Estimation of Drag Coefficient

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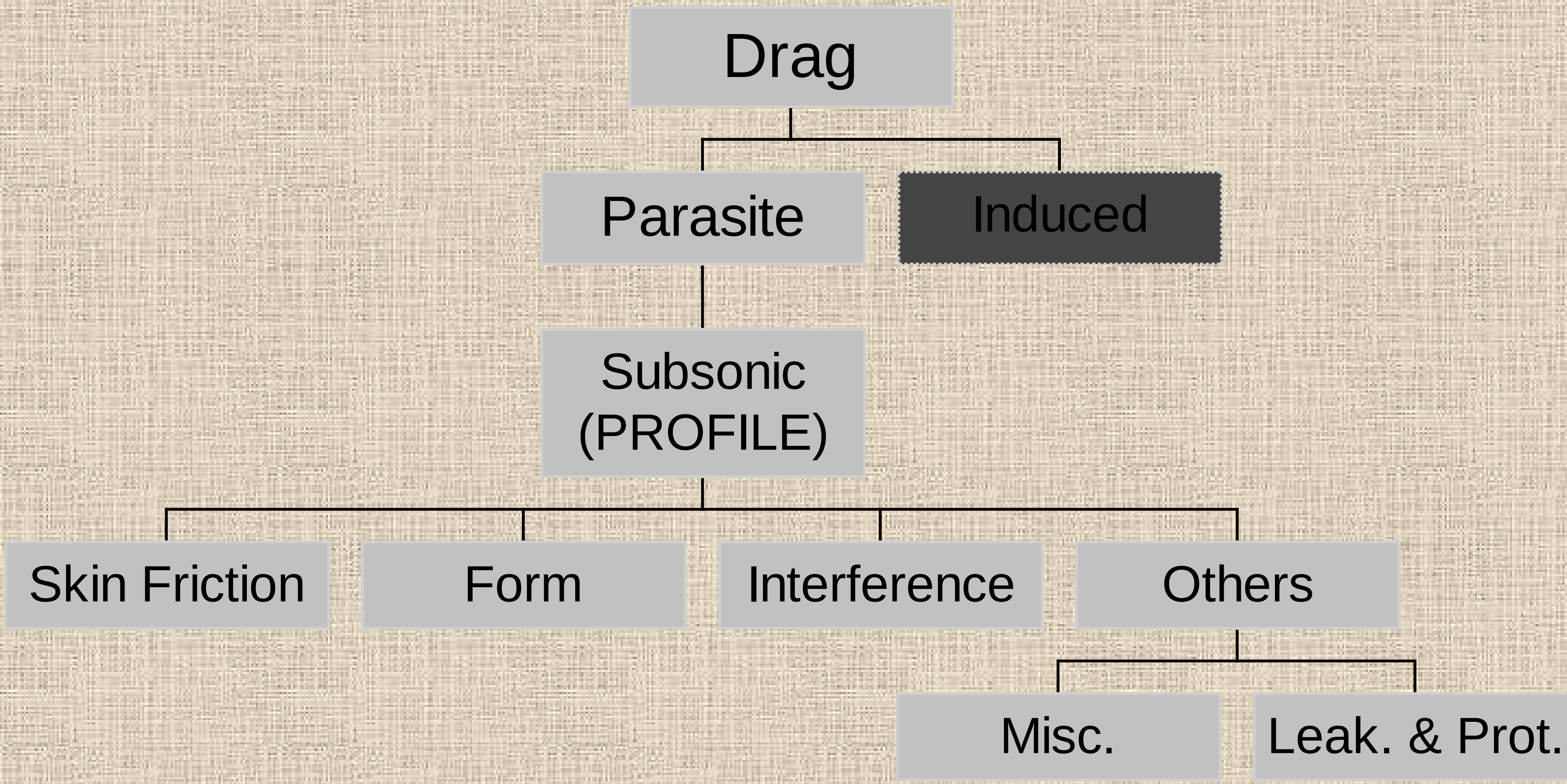
Mostly applicable to Transport Aircraft

SUBSONIC PARASITE DRAG COEFFICIENT ESTIMATION

Subsonic Parasite Drag Components



Two Approaches

Equivalent Skin Friction

- $D_{Parasite} = D_{SF} + D_{press}$
- $= 90\% + 10\%$
- $= D_{SF} + x(D_{SF})$
- C_{fe} = Eq. Skin Friction Coeff.
- $C_{Do} = C_{fe} * (S_{wet}/S_{ref})$

