University of Stuttgart, Aerospace Engineering and Geodesy Dept.

- Lecture -

Hypersonic flow and flight

Master Level, Specialization

4 lecture hours per week in WS, 3-6 LPs/ECTS

Lecturer:

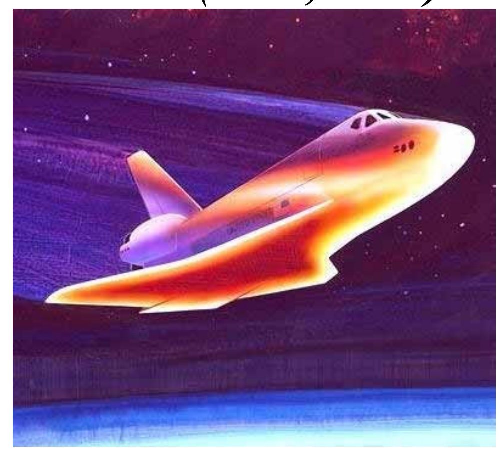
Dr. Markus J. Kloker

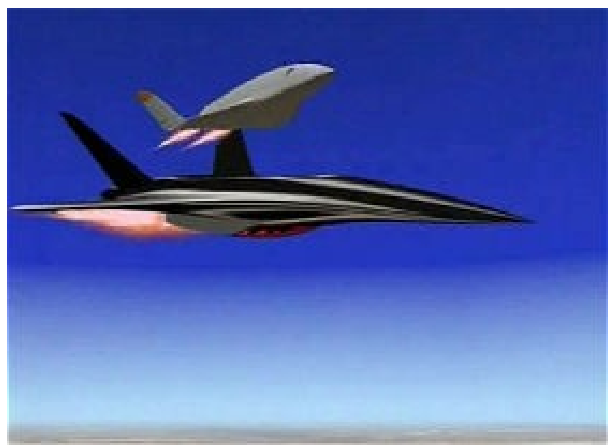
NASP Study (USA, 1986)

X-43 (USA, 2005)

Dryden Flight Research Center ED98-44824-1
X-43/Hyper -X aircraft. NASA/Dryden Illustration by Steve Lighthill

Shuttle (USA, 1981)





Sänger-Studie (GER) 1963/88

When which body shape and why?

Contents (1)

Contents (3)

Contents (4)

Basic literature

[1] John D. Anderson Jr.: *Hypersonic and High-Temperature Gas Dynamics*.
AIAA, 2006, 2nd edition (McGraw-Hill, 1989), ISBN 1-56347-780-7 (ca. € 95)

[2] Ernst H. Hirschel: *Basics of Aerothermodynamics.*
Springer, 2004, ISBN 3-540-22132-8 (ca. € 65/95)

[3] Johann T. Heynatz: *Hyperschallströmungen – Grundlagen und Hinweise.*
Verlag Dieter Thomas, 1997, ISBN 3-931776-11-5 (ca. € 34)

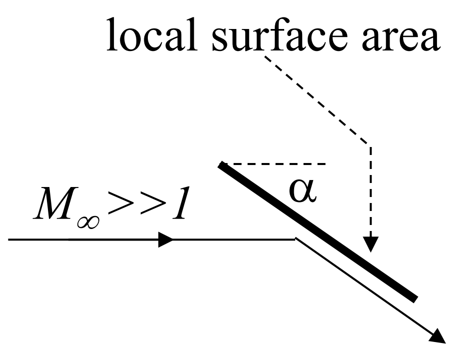
[4] John D. Anderson Jr.: *Modern Compressible Flow.*
McGraw-Hill, 3rd ed. 2004, ISBN 978-0071241366 (€ 60-220).

[5] Maurice Rasmussen: *Hypersonic Flow.*
Wiley Interscience, 1994, ISBN 0-471-51102-1 (€ 185)

[6] Frank M. White: *Viscous Fluid Flow.*
McGraw-Hill, 3rd ed. 2005, ISBN 978-0071244930 (€ 60-220)

[7] Hermann Schlichting, Klaus Gersten: *Boundary-Layer Theory.*
Springer, 8th ed. 2003, ISBN 3-540-66270-7 (or: previous eds. McGraw-Hill)

