SUMMARY REPORT

MEETING No. 97
AEROSPACE CONTROL AND GUIDANCE SYSTEMS COMMITTEE

Harvey's Resort
Lake Tahoe, Nevada

1-3 MARCH 2006

Compiled by:

Dave Bodden
Vice Chairman
March 15, 2006

Table of Contents

4.0 GENERAL COMMITTEE TECHNICAL SESSION

4.1 Government Agencies Summary Reports

4.1.1 US Army – No Report

4.1.2 U.S. Navy

4.1.2.1 NAWCAD S&T - Marc Steinberg

Retrofit Reconfigurable Control Flight Test on an F/A-18C. The retrofit reconfigurable control system works by modifying the pilot inputs (I.e., stick and rudder commands) to make the aircraft behave as expected (as close to normal as possible) even in the face of disturbance and axis coupling that can result from actuator failure or aircraft damage. There are three major parts to the system: 1) a reference model of desired aircraft response, 2) a system model of how the aircraft is actually responding, 3) an optimal controller that adjusts gains on-line to make the actual response track the desired response. The system has been through non-real-time batch simulation testing, software only piloted simulation, hardware-in-the-loop simulation testing, and a flight test program. Flight testing has been restricted to a low dynamic pressure part of the envelope at altitude to ease flight clearance requirements related to software safety. For the software only simulation, the retrofit system modified both the pilot stick and rudder commands. Since the flight test hardware has the limited computational resources of a 1750A processor, an examination of using only pilot stick modifications was undertaken. It was concluded that a meaningful demonstration could be made using a stick-only architecture. The failures under consideration were locking a surface at an offset from trim. The ranges were 30 deg. for the aileron and 6 deg. for the stab. The test maneuvers were doublets, attitude captures, and tracking. The F-18 A/C configuration was clean except for a center-line tank. Both cruise and powered approach points were examined. Flight test data showed the aircraft behavior for the 30 deg. aileron failure for the case without retrofit control. As the failure comes in, it takes a certain amount pilot effort to maintain wings level flight. It also takes the pilot a considerable amount of time to trim the aircraft the best that he can. Once trimmed, the pilot initiates some pitch doublets. A lot of coupling in yaw and roll can be seen and this is accompanied by a lot of activity in the pilot inputs to compensate. A second set of flight test data was shown for the 30 deg. aileron failure with retrofit control. Once trimmed, the pilot initiates some pitch doublets. Some coupling in yaw and minor coupling in roll is still present, but much reduced from the retrofit off case. The retrofit inputs can be seen to be actively compensating for the aileron failure. The improved response when using the retrofit controller translates into improved HQRs. Also, the improvement is on par with that which was seen in the HILS testing. However, this was a limited flight test only.

4.1.3 US Air Force

4.1.3.1 Air Force Research Lab – Dave Doman

The Control Science Center of Excellence at the Air Force Research Laboratory is focused on control related research in three areas: cooperative control of unmanned air vehicles, fault tolerant autonomous space access & prompt global strike and aerodynamic flow control. The current research in UAV cooperative control is focused on providing the ability to and to operate in cluttered urban terrain, identify and tag targets for separate shooters and communicate with special operations personnel on the ground. Flight tests utilizing a small and micro-UAV are scheduled for CY06 and will demonstrate the ability of multiple UAVs to accomplish the objectives outlined above. Research in space-access has focused on providing fault-tolerant autonomous terminal area energy management and autonomous landing capabilities for reentry vehicles. Hardware-in-the-loop simulations were conducted using the X-37 ASIL facility at Boeing this year and demonstrated the ability of the system to operate in real time on the X-37 flight computers. Work has continued on the development of a dynamic model of an airbreathing scramjet powered vehicle that includes interactions between the aerodynamics, propulsion system, structure and thermal environment. The model is being used to identify feasible configuration modifications that can make such vehicles more amenable to feedback control techniques of any type. In the area of prompt global strike, the group has been developing adaptive guidance techniques for CAV type of vehicles that can compensate for the adverse effects of ablation that occurs during reentry. Work has continued in the area of aerodynamic flow control. Identifying order reduction methods for fluid dynamic equations that work well in conjunction with feedback control has been the primary focus of this effort.

