

**Proceedings of**

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***IUTAM SYMPOSIUM "LAMINAR-TURBULENT TRANSITION"***

**1 AUGUST 1999 – 31 DECEMBER 1999**

**To**

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Program Officer Candace Wark ONR  
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800 North Quincy Street  
Arlington, VA. 22217-5660

**By**

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## Preface

The origins of turbulent flow and the transition from laminar to turbulent flow are among the most important unsolved problems of fluid mechanics and aerodynamics. Besides being a fundamental question of fluid mechanics, there are any number of applications for information regarding transition location and the details of the subsequent turbulent flow.

The IUTAM Symposium on Laminar-Turbulent Transition, co-hosted by Arizona State University and the University of Arizona, was held in Sedona Arizona. Although four previous IUTAM Symposia bear the same appellation (Stuttgart 1979, Novosibirsk 1984, Toulouse 1989, and Sendai 1994) the topics that were emphasized were each different and reflect the evolving nature of our understanding of the transition process.

The major contributions of Stuttgart 1979 centered on nonlinear behavior and later stages of transition in two-dimensional boundary layers. Stability of closed systems was also included with Taylor vortices in different geometries. The topics of Novosibirsk 1984 shifted to resonant wave interactions and secondary instabilities in boundary layers. Pipe- and channel-flow transition were discussed as model problems for the boundary layer. Free shear layers were discussed and a heavy dose of supersonic papers appeared for the first time. The character of Toulouse 1989 was also different in that 3-D boundary layers, numerical simulations, streamwise vortices, and foundation papers on receptivity were presented. Sendai 1994 saw a number of papers on swept wings and 3-D boundary layers. Numerical simulations attacked a broader range of problems.

The Sedona 1999 meeting was almost exclusively bounded shear layers as open systems. The major impact topics were receptivity of initial disturbances, crossflow instabilities, supersonic flows, and control of transition. More papers appeared on combined numerical and experimental work. In other cases, teams from different institutes combined resources to solve complicated problems. The objectives of many of these studies were to properly define the fundamental physics of the stability and transition process. One can track certain freestream disturbances that provide the initial conditions for unstable waves in somewhat complicated geometries. As a consequence, this fundamental knowledge now enables different techniques of transition control and its subsequent decrease in drag. One expects increased emphasis on this topic. Papers on transient growth and sub-critical development of 3-D disturbances pointed to future areas of research.

### Countries represented and number of participants

Australia	1	Brazil	1	Canada	2
China	2	France	7	Germany	24
Greece	1	India	2	Israel	1
Italy	1	Japan	15	Russia	11
Sweden	2	Switzerland	3	The Netherlands	1
U.K.	16	Ukraine	1	USA	42
Total participants: 132					

### **Symposium Sponsors**

International Union of Theoretical and Applied Mechanics (IUTAM)  
Arizona State University  
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UA Computational Fluid Dynamics Laboratory  
Army Research Office  
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National Science Foundation  
Air Force Office of Scientific Research.

### **Scientific Committee**

W. Saric (Co-Chair) (USA)	V. Koslov (Russia)
H. Fasel (Co-Chair) (USA)	V. Levchenko (Russia)
D. Arnal (France)	R. Narasimha (India)
P. Baines (Australia)	T. Tatsumi (Japan)
H. Bippes (Germany)	J. van Ingen (Netherlands)
M. Gaster (UK)	H. Zhou (China).
R. Kobayashi (Japan)	

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Jarmo Mönttinen, (ASU)	Edward White (ASU)
Richard Sandberg (UA)	Hui-Liu Zhang (UA)

**Sunday 12 September**

1800 - 2200 Reception and Registration at Poco Diablo Resort-Sedona, AZ.  
(located in the Conference-Center)

**Monday 13 September**

0700 -0845 Registration and continental breakfast  
(Registration at the Conference-Center/continental breakfast on lower patio)

