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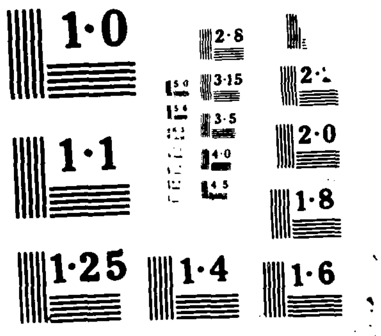
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DYNAMICS AND CONTROL OF TURBULENT SHEAR FLOWS

End-of-Fiscal Year Report
Oct. 1, 1986 to Sept. 30, 1987

Executive Summary

A summary of activities and accomplishments during the first year of the ONR-URI program entitled "Dynamics and Control of Turbulent Shear Flows" is reported herein. Progress reports of work undertaken by individual co-investigators follows the Executive Summary. These reports set forth in summary the goals, accomplishments, and future plans of each task. The scientific objectives of the overall program are as follows:

i) Provide a DYNAMICAL DESCRIPTION of various turbulent shear flows having technological significance.

ii) Define the CONTROLLABILITY of key dynamical events and processes which impact global, engineering performance measures.

iii) Formulate effective and *efficient* CONTROL STRATEGIES for specific types of flows and performance measures.

During the past year there have been two changes concerning the co-investigators identified in the original proposal. First, Prof. R. E. Kaplan, the project director and chairman of the Department of Aerospace Engineering, left the project in March 1987 to assume the position of Vice-Provost for Computing within the university administration. The department administration has been reorganized under two co-chairman, Professors E. P. Muntz and L. G. Redekopp. Prof. Redekopp, an original co-investigator on the project, is now serving as project director with Prof. R. F. Blackwelder serving as assistant director. The second change involved the addition of Prof. J. A. Domaradzki as a co-investigator. Prof. Domaradzki joined the department as an assistant professor in January 1987. His expertise is in the area of computational fluid dynamics with considerable experience in the computation of turbulent flows. Prof. Domaradzki is supported principally by institutional funds as promised from the USC School of Engineering Powell Foundation Grant in support of the ONR-URI program. He was supported only for one month during the summer from URI funds.

The revised budget for the first fiscal year provided for the support of five research assistants. We were on target for the entire year at the budgeted level. We supported four graduate assistants full-time and one post-doctoral fellow half-time. The remaining half-time support for the post-doctoral fellow derives from separate funding under the ONR-CORE program. The post-doctoral fellow and three of the graduate assistants are US citizens. The remaining graduate assistant is a citizen of Japan. We invested considerable effort in recruiting three of our 1987 B.S. degree graduates without success. They are among the top five or six graduates from our department over the last ten years and are presently enrolled at Caltech, MIT and Stanford. We were successful in recruiting two other US citizen graduate students with research interest in fluid dynamics. One will become a research assistant supported by the URI program in January 1988 and the other will serve as a teaching assistant and be transferred later to a research assistant position.

All expenditures for equipment, facility development and supplies were close to what was budgeted with the single exception of one major purchase: a laser-Doppler anemometry system. The purchase of this system was delayed until the large water-channel could be assembled in our new laboratory building which was available for occupancy beginning in April 1987. The manufacturer warranty is valid for only 90 days after delivery and it was deemed appropriate to delay purchase of the system until the facility was completed.

Major advances in the computational capability were achieved through URI funds and the supplemental contribution from the School of Engineering/Powell Foundation Grant during the past year. Through URI funds we purchased six Sun 3/50 Workstations in support of the computational effort and five Maxxum AT Turbos for control of experiments and data analysis. With the institutional supplement we purchased a Sun 3/280S File Server with floating point accelerator. These resources represent a giant leap forward from our obsolete and limited computing facilities from a year ago and have proved to be a major stimulus to research productivity within the department.

