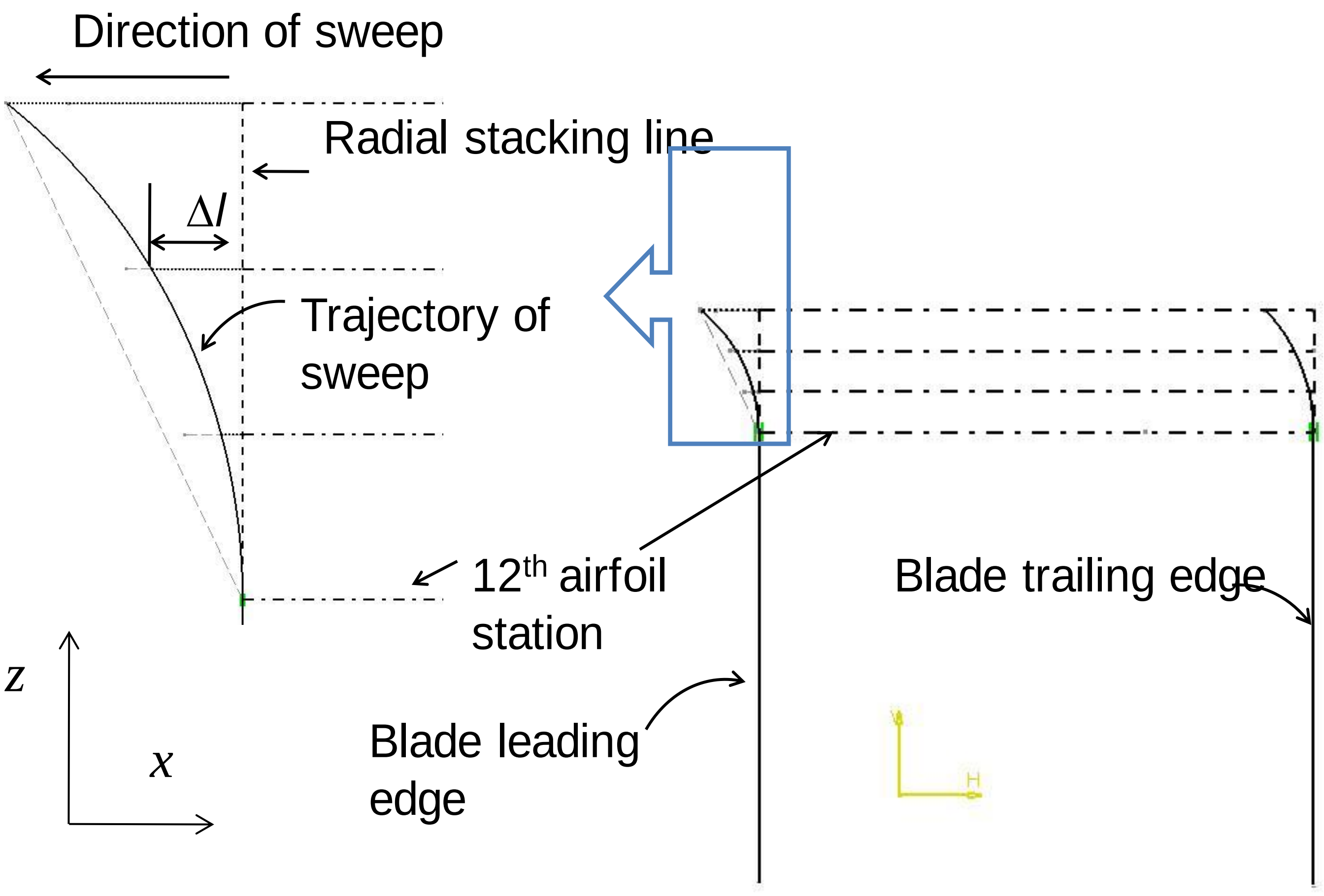
Follow similar step-by-step procedure for STATOR blade design by building up airfoil sections from hub to tip to match with the ROTOR blade design.

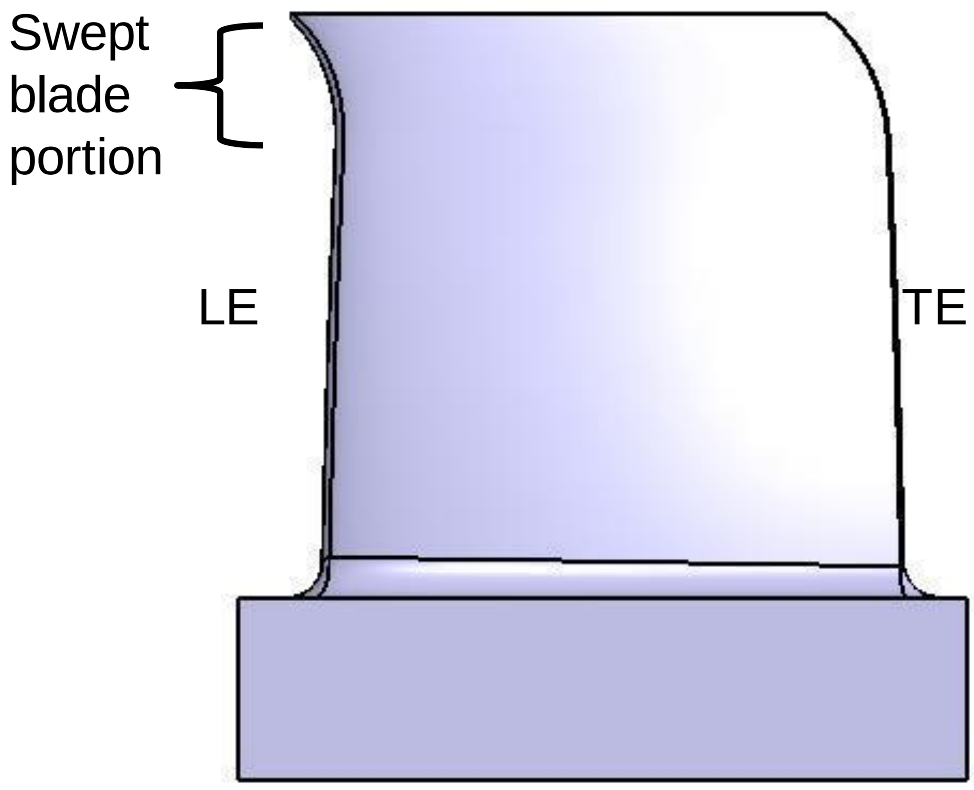
Stage design is completed after the rotor-matched stator design is completed.

Modern Blade designers have started using 3-D airfoils which are set on cylindrical coordinates, even as they are radially stacked.