4.1.4 NASA

4.1.4.1 Dryden Flight Research Denter – Pat Stoliker

While the Aeronautics Mission Directorate continues to formulate the content for the FY07 program, Dryden Flight Research Center works to complete some ongoing flight projects. The F-15 Intelligent Flight Control System project has brought learning neural nets into the flight regime adapting to simulated failures. An UAVSAR pod is being developed to provide the capability to fly accurate repeatable trajectories for Earth Science observations. This capability will be demonstrated on a GIII aircraft for transition to an UAV. Sonic boom mitigation studies continue using the F-18 aircraft to help define boom signatures that would be accepatable for supersonic overland flight. Dryden will be participating in the CEV through the execution of the Launch Abort System testing.

4.1.5 FAA

4.1.5.1 FAA Tech Center - Stanley Pszczolkowski

In FY05 the Federal Aviation Administration (FAA) met over 90% of its goals. Some current FAA organizational and technical activities and events include: contract negotiations with both the controller and the engineer/technician unions, plans for significant controller recruitment and training, a declining Aviation Trust Fund balance (the fund provides a significant portion of the FAA budget) and the centralization and consolidation of functions and processes. Additionally, the Technical Center took delivery of a new project aircraft – Bombardier Global 5000.

The Joint Program and Development Office (JPDO) announced 8 key Next Generation Air Transportation System (NGATS) capabilities, requested acceleration of Automated Dependant Surveillance Broadcast implementation and will release drafts of a concept of operations and an enterprise architecture for constituent agency review. The FAA is working cooperatively with the JPDO to determine the impact of NGATS on the National Airspace System processes, plans, budget and architecture. Roadmaps are under development in 7 major areas (e.g. communication, navigation) that include assumptions, drivers, system evolution, decision points, and cost forecasts and profiles.

4.2 Research Institutions, Industry and University Reports

4.2.1 Research Institutes and Companies

4.2.1.1 Athena Tech, Inc. – Vlad Gavrilets

Athena Technologies is a leading supplier of integrated flight control, navigation, and vehicle management systems to a number of UAV production programs. Shadow 200 Tactical UAV by AAI Corp., achieved 60,000 operational flight hours in a year.

Athena Technologies performs active research to improve reliability & survavibility of unmanned aircraft. Under DARPA damage tolerance program and IR&D funding we are developing a very low-cost, triple-redundant avionics system, and a control adaptation algorithm aimed to regain performance necessary for successful completion of a mission and autonomous vehicle recovery.

In another DARPA program, we designed and extensively tested in simulation a flight control system for SkunkWorks morphing aircraft. Athena's patented Feedback LTI'zation design process yields an autopilot, which seamlessly handles rapid variation of open-loop dynamics during wing folding.

4.2.1.2 Barron Associates – Dave Ward

Barron Associates, Inc. reported on a number of recent and ongoing controls projects, including:

- <u>Retrofit Reconfigurable Flight Control for F/A-18</u>: Recent flight tests demonstrated the ability of a "wrap-around" system to compensate for unforeseen failures.
- <u>Adaptive Control of Morphing Aircraft</u>: Adaptive control is being applied to aircraft with changing wing shapes to ensure stability and performance during wing morphing.
- <u>High-Speed Supercavitating Torpedo</u>: Adaptive Backstepping and Receding-Horizon controllers are being developed for a supercavitating torpedo.
- <u>UAV Upset Recovery Control System</u>: Reinforcement-learning-based path planning and control are being developed to prevent and recover from UAV upset conditions. Of particular interest are shipboard landing applications.
- <u>Adaptive Guidance, Control, and Trajectory Generation for Reusable Launch Vehicles</u>: Recently completed HIL demonstrations showed the merit of real-time trajectory shaping for TAEM and A/L segments fo RLV flight.
- <u>CAV Trajectory Reshaping</u>: Simulation studies demonstrated the benefits of trajectory reshaping to compensate for uncertain aerodynamics, including those caused by ablation, and provide precision targeting.
- <u>High-Speed Vertical Lift Simulation Development</u>: Barron Associates is developing publicly-releasable Matlab/Simulink models of high-speed vertical lift aircraft with innovative effectors. This simulation will include ship motion and airwake and is designed for controls researchers.
- <u>Adaptive Control of Synthetic Jet Arrays with Unknown Nonlinearities</u>: Virtually shape airfoil at low angles of attack and control flow separation at high angles of attack. Goal is wind-tunnel demonstrations.

