Transonic Aerodynamics in Conceptual Aircraft Design

Roelof Vos

Content

- Motivation
- Origins
- Highlights
- Acknowledgements

Motivation

2004

Motivation

Field of application

Flow domain

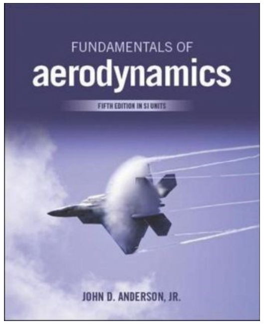
Subsonic

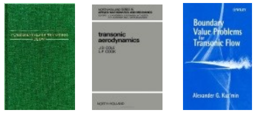
Transonic

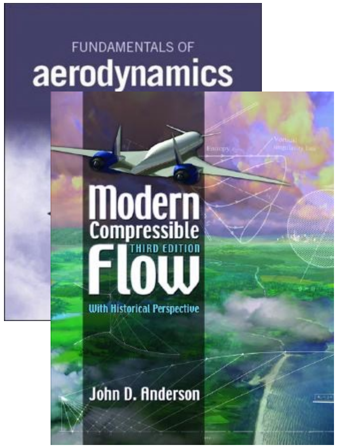
Supersonic

Mach

Suitable Text Book



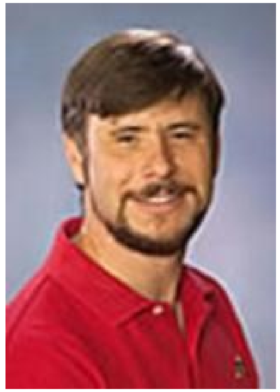


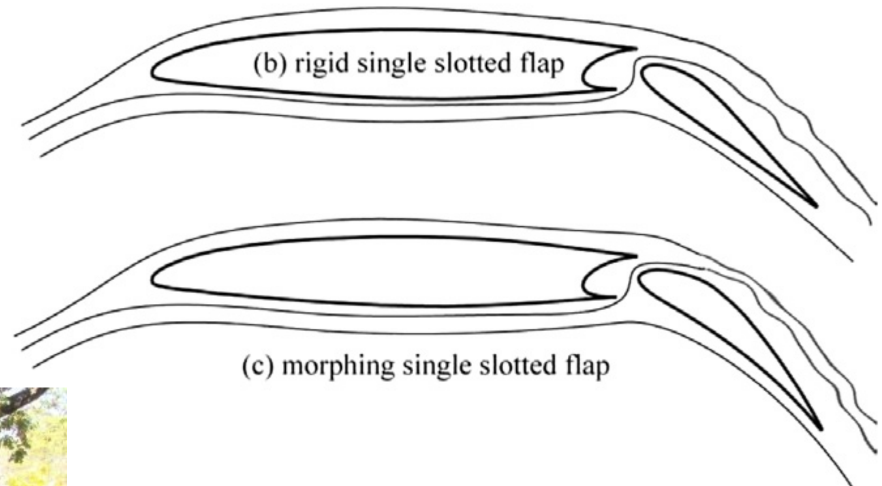


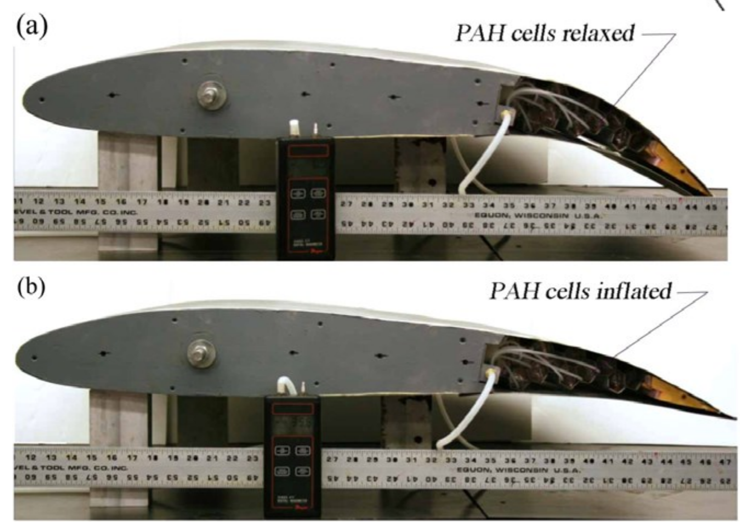
Origins

2008

KU
THE UNIVERSITY OF
KANSAS

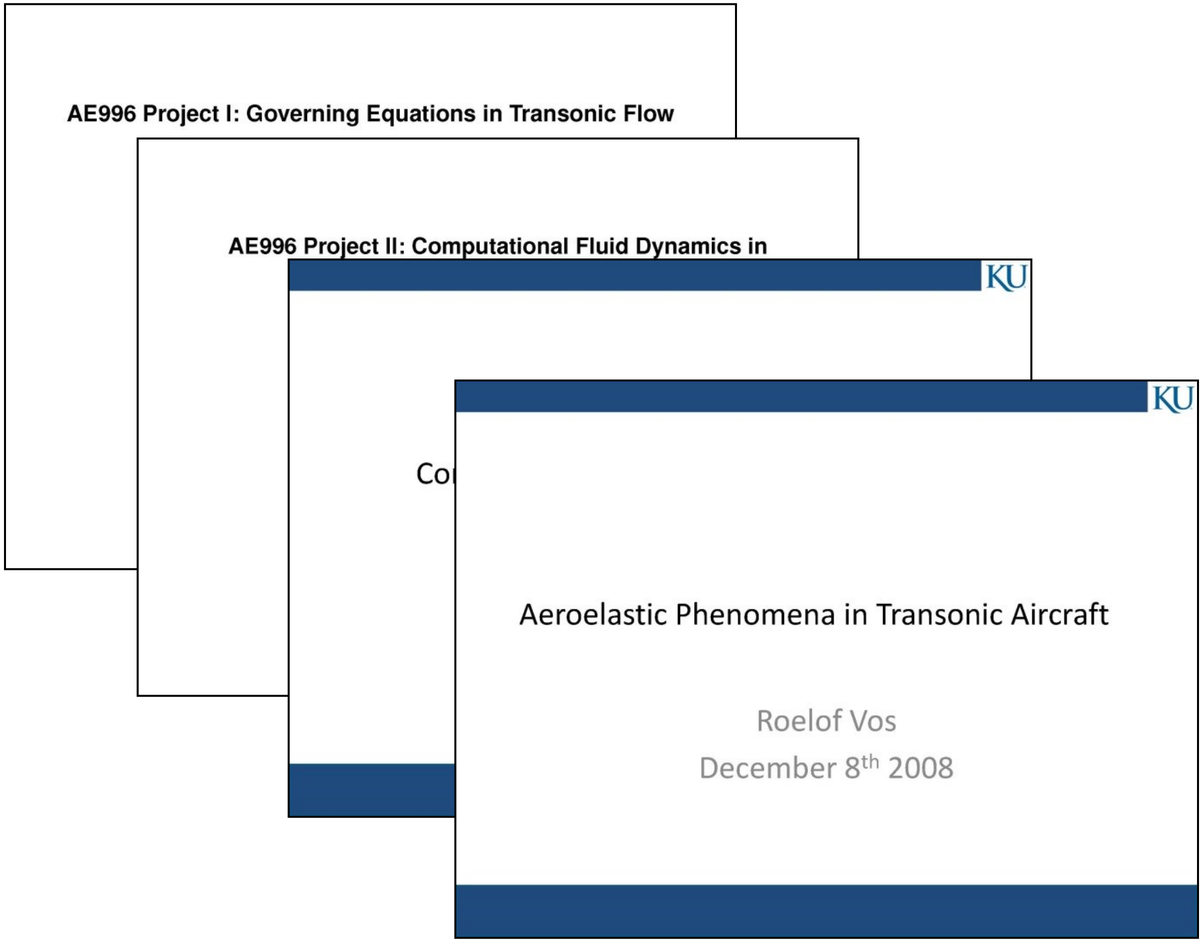




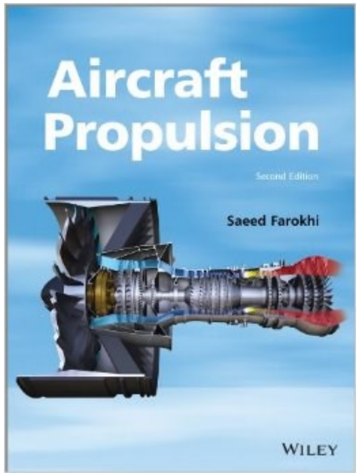


Origins

2008: Special Problems in Aerospace Engineering



Saeed Farokhi

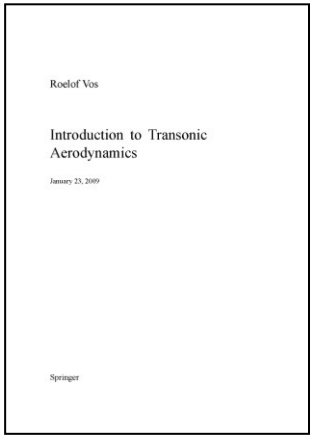