Swept Blade Design




Swept
blade
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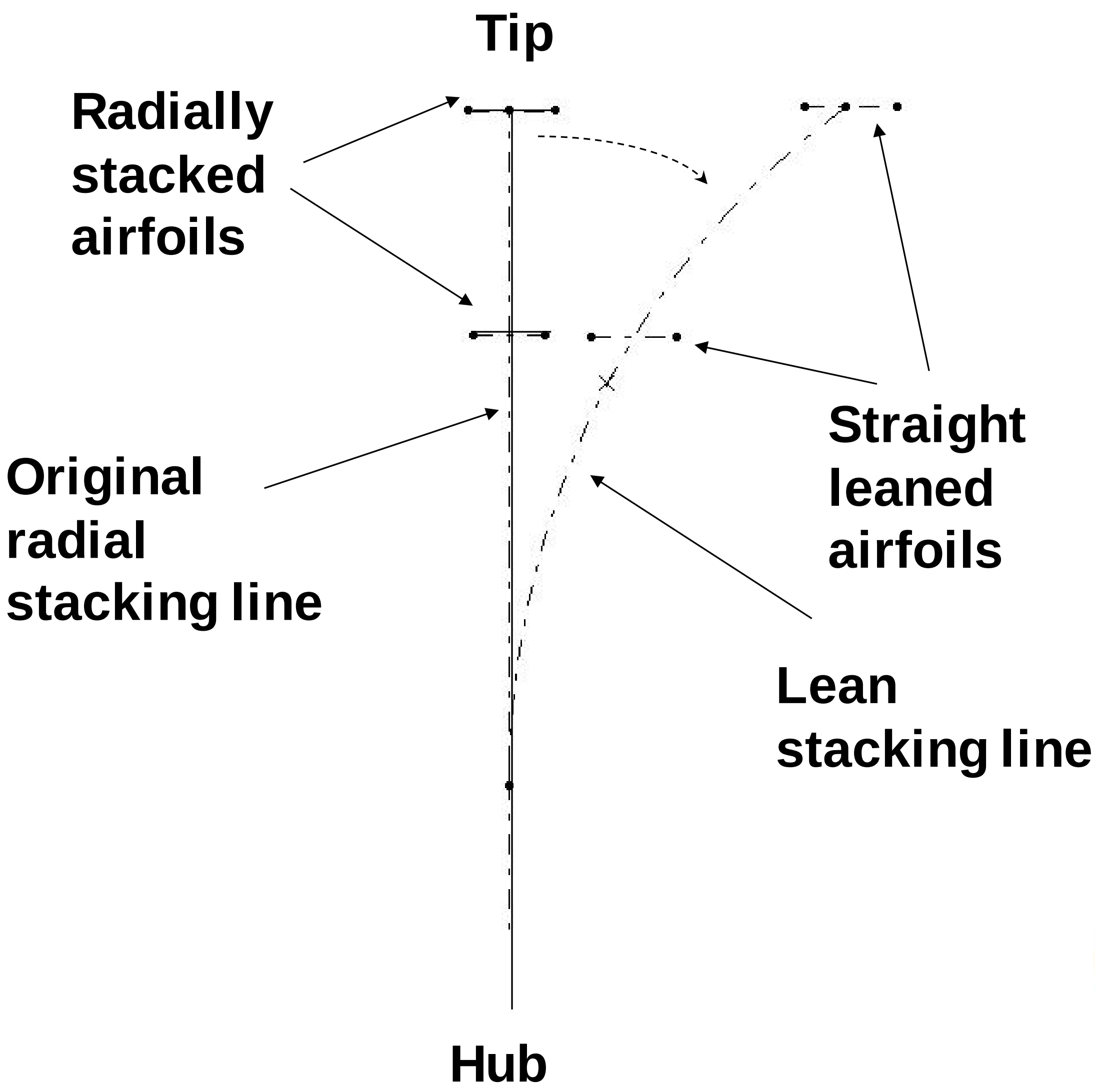
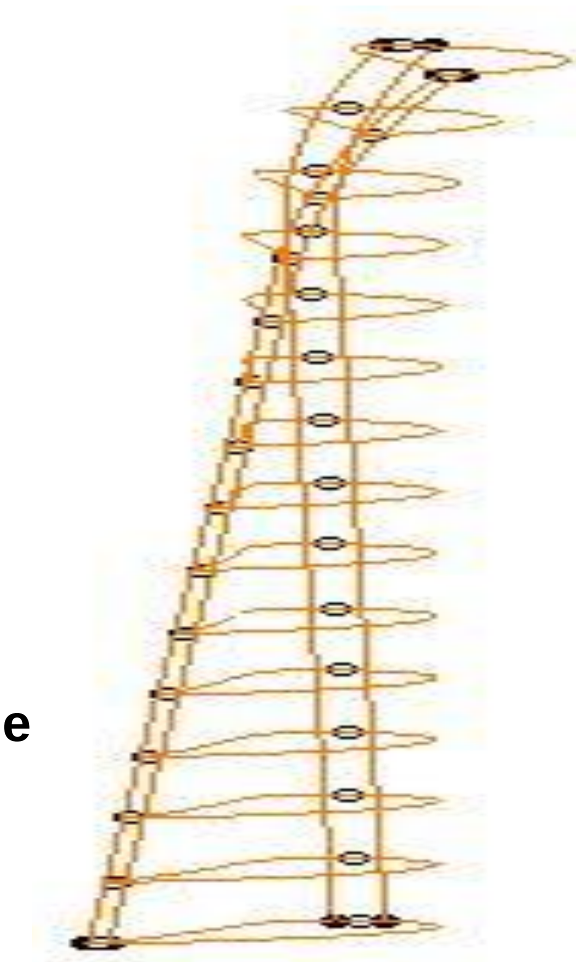
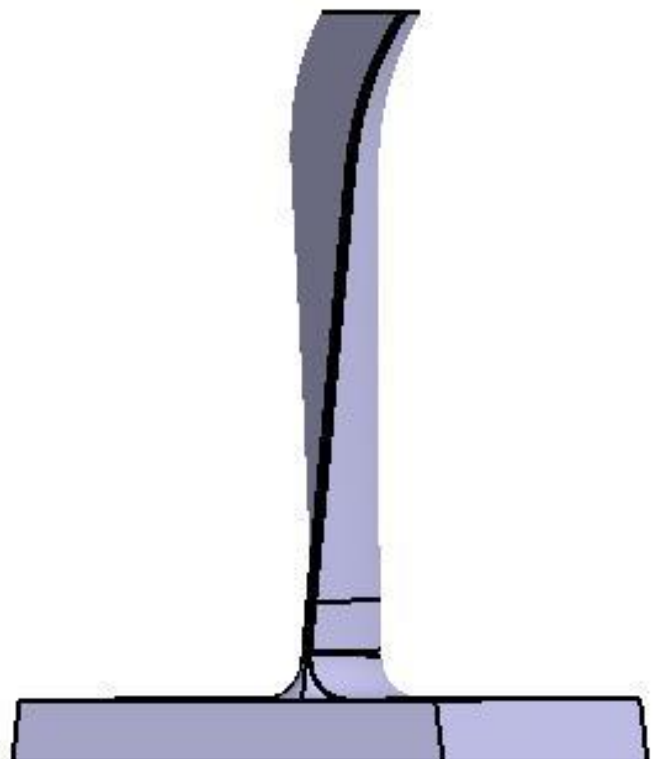
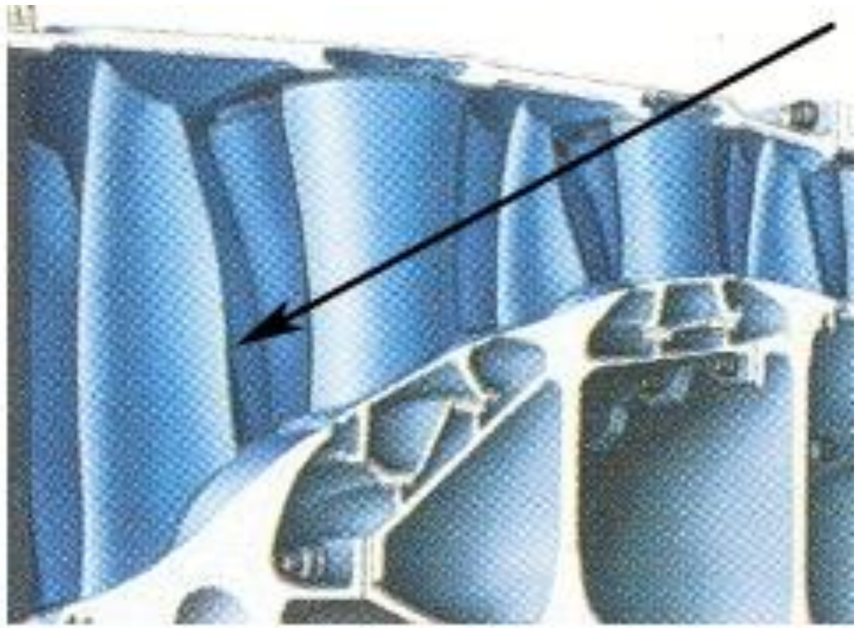
Leaned/dihedral Blade Design