During the first fiscal year we have had extensive and very fruitful interaction with several personnel at the Naval Weapons Center in China Lake, CA. A goodly number of exchange visits between co-investigators at USC and NWC personnel (Drs. Schadow, Koshigoe & Gutmark) have occurred and we are in contact through phone conversations on a weekly basis. Some joint research papers are currently in progress. The interaction experience with NWC has been excellent and we anticipate expanding this to include other Naval Labs in the future. We have had some contact with Dr. Tom Mautner at NOSC in San Diego and we plan visits to NRL and DTNSRDC in the coming year to establish a research interaction with personnel at these laboratories.

A research review of the first years activities was convened at USC on October 15-16, 1987. The Advisory Review Panel consisted of the following:

Dr. Michael Reischman, ONR
Contract Officer

Eric Hendricks, NRL

Jim Fein, DTNSRDC

Dan Ladd, NOSC

Dr. Tom Mautner, NOSC

Dr. Shozo Koshigoe, NWC

Dr. Klaus Schadow, NWC

Dr. Willy Behrens, Staff Scientist
Engineering Sciences Laboratory
TRW Space & Defense Systems Group
Redondo Beach, CA

Heinz Gerhardt, Manager of Aerosciences Research
Northrop Corp.
Hawthorne, CA

CONTROL OF BOUNDED SHEAR FLOWS - EXPERIMENTAL APPROACHES

Principal Investigator: R.F. Blackwelder

Research Summary

Description of Scientific Research Goals.

The principal objective of the research is to understand the dynamics of the bursting process well enough that a significant reduction in drag can be achieved. If the low speed streaks associated with the bursting phenomenon in a turbulent boundary layer could be prevented from lifting away from the surface, then the bursting process would be disrupted. Hence turbulent production would be reduced, and a lower drag should follow. The first problem is that the low speed streaks occur randomly in space and time. Research into aligning these low speed streaks using wall roughness elements was performed. Selective suction will be used to prevent the streaks from lifting off the wall. By using our knowledge of the eddy structure and selectively interacting with it, significantly less suction should be needed than for standard boundary layer control.

Significant Results in the Past Year.

Velocity profiles and bursting statistics were measured in the presence of longitudinal roughness elements (LREs) and compared to similar work by Johansen and Smith (1986). An algorithm was devised to detect low speed streaks (LSS) from the hot-wire rake data, allowing an estimation of the LREs ability to reduce spatial randomness of the sublayer structure. The velocity profiles agree with Johansen and Smith's result that the effects of the LREs are felt only for $y^+ < 15$. The analysis of the bursting statistics and LSS algorithm output shows that the flow relaxes back to a flat plate boundary layer between the LREs. A crude first approximation is that the LREs simply impose the no-slip boundary condition at an elevation equivalent to their diameter. While the LREs might serve as a nucleation site for the LSS, spatial randomness of the structure is effected only very close to the LREs.

Plans for Next Years Research.

Slight suction will be added to the experiment both with and without the LREs present. The idea is to inhibit the lift-up of the LSS and to determine how this effects the bursting process. If the LREs align the LSS very close to the wall, then by placing suction under the LREs, the streaks can be manipulated and even destroyed. When suction is applied both with and without the LREs, comparison of the results will be the final determination of the LREs usefulness. If the differences are minimal, then the added drag due to the additional surface area of the LREs renders them detrimental. If the differences are significant, then the

LREs ability to effect the LSS will give us the location at which any devised control scheme, such as selective suction, should be applied.

List of Publications/Reports/Presentations.

1. Papers Published in Referenced Journals

None

2. Technical Reports

R.F Blackwelder and J.B. Roon, "The Effects of Longitudinal Roughness Elements Upon the Turbulent Boundary Layer", AIAA Paper 88-0134.

3. Presentations

J.B. Roon and R.F. Blackwelder, "Modification of Turbulent Boundary Layers by Longitudinal Roughness Elemtents", American Physical Society, Division of Fluid Dynamics, 40th Anniversary Meeting, November 1987.

J.B. Roon and R.F. Blackwelder, "The Effects of Longitudinal Roughness Elements Upon the Turbulent Boundary Layer", AIAA 26th Aerospace Sciences Meeting, January 1988.

