TURBOMACHINERY AERODYNAMICS

Lect 17

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Axial Compressor Design

3-D Blade Shapes

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- Standard axial compressor rotor blade design is done with a vortex law as guiding principle
- Such designs normally use airfoils picked from cascade data available with the designers
- Such designs normally produce twisted blade
- Such blades normally have a flat tip
- These designs often have strong secondary flow characteristics , inspite of applying radial equilibrium condition for blade design.

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Design of Axial Fan

For driving the flow

Mean line design: In-flow and out-flow parameters (C_a, C_w, α, β) at the mean diameter

Free Vortex design: Radial variation of in-flow and out-flow parameters enables hub to tip design

- $$C_w = C_{wm} \times r_m / r$$

Initial Specifications:	
mass flow rate (kg/sec)	8
N (rpm)	2400
ΔP_0 (Pa)	1000
Tip Diameter (m)	0.496
Hub Diameter (m)	0.25

Deduced Parameters	
Ca1(m/s)	46.3
Ca2(m/s)	46.0
ΔT_0 (K)	0.93034
Power (KW) =	9.9733

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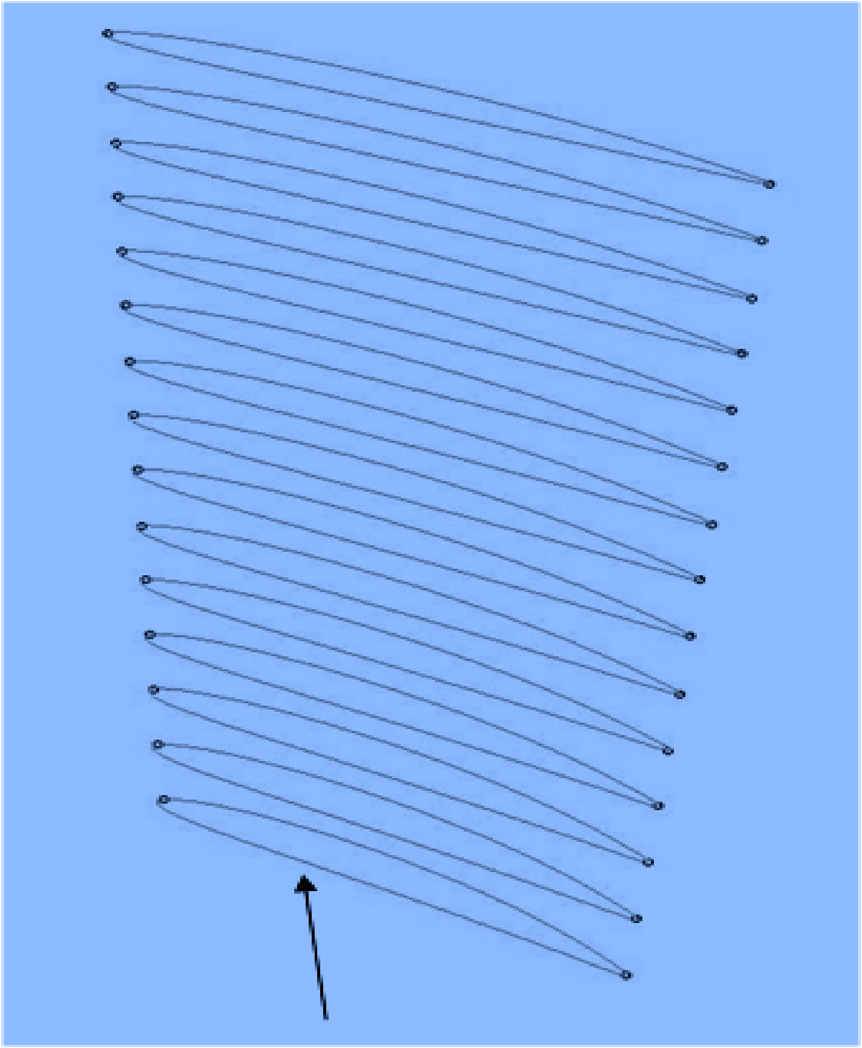
Design of Axial Flow Fan

Aerodynamic Parameters :