Leaned Blade Design




Swept Blades

A Fully Swept Blade

Straight blade

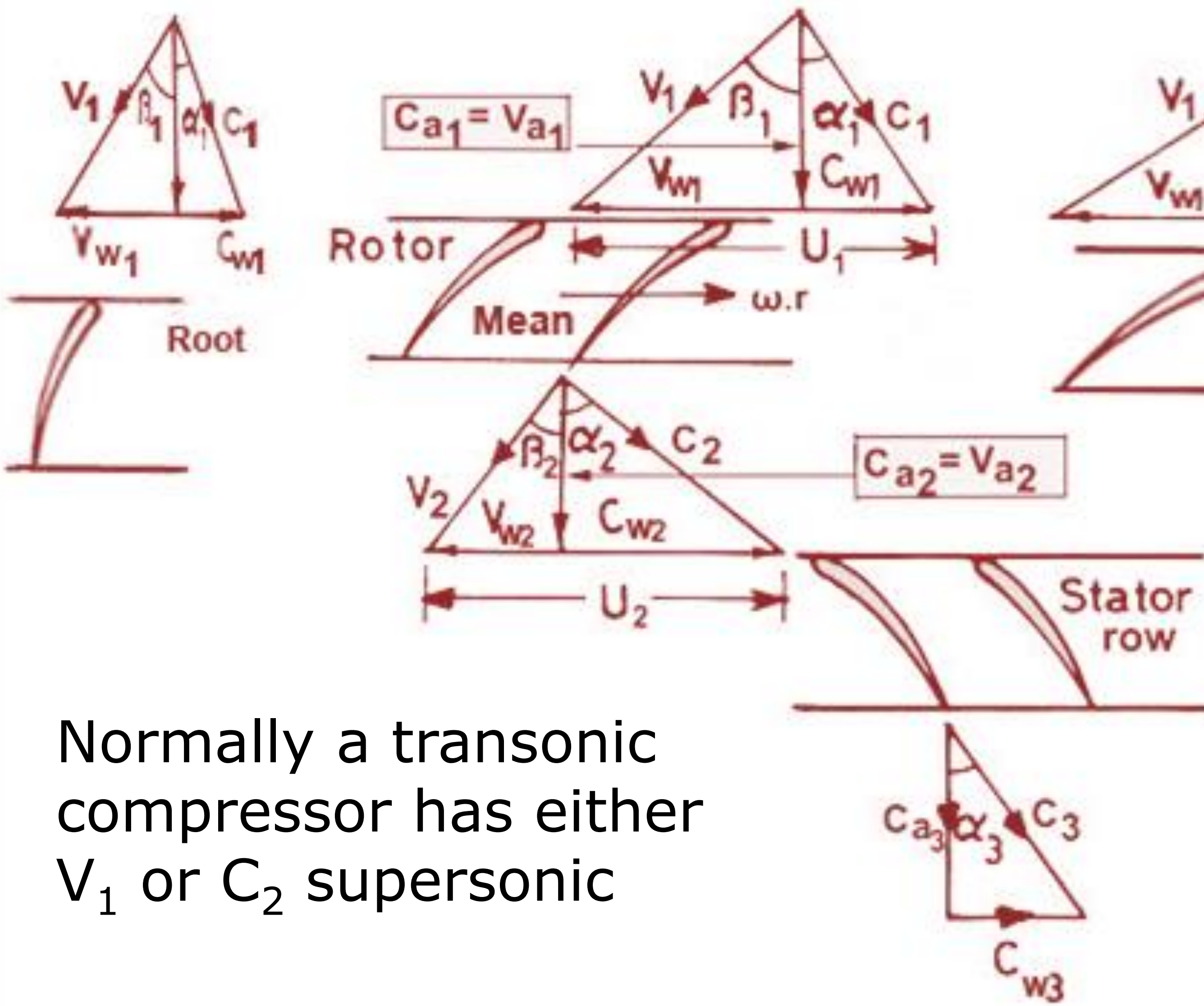
- 3-D Blades are developed from 2-D airfoil stacked blades by geometrical modeling
- These blades are then subject to 3-D CFD analysis under design operating conditions
- Further modification of the blade shapes are done after studying the CFD results
- Further blade shape optimization may be done for off-design operating conditions

Transonic Compressors

- Mach number in an axial compressor rotor may transit from subsonic at the root to supersonic at the tip of the blade

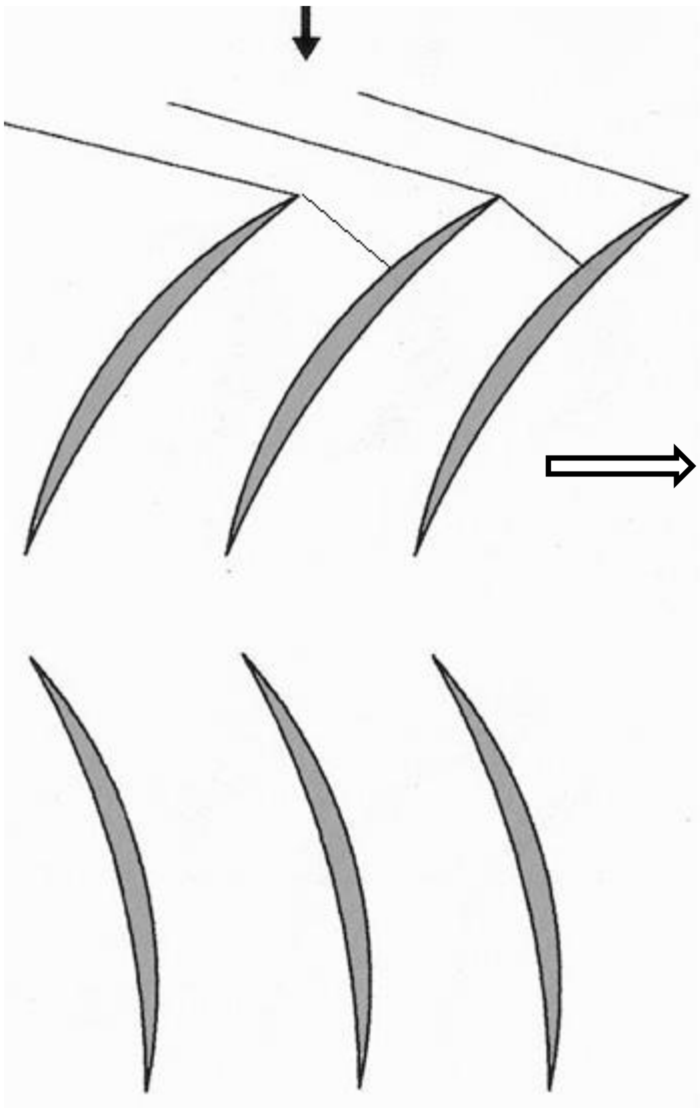
- Alternately, the flow may transit from subsonic to supersonic or from supersonic to subsonic in passing through the blade passage in chord wise direction