0845 - 0900 **OPENING REMARKS**  
**KEYNOTE LECTURES**

Chairman: M. Gaster

0900 - 0920 T. Tatsumi  
*Turbulence in the turn of the century*

0920 - 1005 L. Mack  
*Early history of compressible linear stability theory*

1005 - 1030 **BREAK**  
(coffee, tea, water served in hallway)

**SESSION A: RECEPTIVITY I**

Chairman: V. Kozlov

1030 - 1050 P. Hammerton , E. Kerschen  
*Effect of leading-edge geometry and aerodynamic loading on receptivity to acoustic disturbances*

1050 - 1110 L.M. Cullen , H.P. Horton  
*Acoustic receptivity in boundary layers with surface roughness*

1110 - 1130 N. Peake , R. Lingwood  
*A casual stability analysis of the boundary-layer flow over a compliant wall*

1130 - 1150 C. Airiau, S. Walther, A. Bottaro  
*Nonparallel receptivity and the adjoint PSE*

1150 - 1340 **LUNCH**  
(lunch served on the lower patio/Mexican Fajita Buffet)

**SESSION B: RECEPTIVITY II**

Chairman: V. Levchenko

1340 - 1400 Y. Kachanov  
*Three-dimensional receptivity of boundary layers to external perturbations*

1400 - 1420 J. Wanderley , T. Corke  
*Boundary-layer receptivity to freestream sound on elliptic leading edges of flat plates*

1420 - 1440 R. King, K. Breuer  
*Non-localized acoustic receptivity and subsequent disturbance growth in a Blasius boundary layer*

1440 - 1500 D.G. Lasseigne, W.O. Criminale, R.D. Joslin, T.L. Jackson  
*Receptivity and bypass dynamics*

1500 - 1520 W. Wurz, W. Herr, A. Worner, U. Rist, S. Wagner, Y. Kachanov  
*Study of 3-D wall roughness acoustic receptivity on an airfoil*

1520 - 1540 V. Kosorygin  
*Experiments on receptivity, stability, and transition of 2-D laminar boundary layers with streamwise pressure gradients*

1540 - 1600 E. White, W. Saric, R. Radeztsky Jr.  
*Leading-edge acoustic receptivity measurements using a pulsed-sound technique*

1600 - 1630 **BREAK AND POSTER SESSION SET UP**  
(coffee, teas, assorted soft drinks, water served in the hallway)

1630 - 1830

**POSTER SESSION I (MONDAY AND TUESDAY)****1.1 S. Collis, A. Dobrinsky***Evaluation of adjoint based methods for the prediction of receptivity***1.2 Y. Su, T. Herbert***Receptivity to freestream turbulence and the effect of longitudinal vortices in boundary-layer transition***1.3 D. Nichols, P. Hammerton***Receptivity for a flat plate with a rounded leading edge***1.4 H. Grek, V. Kozlov, D. Sboev***Experiments on the receptivity of a boundary layer to a localized freestream disturbance***1.5 M. Ustinov, M. Kogan, V. Shumilkin, S. Zhigulev***Experimental study of flat-plate boundary layer receptivity to vorticity normal to leading edge***1.6 M. Katasonov, V. Kozlov***Boundary-layer longitudinal localized structures control by means of spanwise wall oscillations***1.7 C. Gmelin, U. Rist, S. Wagner***DNS of active control of disturbances in a Blasius boundary layer***1.8 M. Baumann, D. Sturzebecher, W. Nitsche***Active control of T-S instabilities on an unswept wing***1.9 A. Bakchinov, M. Katasonov, P. Alfredsson, V. Kozlov***Control of streaky structures by localized blowing and suction***1.10 D. Meyer, U. Rist, V. Borodulin, V. Gaponenko, Y. Kachanov, Q. Lian, C. Lee***Late-stage transitional boundary-layer structures. Direct numerical simulation and experiment***1.11 G. Grek, M. Katasonov, V. Kozlov, Y. Chernoray***Experimental study of a  $\Lambda$ -structure development and mechanism: Its transformation into the turbulent spot***1.12 S. Houten, J. Healey, C. Davies***Nonlinear evolution of Tollmien-Schlichting waves at finite Reynolds numbers***1.13 J. Healey***On why oblique waves in the Blasius boundary layer show stronger nonparallel effects than planar waves***1.14 R. Govindarajan, R. Narasimha***Stability of weakly nonsimilar swept-wing boundary layers***1.15 P. Taniguchi, F. Browand, R. Blackwelder***Boundary-layer transition due to the entry of a small particle***1.16 Y. Kohama, P. Alfredsson, Y. Egami, M. Kawakami***Turbulent energy production mechanism in general boundary-layer transition***1.17 S. Reddy, P. Ioannou***Energy transfer analysis of turbulent plane Couette flow***1.18 P. Hall***Nonlinear initial value problems for wave/vortex interactions in channel flows***1.19 S. Wernz, H. Fasel***Numerical investigation of resonance phenomena in wall-jet transition***1.20 S. Gaponov, B. Smorodsky***Supersonic boundary-layer receptivity to streamwise acoustic field***1.21 F. Lundell, P. Alfredsson***Feed-forward control of streak instabilities in plane Poiseuille flow by localized suction***1.22 R. Messing, M. Kloker***Effect of suction through arrays of holes on a 3-D boundary layer investigated by spatial direct numerical simulation***Tuesday 14 September**

