TURBOMACHINERY AERODYNAMICS

Lect - 16

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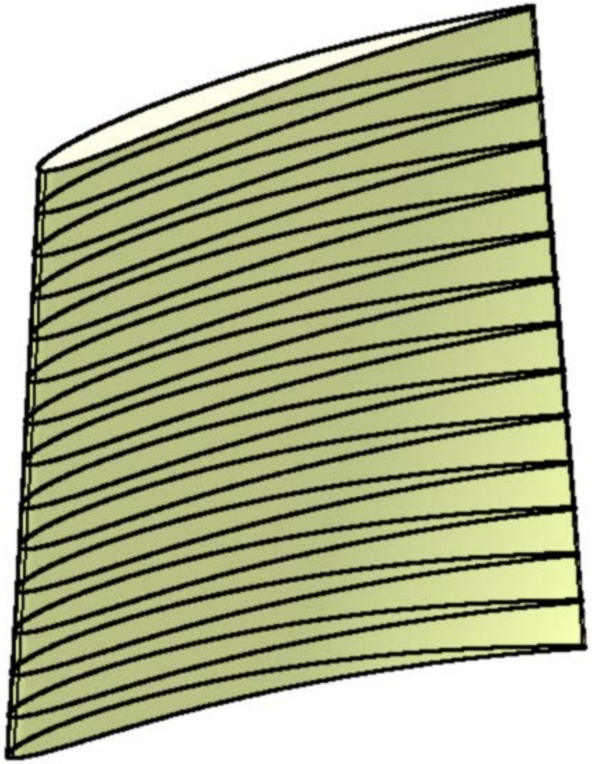
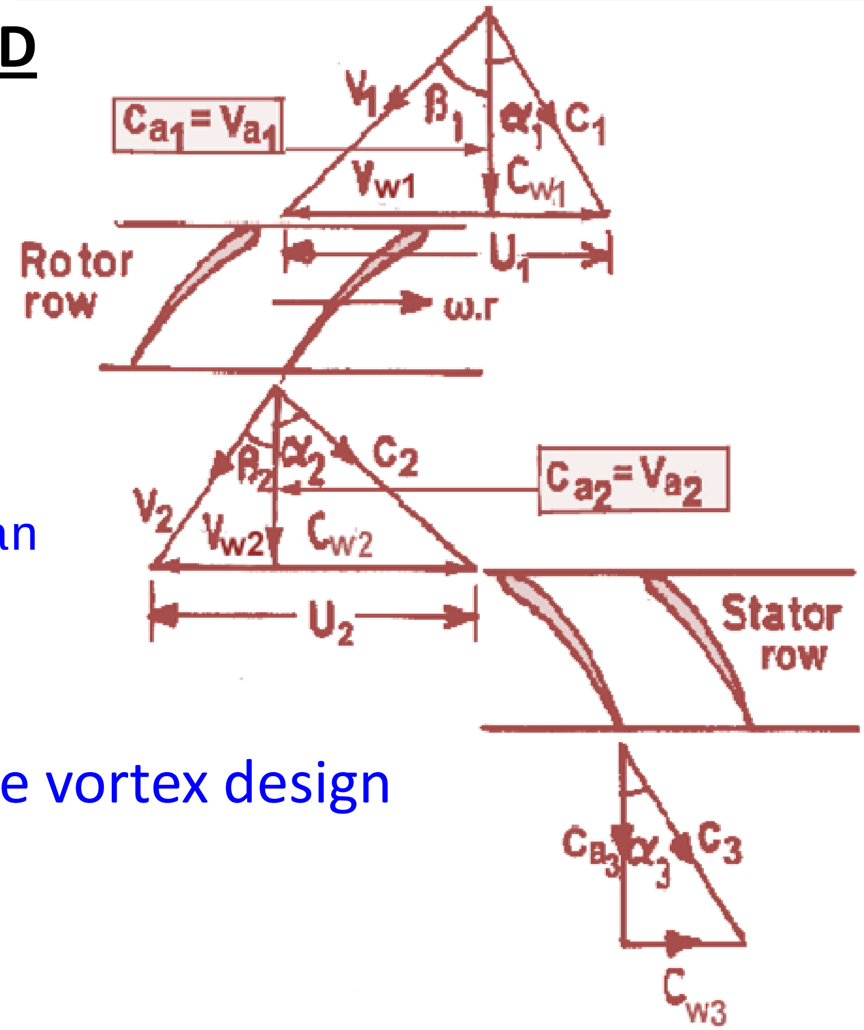
Aerodynamic Design of Axial Compressor

---------------- Blade design Procedure



INDIVIUAL STAGE DESIGN METHOD



Ideal Work Required

$$W_{th} = (C_{w1} - C_{w2})\ U_m$$

$$C_{wm} = \frac{C_{w1} + C_{w2}}{2}$$ At Mean

$$C_{wm}.r = const$$ For free vortex design

$$C_{w,1-r} = C_{w,1m} \cdot \left(\frac{r_m}{r} \right)$$

INDIVIUAL STAGE DESIGN METHOD

$$C_{1-r} = \sqrt{\left(C_{a,1r}^{2} + C_{w,1r}^{2}\right)}$$

Absolute Vel

$$\alpha_{1,r} = \sin^{-1}\left(\frac{C_{w.1r}}{C_{1,r}}\right) = \cos^{-1}\left(\frac{C_{a,1r}}{C_{1,r}}\right)$$

Absolute Angle

$$U_{1,r} = U_{1,m} \cdot \left(\frac{r_1}{r_m}\right)$$

Blade Speed

$$\beta_{1,r} = \tan^{-1}\left(\frac{\left(U_{1,r} - C_{w,1r}\right)}{C_{a,1r}}\right)$$