- In axial passage the flow may transit from supersonic in rotor to subsonic in stator, or vice versa



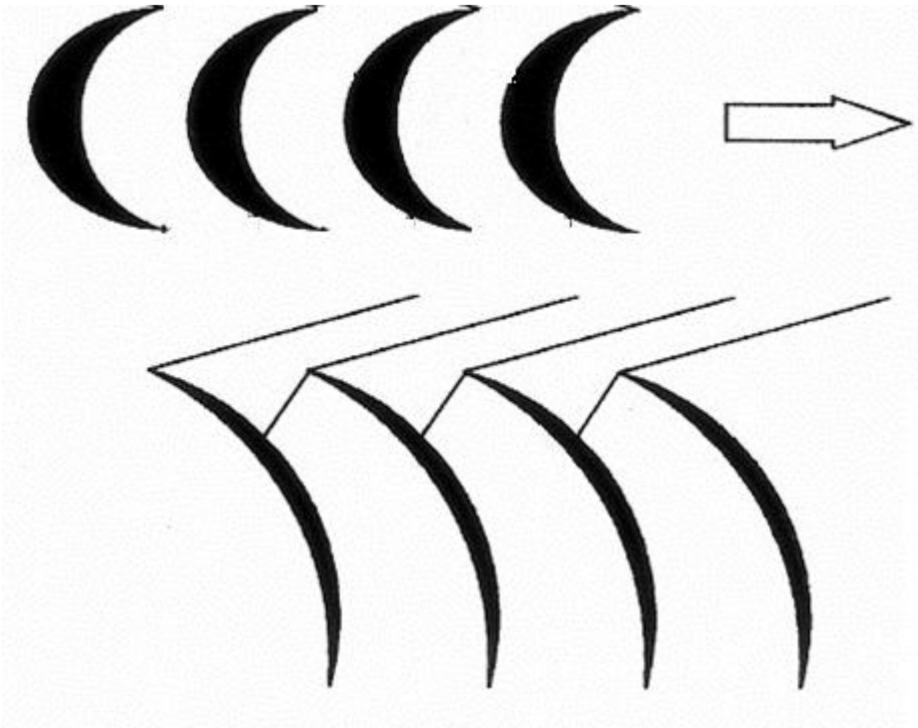
Normally a transonic compressor has either V_1 or C_2 supersonic

V_1 or C_2 may be supersonic at tip or at many sections of the blade



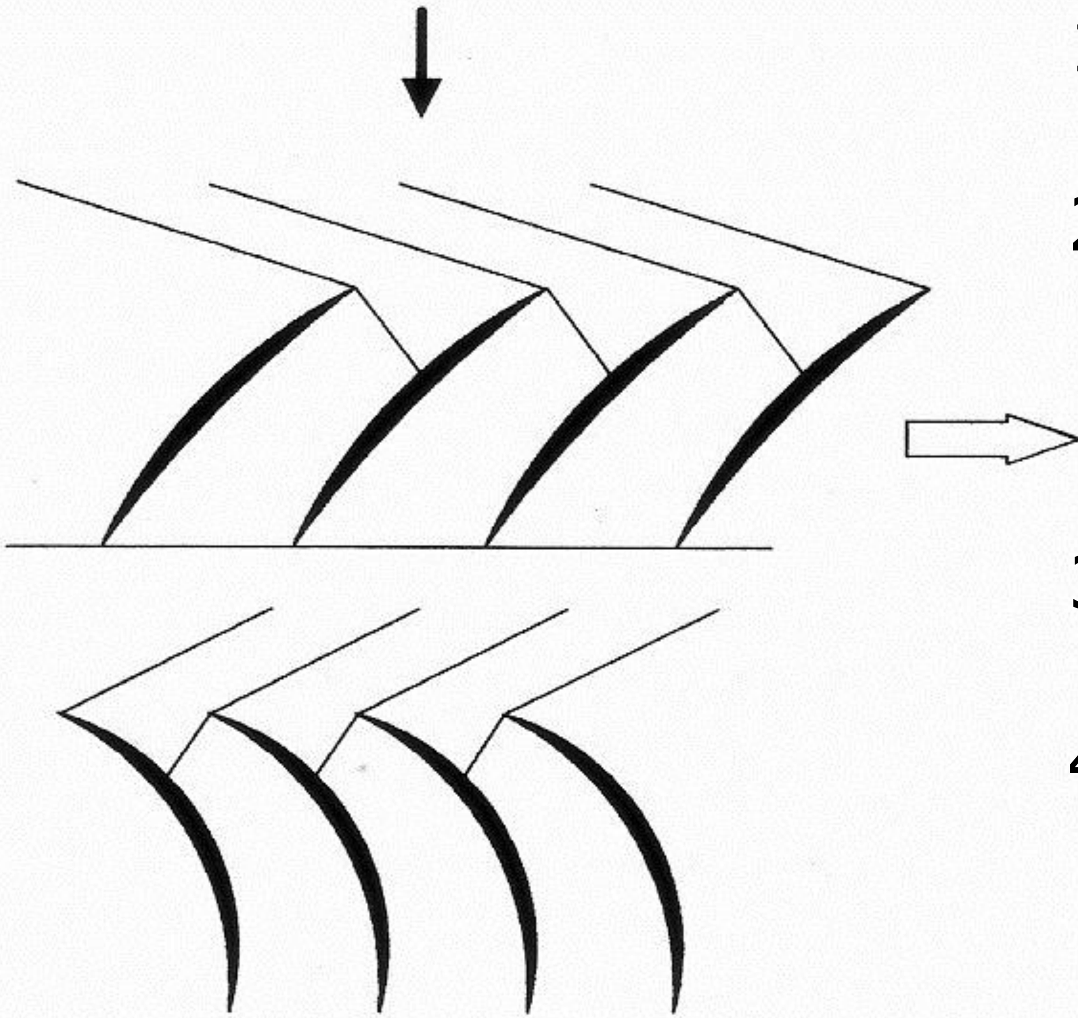
Shock-in-rotor.

1. Supersonic flow enters the rotor.
2. Shock is contained within the rotor blade and leaves the rotor subsonically
3. Flow in the stator is subsonic



Shock-in-stator.

