Collaborative Center of Control Science

Kevin M. Passino
Director
The Ohio State University
Collaborative Center of Control Science
Welcome...

- Welcome to guests / colleagues!
- Thanks to AFOSR and AFRL-VA for funding, DAGSI for cost-share
- Thanks to Ms. Stella Rubia for 2007 CCCS Final Review assistance
- Resources:
  - Final Performance Report (leveraged funding, papers, etc.), Appendix: Slides of talks
  - Paper e-archive
Outline

• Logistics (agenda)
• Mission, objectives, team overview
• Financial (cost share, leveraging, synergies)
• Professional+technical presence
• Brief technical overview, connections to AFRL
• Concluding remarks
CCCS Mission

Collaborative Center of Control Science + AFRL-VA Control Science Center of Excellence = Team of World-Class Researchers for…

Developing innovative and practical solutions to challenging control science and technology problems of highest interest to the United States Air Force
Main Objectives

1. World-Class Center: CCCS + AFRL/VA Control Science Center of Excellence (CSCOE) (proximity facilitates collaboration, collaboration enhances USAF relevance)

2. Focus on key USAF topics (balance CSCOE and CCCS research)

3. Meeting AFRL *agile workforce* objectives (STW-21)

4. Leveraging / synergies with other programs
CCCS Executive Board (2006)

- **Dr. Don Paul**, Chief Scientist, AFRL-VA
- **LtCol. Scott Wells**, Program Manager, AFOSR
- **Dr. Marc Steinberg**, NAVAIR and ONR
- **Dr. Randy Zachery**, ARO
- **Dr. Kevin Wise**, Lead, UCAV Mission Management, The Boeing Company
- **Dr. Jim Buffington**, Technology Lead, Flight Control / Vehicle Management Systems, Lockheed Martin Aeronautics Company
- **Dr. D. Brett Ridgely**, Senior Manager, Dept. Autopilot Design, and GNC Tech. Director, Raytheon
- **Prof. Richard Murray**, Division Chair, Engineering and Applied Science, Caltech (head of Board)
- **Prof. Jonathan How**, Dept. of Aeronautics and Astronautics, MIT
- **Dr. Siva Banda**, Leader, Control Science Center of Excellence, AFRL-VA
- **Prof. Kevin Passino**, Director, CCCS, Dept. Electrical and Computer Engineering, OSU
Team=AFRL-VA COECS+

- Prof. Jose B. Cruz
- *Prof. Hitay Özbay*
- Prof. Ümit Özgüner
- Prof. Kevin M. Passino, Director
- Dr. Keith Redmill
- Prof. M. Samimy
- Prof. Andrea Serrani
- *Prof. Bruce Weide*
- *Prof. R.K. Yedavalli*
- Prof. Stephen Yurkovich
- Ms. Stella Rubia, Prog. Coord.

- Prof. Raúl Ordóñez (UD)
- *Prof. Marios M. Polycarpou (UC)*
- *Prof. Ali Minai (UC)*
- *Prof. Trevor Williams (UC)*
- *Prof. David Jacques (AFIT)*
- *Prof. Meir Pachter (AFIT)*

**DAGSI Cost share**

*italics=not funded in past year*
OSU/AFRL Collaborations…

• Visits, both ways… (seminars, meet with students, etc.), Six Month Reviews, Annual Reviews, and at conferences

• Proximity clearly helps

• Placements at AFRL+OSU (e.g., AFRL: Summer 2003, S. Waun and B. Moore; Summer 2004, K. Groves, J. Malone; Summer 2005, J. Parker, R. Schultz, OSU: T. Shima 2 days/week; Summer 2006, Pete Jankovsky)

• AFRL is clearly impacting university research (making more relevant, access to simulations/expertise)

• Universities are clearly impacting AFRL (e.g., joint publications, simulation code mods/expertise)

• Universities offering nice bridges between AFRL directorates (e.g., Sensors Directorate, J. Layne+)
Financial, Cost Share

- $500K/yr AFOSR + $500K/yr AFRL-VA, 6yrs
- Support, 2004-2007: 7 faculty, 1/5 res. scientist, software eng., 3 post-docs, 8 grad students, 1/4 prog. coord.
- Cost share:
  - 9 graduate students from Dayton Area Graduate Studies Institute (DAGSI), State of Ohio till end of third year ($450K); 4 graduate student stipends per year for each of the 3 years in the 2004-2007 contract period ($254K)
  - OSU cost share on graduate student tuition and fees on all graduate students (UC, UD similar) first three years ($450K), Univ. cost share second three years ($489K)
  - Program coordinator: OSU Dept. Elec & Comp Eng., 1/2 + DARPA MICA 1/4 (OSU EE Dept. $28K), ECE 3/4 ($34K)
  - OSU Dept. Elec & Comp Eng., CCCS physical space: Cooperative control test bed, CCCS offices/meeting area/visitor space ($25K)

