# 2002 Annual Report

# CENTER FOR FLOW PHYSICS AND CONTROL

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## Center Overview

This marks the **first** complete year for the Center. In this, we have embarked on our Mission to *seek larger multidisciplinary research programs, expand our involvement with industry in research and establish long-term Industry Partners, and continue to maintain and grow our more focused core research activities.* Towards attaining the first of these, the Center submitted a $15M proposal for a NASA "Institute for Flow Control Applications in Propulsion." This involved our concept for the use of flow control on a small number of basic but important elements or "flow modules," in the internal and external flow field of Turbo-jet engines. Although it could be applied to existing engines, the full-term vision is to incorporate these concepts in next generation designs, with the potential to significantly reduce the weight and part count of engines, as well as lower engine noise, unsteady loads and emissions. The proposal involved five universities and two government partner laboratories, and covered experiments, large-scale numerical simulations, and low-order modeling.

A second effort in a larger multidisciplinary research program involved a DARPA proposal on "Morphing Wing Structures for Multiple Mission Performance in Unmanned Air Vehicles." This focused on concepts for substantially altering the performance of an aircraft in-flight, to meet different and otherwise conflicting design optimizations. This involved faculty in Multidisciplinary Design Optimization (MDO) and Aerodynamics at Notre Dame, as well as researchers in another university specializing in "smart materials". Fabrication of a concept demonstrator involved a government partner laboratory.

Our involvement with industry in government funded University/Industry research has remained strong. In the past year this has included funded efforts with Boeing, United Technology Research Center, Pratt & Whitney, Lockheed Martin, and Northrop-Grumman.

**Center Overview (continued)**

Efforts are moving to establish 5-year Industry Partner agreements with Boeing and Northrop-Grumman. The initial steps in discussion of a similar agreement with General Electric Aircraft Engines has also been initiated. These are all expected to develop further in the Fall, 2002 when representatives of these companies visit the Notre Dame campus and Center.

In seeking larger multidisciplinary research programs, we have continued to maintain, and even grow, our core research activities. This has involved a broad number of government funding agencies including: the Army Research Office, the Air Force Office of Scientific Research, the Office of Naval Research, the Defense Advanced Research Projects Agency, NASA Langley Research Center, NASA Glenn Research Center, NASA Ames Research Center, and Los Alamos National Laboratory.

The significant growth areas for Center research in the past year have been in "aero-optics" and "flow control". To support these areas, the Center, in conjunction with the AME Department, is opening a Research Assistant Professor position in Fluid Dynamics. We hope to fill this position in the early Fall of this year.

**Major Accomplishments**

In assessing the past year, there have been a number of significant achievements. The first has been the addition of Dr. Scott Morris as a new AME Department Assistant Professor, and Center member. Scott's area of research is experimental fluid dynamics. His Ph.D. research has involved turbulence in free shear layers and boundary layers. Within the Center, Scott has become involved in ONR funded research on aero-acoustics. This is a long-standing area of research that is an important part of the Center. Scott is also planning to develop research in fundamental turbulence and turbulence control, which will impact aero-propulsion areas, that are ongoing in the Center.

One of the signature areas of research in the Center has become aero-optics. This is due to the work of Professor Eric Jumper. The past year has brought significant funding through government sponsored partner grants with Boeing, and a Boeing/Lockheed Martin collaboration. In addition to this, a Notre Dame/Northrop Grumman Joint Program in Aero-optics has been initiated. These programs are a model for University/Industry collaborations which we aspire to in the Center.

**Major Accomplishments (continued)**

The past year has seen a significant development of "plasma actuators" as the flow control devices of choice. Within the Center, they are being used in NASA Langley funded research on jet noise control, in NASA Glenn funded research on turbine blade separation control, in DARPA funded research on helicopter retreating blade stall control, in free-shear layer control for aero-optics, in the phase control of unsteady wakes for AFOSR funded research on jet turbine high-cycle fatigue, for lift enhancement on wings ("plasma flaps") in a joint project with the Air Force Academy, and on producing shock waves for attitude control on small flying vehicles in Air Force funded research. Professor Corke has organized an invited session in the AIAA Aerospace Sciences Meeting in January 2003 on "Weakly Ionized Plasma Actuators" to highlight applications such as these. This will include a panel discussion on government funding opportunities in this area.

Two new wind tunnels became operational in the past year. One was designed to simulate conditions over blades in the low pressure turbine (LPT) stage of a Turbo-jet engine. The 1m square cross-section measurement section is a 95 degree bend which holds a linear cascade of Pratt & Whitney "Pak-B" blades. These blades have a profile which produce a surface pressure distribution which is generic to LPT blades. The tunnel was funded by NASA Glenn Research Center. The ongoing research is funded under a second 3-year grant from NASA Glenn. This tunnel is an open-return design which is the first phase of construction. The fan and other components were sized for the second phase of construction in which the tunnel loop will be closed. This tunnel is located in the lower level of the Hessert Laboratory.