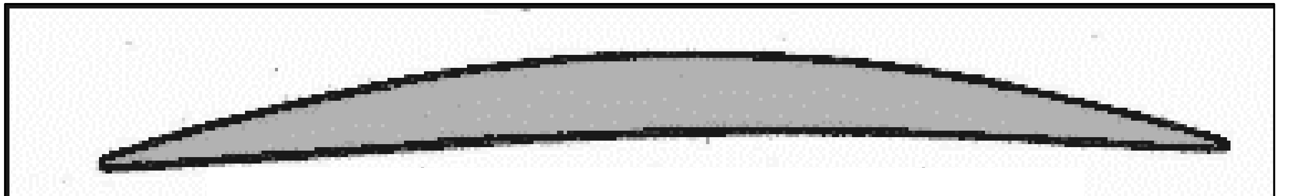
1. Rotor performs a large flow turning "subsonically"
2. Very large energy transfer in rotor
3. Rotor exit flow has large K.E.
4. Large diffusion needs to be done in the stator
5. Thus, stator needs to be supersonic



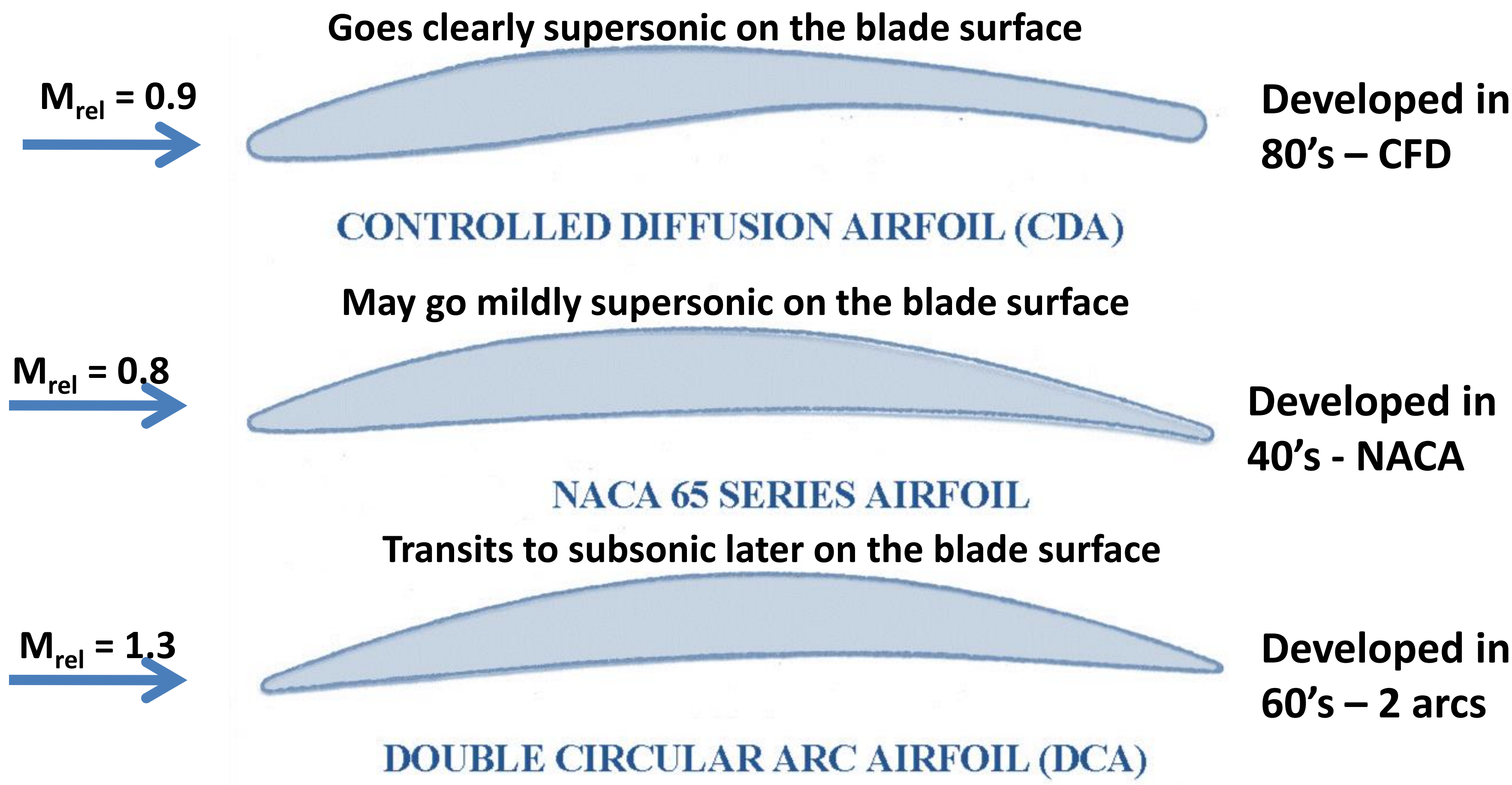
Shock-in-rotor/shock-in-stator.

1. High stage performance
2. Flow enter both rotor and stator supersonically
3. And exit subsonically
4. Both rotor and stator blades are highly loaded

- To utilize supersonic entry flow in a controlled manner, new airfoils needed to be developed.
- Airfoils with sharp leading edges are ruled out due to requirements at off-design operations
- Controlled supersonic diffusion followed by subsonic diffusion, enable transonic compressors to achieve higher compression ratios