List of Honors/Awards

Name of Person Receiving Award	Recipient's Institution	Name of Award	Sponsor of Award
R.F. Blackwelder	Un. So. Calif.	Fellow of the Am. Physical So.	Am. Physical Society
R.F. Blackwelder	Un. So. Calif.	Assoc. Fellow	AIAA
R.F. Blackwelder	Un. So. Calif.	Keynote Address	International Symp. on Transport Phenomena, Tokyo, Japan

List of Participants

R.F. Blackwelder, Professor

J.B. Roon, Ph.D. student

F. Pray, M.S. student

CONTROL OF THE LARGE-SCALE FEATURES IN TURBULENT MIXING LAYERS

Principal Investigator: F. K. Browand

Research Summary

Description of Scientific Research Goals

The broad goal is to explore the requirements for the control of turbulent shear flows. Control is effected introducing perturbations which exert influence upon the underlying (turbulent) vortex structure. The turbulent mixing layer has been chosen as a candidate flow, and the response to a variety of imposed excitations will be investigated. Experimental results will be compared with numerical solutions of various evolution equation models. These equations are simpler than the Navier-Stokes equations, yet hopefully contain the essential features needed to describe the large-scale flow evolution. The connection between experiment and theory will provide a strong predictive capability for the exploration of control strategies.

Significant Results in the Past Year

Perturbations can be applied at the origin of the mixing layer by means of acoustic or mechanical forcing. One excitation of interest is periodic in time and periodic across the span of the flow. Wave lengths and periods are comparable to the streamwise spacing of developing vortices and their average passage period, respectively. Other excitations are designed to produce discrete space-time vortex structure; for example, vortex pattern imperfections or dislocations. The motion and development of pattern imperfections is a central comparison with evolution models.

During the past year we have constructed and tested an array of speakers designed to provide acoustical excitation. Sixteen small dynamic speakers arranged in a linear array across the wind tunnel span in the tunnel ceiling directly above the splitter plate trailing edge (origin of mixing layer). All speakers are operated at constant amplitude, but the phase of any speaker can be varied. A variety of spanwise modes can be generated by simply switching the phase of various speakers between the two states 0 degrees and 180 degrees. Using a three microphone array, and an automated data acquisition system, the acoustic field in the cross section of the plate trailing edge has been equipped for a variety of frequencies and standing wave modes. The results show that low modes are easily excited at the plate trailing edge because these waves are near resonance frequencies of 1 kHz or less. The higher standing wave modes (corresponding to more than four wave lengths across the span) are more difficult excite. The forcing signal decays exponentially away from the wind tunnel ceiling and, at the central plane, the acoustic field is again dominated by lower modes. The presence of unwanted lower modes in this case is probably due to slight differences in amplitude of the different speakers.

A variety of instrumentation amplifiers, audio amplifiers, and hot wire circuits have been purchased or constructed during the year. Computer programs to produce computer generated pulse trains and programs to handle the parallel-ported memory have also been developed.

Plans for Next Years Research.

Three tasks are planned for the coming year. Acoustic surveys with the linear array will test the acoustic field at the plate trailing edge using pulse trains generated by the computer. These pulse trains are designed to produce more sophisticated forcing of individual vortices - the pattern imperfections- rather than simple periodic standing wave structures. In these cases the array is not required to produce variations over a short span length and it should perform adequately.

A second mechanical means for exciting shear layer structure will be tested. This consists of a thin strip of piezoelectric material (Kyhan Film) mounted directly downstream of the plate trailing edge. An applied voltage produces a vertical velocity perturbation if the strip is confined or anchored at two points. The piezoelectric strip can be woven to produce the high mode alternating vertical velocities across the span. A variety of other configurations are possible.

Finally, the complete system will be assembled and will be measured for various excitations. A rake of fourteen hot wires spaced across the span will be used to determine the instantaneous velocity field at fourteen spanwise positions simultaneously. The procedure will be computer controlled as follows:

i) generate a particular pulse train to initiate forcing,

ii) digitize the resulting velocity field at fourteen spanwise positions,

iii) view the velocity field on the computer screen,

iv) move the hot wire array to a new location,

v) repeat the procedure.

