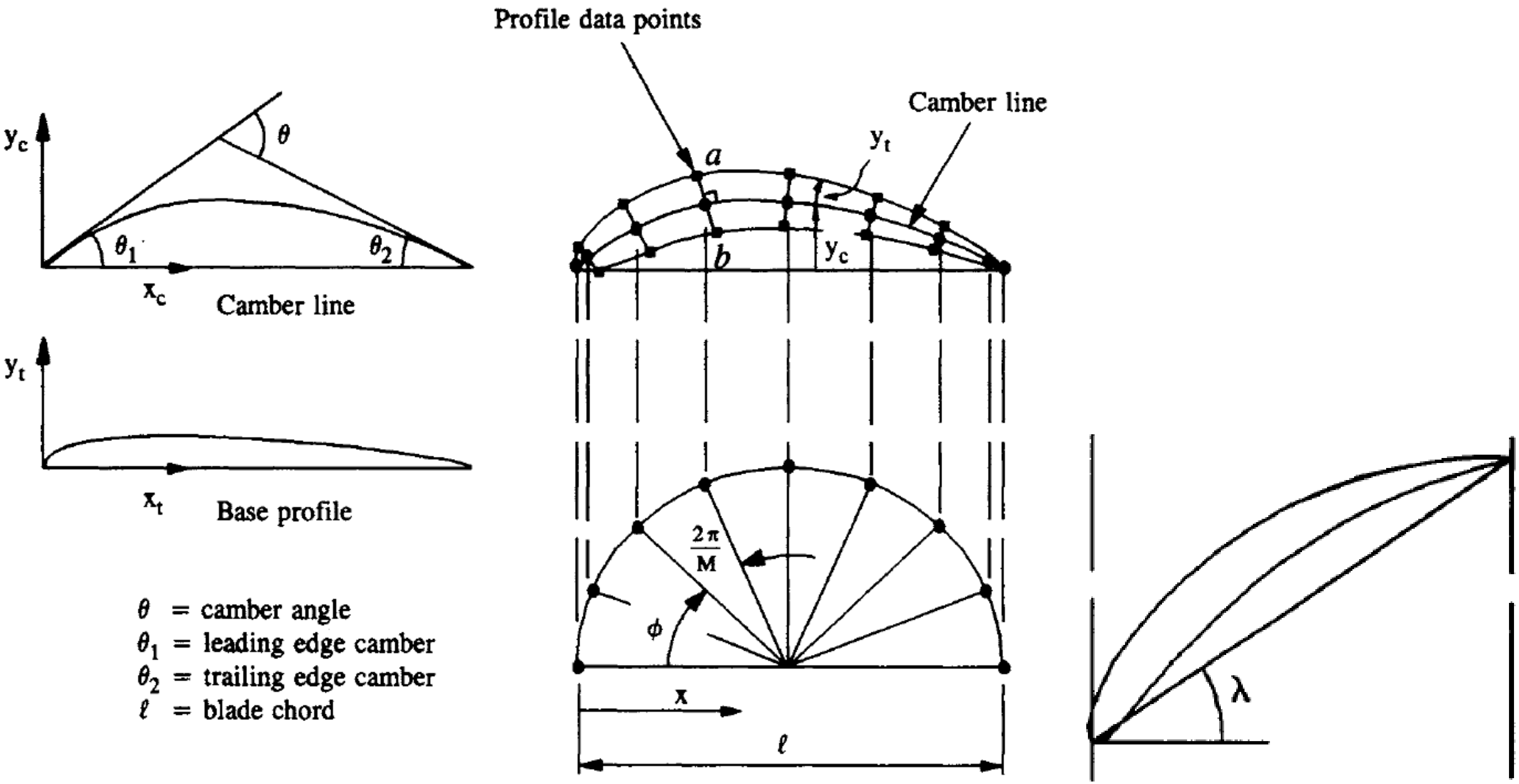
Turbomachinery design
(6 ECTS)