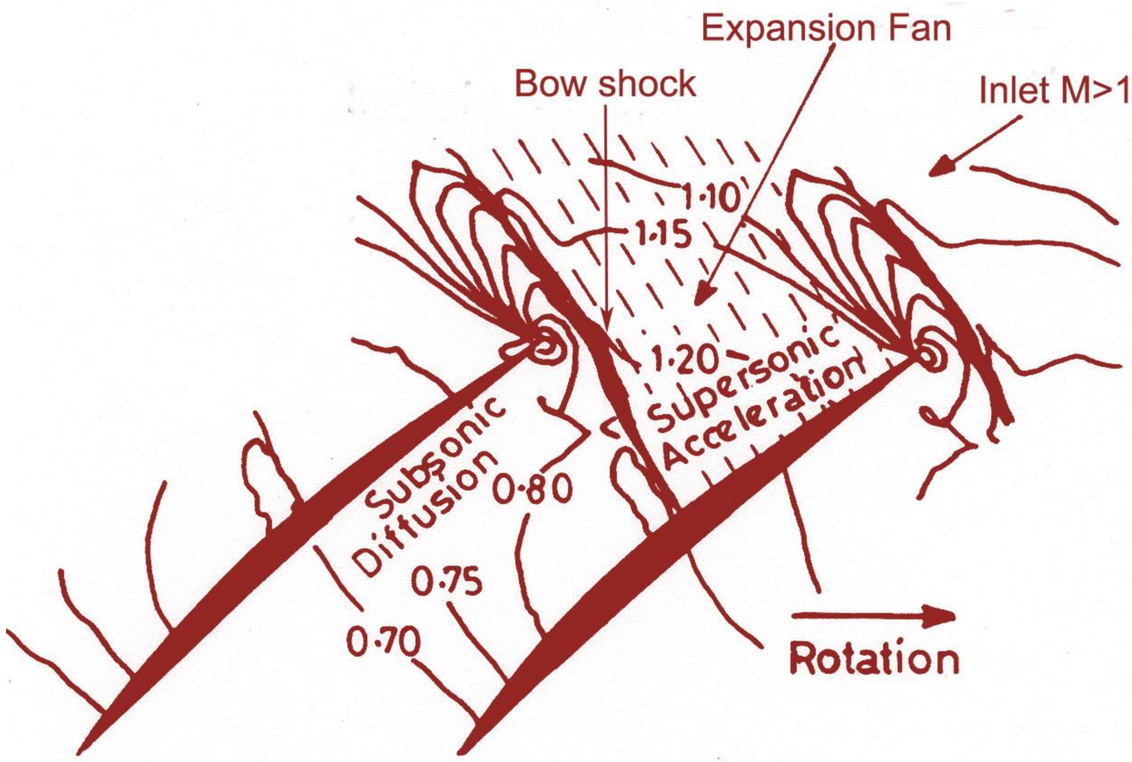
Double Circular Arc Airfoil



Transonic airfoils for axial compressor

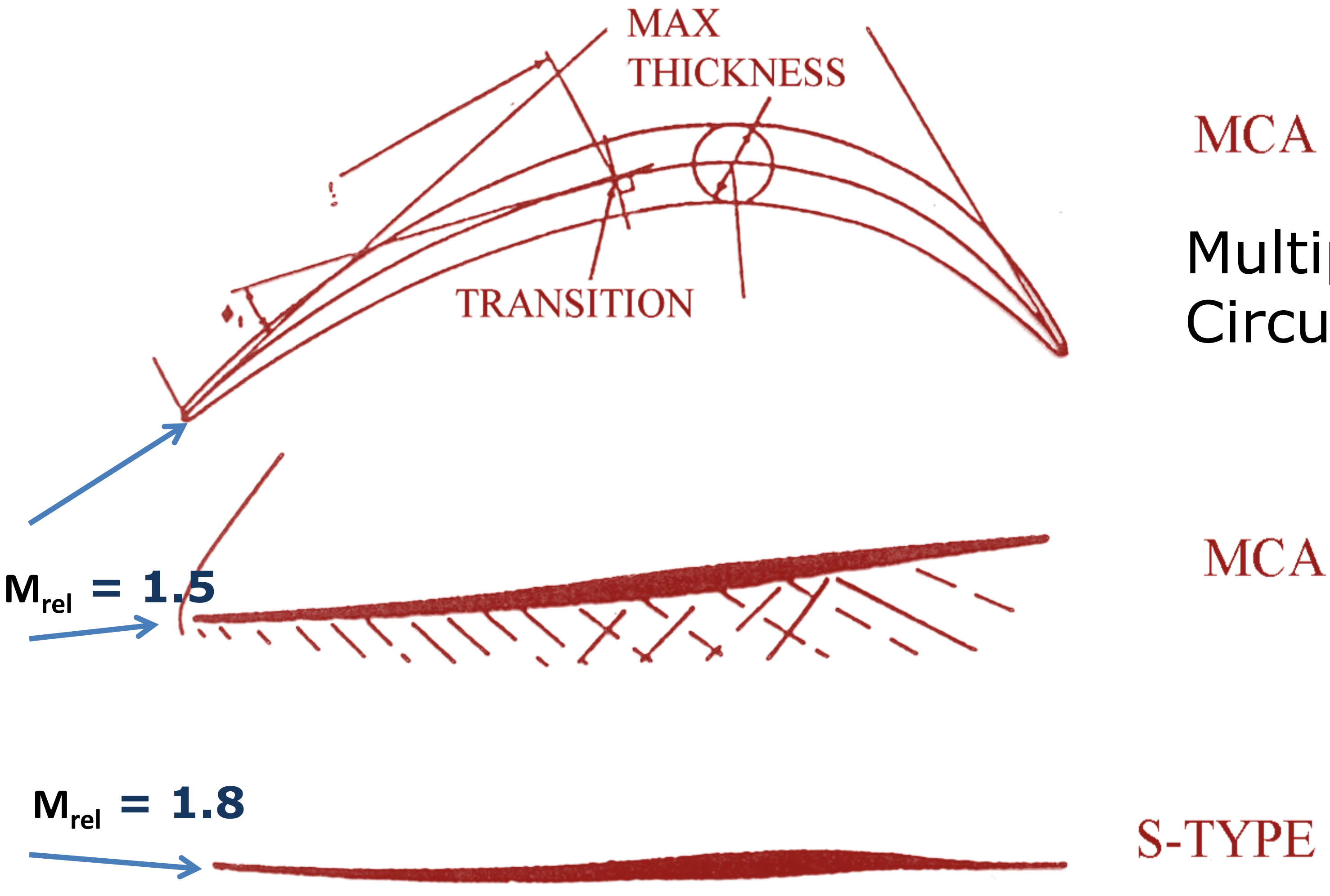
CDA Blades :

- *Controlled Diffusion Airfoil* (CDA) was conceptually derived from supercritical airfoils, first used in aircraft wings in the 60’s. The CDA were created in the 80’s using the established CFD techniques.
- Velocity or C_p distribution on the blade was predetermined to arrive at a 2-D cascade for smooth transition from subsonic-to- supersonic-to-subsonic flow for the minimum loss and maximum diffusion and optimized camber.
- CDA blades are also referred to as *wide chord blades*. Longer chord allows the diffusion control.