List of Publications/Reports/Presentations

1. Papers Published in Refereed Journals

   F.K. Browand and C.-M. Ho. "Forced, Unbounded Shear Flows," Nuclear Physics B, Special Issue to be published.

2. Technical Reports

   None.

3. Presentations

   F.K. Browand, "Forced, Unbounded Shear Flows," The Physics of Chaos and Systems Far from Equilibrium, Monterey, CA. Jan. 11-14, 1987.

List of Honors/Awards

None.

List of Participants

F.K. Browand, Professor

DIRECT NUMERICAL SIMULATIONS OF FLOW CONTROL

Principal Investigator: J.A. Domaradzki

Research Summary

Description of Scientific Research Goals

The principal goal is to simulate numerically specific fluid flows of interest to the Navy in order to better understand their physics, in particular those physical features which can be effectively controlled by either external disturbances or boundary conditions.

Two types of flows were chosen for investigation: free convection and boundary layer flow over a concave surface. The understanding of convective flows is important in the task of designing heat pipes, heat exchangers, and cooling of electronic equipment. The fluid flow over a concave surface develops a regular pattern of Görther vortices which can serve as a general model of counter-rotating vortices encountered in other transitional and turbulent boundary layers. The behaviour of these vortices is important in many practical situations; for example, determining efficiency of turbine blades, drag on objects moving in fluids, etc.

The goals of this research are to *develop numerical* codes capable of simulating these phenomena, investigate possibility of influencing heat transfer through modification of boundary conditions, describe energy transfer in the transitional and turbulent boundary layers over concave walls, and prepare new methods of delaying transition in such flows.

Significant Results in the Past Year.

In the first year of this effort we were able to obtain new physical results in the area of convection. Our rapid progress in this area was possible because we were able to use a numerical code which was developed previously under contract from DOE to simulate convection with the mean shear. We have performed a number of numerical simulations of the convection between two rigid, horizontal plates with nonuniform-temperature boundary conditions at the lower plate. The boundary conditions were chosen to excite n pairs of counter-rotating convective rolls. For given horizontal size of the computational domain, runs with different values of the parameter n were performed. It was shown that different numbers of convective rolls could be accommodated in the same physical domain. In particular, it was possible to generate through the non-uniform-temperature boundary conditions rolls with sizes significantly different from the size of rolls encountered in the natural convection at the same Rayleigh number. The control over the size of the convective elements allowed about 15-20% heat transfer increase as compared with the case of natural convection.

In the area of numerical simulations of Görtler vortices, the first year effort was devoted to the modification of the flat plate boundary layer code to include curvature effects, and the modification of the pressure boundary conditions in the full time-splitting scheme to eliminate the velocity divergence errors. At the present time the numerical code is in the final stages of modification and is being implemented on the Cray X-MP at the San Diego Supercomputer Center.

Plans for Next Years Research.

Next year's effort will be devoted principally to applying a modified boundary layer code to investigate transition to turbulence in the Görtler flow. For low Görtler numbers, we will investigate the structure of the Görtler vortices for high spanwise wavenumbers where effects of the non-parallel character of the boundary layer are relatively unimportant, and compare our results with the linear stability analysis. For higher Görtler numbers, we plan to use the Reynolds stress and energy equations to assess the importance of different physical effects (inflectional velocity profiles in spanwise and normal directions, three-dimensional disturbances, low speed streaks, etc.) in the transition to turbulence.

List of Publications/Reports/Presentations.

1. Papers Published in Refereed Journals

Domaradzki, J.A.(1987). "Active Heat Transfer Enhancement in the Rayleigh-Benard Convection," submitted to Phys. Fluids.