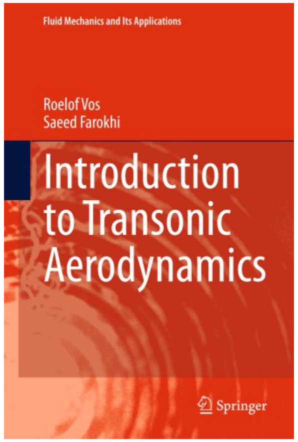
Origins

- IOS Press ✓
- Prentice Hall ✓
- Wiley ✓
- Springer ✓
- AIAA ✗
- Pearson ✓
- CRC Press, Taylor & Francis Group ✓

Contract signed: March 2009

Origins





2009

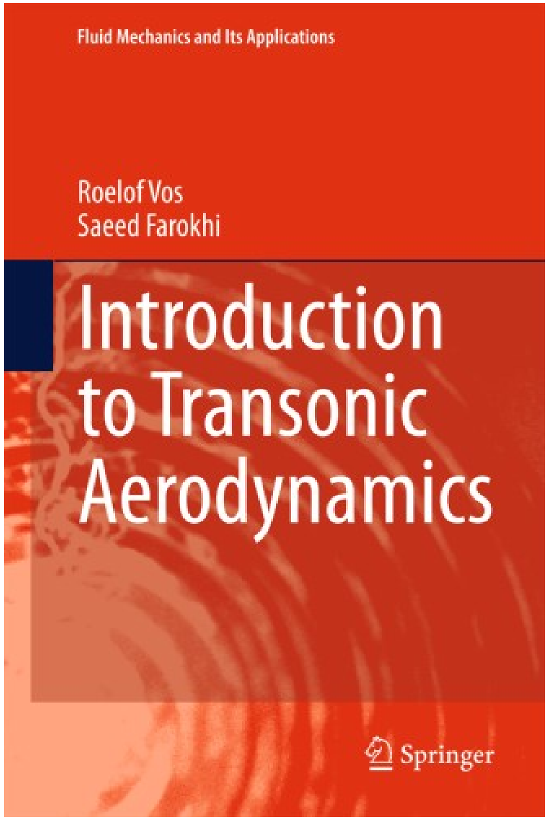
- 1 author
- 4 parts, 18 chapters
- 135 pages
- 37 figures
- 0 examples
- 0 practice problems

2015

- 2 authors
- 8 chapters
- 559 pages
- 440 figures
- 60 examples
- 220 practice problems
- Look-up tables
- Solutions
- Index

Highlights

1. Introduction and Historic Perspective
2. Review of Fundamental Equations
3. Transonic Similarity Rules
4. Shock and Expansion Theory
5. Method of Characteristics
6. Aerodynamics of Nonlifting Bodies
7. Airfoil Aerodynamics
8. Aerodynamics of Swept Wings