Aircraft type	**$C_{fe} * 10^{-4}$**
High Speed Aircraft	25
Bomber & Transport	30
Military Cargo	35
Airforce Fighter	35
Naval Fighter	40
G.A. Twin Engined	45
G.A. Single Engined	55
Propeller Sea Plane	60

Component Buildup

- $D_{total} = \sum D_{comp} + D_{L\&P} + D_{misc.}$
- $D_{comp.} = D_{SF} + D_{Form} + D_{Interference}$
- $D_{SF} = C_f * S_{wet}/S_{ref}$
- $D_{Form} = FF * D_{SF}$
- $D_{interference} = Q * D_{SF}$
- $D_{misc.}$ = Drag of Misc. Items
  - o Flaps
  - o Unretracted Landing Gear
  - o Upsweft Aft Fuselage
  - o Fuselage Base area
- $D_{L\&P}$ = Drag due to
  - o Leakages
  - o Protuberances

Component Buildup Method

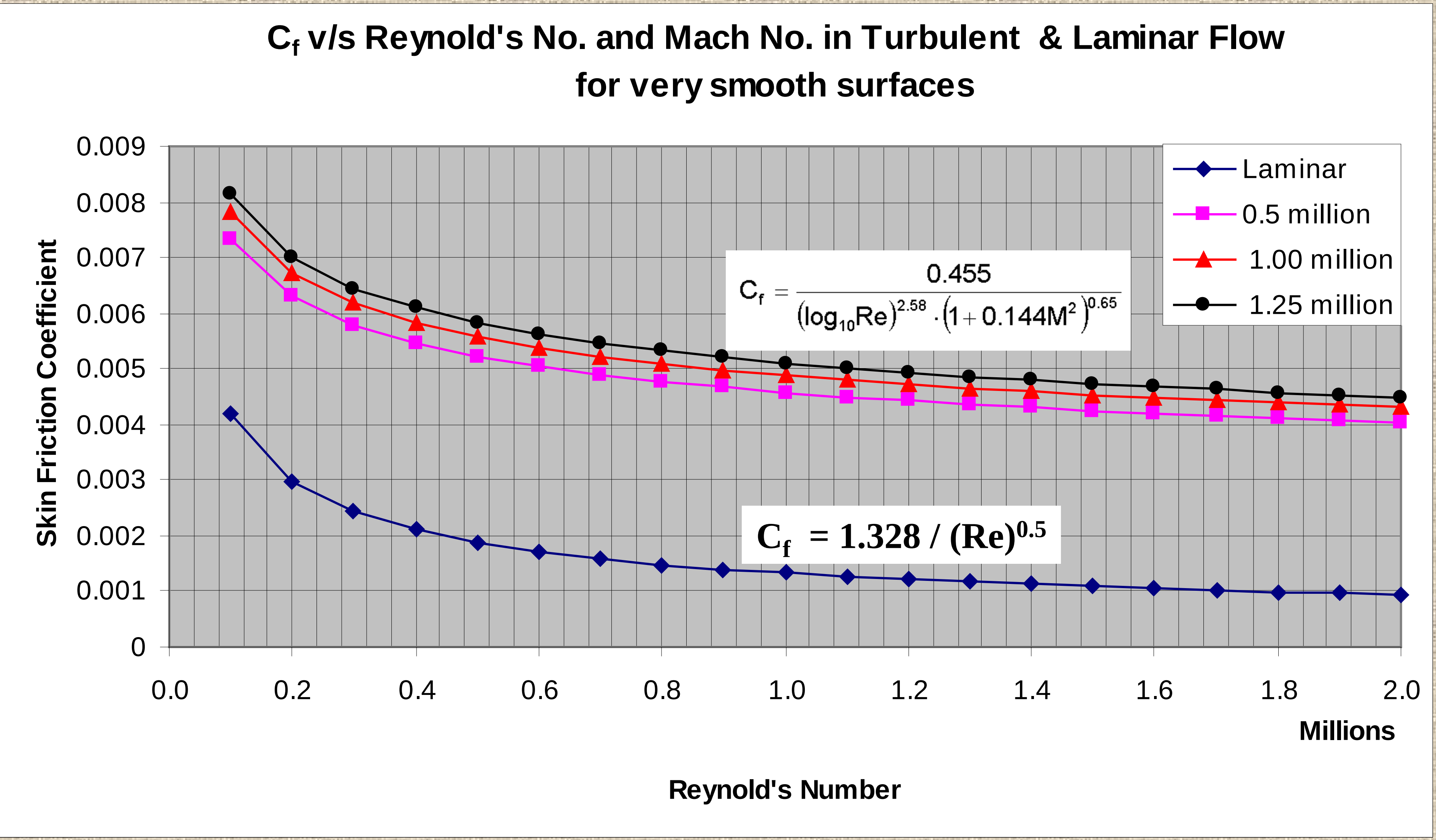
$$C_{D_0} = \frac{\sum \left(C_{F_C} \cdot FF_C \cdot Q_C \cdot S_{wet_C} \right)}{S_{ref}} + C_{D_{misc}} + C_{D_{L\&P}}$$