MISES LAB
Cascade Profile Definition

Universidad Carlos III de Madrid

Cascade profile generation



Cascade profile generation

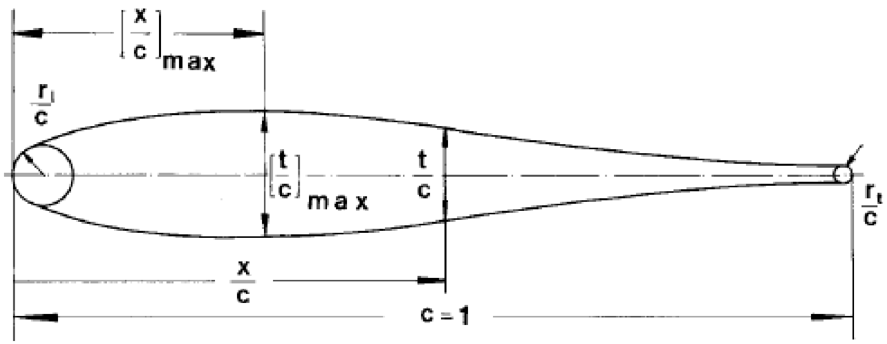


Fig. 10.4: Schematic of a base profile to be superimposed on a camber line

c4 x_t	c4 y_t	T4 x_t	T4 y_t	NACA 0012 x_t	NACA 0012 y_t	NACA 0015 x_t	NACA 0015 y_t	NACA 66-010 x_t	NACA 66-010 y_t	NGTEmod x_t	NGTEmod y_t
0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.0	0.0	0.00	0.000
1.25	1.65	1.25	1.17	1.25	1.894	1.25	2.367	0.5	0.759	1.25	1.375
2.50	2.27	2.50	1.54	2.50	2.615	2.50	3.268	0.75	0.913	2.50	1.910
5.00	3.08	5.00	1.99	5.00	3.555	5.00	4.443	1.25	1.141	5.00	2.680
7.50	3.62	7.50	2.37	7.50	4.200	7.50	5.250	2.5	1.516	7.50	3.195
10.00	4.02	10.00	2.74	10.00	4.683	10.00	5.853	5.0	2.087	10.00	3.600
15.00	4.55	15.00	3.40	15.00	5.345	15.00	6.682	7.5	2.536	15.00	4.180
20.00	4.83	20.00	3.95	20.00	5.737	20.00	7.172	10.0	2.917	20.00	4.550
30.00	5.00	30.00	4.72	25.00	5.941	25.00	7.427	15.0	3.53	30.00	4.950
40.00	4.89	40.00	5.00	30.00	6.002	30.00	7.502	20.0	4.001	40.00	4.820
50.00	4.57	50.00	4.67	40.00	5.803	40.00	7.254	25.0	4.363	50.00	3.980
60.00	4.05	60.00	3.70	50.00	5.294	50.00	6.617	30.0	4.636	60.00	3.250
70.00	3.37	70.00	2.51	60.00	4.563	60.00	5.704	35.0	4.832	70.00	2.450
80.00	2.54	80.00	1.42	70.00	3.664	70.00	4.580	40.0	4.953	80.00	1.740
90.00	1.60	90.00	0.85	80.00	2.623	80.00	3.279	45.0	5.0	85.00	1.500
95.00	1.06	95.00	0.72	90.00	1.448	90.00	1.810	50.0	4.971	90.00	1.270
100.00	0.00	100.00	0.00	95.00	0.807	95.00	1.008	55.0	4.865	92.50	1.170
				100.00	0.000	100.00	0.000	60.0	4.665	95.00	1.080
								65.0	4.302	97.50	0.980
								70.0	3.787	100.00	0.000
								75.0	3.176		
								80.0	2.494		
								85.0	1.773		
								90.0	1.054		
								95.0	0.408		
								100.0	0.0		

Table 10.1: Thickness distribution of a NACA-65 compressor base profile, $\xi = x/c$, $t = t_{max} f(\xi)$