Newtonian Theory for inviscid c_p, c_D, c_L



Locally: $c_p = c_{ps} \sin^2\alpha$

- *Newtonian:* $c_{ps} = 2$
- *modif. Newt.* $c_{ps} = 1.84$ *(air)* *(> 1!)*

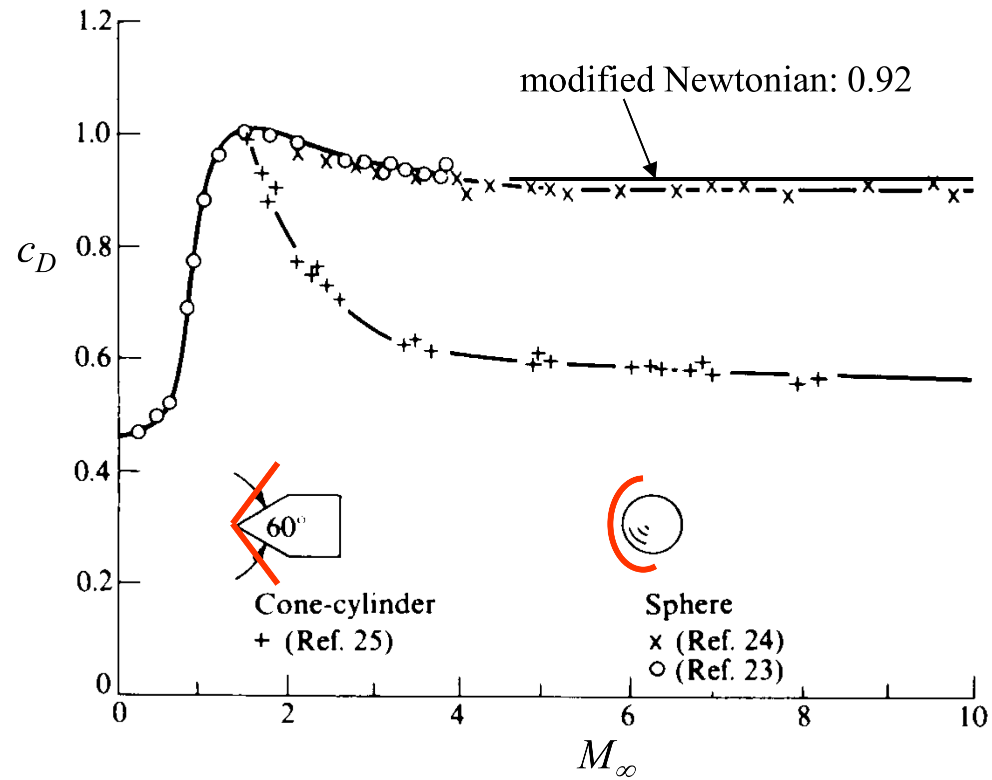


Fig. Drag coefficient for a sphere and cylinder with conical forebody as a function of Mach number (symbols: flight experiments) [1]. Mach number independence starts earlier for blunt bodies because of larger shock angles. c_D *(sphere,* M_∞*=0)* is for $10^3 \leq Re_D \leq 10^5$ (laminar separation).

Laminar-turbulent Transition (5)