Relative Angle

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$$V_{1,r} = \left(\frac{C_{1,a}}{\cos\beta_{1,r}} \right)$$

Relative Vel

$$U_{2,r} = U_{2,m} \cdot \left(\frac{r_2}{r_{2,m}} \right)$$

If, d_m = constant, $U_{1,m} = U_{2,m}$

$$C_{w,2r} = C_{w,2m} \cdot \left(\frac{r_{2m}}{r} \right)$$

Check $DR = 1 - \left(\frac{C_{w,rm}}{2.U.r_m} \right)$

Degree of Reaction, Rx should never be zero anywhere on the rotor blade

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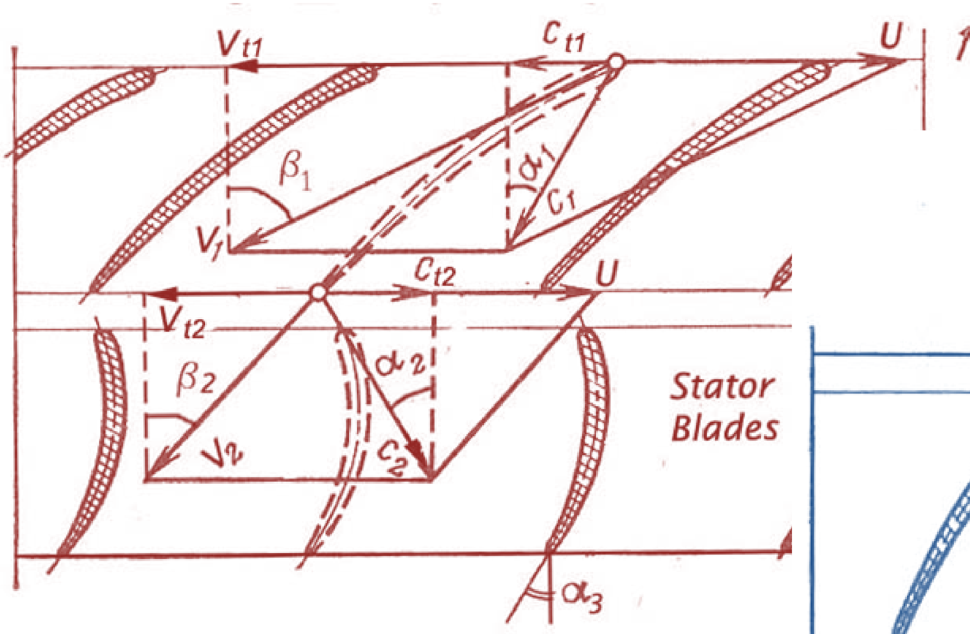
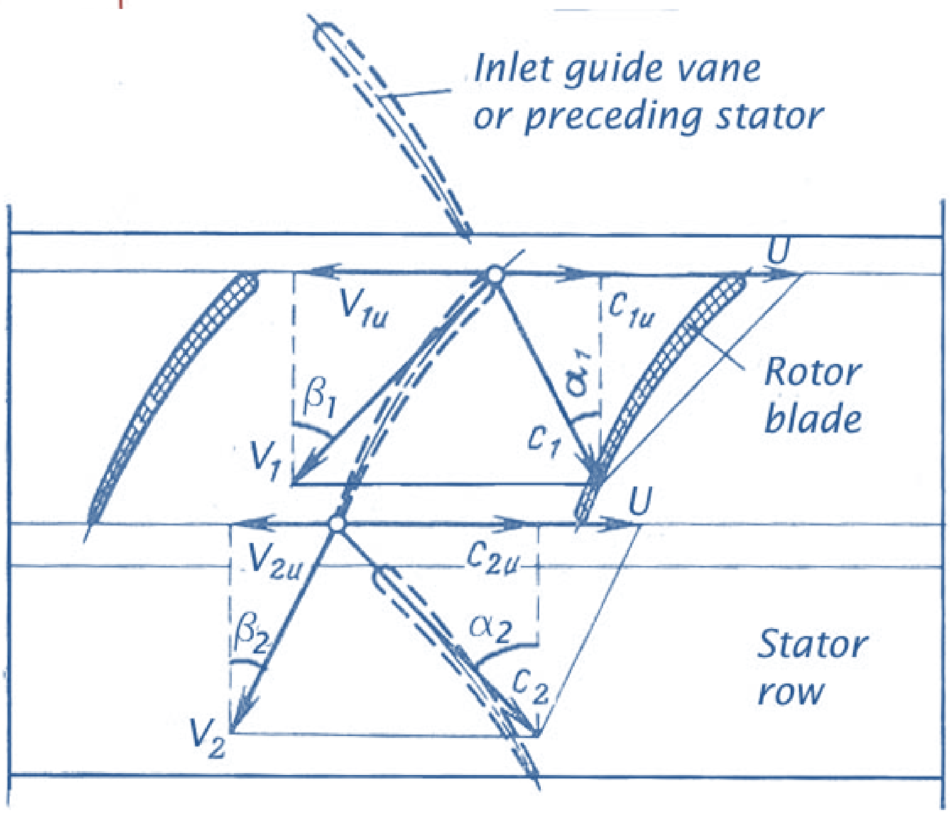
INDIVIUAL STAGE DESIGN METHOD