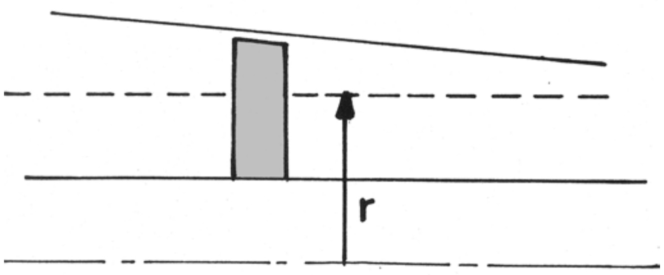
Station number	1	2	3	4	5	8	9	10	13	14	15	16	17	18	19	20	21	24	25	28	29	30	31
Radial distance	0.125	0.1291	0.1332	0.1373	0.1414	0.1537	0.1578	0.1619	0.1742	0.1783	0.1824	0.1865	0.1906	0.1947	0.1988	0.2029	0.207	0.2193	0.2234	0.2357	0.2398	0.2439	0.248
Diameter	0.25	0.2582	0.2664	0.2746	0.2828	0.3074	0.3156	0.3238	0.3484	0.3566	0.3648	0.373	0.3812	0.3894	0.3976	0.4058	0.414	0.4386	0.4468	0.4714	0.4796	0.4878	0.496
Annulus area (m^2)	0.0491	0.0524	0.0557	0.0592	0.0628	0.0742	0.0782	0.0823	0.0953	0.0999	0.1045	0.1093	0.1141	0.1191	0.1242	0.1293	0.1346	0.1511	0.1568	0.1745	0.1807	0.1869	0.1932
Blade velocity (m/s)	31.4	32.4	33.5	34.5	35.5	38.6	39.7	40.7	43.8	44.8	45.8	46.9	47.9	48.9	50.0	51.0	52.0	55.1	56.1	59.2	60.3	61.3	62.3
β_1	34.2	35.0	35.9	36.7	37.5	39.9	40.6	41.3	43.4	44.1	44.7	45.4	46.0	46.6	47.2	47.8	48.4	50.0	50.5	52.0	52.5	53.0	53.4
β_2	1.3	3.8	6.2	8.5	10.7	16.8	18.7	20.5	25.5	27.1	28.5	29.9	31.3	32.6	33.8	35.0	36.2	39.4	40.4	43.1	44.0	44.8	45.6
$\beta_1-\beta_2$	32.9	31.3	29.7	28.2	26.8	23.0	21.9	20.8	17.9	17.0	16.2	15.4	14.7	14.0	13.4	12.7	12.2	10.6	10.1	8.9	8.5	8.1	7.8
C_{w2} (m/s)	30.4	29.4	28.5	27.6	26.8	24.7	24.1	23.4	21.8	21.3	20.8	20.4	19.9	19.5	19.1	18.7	18.3	17.3	17.0	16.1	15.8	15.6	15.3
α_2	33.4	32.6	31.8	31.0	30.3	28.2	27.6	27.0	25.3	24.8	24.3	23.9	23.4	23.0	22.5	22.1	21.7	20.6	20.3	19.3	19.0	18.7	18.4
Degree of rection	0.5167	0.5469	0.5743	0.5994	0.6223	0.6803	0.6967	0.7119	0.7511	0.7624	0.7730	0.7829	0.7921	0.8008	0.8089	0.8166	0.8238	0.8430	0.8487	0.8641	0.8687	0.8731	0.8772
Specific Work	934.99	934.99	934.99	934.99	934.99	934.99	934.99	934.99	934.99	934.99	934.99	934.99	934.99	934.99	934.99	934.99	934.99	934.99	934.99	934.99	934.99	934.99	934.99

