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14. ABSTRACT
During this three year time period significant advancements were made modeling behavior of shape memory alloys for wing warping applications, shape optimization of piezoceramic composite micro actuators, development of a visualization lab for modeling vision based guidance algorithms, concept development of a rapid prototyping and aero characterization lab, vision based control of autonomous vehicles, cooperative flight of autonomous aerial vehicles using GPS and vision information, cooperative and sharing of information in search missions involving multiple autonomous agents, multi-scale modeling of hexagonal closed pack metals, characterization and modeling of cement like materials involved in munitions penetration, modeling and simulation of ceramic matrix composites, and mechanical response of composites in the presents of electromagnetic fields.

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Abstract

The primary objective of this grant is to conduct new, groundbreaking research on agile autonomous munitions, in direct support of the Air Force Research Laboratory Munitions Directorate (AFRL/MN). The grant was awarded with a basic period of performance from 1 April 03 to 31 Dec 03 with three options that could be exercised: **option 1**, 1 Jan 04 to 31 Dec 04; **option 2**, 1 Jan 05 to 31 Dec 05; **option 3**, 1 Jan 06 to 31 March 06. All three of these options were exercised. The basic grant and three options had (2) major research thrusts: (1) The Center for Agile Autonomous Flight and (2) Improving Robustness of Modeling and Simulation (IRMS). The Center for Agile Autonomous Flight had (5) research task areas:

1. Aeroforms and Actuation for Small and Micro Agile Air Vehicles
2. Sensing for Autonomous Control and Surveillance
3. Closed-loop Aerodynamic Flow Control
4. Cooperative Control for Agile and Autonomous Vehicles
5. Laboratory Facilities

The research thrust for Improving Robustness of Modeling and Simulation (IRMS) had 2 research task areas:

1. Modeling and Simulation of localization and failure of solids (HCP metals, cement like materials, and ceramics)
2. Modeling of strength characteristics of conductive fiber composites

During this three year time period significant advancements were made modeling behavior of shape memory alloys for wing warping applications, shape optimization of piezoceramic composite micro actuators, development of a visualization lab for modeling vision based guidance algorithms, concept development of a rapid prototyping and aero characterization lab, vision based control of autonomous vehicles, cooperative flight of autonomous aerial vehicles using GPS and vision information, cooperative and sharing of information in search missions involving multiple autonomous agents, multi-scale modeling of hexagonal closed pack metals, characterization and modeling of cement like materials involved in munitions penetration, modeling and simulation of ceramic matrix composites, and mechanical response of composites in the presents of electromagnetic fields.

Although the original 3 year grant was to conclude March 06, a grant extension was awarded in April 06 that extended the period of performance to 30 Nov 06 and added (5) tasks (original thrust areas and focus areas were concluded as of 31 March 06). The following tasks were added:

1. Full Vehicle Prototyping
2. Integrated Visual-servo Control
3. Aerodynamic and Structural Characterization
4. Control of Biologically Inspired Morphing
5. Computational Aerodynamics of Flexible and Flapping Wings

This effort was executed under the Agile Autonomous Munitions Center of Excellence (AAM COE), which operates as a focus area within the UF-REEF (University of Florida Research and Engineering Educational Facility). The AAM COE serves as a focal point for the research, development and transition of technologies necessary to attain agile, smart munitions operating autonomously or cooperatively in complex, uncertain, adversarial (urban) environments. The Research Institute on Autonomous Precision-Guided Systems (RIAPGS) was developed jointly by the REEF and AFRL/MN as a refinement of the existing partnership between the REEF and Eglin AFB. The RIAPGS Grant includes on-site researchers to finalize and utilize the infrastructure created by the FY04 *(A Hardware-in-the-Loop Experiment and Simulation Facility for Vision-Based Control of Micro-Munitions)* and FY05 *(Rapid Prototyping, Aerodynamic Characterization, and Hardware in-the-Loop Simulation for Small, Agile Autonomous Munitions)* DURIP grants and addresses research directions that have been identified as critical barriers in AAM, but are not covered in the scope of the AVCAAF (*Vision-Based Control of Agile, Autonomous Micro Air Vehicles and Small UAVs in Urban Environments)* grant. Significant advancements include: autonomous or human localized feature point tracking and autonomous closed loop servo control demonstrated in the REEF Visualization Lab; accurate CFD simulations of a dynamic, flexible wing in low Reynolds number flow characterized with laminar separation and transition; morphing MAV vehicle designed, built, and flown based on biologically inspired gull wing.

A second extension (no cost) was added to the contract with the period of performance from 1 Dec 06 to 28 Feb 07. This extension continued the development under the 5 new tasks and used unexpended money under the grant to continue the effort.

The grant initiated in April 03 has had three principal investigators:

Dr. Pasquale Sforza (CY 03)
Dr. Andrew Kurdila (CY 04)
Dr. John Rogacki (CY05-07)

Starting 1 April 06 the following co-principal investigators were identified:

Dr. R.C. Lind
Dr. Warren Dixon

Starting 1 Dec 06 Dr. Lawrence Ukeiley was added as a co-principal investigator

Research under the 5 new task areas will continue into the CY07 and CY 08 with the expected award of a new (2) year grant in March 07.

Overview of the Original Three Year Grant

As stated in the abstract the grant awarded on 1 April 03 had a basic period of performance of (9) months followed by 2 optional 1 year increments and then finally an option for a 3 month increment taking the grant to 31 March 06. All of the options were exercised. The grant during this time period had two major thrust areas (1) The Center for Agile Autonomous Flight and (2) Improving Robustness of Modeling and Simulation (IRMS). The Center for Agile Autonomous Flight had (5) research task areas:

6. Aeroforms and Actuation for Small and Micro Agile Air Vehicles
7. Sensing for Autonomous Control and Surveillance
8. Closed-loop Aerodynamic Flow Control
9. Cooperative Control for Agile and Autonomous Vehicles
10. Laboratory Facilities

The research thrust for Improving Robustness of Modeling and Simulation (IRMS) had (2)research task areas:

3. Modeling and Simulation of localization and failure of solids (HCP metals, cement like materials, and ceramics
4. Modeling of strength characteristics of conductive fiber composites

Annual reports were submitted in CY 03 (appendix A), CY04 (appendix B), and CY 05 (appendix C) that documented the grant activities in the following areas:

- Research projects progress and accomplishments
- Researchers supported by the grant
- Publications and references
- Honors and awards
- AFRL points of contacts
- Transitions
- Discoveries

Refer to those appendices A, B, and C for the above subjects during the three year grant period 1 April 03 to 31 March 06.

Overview of Grant Extension Periods

The grant extension periods began 1 April 06 and ended with the no cost extension to 28 Feb 07. The original focus areas and tasks under the 3 year grant ended 31 March 06 and the grant extension added the (5) new tasks listed below:

1. Full Vehicle Prototyping
2. Integrated Visual-servo Control

3. Aerodynamic and Structural Characterization
4. Control of Biologically Inspired Morphing
5. Computational Aerodynamics of Flexible and Flapping Wings

An annual report was submitted on these tasks in Aug 06 (appendix D) that documented the grant activities in the following areas:

- Research projects progress and accomplishments
- Researchers supported by the grant
- Publications and references
- Honors and awards
- AFRL points of contacts
- Transitions
- Discoveries

Refer to appendix D for the above subjects during the grant period 1 April 06 to 31 Aug 06.

The remainder of the grant period form 1 Aug 06 to 28 Feb 07 is documented below:

Full Vehicle Virtual Prototyping: Control Synthesis and Aero-structural Characterization of Agile Autonomous Munitions and Micro Air Vehicles (MAV) (Task 1)

The vehicle virtual prototyping research has been concentrating and making progress on marrying the facility and simulation requirements of the guidance and control discipline with the aerodynamics characterization requirements needed for hardware in the loop simulations. The hardware-in-the-loop simulation capability is dependent on having a data base for virtual scene generation (two data bases developed and available in the REEF), software to calculate and display virtual camera views (developed and available at REEF for up to 10 views), a camera to record images presented on flat screens with proper coordinate transformation (developed and available at the REEF), guidance/path planning/structure form motion and visual-servo control (initial capability developed and available at the REEF with more refined and mature algorithms under development for implementation in future years), micro air vehicle dynamics model (limited model of a 6 inch wing span MAV available, however models under development are the 24 inch wing span MAV and next year the morphing wing MAV model, followed by the flapping wing model in following year), ability to fly the MAV in a tethered flight condition to allow rapid prototyping investigations (requirements identified for the dynamic mounting system that will allow rolling, pitching and yawing of the vehicle).

The REEF researches have worked out much of the mathematic details of allowing a camera in the loop, hardware in the loop simulation to represent a camera looking at a real 3 dimensional screen. The simulation has a 3 dimensional scene projected onto a 2 dimensional plasma screen that is then projected on to a 2 dimensional camera image. This extra projection threatened to invalidate vision based control methods using camera in the loop simulations unless a proper transformation could be developed. The innovative solution proved to be in classifying the screen to camera relationship as a homography projection where every point on the screen corresponds to only one point in the camera image. Homography can be represented by a matrix G that maps a point into the image, x_c, to a point on the screen, x_s=Gx_c. The mapped points x_s, can be used in vision-based control and estimation methods. The method developed to solve for the G matrix projects a grid pattern on the screen, capturing a camera image, extracting corners, and solving an over determined set of linear equations (see the figure 1 below). To compensate for noise (pixilation, focus, radial distortion, etc.) a RANSAC algorithm is incorporated to eliminate poor feature point correspondences.

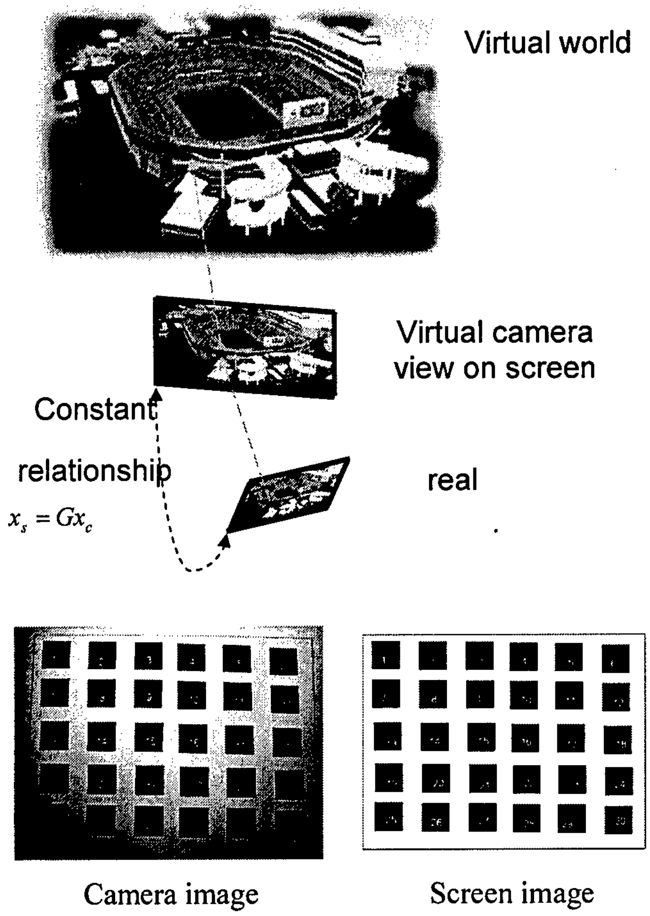

Figure 1: Displays the relationship between the 3D scene and the 2 D projections on to a flat plasma screen and a 2D camera image. The corners of the square patterns are used to determine the G holographic transformation

Integrated Visual-Servo Control and Path Planning for Unmanned Air vehicles (Task 2)

The following research accomplishments were achieved during this review period: Developed and verified "Daisy-Chaining" method for large scale vision-based estimation and visual servo control; developed an advanced nonlinear visual servo method to control both image and pose error; and integrated feature point tracking, adaptive geometry estimation, and receding horizon control into closed-loop simulations of a MAV flying through a virtual urban environment.

A principle concern in visual servo development, particularly for control of aerial vehicles, is the limited field of view of the camera. A method was established that can allow for feature points to enter and leave the field of view while maintaining relative pose estimation, and to relate the pose of objects visible in multiple cameras from multiple points of view. This flexible method coined "daisy chaining" allows a pose estimation of one set of feature points to be correlated to the pose information of a second set of feature points. Similarly it is possible to relate pose information ascertained form one camera view to the pose information ascertained from a second camera view. This information can be "chained" indefinitely, allowing for long term pose estimation or large area scene and pose knowledge. The algorithm has been experimentally verified via a flight test in which camera base pose estimation performed approximately the same as a GPS pose estimation during flight.

There are numerous visual servo methods that often deliver tradeoffs in performance. For instance, methods that regulate the pose are prone to losing sight of image features, and methods that keep features in the field of view are prone to making large, unnecessary motions. Additionally, all visual servo methods need information about distance to feature points and geometry of feature points. Using nonlinear control methods the University of Florida has developed a method that stabilizes both the camera pose and stabilizes the image. Additionally, adaptive control methods alleviate any need for depth measurement of knowledge of the scene.

Feature point tracking, adaptive geometry estimation, and receding horizon path planning and control algorithms have been successfully integrated into a closed-loop control system. The control objective is to enable a MAV to fly to a goal location in an unknown environment. The vision-based geometry estimation process generates an adaptive representation of the scene (see figure 3). This representation is used to enforce obstacle avoidance constraints for locally-optimal receding horizon path planning and control algorithms. The performance of the vision-based control system has been investigated via simulated MAV flights through a virtual environment. In these simulations, the MAV was able to fly to the goal location while avoiding buildings in its path (See the figure 2 below). These initial simulations assumed the vehicle rotational and translational dynamics where being tracked by onboard inertial instruments; therefore, upcoming work will focus on integrating a state estimation process into the closed-loop control system that estimates vehicle dynamics using vision rather than inertial instruments.

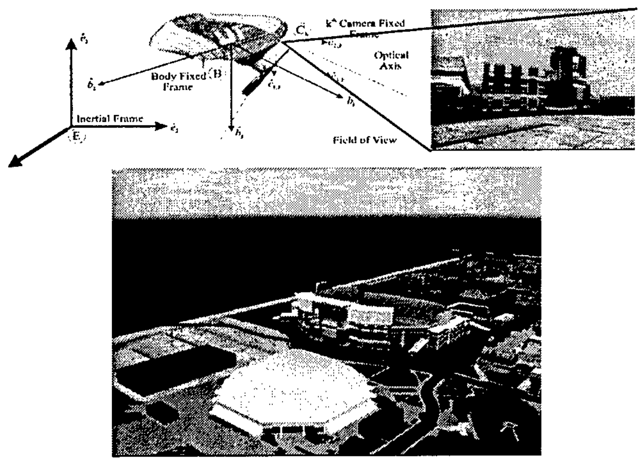

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Figure 2: General MAV mission scenario where the vehicle is commanded to fly from point A to point B without any prior knowledge of obstacles such as buildings or the stadium

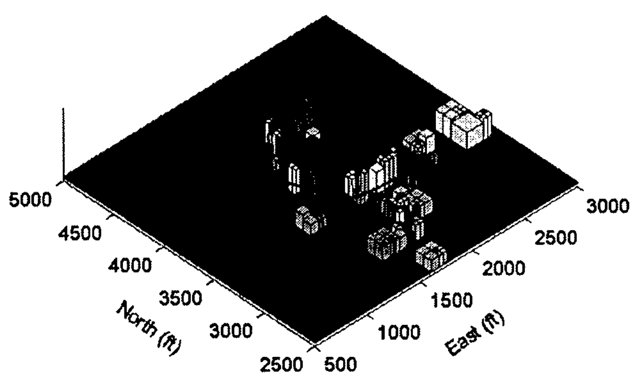

Figure 3: Adaptive estimation of scene geometry from camera images that are built in segments during the receding horizon path planning algorithm process and displayed here for the entire flight

Aerodynamic and Structural Characterization of Flexible and Morphing MAV's in Low Reynolds Number Flow (Task 3)

The primary effort over the extension period has been continued testing and evaluation of the new equipment along with design and initial fabrication of the components for the larger Aerodynamic Characterization Facility. The testing and evaluation with the advanced optical measurement techniques (PIV, VIC and Laser Vibrometery) has been conducted in the pilot wind tunnel which is serving as a staging facility and will allow for an easy transition to the larger more elaborate Aerodynamic Characterization Facility which will be coming online in summer 2007.

The design for the Aerodynamic Characterization Facility was completed over the past 6 months and an order has been placed with a suitable vendor. One of the unique features of the facility will be the dynamic test rig which has the capability of simulating pitching and plunging features through a control system and 2 linear actuators. Extensive modeling of the dynamic rig has been completed using Simulink by the researchers at the REEF. The model results have been used to finalize the configuration of the system and a detailed design of the hardware is currently under way so that it will be available when the facility is complete. In addition to the dynamic rig work on calibration checks of the sting balances has also been performed by the joint REEF/University of Alabama team. This has included tests that were conducted with the supplied calibration body and assembly which allowed the application of three hanging weights (see Figure 6). The configuration enabled independent interactions of normal force/pitch moment, side force/yaw moment, and roll moment, and coupled interactions, dependent on the inclination or rotation angle, between components such as normal and side force, normal/side and axial force, and pitch and yaw moment. In addition the evaluation has included the development of LabView GUI interface and extensive analysis to determine what the uncertainty in the forces will be based on the existing electronics (see Figure 5).

Measurements of the flow quality in the pilot facility have been carried out along with preliminary vibration tests on highly flexible 500 mm and 150 class wings. These experiments have begun the utilization of much of the equipment purchased by the previous DURIP awards such as the Laser Scanning Vibrometer and Dynamic Visual Image Correlation system. A large part of the effort has been to develop specific VIC post-processing routines for the reconstruction of the complex experimentally measured three dimensional geometries. This procedure includes the ability to output the geometries to solid modeling tools as well as tools for CFD grid generation which will be used to help incorporate the experimental effort with those going on as part of task 5. Specific experiments were run obtaining VIC data including rigid body motions (RBM) and different values of latex pretension. The methodology will be used to measure the pretension state on membrane wings and to extrapolate the elastic deformation and strains on flexible objects in the presence of RBM as an alternative to the familiar but in some cases inaccurate application of the Lagrangian operator followed by numerical integration. A similar technique is used to decouple RBM from elastic deformation on flexible wings particularly useful for morphing or flapping wings applications. In addition to the measurements of the surface motions experiments to study separation characteristics of low Reynolds number flow (Re_c=60000) over a solid SD-7003 have been initiated. These studies have been designed in consultation with the Task 5 leader and AFRL contacts and will not only help to understand many external effects on the separation characteristics but will allow for the close collaboration and validation between the experimental and computational efforts.