Degree of Reaction



100% reaction blade



50% reaction blade

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$$C_{a,2r} = C_{a,m} = const$$

or assume a value for

$$AVDR = C_{a1}.\rho_1 / C_{a2}.\rho_2 \approx 1.0$$

$V_2 < V_1 \rightarrow$ Generally accepted

$V_2 = V_1 \rightarrow$ Rarely Used

$V_2 > V_1 \rightarrow$ transonic fan design – possibility

$$\alpha_{2,r} = \tan^{-1}\left(\frac{C_{w,2r}}{C_{a,2r}}\right)$$

$$\beta_{2,r} = \tan^{-1}\left(\frac{\left(U_{2,r} - C_{w,2r}\right)}{C_{a,2r}}\right)$$

$$\Delta\beta = \beta_{2,r} - \beta_{1,r}$$

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INDIVIUAL STAGE DESIGN METHOD

$$V_{2,r} = \left(\frac{C_{a,2r}}{\cos\beta_{2,r}} \right)$$

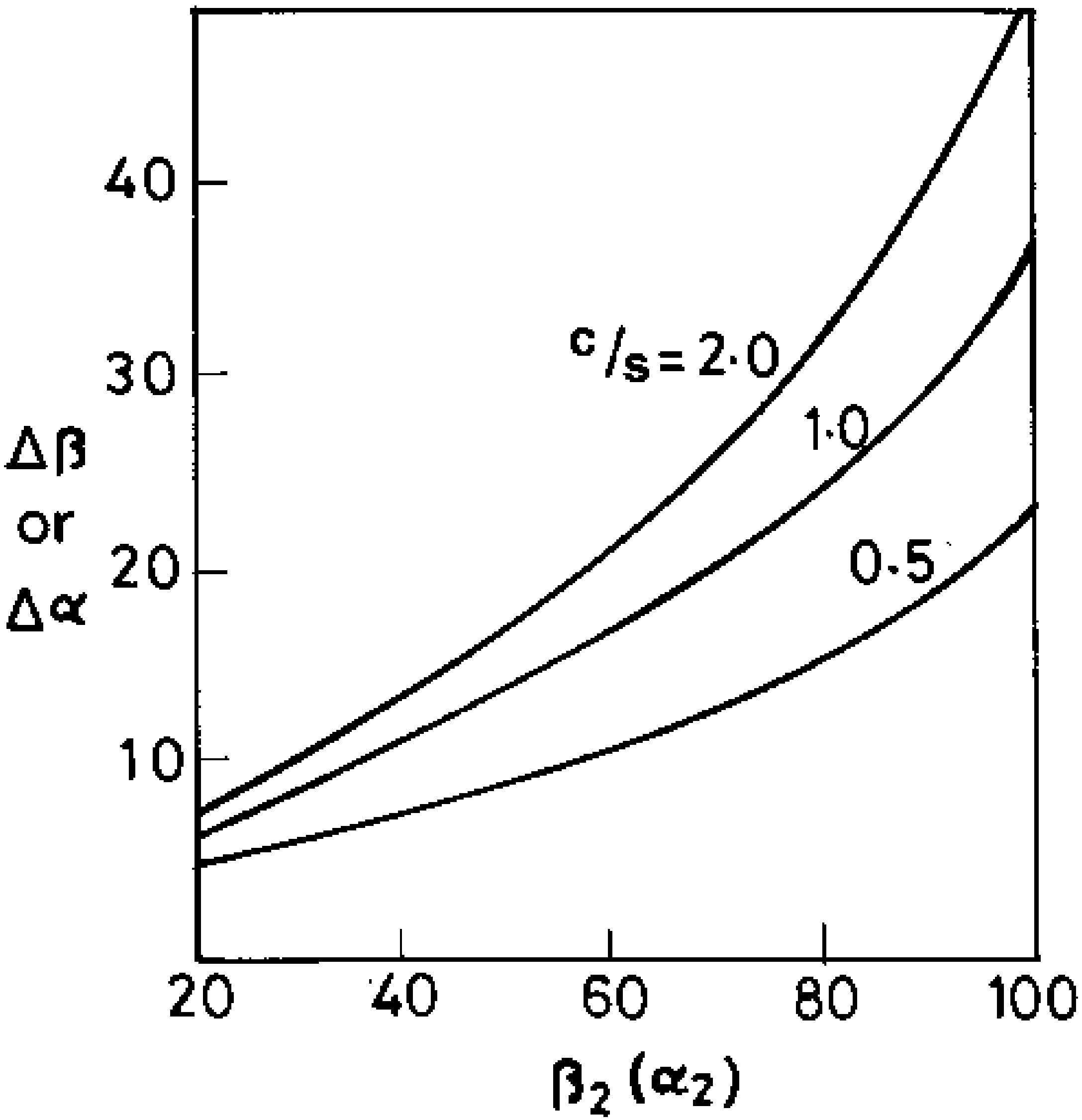
$$\Delta\beta = \beta_{2,r} - \beta_{1,r}$$ -> Flow Turning Angle

