AE 658

Chapter – 1

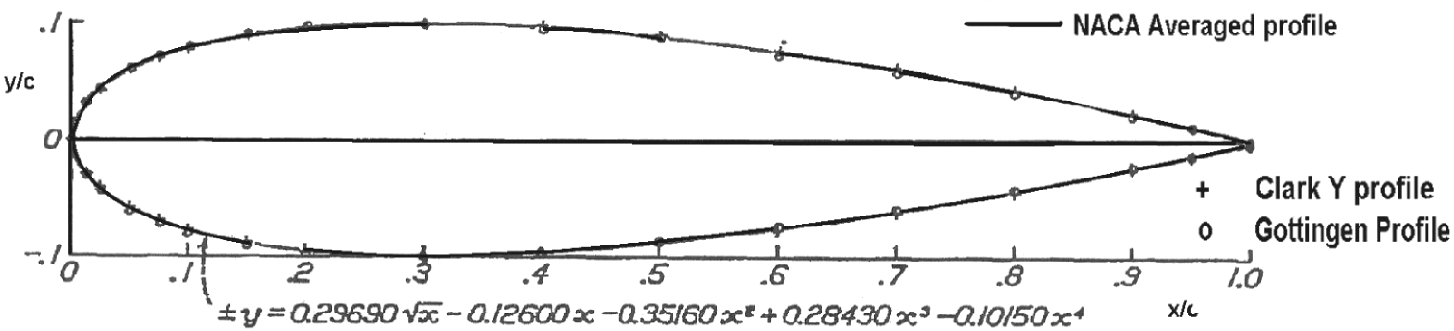
Propeller Theory and Design

Propeller Design

Using any of the theories it is possible to build up a whole blade by stacking of airfoils, each of which is an individually designed element and appropriate airfoil selected for it. For low subsonic propellers over the years a few simple airfoils with flat undersurface has been used. In modern propellers various NACA airfoils are available for selection with their C_l – α curves also available to suit the individual blade element. A typical distribution of the various blade geometrical parameters are shown in Fig. For most design purposes the design is initiated at the reference radius, which is often at 0.75R of the intended propeller. Radial variation of the parameters t/c, c/D and of p/D at various values of β at 0.75R are presented as a typical case (Fig.).

Flat Undersurface Airfoils

	Clark Y		Gö 436		Gö 623		RAF 6E
x	y_U	y_L	y_U	y_L	y_U	y_L	y
0	2.99	2.99	2.50	2.50	3.25	3.25	1.15
1.25	4.66	1.65	4.70	1.00	5.45	1.95	3.19
2.5	5.56	1.26	5.70	0.20	6.45	1.50	4.42
5.0	6.75	0.80	7.00	0.10	7.90	0.90	6.10
7.5	7.56	0.54	8.10	0.05	9.05	0.35	7.24
10	8.20	0.36	8.90		9.90	0.20	8.09
15	9.14	0.13	10.05		10.95	0.10	9.28
20	9.72	0.03	10.25		11.55	0.05	9.90
30	10.00		11.00		12.00		10.30
40	9.75		10.45		11.70		10.22
50	9.00		9.55		10.65		9.80
60	7.82		8.20		9.15		8.98
70	6.28		6.60		7.35		7.70
80	4.46		4.60		5.15		5.91
90	2.39		2.45		2.80		3.79
95	1.27		1.25		1.60		2.58
100	0.10		0		0.30		0.76
LE rad.							1.15
TE rad.							0.76



Basic ordinates of N.A.C.A. family airfoils (percent of chord) L.E. Radius 4.40 % C