2. Technical Reports

None

3. Presentations

None

List of Honors/Awards

None

List of Participants

J.A.Domaradzki, Assistant Professor

Liu Wei, Ph.D. student (not supported by ONR-URI contract)

CONTROL OF ENTRAINMENT IN CONFINED SHEAR LAYERS

Principal Investigator: C.-M. Ho

Research Summary

Description of Scientific Research Goals.

In many engineering applications, such as combustors, rocket engines, chemical lasers, etc., the mixing of two fluids is the central issue in improving the efficiency of these devices. The mass transfer between the two streams is accomplished by the unsteady evolution of coherent structures in the shear layer between the streams. In our laboratories we have developed active and passive control techniques to enhance the entrainment process. In some cases, an order of magnitude improvement has been achieved. These studies were performed in free shear layers in the absence of confining boundaries. However, almost all mixing in engineering devices takes place in a confined environment. The confinement can significantly modify the evolution of the coherent structures and, hence, the entrainment. The major feature is that the shear layer reattaches to a bounding wall and traps fuel-rich fluid inside the recirculation zone. Therefore, understanding of the reattachment process and exploring techniques of controlling the reattachment dynamics are key goals of the present research.

Significant Results in the Past Year.

We have constructed a new facility specifically designed for studying various control methods for reattaching shear flows. Visualization studies of the flow shows that very interesting vortex patterns exist in the confined, starting jet. This facility was designed with several unique design features, including the following.

i) The stagnation chamber is sealed from the atmosphere. The amount of air bleed into the chamber determines the flow speed in the test section. With this method of driving the flow, the fluid in the stilling section is essentially irrotational and a low background turbulence level can be achieved. Furthermore, no characteristic frequency is associated with the driving mechanism. This will facilitate clarification of the typical low frequency problem in these attached flows.

ii) The jet nozzle can be changed to either a rectangular or a square shape. The passive forcing effects can be readily examined. Active forcing devices can provide phase forcing around the perimeter of the nozzle.

iii) The reattachment zone will be the focus of the research since it determines the reattachment length which, in turn, controls the mixing. We are able to vary the dimension of the enclosure and examine its effects on the reattachment process. We have observed several interesting phenomena by using hydrogen bubble visualizations.

iv) An intense starting vortex is generated at the initiation stage of the jet. This vortex is stretched in the transverse direction and the streamwise motion is slowed by the induction of its image vortex. At the same time, an opposite shear is produced by the starting vortex and generates a counterrotating vortex in front of itself. An extremely high level mixing occurs at this stage. This type of flow will not appear in a free starting jet because of the lack of image vortex.

v) Four thin wires are placed around the rectangular nozzle exit. The vortex tagged by small bubbles shows that the four sharp corners move faster than the four flat sides. This distortion, combined with the axis switching, greatly enhances the mass transfer of a jet confined in an enclosure.

Plans for Next Years Research.

Some facility improvements needed include the following.

i) The air-bleed valve will be interfaced with a computer, so that the speed in the test section can be accurately controlled.

ii) Heating elements will be installed at the nozzle exit and near the reattachment region for active and interactive control purposes.

The study will be focused particularly on the reattaching shear layer. The coherent structures in the shear layer approach the wall and interact with the viscous wall layer. The inviscid/viscous interaction could produce a strong feedback perturbation to the nozzle lip. This feedback loop could be significant in determining the reattachment length and, hence, the mixing. This process will be examined in detail. Also, heating elements will be used to alter the reattachment process and techniques for controlling the reattachment process will be explored.

List of Publications/Reports/Presentations:

1. Papers Published in Refereed Journals

F.K. Browand and C.-M. Ho. "Forced, Unbounded Shear Flows," Nuclear Physics B, Special Issue, to be published.

2. Technical Reports

None

3. Presentations

None

List of Honors/Awards

None

List of Participants

Ho, Chih-Ming, Professor

Jean Hertzberg, Research Associate

Scott Reader, Undergraduate Student Research Assistant

THEORETICAL UNDERPINNINGS; AMPLITUDE AND PHASE DESCRIPTIONS OF COHERENT STRUCTURES.