Highlights

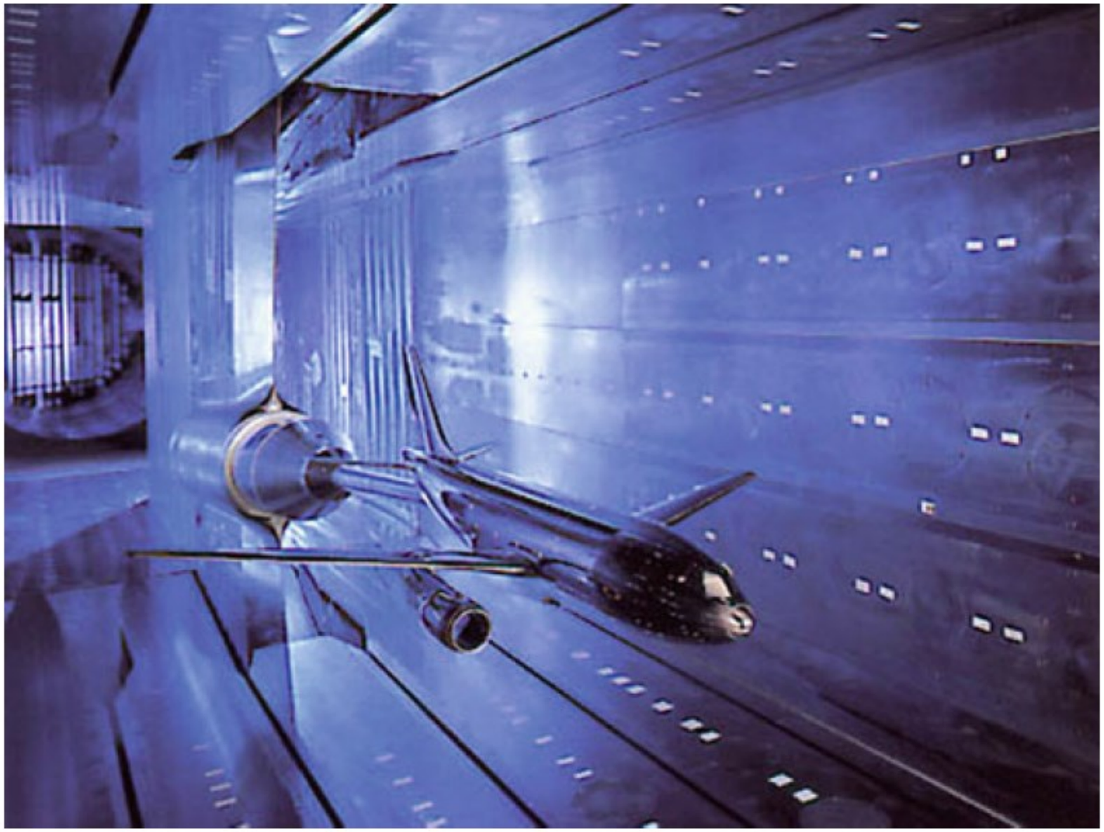


Fig. 1.6 ETW wind tunnel with aircraft model (*Photo* ETW; printed with permission)