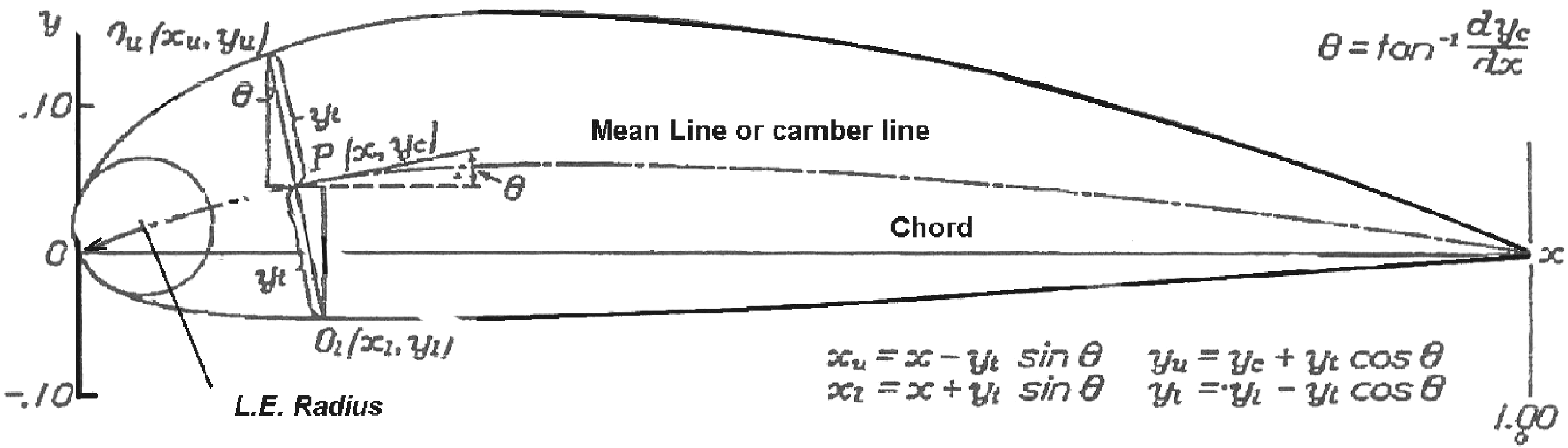
x/c (%)	0	1.25	2.5	5.0	7.5	10	15	20	25	30	40	50	60	70	80	90	95	100
y/c (%)	0	3.157	4.358	5.925	7.000	7.805	8.909	9.563	9.902	10.003	9.672	8.823	7.606	6.107	4.372	2.413	1.344	0.210

NACA airfoils were build on this common basic symmetrical airfoil shape and various camber shapes added on. Thus sections with required maximum thickness, t, can be obtained by :

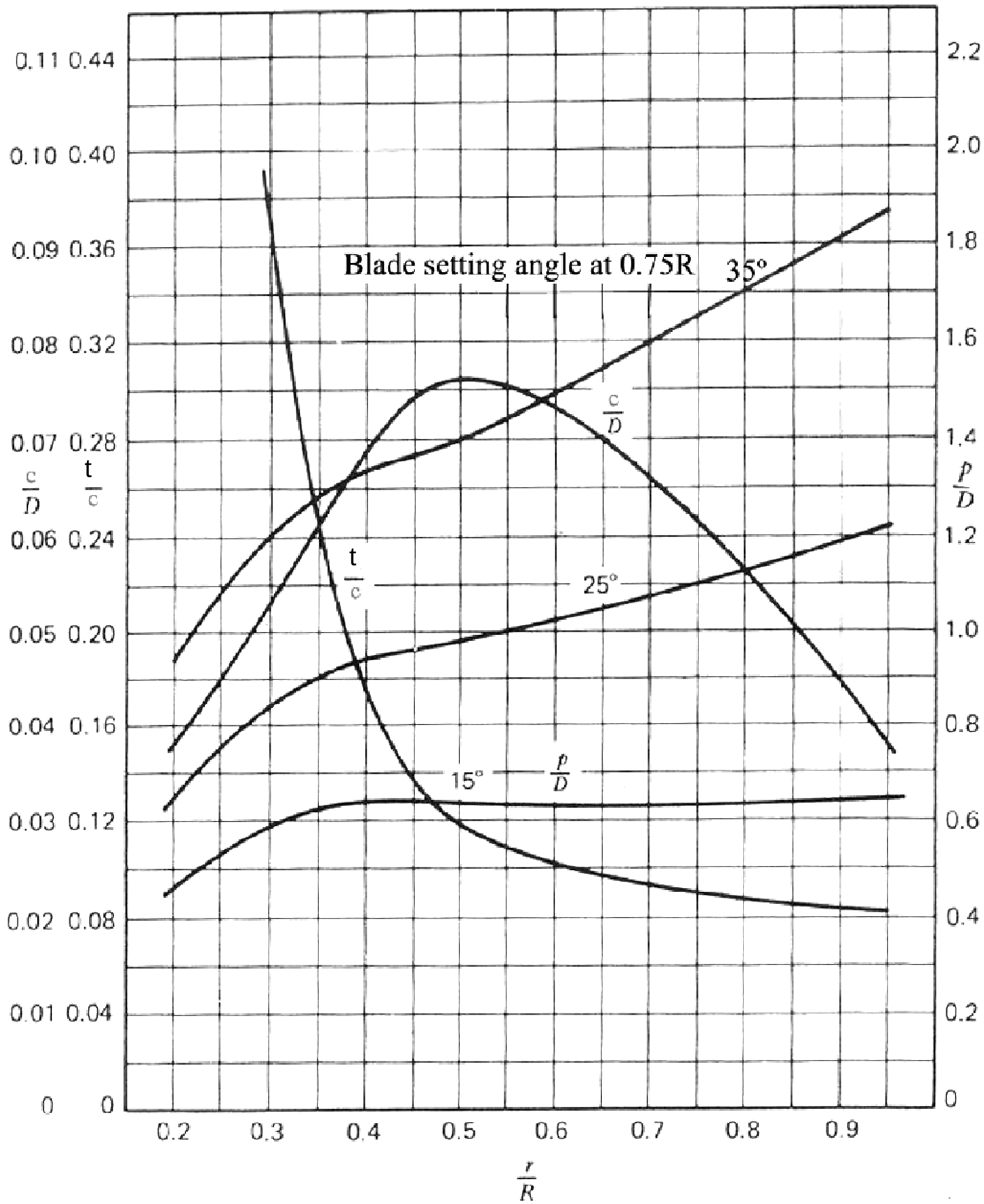
$$\pm y_c = \frac{t}{0.20}\left(0.29690.\sqrt{x} - 0.12600.x - 0.35160x^2 + 0.2843x^3 - 0.10150x^4\right)$$