- Generic Software Wrappers for Runtime V&V: Software wrappers monitor safety-critical systems and handle switching to reversionary modes when the software or algorithm fails.
- Autonomous Health Monitoring System for Hybrid Propulsion Vehicles
- Integrated Control and Diagnostics for Marine Diesel Engines
- Automated Updating of Simulation Data Tables

4.2.1.3 Calspan – Eric Ohmit

Calspan celebrated its one year anniversary in February. Over the last 6 months Calspan's Learjets have been very busy supporting the AAR program. The AAR program is sponsored by AFRL. Participating organizations include Boeing, Northrop-Grumman, Rockwell Collins and Titan. The Lear completed two previous flight tests in 2004 in Buffalo and 2005 at China Lake. In early 2006, the Boeing FCC was integrated in the Lear in anticipation of supporting closed loop testing of the system in August 2006. This closed loop testing will have the safety pilot fly the aircraft into position, engage the AAR control laws and the system will maintain position. Future testing in 2007 will include transitions into observation, pre-contact, contact and breakaway positions.

The installation of an autothrottle into the Learjet in support of the AAR program has opened other opportunities to perform UAV testing. The AFTPS performed a Test Management project during October 2005 demonstrating a low cost closed loop AAR approach by demonstrating station keeping within 2 feet and refueling maneuvers with a C-12 simulating the refueling task. The Lears also supported training at both the AF and Navy Test pilot schools.

The Lear has also been selected to support the AFRL sponsored Sense & Avoid program. Northrop Grumman is the prime on this contract with Defense Research Associates providing the Camera system, detector and tracker. This system will autonomously detect and avoid both cooperative and non-cooperative targets. Head on, overtaking and cross track intrusions scenarios will be tested with a King Air and KC-135 aircraft. This program will fly in the 4th quarter of 2006.

The TIFS aircraft will support a Boeing Proprietary Advanced Control System flight test program in 2006, this will be the second session of this program.

Calspan is developing a 3rd Variable stability Learjet to support future uses of the aircraft including Upset Recovery Training and Test Pilot School Operations. First flight of this aircraft will occur this year and the aircraft will be put to work soon thereafter.

In October 2005 Calspan's Transonic Wind Tunnel inaugurated operation of our Free To Roll (FTR) rig. This system frees the roll rotation degree of freedom to support abrupt wing stall studies and roll damping derivative determination. Transition from the FTR to normal S&C testing is rapid and provides significant flexibility during testing.

4.2.1.4 Hoh Aeronautics, Inc. – Dave Mitchell

HAI has just completed a research effort for the Army's Aviation Engineering Directorate to develop metrics for verification & validation of helicopter simulators. This work included evaluation of the Maximum Unnoticeable Added Dynamics (MUAD) envelopes. A piloted simulation gathered data that show the existing MUAD envelopes to be overly conservative. Alternative Allowable Error (AE) envelopes were created from the simulation results. The AE envelopes are dependent on the dynamics of the aircraft, making their application in a generic specification difficult at best. The final report for this work has been delivered. Results will be reported in an AIAA paper this summer. On a separate topic, HAI has completed negotiations with Chelton Flight Systems to develop, market, and manufacture HAI's HeliSAS autopilot. HeliSAS was the result of a NASA Phase II SBIR. The new product will be marketed as the Chelton HeliSAS Digital Helicopter Autopilot.

4.2.1.5 Institute of Flight Research at DLR – Joerg Dittrich

A couple of on-going and new projects at the Insitute of Flight Systems were shown, including Inflight-Wake-Vortex-Simulation with the ATTAS aircraft, the Electronic Flight Control System Rig (EFCS) which can be used to test new control surface actuators in a real time simulation, flight control concepts for Blended Wing Body aircraft configurations, integration and evaluation of tactile feedback sidesticks into DLR's research helicopter FHS and helicopter slung load operations.