Highlights

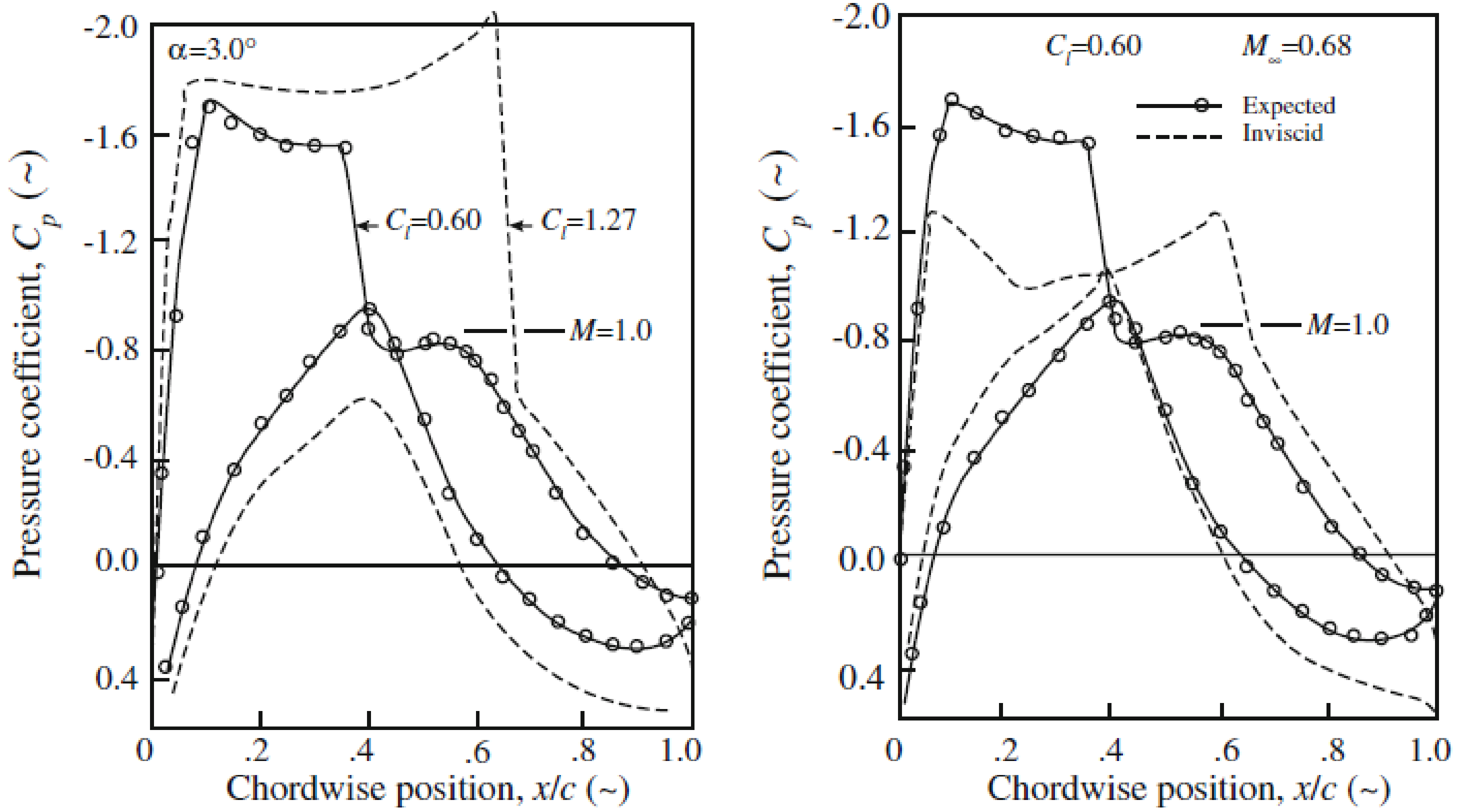


Fig. 2.12 Comparison between predicted and measured pressure distribution at constant angle of attack (*left*) and constant lift coefficient (*right*) (after Ref. [5])

Highlights

3.5 3-D Planar and Axisymmetric Slender Bodies 125

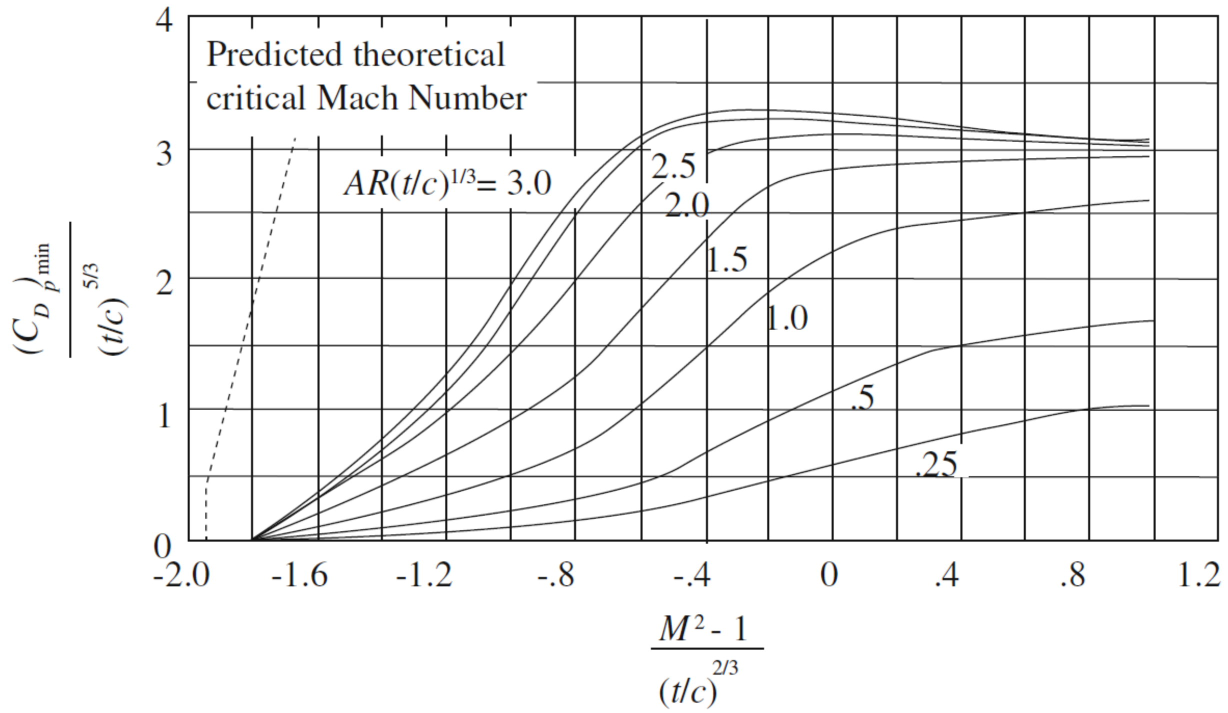


Fig. 3.21 Curves of the generalized drag coefficient for symmetrical wings for $\gamma = 1.4$ (after Ref. [6])