The leading edge radius is found from , $r_t = 1.10.t^2$; And, the mean line equations are, before $y_c = \frac{m}{p}\left[2.p.x - x^2\right]$ **and** $y_c = \frac{m}{(1-p)^2}\left[(1-2p) + 2px - x^2\right]$

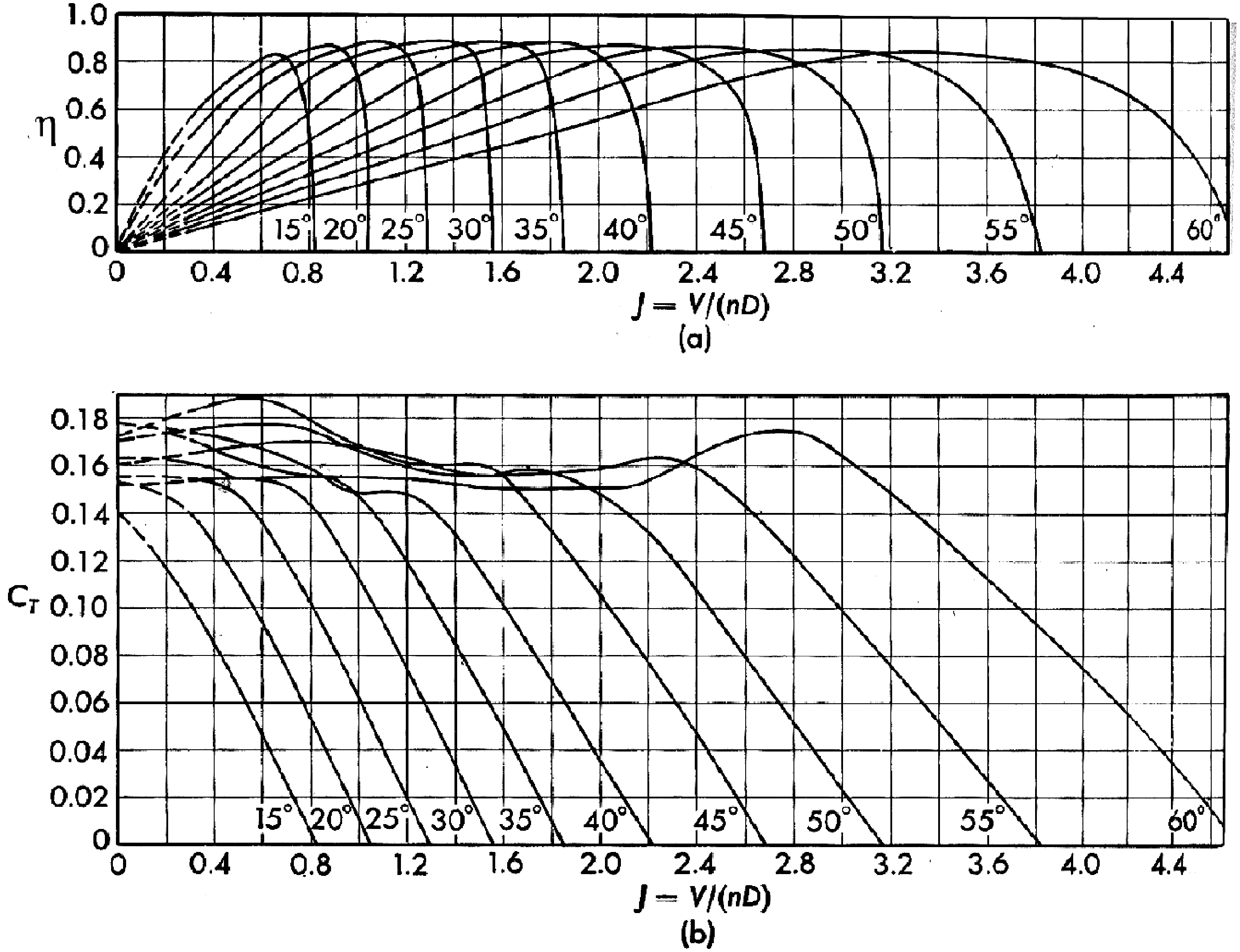
after max t/c. Where, *p* is the position of maximum ordinate, and *m* is the maximum ordinate, where $dy_c/dx=0$