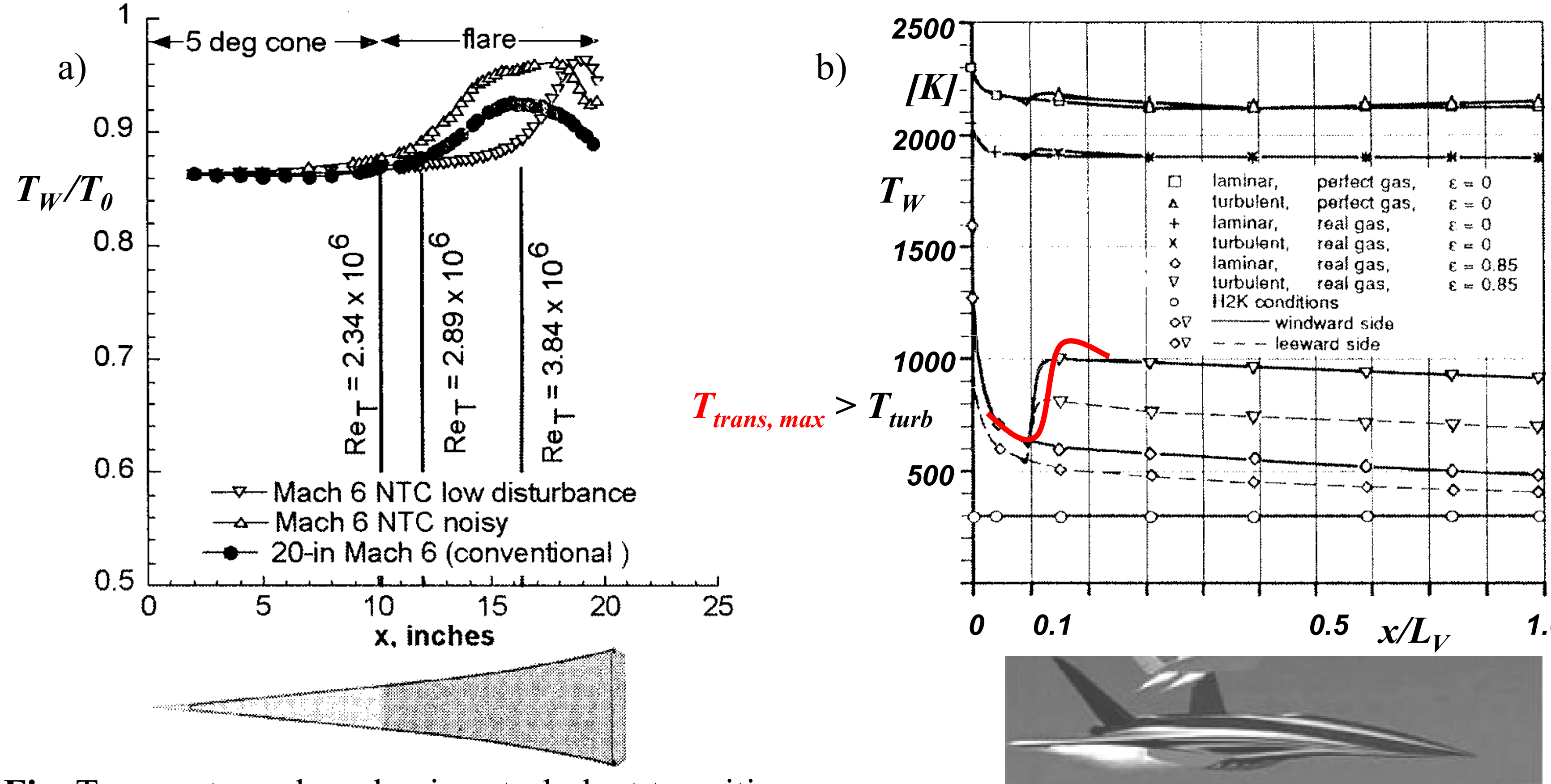


Fig. Temperature along laminar-turbulent transition
a) pointed circular cone with flare, $M=6$, $R_{nose}=2.5\mu m$ [Horvath et. al, RTO-RSM-AVT-111, Prag, 2004].
b) symmetry line for Sänger lower stage, $Re_{unit}=1.5\cdot10^6/m$, $L_V=55m$, $M=6.8$, $\alpha=6°$ at adiabatic ($\varepsilon=0$) and radiation-adiabatic (cooled, $\varepsilon=0.85$) wall; steady CFD with transition position fixed [2]). With radiative equilibrium the temperature increase is strong. During transition the turbulent value is often surpassed.

Viscous interaction (1)