Designed Blade Geometry

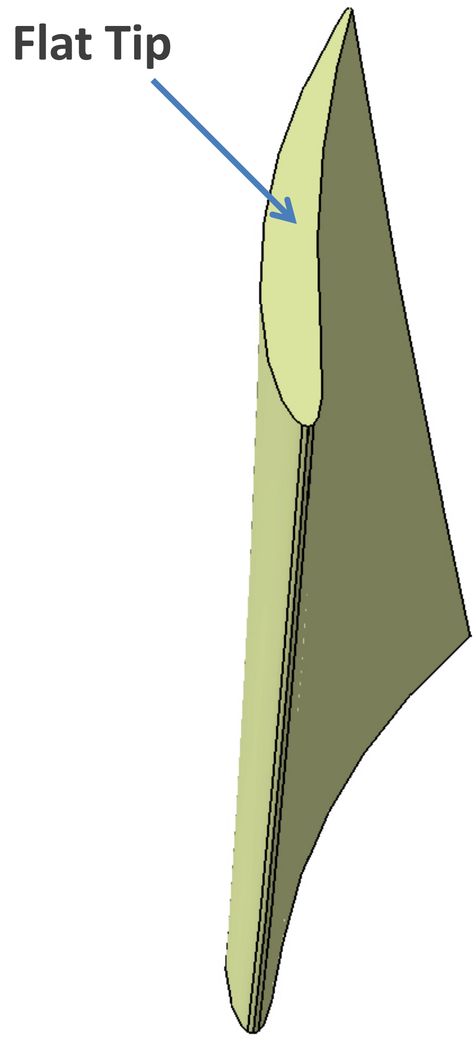
Station number	1	2	3	4	5	8	9	10	13	14	15	16	17	18	19	20	21	24	25	28	29	30	31
chord	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
No. of blades	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
s, actual	0.0785	0.0811	0.0837	0.0863	0.0888	0.0966	0.0991	0.1017	0.1095	0.1120	0.1146	0.1172	0.1198	0.1223	0.1249	0.1275	0.1301	0.1378	0.1404	0.1481	0.1507	0.1532	0.1558
c/s, actual	1.0186	0.9862	0.9559	0.9273	0.9005	0.8284	0.8069	0.7864	0.7309	0.7141	0.6980	0.6827	0.6680	0.6539	0.6405	0.6275	0.6151	0.5806	0.5699	0.5402	0.5310	0.5220	0.5134
s/c, actual	0.9817	1.0139	1.0462	1.0784	1.1106	1.2072	1.2394	1.2716	1.3682	1.4004	1.4326	1.4648	1.4970	1.5292	1.5614	1.5936	1.6258	1.7224	1.7546	1.8512	1.8834	1.9156	1.9478
DF	0.4404	0.4447	0.4475	0.4492	0.4498	0.4466	0.4442	0.4413	0.4303	0.4260	0.4215	0.4168	0.4120	0.4070	0.4020	0.3969	0.3917	0.3762	0.3711	0.3558	0.3508	0.3459	0.3410
incidence, i	2.00	1.87	1.73	1.60	1.47	1.07	0.93	0.80	0.40	0.27	0.13	0.00	-0.13	-0.27	-0.40	-0.53	-0.67	-1.07	-1.20	-1.60	-1.73	-1.87	-2.00
m	0.3246	0.3196	0.3149	0.3102	0.3058	0.2935	0.2898	0.2861	0.2761	0.2731	0.2701	0.2673	0.2646	0.2620	0.2595	0.2571	0.2548	0.2484	0.2464	0.2409	0.2392	0.2376	0.2360
camber,θ	45.5	43.3	41.3	39.3	37.4	32.4	30.9	29.5	25.8	24.8	23.7	22.8	21.9	21.1	20.4	19.7	19.0	17.3	16.8	15.6	15.2	14.9	14.6
deviation,δ	14.6	14.0	13.3	12.7	12.1	10.5	10.0	9.5	8.3	8.0	7.7	7.4	7.1	6.8	6.6	6.4	6.2	5.6	5.5	5.1	5.0	4.9	4.8
corr deviation	17.6	17.0	16.3	15.7	15.1	13.5	13.0	12.5	11.3	11.0	10.7	10.4	10.1	9.8	9.6	9.4	9.2	8.6	8.5	8.1	8.0	7.9	7.8
final camber,θ	48.5	46.3	44.3	42.3	40.4	35.4	33.9	32.5	28.8	27.8	26.7	25.8	24.9	24.1	23.4	22.7	22.0	20.3	19.8	18.6	18.2	17.9	17.6
stagger	7.9	10.0	12.0	14.0	15.8	21.1	22.7	24.3	28.6	29.9	31.2	32.5	33.7	34.8	35.9	37.0	38.0	40.9	41.8	44.3	45.1	45.9	46.6
m (from plot)	0.138	0.145	0.15	0.152	0.158	0.174	0.178	0.182	0.195	0.2	0.205	0.209	0.213	0.217	0.22	0.224	0.229	0.239	0.242	0.251	0.253	0.257	0.259
camber,θ	35.8	34.4	33.1	31.6	30.4	27.1	26.1	25.2	22.7	21.9	21.3	20.7	20.1	19.5	19.0	18.5	18.1	17.0	16.7	15.9	15.7	15.5	15.4
deviation,δ	4.9	5.0	5.1	5.0	5.1	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.3	5.3	5.3	5.4	5.4	5.5	5.5
corr deviation	7.9	8.0	8.1	8.0	8.1	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.3	8.3	8.3	8.4	8.4	8.5	8.5
final camber,θ	38.8	37.4	36.1	34.6	33.4	30.1	29.1	28.2	25.7	24.9	24.3	23.7	23.1	22.5	22.0	21.5	21.1	20.0	19.7	18.9	18.7	18.5	18.4
stagger	12.8	14.5	16.1	17.8	19.3	23.7	25.1	26.5	30.2	31.3	32.5	33.5	34.6	35.6	36.6	37.6	38.5	41.1	41.9	44.2	44.9	45.6	46.2