ξ	0	0.0125	0.0250	0.0500	0.0750	0.1000	0.1500	0.200	
f(ξ)	0.	0.2338	0.3148	0.4354	0.5294	0.6080	0.7333	0.8268	
ξ	0.30	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	0.9500	1.00
f(ξ)	0.952	0.9992	0.9624	0.8292	0.6312	0.3974	0.1620	0.0612	0.00

Cascade profile generation

Typical thickness distributions for compressors

x/c (%)	NACA (A_{10}) (línea media)	C4	C7	NACA65	NACA65 (con b/s grueso)
0.000	0.000	0.00	0.00	0.000	0.000
0.5	0.250			0.772	0.772
0.75	0.350			0.932	0.932
1.25	0.353	1.65	1.51	1.169	1.169
2.50	0.930	2.27	2.04	1.574	1.574
5.00	1.580	3.08	2.72	2.177	2.177
7.500	2.120	3.62	3.18	2.647	2.647
10.00	2.585	4.02	3.54	3.040	3.040
15.00	3.365	4.55	4.05	3.666	3.666
20.00	3.980	4.83	4.43	4.143	4.143
25.00	4.475			4.503	4.510
30.00	4.860	5.00	4.86	4.760	4.775
35.00	5.150			4.924	4.945
40.00	5.355	4.89	5.00	4.996	5.000
45.00	5.475			4.963	4.945
50.00	5.515	4.57	4.86	4.812	4.782
55.00	5.475			4.530	4.513
60.00	5.355	4.05	4.42	4.146	4.159
65.00	5.150			3.682	3.754
70.00	4.860	3.37	3.73	3.156	3.349
75.00	4.475			2.584	2.944
80.00	3.980	2.54	2.78	1.987	2.539
85.00	3.365			1.385	2.134
90.00	2.585	1.60	1.65	0.810	1.729
95.00	1.580	1.06	1.09	0.306	1.324
100.00	0.000	0.00	0.00	0.000	0.000
Radio del borde de ataque		1.20	1.20	0.687	0.687
Radio del borde de salida		0.60	0.60	-	1.000

Cascade profile generation

Typical thickness distributions for turbines

Trazado clásico de perfiles de turbina

TURBINAS DE IMPULSO (K ~ 0)
Línea de curvatura : Parábola
Distribución de espesores: T6

Base profile T6

Table 7. Base Profile T6

Station, percentage of chord	0	1·25	2·5	5·0	7·5	10·0	15	20	30
Upper and lower surface; percentage of chord	0	1·17	1·54	1·99	2·37	2·74	3·4	3·95	4·72
Station, percentage of chord	40	50	60	70	80	90	95	100	
Upper and lower surface, percentage of chord	5·00	4·67	3·70	2·51	1·42	0·85	0·72	0	

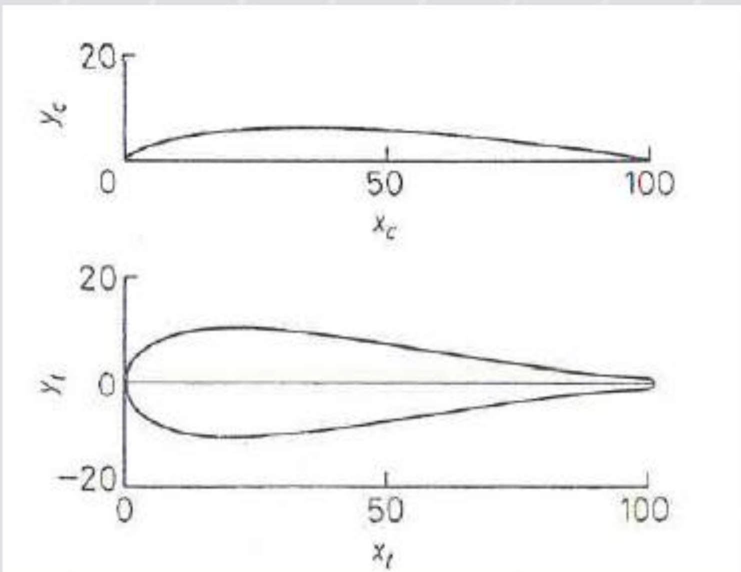
Leading edge radius = 12 per cent t; trailing edge radius = 6 per cent t; t/l = 10 per cent; station of maximum thickness = 40 per cent l.