Highlights

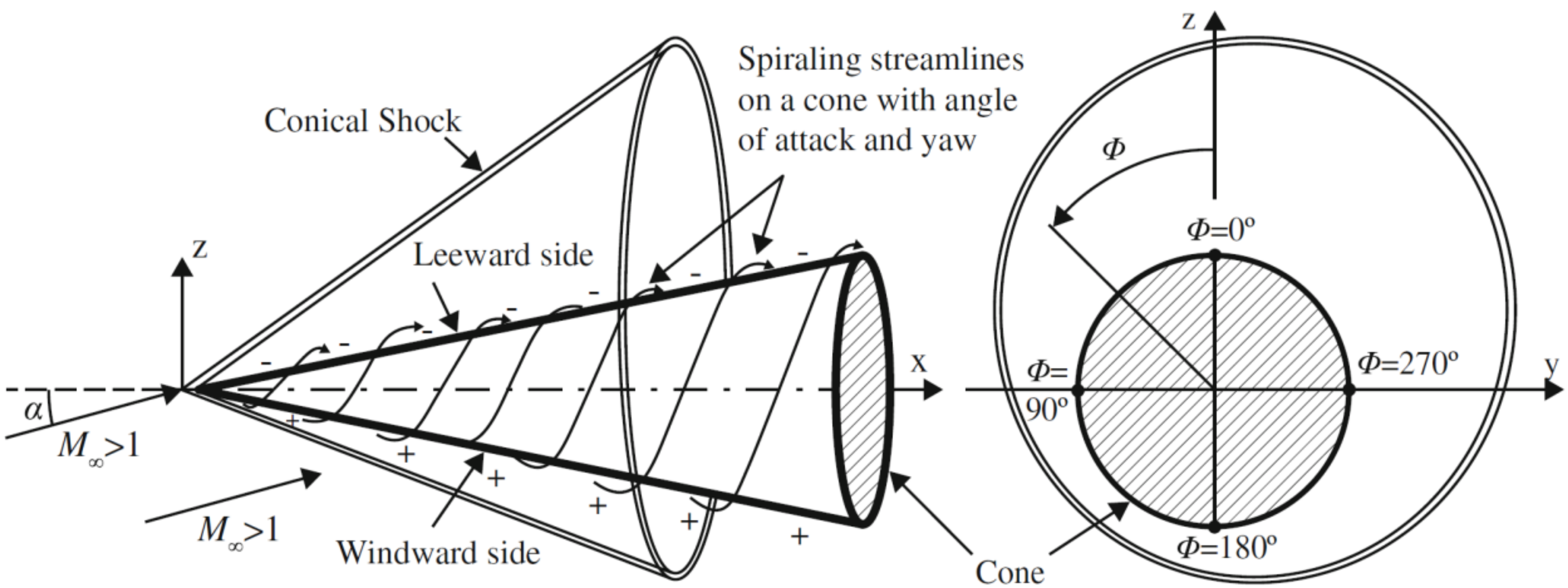


Fig. 4.29 Spiraling streamlines on a cone in supersonic flow at angle of attack and yaw

Highlights

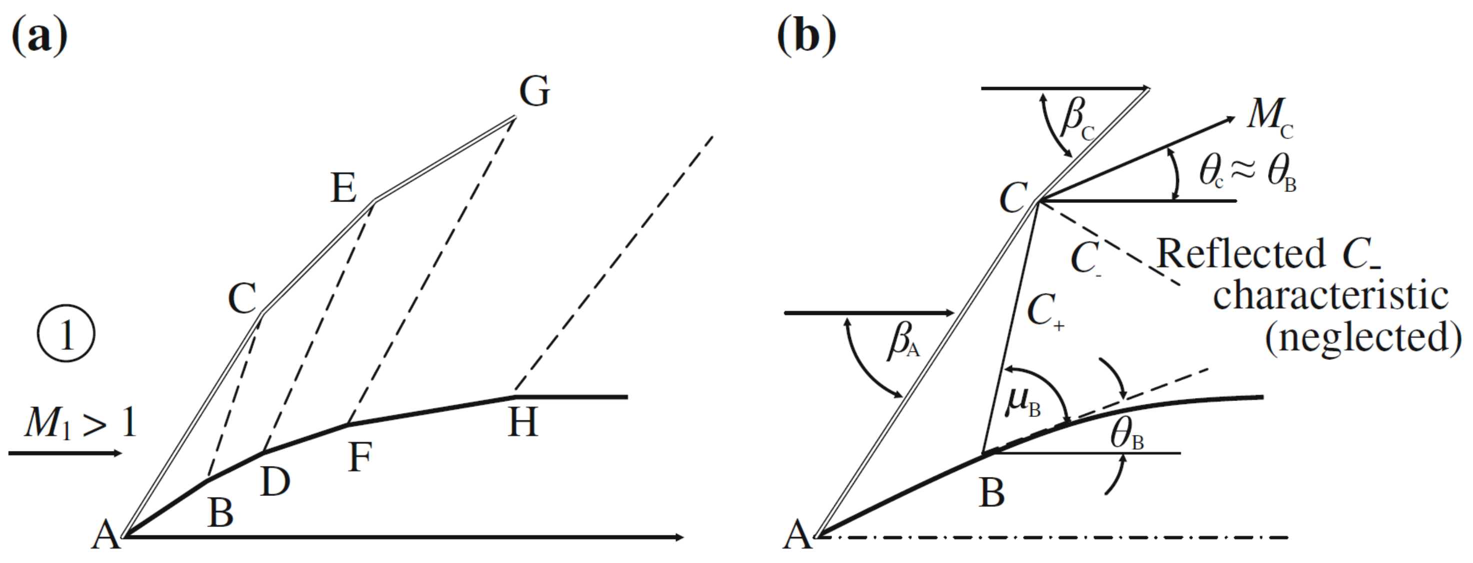


Fig. 5.35 The waves on a slender body in supersonic flow **a** Interaction of Mach waves and an oblique shock (simplified view), **b** expanded view of the flow and shock angles