0700 - 0820

**Registration and continental breakfast**

(Registration at the Conference-Center/continental breakfast on lower patio)

**SESSION C: ATTACHMENT LINE AND GENERAL TOPICS**

Chairman: R. Kobayashi

- 0820 - 0840 **R. Mukund, P. Viswanath, J. Crouch**  
*Relaminarization and retransition of accelerated turbulent boundary layers on a convex surface*
- 0840 - 0900 **A. Dietz, C. Coleman, J. Laub, D. Poll**  
*Effect of wall temperature on roughness induced attachment-line transition*
- 0900 - 0920 **S. Seddougui, B. Orme**  
*Nonlinear Instability of Hypersonic Flow over a cone*
- 0920 - 0940 **M. Gaster**  
*On the growth of waves in boundary layers*
- 0940 - 1020 **BREAK**  
(coffee, tea, water served in hallway)

**SESSION D: 3-D TRANSITION IN 2-D FLOWS**Chairman: **D. Arnal**

- 1020 - 1040 **S. Bake, H. Fernholz**  
*The formation of secondary structures and random perturbations in the development of periodic Lambda structures in a laminar boundary layer*
- 1040 - 1100 **M. Asai, M. Minagawa, M. Nishioka**  
*Instability and breakdown of the three-dimensional high-shear layer associated with a near-wall low-speed streak*
- 1100 - 1120 **R. Bowles**  
*On vortex interaction in the later stages of boundary-layer transition*
- 1120 - 1140 **E. Malkiel, V. Levinski, M. Rosenfeld, J. Cohen**  
*The evolution of hairpin vortices in shear flows*
- 1140 - 1200 **M. Medeiros, M. Mendonca**  
*Nonlinear three-dimensional wavetrains of small amplitude in boundary layers: experiments, theory and computations*
- 1200 - 1220 **V. Kozlov, G. Grek**  
*Stationary and nonstationary streaky structures and secondary instability of boundary layers*
- 1220 - 1340 **LUNCH**  
(lunch served on lower patio/Hot Dog, Burger Buffet)