Provide angle of incidence, i_r at design point

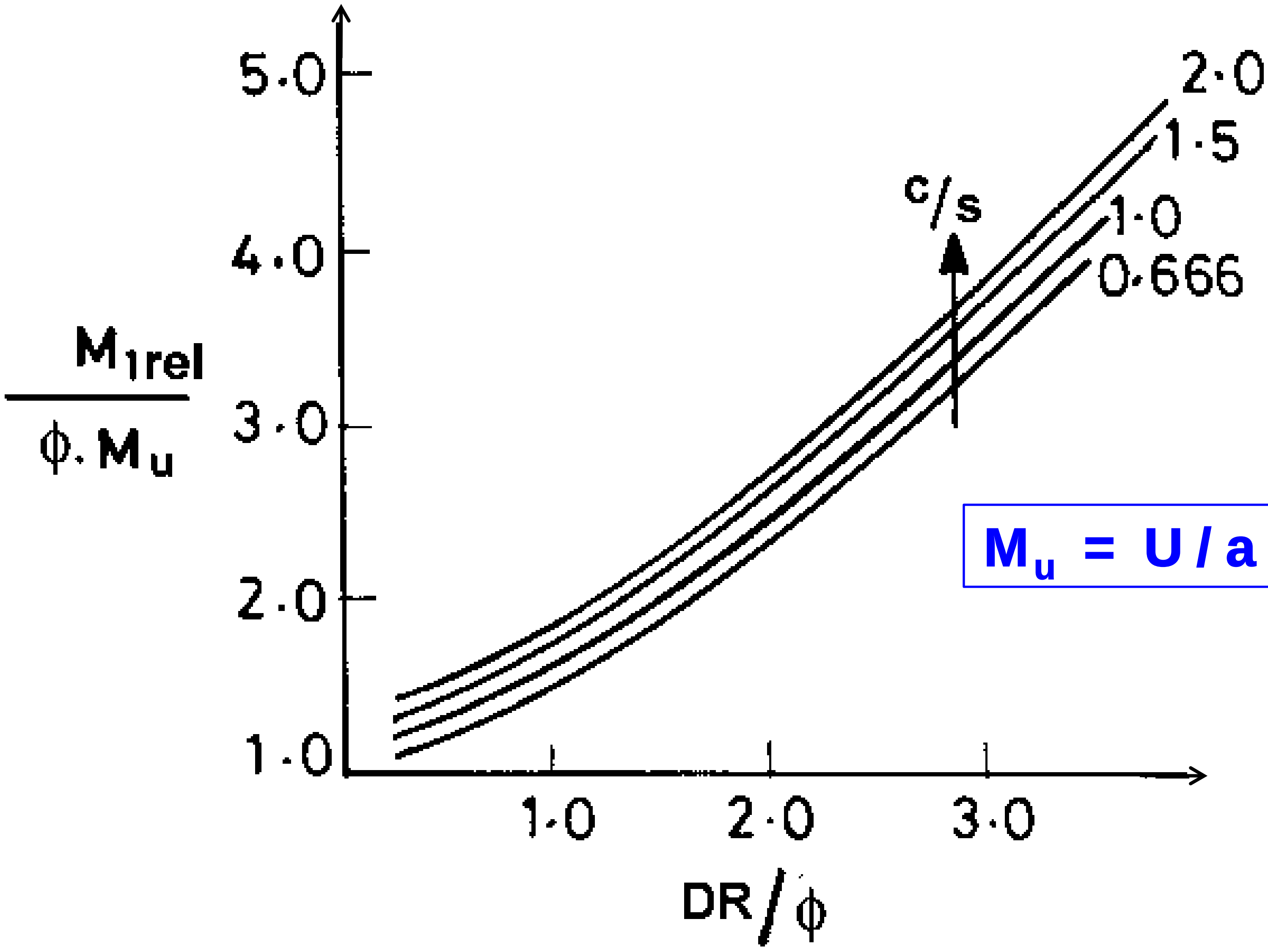
Usually, $i_{tip} = -(1^o \text{ to } 2^o)$ and

$i_{root} = +(1^o \text{ to } 2^o)$

Need to choose solidity of the blade section



c/s = σ, solidity



$M_u = U / a$

INDIVIUAL STAGE DESIGN METHOD

$$\beta'_{1,r} = \beta_{1,r} + i_r$$

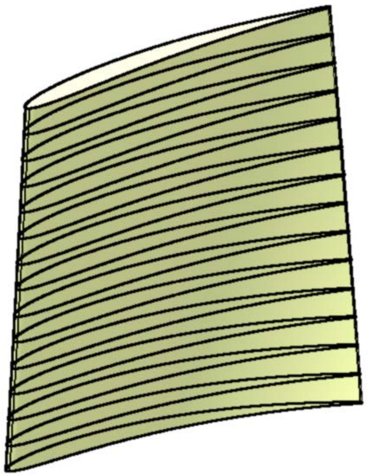
$$\beta'_{2,r} = \beta_{2,r} - \delta^{*}_{r}$$

(Carter's deviation – valid at design point)

At any radius

Deviation, $\delta^{*}_{r} = \beta'_{2,r} - \beta_{2,r} = m_r\,.\,\theta.\sqrt{\frac{s}{c}}$

Blade camber angle at any blade element



$$\theta_r = \beta'_{2,r} - \beta'_{1,r} = \frac{\Delta\beta - i_r}{1 + m_r\sqrt{\frac{s}{c}}}$$

Where,

$$m = 0.23\left(2 * \frac{a_i}{c_i}\right)^2 + 0.1\left(\frac{90^{\circ}\beta_{2,r}}{50}\right)$$

$$\frac{a_i}{c_i} = 0.4 \text{ to } 0.5$$

1. Degree of reaction vary along the radius depending on the law of profile and its values change from 0 to 0.2 at the root to 0.8 to 1 at the tip.