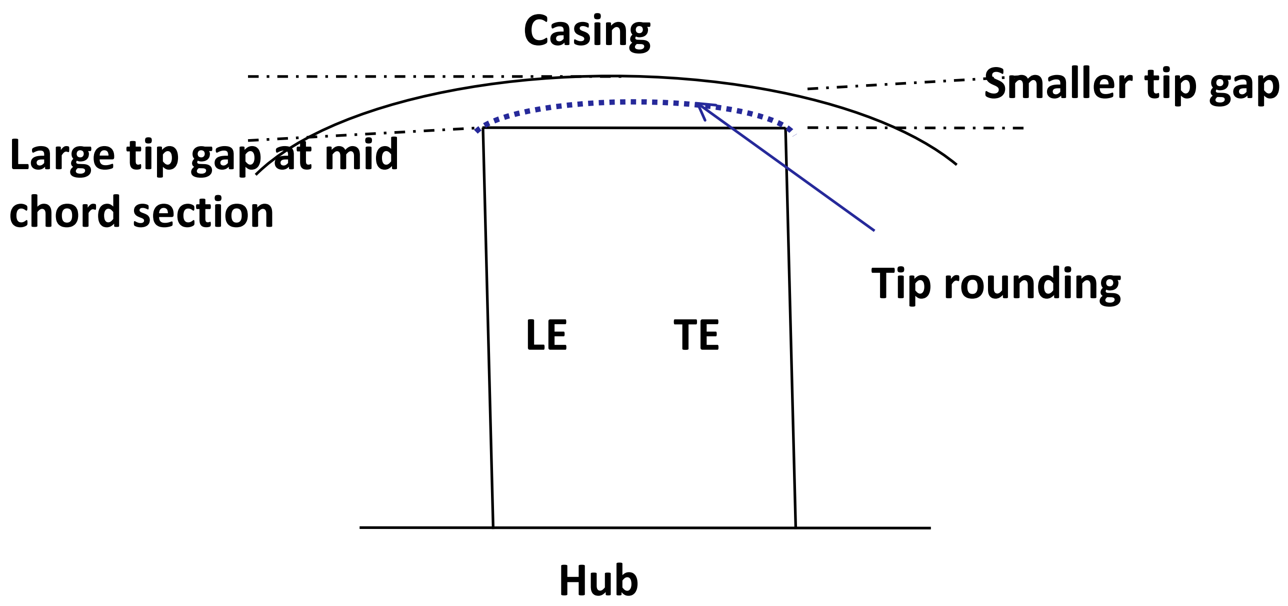
Airfoil profiles



- Airfoils at various radial stations are arranged in a manner such that the airfoils are at constant radius (from LE to TE).
- The centroids of the airfoils are in a radial locus



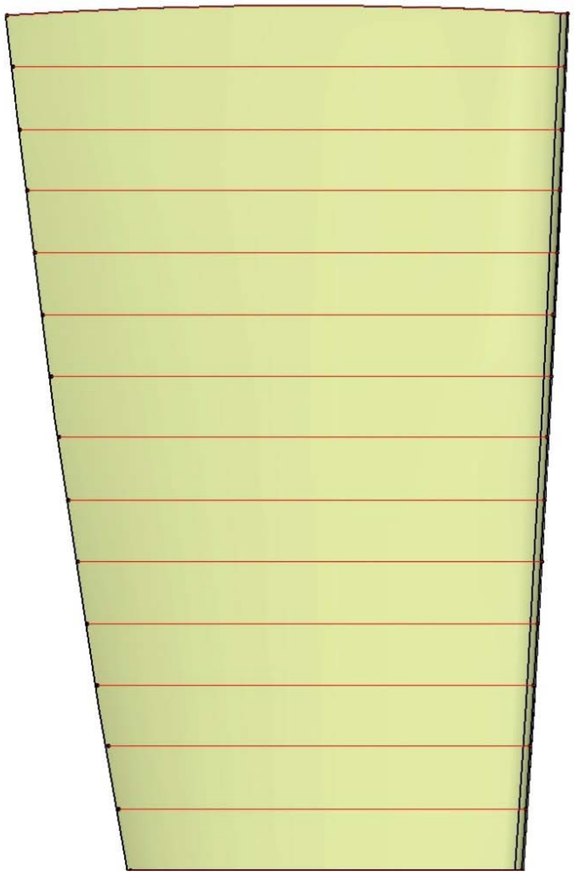
- Such designs normally produce a flat airfoil tip
- The entire L.E is linear or in a smooth line
- The blade T.E by design is normally a smooth non-linear line



- A Flat tip creates a divergent-convergent tip gap (from LE to TE) which is meridionally arranged as per tip-airfoil stagger

- To ensure a constant tip gap along tip airfoil needs to be arranged in a 3-D surface

3D Airfoil at tip section



During this tip rounding all the other airfoils along the blade length may be held in their flat constant radius meridional planes

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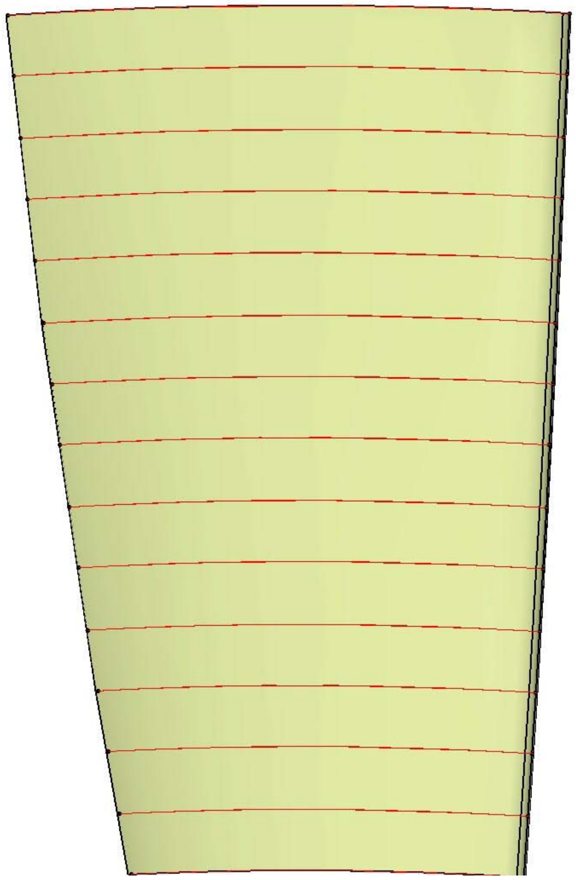
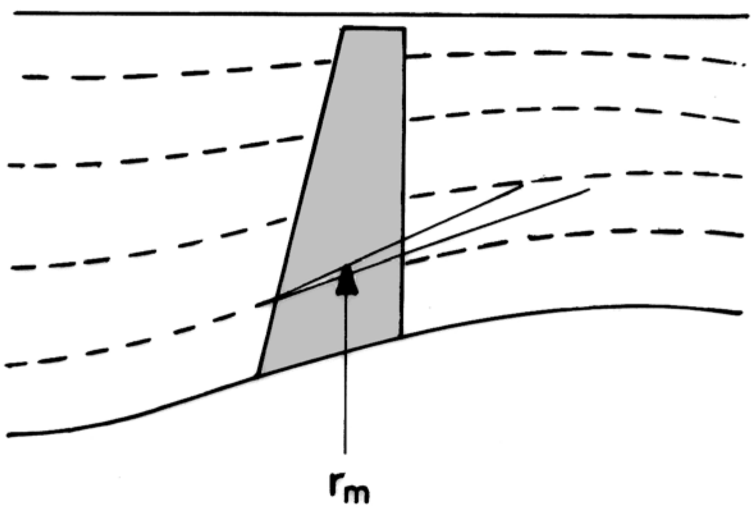
- 3D Airfoils at all sections