Cost share total=$1.73M
Leveraged Funding (samples, see report)

- **NASA Glenn:** Active Noise Control in High Speed Jets Using Plasma Actuators, M. Samimy, $250K
- **Air Force/SIBR:** Development of High Frequency Flow Control for Mitigation of Aero-optic Distortion, Samimy, $333K
- **NASA Glenn:** Jet Noise Mitigation Using Plasma Actuators, M. Samimy, $330K
- **DAGSI/AFRL:** Flow Control Design, Samimy/Serrani, $182K
- **Intelligent Automation Corp (Navy/Army/SIBR):** Cooperative vehicle control and pursuit-evasion games, J. Cruz, 2 phase 1, $210K + $225K (2 phase 2 contracts)
- **AFRL:** Control and Navigation of Air Vehicles, R. Ordonez, $50K
Leveraged Funding (samples)

- **DARPA LAGR/NIST**: Learning for autonomous robots, Passino, $50K
- **General Dynamics**: Cooperative Operations in Urban Terrain (AFRL, COUNTER), Ozguner, $42K
- **AFRL (RASER)**: Robust data alignment, Ozguner, $33K
- **MRLets Technologies (sub. from AFRL-SN)**: Tracking of mobile systems and hospitality map concepts", U. Ozguner, $25K
- **Orbital Research (SIBR)**: Novel, biologically inspired integrative architecture for ultra-tightly coupled GPS/INS, U. Ozguner, $28K
- **DAGSI (other) and OSGC Fellowships…**
Funding/ additions/ leveraging, testbeds... (samples)

- **AFRL-VA**: Cooperative Control Testbed, $30K + $255K
- **AFRL-VA**: Flow Control Testbed, $50K
- **DURIP**: Equipment for Flow Diagnostics and Control, M. Samimy, $444K
- **NASA Glenn**: Flow control, J. DeBonis (time, not included in total)

**Leveraging total=$5.54M**

Leveraging + Cost Sharing Total=$5.54+$1.73=$7.27M>$6M
Funding, Synergies (samples)

- **DARPA MICA Program**: Strategies for Human-Automaton Resource Entity Deployment (SHARED), J. Cruz, PI, $2.4M
- **NASA Goddard**: Solar Radiation Pressure and Formation Control in Highly Elliptical Orbits, T. Williams, $410K
- **NIST**: Real-Time Control Systems, K. Passino, $200K
- **DAGSI/AFRL**: Development and Application of High Bandwidth and Amplitude Fluidic Actuators for High Speed Flow Control, M. Samimy, $210K
- **State of Ohio**: Ohio Center for Advanced Propulsion and Power (OCAPP), M. Samimy, $1,350K.

**Synergies total=$4.57M**
Impact?

- **UAVs:**
  - Second to third generation UAV research
  - MultiUAV simulation code, Matlab, Networked UAVs (AFRL improvements, NASA and AFRL-MN use)
  - Spawned ideas into research community, international

- **Flow Control:**
  - DAGSI/AFRL-NASA synergies
  - DURIP established world-class OSU flow control lab
  - NASA Glenn contributes significant time/expertise

- **RLVs:** Working on establishing collaborations and expanding funding in this area (e.g., NASA, NSF, DAGSI)
## Most Important Product: Students