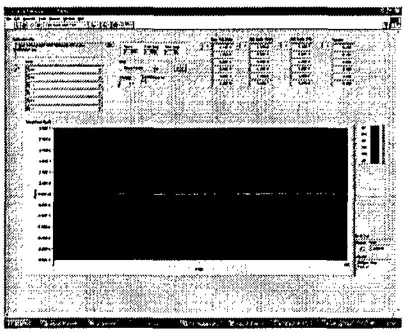

Figure 6: LabView GUI Interface for Balance Calibration

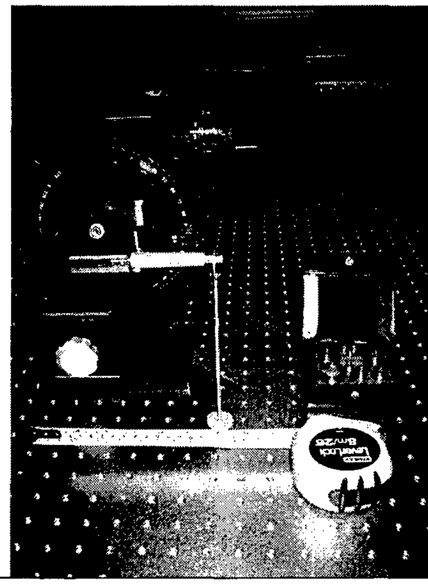

Figure 5: Balance Calibration Rig

Control of Biologically-Inspired Morphing for Variable-Geometry MAV (Task 4)

This task seeks to incorporate morphing into micro air vehicles to enable multi-role capabilities for a single vehicle. Essentially, the vehicle changes shape by altering parameters, such as sweep or dihedral, during flight (see figure 7). The resulting range of configurations will have an associated range of flight dynamics and, consequently, maneuvering.

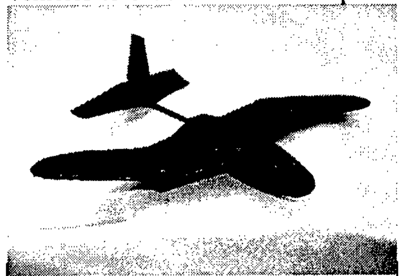

Figure 7, Biologically Inspired Morphing MAV Configuration

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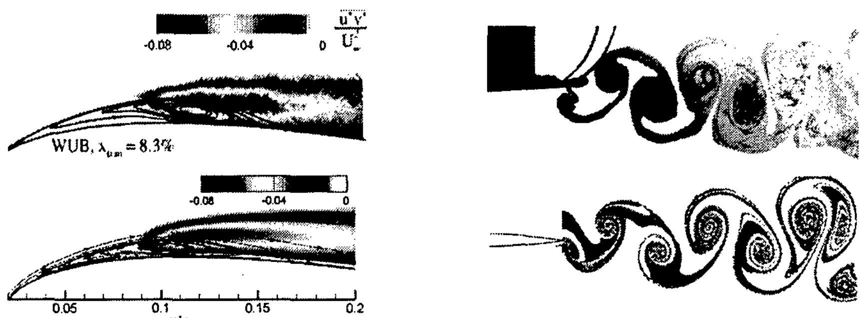
The recent progress has resulted in consideration of a variable-sweep aircraft that mimics properties of a seagull. This aircraft can independently change the sweep angle of both inboard and outboard wing sections. Additionally, the independence of separate actuation for right and left wings allows both symmetric and asymmetric configurations to be flown.

The aerodynamics and associated flight dynamics are analyzed for the vehicle across a range of sweep configurations. A set of parameters are computed that related both stability properties and performance characteristics of the configurations. Most importantly, the ability of the vehicle to minimize turn radius for urban maneuvering and maximize angle of sideslip for sensor pointing in a crosswind are shown to be significantly enhanced using the degrees of freedom associated with the independent multi-joint structure.

Computational Aerodynamics of Flexible and Flapping Wings for Micro Air Vehicles (Task 5)

The state-of-the-art of the computational capabilities for micro air vehicle aerodynamics can be found in Refs. [1,2]. Laminar-turbulent transition in the MAV flight regime, with the Reynolds number of 10^4-10^5, is particularly challenging, and has yet been adequately addressed. This research represents a serious effort in investigating such transitional fluid dynamics. In order to gain better understanding of the fluid physics and associated aerodynamics characteristics, the (i) a Navier-Stokes solver, (ii) the e^N method transition model, and (iii) a Reynolds-averaged two-equation closure were coupled together to study the low Reynolds number flow characterized with laminar separation and transition. A new intermittency distribution function suitable for low Reynolds number transitional flow was formulated and tested. To support the MAV applications, both rigid and flexible airfoils were investigated. These airfoils have a portion of their upper surface mounted with a flexible membrane, using SD7003 as the airfoil configuration.

Our numerical simulations follow the set up of Ol et al. [3]. The geometry is based on the SD7003 airfoil, which exemplifies the laminar separation bubble layer (LSB) at low Reynolds number conditions. Based on freestream velocity and airfoil chord length of 20 cm the Reynolds number is 60,000. In the current transitional flow regime, though the Reynolds number affects the size of the laminar separation bubble, it does not place consistent impact on lift or drag (see figure 8). The gust exerts a major influence on the transition position, resulting in lift and drag coefficients hysteresis. It is also observed that thrust instead of drag can be generated under certain gust condition. For a flexible wing, self-excited vibration affects the separation and transition positions; however, the time-averaged lift and drag coefficients are close to those of the rigid airfoil. See Ref. [5] for results obtained under the sponsorship of the present grant.



(i) Fixed Airfoil: Re = 60,000, laminar separation bubble transitioning to turbulent flow

(ii) Plunging Airfoil: Re = 40,000

at reduced frequency k=3.93

& plunging amplitude h=0.075c

Figure 8: Assessment between CFD analysis and experimental results for (i) laminar separation bubble transitioning to turbulent flow, over a fixed airfoil, and (ii) wake structure behind a plunging airfoil

Acknowledgment/Disclaimer

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References:

[1]Shyy, W., Berg, M., and Ljungqvist D., "Flapping and Flexible Wings for Biological and MicroVehicles," *Prog. Aerospace Science*, 35, pp. 455-506, 1999.

[2]Lian, Y., Shyy, W., Viieru, D., and Zhang, B. N., "Membrane Wing Aerodynamics for Micro Air Vehicles," *Progress in Aerospace Sciences*, Vol. 39, 2003, pp. 425-465.

[3]Ol, M., McAuliffe, B. R., Hanff, E. S., Scholz, U., and Kaehler, C., "Comparison of Laminar Separation Bubble Measurements on a Low Reynolds Number Airfoil in Three Facilities," AIAA Paper 2005-5149, 23rd AIAA Applied Aerodynamics Conference, Toronto, June 6-9, 2005.

[4]Radespiel, R., Graage, K., and Brodersen, O., "Transition Predictions Using Reynolds-Averaged Navier-Stokes and Linear Stability Analysis Methods," AIAA Paper 91-1641, June 1991.

[5]Lian, Y. and Shyy, W., "Laminar-Turbulent Transition of a Low Reynolds Number Rigid or Flexible Airfoil,"AIAA 36th Fluid Dynamicvs Conference and Exhibit, June 5-8, 2006, Paper No. 2006-3051.

Personnel Supported During the Grant Extension period (1 April 06 to 28 Feb 07)

Dr. Warren Dixon	Assistant Professor, University of Florida
Dr. Rick Lind	Assistant Professor, University of Florida
Dr. Andrew Kurdila	Adjunct Professor, University of Florida
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Dr. Lawrence Ukeiley	Assistant Professor, University of Florida
Dr. Roberto Albertani	Visiting Assist. Professor, University of Florida
Dr. Bruce Carroll	Associate Professor, University of Florida
Dr. James Hubner	Assistant Professor, University of Alabama
Dr. Wei Shyy	Professor University of Michigan
Dr. Richard Prazenica	Visiting Assist. Professor, University of Florida
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Bret Stanford	Graduate Assistant, University of Florida
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Patrick Trizilla	Graduate Assistant, University of Michigan

Recent Publications not Previously Reported

G. Hu, W. E. Dixon, S. Gupta, and N. Fitz-Coy, "A Quaternion Formulation for Homography-based Visual Servo Control," *IEEE Transactions on Systems Man and Cybernetics: Part B Cybernetics*, submitted.

S. Gupta, D. Aiken, G. Hu, W.E. Dixon, "Lyapunov-Based Range Identification For A Paracatadioptric System," *IEEE Transactions on Automatic Control*, submitted.

R.J. Prazenica, A.J. Kurdila, R.C. Sharpley, P. Binev, M. Hielsberg, J. Lane, and J. Evers, "Vision-Based Receding Horizon Control for Micro Air Vehicles in Urban Environments," *Journal of Guidance, Control, and Dynamics*, submitted.

T.P. Webb, R.J. Prazenica, A.J. Kurdila, and R. Lind, "Vision-Based State Estimation for Autonomous Micro Air Vehicles," *Journal of Guidance, Control, and Dynamics*, accepted, to appear.

R.J. Prazenica, A.J. Kurdila, and R.C. Sharpley, "Receding Horizon Control for MAVs with Vision-Based State and Obstacle Estimation," invited paper submitted to the *AIAA Guidance, Navigation, and Control Conference*, Hilton Head, SC, August 2007.

K. Dupree, N.R. Gans, W. Mackunis, W. E. Dixon, "Euclidean Calculation of Feature Points of a Rotating Satellite: A Daisy Chaining Approach," *Proc. American Control Conference*, 2007, accepted, to appear.

K. Kaiser, N.R. Gans, W.E. Dixon, "Localization and Control of an Aerial Vehicle through Chained, Vision-Based Pose Reconstruction," *Proc. American Control Conference*, 2007, accepted, to appear.

S. Mehta, G. Hu, N. Gans, and W. E. Dixon, "Adaptive Vision-Based Collaborative Tracking Control of an UGV via a Moving Airborne Camera: A Daisy Chaining Approach," *IEEE Conference on Decision and Control*, San Diego, CA, 2006, pp. 3867-3872.

D. Aiken, S. Gupta, G. Hu, W. E. Dixon, "Lyapunov-Based Range Identification for a Paracatadioptric System," *IEEE Conference on Decision and Control*, San Diego, CA, 2006, pp. 3879-3884.

G. Hu, S. Gupta, N. Fitz-coy, and W. E. Dixon, "Lyapunov-Based Visual Servo Tracking Control via a Quaternion Formulation," *IEEE Conference on Decision and Control*, San Diego, CA, 2006, pp. 3861-3866.

S. Mehta, W. E. Dixon, D. MacArthur, C. D. Crane, "Visual Servo Control of an Unmanned Ground Vehicle via a Moving Airborne Monocular Camera," *IEEE American Control Conference,* Minneapolis, Minnesota, 2006, pp. 5276-5281.

S. Gupta, D. Aiken, G. Hu, W .E. Dixon, "Lyapunov-Based Range and Motion Identification for a Nonaffine Perspective Dynamic System," *IEEE American Control Conference,* Minneapolis, Minnesota, 2006, pp. 4471-4476.

Albertani, R, B Stanford, JP Hubner, and PG Ifju (2007) "Aerodynamic Characterization and Deformation Measurement of a Flexible Wing Micro Air Vehicle," Experimental Mechanics, DOI: 10.1007/s11340-006-9025-5.

Stanford, B, D Viieru R Albertani W Shyy, and P Ifju (2007) "StaticAeroelastic Model Validation of Membrane Micro Air Vehicle Wings," AIAAPaper 2007-1067.

Stanford, B., Albertani, R., Ifju, P. (2007) "Static Finite Element Validation of a Flexible Micro Air Vehicle," Experimental Mechanics, DOI: 10.1007/s11340-006-9003-y

Ifju, P., Albertani, R., Stanford, B., Claxton, D., Sytsma, M. (2007) "Flexible-Wing Micro Air Vehicles," Chapter 5 of Introduction to the Design of Fixed-Wing Micro Air Vehicles, Mueller, T., Kellogg, J., Ifju, P., Shkarayev, S., (editors), AIAA

Stanford, B., Abdulrahim, M., Lind, R., Ifju, P. (2007) "Investigation of Actuation of a Flexible Membrane for Roll Control of a Micro Air Vehicle," Journal of Aircraft, accepted for publication

Johnson, B., Claxton, D., Stanford, B., Jagdale, V., Ifju, P. (2007)
"Development of a Composite Bendable-Wing Micro Air Vehicle," 2007
AIAA Aerospace Sciences Meeting, Reno, NV, January

K. Wright and R. Lind, ``Investigating Sensor Emplacement on Vertical Surfaces for a Biologically-Inspired Morphing Design from Bats," AIAA Atmospheric Flight Mechanics Conference, Hilton Head, SC, August 2007, accepted.

D.T. Grant and R. Lind, ``Effects of Time-Varying Inertias on Flight Dynamics of an Asymmetric Variable-Sweep Morphing Aircraft," AIAA Atmospheric Flight Mechanics Conference, Hilton Head, SC, August 2007, accepted.

D.T. Grant, M. Abdulrahim and R. Lind, ``Sensor Pointing using Biomimetic Joints and Structures on Morphing Micro Air Vehicles," International Forum on Aeroelasticity and Structural Dynamics, Stockholm, Sweden, June 2007, accepted.

D.T. Grant, M. Abdulrahim and R. Lind, ``The Role of Morphing to Enhance Mission Capability of Micro Air Vehicles," World Forum on Smart Materials and Smart Structures Technology, invited paper, Chongqing and Nanjing, China, May 2007, accepted.

D.T. Grant, M. Abdulrahim and R. Lind, ``Enhancing Mission Capability for Micro Air Vehicles using Biomimetic Joints and Structures," Australian International Aerospace Congress, Melbourne, Australia, March 2007, accepted.

O. Bilgen, D. Inman, A. Kurdila and R. Lind, ``Active Materials for Wing Morphing Micro Air Vehicles," AUVSI Unmanned Systems North America Conference, Orlando, FL, August 2006.

Lian, Y. and Shyy, W., "Laminar-Turbulent Transition of a Low Reynolds Number Rigid or Flexible Airfoil,"AIAA 36th Fluid Dynamicvs Conference and Exhibit, June 5-8, 2006, Paper No. 2006-3051, also to appear in the AIAA Journal.

M. Abdulrahim and R. Lind , ``Using Avian Morphology to Enhance Aircraft Maneuverability," AIAA Guidance, Navigation and Control Conference, invited paper, Keystone, CO, August 2006, AIAA-2006-6643.

Book Chapter

Ifju, P., Albertani, R., Stanford, B., Claxton, D., Sytsma, M. (2007) Flexible-Wing Micro Air Vehicles," Chapter 5 of Introduction to the Design of Fixed-Wing Micro Air Vehicles, Mueller, T., Kellogg, J., Ifju, P., Shkarayev, S., (editors), AIAA

Honors & Awards Received:

Warren Dixon – 2006, IEEE Robotics and Automation Society Early Career Award

Dan Grant, Mujahid Abdulrahim, and Rick Lind: AIAA Best Paper Award for Atmospheric Flight Mechanics (Aug 2007)

AFRL Points of Contact

Dr. Robert Sierakowski, AFRL/MN, Eglin AFB, 850-882-3004
Dr. David Jeffcoat, AFRL/MNG, Eglin AFB, 850-883-2963
Johnny Evers, AFRL,MNGN, Eglin AFB, 850-883-1887
Dr. Gregg Abate, AFRL/MNAV, Eglin AFB, 850-883-2596
Dr. Michael Ol, AFRL/VA, Wright Patterson AFB, Ohio

Transitions:

U.S. Provisional Patent Application Serial No. 60/838,951, "Position and Orientation of an Aerial Vehicle through Chained, Vision-Based Pose Reconstruction."

Unspecified, Johnny Evers, AFRL, MNGN, Eglin AFB, 850-883-1887

New Discoveries: None

Appendix A

RESEARCH INSTITUTE FOR AUTONOMOUS

PRECISION GUIDED SYSTEMS

F49620-03-1-0170

Pasquale M. Sforza

Graduate Engineering & Research Center

University of Florida

a report covering the period

September 2, 2002 – September 1, 2003

prepared for

Pasquale M. Sforza

by

Andrew J. Kurdila

submitted to

Dr. Fariba Fahroo

Program Manager, Computational Mathematics

DEPARTMENT OF THE AIR FORCE
Air Force Office of Scientific Research (AFOSR)
4015 Wilson Boulevard, Room 713
Arlington VA 22203-1954

Overview

This document outlines the progress completed under AFOSR Project F49620-03-0170

entitled

"A Research Institute for Autonomous

Precision Guided Systems."

The period covered by this report spans the period from the

June 15, 2002 – September 1, 2003

To provide a framework for the detailed report that follows, we review several critical objectives and milestones from the original proposal. As noted in Section 1.2, page 5, Research Objective of this project can be concisely stated:

> *The Research Institute expands an existing science and engineering partnership between the University of Florida Graduate Engineering & Research Center and Team Eglin, the group of organizations housed at Eglin Air Force Base, to leverage research manpower pursuing technologies relevant to autonomous precision systems. The concept is consistent with the aims and procedures espoused by the STW-21 initiative.*

> *...Currently, Research Institute activities are concentrated on four research focus areas in which the team members have an established scientific base:*
>
> - *Innovative Computational Techniques Applied to Air Force Problems*
> - *Thermo-Mechanics of High-Speed Penetration of Geo-Materials & Concrete*
> - *Nanoscale Energetic Materials*
> - *Integrated Guidance/Cooperative Attack*

> *....efforts of research that have been identified and defined in collaboration with AFRL/MN in four key technology areas*

Area 1: Aeroforms and Actuation for Small and Micro Agile Air Vehicles

Area 2: Sensing For Autonomous Control and Surveillance

Area 3: Closed Loop Flow Control

Area 4: Cooperative Control for Agile and Autonomous Vehicles

Transition of Program Administration

This report has been prepared by Professor Andrew J. Kurdila, Acting Director of UF-GERC. Due credit for the success of the Research Institute must be given to Professors Pasquale Sforza and Dr. Robert Sierakowski (AFRL/MN) as they worked together to initiate the Research Institute.

With the change in overall administration of the grant by the University of Florida, the author of this report felt obligated to provide a clear, concise and accurate description of the status and nature of all activities within the grant. Necessarily, this required that the author spend significant effort and time in learning the diverse nature of the grant, the current set of focused research activities and the direction for future research.

The author of this document accepts all responsibility for the delay in preparation of the document. He would also like to thank the gracious patience of Dr. Fariba Fahroo and Dr. Clifford Rhoades. The author trusts that the quality of the report will compensate for the delay in its preparation.