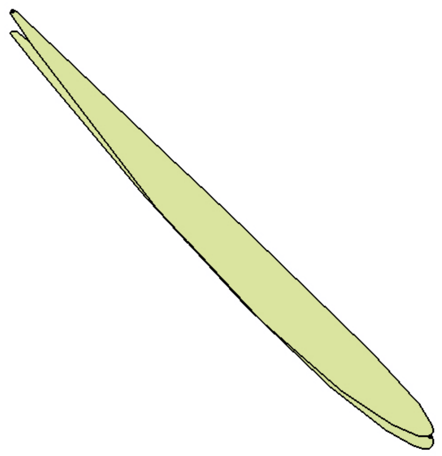




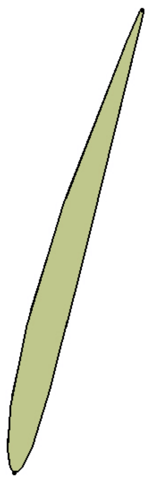
- Each of the airfoils at various blade lengths is set on a curved meridional plane

3D Airfoil

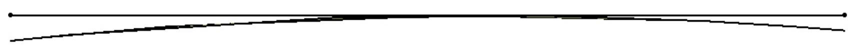
Isometric View



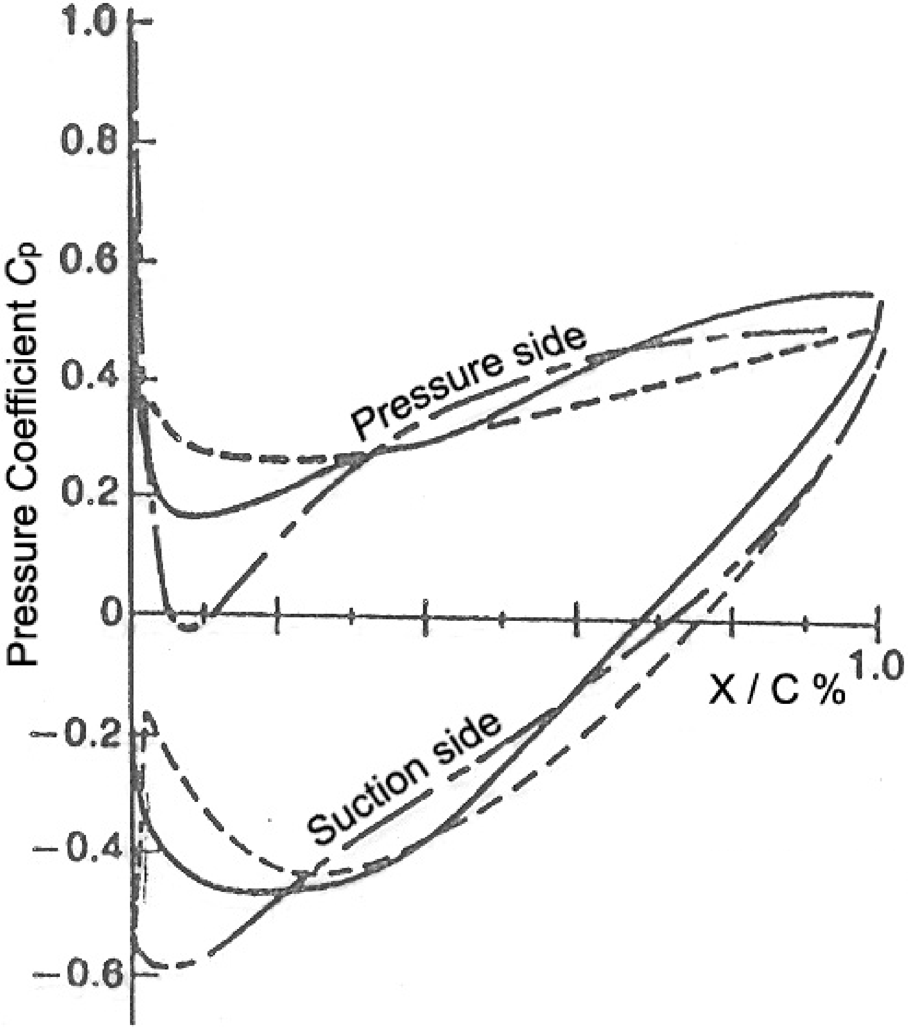
Top View



Axial View



Circumferential View



- Cp distribution of a standard airfoil shall change when it is set on a meridional plane and in cylindrical coordinate system
- Restoration of the original Cp distribution shall require the original airfoil shape to be altered