Cascade profile generation

Typical thickness distributions for turbines

Trazado clásico de perfiles de turbina

TURBINAS DE REACCIÓN (K ~ 0.5)
Distribución de espesores: A3K7
Línea media: Arco de circulo y línea recta o seriada.



A_3K_7 Mean Line, Thickness Distribution and Coordinates for Primary Turbine-blade Series

A_3K_7 mean-line coordinates for C_{L_0} = 1·0		*Thickness distribution co-ordinates t/c = 20%*	
x_c	y_c	x_t	y_t
0	0	0	0
0·5	0·397	1·25	3·469
1·25	0·836	2·5	4·972
2·5	1·428	5·0	6·918
5·0	2·359	10	9·007
10	3·689	15	9·827
15	4·597	20	10·000
20	5·217	25	9·899
25	5·623	30	9·613
30	5·852	35	9·106
35	5·936	40	8·594
40	5·897	45	7·913
45	5·753	50	7·152
50	5·516	55	6·339
55	5·200	60	5·500
60	4·814	65	4·661
65	4·367	70	3·848
70	3·870	75	3·087
75	3·328	80	2·406
80	2·746	85	1·830
85	2·133	90	1·387
90	1·485	95	1·101
95	0·801	100	0
100	0		

$\frac{dy_c}{dx_{c(0\cdot5)}} = 0\cdot8574$ $\frac{dy_c}{dx_{c(95)}} = -0\cdot1602$ Leading edge radius = 4·407% of chord
Trailing edge radius = 1·000% of chord

Cascade profile generation

Example of profile generation (after Lewis)

2.4 Use of program CASCADE to perform the *direct* analysis

A limited number of well-known thickness distributions have been provided in the data file PROFILES for use with the program CASCADE in the standard published format. These are recorded in Table 2.1. Although they are likely to be adequate for most purposes, instructions are given in Appendix II for the inclusion of more base profiles if required.

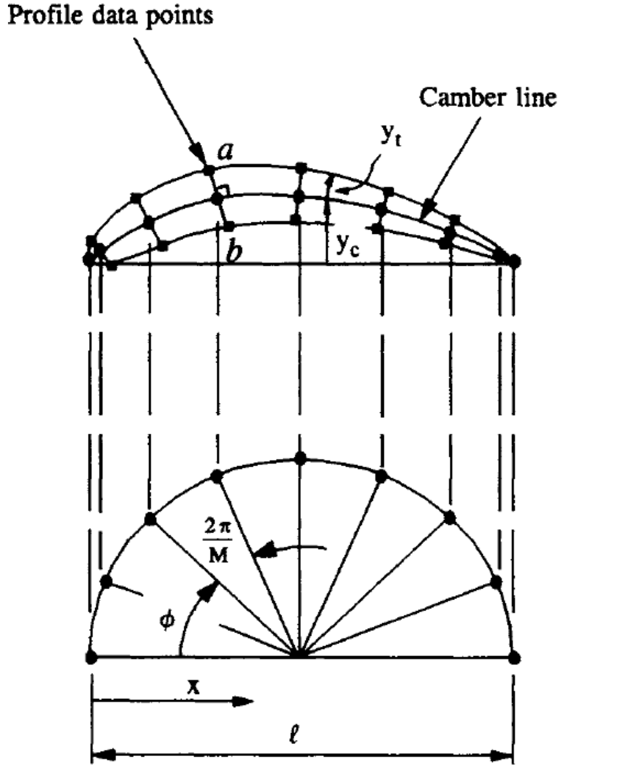
The program CASCADE is able to construct the blade profile of your choice following the geometrical strategy shown in Fig. 2.8 which concentrates the profile data points into the leading and trailing edge region. If we first construct a semi-circle of radius $l/2$ as shown and divide it into M equal segments $\Delta\phi = 2\pi/M$, camber line x_c coordinates are then given by