<table>
<thead>
<tr>
<th>Name</th>
<th>Degree granted</th>
<th>Post-degree affiliation</th>
<th>Research Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andrews, Burton</td>
<td>MS</td>
<td>PhD program, Johns Hopkins</td>
<td>Ohio Space Grant Fellow</td>
</tr>
<tr>
<td>Baum, Michael</td>
<td>MS</td>
<td></td>
<td>DACSI</td>
</tr>
<tr>
<td>Bohm, Christopher</td>
<td>PhD</td>
<td>AFIT</td>
<td>USAF</td>
</tr>
<tr>
<td>Carahalos, Edger</td>
<td>MS</td>
<td>PhD program, OSU</td>
<td>DACSI, CCCS</td>
</tr>
<tr>
<td>Chen, Andy</td>
<td>MS</td>
<td></td>
<td>CCCS</td>
</tr>
<tr>
<td>Chen, Kangping</td>
<td>PhD</td>
<td></td>
<td>CCCS</td>
</tr>
<tr>
<td>Dagci, Ozgur Hasan</td>
<td>MS</td>
<td></td>
<td>DACSI</td>
</tr>
<tr>
<td>Dankwa, Boakye</td>
<td>MS</td>
<td>MS program, UD</td>
<td>AFRL, CCCS</td>
</tr>
<tr>
<td>Finke, Jorge</td>
<td>MS, PhD</td>
<td>Ford Dec, OSU</td>
<td>CCCS</td>
</tr>
<tr>
<td>Fiorentini, Lisa</td>
<td>PhD Student</td>
<td>PhD program, OSU</td>
<td>CCCS</td>
</tr>
<tr>
<td>Flint, Matthew</td>
<td>PhD</td>
<td>Alpha Tech</td>
<td>CCCS</td>
</tr>
<tr>
<td>Guhapadhy, Strain</td>
<td>MS</td>
<td>General Motors, Research and Development Laboratory</td>
<td>DACSI</td>
</tr>
<tr>
<td>Guinussoy, Sant</td>
<td>PhD Student</td>
<td>MIKES Inc, Turkey</td>
<td>CCCS</td>
</tr>
<tr>
<td>Greaves, Kevin</td>
<td>MS</td>
<td>Harris Corporation</td>
<td>DACSI, CCCS</td>
</tr>
<tr>
<td>Iankovskiy, Pete</td>
<td>MS</td>
<td>Procter and Gamble</td>
<td>CCCS</td>
</tr>
<tr>
<td>Jennings, Alan</td>
<td>MS</td>
<td>MS program, UD</td>
<td>DACSI</td>
</tr>
<tr>
<td>Jiang, Zheshen</td>
<td>PhD</td>
<td>PhD program, UD</td>
<td>DACSI, CCCS</td>
</tr>
<tr>
<td>Jin, Yan</td>
<td>MS</td>
<td>PhD program, UC</td>
<td>DACSI</td>
</tr>
<tr>
<td>Kanchanavally, Shreecharan</td>
<td>MS, PhD (UD)</td>
<td>Whirlpool, St Joseph, MI</td>
<td>CCCS</td>
</tr>
<tr>
<td>Kamakarpally, Carko</td>
<td>MS</td>
<td>PhD program, OSU</td>
<td>CCCS</td>
</tr>
<tr>
<td>Kiss, Zaher</td>
<td>MS</td>
<td></td>
<td>CCCS</td>
</tr>
<tr>
<td>L. (Chyntial) Xu</td>
<td>PhD</td>
<td></td>
<td>CCCS</td>
</tr>
<tr>
<td>Li, Weihua</td>
<td>PhD</td>
<td>OSU</td>
<td>CCCS</td>
</tr>
<tr>
<td>Li, Weidong</td>
<td>MS</td>
<td>PhD program, OSU</td>
<td>DACSI</td>
</tr>
<tr>
<td>Liao, Yan</td>
<td>PhD</td>
<td>PhD program, UC</td>
<td>DACSI</td>
</tr>
<tr>
<td>Lilly, Azad</td>
<td>MS</td>
<td></td>
<td>CCCS</td>
</tr>
<tr>
<td>Little, Jessica</td>
<td>MS</td>
<td>PhD program, OSU</td>
<td>DACSI, CCCS</td>
</tr>
<tr>
<td>Liu, Yanfei</td>
<td>PhD</td>
<td>Caterpillar Corp.</td>
<td>CCCS</td>
</tr>
<tr>
<td>Liu, Yu</td>
<td>PhD</td>
<td></td>
<td>CCCS</td>
</tr>
<tr>
<td>Maddula, Theju</td>
<td>MS</td>
<td></td>
<td>CCCS</td>
</tr>
<tr>
<td>McWilliams, George</td>
<td>MS</td>
<td></td>
<td>CCCS</td>
</tr>
<tr>
<td>Mitchell, Doug</td>
<td>MS</td>
<td>AFRL/MBR</td>
<td></td>
</tr>
<tr>
<td>Moore, Brandon</td>
<td>MS, PhD</td>
<td>Job search now</td>
<td>DACSI, CCCS</td>
</tr>
<tr>
<td>Ogras, Emel</td>
<td>MS</td>
<td></td>
<td>CCCS</td>
</tr>
<tr>
<td>Parker, Jason</td>
<td>MS</td>
<td>AFRL-SN, Wright</td>
<td>NSF Fellowship</td>
</tr>
</tbody>
</table>

## Research Support

<table>
<thead>
<tr>
<th>Name</th>
<th>Current affiliation</th>
<th>Research Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>DeBiasi, Marco</td>
<td>Temasek Laboratories, National University of Singapore</td>
<td>CCCS</td>
</tr>
<tr>
<td>Efe, Onder</td>
<td>TOBB University, Turkey</td>
<td>CCCS</td>
</tr>
<tr>
<td>Gil, Alvaro</td>
<td>Xerox Corp</td>
<td>CCCS</td>
</tr>
<tr>
<td>Kim, Kihwan</td>
<td>OSU</td>
<td>CCCS</td>
</tr>
<tr>
<td>Liu, Yong</td>
<td></td>
<td>CCCS</td>
</tr>
<tr>
<td>Yan, Peng</td>
<td>Seagate Research Center</td>
<td>CCCS</td>
</tr>
<tr>
<td>Tang, Zhijun</td>
<td>Eaton Corp., Eaton Innov. Center</td>
<td>CCCS</td>
</tr>
</tbody>
</table>