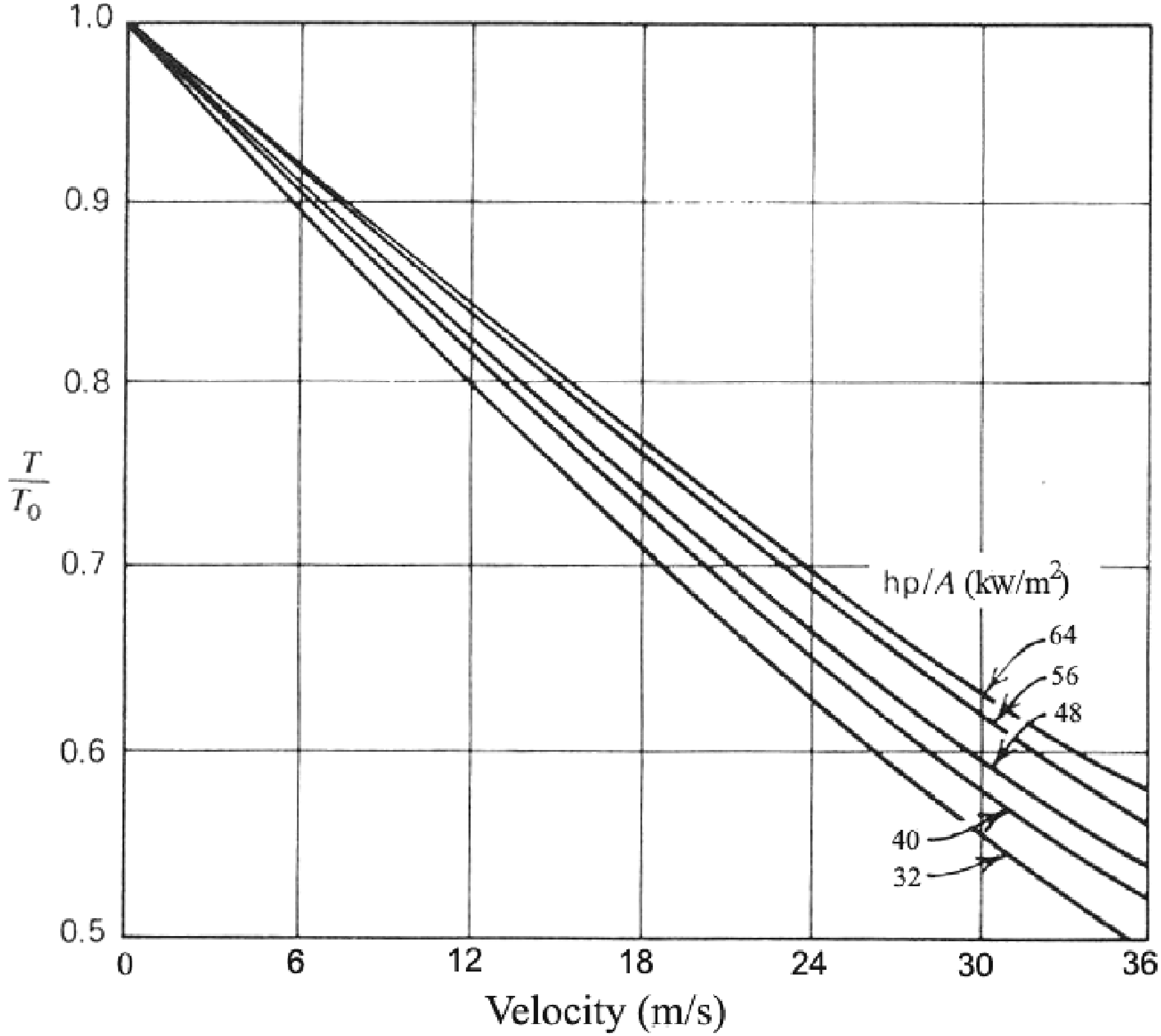
y
.10
0
-.10
$U_u\,(x_u, y_u)$
θ
y_t
$P\,(x, y_c)$
θ
y_t
$O_l\,(x_l, y_l)$
L.E. Radius
Mean Line or camber line
Chord
$\theta = \tan^{-1}\frac{dy_c}{dx}$
x
1.00
$x_u = x - y_t \sin\theta \quad y_u = y_c + y_t \cos\theta$
$x_l = x + y_t \sin\theta \quad y_l = y_l - y_t \cos\theta$