**SESSION E: CONTROL**Chairman: **R. Narasimha**

- 1340 - 1400 **Y. Fukunishi, I. Ebina, R. Kobayashi**  
*Generation of oblique waves in a Blasius boundary layer by thin Piezo-film actuators attached to the wall surface*
- 1400 - 1420 **P. Cathalifaud, P. Luchini**  
*Optimal control by blowing and suction at the wall of algebraically growing boundary-layer disturbances*
- 1420 - 1440 **C. Davies, P. Carpenter, D. Lockerby**  
*A novel velocity-vorticity method for simulating boundary-layer disturbance evolution and control*
- 1440 - 1500 **P. Andersson, M. Berggren, D. Henningson**  
*Optimal three-dimensional perturbations in the Blasius boundary layer*
- 1500 - 1520 **N. Yurchenko, J. Delfs**  
*Optimal control of boundary layers under body forces*
- 1520 - 1720 **BREAK AND POSTER SESSION SET UP**  
(coffee, teas, assorted soft drinks, water served in the hallway)
- 1720 - 1750 **Poster session break down**
- 1900 - 2130 **BANQUET**  
(located in the conference center building)

**Wednesday 15 September**

- 0630 - 0730 continental breakfast served on lower patio
- 0715-0730 board buses for Grand Canyon-main entrance
- 0715 - 1730 **GRAND CANYON TOUR**

**Thursday 16 September**

0700 - 0800 **Registration and continental breakfast**  
(Registration at the Conference-Center/continental breakfast on lower patio)

**SESSION F: GENERAL TOPICS**

Chairman: H. Zhou

0820 - 0840 **S. Becker, K. Condie, C. Stoots, D. McEligot**  
*Reynolds-stress development in the viscous layer of a transitional boundary layer*

0840 - 0900 **J. Watmuff**  
*Distortion of Tollmien-Schlichting waves by leading-edge vortices*

0900 - 0920 **P. Moresco , J. Healey**  
*Convective and absolute instability in the mixed convection boundary layer over a vertical flat plate*

0920 - 0940 **A. Cabal, J. Szumbarski, J. Floryan,**  
*Stability of Poiseuille flow in a corrugated channel*

0940 - 1000 **R. Govindarajan , R. Narasimha**  
*The transition zone on a heated axisymmetric body*

1000 - 1030 **BREAK**  
(coffee, tea, water served in hallway)

**SESSION F: GENERAL TOPICS CONTINUED**

Chairman: J. van Ingen

1030 - 1050 **G. Walker , J. Hughes**  
*The occurrence of natural transition phenomena in periodic transition on axial compressor blades*

1050 - 1110 **J.P. Gostelow, H.P. Hodson, G.J. Walker**  
*Comparisons between triggered turbulent spots and unsteady transition phenomena on compressor and turbine blading*

1110 - 1130 **M. Matsubara, A. Bachinov, J. Fransson, P. Alfredsson**  
*Growth and breakdown of streaky structures in boundary layer transition induced by freestream turbulence*

1130 - 1150 **A. Tumin**  
*Onset of turbulence in circular pipe flows*

1150 - 1210 **J. Reuter , D. Rempfer**  
*A hybrid spectral/finite-difference scheme for the simulation of pipe-flow transition*

1210 - 1320 **LUNCH**  
(lunch served on lower patio /Chef's Deli Buffet)

**SESSION G: SUPERSONIC**

Chairman: H. Fasel

1320 - 1340 **S. Gaponov**  
*Transition of supersonic boundary layers (experiment and theory review)*

1340 - 1400 **C. Mielke, L. Kleiser**  
*Investigation of transition to turbulence in a 3-D supersonic boundary layer*

1400 - 1420 **E. Reshotko , A. Tumin**  
*The blunt body paradox: A case for transient growth*

1420 - 1440 **M. Malik**

*Hypersonic boundary-layer receptivity and stability*

1440 - 1500

**A. Fezer , M. Kloker***Spatial direct numerical simulation of transition phenomena in supersonic flat-plate boundary layers*