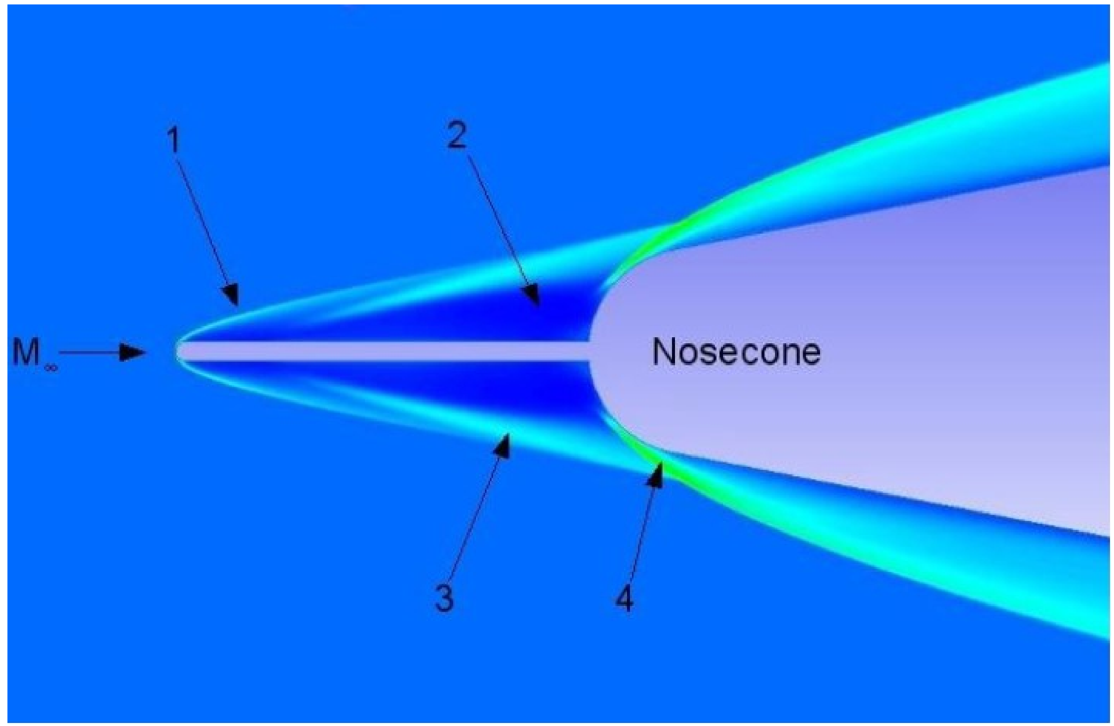


Fig. a Effect of an aerospike.
1 – front shock by spike, 2 – recirculation region, 3 – separation shock, 4 – re-attachment shock.
Density, Mach 7, thesis by Gauer, HyShot-IAG, 2006 (2-d axisymmetric CFD).

Viscous interaction (2)

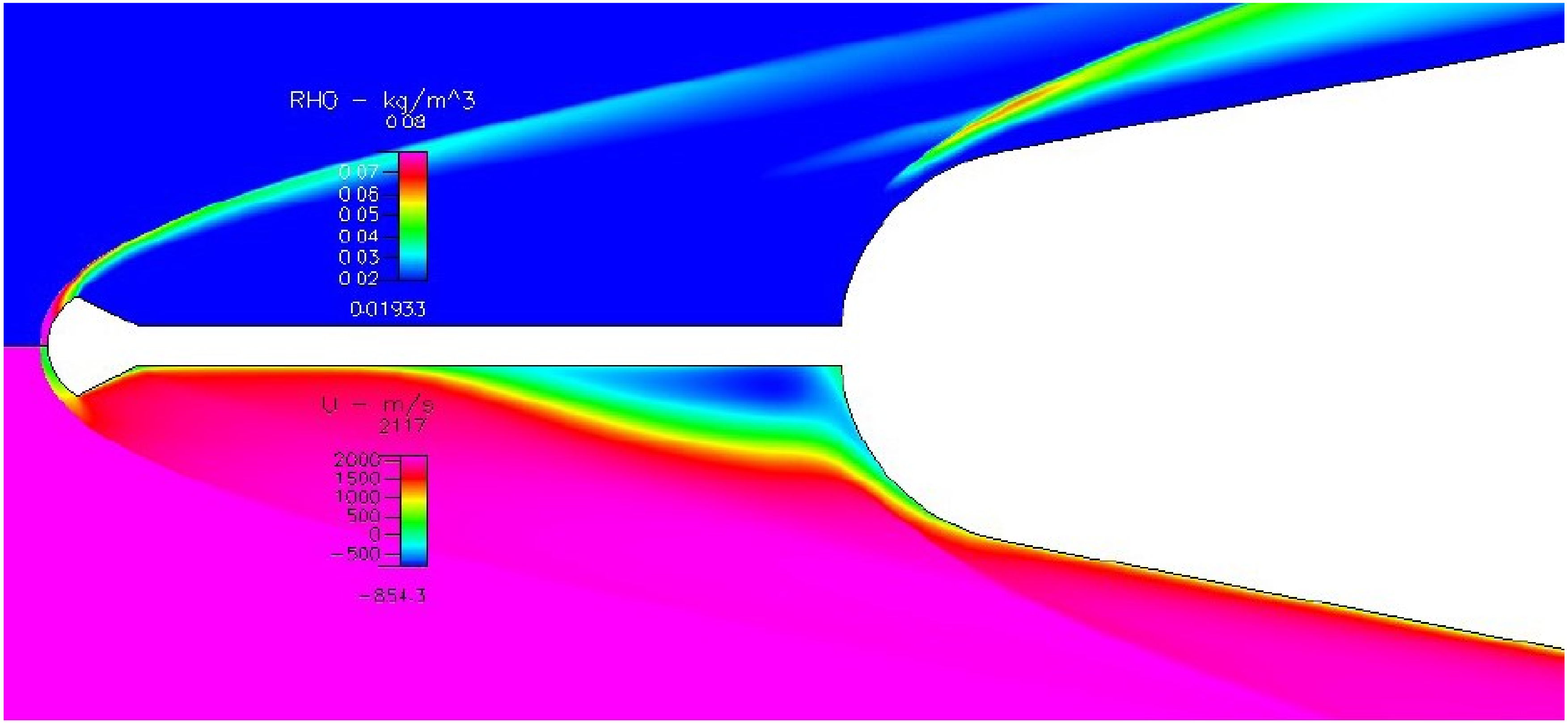


Fig. b Aerospike with L/D=2, D/d=4, density- and axial velocity at M=7.
L – spike length, D – nose diameter of main body, d – of forebody; drag reduction: 46%.