2. There are certain other parameters that affect the dynamics of flow. These geometrical parameters are:-

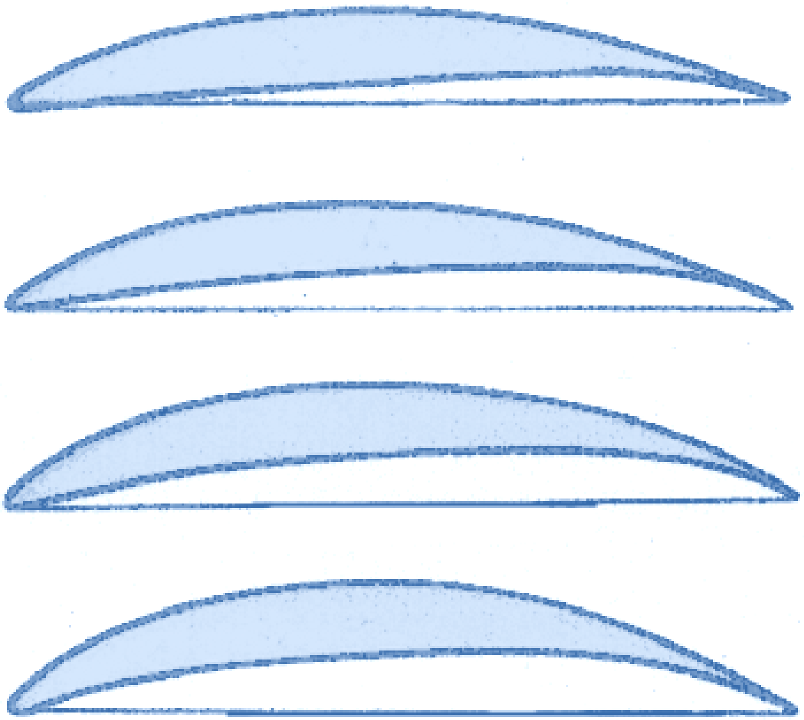
Degree of divergence, θ_D

Flow turning angle, $\Delta\beta$

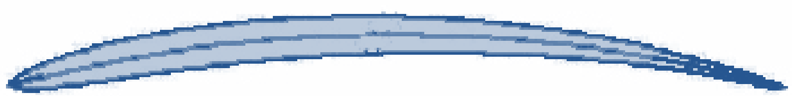
Blade solidity, c/s

These three are connected by

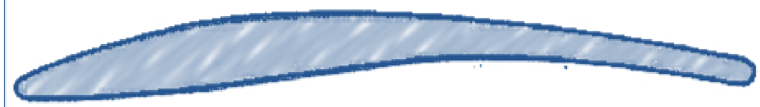
$$\theta_D = \frac{180}{\pi}\frac{c}{h_c}\times\frac{\cos(\beta_1 + \Delta\beta) - \cos\beta_1}{c/s}$$



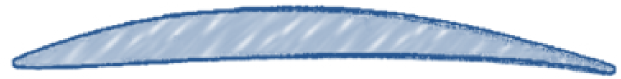
NACA 65 - series



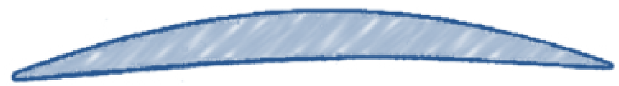
C4 Airfoil



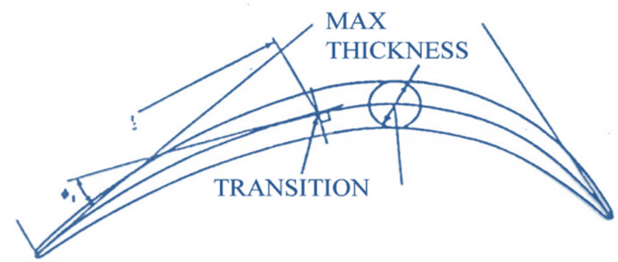
CONTROLLED DIFFUSION AIRFOIL (CDA)



NACA 65 SERIES AIRFOIL



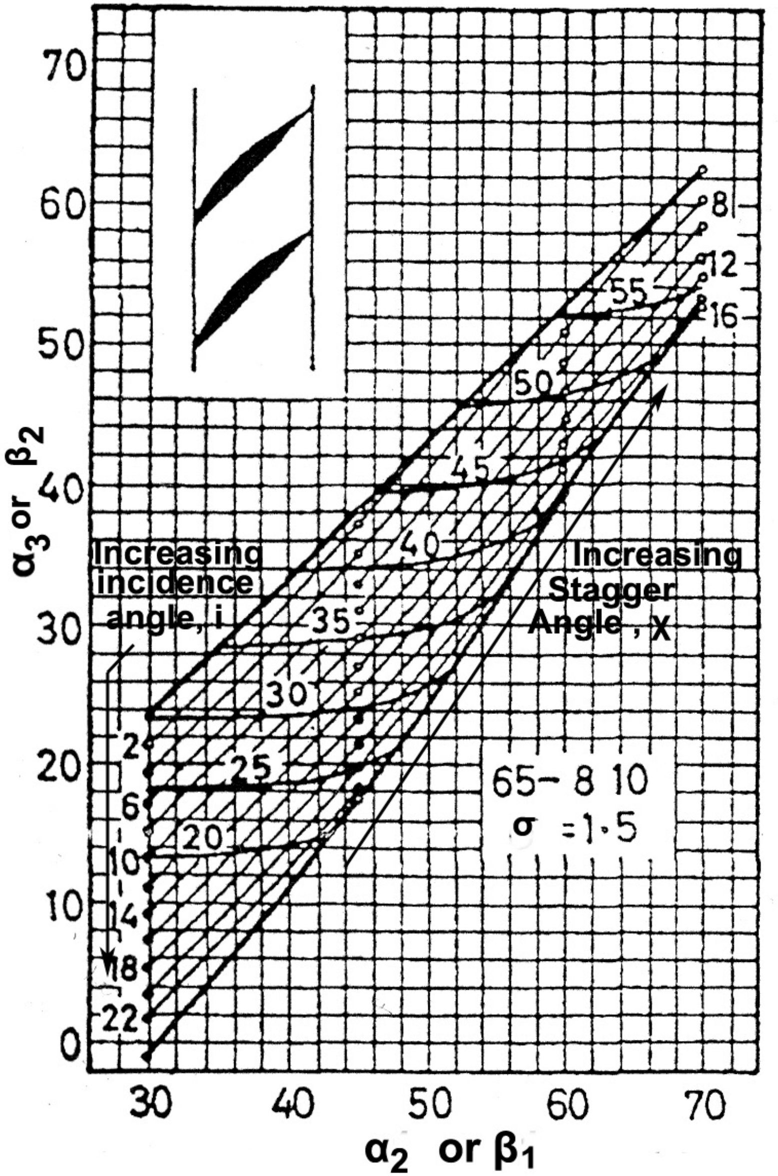
DOUBLE CIRCULAR ARC AIRFOIL (DCA)