1500 - 1530

**BREAK***(coffee, teas, assorted soft drinks, water served in the hallway)*

1530 - 1550

**A. Maslov, S. Mironov***Experimental investigations of the hypersonic boundary-layer stability*

1550 - 1610

**S. Schneider***Development of a Mach-6 quiet-flow Ludwig tube for transition research*

1610 - 1630

**X. Yuan, H. Zhou***A numerical study for a small amplitude T-S wave in a supersonic boundary layer*

1650 - 1710

**BREAK AND POSTER SESSION SET UP***(coffee, teas, assorted soft drinks, water served in the hallway)*

1710 - 1910

**POSTER SESSION II (THURSDAY AND FRIDAY)****2.1 X. Zhong***DNS of boundary-layer receptivity to freestream sound for hypersonic flows over blunt elliptical cones***2.2 N. Semionov , A. Kosinov***Experimental study of supersonic boundary-layer receptivity in controlled conditions***2.3 V. Lysenko, A. Kosinov, Y. Yermolaev***Development of artificial disturbances in the boundary layer on a plate and in the wake behind it at supersonic free-flow speed***2.4 A. Kosinov, Y. Yermolaev, N. Semionov***On anomalous wave processes in supersonic boundary layer***2.5 A. Karabis, S. Shaw, V. Theofilis***On the inviscid spatial instability of supersonic boundary-layer flow along bodies of revolution***2.6 D. Bountin, A. Shipliyuk, A. Sidorenko***Experimental investigations of disturbance development in the hypersonic boundary layer on a conical model***2.7 S. Sakaue, M. Asai, M. Nishioka***On the receptivity process of supersonic laminar boundary layer***2.8 D. Mitra, R. Seshadri, K. Rao, R. Govindarajan***Low-order stability theory for non-parallel compressible boundary layer flow***2.9 A. Kosinov, Y. Yermolaev, N. Semionov***On correspondence of laminar-turbulent transition processes at natural and controlled supersonic experiments on flat plate***2.10 C. Stemmer, M. Kloker***Later stages of transition of an airfoil boundary layer flow excited by a harmonic point source***2.11 L. Schouveiler, P. LeGal, M.P. Chauve***Experiments on the transition to turbulence of the flow between a stationary and a rotating disk***2.12 M. Högberg , D. Henningson***Secondary instability of crossflow vortices in Falkner-Skan-Cooke boundary layers***2.13 C. Cossu, J. Chomaz, M. Costa***Maximum growth of Görtler vortices***2.14 P. Ardonneau, D. Aymer de la Chevalerie***Non-normality of the Görtler operator and spatial amplification***2.15 I. Girgis , J. Liu***Linear stability of the supersonic turbulent boundary layer to Görtler vortices on a concave wall***2.16 C. Whang , X. Zhong***Direct numerical simulation of Görtler instability in hypersonic boundary layers***2.17 F. Bahri, Y. Kohama, J. Iino and Aota***Effect of the pressure gradients on the secondary instability of Görtler flow***2.18 H. Stuer, A. Gyr, W. Kinzelbach**

*Laminar-turbulent transition of a separation flow on a forward facing step*

2.19 A. Dovgal

*Flow instability in laminar separation bubbles*

2.20 R. Lingwood , P. Alfredsson

*Experimental study of the stability of the Bödewadt layer*

2.21 G. Han, A. Tumin, I. Wygnanski

*Late stage of transition in a circular pipe flow*

2.22 P. Wassermann , M. Kloker

*DNS investigations of the development and control of crossflow vortices in a 3-D boundary layer flow*

2.23 Y. Kachanov, D. Koptsev, B. Smorodskiy

*3-D stability and receptivity of 2-D self-similar boundary layer with adverse pressure gradient*

2.24 E. Reshotko, M. Vargas, H. Reed

*Relation of glaze ice formations on swept wings to crossflow instability*

2.25 T. Wintergerste , L. Kleiser

*Secondary stability analysis of nonlinear crossflow vortices*

## Friday 17 September

0700 - 0800 Registration and continental breakfast

(Registration at the Conference-Center/continental breakfast on lower patio)

### SESSION H: CROSSFLOW

Chairman: E. Kerschen

0800 - 0820 D. Arnal , A. Seraudie, J. Archambaud

*Influence of surface roughness and suction on the receptivity of a swept wing boundary layer*