Visiting Researchers Program

As described in Section (1), the foremost goal of the Research Institute is to provide "*...research manpower pursuing technologies...*" consistent with the goals of AFRL/MN. The specific goals are outlined in the objectives in Section (1). Excellent progress in identifying, recruiting, and coordinating the efforts of researchers within the Research Institute has been made during the reporting period. Table (1) summarizes the

Researcher	Institution	Research Topic
John Burns	**Virginia Polytechnic University**	**Plasma actuators / flow control**
Oana Cazacu	**University of Florida**	**Penetrator mechanics**

David Chichka	George Washington University	Flight control instrumentation
Altannar Chinchuluun	University of Florida	Cooperative control
Yunfei Feng	University of Florida	Flow control
Satya Hanagud	Georgia Institute of Technology	Mechanics of materials
M. Herrnberger	Virginia Institute of Technology	Adaptive formation control
Naira Hovakimyan	Virginia Polytechnic University	Adaptive formation control
Paul Hubner	University of Florida	Experimental MAVs
Marc Jacobs	AFOSR (ret)	Strategic planning
Myungsoo Jun	Cornell University	Dynamic resource allocation
Borislav Karaivanov	University of South Carolina	Complex wavelet methods
Parvez Khambatta	University of Florida	Cooperative control
Martin Kruzik	Charles University, Prague	Mechanics of materials
Adam Nadel	George Washington Univ	Robotics
Tony Okafor	Case Western University	Robotics
Carlos Oliveira	UF	Robotics
Michael Plesha	Wisconsin	Computational methods
Richard Prazenica	University of Florida	Robust vision estimation
Tomas Roubicek	Charles University, Prague, CR	Hysteresis in SMA
David Schrader	George Washington University	Flight control instrumentation
Jeff Shamma	UCLA	Fictitious play control
Jennifer Simonotto	University of Florida	Neuronal simulation
Vahram Stepanyan	Virgina Polytechnic University	Adaptive formation control
Allen Tannenbaum	Georgia Institute of Technology	PDE based segmentation
Abhishek Tiwari	CalTech	Cooperating control
Stan Uryasev	University of Florida	Uncertainty, resource alloc.

Patricio Vela	**Georgia Institute of Technology**	**PDE based segmentation**
Ravi Vaidyanthan	**Case Western Reserve Univ**	**Robotics**
Yunjun Xu	**University of Florida**	**Virtual environments**
Lei Zhu	**Cal Tech**	**Passive ranging from vision**

Table (1) Research Institute visitors, their institution, and area of focus

visiting researchers program for the FY03-FY04 reporting period. Over 35 graduate students, postdoctoral researchers or academic faculty members have participated in the program over this period. The researchers have been selected to address research topics in all of the areas summarized in Section (1).

Seminar Title, Seminar Speaker and Affiliation	**Date**
"Time-Dependent Telecommunications Models," Dr. Andrew Ross, Lehigh University, Bethlehem, PA	**6/08/04**
"An Investigation of Vortical Flowfields due to Discrete Surface Perturbation in the Forebody" Howard Hamilton, Stanford University, Palo Alto, CA	**4/26/04**
"Fatigue Life Estimation in Single Crystal Superalloy Turbine Blades" Dr. Nagaraj K. Arakere, University of Florida, Gainesville, FL	**04/23/04**
"Fatigue Life Estimation in Single Crystal Superalloy Turbine Blades," Mr. Scott Rosengren	**03/26/04**
"Uncertainty in Analysis & Design: A Dynamical Systems Perspective," Dr. Igor Mezic, University of California, Santa Barbara, CA	**03/23/04**
"Electromagnetic Interrogation and Detection in Problems in Dielectric Materials," Dr. H. T. Banks, N. C. State University,	**03/22/04**

Raleigh, NC	
"A Multiple Autonomous Vehicle System with Partial Information," Dr. Myungsoo Jun, University of Florida, Gainesville, FL	**5/14/04**
"On Continuous Sensitivity Equations and Numerical Noise," Dr. Jeff Borggaard, Virginia Polytechnic Institute, Blacksburg, VA	**03/11/04**
"Nonlinear Pathologies in the Aeroelastic System," Dr. Thomas Strganac, Texas A&M University, College Station, TX	**0/03/04**
"Visual Information for Flight Control and Gaze Stabilization in Flying Insects," Dr. Holger Krapp, University of Cambridge England, UK	**11/20/03**
"X-45 J-UCAS Program Overview and Flight Test Status" Dr. Kevin Wise, Boeing Phantom Works	**11/18/03**
"On the Origins of the Negative Strain Rate Sensitivity in Al-MG Alloys" Professor R. C. Picu, Rensselaer Polytechnic Institute	**8/21/03**
"Cooperative Control and Neglect – Tolerant Human Interaction with Teams of Unmanned Air Vehicles," Dr Randy Beard, Brigham Young University, Provo Utah	**6/16/03**
"Arbitrary Discontinuities and Level Sets in Finite Elements Methods," Professor T. Belytschko, Northwestern University	**5/19/03**
"Desktop Micro Robots Factory and Micro-Hopping Robot," Dr. Hisayuki Aoyama, University of Electro Communications, Tokyo, Japan	**4/15/03**
"Micromechanical approach to the macroscopic behavior of damaged & poroelastic materials," Dr. Djimedo Kondo, University of Lille, France	**03/27/03**
"A Particle-Level Set Based Sharp-Interface Eulerian Method For Simulating Impact, Penetration and Void Collapse"	**03/19/03**

Dr. H. S. Uday kumar, University of Iowa	
"Stability and Applications of the Linear Time Invariant, Time Delayed Systems LTI-TDS" Dr. Nejat Olgac, University of Connecticut	3/13/03
"The Navigation of Autonomous Vehicles In Uncertain Dynamic Environments VIA A Probabilistic Approach" Dr. Myungsoo Jun, Cornell University, Ithaca, NY	3/7/03
"Finite Elasto-Plasticity of Crystalline Materials" Professor Sanda Cleja-Tigoiu, University of Bucharest	2/27/03

Table (2) Research Institute Seminar Speakers

Perhaps the most progress during the reporting period has been made in the areas of developing methodologies for computational mechanics, aeroforms for small and micro air vehicles and cooperative control for agile autonomous vehicles. A quick survey of the table will show that most of the research during the reporting period has focused on these areas. Other significant areas of focus include vision processing for guidance, navigation and control of unmanned air vehicles.

Table (2) summarizes the specific seminars given over the reporting period. Presentations by invited speakers cover more diverse topics than the topics represented in Table (1). The researchers in Table (1) have been invited to address a specific topic of interest to AFRL/MN. Their appointment as a visitor represents a significant cost. On the other hand, the invitees in Table (2) are in house for only a few days. Their associated expense is considerably less. Invitations are made more broadly. Clearly, the visitors program has been highly successful in providing expertise to AFRL/MN researchers in a number of diverse technical areas. However, some issues in the administration of the Research Institute that have been noted over the past year

Workshop / Meeting Title	Date
2004	

Robust Optimization-Directed Design	04/19-21/04
Plasma Actuator Modeling Workshop	05/13/04
Aircraft Battle Damage Repair (ABDR) Technical Group Meeting	02/27/04
Workshop on Plasma Actuators for Subsonic Applications	02/25/04
Mission Planning Software Development ESC/ACU OL1	
BATCAM Transition Meeting	02/24/04
2003	
Discussions for Layout of GUI of MAV Ground Station	12/22/03
Formation Flying	11/21/03
Vision-Based Control of Agile Autonomous Micro Air Vehicles and Small UAV's in Urban Environments	10/27/03
AFOSR Computational Mathematics	5/29–30/03
Flow Control for Agile Autonomous Flight	3/24 –25/03
Nonlinear Aspects of Aeroelasticity, Related Structural Dynamics,	3/5/03

Table (3) Workshops and Technical Meetings supported via the Research Institute

Finally, Table (3) summarizes the major workshops and technical meetings that have been supported through the Research Institute. It is important to note that the participants in the technical meetings listed in Table (3) are academics and researchers of national and international recognition. As an example, participants in the Robust Optimization-Direct Design Conference included stellar researchers such as Tyrell Rockafellar, Roger Wets, and Elijah Polak. Researchers at the Workshop on Flow Control for Agile Autonomous Vehicles included Professor Tom Corke of Notre Dame University and Professor Ari Glezer of the Georgia Institute of Technology. The caliber of these researchers cannot be overstated.

Research Institute Management

It must be emphasized that the day to day management of the Research Institute activities is a labor intensive effort involving a number of UF-GERC staff, faculty and administrators. Accurate and current projections for the cash flow during the project are a continuous requirement. That is, as new invitations are made, declined or accepted, and old invitees seek to update their stay, the fiscal standing of the Research Institute grant must be updated. In fact, it is fair to say that the collection of researchers supported under the Research Institute is in a constant state of flux. This fact is inevitable in that the research topics, and the researchers selected to carry out study of those topics, supported under the Research Institute Grant are selected based on direct input from AFRL/MN management and bench scientists. For example Table (4) depicts the Residence Planning Projection that must be updated on a weekly, and sometimes daily, basis as researchers are admitted to the program. This Table depicts what facilities will be used to house visitors: local hotels or rental properties leased by UF-GERC.

Visitors **2004**

					FEB					MAR					APR				MAY					JUN				JUL				AUG				
Room #	Name	Title	Begin	End	3	10	17	24	31	1	8	15	22	29	5	12	19	26	3	10	17	24	31	7	14	21	28	5	12	19	26	2	9	16	23	30
	Karaivanov, Borislav		01/02/04	05/02/04																																
	Xu, Yunjun		01/01/04	12/31/04	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Feng, Yunfei		01/12/04	04/23/04	X	X	X	X	X	X	X	X	X	X	X	X	X																			
	Vela, Patricio		03/08/04	05/03/04							X	X	X	X	X	X	X	X	X																	
	Prazenica, Richard		02/02/04	12/31/04																																
	Schrader, David		03/01/04	04/15/04																																
	Jun, Mysungsoo		04/01/04	03/31/05																																
	Chichka, David		05/24/04	08/13/04																																
	Hovakimyan - Masters Stud.		04/19/04	08/13/04																																
	Hovakimyan - PhD Stud.		03/08/04	08/13/04																																
	Binev, Peter		SMR 04																																	
	Rossi, Massimiliano																																			
	Tran, Linhbao																																			
	Zhu, Lei																																			
	Hovakimyan, Naira		03/06/04	03/12/04																																
	Hovakimyan, Naira		06/07/04	06/28/04																																
	Hovakimyan, Naira		07/26/04	08/13/04																																
	Tannenbaum, Allen		03/29/04	04/05/04																																
	Calise, Anthony		03/08/04	03/31/04																																
	Shamma, Jeff																																			
	Sumrall, Theodore																																			
	Hanagud																																			
	Roubicek, Tomas		SMR 04	2 weeks																																
	Kruzik, Martin		SMR 04	2 weeks																																

Table (4) Example residence planning projection used in Research Institute administration

Table (5) depicts a similar projection that is maintained by the staff for the Research Institute program. Visitors must be supplied with i) offices that reflect the stature and standing of the visitor, ii) computing facilities, and iii) access to high speed internet.

Staff member Keith Stephens (finances), Kelly-Marie Duffy (travel), and Tammy Edmondson (personnel) carry a considerable burden in administration of the Research Institute grant.

Visitors **2004**

Room #	Name	Title	Begin	End	FEB					MAR					APR					MAY					JUN					JUL					AUG				
					3	10	17	24	31	1	8	15	22	29	5	12	19	26		3	10	17	24	31	7	14	21	28		5	12	19	26		2	9	16	23	30
131	Strunk, David		07/01/03																																				
132	Phillips, Ed		07/01/03																																				
133	Zabarankin, Michael		07/01/03																																				
134	Cornette, Jim		07/01/03																																				
135	Hovakimyan, Naira		03/08/04	03/12/04																																			
135	Hovakimyan, Naira		06/07/04	06/28/04																																			
135	Hovakimyan, Naira		07/26/04	08/13/04																																			
135	Tannenbaum, Allen		03/29/04	04/05/04																																			
136	Anderson, Chris		07/01/03	05/06/04																																			
137	Sulton, Eric		07/01/03																																				
138	Zmuda, Henry		07/01/03																																				
149	Schrader, David		03/01/04	04/15/04																																			
150	Krokhmal, Pavlo		07/01/03																																				
151	Ashokkurar, C. R.		12/04/03	07/08/04																																			
152	Dominiak, Ken		07/01/03																																				
153	Cazacu, Oana		07/01/03																																				
154	Jacobs, Marc		07/01/03		X	X	X	X	X	X	X	X	X	X																									
155	Stephens, Keith		07/01/03																																				
162	Ross, Allen		07/01/03																																				
166	Xu, Yunjun		01/01/04	12/31/04	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
166	Feng, Yunfei		01/12/04	04/23/04	X	X	X	X	X	X	X	X	X	X	X	X	X																						
166	Vela, Patricio		03/08/04	05/03/04																																			
166	Chichka, David		05/24/04	08/13/04																																			
168	Karaivanov, Borislav		01/02/04	05/02/04																																			
168	Prazenica, Richard		02/02/04	12/31/04																																			
172	Jun, Mysungsoo		04/01/04	03/31/05																																			
166	Hovakimyan - Masters Stud.		04/19/04	08/13/04																																			
166	Stepanyan, Vahram		03/15/04	08/13/04																																			
131	Calise, Anthony		03/08/04	03/31/04																																			
?	Zhu, Lei		05/09/04	06/18/04																																			
	Simonotto, Jennifer		06/01/04	12/31/04																																			
?	Binev, Peter		SMR 04																																				
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?	Kruzik, Martin		SMR 04	2 weeks																																			
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?	Roubicek, Tomas		SMR 04	2 weeks																																			
?	Shamma, Jeff																																						
?	Sumrall, Theodore																																						
?	Tran, Linhbao																																						
	Current GERC Faculty & Staff																																						
	Non-UF / Emeritus Faculty																																						
	Visitors																																						

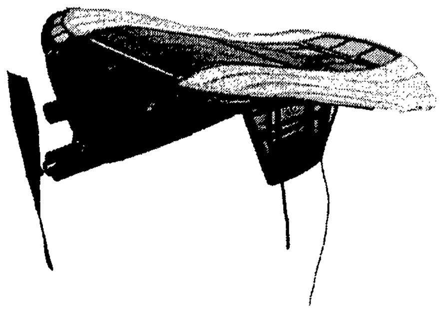
Table (5) Example office space planning projection used in Research Institute administration

Research Institute: Overview of Initiatives

A detailed summary of research initiatives that have been coordinated with AFRL/MN researchers has been given at the AFOSR Computational Mathematics Program Review, organized by Dr. Fariba Fahroo, on June 5-6, 2004. In this section, we overview some of the most recent and promising research efforts sustained under the program.

Computational Modeling of Hysteretic Behavior in Shape Memory Alloys

AFRL/MN has expressed a sustained, intense interest in new technologies for Micro Air Delivered Munitions (MADMs). The need for highly agile flight vehicles is one of the technology drivers for this area of research. This year, to address the need for high performance, agile MADMs, the University of Florida has initiated a study of modeling, simulation and control of shape memory alloys. Shape memory alloys are a class of so-called active materials that change crystalline variants through diffusionless phase transformations with the application of stress (a stress induced phase transformation) or the application of an electrical current (a thermally induced phase transformation enabled by resistive heating.) Ultimately, the goal is to be able to design and fly Micro Air Vehicles (MAVs) or MADMs with reconfigurable, actively "morphing" lift surfaces. Nominally, the concept is to replace the graphite composite and membrane wing MAV pictured in Figure (1) with one that can achieve actively controlled wing morphing. The goal is to attain levels of flight control that permit urban navigation via MADMs, as depicted schematically in Figure (2). Wing morphing may be achieved with the judicious incorporation of SMA fibers or thin films to selectively deform the structure.



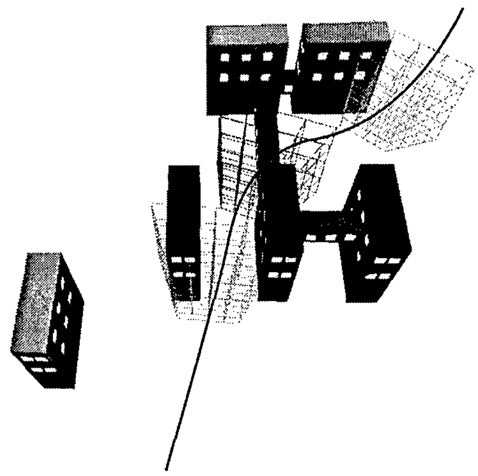


Figure (1) Carbon fiber and membrane Micro-Air-Vehicle (MAV)

Figure (2) Schematic of desired operation profile: urban navigation

There are an enormous number of technical barriers that must be overcome to realize this goal. But as we argue shortly, these difficulties *decrease* as we decrease the physical scale of the vehicle. That is, small scale works to our advantage in this case. Resistive heating can be costly, so that highly efficient designs with minimal dimension actuators must be developed. Very thin wires of SMA require little energy, while bulk SMA or SMA embedded in a structural matrix require much more energy. Also, the bandwidth of bulk SMA embedded in a matrix composite may have exceptionally low bandwidth. On the other hand, thin film SMA's subject to ambient convection have exhibited on the order of 100hz.

But these design considerations are predicated on the availability of an accurate, reliable and robust simulation capability. Currently, this simulation capability is in its infancy. Roughly speaking, simulation of shape memory alloys is either based on ad hoc, phenomenological models, or micromechanically based models that are appropriate only for highly idealized settings (single crystals, perfectly twinned variants...etc). The Research Institute has engaged some of the worlds leading experts in the modeling, approximation and simulation of shape memory alloys through its visitor program to build a knowledge base at AFRL/MN in this highly complex area of research. Profs. Tomas Roubicek and Martin Krucik of Charles University are working with researchers at the University of Florida and AFRL/MN (Johnny Evers) to develop this program. Shown in Figure (3) is a collection of the length scales that are involved in the simulation process. Figure (4) is an example simulation of the phase transformation in single crystal SMA. Current efforts are to extend this work to polycrystalline models, and subsequently to develop multiscale models to propagate the micromechanical models to larger length scales. The result will be structural scale level models appropriate for control design and optimization.

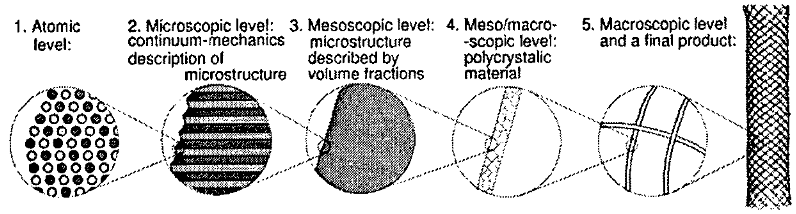


Fig. 1. Multiscale character of modeling of single crystal and polycrystalline SMAs up to a final product, here a knitted Ni-Ti peripheral vascular stent.

Figure (3) Length scales in the simulation of SMA, Roubicek and Krucik [2004]

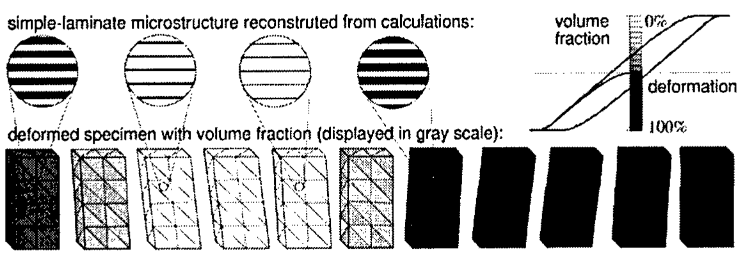


Figure 2. Isothermal 3D simulations of re-orientation of monoclinic martensite induced by shear of a single crystal governed by (12)–(13); only a test double-well problem from [R03].