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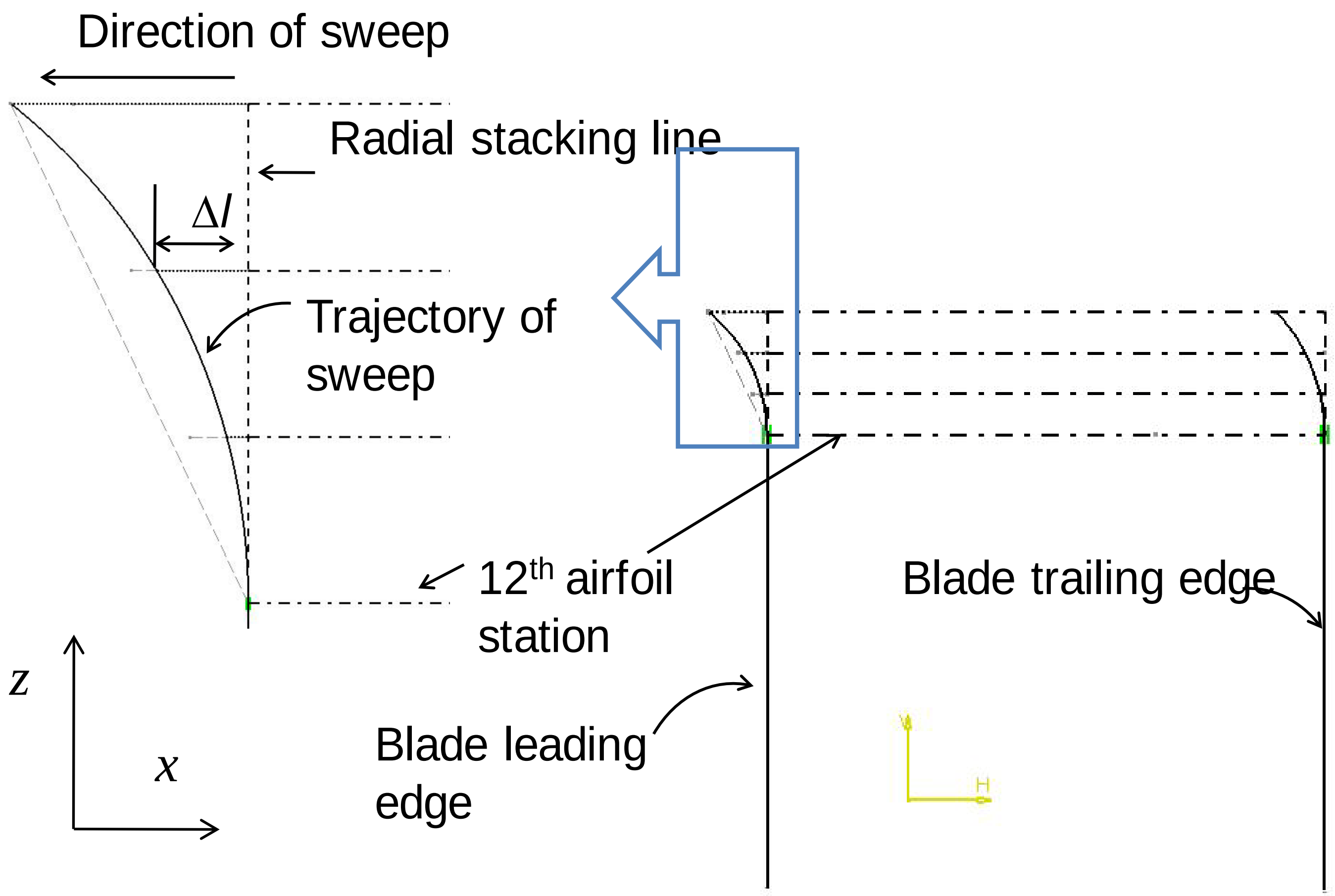
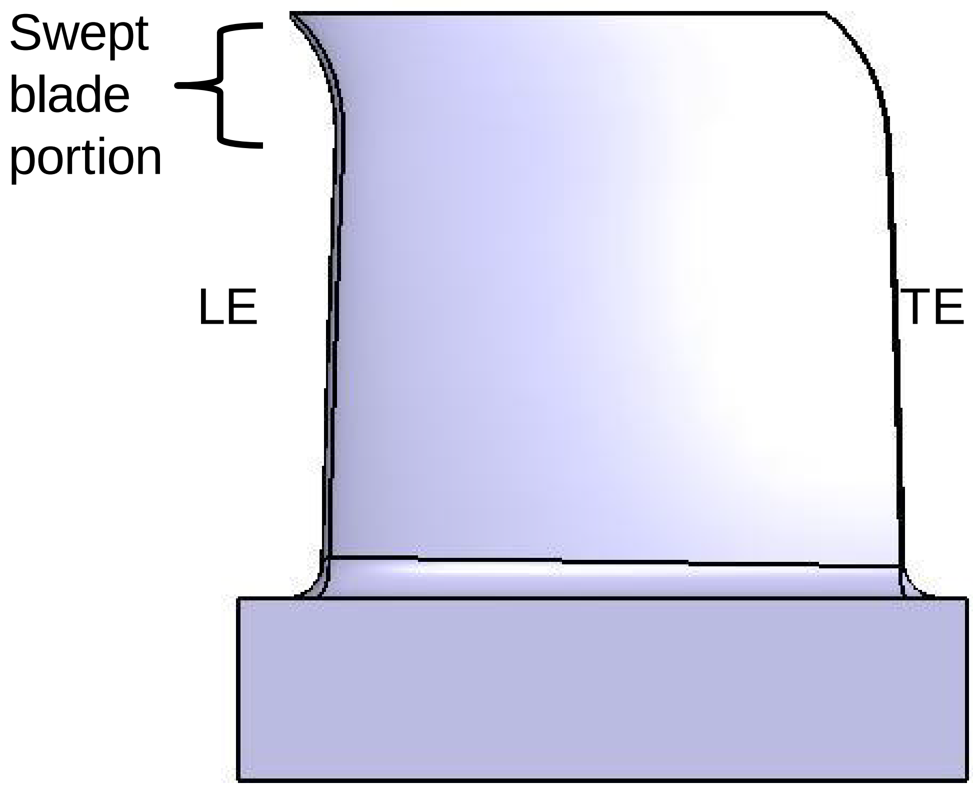