Geometry distribution of a typical subsonic propeller



Efficiency (a) and Thrust Coefficient (b) curves for high advance ratio propeller



Decay of nett thrust during TO with velocity for different power loadings.

Propeller manufacturers offer propellers covering a range of diameters, pitch values, and solidities. The choice of these parameters can depend on considerations other than the aerodynamic efficiency. For example, to keep the noise level of a propeller low, one may have to employ wide blades with low tip speeds. As another example the propeller diameter is sometimes limited by ground clearance considerations, or by the distance from a nacelle to the fuselage. The dynamics of the propeller must also be matched to the engine. If a propeller being driven by the engine has a natural frequency close to 3/rev. it can lead to excessive vibration and fatigue stresses. *Aerodynamically*, one strives to select a propeller that provides a *high efficiency and sufficient thrust for cruise* and a *high static thrust for takeoff*. These two requirements are easier to satisfy with a automatically variable pitch (constant speed) propeller. A fixed pitch propeller is usually a compromise between these two operating regimes.

Station x	0.3	0.45	0.6	0.7	0.75	0.80	0.85	0.90	0.95	1.00
x^2										
x^3										
Section designation										
Chord b										
$\sigma_R = Bb/(\pi R)$										
β										
$\Omega r = x\Omega R$										
$\phi = \tan^{-1}[V/(\Omega r)]$										
$\sin \phi$										
a_0										
$\beta - \phi$										
θ										
$\phi_0 = \phi + \theta$										
$\alpha_0 = \beta - \phi_0$										
$c_l = a_0 \alpha_0$										
c_d										
$\cos^2 \theta$										
$\cos^2 \phi$										
$\cos \phi_0$										
$\sin \phi_0$										
$c_l \cos \phi_0$										
$c_d \sin \phi_0$										
λ_T										
$c_l \sin \phi_0$										
$c_d \cos \phi_0$										
λ_Q										
dC_T/dx										
dC_Q/dx										
$V/(nD)$										

Data: $V = (\quad)$; $\Omega = (\quad)$; $D = (\quad)$. $C_T = \int_0^1 (dC_T/dx)\,dx$; $C_Q = \int^1 (dC_Q/dx)\,dx$.

Propeller design chart

Station x	0.3	0.45	0.6	0.7	0.75	0.80	0.85	0.90	0.95	1.00
x^2										
x^3										
Section designation										
Chord c										
$\sigma_R = Bc/(\pi R)$.										
β										
$\omega r = x\omega R$ . .										
$\phi = \tan^{-1}[V/(\omega r)]$.										
$\sin\phi$ . . .										
a_0										
$\beta - \phi$ . . .										
α_i .										
$\phi_0 = \phi + \alpha_i$ . .										
$\alpha_0 = \beta - \phi_0$ . .										
$c_l = a_0\alpha_0$ . .										