Figure (4) Single crystal SMA simulations, Roubicek and Krucik [2004]

Multiscale Modeling of HCP Alloy Sheets

Researchers at AFRL/MN have emphasized that there is an urgent need at the laboratory to develop the fundamental understanding necessary to design robust warm forming processes for HCP (hexagonal close packed) alloy sheets. Professor Oana Cazacu is addressing this need by using a multi-scale approach, with a focus on material behavior at elevated temperatures and high strain rates. Generally speaking, the methodology consists of three primary steps:

(i) Use macroscopic experimental results and polycrystalline simulations to generate yield loci;

(ii) Develop isotropic formulations for describing the asymmetry in yielding (tension versus compression) due to deformation twinning

(iii) Extend the isotropic criteria to orthotropy.

The overall approach is extremely promising. Professor Cazacu has derived and developed new orthotropic yield criterion for HCP metals describing both anisotropy and asymmetry (tension vs. compression). Figure (5) depicts the excellent agreement between theory, computation and experimental results for Mg and Mg-4%Li alloy.

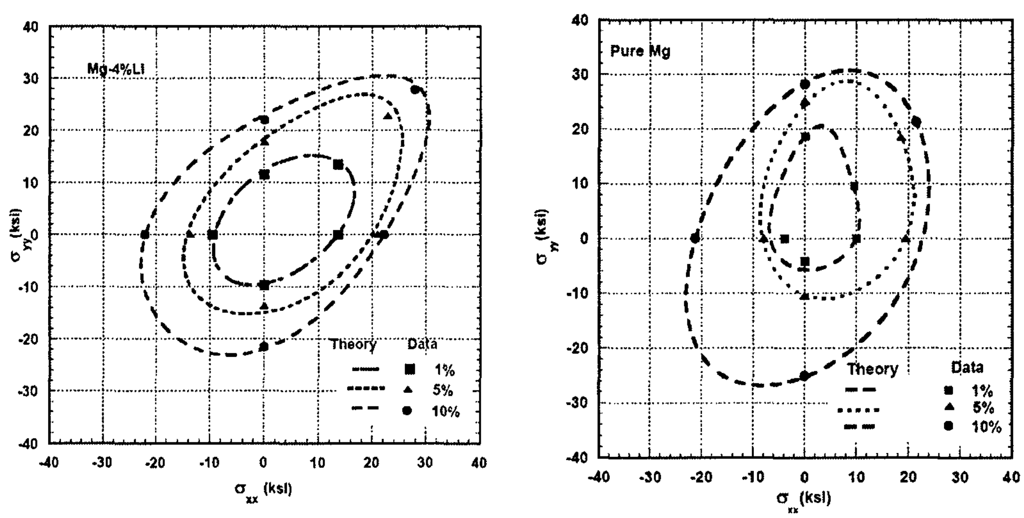


Figure (5) Comparison of theory, computation and experiment for Mg and Mg-4%Li.

Cazacu and Barlat, *Int. J. Plasticity* (2004).

Partial support for this work was also provided by NSF DMI-0322730 and ALCOA Inc. Collaboration with Dr. Rusty Gray and Dr. Ricardo Lebenson of Los Alamos National Laboratory has been established.

Characterization and modeling of high-strain rate behavior of cementitious materials

For as long as the Research Institute has been in existence, one of the research goals that AFRL/MN has identified and has persisted as a critical need is gaining fundamental understanding of penetration. AFRL/MN has sought to develop a strong experimental data base for a variety of cementitious materials and develop constitutive models that could describe adequately their behavior. Dr. Martin Schmidt of AFRL/MNAC and Mark Green of AFRL/MNMW in collaboration with Professor Oana Cazacu have conducted a comprehensive experimental study aimed at characterization of the combined effects of high confinement and high strain rate on the deformation and strength of cementitious Quasi-static triaxial compression tests were performed for confining pressures ranging from 0 to 500 MPa were performed. Dynamic tests for strain rates in the range 60/s to 160/s under unconfined and confined conditions were conducted using a split Hopkinson pressure bar. A decrease in strain rate sensitivity with increasing confining pressure was observed. A new elastic/viscoplastic model that captures compressibility, dilatancy, and strain rate effects has been developed for concrete. Comparisons between model predictions and data showed the proposed model describes with very good accuracy the high-pressure behavior of concrete.

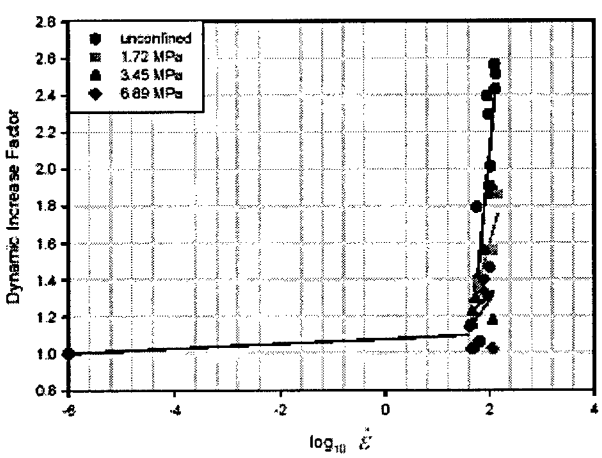


Figure (6): Effect of confinement on dynamic strength increase factor for concrete

(Schmidt et al, IUTAM , 2004).

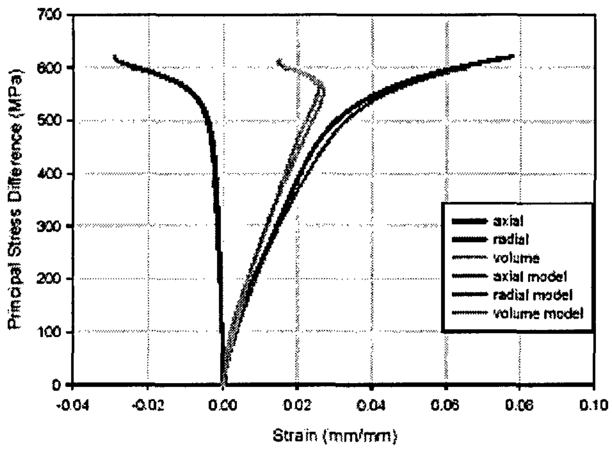


Figure (7): Experimental vs. Theoretical stress-strain curves for 375 MPa confining pressure.

Currently, through direct AFOSR support and continuous guidance from the cognizant program manager Dr. Arje Nachman, Professor Cazacu is doing research on penetrator's trajectory stability.

This research effort has five primary goals

- **To predict** the density changes in the target,
- **Determine** the shape and location of the free boundaries caused by separation and **anisotropic damage ahead** of the projectile,
- **Model** the onset of trajectory instabilities,
- **Identify** the target material characteristics responsible for a given behavior during the onset of the instability phase,
- **Propose** new designs for the penetrator nose such as to achieve stability.

Shape Optimization of Flow Control Actuators

Perhaps more than any other research area, there has been a concerted effort by researchers at AFRL/MN to emphasize topics in the Research Institute that deal with the study of unmanned autonomous vehicles. These topics of research can be surprisingly diverse in the fields of expertise that they embrace. In fact, the new directions in the list of research areas selected by AFRL/MN in the most recent grant includes aerodynamic flow control (Area 3) and actuators for agile Micro Air Vehicles (MAVs). In this section we summarize a research topic introduced into the Research Institute this year that addresses aspects of both of these topics. Figure (8) illustrates a PLOCAAS autonomous vehicle and a superimposed schematic of a region of the wing that exhibits detached flow. The goal proposed by Johnny Evers, AFRL/MN, is to design, simulate, develop and evaluate flow control actuators to enable modification of the flight capabilities of the nominal flight vehicle.

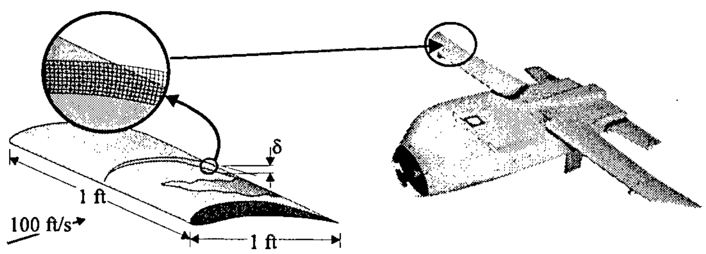


Figure (8) PLOCAAS autonomous flight vehicle,

targeted flow control of separation

The flow control methodology targeted by the research effort is depicted in Figure (9). The strategy builds on the initial and foundational work by Carroll et al. in [C01]. As shown in Figure (9), a piezoceramic composite is imbedded in the airfoil at a location where its oscillation can induce flow reattachment downstream. Figure (10) depicts the geometry and layout of the PZT in the piezoceramic composite.

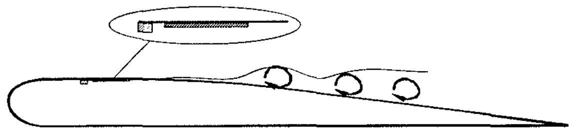


Figure (9) Schematic of embedded piezoceramic flap actuator, used to induce reattachment of separated flow

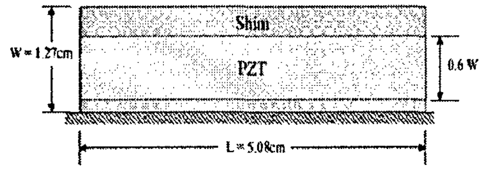


Figure (10) Geometry of embedded piezoceramic flap actuator depicting PZT and host structural flap

Unfortunately, for the simplest geometry of the piezoceramic composite, highly nontrivial deformation patterns may result on actuation. From a practical standpoint, this effect can induce undesired three dimensional effects in what otherwise may be modeled as a two-dimensional control design problem. Figures (11) and (12) depict the first two vibrational modes of a sample actuator depicted in Figure (10).

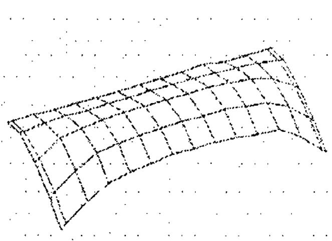


Figure (11) First bending mode measured by laser Doppler vibrometry

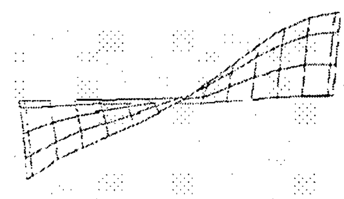


Figure (12) First torsional mode measured by laser Doppler vibrometry (300hz)

The goal of the shape optimization process is to re-design the electroded region on the surface of the PZT, thereby modifying the dynamic response shapes of the actuator. Figures (13) and (14) illustrate a comparison of the results of two optimization techniques. The ad hoc, intuitive approach yields a highly oscillatory electrode pattern that becomes increasingly oscillatory as the dimension of the parameterization of the electrode boundary is increased. This phenomenon is quite typical of ad hoc implementations of shape optimization. Figure (14) depicts the results of a design optimization that derives from a Γ-convergent formulation of the shape optimization problem. As the dimensionality of the parameterization of the boundary is increased, the contour stabilizes and converges to the solution of the shape optimization problem.

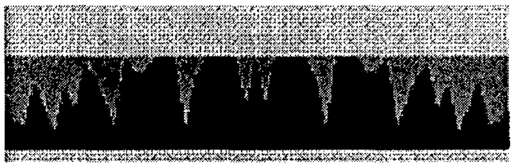


Figure (13) Highly oscillatory optimal electrode shape obtained via ad hoc shape optimization methodology

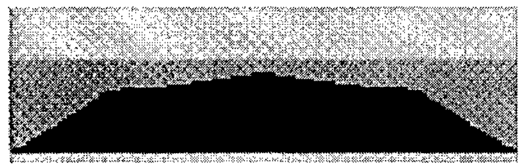


Figure (14) Convergent and regular optimal electrode shape obtained via Γ-Convergent formulation of shape optimization

UF-GERC and AFRL/MN Collaboration

In addition to the direct, peer-reviewed research carried out under the Research Institute, it is important to note that the ongoing interaction afforded to AFRL/MN and UF-GERC results in tangible, infrastructural development. The degree of progress in this area can be appreciated by considering two separate issues : a) the organization of research teams through the research institute that integrate researchers from across he country with AFRL researchers, and b) the development of new, shared laboratory facilities that enable the coordinated research efforts.

Evolving Research Groups

Many of the visiting researchers listed in Table (1) can be organized thematically in there research topics. These research groups include

- Flow Control via Plasma Actuators
- Computational Mathematics
- Control of Autonomous Flight Vehicles
- Cooperative Control and Weapon Allocation

For example, there are distinct subteams of researchers who work in these focus groups are summarized in the next table:

Topic	AFRL Point of Contact	Researcher
Flow control via plasma actuators	William Hilbun	William Hilbun, AFRL/MN
		Mike Valentino, AFRL/MN
		Datta Gaitonde, AFRL/VA
		Tom Corke, ND
		Tom McLaughlin, USAFA
		Lon Enloe, USAFA
		Joe Shang, Wright State Univ.
		Wei Shyy, UFL
		John Burns, VPI
Computational Mathematics		
		Oana Cazacu, UF
		Tomas Roubicek, CU, CR
		Martin Krucik, CU, CR
		Mike Plesha, Univ. Wisconsin
Control of Autonomous Vehicles	Johnny Evers	Johnny Evers, AFRL/MN
		Gabe Chedister, AFRL/MN
		Kent Kaiser, AFRL/MN
		Anthony Calise, GaTech
		Naira Hovakimyan, VPI
		David Chichka, GWU

		Patricio Vela, GaTech
		M. Hernnberger, VPI
		V. Stepanyam, VPI
Cooperative Control & Allocation	Robert Murphey	Robert Murphey
		S. Uryasev, UF
		M. Jun, Cornell
		A. Tiwari, CalTech
		P. Khambatta, UF
		A. Chinchillum

Evolving Laboratories and Facilities

In addition to the development of research teams that focus on problems of interest to AFRL/MN, investment by the College of Engineering to match the AFOSR investment in the Research Institute Grant has enabled the creation of a number of labs that form the hub the team interaction. These laboratories include

- Micro Air Vehicle Instrumentation Laboratory
- Micro Air Vehicle Fabrication Laboratory
- Guidance, Navigation and Control Laboratory
- Visualization and Computation Laboratory

In addition, the UF-GERC management has planned a separate Computational Laboratory and Aerodynamic Testing Laboratory. Figure (15) depicts the organization of the new labs and their respect tasks. It is important to note that each laboratory has a designated coordinator from AFRL/MN. Within the current plan, laboratory mission, research directions, research protocols and performance reviews are a shared responsibility, while the laboratories remain UF facilities.

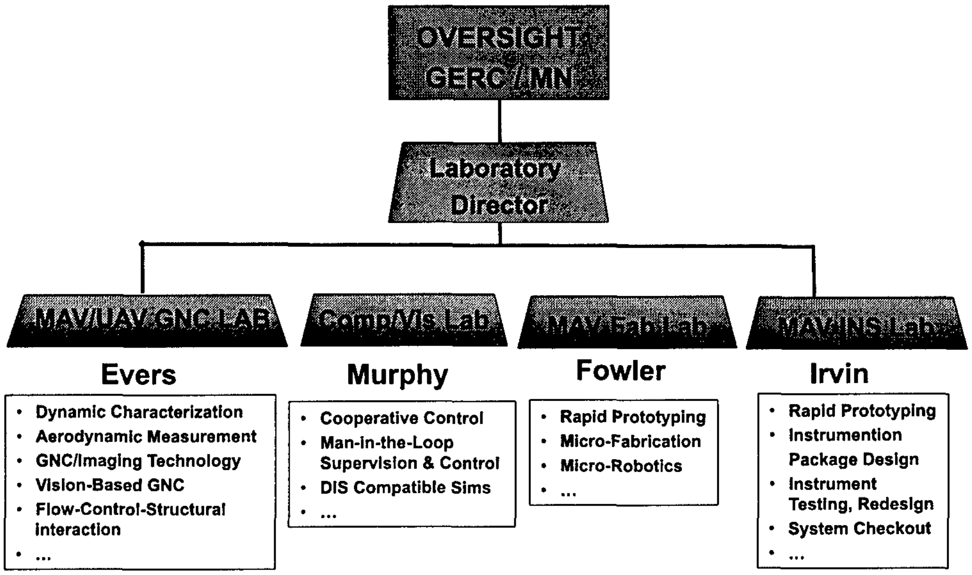


Figure (15) Organization of Laboratories at UF-GERC in Support of AFRL/MN and the Research Institute Grant

The reader is urged to recall that as of 6/03, there was essentially no laboratory collaboration in the UF-GERC facilities. Figure (18) depicts the layout of laboratories that have been assembled during the period 6/03 through 6/04. It should be recalled that all of these laboratories have been funded, for the most part, through the U F College of Engineering.

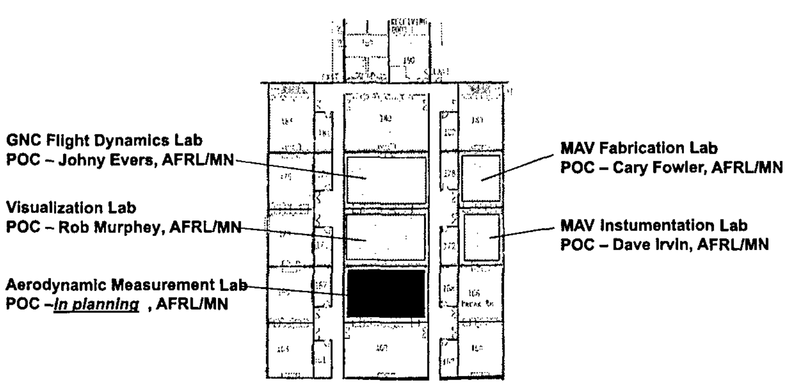


Figure (16) Layout of UF-GERC – AFRL/MN Laboratories Developedin Support of the Research Institute Grant

Conclusions

As the Acting Director for UF-GERC during the reporting period, some period of education has been necessary in gaining a familiarization with both the scientific content as well as the functionality of the Research Institute Program. Still, important observations can be made that underscore the effectiveness of this program in meeting the needs of the Air Force, and concurrently, those of the University of Florida.

- For any of the AFRL/MN management members or bench scientists, it is evident that the Research Institute Grant is exceptionally successful in its stated mission: providing efficient, time-critical, highly specialized, highly qualified research expertise in critical research focus areas.
- In addition, the Research Institute Grant has been critical in fostering an atmosphere of collaboration and the further development of critical infrastructural needs at UF-GERC. The associated infrastructural development has been funded, in the large part, through the College of Engineering. The infrastructure supports both the educational and research needs of the University of Florida, but likewise is goal-oriented in that it addresses the needs of focused AFRL/MN research directions.

In addition, there are several recommendations that can be made that will further improve the efficiency of the Research Institute Grant and its impact on AF relevant research:

- The Research Institute Grant is heavily leveraged via investment by the University of Florida, particularly during the past year. This fact does not seem to be fully recognized by bench researchers at AFRL/MN, the management of AFRL/MN, or, perhaps to a lesser degree, AFOSR. For example,
    - Some fraction of the operating budget of UF-GERC, which is in the vicinity of $1 M/year, goes to the support of the Research Institute Projects.
    - The laboratory space is provided at no cost, which represents a huge cost matching by the University.
    - The staff support of 4 secretaries, a financial planner and one administrator is likewise essentially unsupported.