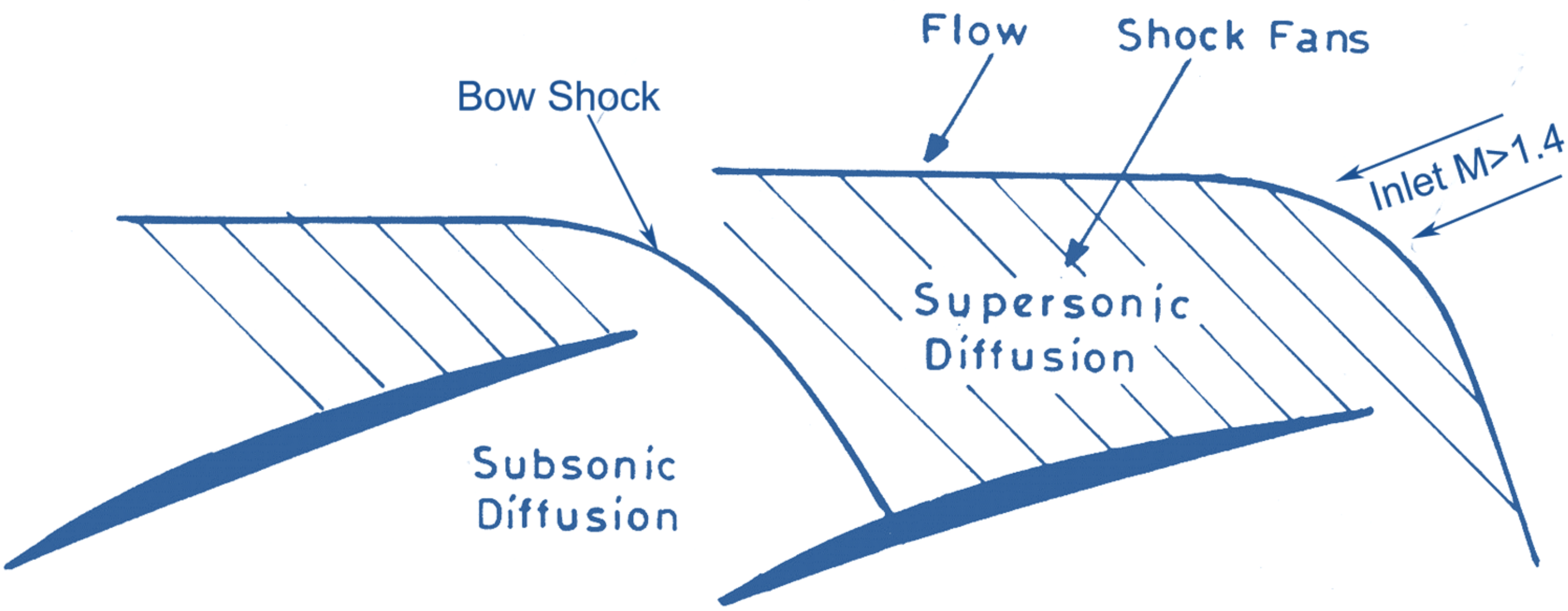
DCA blades

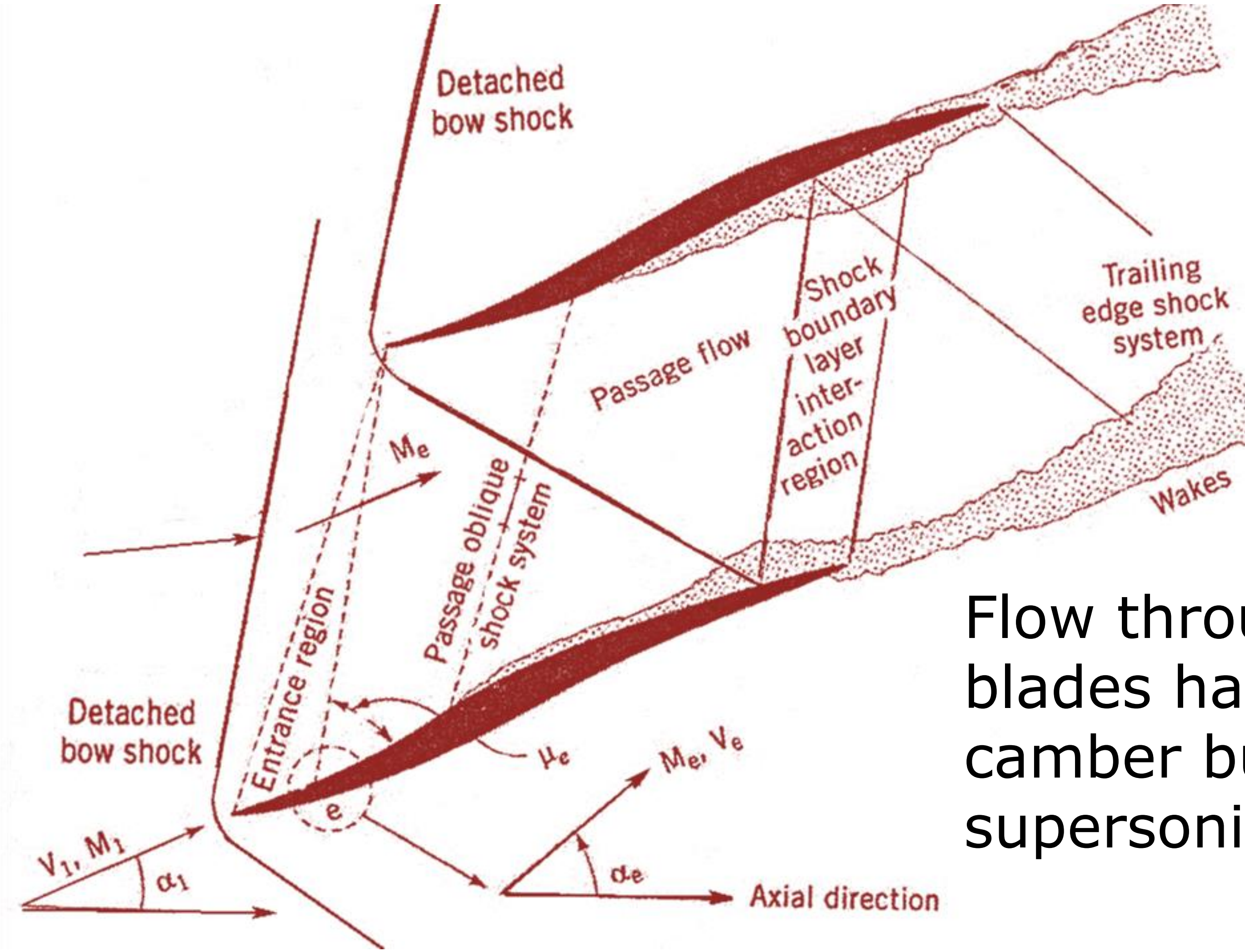
Flow through a transonic blading would diffuse through the shocks before further diffusing and exiting as subsonic flow



Multiple Circular Arc

Shocks in MCA blades





Flow through S-type blades has minimal camber but high supersonic diffusion

Common features of the shock structures

- Shock models allow designers to carry out detailed performance prediction of axial compressors
- The rounded L.E. creates a *detached bow shock*, which stands in front of the row of blades
- One leg of the bow shock bends inside and stands across the blade passage, could act as a terminal normal shock (*passage shock)*. The other leg goes outward approximately parallel to the face of the blade row, and is considered an oblique shock .
- The *stand off distance* is decided by the L.E radius and the entry Mach number of the flow. The shape of the bow shock is decided by the shape of the profiles and the incident Mach number.

DCA Blades:

- At low supersonic Mach number (<1.4) the flow *supersonically accelerates* through a series of expansion fans after the front oblique shock and transits to subsonic through the passage shock.

- According to the model used, the shock diffusion and the supersonic expansion are approximately equal to each other and the flow regains its original entry Mach number in front of the normal shock.

- Flow parameters to be estimated across the passage shock using the normal shock theories