$C_{F,c}$	=	Flat-plate skin-friction drag coefficient for component c
FF_c	=	Form factor for component c
Q_c	=	Interference factor for component c
$S_{wet,c}$	=	Wetted area for component c
S_{ref}	=	Reference area
$C_{D,misc}$	=	Drag coefficient due to miscellaneous factors
$C_{D,L\&P}$	=	Drag Coefficient for Leakages & Protuberances

Flat Plate Skin Friction Coefficient

- C_f depends on Re, M & k (surface roughness)
- Strong function of extent of Laminar Flow
  - Re > ½ million :Difficult to maintain laminar flow
  - Re = 1 million :Turbulent SFD = 3 x Laminar SFC
    - Very smooth skin (molded composite or polished metal)
      - Typically, over 15-20 % of wing & tails, none over fuselage

Determination of C_f



Piaggio P-180 Avanti
Twin turboprop executive transport

Three Surface Aircraft

V_{max} 400 kt, V_{cr} 350 kt

Laminar Flow over 50% of wing & tail and 35 % of fuselage

NLF wing designed by Ohio University

Effect of surface roughness

- Roughness leads to higher C_f
- Re_{cutoff} used for skin roughness effect
  - If $M < 0.75$: $Re_{cutoff} = 38.21\,(l/k)^{1.053}$
  - Else : $Re_{cutoff} = 44.62\,(l/k)^{1.053} \cdot M^{1.16}$
  - $Re = \min(Re_{cutoff}, Re_{actual})$ in Turbulent Flow
  - l = Characteristic Length

Surface	k (mm)
Camouflage paint on Aluminum	0.1015
Smooth Paint	0.0634
Production Sheet metal	0.0405
Polished Sheet metal	0.0152
Smooth molded composite	0.0052

Estimation of Form Factors

For Wing, HT & VT

$$FF = \left[1 + \frac{0.6}{(x/c)_m}(t/c) + 100(t/c)^4\right] \cdot \left[1.34M^{0.18}(\cos\Lambda_m)^{0.28}\right]$$

For Fuselage

$$FF = \left[1 + \frac{60}{f^3} + \frac{f}{400}\right], \text{where } f = \frac{l}{\sqrt{(4/\pi)A_{max}}}$$

For Nacelle & smooth External store

FF = 1.0+(0.35/f)

f = l/d

- ❑ $(x/c)_m$ = chordwise location of max. thickness
  - = 0.3 for low speed aerofoil
  - = 0.5 for high speed aerofoil
- ❑ Λ_m = sweep of maximum thickness line
- ❑ Pressure Drag due to viscous separation
- ❑ Note: Formulae not valid beyond M_{DD}

Interference Factor (Q)

- Measure of increased drag due to interference between components
  - External store mounted near fuselage has high Q compared to wing-tip mounted missile
- Typical Values of Q
  - Fuselage = 1.00
  - V- Tail = 1.03
  - Conv. Tail = 1.05
  - H-Tail = 1.08

Q factors

- Nacelle & Store mounting
  - Function of
    - Distance of store from fuselage (l) vis-à-vis Fuselage dia (d_{fus})
  - $l = 0$ (mounted directly on Fuselage) $Q = 1.5$
  - $l < d_{fus}$, $Q = 1.3$ $l > d_{fus}$, $Q = 1.0$
  - $Q = 1.25$ for wing-tip mounted missiles
- Wing Location
  - For high / mid wing, or well filleted low wing, $Q = 1.0$
  - For unfilleted low wing, $Q = 1.1$ to 1.4

Leakage & Protuberance Drag

- Leakage
  - Tendency to “inhale/exhale air through holes”
- Protuberances
  - Antennae, lights, door edges, fuel vents, protruding rivets,..
- Estimated as a % of total parasite drag coefficient.
  - Bombers 02-05 %
  - Propeller a/c 05-10 %
  - Fighters 10-15 %