- In addition, during the last year cash support from the College of Engineering included
    - $60K for the development of Micro Air Vehicle Instrumentation and Fabrication Laboratories.
    - $90K for the investment of computing facilities, office partitions and furniture for Research Institute guests.
    - $36K for the lease of Research Institute housing.

It is imperative that Eglin AFB bear some financial burden for the infrastructural investments that benefit its research mission.

- Feedback from AFOSR Program Managers has emphasized that the scientific content of the Research Institute evolves with AFOSR essentially "out of the loop." This is a fair assessment. The original grant gave great flexibility to the Research Institute Grant to respond to Eglin AFB needs. While the success of the program in carrying out this goal has been nothing less than spectacular, it is true that AFOSR has not been completely included in the development of the research portfolio. *It is imperative that the development of the research portfolio supported under the Research Institute Grant be carried out in a more formal, rigorous, scheduled fashion with the full involvement of relevant AFOSR Program Managers.*
- The Research Institute Grant is unlike nearly all other grants under the supervision of any single Program Manager at AFOSR. There are nearly 40 researchers, visitors, students and postdocs whose research efforts must be planned, reviewed, and assessed for performance, and finally reported out to AFOSR. As an administrative exercise, this effort in and of itself, may be greater than the administrative efforts of any AFOSR Program Manager. Thus, while the budget for the Research Institute Grant is much smaller than that for an AFOSR Program Manager, the bookkeeping, schedule arrangement, travel arrangement, reimbursement processing, performance evaluation and performance reporting may be a task of similar dimensions. *It is imperative that AFOSR, AFRL/MN and UF-GERC develop a reporting structure that satisfies all institutions and is coordinated (to the extent possible) in a single event for all relevant management from AFOSR and AFRL.*

Finally, the most important recommendation is provided last. UF-GERC is undergoing yet another transition to a new Director in August, 2004. *It is essential that the new Director is afforded the time and guidance to continue the strong trends of growth that have been possible under the Research Institute Grant during the past year.*

Appendix B

RESEARCH INSTITUTE FOR AUTONOMOUS

PRECISION GUIDED SYSTEMS

F49620-03-1-0170

Andrew J. Kurdila

Graduate Engineering & Research Center

University of Florida

a report covering the period

September 2, 2003 – September 1, 2004

submitted to

Dr. Fariba Fahroo
Program Manager, Computational Mathematics
DEPARTMENT OF THE AIR FORCE
Air Force Office of Scientific Research (AFOSR)
4015 Wilson Boulevard, Room 713
Arlington VA 22203-1954

1 Overview

This document outlines the progress completed under AFOSR Project **F49620-03-1-0170** entitled

"A Research Institute for Autonomous Precision Guided Systems."

The period covered by this report spans the period from the

September 2, 2003 – September 1, 2004

To provide a framework for the detailed report that follows, we review several critical objectives and milestones from the original proposal. As noted in Section 1.2, page 5, Research Objective of this project can be concisely stated:

The Research Institute expands an existing science and engineering partnership between the University of Florida Graduate Engineering & Research Center and Team Eglin, the group of organizations housed at Eglin Air Force Base, to leverage research manpower pursuing technologies relevant to autonomous precision systems. The concept is consistent with the aims and procedures espoused by the STW-21 initiative. ... Currently, Research Institute activities are concentrated on four research focus areas in which the team members have an established scientific base:

Innovative Computational Techniques Applied to Air Force Problems

Thermo-Mechanics of High-Speed Penetration of Geo-Materials & Concrete

Nanoscale Energetic Materials

- *Integrated Guidance/Cooperative Attack ....efforts of research that have been identified and defined in collaboration with AFRL/MN in four key technology areas*

  Area 1: Aeroforms And Actuation For Small And Micro Agile Air Vehicles Area 2: Sensing For Autonomous Control And Surveillance Area 3: Closed Loop Flow Control Area 4: Cooperative Control For Agile And Autonomous Vehicles

2 Transition of Program Administration

This report has been prepared by Professor Andrew J. Kurdila, Acting Director of UF-GERC for the period of June, 2003 – August 2004. Due credit for the success of the Research Institute must be given to Professors Pasquale Sforza and Dr. Robert Sierakowski (AFRL/MN) as they worked together to initiate the Research Institute. Dr. Pasquale Sforza is the author of the original grant proposal. With the change in overall administration of the grant by the University of Florida, the author of this report felt obligated to provide a clear, concise and accurate description of the status and nature of all activities within the grant. Necessarily, this required that the author spend significant effort and time in learning the diverse nature of the grant, the current set of focused research activities and the direction for future research. We make the following important observation: *The last annual report prepared by this author was submitted to AFOSR during June, 2004. The delay in preparing the last annual report can be attributed to the Acting Director's insistence on reviewing those aspects of the program over which he had direct supervision. Therefore, much of the programmatic material included in the last annual report was, in fact, research carried out in the Period June 2003 – August 2004. This report covers all research supported under this research program during the period September, 2003 through August, 2004, including material reviewed in the June report.*

3 Visiting Researchers Program

As described in Section (1), the foremost goal of the Research Institute is to provide "*...research manpower pursuing technologies...*" consistent with the goals of AFRL/MN. The specific goals are outlined in the objectives in Section (1). Excellent progress in identifying, recruiting, and coordinating the efforts of researchers within the Research Institute has been made during the reporting period. Table (1) summarizes the

Researcher	Institution	Research Topic
John Burns	Virginia Polytechnic University	Plasma actuators / flow control
Oana Cazacu	University of Florida	Penetrator mechanics
David Chichka	George Washington University	Flight control instrumentation
Altannar Chinchuluun	University of Florida	Cooperative control
Yunfei Feng	University of Florida	Flow control
Satya Hanagud	Georgia Institute of Technology	Mechanics of materials
M. Herrnberger	Virginia Institute of Technology	Adaptive formation control
Naira Hovakimyan	Virginia Polytechnic University	Adaptive formation control
Paul Hubner	University of Florida	Experimental MAVs
Marc Jacobs	AFOSR (ret)	Strategic planning
Myungsoo Jun	Cornell University	Dynamic resource allocation
Borislav Karaivanov	University of South Carolina	Complex wavelet methods
Parvez Khambatta	University of Florida	Cooperative control
Martin Kruzik	Charles University, Prague	Mechanics of materials
Adam Nadel	George Washington Univ	Robotics
Tony Okafor	Case Western University	Robotics
Carlos Oliveira	UF	Robotics
Michael Plesha	Wisconsin	Computational methods
Richard Prazenica	University of Florida	Robust vision estimation
Tomas Roubicek	Charles University, Prague, CR	Hysteresis in SMA
David Schrader	George Washington University	Flight control instrumentation
Jeff Shamma	UCLA	Fictitious play control
Jennifer Simonotto	University of Florida	Neuronal simulation
Vahram Stepanyan	Virgina Polytechnic University	Adaptive formation control
Allen Tannenbaum	Georgia Institute of Technology	PDE based segmentation
Abhishek Tiwari	CalTech	Cooperating control
Stan Uryasev	University of Florida	Uncertainty, resource alloc.
Patricio Vela	Georgia Institute of Technology	PDE based segmentation
Ravi Vaidyanthan	Case Western Reserve Univ	Robotics
Yunjun Xu	University of Florida	Virtual environments

Lei Zhu	**Cal Tech**	**Passive ranging from vision**

Table (1) Research Institute visitors, their institution, and area of focus
visiting researchers program for the FY03-FY04 reporting period. Over 35 graduate students, postdoctoral researchers or academic faculty members have participated in the program over this period. The researchers have been selected to address research topics in all of the areas summarized in Section (1).

Seminar Title, Seminar Speaker and Affiliation	Date
"Time-Dependent Telecommunications Models," Dr. Andrew Ross, Lehigh University, Bethlehem, PA	**6/08/04**
"Fatigue Life Estimation in Single Crystal Superalloy Turbine Blades" Dr. Nagaraj K. Arakere, University of Florida, Gainesville, FL	**04/23/04**
"Fatigue Life Estimation in Single Crystal Superalloy Turbine Blades," Mr. Scott Rosengren	**03/26/04**
"Uncertainty in Analysis & Design: A Dynamical Systems Perspective," Dr. Igor Mezic, University of California, Santa Barbara, CA	**03/23/04**
"Electromagnetic Interrogation and Detection in Problems in Dielectric Materials," Dr. H. T. Banks, N. C. State University, Raleigh, NC	**03/22/04**
"A Multiple Autonomous Vehicle System with Partial Information," Dr. Myungsoo Jun, University of Florida, Gainesville, FL	**03/22/04**
"On Continuous Sensitivity Equations and Numerical Noise," Dr. Jeff Borggaard, Virginia Polytechnic Institute, Blacksburg, VA	**03/11/04**
"Nonlinear Pathologies in the Aeroelastic System," Dr. Thomas Strganac, Texas A&M University, College Station, TX	**0/03/04**
"Visual Information for Flight Control and Stabilization in Flying Insects," Dr. Holger Krapp, University of Cambridge England, UK	**11/20/03**
"X-45 J-UCAS Program Overview and Flight Test Status" Dr. Kevin Wise, Boeing Phantom Works	**11/18/03**
"On the Origins of the Negative Strain Rate Sensitivity in Al-MG Alloys" Professor R. C. Picu, Rensselaer Polytechnic Institute	**8/21/03**
"Cooperative Control and Neglect – Tolerant Human Interaction with Teams of Unmanned Air Vehicles," Dr Randy Beard, Brigham Young University, Provo Utah	**6/16/03**
"Arbitrary Discontinuities and Level Sets in Finite Elements Methods," Professor T. Belytschko, Northwestern University	**5/19/03**
"Desktop Micro Robots Factory and Micro-Hopping Robot," Dr. Hisayuki Aoyama, University of Electro Communications, Tokyo, Japan	**4/15/03**
"Micromechanical approach to the macroscopic behavior of damaged & poroelastic materials,"Dr. Djimedo Kondo, University of Lille, France	**03/27/03**
"A Particle-Level Set Based Sharp-Interface Eulerian Method For Simulating Impact, Penetration and Void Collapse" Dr. H. S. Udaykumar, University of Illinois	**03/19/03**
"The Navigation of Autonomous Vehicles In Uncertain Dynamic Environments VIA A Probabilistic Approach" Dr. Myungsoo Jun, Cornell University, Ithaca, NY	**3/7/03**

"Finite Elasto-Plasticity of Cristalline Materials" Professor Sanda Cleja-Tigoiu, University of Bucharest	**2/27/03**

Table (2) Research Institute Seminar Speakers

Perhaps the most progress during the reporting period has been made in the areas of developing methodologies for computational mechanics, aeroforms for small and micro air vehicles and cooperative control for agile autonomous vehicles. A quick survey of the table will show that most of the research during the reporting period has focused on these areas. Other significant areas of focus include vision processing for guidance, navigation and control of unmanned air vehicles.

Table (2) summarizes the specific seminars given over the reporting period. Presentations by invited speakers cover more diverse topics than the topics represented in Table (1). The researchers in Table (1) have been invited to address a specific topic of interest to AFRL/MN. Their appointment as a visitor represents a significant cost. On the other hand, the invitees in Table (2) are in house for only a few days. Their associated expense is considerably less. Invitations are made more broadly. Clearly, the visitors program has been highly successful in providing expertise to AFRL/MN researchers in a number of diverse technical areas. However, some issues in the administration of the Research Institute that have been noted over the past year

Workshop / Meeting Title	**Date**
2004	
Robust Optimization-Directed Design	04/19-21/04
Plasma Actuator Modeling Workshop	05/13/04
Aircraft Battle Damage Repair (ABDR) Technical Group Meeting	02/27/04
Workshop on Plasma Actuators for Subsonic Applications	02/25/04
Mission Planning Software Development ESC/ACU OL1	
BATCAM Transition Meeting	02/24/04
2003	
Discussions for Layout of GUI of MAV Ground Station	12/22/03
Formation Flying	11/21/03
Vision-Based Control of Agile Autonomous Micro Air Vehicles and Small UAV's in Urban Environments	10/27/03
AFOSR Computational Mathematics	5/29–30/03
Flow Control for Agile Autonomous Flight	3/24 –25/03
Nonlinear Aspects of Aeroelasticity, Related Structural Dynamics,	3/5/03

Table (3) Workshops and Technical Meetings supported via the Research Institute

Finally, Table (3) summarizes the major workshops and technical meetings that have been supported through the Research Institute. It is important to note that the participants in the technical meetings listed in Table (3) are academics and researchs of national and international recognition. As an example, participants in the Robust Optimization-Direct Design Conference included stellar researchers such as Tyrell Rockafellar, Roger Wets, and Elijah Polak. Researchers at the Workshop on Flow Control for Agile Autonomous Vehicles included Professor Tom Corke of

Notre Dame University and Professor Ari Glezer of the Georgia Institute of Technology. The caliber of these researchers cannot be overstated.

4 Research Institute Management

It must be emphasized that the day to day management of the Research Institute activities is a labor intensive effort involving a number of UF-GERC staff, faculty and administrators. Accurate and current projections for the cash flow during the project are a continuous requirement. That is, as new invitations are made, declined or accepted, and old invitees seek to update their stay, the fiscal standing of the Research Institute grant must be updated. In fact, it is fair to say that the collection of researchers supported under the Research Institute is in a constant state of flux. This fact is inevitable in that the research topics, and the researchers selected to carry out study of those topics, supported under the Research Institute Grant are selected based on direct input from AFRL/MN management and bench scientists. For example Table (4) depicts the Residence Planning Projection that must be updated on a weekly, and sometimes daily, basis as researchers are admitted to the program. This Table depicts what facilities will be used to house visitors: local hotels or rental properties leased by UF-GERC.

Visitors 2004

					FEB					MAR					APR				MAY					JUN				JUL				AUG				
Room #	Name	Title	Begin	End	3	10	17	24	31	1	8	15	22	29	5	12	19	26	3	10	17	24	31	7	14	21	28	5	12	19	26	2	9	16	23	30
	Karalvanov, Borislav		01/02/04	05/02/04																																
	Xu, Yunjun		01/01/04	12/31/04	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Feng, Yunfei		01/12/04	04/23/04	X	X	X	X	X	X	X	X	X	X	X	X	X																			
	Vela, Patrico		03/08/04	05/03/04							X	X	X	X	X	X	X	X	X																	
	Prazenica, Richard		02/02/04	12/31/04																																
	Schrader, David		03/01/04	04/15/04																																
	Jun, Mysungsoo		04/01/04	03/31/05																																
	Chichka, David		05/24/04	08/13/04																																
	Hovakimyan - Masters Stud.		04/19/04	08/13/04																																
	Hovakimyan - PhD Stud.		03/08/04	08/13/04																																
	Binev, Peter		SMR 04																																	
	Rossi, Massimiliano																																			
	Tran, Linhbao																																			
	Zhu, Lei																																			
	Hovakimyan, Naira		03/06/04	03/12/04																																
	Hovakimyan, Naira		06/07/04	06/28/04																																
	Hovakimyan, Naira		07/26/04	08/13/04																																
	Tannenbaum, Allen		03/29/04	04/06/04																																
	Calise, Anthony		03/08/04	03/31/04																																
	Sharma, Jeff																																			
	Sumrall, Theodore																																			
	Hanagud																																			
	Roubicek, Tomas		SMR 04	2 weeks																																
	Kruzik, Martin		SMR 04	2 weeks																																

Table (4) Example residence planning projection used in Research Institute administration

Table (5) depicts a similar projection that is maintained by the staff for the Research Institute program. Visitors must be supplied with i) offices that reflect the stature and standing of the visitor, ii) computing facilities, and iii) access to high speed internet.

Staff member Keith Stevens (finances), Kelly-Marie Duffy (travel), and Tammy Edmondson (personnel) carry a considerable burden in administration of the Research Institute grant.

Visitors **2004**

Room #	Name	Title	Begin	End
131	Strunk, David		07/01/03	
132	Phillips, Ed		07/01/03	
133	Zabarankin, Michael		07/01/03	
134	Cornelle, Jim		07/01/03	
135	Hovakimyan, Naira		03/03/04	03/12/04
135	Hovakimyan, Naira		06/07/04	06/28/04
135	Hovakimyan, Naira		07/28/04	08/13/04
135	Tannenbaum, Allen		03/29/04	04/05/04
136	Anderson, Chris		07/01/03	05/06/04
137	Sutton, Eric		07/01/03	
138	Zmuda, Henry		07/01/03	
149	Schrader, David		03/01/04	04/15/04
150	Krokhmal, Pavlo		07/01/03	
151	Ashokkumar, C. R.		12/04/03	07/08/04
152	Dominiak, Ken		07/01/03	
153	Cazacu, Oana		07/01/03	
154	Jacobs, Marc		07/01/03	
155	Stephens, Keith		07/01/03	
162	Ross, Allen		07/01/03	
166	Xu, Yunjun		01/01/04	12/31/04
168	Feng, Yunfei		01/12/04	04/23/04
168	Vela, Patricio		03/09/04	05/03/04
166	Chichka, David		05/24/04	09/13/04
168	Karaivanov, Borislav		01/02/04	05/02/04
168	Prazenica, Richard		02/02/04	12/31/04
172	Jun, Myungsoo		04/01/04	03/31/05
166	Hovakimyan - Masters Stud.		04/19/04	08/13/04
168	Stepanyan, Vahram		03/15/04	08/13/04
131	Calise, Anthony		03/09/04	03/31/04
?	Zhu, Lei		05/09/04	06/19/04
	Simonotto, Jennifer		06/01/04	12/31/04
?	Binev, Peter		SMR 04	
?	Hanagud			
?	Krstic, Martin		SMR 04	2 weeks
?	Rossi, Massimiliano			
?	Roubicek, Tomas		SMR 04	2 weeks
?	Shamma, Jeff			
?	Sumrall, Theodore			
?	Tran, Linhbao			
	Current GERC Faculty & Staff			
	Non-UF / Emeritus Faculty			
	Visitors			

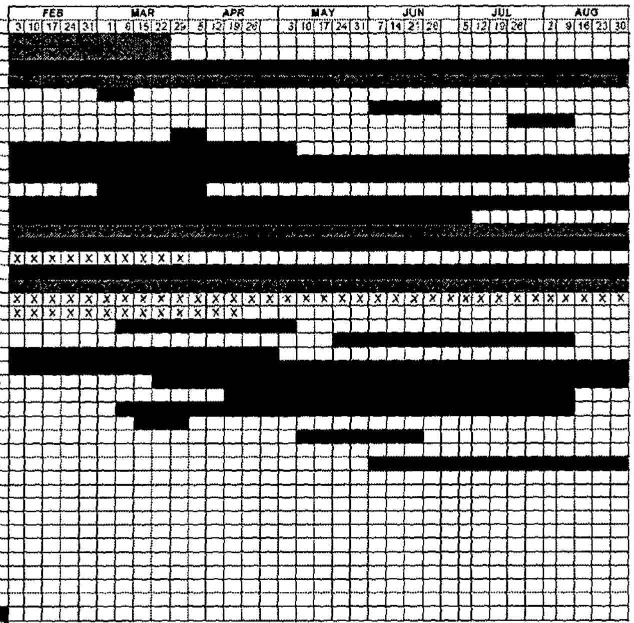


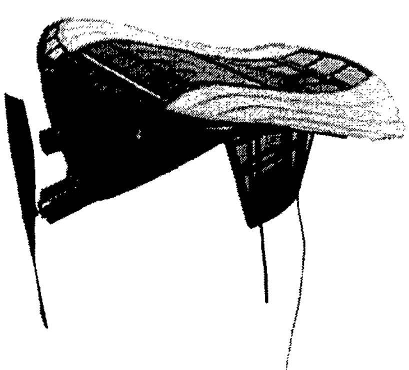
Table (5) Example office space planning projection used in Research Institute administration

5 Research Institute: Overview of Initiatives

A detailed summary of research initiatives that have been coordinated with AFRL/MN researchers has been given at the AFOSR Computational Mathematics Program Review, organized by Dr. Fariba Fahroo, on June 5-6, 2004. In this section, we overview some of the most recent and promising research efforts sustained under the program.

