Outline of Laminar-Turbulent Transition

From A&AE 624/690T, Laminar-Turbulent Transition
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The following is an outline of the topics covered. While there are some analytical topics, most are covered by discussing figures from various papers. The results are for low speed flow except as indicated, but there is an emphasis on high-speed transition due to the instructor's research background. The paper figures have been sorted, labeled, and scanned into PDF files. AAE624 has about 45 lecture hours, but covers only a small fraction of the more than 3000 papers I have on transition.

The handouts are continually being revised, although the existing material already fills the available lecture hours. Each handout cites the reference from which it was obtained, providing supporting documentation and paths for further study. Most of the material is copyrighted and so it cannot be placed on the web. A few of the public-domain handouts are on the AAE624/690T website; a particular effort is being made to place the images there, since it is difficult to hand out high resolution paper copies. See also the documents and papers on the AAE519 website, many of which relate to transition.

The sequence of some of the documents has been changed somewhat compared to the sequence used for collation of the 23 August 2004 paper copies, so be prepared to reorder some of your pages.

1. Introduction to Transition
   (a) Importance of Transition
   (b) Schlieren of Mach-4 Transition – Reda
   (c) Heat Transfer Affected by Transition at Mach 8 – Martellucci
   (d) Reentry-Vehicle Temperatures Showing Transition – Williamson
   (e) Flow Visualization of Boundary Layers and Transition - Van Dyke
   (f) Paths to Transition (Morkovin Diagram) – Morkovin and Reshotko
   (g) Tollmien-Schlichting Waves on Low-Speed Flat Plate – Schubauer and Skramstad
   (h) Introduction to Wave Processes
   (i) Introduction to Random Processes
   (j) Introduction to Power Spectra
2. Shear-Flow Instability Basics
   (a) Kelvin-Helmholtz Instability of the Vortex Sheet
   (b) Nonlinear K-H Rollup Simulations – Krasny
   (c) Orr-Sommerfeld Equation for Linear Viscous Instability of Parallel Flow
   (d) Rayleigh Equation for Inviscid Instability and the Rayleigh Criterion

(e) Issues with Orr-Sommerfeld Solvers

(f) Instabilities of Shear Layers and Wakes – Koochesfahani and Taneda

(g) Tollmien-Schlichting (TS) Instabilities

i. Introduction to Flat-Plate Instability and Transition Phenomena (SPS thesis)
ii. A Simple Criterion for Viscous Instability
iii. TS Instability of Couette Flow – Nishioka
iv. Best Available TS Experiment – Klingmann
v. Pressure Gradient Effects on TS – Wazzan
vi. Integrated Amplification of TS – Mack
vii. The e^N Method – Jaffe
viii. Fast e^N Solvers – Drela and Gaster
ix. Vortical Breakdown via 3D Vortex Stretching Effects – Liepmann
x. Oblique TS Waves – Squire's Theorem
xi. Oblique TS Wave Properties – Stuart, Dhanak, Hama et al.
xii. More Oblique Wave Properties – Robey and Mack
xiii. Oblique Wave Observations – Schneider
xiv. Oblique Wave Measurements – Kachanov et al.
xv. Localized Wave Packets – Gaster et al.
xvi. Harmonic Point Source – Mack et al.
xvii. Harmonic Point Source – Kachanov et al.

(h) Görtler Instability

i. Centrifugal Instabilities – Basic Arguments – Karman
ii. Görtler and TS Instability Experiments – Liepmann
iii. Görtler Instabilities – Mangalam and Dagenhart et al.
iv. Görtler Review and Flow Visualization – Floryan
v. Gortler Nonidealities – Kalburgi

(i) 3D Instabilities

i. 3D Instabilities – Review – Reed & Saric
ii. Crossflow vortices on a Cone at Mach 8 – Oberkampf and McDevitt
iii. Attachment-Line Instability – Hardy
iv. Crossflow Instability – Nitschke
v. Crossflow and Tunnel Noise – Bippes
vi. Crossflow Wave Directions – Deyhle
vii. Crossflow Waves and Roughness – Radetzsky
viii. Crossflow & Curvature and Attach. Line Contamination – Arnal
ix. Nonlinear Crossflow, Expt. and Simulation Agree – Haynes, Reed, and Saric