MCA

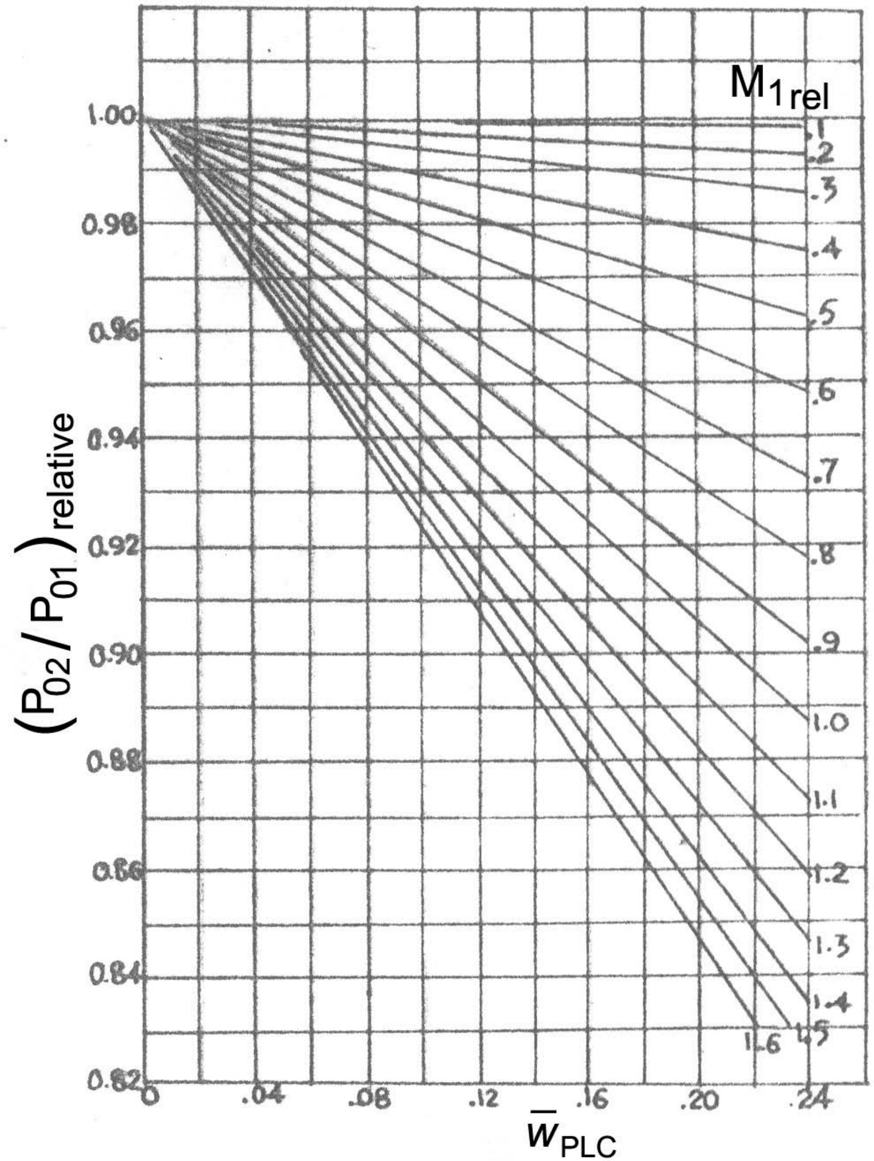
MCA

S-TYPE



65-Series Airfoil Data in percentage chord

	Camber definition for $C_{L_0} = 1$		NACA 65-010
x	y_c	dy_c/dx	$\pm y_t$
0	0	-------	0
.5	.250	0.42120	.772
.75	.350	.38875	.932
1.25	.535	.34770	1.169
2.5	.930	.29155	1.574
5.0	1.580	.23430	2.177
7.5	2.120	.19995	2.647
10	2.585	.17485	3.040
15	3.365	.13805	3.666
20	3.980	.11030	4.143
25	4.475	.08745	4.503
30	4.860	.06745	4.760
35	5.150	.04925	4.924
40	5.355	.03225	4.996
45	5.475	.01595	4.963
50	5.515	0	4.812
55	5.475	−.01595	4.530
60	5.355	−.03225	4.146
65	5.150	−.04925	3.682
70	4.860	−.06745	3.156
75	4.475	−.08745	2.584
80	3.980	−.11030	1.987
85	3.365	−.13805	1.385
90	2.585	−.17485	.810
95	1.580	−.23430	.306
100	0	-------	0
		LE rad.	.687