0820 - 0840 T. Herbert

*Stability and transition in 3-D boundary layers*

0840 - 0900 W. Koch

*Absolute/convective instability analysis of secondary crossflow vortices in a 3-D boundary layer*

0900 - 0920 C. Abegg, H. Bippes, E. Janke

*Stabilization of boundary-layer flows subject to crossflow instability with the aid of suction*

0920 - 0940 Y. Yokokawa, Y. Fukunishi, N. Itoh

*Numerical study of excitation of two different instabilities in e-D boundary layer on a yawed cylinder*

0940 - 1000 G. Bonfigli , M. Kloker

*Three-dimensional boundary-layer transition phenomena investigated by spatial direct numerical simulation*

1000 - 1030 **BREAK**

(coffee, tea, water served in hallway)

1030 - 1050 F. Bertolotti

*On the connection between crossflow vortices and attachment-line instabilities*

1050 - 1110 J.S. Luo , H. Zhou

*A theoretical investigation of the development of the stationary crossflow vortices in the boundary layer on a swept wing*

1110 - 1130 V. Levchenko , V. Scherbakov

*Experimental study of traveling waves in 3-D boundary layer on a swept wing*

1130 - 1150 S. Takagi, N. Itoh, N. Tokugawa

*Characteristic features of traveling disturbances originating from a point source on a rotating-disk*

1150 - 1210 N. Itoh

*Multimode instability of the 3-D boundary layer along an infinite attachment line*

1210 - 1340 **LUNCH**

(lunch served on lower patio/East meets West Buffet)

### SESSION I: WALL JETS AND SEPARATION

Chairman: E. Reshotko

- 1340 - 1400 **J. Seidel , H. Fasel**  
*Numerical investigation of the heat transfer mechanisms in wall-jet transition*
- 1400 - 1420 **U. Maucher, U. Rist, S. Wagner**  
*Secondary disturbance amplification and transition in laminar separation bubbles*
- 1420 - 1440 **V. Theofilis**  
*Global linear instabilities in laminar separated boundary layer flow*
- 1440 - 1500 **B. Wang, D. Boducki, L. Redekopp,**  
*Transition in separated flows via global instability*
- 1500 - 1520 **A. Dovgal , A. Boiko**  
*Effect of harmonic excitation on instability of laminar separation bubble on an airfoil*
- 1520 - 1540 **S. Hein**  
*Linear and nonlinear nonlocal instability analyses for two-dimensional laminar separation bubbles*
- 1540 - 1550 **Closing Remarks**
- 1550 - 1620 **BREAK AND POSTER SESSION SET UP**  
(coffee, teas, assorted soft drinks, water served in the hallway)
- 1620 - 1840 **POSTER SESSION II CONTINUED**
- 1840 - 1910 **Poster session breakdown**

# REPORT DOCUMENTATION PAGE

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<p>13. ABSTRACT (<i>Maximum 200 words</i>)</p> <p>The IUTAM Symposium on Laminar-Turbulent Transition, co-hosted by Arizona State University and the University of Arizona, was held in Sedona Arizona. Although four previous IUTAM Symposia bear the same appellation (Stuttgart 1979, Novosibirsk 1984, Toulouse 1989, and Sendai 1994) the topics that were emphasized were each different and reflect the evolving nature of our understanding of the transition process.</p> <p>The Sedona 1999 meeting was almost exclusively bounded shear layers as open systems. The major impact topics were receptivity of initial disturbances, crossflow instabilities, supersonic flows, and control of transition. More papers appeared on combined numerical and experimental work. In other cases, teams from different institutes combined resources to solve complicated problems. The objectives of many of these studies were to properly define the fundamental physics of the stability and transition process. One can track certain freestream disturbances that provide the initial conditions for unstable waves in somewhat complicated geometries. As a consequence, this fundamental knowledge now enables different techniques of transition control and its subsequent decrease in drag. One expects increased emphasis on this topic. Papers on transient growth and sub-critical development of 3-D disturbances pointed to future areas of research.</p>			
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