3. Parametric Effects at Low Speed

(a) Temperature on TS – Liepmann

(b) Temperature on TS – Wazzan

(c) Temp. and Particles on TS – Ladd

(d) Temp. and Suction on Attachment – Lasseigne

(e) Temp. Variations on TS – Masad

(f) Suction on TS – Reynolds and Saric

(g) Airbus Laminar-Flow Suction Fin Test – Aviation Week

(h) Suction Nonuniformities Cause Streamwise Vortices – Roberts

4. Introduction to High-Speed Instability and Transition

(a) Schlieren of Transition on a Cone at Mach 4 Revisited – Reda

(b) The Higher Modes – Mack

(c) The Second Mode Observed – Kendall

(d) More Second Mode Observations – Demetriades

(e) Controlled Mach-2 Experiments – Kosinov

(f) The Hypersonic Shock-Layer Instability – Hornung

(g) Tunnel Noise Issues at Low Speed – Spangler and Wells

(h) Source of Supersonic/Hypersonic Tunnel Noise – Laufer

(i) Images and Movies of Noise Radiation from Mach-2 Jet – Darke

(j) Dominance of Tunnel Noise for Smooth Cones and Plates – Pate

(k) Review of Tunnel Noise Effects – Schneider

(l) Development of Quiet Tunnels – Beckwith

(m) Instability and Transition Review – Stetson. Note that we hope to schedule a visit by Ken Stetson in Fall 2004 so he can present his perspective in person.

(n) Wall Temperature and Roughness Effects on a Supersonic Cone – Van Driest and Boison

(o) High Enthalpy Effects – Hornung

(p) Acoustic Absorption for 2nd Mode Control – Hornung

(q) Rotational and Vibrational Relaxation Effects – Bertolotti

(r) Effects of Ablation and Blowing – Kaattari

5. Nonlinear and Nonparallel Effects

(a) Nonparallel TS – Fasel

(b) Streamwise Vortices Imaged on a Hemispherical Nose - Buck

(c) Instability without Eigenvalues – Trefethen

(d) Transient Growth Model Example – Schmid and Henningson

(e) Transient Growth Simulation – Breuer

(f) More Transient Growth – Tumin and Reshotko

(g) Images of Secondary Instabilities – Herbert

(h) 3D TS Breakdown on Flat Plate – Klebanoff

(i) 3D TS Breakdown on Plate Plate – Kozlov

(j) 3D Breakdown in Shear Layer, Noise Effects – Yang

6. Prediction Methods

(a) e^N Methods – Bushnell

(b) Mixed-Mode e^N Methods – Schrauf

(c) Parabolised Stability Equations – Herbert

(d) 3D PSE Method – Herbert

(e) Issues with e^N Methods on Wings – Arnal (new handout TBP)

(f) Review of Various Methods in 3D – Chang et al (new handout TBP)

7. Transitional Extent – Intermittent Region

(a) Turbulent Spot Images – Van Dyke

(b) Turbulent Spots – Emmons

(c) Spot Measurements – Schubauer and Klebanoff

(d) Spot Interference and Linearity – Elder

(e) Spot Observations – Schneider

(f) Predictions Using Spot Theory – Dhawan

(g) Review of Spot-Theory and Predictions – Narasimha

(h) Spots in Pressure Gradient – Dey

(i) Spots in Pressure Gradient – Seifert

(j) Spots in 3D Flows with Streamline Spreading – Dey

(k) Spots in Supersonic Flow – James

(l) Intermittency in Supersonic Flows – Narasimha

(m) Spot Wedge Angle in Supersonic Flows – Fischer

(n) Effects of Tunnel Noise on Intermittency – Schneider/Chen

(o) Spots in Gas Turbines – Gostelow

8. Roughness Effects on Transition

(a) Critical and Effective Roughness – Van Driest

(b) Detailed Measurements of Roughness Wakes – Liepmann and Fila

(c) Critical Roughnesses – Smith and Clutter

(d) 2D and 3D Roughness at Low Speed – Klebanoff

(e) Correlation with Displacement Thickness – Dryden

(f) 2D and Isolated Roughness – Tani

(g) Distributed Roughness – Von Doenhoff

(h) Isolated Trips on Supersonic Cones – Van Driest

(i) Effects of Mach Number on Re_k Correlation – Braslow

(j) More Mach-Number Effects – Morrisette

(k) Re_k Not Constant for Mach-6 Plate – Cary

(l) Roughness on Blunt Noses and Nozzle Throats – Demetriades

(m) Roughness on Nosetips – Batt and Legner

(n) Cone Frustum Roughness – Boudreau

(o) Nosetip Roughness Effects on Frustum Transition – Stetson

(p) e^N in Separated Flow over 2D Roughness – Masad

(q) Single Roughness in Pressure Gradient – de Bruin

(r) Acoustic Receptivity with Roughness – Wlezian

(s) Acoustic Receptivity with Roughness – Saric

(t) Roughness Correlated with Re_k – Reda

9. Development into Fully Developed Turbulence – Klebanoff

10. Case Studies

(a) Transition on the Shuttle – An & Wang et al.

(b) Roughness Effects on Shuttle Transition – Bertin et al.

(c) Re-Entry F – Wright

(d) Slat Roughness and Transition, Effects on Lift – Valarezo

(e) Gas Turbine Intermittency and Transition – Mayle