The other new wind tunnel is a smaller diagnostic facility located in Rm 002 of the Hessert Laboratory. It has a $0.3 \times 0.46$ m. cross-section test section, a maximum test section velocity of 40 m/s, and very low turbulence levels of less than 0.05%. This tunnel is intended to develop new concepts on a smaller scale before moving to the larger-scale, more heavily used, facilities in the Center.

**Major Accomplishments (continued)**

Significant new equipment obtained in the past year include a Digital Stereo Particle Image Velocimeter for non-intrusive velocity measurements with plasma flow actuators, a high-speed conform-able mirror for aero-optic control, and an 80 channel simultaneous sampled microphone array for aero-acoustic research. These amounted to approximately $350K in capital equipment purchased for the Center.

Professor Mueller organized and hosted the 97th Meeting of the Supersonic Tunnel Association International organization this past June on the Notre Dame campus. Professors Mueller, Nelson and Corke are organizing the 11th International Symposium on Flow Visualization that will be held at Notre Dame in August, 2004.

**Multidisciplinary Initiatives**

There were a number of multidisciplinary initiatives from the Center in the past year. These include the "Institute for Flow Control Applications in Propulsion" (IFCAP); "Morphing Wing Structures for Multiple Mission Performance in Unmanned Air Vehicles"; the Boeing Directed Energy Proposal (DEBI-FX); and Single Dielectric Barrier Plasma Discharge research with members of the Physics Department of the U. S. Air Force Academy.

The proposal for IFCAP involved five universities and two government laboratories. It tightly incorporated controlled experiments, high-fidelity numerical simulations, and low-order modeling that would lead to new paradigms for turbo-jet engine design. Within Notre Dame it involved members in the AME department in Fluid Dynamics, Controls, and Optimum Design; in the EE department it involved faculty in micro-fabrication.

The proposal on Morphing Wings involved one other university and one government laboratory. It was designed to examine concepts for radical changes in wing geometries in order to optimize performance in different mission objectives. Within the AME department it involved Fluid Dynamics, Aerodynamic Control, and Optimum Design. The university partner provided expertise in shape-memory materials. Manufacturing expertise was provided by the laboratory partner. We are presently pursuing opportunities for funding in this area through a Phase I DARPA program.

**Multidisciplinary Initiatives (continued)**

The DEBI-FX proposal involves the control of an unsteady compressible flow field to minimize aero-optic disturbances. This involves a number of technical disciplines including flow control, optics, feedback control, numerical simulations and system modeling. Notre Dame is providing the expertise in the area of unsteady optics for this work. However, in other aero-optic research with Northrop-Grumman, the Center is involved in both the unsteady aero-optics and flow control.

The Single Dielectric Barrier Plasma Discharge research involves a collaboration with plasma physicists at the U. S. Air Force Academy in Bolder Colorado. This is intended to provide a physical model for the plasma actuators that can be used in numerical simulations of flow control applications. Complimentary experiments have been conducted in the Center and at the Academy. This is expected to lead to a joint paper and possible patents.

**Visiting Faculty**

In the past year, three visiting faculty have spent time working in the Center. These have included Dr. Stanislav Gordeyev, Visiting Assistant Professor; Dr. Amr Ali, Visiting Assistant Professor; and Dr. Romeo Susan-Resiga, Visiting Associate Professor. Drs. Gordeyev and Ali are planning to continue working in the Center through the Fall, 2002.

Dr. Osamah Haddad, an Associate Professor from the Jordan University of Science and Technology, will be joining the Center for a year, starting this September. His research is in the area of Computational Fluid Dynamics and Heat Transfer. He is expected to work on numerical simulations for plasma-based flow control.

**Center Research Faculty Openings**

The Center has an opening for a Research Faculty position at the Assistant Professor level in the area of Experimental Fluid Dynamics/Aerodynamics. Requirements include an earned doctorate, demonstrated research expertise in the experimental fluid dynamics area, and an interest in assisting existing research, and developing new research areas. Of special interest are candidates with experience in aero-optics, flow control, and advanced data analysis techniques such as Linear Stochastic Estimation and Proper Orthogonal Decomposition. Successful candidates will be expected to support an active externally funded research program.

**Center Specific Funding**

In the first year, the Center has been supported from internal funds jointly provided by the Graduate Research Office, Engineering College, and AME Department. The total funding was $40K.

This has supported a variety of activities including the production of a web page for the Center, additional hard-copy promotional graphics, capital improvements to the conference room in the Hessert Laboratory, invited seminar speakers, a Center Graduate Fellowship, and a small amount of travel towards the development of Center-based research proposals.

The Center Graduate Fellowship was awarded to Kortny Hall. This provided $2,000 with which he purchased a personal computer. Kortney has a B.S. degree from Notre Dame, and is pursuing a Ph.D. with Professor Jumper.