Highlights

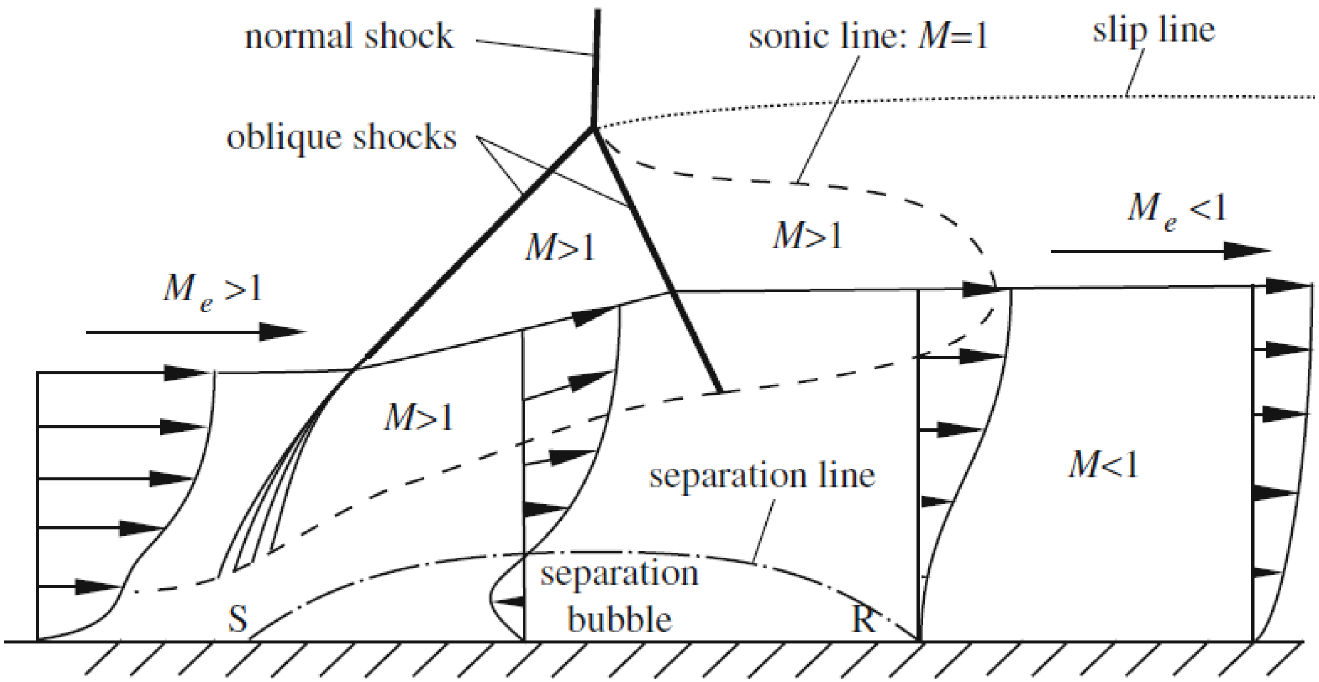


Fig. 6.41 Detail of strong shock-wave boundary-layer interaction for a turbulent boundary layer (after: [16])

Highlights

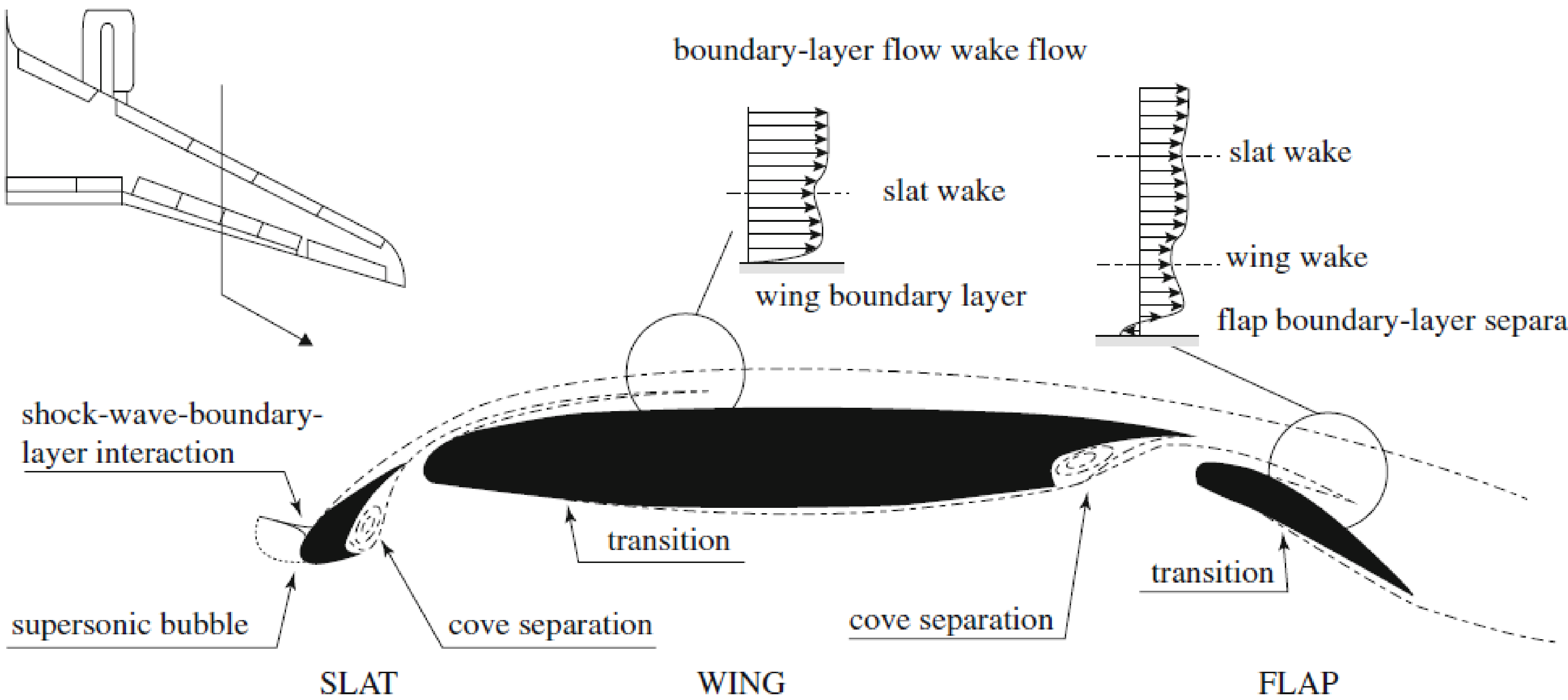


Fig. 7.29 A320 airfoil in landing configuration (modified from Ref. [13])