Transonic Compressor Basic Characteristics

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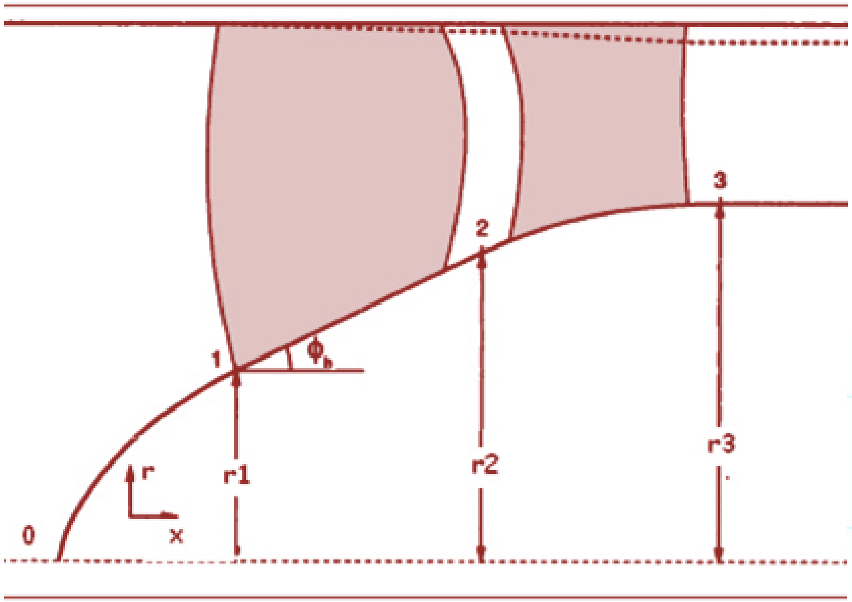
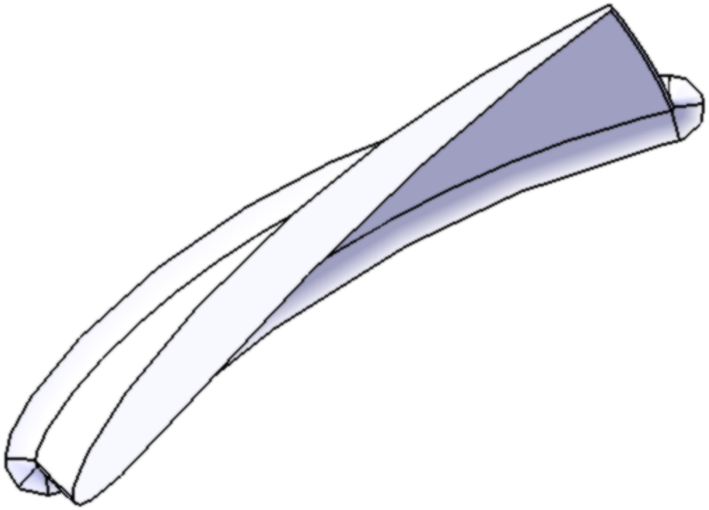
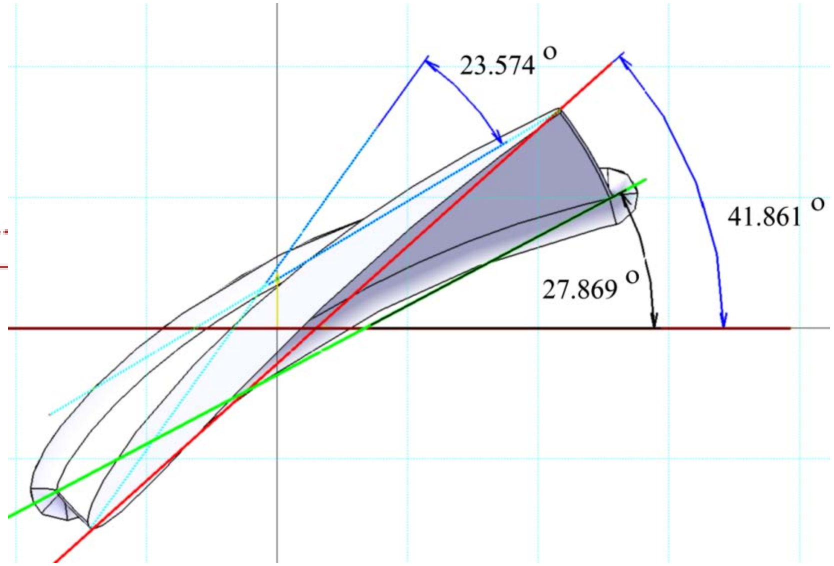
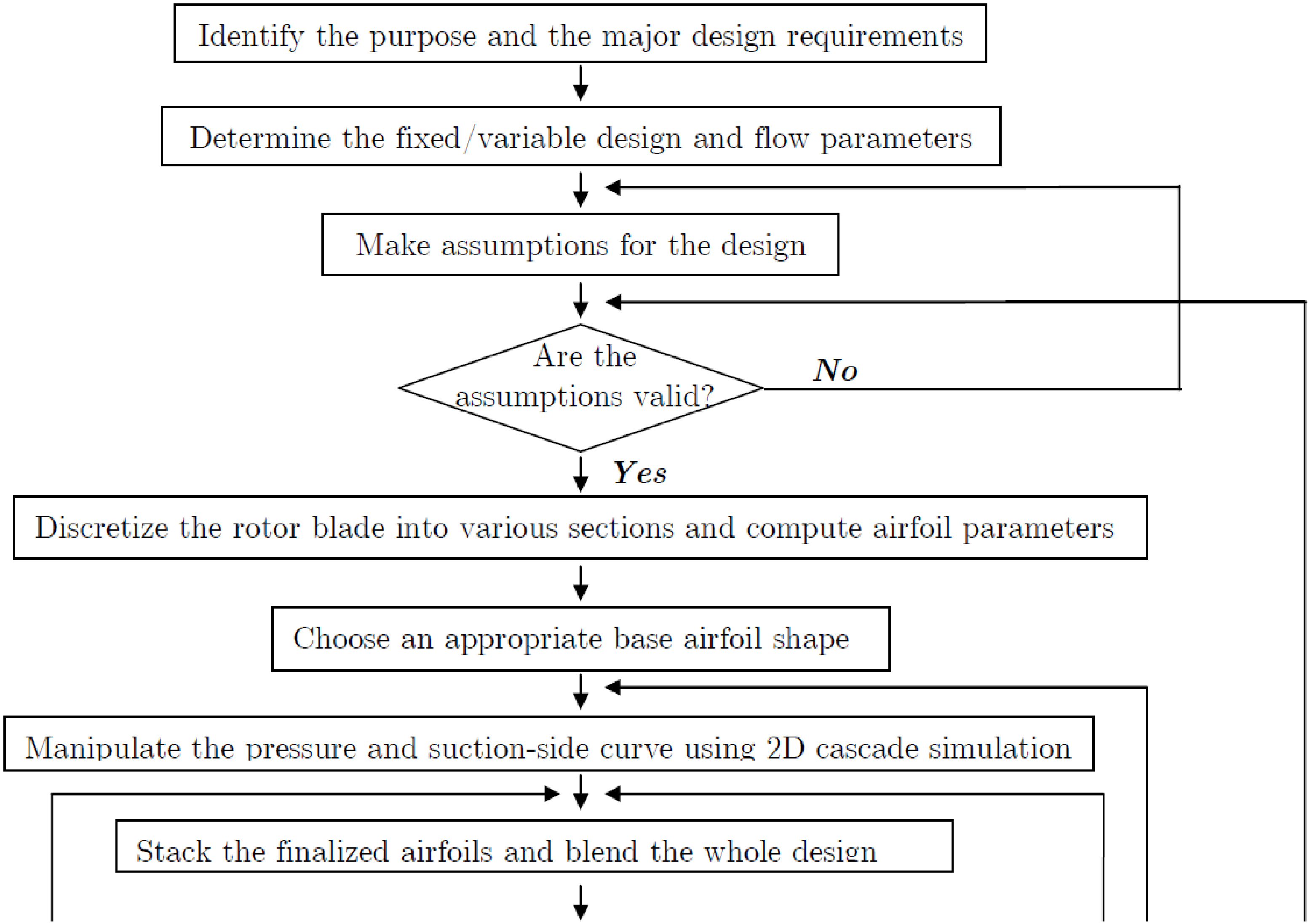
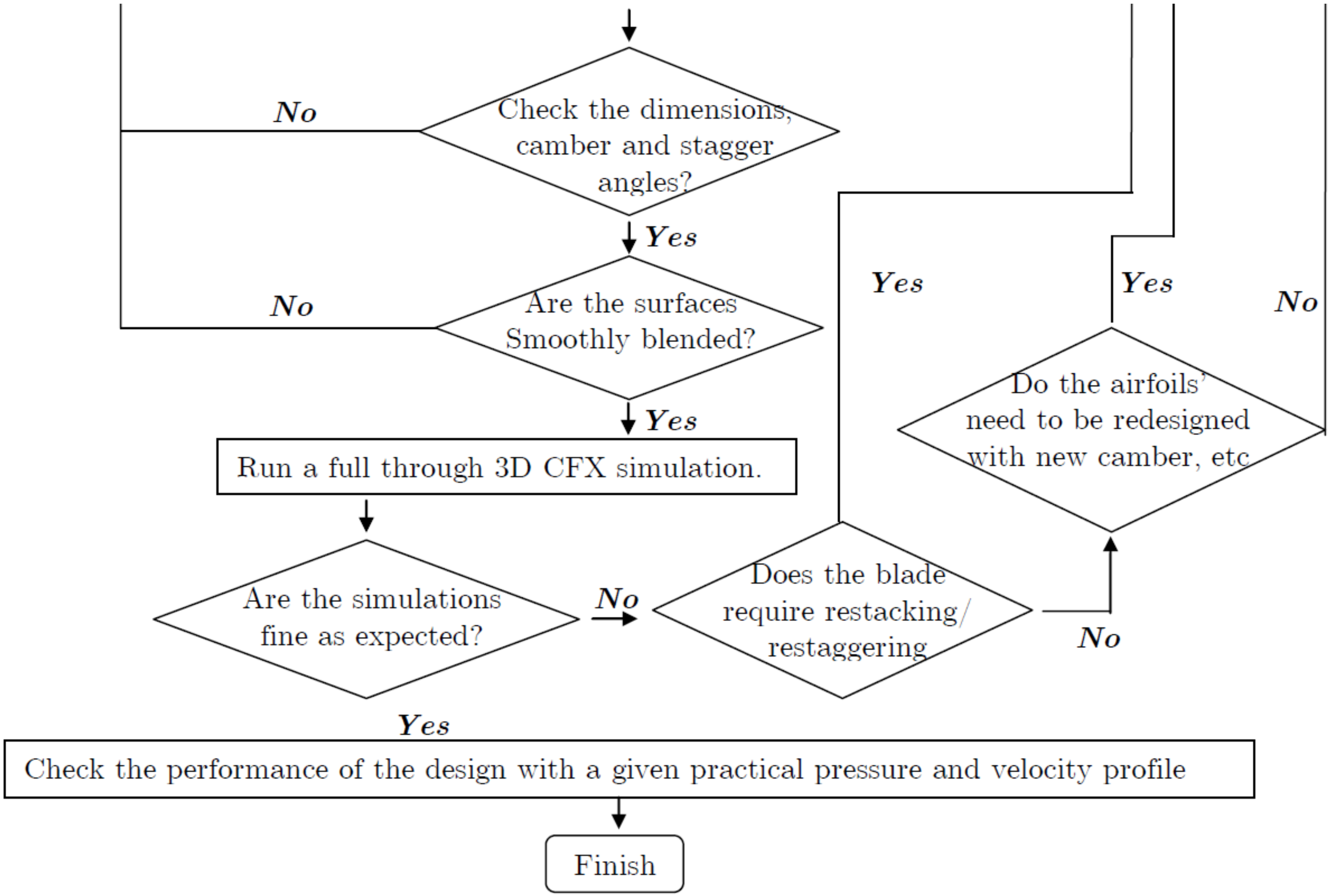
3-D Blade Shapes








Identify the purpose and the major design requirements
Determine the fixed/variable design and flow parameters
Make assumptions for the design
Are the assumptions valid?
No
Yes
Discretize the rotor blade into various sections and compute airfoil parameters
Choose an appropriate base airfoil shape
Manipulate the pressure and suction-side curve using 2D cascade simulation
Stack the finalized airfoils and blend the whole design



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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.