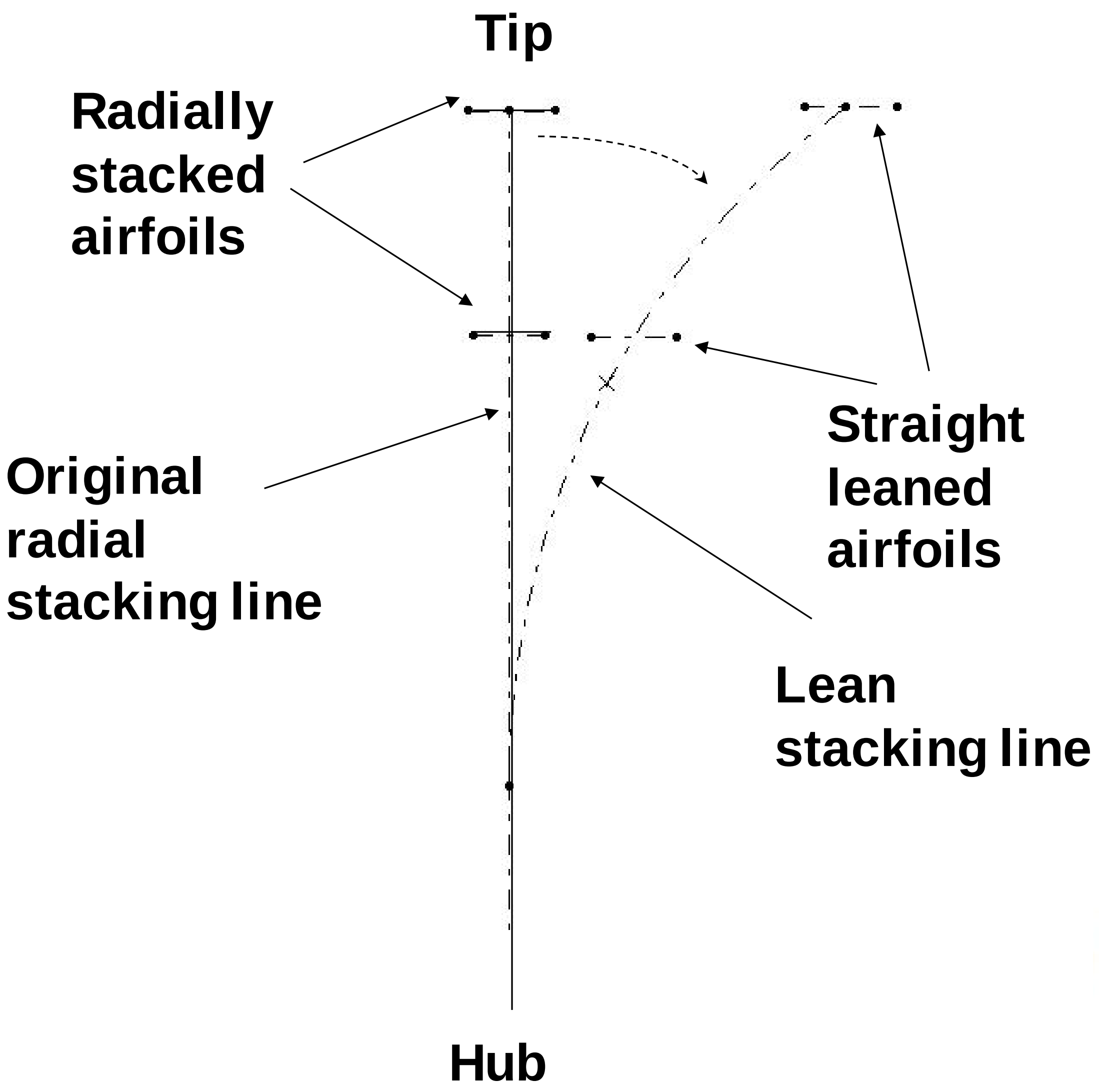
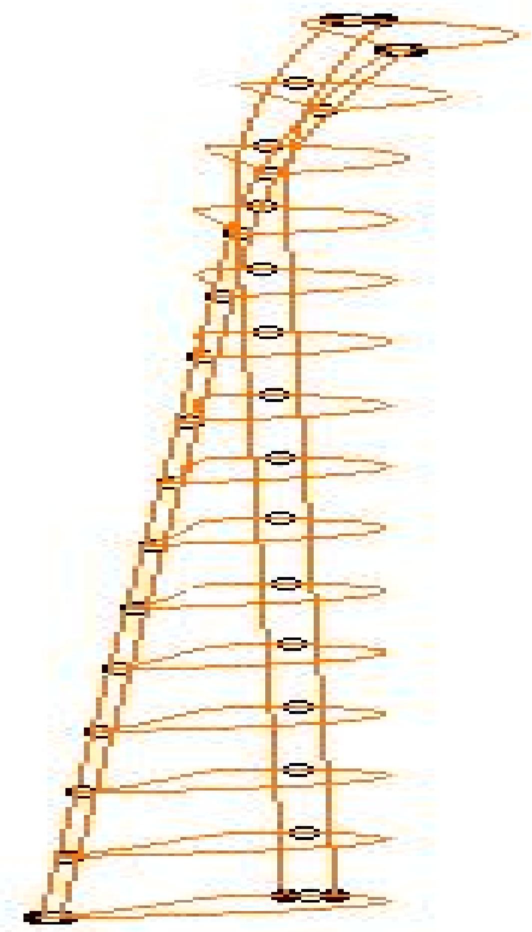
Swept Blade Design