Highlights

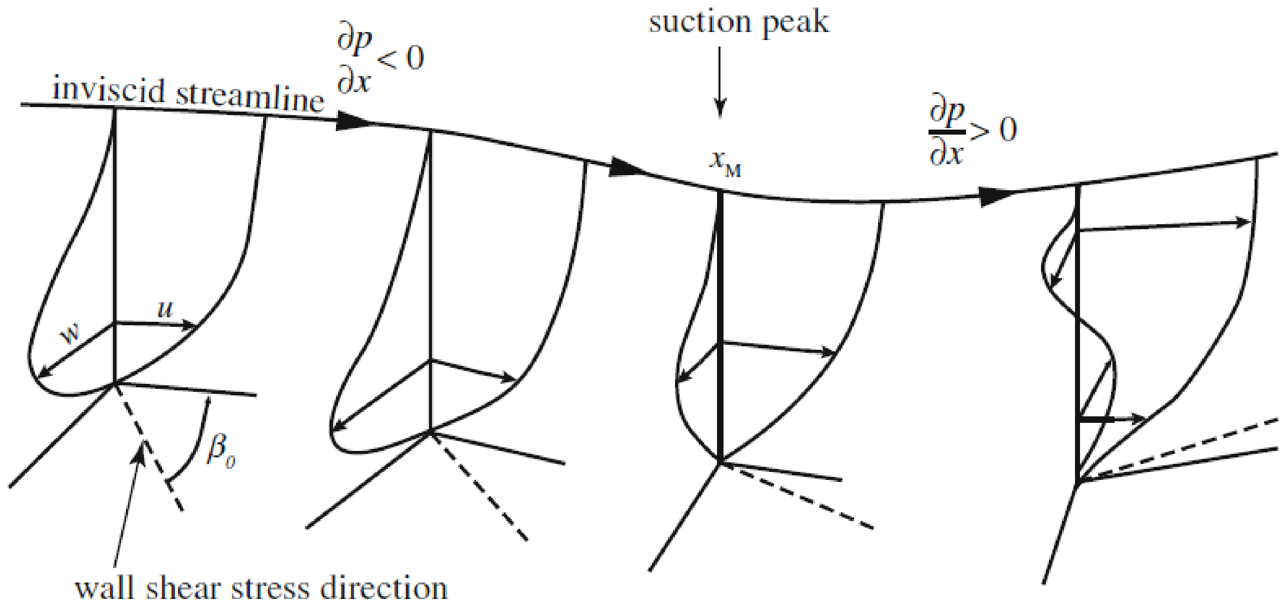
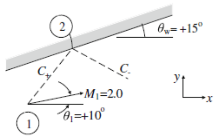


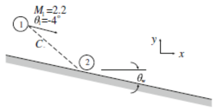
Fig. 8.29 Laminar boundary layer development on a swept wing. x_M is the location of the inviscid streamline inflection point. β_0 is the angle between the wall shear stress vector and the inviscid streamline (after Ref. [9])

Highlights

problems

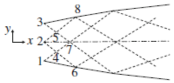


5.2 In a steady, 2-D, irrotational, isentropic supersonic nozzle flow, we have the flow Mach number and direction at point 1, as shown. The nozzle wall is straight and makes an angle, $\theta_w = -9.5°$ with respect to x-axis. Calculate the flow Mach number on the nozzle wall that corresponds to the C_- characteristic that passes through point 1 (i.e., point 2, M_2). Also calculate the slope of the C_- characteristic, dy/dx, between points 1 and 2.



5.3 Based on the initial data line in a diverging section of a 2-D supersonic nozzle, as shown, $M_1 = M_3 = 1.6, \theta_1 = -\theta_3 = -15°$, $M_2 = 1.8, \theta_2 = 0°$. Use Method of Characteristics (MOC) for 2-D irrotational flow to calculate:

(a) M_5 and θ_5
(b) M_7 and θ_7



5.4 A 2-D C_+ characteristic intersects an oblique shock, as shown. Assuming the flow angle at point 2 is 12°, calculate:

(a) Oblique shock angle, β_2
(b) Downstream Mach number, M_2
(c) Constants K_{+1} and K_{+2}
(d) Was the assumption about θ_2 correct?

solutions

4.27

(a) $\bar{R} = 6.5$
(b) $\delta_0 = 22.6$
(c) $C_{pp} = 0.05, C_{pv} = 0.20$
(d) $C_D = 0.118$

4.31

(a) $\sigma = 48°$
(b) $M_c = 0.8$
(c) $C_{D_p} = 0.65$

4.33

(a) $C_{p1} = 0, C_{p2} = 0.837$
(b) $c_d = 0.4835$
(c) $c_l = 0.8374$

4.35 $M_3 = 2.85$

4.39

(a) $|\alpha| > 3°$
(b) $\alpha = \pm 2.5°$

Chapter 5

5.1 $M_2 \approx 2.2$, $dy/dx = 0.869$

5.3

No	K_-	K_+	θ (deg)	ν (deg)	M	μ (deg)
1	−0.14	−29.86	−15	14.86	1.6	36.68
2	20.73	−20.73	0	20.73	1.8	33.75
3	29.86	0.14	15	14.86	1.6	36.68
4	20.73	−29.86	−4.565	25.295	1.96	30.68
5	29.86	−20.73	4.565	25.295	1.96	30.68
6	20.73	−29.86	−4.565	25.295	1.96	30.68
7	29.86	−29.86	0	29.86	2.1	28.44
8	29.86	−20.73	4.565	25.295	1.96	30.68

5.5

(a) $\theta_{w,max} = 22.875°$
(c) $dy/dx = -2.37$
(d) $dy/dx = 0.3823$

Highlights

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Appendix B
Normal Shock Table

Table B.1 shows the normal shock table for $\gamma = 1.4$.