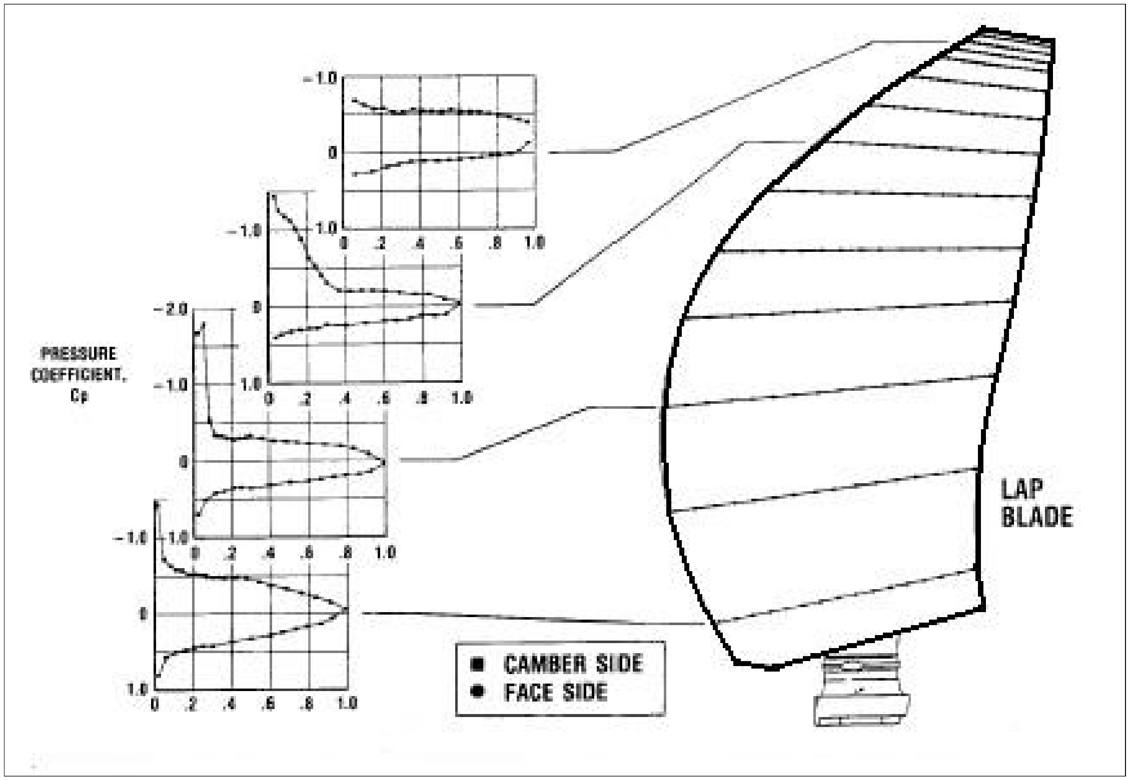
Propeller design chart - Top Half

$c_l = a_0 \alpha_0$										
c_d										
$\cos^2 \theta$										
$\cos^2 \phi$										
$\cos \phi_0$										
$\sin \phi_0$										
$c_l \cos \phi_0$										
$c_d \sin \phi_0$										
λ_T										
$c_l \sin \phi_0$										
$c_d \cos \phi_0$										
λ_Q										
dC_T/dx										
dC_Q/dx										
$V/(nD)$										

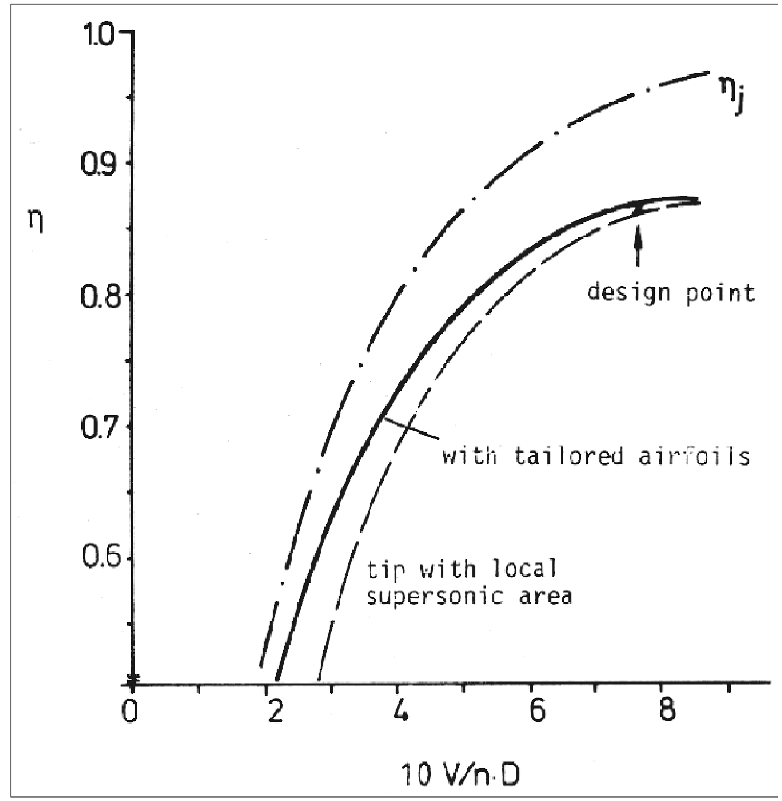
Data: $V = (\quad)$; $\Omega = (\quad)$; $D = (\quad)$. $C_T = \int_0^1 (dC_T/dx)\,dx$; $C_Q = \int^1 (dC_Q/dx)\,dx$.