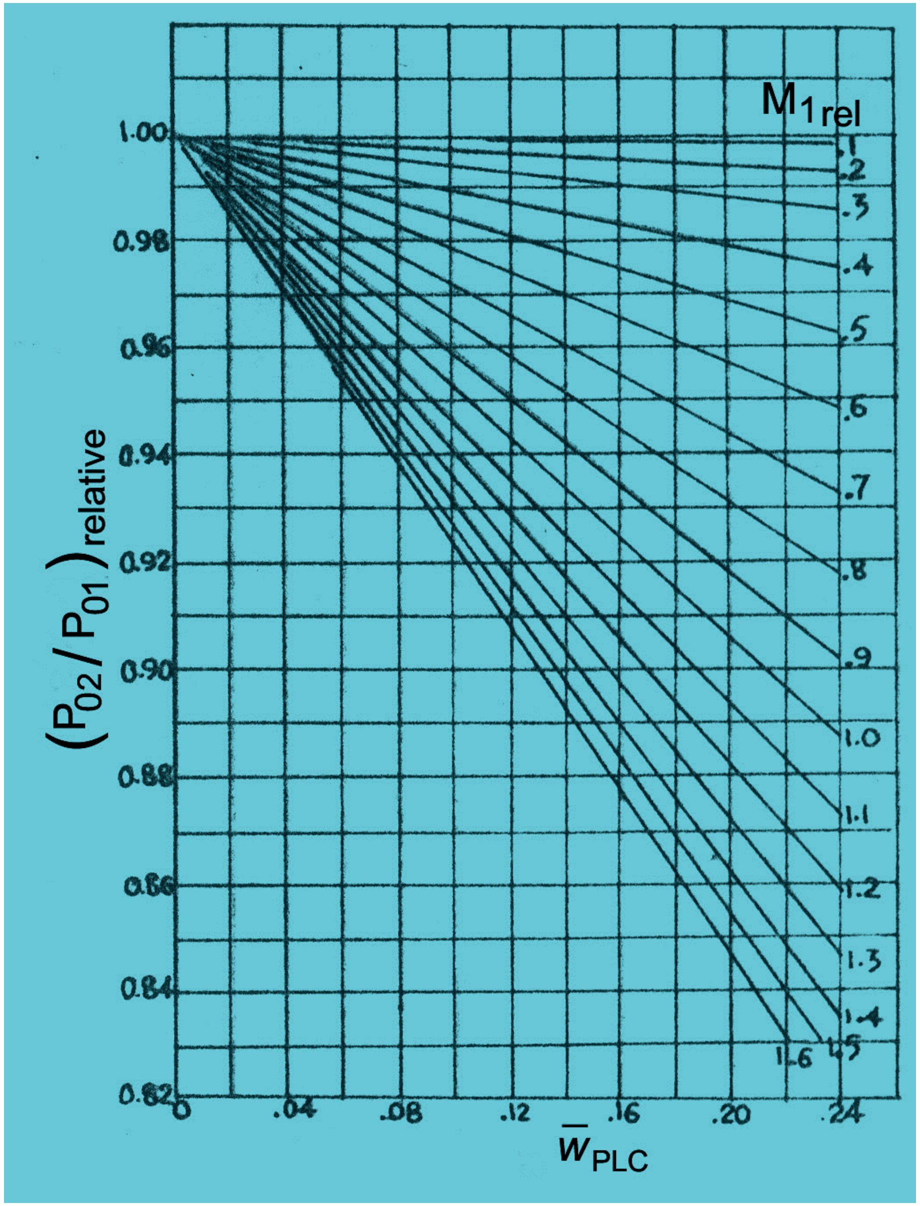
MCA Blades :

- MCA blades are used for compressors / fans with low solidity and higher Mach number (>1.4).
- This shape was created for greater control of the blade profile by using multiple arcs.
- These blade shapes create a bow shock.
- These MCA blades, used near the tips, are set at high stagger, due to which the inflow experiences a mildly converging (virtual) passage. The suction surface of the blade is convexly curved resulting in a series of mild shock fans.
- The entry flow through the shock fans is, thus, supersonically diffused till the passage shock , through which it finally becomes subsonic.

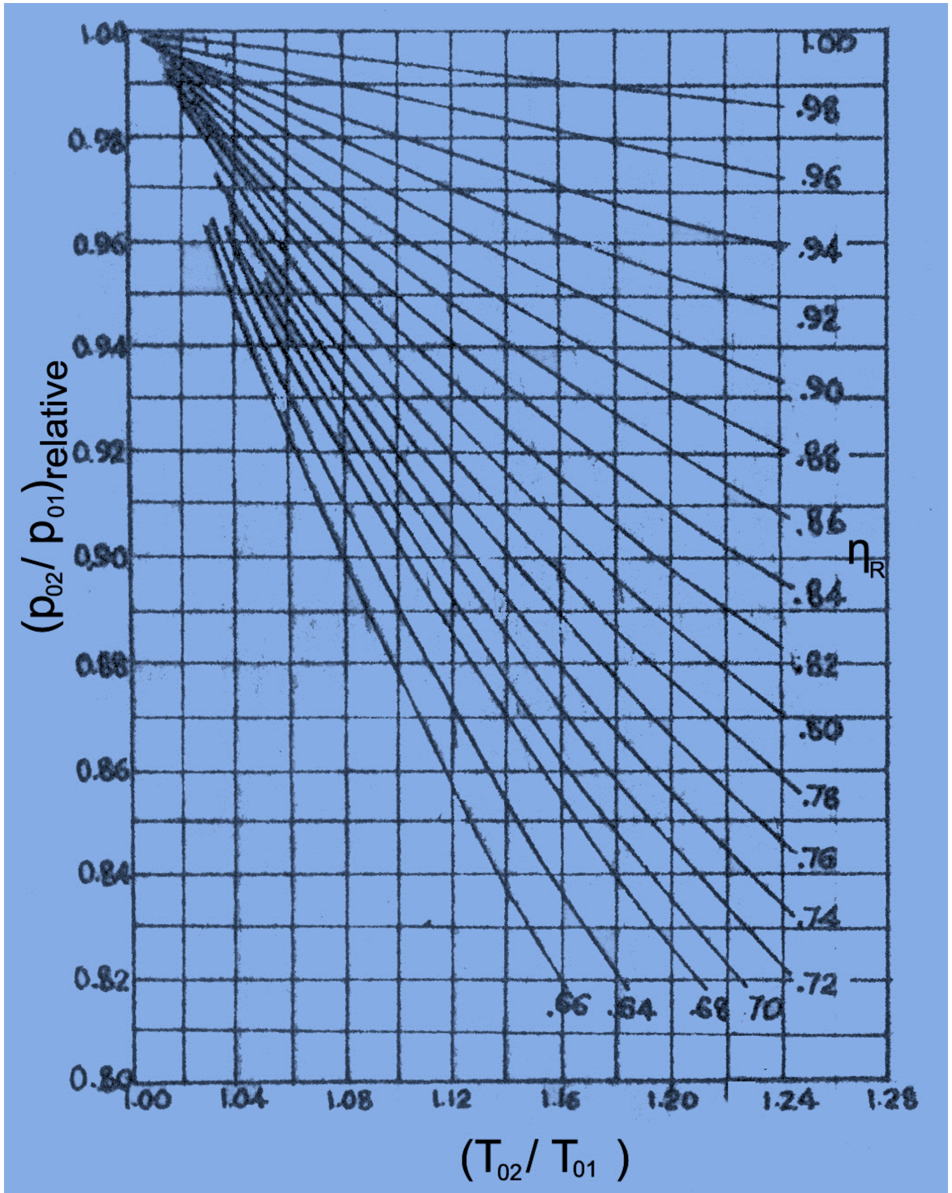
S-type Blades:

- In S-type (MCA) blades the inflow Mach number is higher (M>1.6) and the bow shock goes further inside the passage and hits the next blade near its trailing edge.

- This results in a longer supersonic diffusion flow through the passage in S-type blades. Most of the diffusion is then conducted supersonically, and a small amount of subsonic diffusion is done after the passage shock



- The rotor loses are measured in relative frame of reference and thus relative total pressure ratio gives a measure of the losses in the rotor.
- Rotor or stage maps (characteristics) of transonic compressors are much sharper and are more sensitive to inflow characteristics



When a designer tries to maximize the absolute total pressure ratio by increasing the total temperature ratio, the relative total pressure ratio falls, depending on the design point efficiency chosen based on state of art of design capability available at hand.

Fan blade with a part-span snubber