The Center budget supported 5 undergraduate students during the Summer, 2002. Two of the students worked on "Morphing Airplane" concepts for the submitted DARPA proposal. The other three worked on a variety of research projects in the Center.

The Center took an active role in recruiting candidates in Fluid Dynamics for the open Assistant Professor position in the AME Department. This involved inviting potential candidates for Center seminars.

We are presently seeking external Center-specific funding through a group of Industry Partners. In these, we are seeking 5 year Consortium Agreements which will form the formal working relationship with an Industry Partner. This will involve an annual payment to the Center. This is presently being discussed with Boeing and Northrop Grumman. In particular, there is a pending proposal for a "Notre Dame/Northrop Grumman Corporation Joint Program in Aero-optics" which is viewed as a first step in formalizing an Industry Partner relationship.

We have been in negotiation with Boeing for the past year and have a new draft of a MOA which we plan to discuss with Boeing representatives this September. With all of the Industry Partners, we are seeking $50K per year commitment.

**Future Outlook**

The future of the Center looks extremely positive. We have observed both a growth in the amount of core funding, and in the number of graduate assistants. We have added a new Assistant Professor in the Experimental Fluid Dynamics area, and are presently seeking to hire a Research Assistant Professor. The mix of graduate assistants is quite good, with approximately 55 percent being U.S. citizens and approximately 17 percent being women.

In the coming year we expect a continued growth in research areas pertaining to Aero-optics, Plasma-based Flow Control, and Intelligent Aero-Propulsion.


Several Aero-optics initiatives are in place with Boeing, Northrop-Grumman and Lockheed Martin. The plasma-based flow control is presently being used in three research projects. We are likely to add additional projects, and be involved in the formation of a new NASA Center related to weakly ionized plasmas. Finally we will are looking to leverage our IFCAP proposal through other funding agencies in the form of a new program, as well as towards developing an industry partner relationship with General Electric Aircraft Engines.

**Future Outlook (continued)**

The **major challenges** in the coming years will be:

1. obtaining Center-specific funding to support the activities and growth of the Center,
2. developing a broad group of Industry Partners,
3. expanding the number of External Advisors,
4. promoting the Center's activities to a broader number of faculty in order to identify synergies,
5. planning of new facilities to be more competitive in new research initiatives,
6. development of a graduate curriculum on "intelligent systems",
7. increasing space for additional technical staff, visiting faculty, graduate students and facilities.

As we move to develop Industry Partners, we have enumerated a list of "benefits" that they derive. These include:

1. A committed cross-interaction with a University Center whose focus is on
   (a) the organization of multi-disciplinary groups that can address broad issues, applications, and benefits of flow modeling and control;
   (b) that builds on a number of individual efforts that have demonstrated broad flow control capabilities;
   (c) that is committed to the belief that evolutionary changes in aerodynamics that are coming, will require designs in which flow control is *planned from the beginning,*

   e.g., blended wing, tail-less designs; un-piloted, highly maneuverable combat aircraft; morphing aircraft; propulsion systems; smart weapons; supersonic commercial aircraft; earth-to-orbit vehicles.

**Future Outlook (continued)**

2. Provide assistance in bidding proposals including, technical and writing support.
   (a) Can involve use of facilities for proof-of-concept experiments.
3. A *Partner in Research* which provides access to research facilities and staff including
   (a) state-of-the-art instrumentation,
   (b) digital storage and on-line access,
   (c) low overhead,
   (d) technical research training.
4. Partners in research with a long-term Proprietary Agreement in place, to benefit
   (a) a more immediate response to requests for proposals,
   (b) a more up-to-date understanding of future Partner issues, where the Center can direct activities.
5. In-depth access to Center public domain research.
6. Involvement in Center sponsored technical workshops, seminar series, and distance learning.
7. An exchange of technical personnel through *Visiting Research Appointment* and *Employee in Residence* programs.
8. Interactions with Center *External Advisory Committee* made up of individuals from government laboratories and academia.
   (a) Providing broad insight to future directions of potential interest to Industry Partners.

**Future Outlook (continued)**

We will continue to seek **on-campus** multi-disciplinary partnerships. The AME department is diverse, and the DARPA initiative on "Morphing Aircraft" with Professor John Renaud who brings expertise in Multi-disciplinary Design Optimization (MDO), is an example where local partnerships have been developed. In other areas, such as our partnership with plasma physicists at the Air Force Academy, we have not found equivalent expertise on our campus. This remains a challenge in the coming years.

One of the major initiatives we foresee is the development of a multi-disciplinary graduate program in "Intelligent Systems" that incorporates simulation/modeling/MDO, nonlinear control, signal analysis/processing, and sensors/actuators. This would provide the structure for a variety of applications including "intelligent flow control." This is in the spirit of our original IFCAP proposal, and is consistent with new industry programs such as GE's "Intelligent Engine" concept.