Swept
blade
portion
LE
TE

Leaned Blade Design





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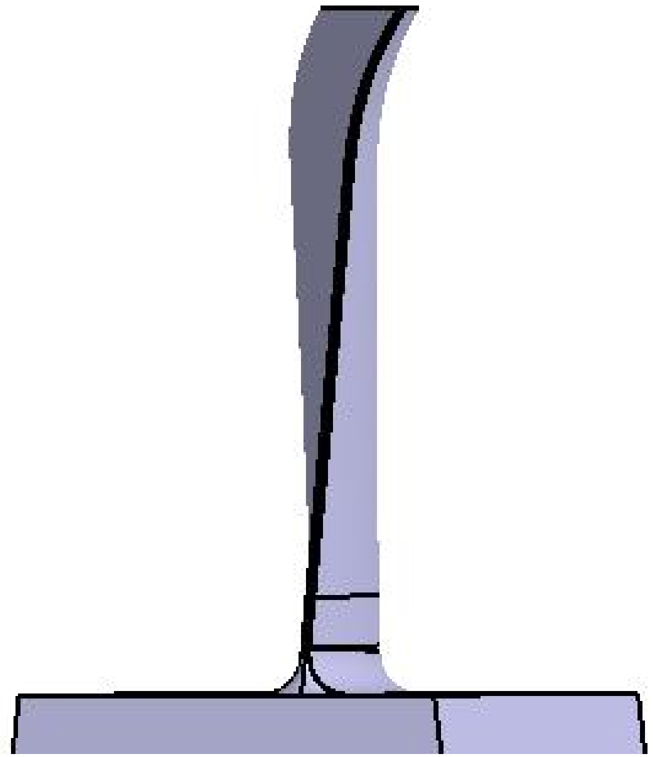
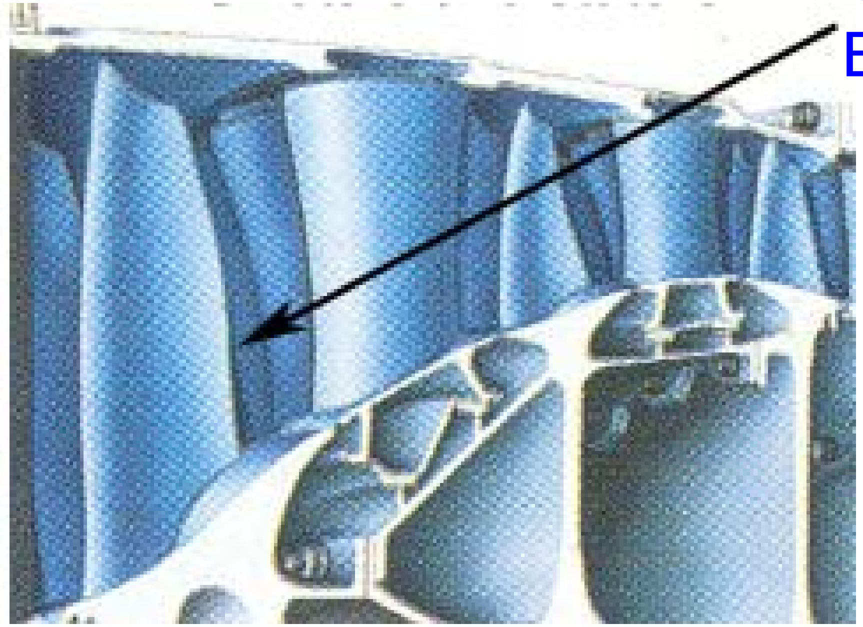
Leaned Blade Design




Swept
Blades

A Fully Swept Blade

Straight blade

- 3-D Blades are developed from 2-D airfoil stacked blades by geometrical modelling
- 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

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Next Lecture

Compressor / Fan Noise

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