5.1 Computational Modeling of Hysteretic Behavior in Shape Memory Alloys

AFRL/MN has expressed a sustained, intense interest in new technologies for Micro Air Delivered Munitions (MADMs). The need for highly agile flight vehicles is one of the technology drivers for this area of research. This year, to address the need for high performance, agile MADMs, the University of Florida has initiated a study of modeling, simulation and control of shape memory alloys. Shape memory alloys are a class of so-called active materials that change crystalline variants through diffusionless phase transformations with the application of stress (a stress induced phase transformation) or the application of an electrical current (a thermally induced phase transformation enabled by resistive heating.) Ultimately, the goal is to be able to design and fly Micro Air Vehicles (MAVs) or MADMs with reconfigurable, actively "morphing" lift surfaces. Nominally, the concept is to replace the graphite composite and membrane wing MAV pictured in Figure (1) with one that can achieve actively controlled wing morphing. The goal is to attain levels of flight control that permit urban navigation via MADMs, as depicted schematically in Figure (2). Wing morphing may be achieved with the judicious incorporation of SMA fibers or thin films to selectively deform the structure.



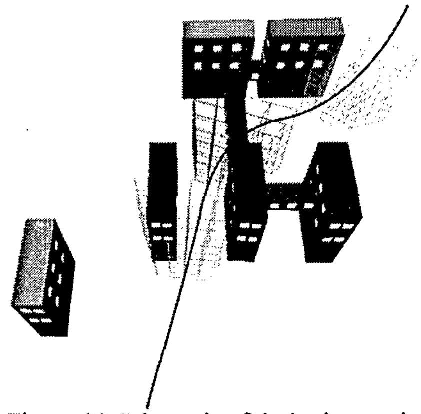


Figure (2) Schematic of desired operation profile: urban navigation

There are an enormous number of technical barriers that must be overcome to realize this goal. But as we argue shortly, these difficulties *decrease* as we decrease the physical scale of the vehicle. That is, small scale works to our advantage in this case. Resistive heating can be costly, so that highly efficient designs with minimal dimension actuators must be developed. Very thin wires of SMA require little energy, while bulk SMA or SMA embedded in a structural matrix require much more energy. Also, the bandwidth of bulk SMA embedded in a matrix composite may have exceptionally low bandwidth. On the other hand, thin film SMA's subject to ambient convection have exhibited on the order O(100hz).

But these design considerations are predicated on the availability of an accurate, reliable and robust simulation capability. Currently, this simulation capability is in its infancy. Roughly speaking, simulation of shape memory alloys is either based on ad hoc, phenomenological models, or micromechanically based models that are appropriate only for highly idealized settings (single crystals, perfectly twinned variants...etc). The Research Institute has engaged some of the worlds leading experts in the modeling, approximation and simulation of shape memory alloys through its visitor program to build a knowledge base at AFRL/MN in this highly complex area of research. Profs. Tomas Roubicek and Martin Krucik of Charles University are working with researchers at the University of Florida and AFRL/MN (Johnny Evers) to develop this program. Shown in Figure (3) is a collection of the length scales that are involved in the simulation process. Figure (4) is an example simulation of the phase transformation in single crystal SMA. Current efforts are to extend this work to polycrystalline models, and subsequently to develop multiscale models to propagate the micromechanical models to larger length scales. The result will be structural scale level models appropriate for

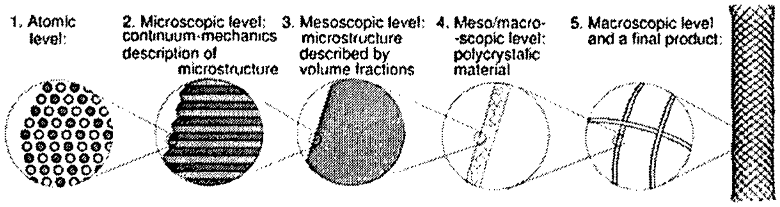


Fig. 1. Multiscale character of modeling of single crystal and polycrystalline SMAs up to a final product, here a knitted Ni-Ti peripheral vascular stent.

Figure (3) Length scales in the simulation of SMA, Roubicek and Krucik [2004]

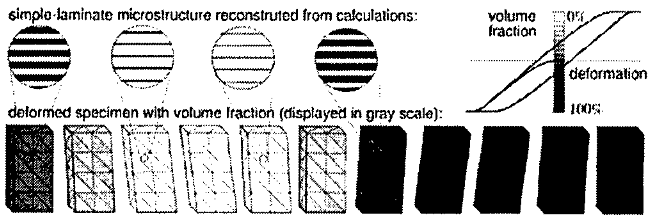


Figure 2. Isothermal 3D simulations of re-orientation of monoclinic martensite induced by shear of a single crystal governed by (12) (13): only a test double-well problem from [R03].

Figure (4) Single crystal SMA simulations, Roubicek and Krucik [2004]

5.2 Multiscale Modeling of HCP Alloy Sheets

Researchers at AFRL/MN have emphasized that there is an ugent need at the laboratory to develop the fundamental understanding necessary to design robust warm forming processes for HCP(hexagonal close packed) alloy sheets. Professor Oana Cazacu has addressed this need by using a multi-scale approach, with a focus on material behavior at elevated temperatures and high strain rates. Generally speaking, the methodology consists of three primary steps:

Use macroscopic experimental results and pollycrystalline simulations to generate yield loci;
Develop isotropic formulations for describing the asymmetry in yielding (tension versus compression) due to deformation twinning

Extend the isotropic criteria to orthotropy.

The overall approach is extremely promising. Professor Cazacu has derived and developed new orthotropic yield criterion for HCP metals describing both anisotropy and asymmetry (tension vs compression). Figure (5) depicts the excellent agreement between theory, computation and experimental results for Mg and Mg-4%Li alloy.

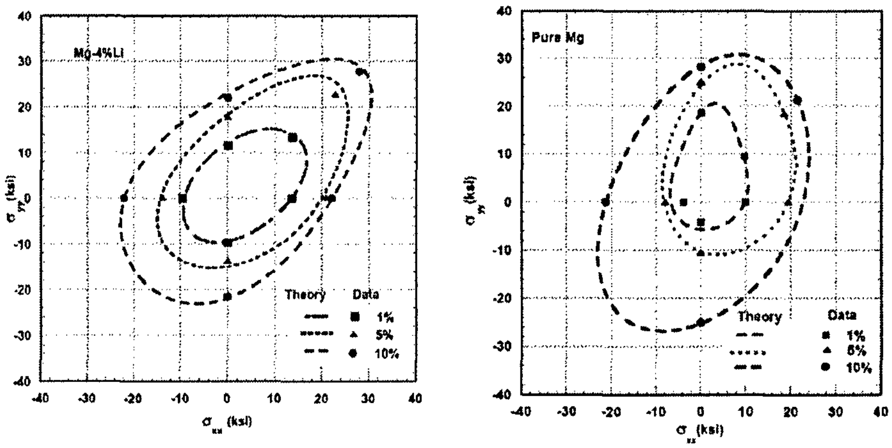


Figure (5) Comparison of theory, computation and experiment for Mg and Mg-4%Li. Cazacu and Barlat, *Int. J. Plasticity* (2004)

5.3 Trajectory Deviation for Penetrator Impacts

For as long as the Research Institute has been in existence, one of the research goals that AFRL/MN has identified has persisted as a critical need. AFRL/MN has sought to develop a fundamental understanding of dominant physical phenomena responsible for trajectory deviations of a hard penetrator impacting brittle targets for striking velocities in the transition regime. An example of the variable, uncertain nature of the dynamics of penetratorsas they pass through brittle materials is depicted in Figure (6). This graphic has been provided by AFRL/MN.

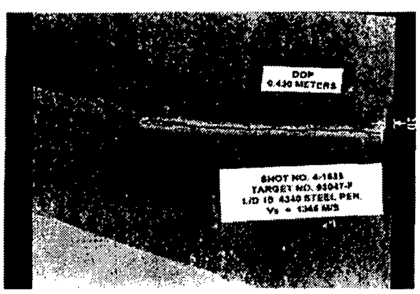


Figure (6) Example penetrator trajectory through brittle material, courtesy AFRL/MN

Professor Oana Cazacu has initiated research in this exceptionally difficult area, and she has already demonstrated novel, highly promising results. Roughly speaking, her program of research has had five primary goals

Predict the density changes in the target,

Determine the shape and location of the free boundaries caused by separation and **anisotropic damage ahead** of the projectile,

Model the onset of trajectory instabilities,
Identify the target material characteristics responsible for a given behavior during the onset of the instability phase,

Propose new designs for the penetrator nose such as to achieve stability.

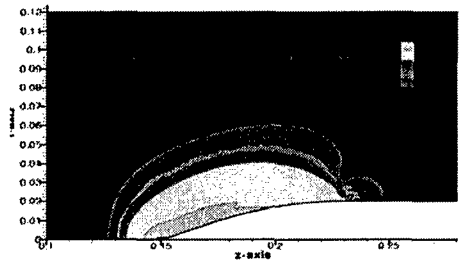


Figure (7) Computational prediction of deformation rate for typical penetrator head

5.4 Modeling and Simulation of Ceramic Matrix Composites

Another area of great interest to AFRL/MN is the modeling and simulation of ceramic matrix composites (CMCs). Again, Professor Oana Cazacu has been the key in developing a strong, cutting edge collaboration with AFRL/MN in this area of research. CMCs have been developed to overcome intrinsic brittleness of ceramics. They are specifically well-suited for applications such as in structural parts in severe environments
(e.g. rocket and jet engines, heat shields for space vehicles, and air craft brakes). They have several advantages including significant weight savings, increase of the temperature at which the engine can operate, and potentially the elimination of the cooling fluid in some designs. Still, Applications are limited due to the lack of suitable reinforcements, processing difficulties, the lack of material data bases, and the lack of understanding of dissipation mechanisms.

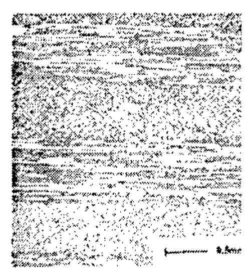


Figure (8) Typical ceramic matrix composite

Again, owing to the limitations on space in this report, only the overall strategy in Professor Cazacu's approach is summarized below. The interested reader is referred to the references for a complete, detailed analysis. The scientific methodology is comprised of three major steps:

Introduce fabric tensors to give a statistical representation of the cracks density distribution ρ (n)
Use the representation theory to construct the macroscopic free energy

Simplify (or identify) some of the parameters of the formulation using known analytical results from micromechanics (i.e. expression of the energy in the case of parallel cracks along the fibers)

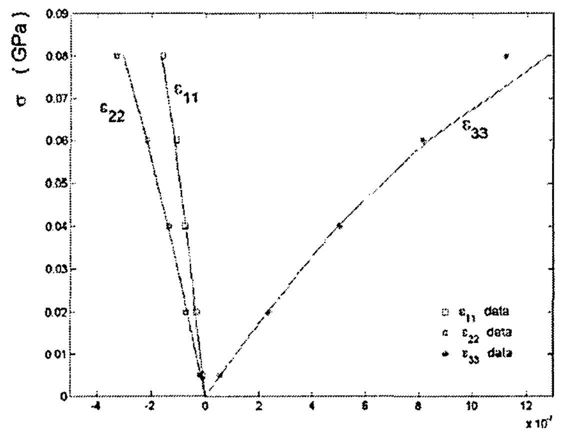


Figure (9) Stiffness degradation comparison between theory and data in off-axis tensile test Cazacu, Soare, Kondo Mechanics of Materials (2004)

5.5 Shape Optimization of Flow Control Actuators

Perhaps more than any other research area, there has been a concerted effort by researchers at AFRL/MN to emphasize topics in the Research Institute that deal with the study of unmanned autonomous vehicles. These topics of research can be surprisingly diverse in the fields of expertise that they embrace. In fact, the new directions in the list of research areas selected by AFRL/MN in the most recent grant includes aerodynamic flow control (Area 3) and actuators for agile Micro Air Vehicles (MAVs). In this section we summarize a research topic introduced into the Research Institute this year that addresses aspects of both of these topics. Figure (10) illustrates a PLOCAAS autonomous vehicle and a superimposed schematic of a region of the wing that exhibits detached flow. The goal proposed by Johnny Evers, AFRL/MN, is to design, simulate, develop and evaluate flow control actuators to enable modification of the flight capabilities of the nominal flight vehicle.

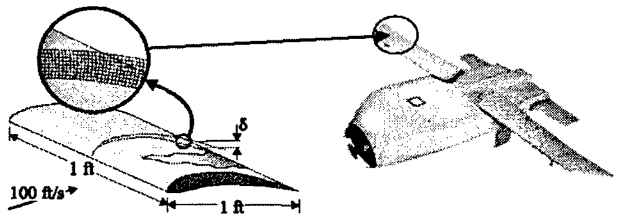


Figure (10) PLOCAAS autonomous flight vehicle, targeted flow control of separation

The flow control methodology targeted by the research effort is depicted in Figure (11). The strategy builds on the initial and foundational work by Carroll et. al. in [C01]. As shown in Figure (11), a piezoceramic composite is imbedded in the airfoil at a location where its oscillation can induce flow reattachment downstream. Figure (12) depicts the geometry and layout of the PZT in the piezoceramic composite.

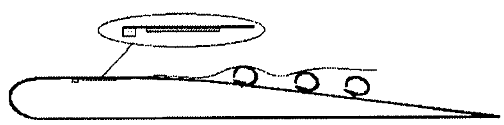


Figure (11) Schematic of embedded piezoceramic flap actuator, used to induce reattachment of separated flow

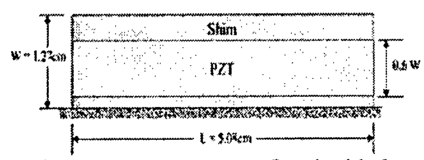
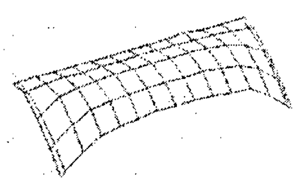
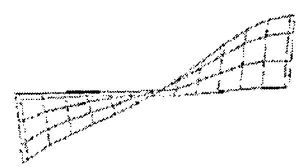


Figure (12) Geometry of embedded piezoceramic flap actuator depicting PZT and host structural flap

Unfortunately, for the simplest geometry of the piezoceramic composite, highly nontrivial deformation patterns may result on actuation. From a practical standpoint, this effect can induce undesired three dimensional effects in what otherwise may be modeled as a two-dimensional control design problem. Figures (13) and (14) depict the first two vibrational modes of a sample actuator depicted in Figure (12).





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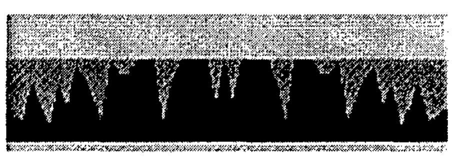
composite.

Figure (11) Schematic of embedded Figure (12) Geometry of embedded piezoceramic flap actuator, used to induce piezoceramic flap actuator depicting reattachment of separated flow PZT and host structural flap

Unfortunately, for the simplest geometry of the piezoceramic composite, highly nontrivial deformation patterns may result on actuation. From a practical standpoint, this effect can induce undesired three dimensional effects in what otherwise may be modeled as a two-dimensional control design problem. Figures (13) and (14) depict the first two vibrational modes of a sample actuator depicted in Figure (12).

Figure (13) First bending mode measured Figure (14) First torsional mode measured by laser Doppler vibrometry by laser Doppler vibrometry (300hz)

The goal of the shape optimization process is to re-design the electroded region on the surface of the PZT, thereby modifying the dynamic response shapes of the actuator. Figures (15) and (16) illustrates a comparison of the results of two optimization techniques. The ad hoc, intuitive approach yields a highly oscillatory electrode pattern that becomes increasingly oscillatory as the dimension of the parameterization of the electrode boundary is increased. This phenomenon is quite typical of ad hoc implementations of shape optimization. Figure (16) depicts the results of a design optimization that derives from a Γ-convergent formulation of the shape optimization problem. As the dimensionality of the parameterization of the boundary is increased, the countour stabilizes and converges to the solution of the shape optimization problem.



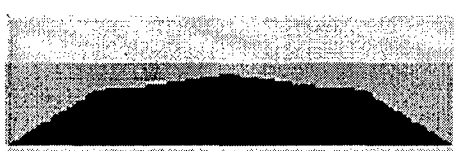


Figure (15) Highly oscillatory optimal Figure (16) Convergent and regular optimal electrode shape obtained via ad hoc shape electrode shape obtained via Γ-Convergent optimization methodology formulation of shape optimization

6 UF-GERC and AFRL/MN Collaboration

In addition to the direct, peer-reviewed research carried out under the Research Institute, it is important to note that the ongoing interaction afforded to AFRL/MN and UF-GERC results in tangible, infrastructural development. The degree of progress in this area can be appreciated by considering two separate issues : a) the organization of research teams through the research institute that integrate researchers from across he country with AFRL researchers, and b) the development of new, shared laboratory facilities that enable the coordinated research efforts.