Propeller Design chart

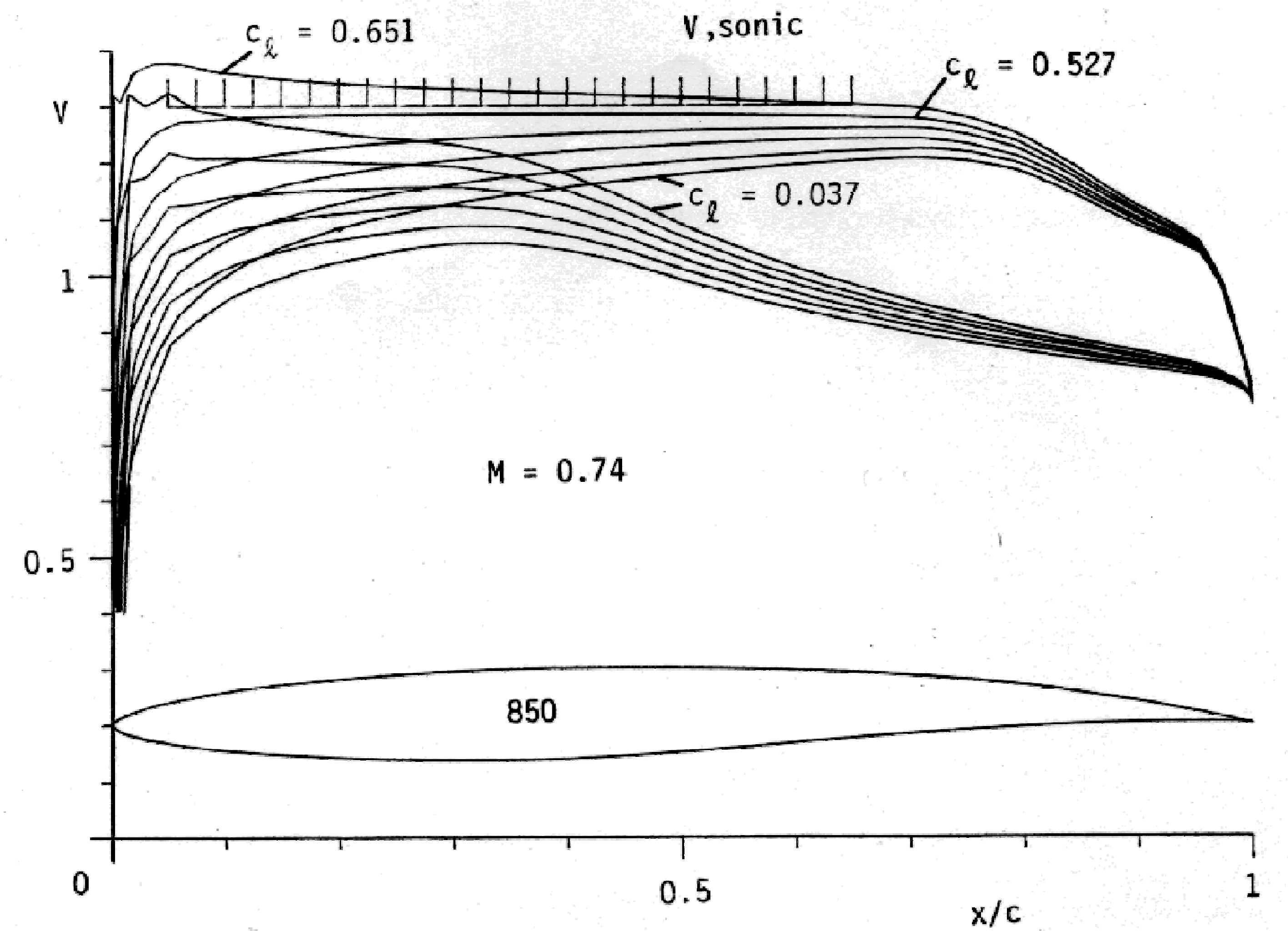
- Bottom half



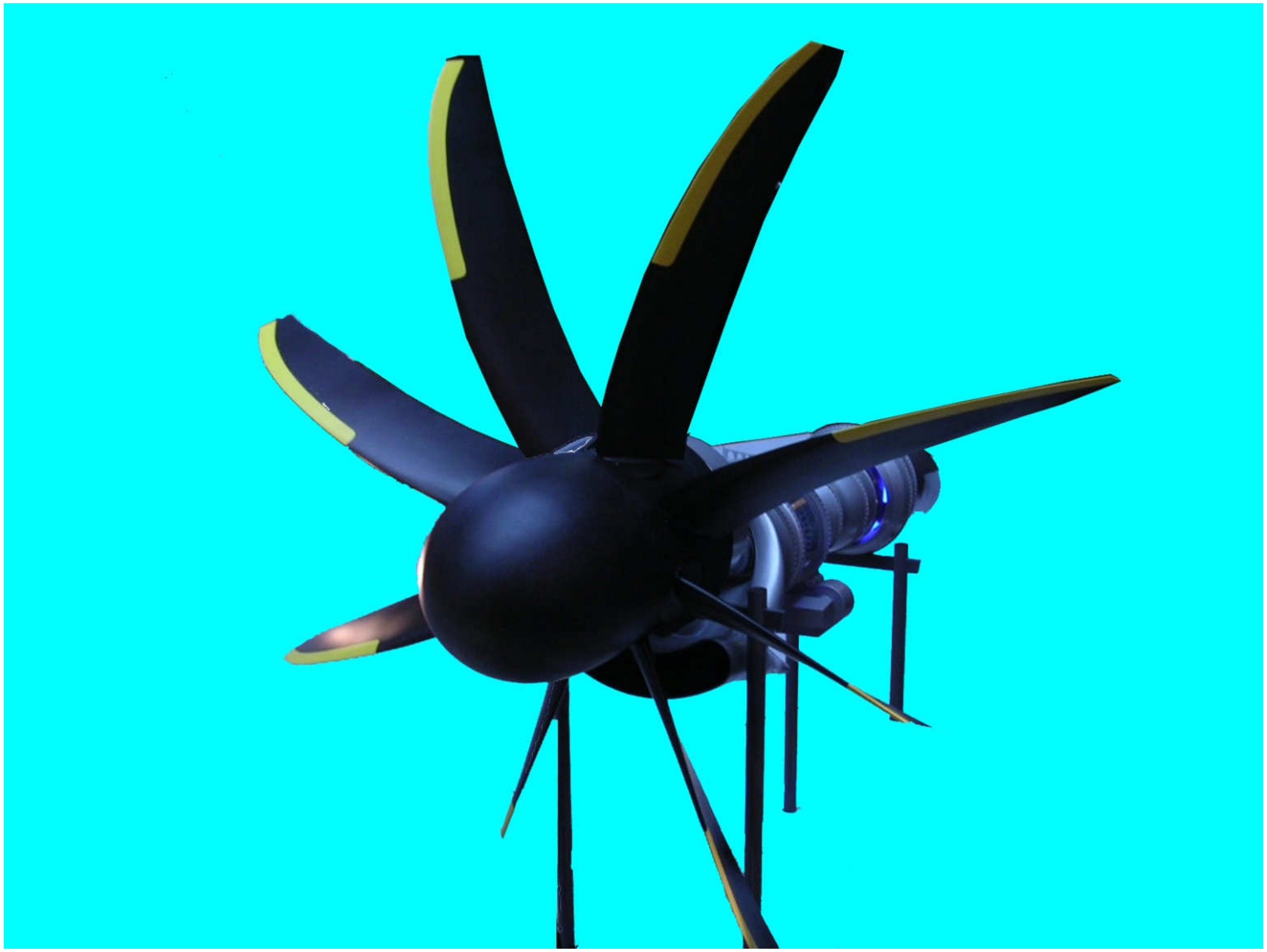
Blade shape and pressure measurements at low speed on a large swept bladed prop-fan



High subsonic propeller efficiency vs advance ratio



Velocity distributions for M = 0.74 for the propeller tip (r/R = 1)



A Modern Swept Back Propeller (8-bladed)