Principal Investigators: P. Huerre, L.G. Redekopp.

Research Summary

Description of Scientific Research Goals.

The dynamics and control of coherent structures in free shear flows such as mixing layers and wakes is to be analyzed in terms of a suitable superposition of interacting instability waves subjected to external forcing. Rational analytical models of the global dynamics are to be obtained in terms of nonlinear evolution equations governing either the amplitude or the phase of the wave. The spatio-temporal dynamics of the structures under both natural and controlled conditions will be studied numerically on both types of models. Efficient flow control strategies are to be developed to alter the long-range interactions between structures.

Significant results of the past year.

Progress has been made in 3 distinct areas as summarized below.

A phase dynamics description of the evolution of Kelvin-Helmholtz vortices in stratified mixing layers has been obtained when the Richardson number is close to critical [Huerre (1987)]. The model has been rationally derived from the basic governing equations in the viscous critical layer limit. The combined translational and Galilean invariance of the initial problem has been shown to give rise to strong coupling between the structures and a large scale, horizontal, velocity field. Two types of phase instabilities have been identified. A modified Eckhaus instability can occur as local "compressions" and "expansions" of the vortex array are induced along the stream. This mechanism, which is primarily one-dimensional, could account for phase decorrelations between structures. The second type of phase instability is three-dimensional in character, the most amplified disturbance being obtained at a wavenumber inclined to the flow direction. Finally, in the region of stable configurations, anistropic phase waves may propagate on the vortex structures.

Concurrently, Mr. Ruixin Yang, a Ph.D. student supported by the ONR core program, has begun a numerical study of a two-dimensional model of pattern evolution in mixing layers. This investigation is a joint collaboration with F.K. Browand who is performing companion experiments. In contrast with the previous case, the field equation governing the amplitude evolution of the waves has been postulated. The invariance properties of the problem, together with the presence of shear, placestrict constraints on the nature of the linear operator, as observed in the context of convection by Swift and Hohenberg at Bell

Laboratories. Interactions with the large scale field have been inferred from the asymptotic model described earlier. Preliminary results are very encouraging. In qualitative agreement with experiments, the model is found to be highly selective, white noise initial conditions progressively giving rise to strongly two-dimensional Kelvin-Helmholtz vortices. Imperfections are found to be mediated by dislocations within the flow, a feature which is also present in the experiments of F.K. Browand.

Hiroshi Asano, a Ph.D. student has undertaken analytical studies of the amplitude evolution of coherent structures in confined mixing layers [Asano, Huerre and Redekopp (1987)]. A promising feature of this configuration is the fact that all unstable wavenumbers from zero to the neutral wave can be accounted for. Thus, in contrast with phase dynamics descriptions, transfer of energy to larger scales freely takes place and vortex pairing is uninhibited. The nature of the finite-amplitude dynamics has been found to crucially depend on both the structure of the critical layer around the inflection point of the basic velocity profile and the order of magnitude of spanwise deformations. As in the first problem, coupling between the amplitude of the waves and a large-scale velocity field also plays a crucial role in the development of the structures. All these phenomena need to be brought in consistently to obtain a distinguished limit.

Plans for Next Years Research.

Research in the above three areas will be actively pursued.

The phase description is, so far, limited to slow variations. However, irregularities are known to arise in laboratory situations. The structure of these dislocations will be analyzed theoretically by means of singular perturbation techniques. The main goal will be to obtain the equations governing the motion of defects within a slowly-varying phase field.

The pattern evolution observed in the second problem needs to be carefully correlated with an analytical description of the various secondary instabilities arising in the model. The objective will then be to undertake a numerical study of the nonlinear regime associated with these various instabilities. The pattern evolution model will also allow us to derive a generic phase evolution equation pertaining to free shear flows far away from the instability threshold. This should provide us with a more fundamental understanding of the various large scale instabilities prevailing in free shear flows.

The analytical study of the amplitude evolution of instability waves within confined shear layers will be completed for different settings of the spanwise length scale. The results will then be compared with existing studies of monochromatic instability waves. This is viewed as a prerequisite to a full numerical study of the problem.