Table B.1 Normal shock table for $\gamma = 1.4$

M_1	M_2	T_2/T_1	p_2/p_1	ρ_2/ρ_1	p_{t2}/p_{t1}	P_{t2}/p_1	$\Delta s/R$
1	1	1	1	1	1	1.8929	0
1.02	0.9805	1.01E+00	1.05E+00	1.03E+00	1.00E+00	1.94E+00	9.96E-06
1.04	0.962	1.03E+00	1.10E+00	1.07E+00	1.00E+00	1.98E+00	7.67E-05
1.06	0.9444	1.04E+00	1.14E+00	1.10E+00	1.00E+00	2.03E+00	2.49E-04
1.08	0.9277	1.05E+00	1.19E+00	1.13E+00	9.99E-01	2.08E+00	5.69E-04
1.1	0.9118	1.06E+00	1.25E+00	1.17E+00	9.99E-01	2.13E+00	1.07E-03
1.12	0.8966	1.08E+00	1.30E+00	1.20E+00	9.98E-01	2.19E+00	1.79E-03
1.14	0.882	1.09E+00	1.35E+00	1.24E+00	9.97E-01	2.24E+00	2.74E-03
1.16	0.8682	1.10E+00	1.40E+00	1.27E+00	9.96E-01	2.29E+00	3.96E-03
1.18	0.8549	1.12E+00	1.46E+00	1.31E+00	9.95E-01	2.35E+00	5.45E-03
1.2	0.8422	1.13E+00	1.51E+00	1.34E+00	9.93E-01	2.41E+00	7.23E-03
1.22	0.83	1.14E+00	1.57E+00	1.38E+00	9.91E-01	2.47E+00	9.31E-03
1.24	0.8183	1.15E+00	1.63E+00	1.41E+00	9.88E-01	2.53E+00	1.17E-02
1.26	0.8071	1.17E+00	1.69E+00	1.45E+00	9.86E-01	2.59E+00	1.44E-02
1.28	0.7963	1.18E+00	1.74E+00	1.48E+00	9.83E-01	2.65E+00	1.75E-02
1.3	0.786	1.19E+00	1.81E+00	1.52E+00	9.79E-01	2.71E+00	2.08E-02
1.32	0.776	1.20E+00	1.87E+00	1.55E+00	9.76E-01	2.78E+00	2.45E-02
1.34	0.7664	1.22E+00	1.93E+00	1.59E+00	9.72E-01	2.84E+00	2.86E-02
1.36	0.7572	1.23E+00	1.99E+00	1.62E+00	9.68E-01	2.91E+00	3.30E-02
1.38	0.7483	1.24E+00	2.06E+00	1.65E+00	9.63E-01	2.98E+00	3.77E-02
1.4	0.7397	1.25E+00	2.12E+00	1.69E+00	9.58E-01	3.05E+00	4.27E-02
1.42	0.7314	1.27E+00	2.19E+00	1.72E+00	9.53E-01	3.12E+00	4.81E-02
1.44	0.7235	1.28E+00	2.25E+00	1.76E+00	9.48E-01	3.19E+00	5.38E-02

(continued)

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Fluid Mechanics and Its Applications 110, DOI 10.1007/978-94-017-9747-4

Highlights

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Fluid Mechanics and Its Applications 110, DOI 10.1007/978-94-017-9747-4

Glossary

Latin symbols

A	Cross-sectional area or axial force (m^2, N)
a	Ambient speed of sound ($a = \sqrt{\gamma RT}$) (m/s^2)
$\mathcal{R}$	Aspect ratio (~)
B	Non-dimensional constant in *law of the wake* (6.109) (~)
b	Wing span (m)
C	Characteristic curve in physical space (N/A)
c	Chord length, wave propagation speed, or specific heat capacity in a soild (m, m/s, J/kg/K)
c_a	Section axial force coefficient (~)
C_D	Three-dimensional drag coefficient or dissipation coefficient (~, ~)
c_d	Section drag coefficient (~)
C_f	Friction coefficient $C_f = \frac{1}{c}\int_0^l c_f \mathrm{d}x$ (~)
c_f	Local friction coefficient (~)
C_L	Lift coefficient (~)
c_l	Section lift coefficient (~)
c_m	Section moment coefficient (~)
c_n	Section normal force coefficient (~)
C_p	Pressure coefficient (~)
c_p	Specific heat at constant pressure (J/kg/K)
c_v	Specific heat at constant volume (J/kg/K)
D	Drag (N)
E	Young's modulus (N/m^2)
e	Internal energy, Oswald factor or normalized distance between elastic axis and aerodynamic center (J/kg, ~, ~)
E_t	Total energy (J/m^3)
F	Fineness ratio of a body (~)
G	Shear modulus (N/m^2)
g	Gravitational constant (m/s^2)

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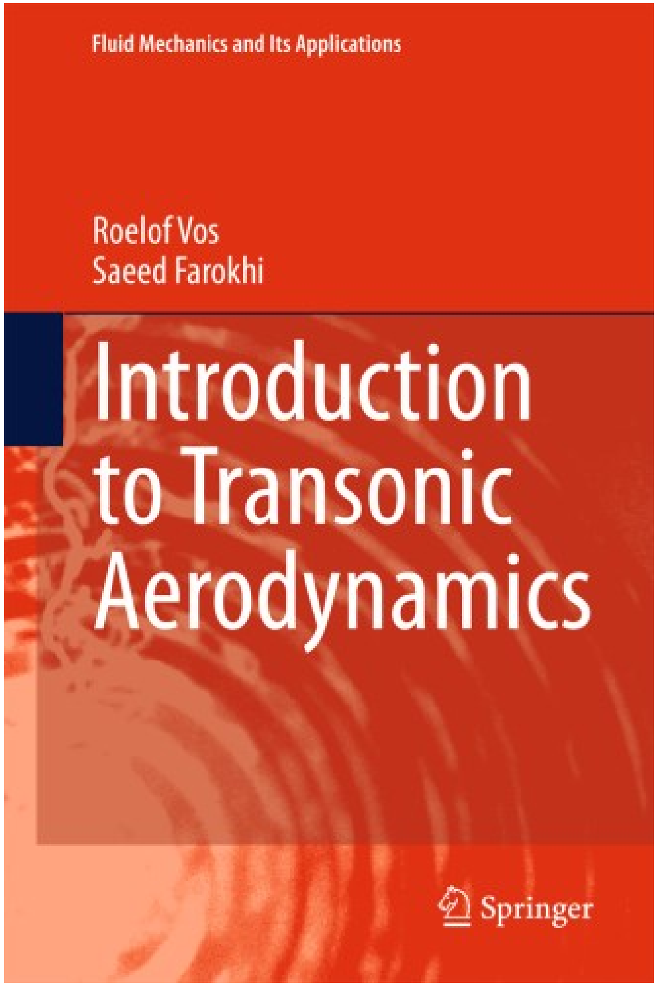
R. Vos and S. Farokhi, *Introduction to Transonic Aerodynamics*,
Fluid Mechanics and Its Applications 110, DOI 10.1007/978-94-017-9747-4

Acknowledgements

- TU Delft leadership:
  - Leo Veldhuis
  - Hester Bijl
  - Michel van Tooren
- Feedback + assistance:
  - Egbert Torenbeek
  - Ali Elham
  - Luca Guadani
- Student assistants:
  - Lisanne van Veen
  - Kevin Haagen
  - Maaike Weerdesteyn
  - Thomas Stasny
  - Amool Raina

Questions?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