$$\frac{x_c}{l} = \frac{1}{2}(1 - \cos\phi) \qquad (2.17)$$

Camber line y_c coordinates and slopes dy_c/dx_c may then be calculated. The half-thickness y_t may then be interpolated from the tabulated base profile data. The coordinates of profile points a and b on the upper and lower surface then follow from

$$\left.\begin{aligned} x_a &= x_c - y_t \sin\theta_c && \text{upper surface} \\ y_a &= y_c + y_t \cos\theta_c && \ldots\ldots \end{aligned}\right\} \qquad (2.18a)$$

$$\left.\begin{aligned} x_b &= x_c + y_t \sin\theta_c && \text{lower surface} \\ y_b &= y_c - y_t \cos\theta_c && \ldots\ldots \end{aligned}\right\} \qquad (2.18b)$$



Cascade profile generation

where $\theta_c = \arctan(dy_c/dx_c)$ is the slope of the camber line. The camber angle θ is defined in Fig. 2.8 together with the leading and trailing edge camber angles θ_1 and θ_2.

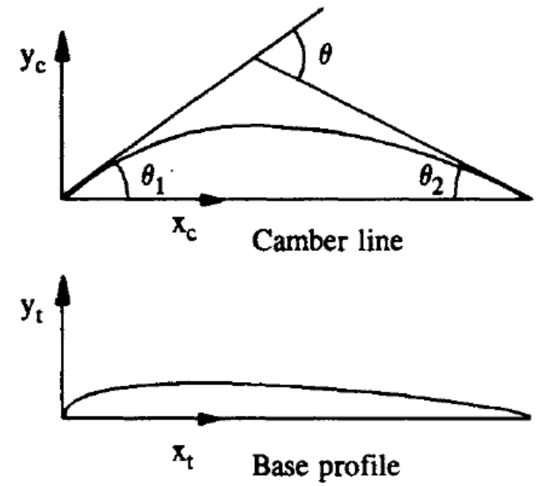
An interesting application of the *direct* method is shown in Fig. 2.9 where three different cascade profiles have been selected to achieve the same overall design requirements as the cascade shown in Fig. 2.7, namely

(1) $t/l = 1.0$, $\beta_1 = 54.59°$, $\beta_2 = 30.69°$,
(2) shock-free inflow, and
(3) three camber line types:
  (a) Circular arc.
  (b) Parabola with position of maximum camber $x_c/l = 0.3$.
  (c) Parabola with position of maximum camber $x_c/l = 0.7$.

Fluid dynamic analysis of these three cascades illustrates the important effect which camber line shape has upon the surface pressure distribution and especially that of the upper surface u. By moving the position of maximum camber forward towards the leading edge, the blade loading $C_{p1l} - C_{p1u}$, and centre of lift are also moved forward and vice versa.

In case (b), $(x_c/l)_{max} = 0.3$, the upper surface pressure falls rapidly to a very low value $C_{p_1} = -1.0$ at $x/l = 0.2$ and then diffuses steadily towards the trailing edge. On the lower surface the pressure remains almost constant over most of the chord length. This profile might exhibit better aerodynamic characteristics than profile (a) but would be less attractive for pumps where its low $C_{p_{1u}}$ would reduce its threshold for resisting cavitation.

Considering case (c), $(x_c/l)_{max} = 0.7$, moving the position of maximum camber towards the trailing edge has produced a fairly constant pressure over most of the upper surface $0.1 < x/l < 0.8$ followed by a dramatic diffusion. Although the latter might result in flow separation approaching the trailing edge, this profile would certainly offer better cavitation performance due to its lightly loaded leading edge and generally higher upper surface pressure distribution.