Viscous interaction (3)

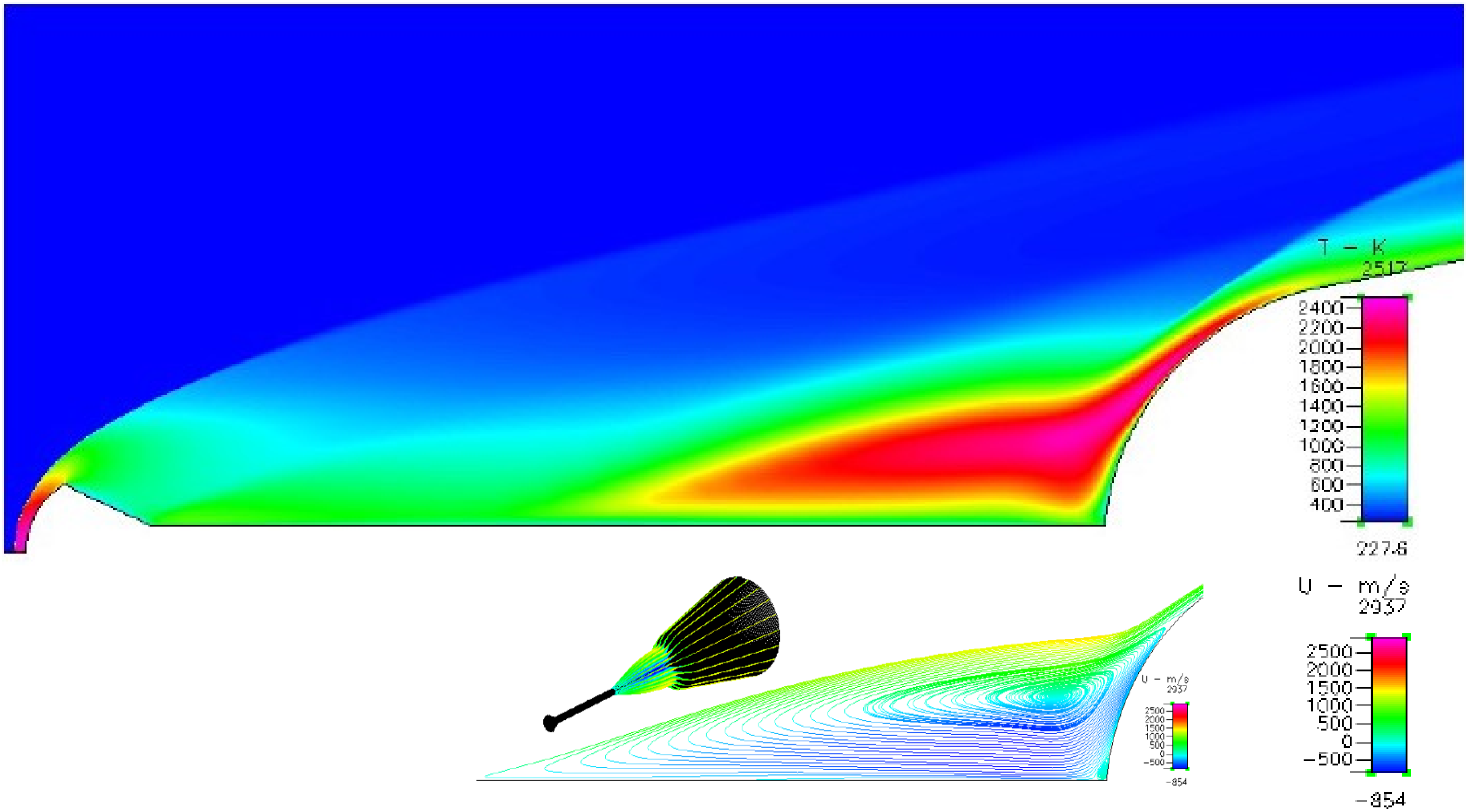


Fig. c Like fig. b, temperature distribution (upper) and u-isolines in the recirculation region (lower); middle: perspective view.