6.1 Evolving Research Groups

Many of the visiting researchers listed in Table (1) can be organized thematically in there research topics. These research groups include

Flow Control via Plasma Actuators
Computational Mathematics
Control of Autonomous Flight Vehicles
Cooperative Control and Weapon Allocation

For example, there are distinct subteams of researchers who work in these focus groups are summarized in the next table:

Topic	AFRL Point of Contact	Researcher
Flow control via plasma actuators	William Hilbun	William Hilbun, AFRL/MN
		Mike Valentino, AFRL/MN
		Datta Gaitonde, AFRL/VA
		Tom Corke, ND
		Tom McLaughlin, USAFA
		Lon Enloe, USAFA
		Joe Shang, Wright State Univ.
		Wei Shyy, UFL
		John Burns, VPI
Computational Mathematics		
		Oana Cazacu, UF
		Tomas Roubicek, CU, CR
		Martin Krucik, CU, CR
		Mike Plesha, Univ. Wisconsin
Control of Autonomous Vehicles	Johnny Evers	Johnny Evers, AFRL/MN
		Gabe Chedister, AFRL/MN
		Kent Kaiser, AFRL/MN
		Anthony Calise, GaTech
		Naira Hovakimyan, VPI
		David Chichka, GWU

		Patricio Vela, GaTech
		M. Hernnberger, VPI
		V. Stepanyam, VPI
Cooperative Control & Allocation	Robert Murphey	Robert Murphey
		S. Uryasev, UF
		M. Jun, Cornell
		A. Tiwari, CalTech
		P. Khambatta, UF
		A. Chinchillum, UF

6.2 Evolving Laboratories and Facilities

In addition to the development of research teams that focus on problems of interest to AFRL/MN, investment by the College of Engineering to match the AFOSR investment in the Research Institute Grant has enabled the creation of a number of labs that form the hub the team interaction. These laboratories include

Micro Air Vehicle Instrumentation Laboratory
Micro Air Vehicle Fabrication Laboratory
Guidance, Navigation and Control Laboratory
Visualization and Computation Laboratory

<u>Status as of 6/04 , Submission Date of Last Annual Report</u>

Within the last annual report, the author noted that, the UF-GERC management had planned a separate Computational Laboratory and Aerodynamic Testing Laboratory. Figure (17) depicts the organization of the new labs and their respect tasks. It is important to note that each laboratory has a designated coordinator from AFRL/MN. Within the current plan, laboratory mission, research directions, research protocols and performance reviews are a shared responsibility, while the laboratories remain UF facilities.

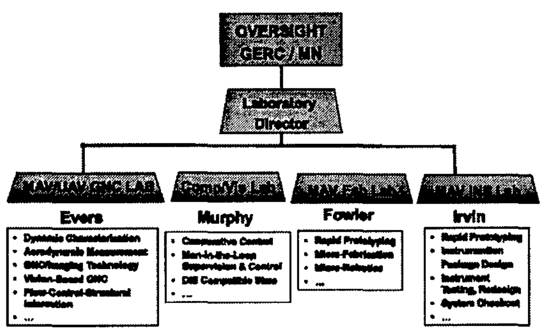


Figure (17) Organization of Laboratories at UF-GERC in Support of AFRL/MN and the Research Institute Grant, June, 2004

The reader is urged to recall that as of 6/03, there was essentially no laboratory collaboration in the UF-GERC facilities. Figure (18) depicts the layout of laboratories that have been assembled during the period 6/03 through 6/04. It should be recalled that all of these laboratories have been funded, for the most part, through the U F College of

Engineering.

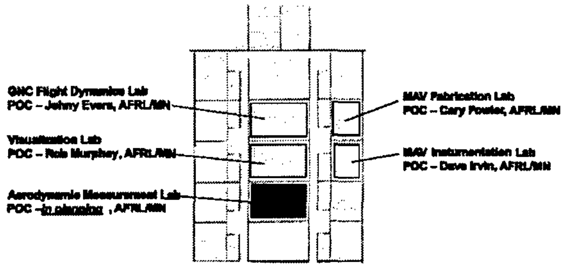


Figure (18) Layout of UF-GERC – AFRL/MN Laboratories Developed in Support of the Research Institute Grant, June, 2004

<u>**Developments during the period 6/04-8/04 , Submission Date of Last Annual Report**</u>

It is important to note that the Research Institute empowers researchers at Eglin AFB, and AFRL/MN in particular, to build and expand their research activities and programs. In the last section, the author summarized the laboratories that had been created or funded through June, 04 to sustain and house researchers supported through the Research Institute Grant. In Figure (19), the organization chart for the proposed research laboratories at UF-GERC are outlined. It is important to note that this expansion in capability is directed toward the development of a rapid prototyping facility for small and micro UAV. This facility will enhance and leverage the investment by AFOSR in the Research Institute. Researchers supported under the Institute will be coordinated with numerous topics in rapid prototyping including : aerodynamic simulation, computational mechanics, design-directed optimization, multidisciplinary optimization, aerodynamic experimental characterization.... and other topics vital to realizing rapid prototyping of small and micro UAV.

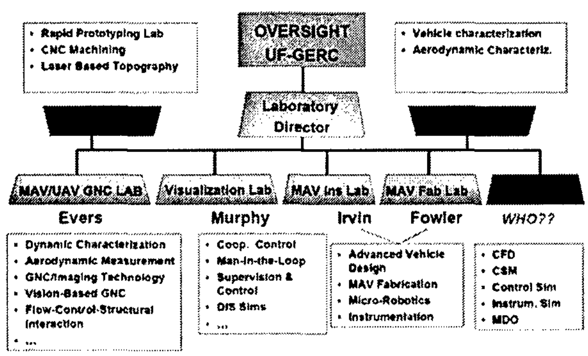


Figure (19) Proposed Laboratories at UF-GERC in Support of

AFRL/MN and the Research Institute Grant, September, 2004

Again, the design and deployment of the additional labs enabling rapid prototyping, wind tunnel characterization and computational studies depicted in Figure (19) . It should be noted that a) points of contact for coordination of the labs have been identified at AFRL/MN, b) the design and layout has been reviewed and endorsed by Director John Rogacki, Dean Pramod Khargonekar and Deputy Director of Weapons Steve Korn, SES.

AFRL/MN POC	Laboratory
Robert Murphey	Visualization and Immersive Environment Lab
Johnny Evers	Guidance, Navigation and Control Lab
Carrie Fowler	Micro-Air-Vehicle Fabrication Lab
Chris Perry (Dave Irvin)	Micro-Air-Vehicle Electronics Lab
Bill Hilbun (?)	Computational Mechanics Laboratory

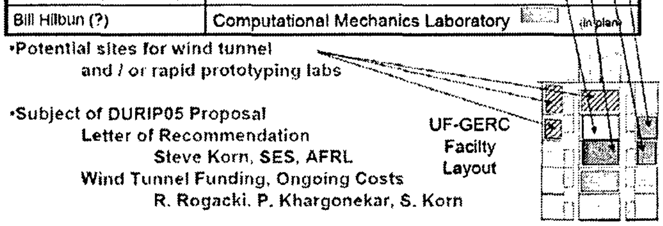


Figure (20) Layout of Proposed UF-GERC – AFRL/MN Laboratories in Support of the Research Institute Grant, June, 2004

7 Annual Review, Second Annual Strategic Planning Meeting

In addition, to the program summary given at the Annual Program Review held by Dr. Fariba Fahroo, a second detailed review of this grant was held this year. The strategic directions and recommendations for improving the Research Institute were discussed at the Second Annual Strategic Planning Meeting (SPM II) held in August, 2004, at UFGERC. The panel discussion and review of the Research Institute Grant was carried out with

Dr. Fariba Fahroo, AFOSR, Program Manager, Computational Mathematics Dr. Arje Nachman, AFOSR, Program Manager, Applied Analysis Dr. Sharon Heise, AFOSR, Program Manager, Dynamics and Control Dr. Neal Glassman, Optimization and Discrete Mathematics Dr. David Jeffcoat, AFRL/MN Mr. Johnny Evers, AFRL/MN

The following observations and recommendations were made:

1) The bench scientists at AFRL/MN are highly supportive of the grant and have benefited greatly from the Research Institute.

2) Dr. Fariba Fahroo, the new PM for the grant, did not feel that sufficient communication and reporting was carried out to give her a good assessment of the content of the portfolio.

3) A recommendation was made that a joint AFOSR – AFRL/MN – UF panel convene at the beginning of each funding cycle to guarantee that the research is strategically selected consistent with the needs of all stakeholders.

4) A recommendation was made that the above joint panel likewise plan a subset of the workshops to be held over the next Fiscal Year to meet the needs of all stakeholders.

5) A recommendation was made to consolidate reporting of the Research Institute, the AVCAAF grant, and the annual Strategic Planning Meeting for UF-GERC.

6) A recommendation was made by the Acting Director to report on aspects of the Research Institute Grant that are topically appropriate for different Program Managers at the Program Manager's Annual Reviews.

All in all, it was also the concensus of the Program Managers that the current research mandate is too broad and should be focused by a governing panel.

8 Recommendations and Conclusions

As the Acting Director for UF-GERC during the reporting period, some period of education has been necessary in gaining a familiarization with both the scientific content as well as the functionality of the Research Institute Program. Still, important observations can be made that underscore the effectiveness of this program in meeting the needs of the Air Force, and concurrently, those of the University of Florida.

> For any of the AFRL/MN management members or bench scientists, it is evident that the Research Institute Grant is exceptionally successful in its stated mission: providing efficient, time-critical, highly specialized, highly qualified research expertise in critical research focus areas.
> In addition, the Research Institute Grant has been critical in fostering an atmosphere of collaboration and the further development of critical infrastructural needs at UF-GERC. The associated infrastructural development has been funded, in the large part, through the College of Engineering. The infrastructure supports both the educational and research needs of the University of Florida, but likewise is goal-oriented in that it addresses the needs of focused AFRL/MN research directions.

In addition, there are several recommendations that can be made that will further improve the efficiency of the Research Institute Grant and its impact on AF relevant research:

- The Research Institute Grant is heavily leveraged via investment by the University of Florida, particularly during the past year. This fact does not seem to be fully recognized by bench researchers at AFRL/MN, the management of AFRL/MN, or, perhaps to a lesser degree, AFOSR. For example,
  - Some fraction of the operating budget of UF-GERC, which is in the vicinity of $1M/year goes to the support of the Research Institute Projects.
  - The laboratory space is provided at no cost, which represents a huge cost matching by the University.
  - The staff support of 4 secretaries, a financial planner and one administrator is likewise essentially unsupported.
  - In addition, during the last year cash support from the College of Engineering included
  - $60K for the development of Micro Air Vehicle Instrumentation and Fabrication Laboratories.
  - $90K for the investment of computing facilities, office partitions and furniture for Research Institute guests.
  - $36K for the lease of Research Institute housing.

  It is imperative that Eglin AFB bear some financial burden for the infrastructural investments that benefit its research mission.

- Feedback from AFOSR Program Managers has emphasized that the scientific content of the Research Institute evolves with AFOSR essentially "out of the loop." This is a fair assessment. The original grant gave great flexibility to the Research Institute Grant to respond to Eglin AFB needs. While the success of the program in carrying out this goal has been nothing less than spectacular, it is true that AFOSR has not been completely included in the development of the research portfolio. *It is imperative that the development of the research portfolio supported under the Research Institute Grant be carried out in a more formal, rigorous, scheduled fashion with the full involvement of relevant AFOSR Program Managers.*
- The Research Institute Grant is unlike nearly all other grants under the supervision of any single Program Manager at AFOSR. There are nearly 40 researchers, visitors, students and postdocs whose research efforts must be planned, reviewed, and assessed for performance, and finally reported out to AFOSR. As an administrative exercise, this effort in and of itself, may be greater than the administrative efforts of any AFOSR Program Manager. Thus, while the budget for the Research Institute Grant is much smaller than that for an AFOSR Program Manager, the bookkeeping, schedule arrangement, travel arrangement, reimbursement processing, performance evaluation and performance reporting may be a task of similar dimensions. *It is imperative that AFOSR, AFRL/MN and UF-GERC develop a reporting structure that satisfies all institutions and is coordinated (to the extent possible) in a single event for all relevant management from AFOSR and AFRL.*

Finally, the most important recommendation is provided last. UF-GERC is undergoing yet another transition to a new Director in August, 2004. *It is essential that the new Director is afforded the time and guidance to continue the strong trends of growth that have been possible under the Research Institute Grant during the past year.*

Appendix C

RESEARCH INSTITUTE FOR AUTONOMOUS PRECISION-GUIDED SYSTEMS

F49620-03-1-0170

Dr. John R. Rogacki
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Abstract

The primary objective of this grant, which runs through March 06, is to conduct new, groundbreaking research on agile autonomous munitions, in direct support of the Air Force Research Laboratory Munitions Directorate (AFRL/MN). This effort is being executed under the Agile Autonomous Munitions Center of Excellence (AAM COE), which operates as a focus area in the REEF's (formerly GERC) Research Institute for Autonomous Precision-Guided Systems (RIAPGS). The AAM COE serves as a focal point for the research, development and transition of technologies necessary to attain agile, autonomous, smart munitions operating autonomously or cooperatively in complex, uncertain, adversarial environments. The secondary objective is to develop new methods for Improving Robustness of Modeling and Simulation (IRMS) in a key area of importance to AFRL/MN, viz., strain localization and failure in solids. The Research Institute on Autonomous Precision-Guided Systems (RIAPGS) was developed jointly by the REEF and AFRL/MN as a refinement of the existing partnership between the REEF and Eglin AFB. The RIAPGS Grant includes on-site researchers to finalize and utilize the infrastructure created by the FY04 *(A Hardware-in-the-Loop Experiment and Simulation Facility for Vision-Based Control of Micro-Munitions)* and FY05 *(Rapid Prototyping, Aerodynamic Characterization, and Hardware the-Loop Simulation for Small, Agile Autonomous Munitions)* DURIP grants and addresses research directions that have been identified as critical barriers in AAM, but are not covered in the scope of the AVCAAF *(Vision-Based Control of Agile, Autonomous Micro Air Vehicles and Small UAVs in Urban Environments)* grant.

This year marked a period of transition for the RIAPGS from several key perspectives. First, Dr Rogacki was named Principal Investigator (PI) and Dr Kurdila Co-PI. Second, the emphasis was shifted away from short-term researcher appointments (e.g., summer faculty and students) toward longer term appointments. Third, priority was given to integrating the RIAPGS activities with the FY-04 and 05 DURIP and AVCAAF grants.

REEF Visualization Laboratory The REEF Visualization Laboratory, funded via AFOSR FY-04 DURIP grant, is a key component in the REEF's experimental capabilities for studying vision-based control of autonomous vehicles. The lab is composed of a cluster of 11 computers that are able to generate 10 different camera views within a virtual environment. Any 4 of these 10 camera views can be viewed at one time on four 50-inch plasma screen displays. The lab is capable of supporting hardware-in-the-loop simulations which will enable researchers to study the performance of vision processing and control algorithms using the actual hardware that will be used in practice (e.g. cameras, ground stations, and autopilots). The REEF Visualization Lab will have 2 virtual databases: a UF campus database developed by the UF Digital Worlds Institute and a database of the MOUT site at Ft. Benning, to be developed by Quantum 3D. Both of these databases provide suitable virtual environments for studying autonomous flight in urban environments. A substantial portion of Dr. Prazenica's efforts under RIAPGS in FY04 were dedicated towards the design and development of the REEF Visualization Lab. The lab is scheduled to become operational in mid-August of 2005.

REEF Rapid Prototyping and Aerodynamic Characterization (RPAC) Lab The REEF RPAC Laboratory instrumentation funded via AFOSR 05 DURIP grant is a another key component in the REEF experimental capabilities to conduct hardware in the loop simulations where revolutionary aerodynamic flying qualities associated with morphing wing aerodynamics are tied to revolutionary breakthroughs in vision-based guidance and control for small agile autonomous munitions. A substantial portion of Dr. Hubner's efforts under RIAPGS were directed toward the design and development of an aerodynamic characterization capability that utilizes a time resolved stereo Particle Image Velocimetry system and a Vibrometer system to allow research into flow structure around complex morphing wing shapes and structural vibration do to the unusual wing loading on flexible these flexible light weight wing structures. The equipment is currently under procurement and delivery is expected by Oct 05.

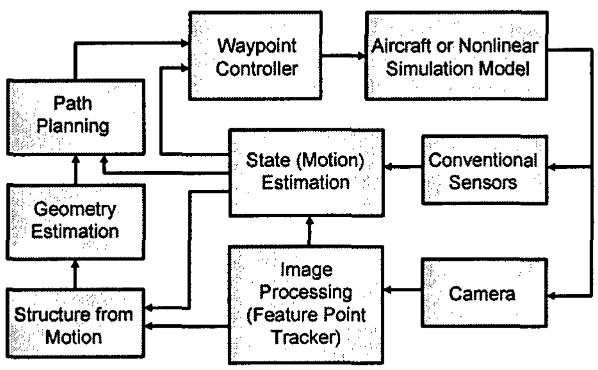

Figure 1: Vision-Based Control Framework

Vision-Based Control for Autonomous Vehicles Dr. Prazenica performed research supported by the RIAPGS and AVCAAF in the following areas related to vision-based control of autonomous vehicles:

- Feature point tracking and structure from motion
- Vision-based estimation of aircraft motion (velocity, angular velocity, position, and attitude) using tracked feature points

- Adaptive multiresolution-based learning algorithms for geometry estimation
- Receding horizon control strategies for adaptive path planning and control

These research areas can be viewed as components of an overall framework for autonomous flight in urban environments. This framework is shown in Figure 1. Dr. Prazenica's research efforts have focused on developing many of the individual algorithms needed to realize the strategy outlined in Figure 1. In addition, he has been involved in initial efforts to synthesize these individual components in simulations in the HILS virtual environment and in the real-time operation of a wheeled mobile robot.

Use of Vision Data for Path Planning An important research problem in vision-based MAV is processing and utilization of vision data for navigation. The objectives of the research are to contrive an algorithm to estimate locations (or orbits) of objects from a sequence of two dimensional vision data and plan a path to a destination and to design test beds for experiments. Tracking objects through highly cluttered scenes is difficult. For tracking to be robust when following agile moving objects, in the presence of dense background clutter, probabilistic algorithms are essential. Previous algorithms (like the Kalman filter) have been limited in the range of probability distributions they represent as they usually represent the Gaussian distribution. The *Condensation* algorithm (*Con*ditional *Dens*ity Propag*ation*) allows quite general representations of probability. Experimental results showed that this increased generality leads to marked improvements in tracking performance. This algorithm may be applied to our vision tracking problems. As a first step of the research, the condensation algorithm has been implemented for object tracking.

Cooperative Flight of Autonomous Aerial Vehicles using GPS and Vision Information During summer 2004, Professor Chichka developed the framework for the control logic to be programmed into the aerial vehicles used in the AFRL/MN vision-based micro munitions testbed. This led in turn to the beginnings of the Cooperative Vehicles Systems Group (CVSG) laboratory under his direction at the George Washington University. Several undergraduate and graduate students are working at the CVSG to build and program UAVs that will be used to demonstrate the techniques being developed at AFRL/MN. Currently, code written by one of Chichka's students is being ported to the computer stack being developed at AFRL/MN for their testbed craft. The work currently being done by Professor Chichka concentrates on the use of GPS in urban environments by UAVs, particularly in the case in which too few satellites are available to get a complete solution from GPS. In this case, the range rate to the available satellites can be used to get a velocity reading in a particular direction. A full inertial velocity computation can be made with as few as three satellites in view, as opposed to the five generally required for reasonable position solutions.

Cooperation and Sharing of Information in Search Missions Involving Multiple Autonomous Agents The Air Force has the need for research in the area of cooperation and sharing of information among autonomous munitions flying in large numbers over a battlespace. In this project we considered the effects of cueing in a cooperative search mission that involved several autonomous agents. Two scenarios are discussed: one in which the search is conducted by a number of identical search-and-engage vehicles, and one where these vehicles are assisted by a search-only (reconnaissance) asset. The cooperation between the autonomous agents is facilitated via cueing, i.e. the information transmitted to the agents by a searcher that has just detected a target. The effect of cueing on the target detection probability is derived from first principles using a Markov chain analysis. Exact solutions to Kolmogorov-type differential equations are presented, and existence of an upper bound on the benefit of cueing is demonstrated.