Much work finishing up with PhD students and Post Docs…
Professional and Technical Presence

- **Publications**: See performance report + web
- **Journal, Conf. Papers, Book chapters, Invited Sessions** (e.g., CDC’03 & CDC’04, Cooperative Control for Networked Uninhabited Autonomous Vehicles I&II, Passino-Sparks, CDC’05 papers)
- **CCCS part of “Control Research Laboratory”; long tradition of theory/experimentation, internationally recognized faculty in ECE, Aero, ME [more expertise available, smart structures, engine control, FDI, sliding mode control]**
International Reputation, Reach-out

• Control Research Laboratory (CRL)
  – 7 faculty + other depts + excellent sig. proc. group
  – Workshops/conferences/service (Ed., Gen./Prog. Chair)
  – Publications, books, honors (Fellows, Nat. Acad. Eng.)
  – >30 graduate students in ECE, facilities
  – Extensive curriculum (e.g., wide range of theory, cooperative robotics lab, decentralized control lab)

• Significant *additional* funded research... [>$7M]
  – Center for Automotive Research and...
  – Int. Trans. Sys. (CAR-IT), DARPA Gr/Urb Challenge
  – Many additional projects, visitors

AFOSR+AFRL-VA bought into a large, successful, and well-established program
CCCS Visitor Program / Seminar Series

• CCCS visitors/experts in main topical areas:
  – RLVs: J. Zhu, J. Hanson (NASA), D. Schmidt, A. Teel, A. Isidori

• International Visitors+Collaborators:
  – Air Force's Window on Sci.: Dr. Bernd Noack of Tech. Univ. of Berlin, Germany, Jan. 2004
  – O. Efe, TOOB Univ Sci Tech, Turkey
  – H. Ozbay, Bilkent U, Turkey
  – Tomonari Furukawa, U New South Wales, Australia
  – L. Rogondino, Univ. Pisa, Italy

• Visiting Scholar, US: Z. Jin (Caltech)
Reach-Out, Industry/Government

- **CCCS Annual Review** (85-100 attendees / year) helps with reach-out

- **Visitors:**
  - **Government:** AFRL (VA, SN, ENY, MNGN), NASA, DARPA, USAF Academy, AFOSR, NAVAIR, ARO, ONR/NAVAIR, AFIT, NRC, NSF, Southwest Research Inst.
  - **Universities:** UCLA, MIT, Caltech, Boston Univ., Texas A&M, Ohio Univ., Notre Dame, Univ. Michigan, Univ. Florida, Univ. Pisa,…
Reach-Out: Reviews/Overviews

- CCCS Review, Dr. Lyle Schwartz, Director, AFOSR, April 18, 2003
- CCCS Review, Dr. Belinda King, Program Manager, AFOSR, June 16, 2003
- CCCS Overview/poster, AFOSR SAB Review, 2003
- CCCS Overview in AFRL-VA SAB Review, 2003, 2005
- CCCS Research Summary, DAGSI Legislative Open House, State of Ohio Senate, Nov. 30, 2004
- CCCS Overview, AFRL-VA: Dr. Brendan Godfrey, Director, AFOSR, Oct. 2004; Gen. Lamy Aug. 2005
- CCCS Overview, AFOSR Corporate Board, Sept. 29, 2005
Lessons learned… challenges…

- **Flexibility difficult** for OSU and AFRL (e.g., in establishing new programs, de-emphasizing or eliminating others)
- **Director’s discretionary funds necessary** (e.g., to enhance visitor’s program, seed new initiatives)
- **Visiting scholar opportunities are significant**
2006 Executive Board Feedback

- Collaboration, Professional-technical presence, and leveraging maintained/developed as expected
- “Should pave way for next set of programs” (e.g., UAV work with C. Schumacher, RLVs)
- “Integrate UAV work” (past years, several ways)
- Increased visitor program (see report)
- Specific technical objectives: Continue to be on track as you will see…
Technical Overview

- Cooperative Control (40% budget)

- Aerodynamic Flow Control (40% budget)

- Reusable Launch Vehicles (20% budget)
Capability Focused Tech Investment

AFRL connections

CCCS/UAV
CCCS/RLV
CCCS/AFC
AFRL
Concluding Remarks

• CCCS finishing, second-third generation research, now a leader in aerospace control systems

• CCCS/AFRL-CSCOE collaboration went well, with clear evidence:
  – Technical program coordination/re-orientation
  – Serving as AFRL collaboration focal point
  – Publications (joint)
  – Cost share/leveraging, synergies with other programs
  – Visitors/seminars
  – Professional-technical presence