Finally, a study of the influence of external forcing will be initiated in the above three areas, as dictated by the results of the natural spatio-temporal dynamics. Various inputs will be selected at a given streamwise station, or along the stream, and the response of the flow will be analyzed and compared with available experimental results.

List of Publications/Reports/Presentations

1. Papers Published in Refereed Journals.

Huerre, P. (1987). "Evolution of Coherent Structures in Shear Flows: A Phase Dynamics Approach." To appear in Nuclear Physics B.

2. Technical Reports.

None.

3. Presentations.

Asano H., Huerre P. and Redekopp, L.G. (1987). "Finite Amplitude, Three-Dimensional, Kelvin-Helmholtz Instability Waves in Bounded Shear Layers." 40th meeting of the Division of Fluid Dynamics of the American Physical Society, November 1987, Eugene, Oregon.

Huerre, P. (Sept. 11, 1987). "Dynamique de Structures Coherentes et Ondes d'Instabilite dans les Ecoulements Cisailles." Special seminar, Universite d'Orsay, Paris, France.

Huerre P. (Aug. 20-21, 1987). "Heuristic Introduction to Chaos." Miniworkshop, Naval Weapons Center, China Lake, California.

Huerre, P. (July 23, 1987). "Amplitude and Phase Evolution of Coherent Structures in Free Shear Flows." Invited talk, American Mathematical Society Conference on. "The Connection Between Infinite Dimensional and Finite Dimensional Dynamical Systems." University of Colorado, Boulder, Co.

Huerre, P. (March 18, 1987). "Hydrodynamic Instabilities in Open Flows: A Bird's Eye View." Workshop in Propagation in Far-From-Equilibrium Structures, Les Houches, France.

Browand, F. K., and Huerre, P. (Jan. 13, 1987). "The Structure of the Turbulent Mixing Layer." International

Conference on the Physics of Chaos and Systems Far from Equilibrium, Monterey, California.

Huerre, P. (Oct. 24, 1986). "Phase Dynamics of Large Structures in Benard Convection and Stratified Mixing Layers." Applied Mathematics Colloquim, University of Arizona, Tuscon.

List of Honors/Awards

None.

List of Participants

H. Asano, Ph.D. student

P. Huerre, Associate Professor

L. G. Redekopp, Professor

R. Yang, Ph.D. student (not supported by ONR-URI contract)

PHASE CONTROL OF VORTEX STRUCTURES IN SHEAR FLOWS

Principal Investigator: T. Maxworthy

Research Summary

Description of Scientific Research Goals.

Persistent patterns of vortex structures emerge as a result of instability processes in many shear flows. These patterns exhibit a high degree of spatial coherence and determine the characteristic scales which dominate the turbulent energy spectrum. One approach toward control or influence of the turbulent scales is through external control of the phase relationships between vortex structures on length scales which encompass many individual features. The goal of this task is to produce laboratory flows containing an extensive pattern of vortex structures driven by a common instability mechanism, and then to explore the response of these patterns to control inputs which principally influence the phase relationship within the pattern. In particular, we seek to clarify the response of vortex patterns to phase disturbances which are incommensurate with the underlying instability scale.

Significant Results in the Past Year

After careful study of candidate laboratory flows, we have chosen to study the flow in a large aspect ratio, annular region between two rotating cylinders. The apparatus will permit independent control of the inner and outer cylinders and allow a controlled axial mass flux. In this way one can specify the principal instability mechanism; ie, either of centrifugal or boundary layer type.

Plans for Next Years Research

We hope to have the apparatus operational by the end of Feb. 1988. The motor drives for the rotating cylinders have been purchased as well as the accurate pumping system for the axial flow.

A second experiment is being proposed to complement the numerical work of J. A. Domaradzki on unsteady Görtler instability. It is proposed to study the controlled spin-down of a rotating cylinder initially containing a fluid in solid body rotation. As the boundary layer of the concave cylinder surface grows, it will become unstable to temporal Görtler instability as opposed to the spatially-growing instability studied previously in spatially developing flow. Flow control will be established using time variation of the cylinder speed and by placing various kinds of perturbations on the cylinder surface.