Modeling and Simulation of Coupling between Initial and Damage Induced Anisotropy in Anisotropic Media The basic mechanism of deformation of a large class of materials ranging from man-made materials to geologic materials is microcracking. Since the orientation distribution of the crack arrays depends on the loading direction, damage is anisotropic. Very few damage models for initially anisotropic materials have been proposed in the literature. The correct modeling of the interaction between material initially anisotropic and subsequent damage-induced anisotropy remains a much debated issue. Professor Oana Cazacu has been the key in developing a strong, cutting edge collaboration with AFRL/MN in this area of research. Within the framework of irreversible thermodynamics, a new general constitutive model for describing damage and its effect on the overall properties of transversely isotropic solids (layered material that is isotropic within layers but anisotropic across layers) was developed. The ability of the model to describe the overall stress-strain response as well as the loss of symmetry resulting from the coupling between initial and induced anisotropy was demonstrated.

Mechanical Response of Composites in the Presence of an Electromagnetic Field The USAF needs reliable, high performance materials for various applications. Hence, there is a strong interest in analytical research pertaining to the strengthening and toughening of organic matrix composites in the presence of electromagnetic fields. The existing experimental evidence suggests that exposure of composite materials to electromagnetic fields leads to changes in the material's strength and resistance to delamination. In this project we have developed a mathematical framework allowing for a description of the response of composite materials in the presence of electromagnetic fields. Derivations for a coupled nonlinear system of 3D equations of motion and Maxwell's equations, which takes into account mechanical and electrical anisotropy of composites were completed. In application to thin composites plates, we have obtained the equivalent 2D formulation. The numerical solution procedure for such coupled systems has been developed. Interacting effects of the in-plane steady and slowly varying electric current, external magnetic field and mechanical load as well as effects of mechanical and electrical anisotropies are also investigated.

Frictional Contact Problems The rapid growth of the areas of MEMS and nanotribology combined with their critical importance to the Air Force calls for in-depth studies of both fundamental and technological aspects of contact problems with friction. The goal of this project was construction of analytical solutions to nonlinear contact problems with friction that allow for detailed analysis of mechanical (stress and displacement fields) and geometrical (size of contact area, stick/slip boundaries) characteristics. We have developed a new analytical framework allowing for efficient high fidelity predictions for the contact stresses, strain, displacement, and relative slip zone sizes in the frictional contact problems. The solution procedure includes a new formulation of the contact problems in bipolar coordinates, reducing the problem to a single singular integral equation, and an exact solution of this equation using Wiener-Hopf technique.

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References: None

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Publications (published or accepted)

"Aerodynamic Characterization and Deformation Measurement of a Flexible Wing Micro Air Vehicle", R. Albertani, B. Stanford, J. Hubner, and P.G. Ifju, SEM Annual Conference and Exposition, Paper #302, June 2005.
"A Markov Chain Approach to Analysis of Cooperation in Multi-Agent Search Missions", Jeffcoat D.E., Krokhmal P.A., and Zhupanska O.I., to appear in *a refereed volume on Cooperative Control and Optimization* (edited by P. Pardalos), 2005 (b).

"A Micromechanics Inspired Damage Model for Initially Transversely Isotropic Materials", C. Gruescu*, D. Kondo, and O. Cazacu, The 11th International Conference on Fracture, March 20-25 [2005], Turin, Italy (in press).
"Characterization of Flexible Wing MAVs: Aeroelastic and Propulsion Effects on Flying" Qualities", R. Albertani, J. Hubner, P.G. Ifju, and B. Stanford, AIAA Atmospheric Flight Mechanics Conference and Exhibit, Paper 2005-6324, August 2005
"Contact with Friction of a Rigid Cylinder with an Elastic Half-Space", Zhupanska O. I., Ulitko A. F., *Journal of the Mechanics and Physics of Solids,* 53 (5), 2005, pp. 975-999.
"Convergence properties of continuous-time Markov chains with application to target search", M. Jun and D. E. Jeffcoat, *In Proceedings of the American Control Conference*, Portland, OR, 2005.
"Damage model for brittle matrix composites" O. Cazacu, S. Soare, and D. Kondo ASME/ASCE/SES Joint Mechanics of Materials Conference, June 1-3 [2005], Baton Rouge, LA.
"Deformation of Composite Plates Subjected to Mechanical and Electromagnetic Loads", Zhupanska O. I., Sierakowski R. L., *Proceedings of the American Society for Composites, 2005 Conference, Philadelphia, PA,* 2005 (a).
"Estimating Nonlinearity using Volterra Kernels in Feedback with Linear Models", R. Lind, R.J. Prazenica and M.J. Brenner, *Nonlinear Dynamics*, invited paper for special
"Experimental Analysis of Deformation for Flexible Wing Micro Aerial Vehicles", R. Albertani, B. Stanford, J. Hubner, R. Lind, and P.G. Ifju, 46th AIAA Structures, Structural Dynamics and Materials Conference, AIAA Paper 2005-2231, April 2005.
issue on nonlinear system identification, Vol. 39, No. 1, January 2005, pp. 3-23.
"Mechanical Response of Composites in the Presence of an Electromagnetic Field", Zhupanska O. I., Sierakowski R. L., *Proceedings of 46th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics & Materials Conference, Austin, TX,* 2005 (b).
"Multiwavelet Constructions and Volterra Kernel Identification", R.J. Prazenica and A.J. Kurdila, *Nonlinear Dynamics*, accepted.
"On Modeling the Interaction Between Initial and Damage-induced Anisotropy in Transversely Isotropic Solids", O. Cazacu, S. Soare, D. Kondo, *Mathematics and Mechanics of Solids* [2005], accepted.

Honors & Awards Received: None

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Appendix D

RESEARCH INSTITUTE FOR AUTONOMOUS PRECISION-GUIDED SYSTEMS

F49620-03-1-0170
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Abstract

The primary objective of this grant is to conduct new, groundbreaking research on agile autonomous munitions, in direct support of the Air Force Research Laboratory Munitions Directorate (AFRL/MN). Although the original 3 year grant was to conclude March 06, a grant extension was awarded in April 06 that extended the period of performance to 30 Nov 06 and added (5) tasks. This effort is being executed under the Agile Autonomous Munitions Center of Excellence (AAM COE), which operates as a focus area within the UF-REEF (University of Florida Research and Engineering Educational Facility). The AAM COE serves as a focal point for the research, development and transition of technologies necessary to attain agile, smart munitions operating autonomously or cooperatively in complex, uncertain, adversarial (urban) environments. The Research Institute on Autonomous Precision-Guided Systems (RIAPGS) was developed jointly by the REEF and AFRL/MN as a refinement of the existing partnership between the REEF and Eglin AFB. The RIAPGS Grant includes on-site researchers to finalize and utilize the infrastructure created by the FY04 *(A Hardware-in-the-Loop Experiment and Simulation Facility for Vision-Based Control of Micro-Munitions)* and FY05 *(Rapid Prototyping, Aerodynamic Characterization, and Hardware in-the-Loop Simulation for Small, Agile Autonomous Munitions)* DURIP grants and addresses research directions that have been identified as critical barriers in AAM, but are not covered in the scope of the AVCAAF (*Vision-Based Control of Agile, Autonomous Micro Air Vehicles and Small UAVs in Urban Environments)* grant. Significant advancements include: autonomous or human localized feature point tracking and autonomous closed loop servo control demonstrated in the REEF Visualization Lab; accurate CFD simulations of a dynamic, flexible wing in low Reynolds number flow characterized with laminar separation and transition; morphing MAV vehicle designed, built, and flown based on biologically inspired gull wing.

This year marked a period of transition for the RIAPGS from several key perspectives. First, Dr. Dixon and Dr. Lind were added as co-PI's. Second, the grant extension added (5) new tasks and progress on those tasks will be the main focus reported under this program summary. The intent with the (5) new tasks was to smooth the transition from the current grant to a new three year grant that will be considered for FY 07 to FY09.

The new three year grant will propose objectives and milestones in years 2007, 2008, and 2009 under each of the five tasks.

Full Vehicle Virtual Prototyping: Control Synthesis and Aero-structural Characterization of Agile Autonomous Munitions and Micro Air Vehicles (MAV) (Task 1)

The vehicle virtual prototyping research has been concentrating and making progress on marrying the facility and simulation requirements of the guidance and control discipline with the aerodynamics characterization requirements needed for hardware in the loop simulations. The hardware-in-the-loop simulation capability is dependent on having a data base for virtual scene generation (two data bases developed and available in the REEF), software to calculate and display virtual camera views (developed and available at REEF for up to 10 views), a camera to record images presented on flat screens with proper coordinate transformation (developed and available at the REEF), guidance/path planning/structure form motion and visual-servo control (initial capability developed and available at the REEF with more refined and mature algorithms under development for implementation in future years), micro air vehicle dynamics model (limited model of a 6 inch wing span MAV available, however models under development are the 24 inch wing span MAV and next year the morphing wing MAV model, followed by the flapping wing model in following year), ability to fly the MAV in a tethered flight condition to allow rapid prototyping investigations (requirements identified for the dynamic mounting system that will allow rolling, pitching and yawing of the vehicle).

Integrated Visual-Servo Control and Path Planning for Unmanned Air vehicles (Task 2)

The following research accomplishments were achieved during this review period: developed and demonstrated automated and human directed feature point tracking at the REEF visualization facility; developed and demonstrated the ability to execute closed-loop visual servo control at the REEF visualization facility; developed and demonstrated basic path planning through a known topology at the REEF visualization facility.

Automated feature point tracking was developed via a multi-scale implementation of the Lucas-Kanade tracker. The standard tracker searches the entire image and automatically selects points that are amenable to tracking (i.e. corners). Alternatively, a human can select corners of interest. This algorithm was then extended so that a human can use a touch-screen monitor or mouse to select a region of interest in an image. The region is isolated based on color and intensity values. The tracker then selects feature points within that region and tracks those points in subsequent image frames.

Homography-based visual servo control methods were developed to regulate a camera to a goal pose using tracked coplanar feature points to determine errors in the camera position and orientation. The pose error signals are regulated to bring the camera to the goal pose. These closed-loop visual servo control methods were demonstrated via camera-in-the-loop simulations in the REEF visualization facility.

Finally, a locally-optimal receding horizon path planning algorithm was developed in order to plan vehicle trajectories through cluttered environments. With this approach, the vehicle is commanded to follow a limited number of waypoints after which a new locally-optimal path is determined. This enables the path planner to incorporate obstacle-avoidance constraints based on updated estimates of the three-dimensional scene. These estimates are obtained via adaptive learning techniques that operate on structure-from-motion data to generate a functional representation of the scene.

Aerodynamic and Structural Characterization of Flexible and Morphing MAV's in Low Reynolds Number Flow (Task 3)

The primary efforts to date have been the testing and implementation of equipment purchased as part of the 2005 *Rapid Prototyping and Aerodynamic Characterization Facility* DURIP and the eventual integration with the open jet facility currently under design by UF-REEF and UF-Gainesville (free jet low Reynolds number tunnel planned availability at the REEF is Jan 07). The laboratory situated in room 169 at the REEF, Shalimar FL, was designed and equipped as a staging facility in support of the current and future experimental activities to begin in CY07. A small ad interim open jet wind tunnel, designed at the REEF, installed in Aug 06, is being used for basic aerodynamic and fluid-structure experiments and will also function as testing and set-up facility for instrumentation, data acquisition techniques and dynamic mountings shake-down tests. It will effectively decrease the non-testing occupancy time of the future larger, high quality flow open jet facility. This equipment is a key for experimental capabilities to conduct flow and structural deformation studies as well as assess flying qualities via hardware-in-the-loop simulations on small, flexible geometries. A scanning laser vibrometer, a time-resolved PIV system, a time-resolved VIC system, and other supporting equipment were received in the beginning of 2006 (two six-component balances are schedule for delivery this fall). Training and shakedown at UF-REEF with manufacturer representatives for the LV, PIV, and VIC systems were conducted in June 06. In attendance were faculty and students from UF-Gainesville, UF-REEF, and University of Alabama. Initial investigations evaluating and documenting spatial and temporal resolution are currently being conducted. Preliminary vibrations tests on a 60 cm MAV wing were performed with positive results. With cooperation from Dr. Shyy (Task 5) and Dr. Kurdila (Task 1), specifications were defined for dynamic mounting systems and sensors to enable experimental validation of both numerical investigations on low Re airfoils and hardware-in-the-loop investigations on vehicle control laws.

Control of Biologically-Inspired Morphing for Variable-Geometry MAV (Task 4)

A series of investigations considered the effect of morphing on flight dynamics. A principle aspect of these investigations was correlating the ways in which biological systems will morph to requirements for maneuvering. For example, the aircraft shown in Figure 1 utilized multiple-joint wing sweep that allows a range of configurations including symmetric and asymmetric planforms. This morphing is particularly valuable for sensor pointing missions in that the asymmetric sweep allows the vehicle to maintain angles of sideslip above 40 degrees so the sensor can point towards the target despite effects of urban crosswinds. An additional effect of the multi-joint configuration is the ability to maximize sweep of the outboard section so the vehicle can be stabilize and yet greatly decrease the turn radius which is needed for urban maneuvering. Along with vehicle design, analysis tools for understanding the modal properties of morphing wings are being developed. Both finite element models and modal filters will determine the actual shape of the wing while under loads, as happens in flight, so any resulting studies of aerodynamics will have the correct airfoil to model.

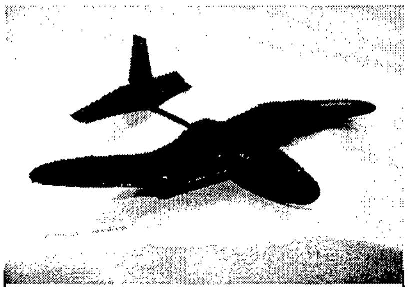

Figure 1, Biologically Inspired Morphing MAV Configuration

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Computational Aerodynamics of Flexible and Flapping Wings for Micro Air Vehicles (Task 5)

The state-of-the-art of the computational capabilities for micro air vehicle aerodynamics can be found in Refs. [1,2]. Laminar-turbulent transition in the MAV flight regime, with the Reynolds number of 10^4-10^5, is particularly challenging, and has yet been adequately addressed. This research represents a serious effort in investigating such transitional fluid dynamics. In order to gain better understanding of the fluid physics and associated aerodynamics characteristics, the (i) a Navier-Stokes solver, (ii) the e^N method transition model, and (iii) a Reynolds-averaged two-equation closure were coupled together to study the low Reynolds number flow characterized with laminar separation and transition. A new intermittency distribution function suitable for low Reynolds number transitional flow was formulated and tested. To support the MAV applications, both rigid and flexible airfoils were investigated. These airfoils have a portion of their upper surface mounted with a flexible membrane, using SD7003 as the airfoil configuration.

Our numerical simulations follow the set up of Ol et al. [3]. The geometry is based on the SD7003 airfoil, which exemplifies the laminar separation bubble layer (LSB) at low Reynolds number conditions. Based on freestream velocity and airfoil chord length of 20 cm the Reynolds number is 60,000. In the current transitional flow regime, though the Reynolds number affects the size of the laminar separation bubble, it does not place consistent impact on lift or drag. The gust exerts a major influence on the transition position, resulting in lift and drag coefficients hysteresis. It is also observed that thrust instead of drag can be generated under certain gust condition. For a flexible wing, self-excited vibration affects the separation and transition positions; however, the time-averaged lift and drag coefficients are close to those of the rigid airfoil. See Ref. [5] for results obtained under the sponsorship of the present grant.

Acknowledgment/Disclaimer

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the official policies or endorsements, either expressed or implied, of the Air Force Office of Scientific Research or the U.S. Government.

References:

[1]Shyy, W., Berg, M., and Ljungqvist D., "Flapping and Flexible Wings for Biological and MicroVehicles," *Prog. Aerospace Science*, 35, pp. 455-506, 1999.

[2]Lian, Y., Shyy, W., Viieru, D., and Zhang, B. N., "Membrane Wing Aerodynamics for Micro Air Vehicles," *Progress in Aerospace Sciences*, Vol. 39, 2003, pp. 425-465.

[3]Ol, M., McAuliffe, B. R., Hanff, E. S., Scholz, U., and Kaehler, C., "Comparison of Laminar Separation Bubble Measurements on a Low Reynolds Number Airfoil in Three Facilities," AIAA Paper 2005-5149, 23rd AIAA Applied Aerodynamics Conference, Toronto, June 6-9, 2005.

[4]Radespiel, R., Graage, K., and Brodersen, O., "Transition Predictions Using Reynolds-Averaged Navier-Stokes and Linear Stability Analysis Methods," AIAA Paper 91-1641, June 1991.

[5]Lian, Y. and Shyy, W., "Laminar-Turbulent Transition of a Low Reynolds Number Rigid or Flexible Airfoil,"AIAA 36th Fluid Dynamicvs Conference and Exhibit, June 5-8, 2006, Paper No. 2006-3051.

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Publications

P. Setlur, A. Behal, W. E. Dixon, and D. M. Dawson, "Adaptive Position and Orientation Regulation for the Camera-in-Hand Problem," Journal of Robotic Systems, Vol. 22, No. 9, pp. 457-473, (2005).

J. Chen, D. M. Dawson, W. E. Dixon, and A. Behal, "Adaptive Homography-Based Visual Servo Tracking for Fixed and Camera-in-Hand Configurations," IEEE Transactions on Control Systems Technology, Vol. 13, No. 5, pp. 814-825, (2005)

Lian, Y. and Shyy, W., "Laminar-Turbulent Transition of a Low Reynolds Number Rigid or FlexibleAirfoil,"AIAA 36th Fluid Dynamicvs Conference and Exhibit, June 5-8, 2006, Paper No. 2006-3051.

Albertani, R, B Stanford, J Hubner, and P Ifju, "Wind Tunnel System Characterization Applied to Powered Micro Aerial Vehicles with LAR Fixed Flexible Wings," 21th Bristol UAV Systems Conference, April 3-5, 2006.

Ifju, PG, B Stanford, M Systma, and R Albertani (2006) "Analysis of a Flexible Wing Micro Air Vehicle," 25th AIAA AMT/GT Conference, Paper 2006-3311, June.

D. Grant, M. Abdulrahim and R. Lind, "Flight Dynamics of a Morphing Aircraft utilizing Independent Multiple-Joint Wing Sweep, AIAA Guidance, Navigation and Control Conference, AIAA-2006-6505

K. Kaiser, N. Gans, S. Mehta, W. E. Dixon, "Position and Orientation of an Aerial Vehicle through Chained, Vision-Based Pose Reconstruction," *Proceedings of AIAA Guidance, Navigation, and Control Conference*, Keystone, Colorado, 2006, to appear.

R. Prazenica, A. Kurdila, R. Sharpley, and J. Evers, "Vision-Based Geometry Estimation and Receding Horizon Path Planning for UAVs Operating in Urban Environments," invited paper, *American Control Conference*, Minneapolis, MN, 2006.

Honors & Awards Received: None

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