θ = camber angle
θ_1 = leading edge camber
θ_2 = trailing edge camber
ℓ = blade chord

Cascade profile generation

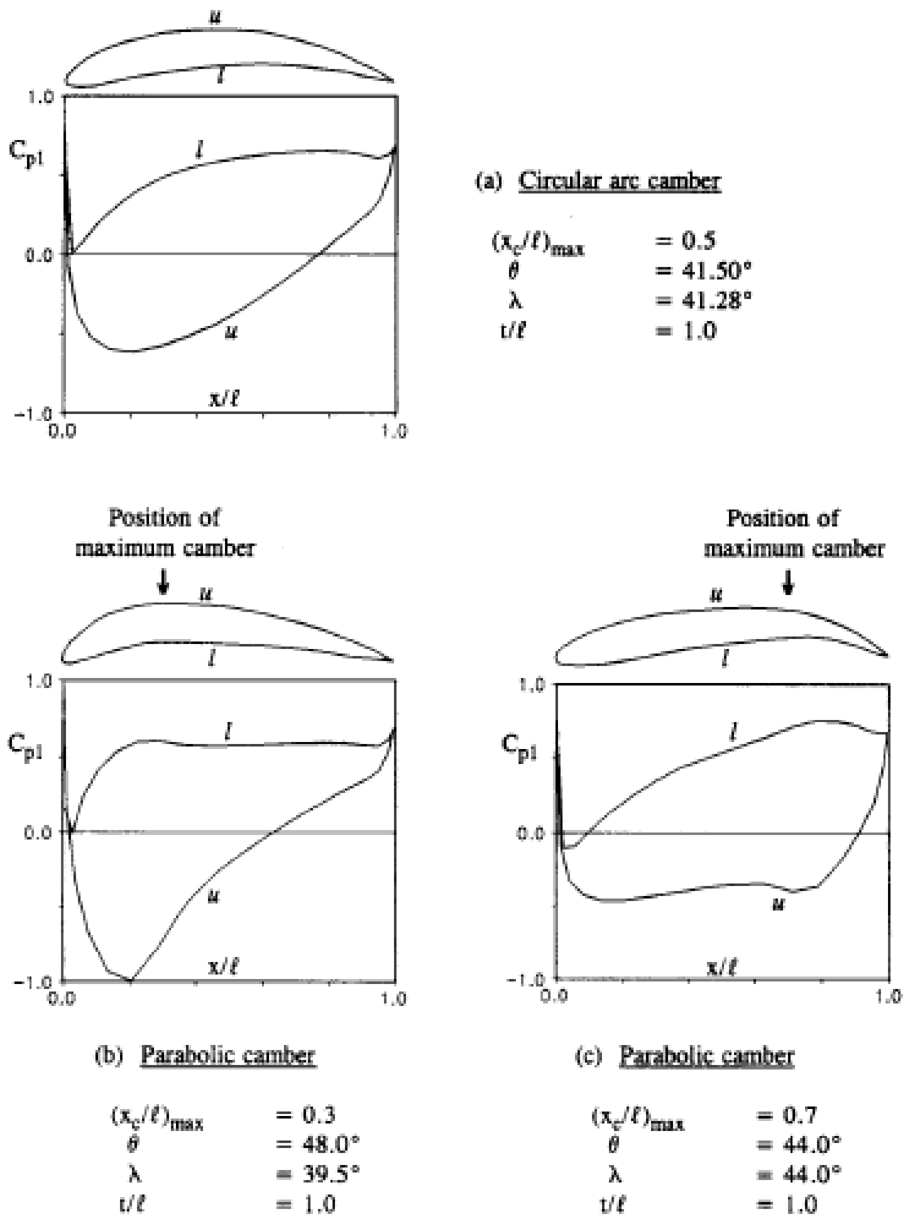


Fig. 2.9 Effect of camber line shape on surface pressure distribution of a fan cascade designed for shock-free inflow with β_1 = 54.59° and β_2 = 30.69°