Concept of Drag Area

- Drag Area = DA = C_D . S
- Since D = q S C_D hence DA = D/q
  - Usually, S = S_{ref}
- $C_{Do\ misc}$ = DA / Wing reference area
- Thus, DA is an Indication of Drag Coefficient
- Very common in automobile aerodynamics
  - S_{REF} = Frontal Area
- DA of a bicycle = 0.6 to 0.7 m^2

DA of some cars

Model Name	Drag Area (m^2)
Volkswagen XL1	0.279
Honda Insight	0.474
Hummer H2	2.46

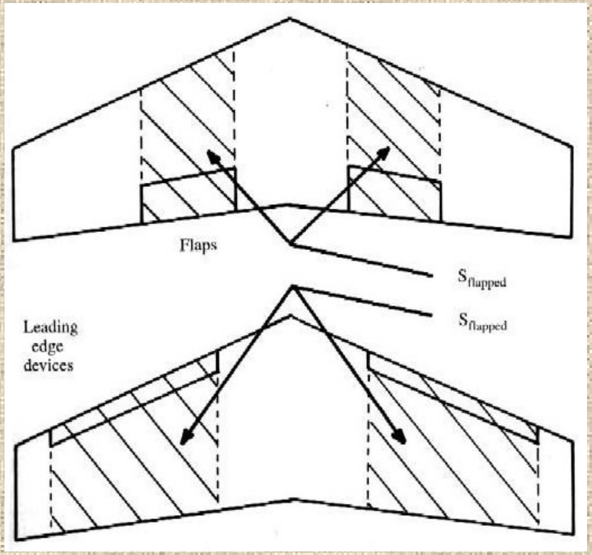
Source: http://en.wikipedia.org/wiki/Automobile_drag_coefficient#Drag_area

Miscellaneous Drag

- Store Drag
  - using empirical relationships for D/q v/s M
- Landing Gear Drag
  - Comparison with test data
  - Component build up, 20% extra for interference
  - 7% additional drag for open gear wells
- Fuselage Upsweep Drag
  - D/q (upsweep) = $3.83u^{2.5}A_{max}$, u in radians

Flap and Speed Brake Drag

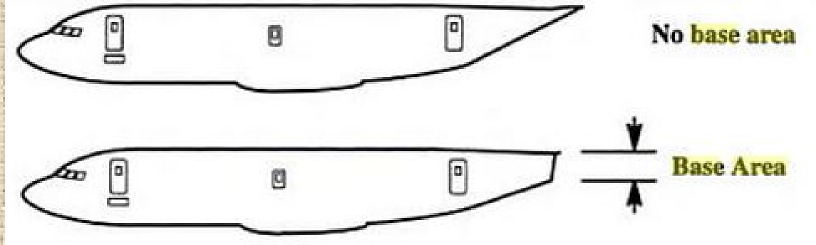
- Flap Drag
  - $\Delta C_{Do\ flap} \cong F_{flap}\ (C_f/C)\ (S_{flapped}/S_{ref})\ (\delta_{flap}\ - 10)$
  - $F_{flap} = 0.0144$ for plain flaps
  - $F_{flap} = 0.0074$ for slotted flaps
  - $\delta_{flap} = 20 – 40^o$ @ Takeoff
  - $\delta_{flap} = 60 – 70^o$ @ Landing



- Speed brake drag
  - $\Delta C_{Do} \cong 1.0$ to 1.6* speed brake frontal area

Base and Canopy Drag

- Fuselage Base Drag
  - A_{base} = area of aft facing flat surface or portions of aft fuselage experiencing highly separated flow
    - If $M < 1$, $D/q_{\,base} = [0.139 + 0.419(M-0.161)^2]\, A_{base}$
    - If $M \geq 1$, $D/q_{\,base} = [0.064 + 0.042(M-3.84)^2]\, A_{base}$
  - *Why Pusher propellers may have low base drag even with high aft fuselage angles?*



- Canopy Drag
  - $D/q \cong K$ * windshield frontal area
    - K = 0.07 for smoothly faired windshield
    - K = 0.15 for sharp edged poorly faired windshield
    - K = 0.50 for open cockpit

Miscellaneous Drag contd.

- Air to Air Cannon port D/q = 0.019 m^2
- Arrestor Hook on naval a/c D/q = 0.014 m^2
- Emergency Arresting hook D/q = 0.009 m^2
- Machine Gun port D/q = 0.002 m^2