List of Publications/Reports/Presentations

1. Papers Published in Refereed Journals

   None

2. Technical Reports

   None

3. Presentations

   None

List of Honors/Awards

None

List of Participants

T. Maxworthy, Professor

J. Wiggert, Graduate Assistant

INVARIANT MANIFOLD THEORY FOR HYDRODYNAMIC TRANSITION

Principal Investigator: S. Sritharan

Research Summary

Description of Scientific Research Goals

The basic aim if this research is to identify local and global invariant manifolds (active modes characterizing the solution) of hydrodynamic flows in bounded and unbounded geometries. Such a theory would lay a bridge between modern developments in the theory of finite dimensional dynamical systems and hydrodynamic turbulence. Two classes of flows are presently being studied: motion in bounded containers (multiply connected) and flow through channels with various openings at infinity. In the second category very few mathematical questions have been answered in the literature. As a first step we would like to establish the existence, uniqueness and regularity theory for this class of fluid flows. Other relevant issues in such flow fields are spectral theory of the linearised operators (including the study of the continuous spectrum) and the characterization of the nonlinear hydrodynamic semigroup.

The outcome of such research will be twofold; precise understanding of the onset dynamics of turbulence and efficient numerical algorithms for the computations.

Significant Results in the Past Year.

A. For flow in bounded (multiply connected) containers, the main results are:

(i) Existence theorem of Hopf-class, time periodic solutions.
(ii) Frechet analyticity of the nonlinear hydrodynamic semigroup with respect to the initial data.
(iii) Exponential stability and Lyapunov instability theorems for time periodic basic fields.
(iv) Existence of invariant cones and F-analytic finite dimensional invariant manifolds (for hyperbolic fixed points) in the neighborhood of periodic basic flows.

B. A modification of the conventional Navier Stokes equations using an additional artificial viscosity was studied. It was proved that the solutions of such regularized equations approach (in the appropriate norm) the weak solutions the Navier Stokes equations as the artificial viscosity parameter tends to zero. For the regularized system, it is possible to establish both local as well as global invariant manifolds (inertial manifolds). Mr. Y.-R. Ou will be completing a dissertation on this subject by the end of 1988.

C. For two dimensional aperture domains (divergent channels with many openings at infinity), an existence theorem has been established for the class of flow fields with finite enstrophy (Dirichlet integral). This research is performed in collaboration with Prof. J. G. Heywood of the University of British Columbia, Canada.

Plans for Next Years Research.

For the flow in bounded domains, we would like to extend the invariant manifold theory to general hyperbolic invariant sets and functional attractors. This will involve the study of stability properties of the orbits nearby the attractors. Such attractors can be either a manifold (for example higher dimensional tori) of finite integer dimension or a "strange" attractor of fractional dimension. This research will be done in collaboration with Prof. R. Johnson of USC (Mathematics). For the flow fields in aperture domains we would like to establish an existence theorem for time dependent flow through channels with prescribed constant of time-dependent flux. The possibility of deriving numerical algorithms and far field conditions will be also studied.

List of Publications/Reports/Presentations

1. Papers published in Refereed Journals

None

2. Technical Reports

None

3. Presentations

Y.-R. Ou & S.S. Sritharan. "Local and Global Invariant Manifolds for Modified Navier Stokes Equations." SIAM Annual Meeting, Denver, Colorado, October 1987.

Y.-R. Ou & S.S. Sritharan. "Existence, Uniqueness and Limit Solutions to Modified Navier Stokes Equations." SIAM Annual Meeting, Denver, Colorado, October 1987.

List of Honors/Awards

None

List of Participants

S. Sritharan, Assistant Profesor

Y.-R. Ou, Graduate Assistant (not supported by ONR-URI Contract).

Prof. J. G. Heywood, Univ. of British Columbia, Consultant

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