In the field of UAV research, simulations of self-organizing formation flight for aircraft using classical swarming rules were shown. A brief introduction of the UAV rotorcraft maxiARTIS was given, extensions of the identified flight mechanics models to include ground interaction were made. Concluding the presentation, a video of the now operational coupled hardware-in-the-loop simulation for Manned-Unmanned-Teaming Scenarios was shown. In this simulation environment, the ARTIS rotorcraft UAV can be controlled directly from the cockpit of DLR's FHS helicopter.

4.2.1.6 Moscow Aviation Institute – Alexander Efremov

There are considered a number of perspective researches and some results developed in flight dy-namics and control area.

− flying qualities evaluation in ground-based simulation.

There are discussed: the role of methodology for fulfillment of ground-based simulation, necessity in definition of task performances (desired and adequate) and simultaneous evaluation of flying qualities in longitudinal and lateral channels, the role of aircraft dynamics and input signal model-ing. There is demonstrated the agreement between pilot ratings received in ground and in-flight in-vestigations for a number of piloting tasks.

− extremely short and take-off landing.

There are exposed problems in dynamics of landing in such conditions: reversible control in longi-tudinal channel and unsatisfactory flying qualities in lateral channel and practical absence of infor-mation support for pilot. There is shown the solution of these problems by aircraft augmentation and installations of display additional metrics synthesized on aircraft board allowed to realize the landing with high accuracy.

− MAV control and designing.

The dynamic peculiarities of such vehicles are the considerable influence of propeller and low Reynold's numbers on aerodynamic characteristics, high increase of zeros and poles in longitudinal mo-tion in comparison with aircraft flying with higher velocities.

There are determined the ways for improvement of flying qualities of such vehicles by augmentation.

− modeling of pilot behavior characteristics in manual control.

There is given analysis of pilot control response characteristics calculated with help of well-known models with results of experimental investigations. There are considered the reasons of disagree-ment in low and crossover frequency ranges and are discussed the other approaches to the model-ing, in particular based on semi-soft modeling.

4.2.1.7 Robert Heffley Engineering – Ron Hess for R. Heffley

This presentation describes our main ongoing project during 2005-2006, the development of pilot behavioral models for flight operations near ships. This work described is part of an SBIR Phase II project sponsored by the Naval Air Warfare Center AD at Patuxent River, Maryland. These behavioral models consist of a set of multi-axis, multi-segment representations of the human pilot that can simulate the launch and recovery of several diverse types of US Navy aircraft, i.e., the F/A-18 Hornet, MV-22 Osprey, AV-8 Harrier and SH-60 Blackhawk. Each simulation can be driven by a variety of disturbances, including CFD airwake, turbulence and ship motion. The ships from which the aircraft operate are modeled in the Navy Control Analysis and Simulation Test Loop Environment (CASTLE). The aircraft and ship combinations are the F/A-18 and a CVN (Nimitz-class carrier), the SH-60 and a DDG (Arleigh Burke-class guided missile destroyer with Flight IIA deck layout), and the AV-8 or MV-22 and an LHA (Tarawa-class amphibious assault carrier).

4.2.1.8 SAIC – Roger Burton

IDEAS was developed by SAIC in response to Navy requirements to reduce the time from flight test to updating the aerodynamic characteristics of an aircraft simulation. The overall program objective was to improve the Navy's system identification capabilities, streamline data analysis process and create a uniform environment for flight data analysis. IDEAS was developed on a high performance workstation using existing and off-the-shelf programs and employed a data-driven, client/server model and was coded with modern, portable software methods.

The IDEAS structure consists of an information gateway that provides a user interface, data management capability and analysis tools. Thus IDEAS contains a database management system that provides for maneuver segmenting and analysis grouping. A general pre-processing tools (DATPAR) provides for basic math operations, unit conversions, wild point editing, filtering, smoothing, differentiation, axis rotation / translation and signal time synchronization. In addition, DATPAR provides specialized flight test tools that allow for total force and moment aerodynamic reconstruction and sensor measurement translation. Parameter identification tools include kinematic consistency analysis (NAVIDNT), equation error identification (Athena) and non-linear least squares output error identification (LSIDNT). NRTPID algorithms provide for overall control, data consistency and maneuver detect with multiple cooperating rules. IDEAS also contains a full six degree of freedom simulation.

The IDEAS parameter identification model provides a single, generic model used to represent aerodynamics, engine, gear, etc. This identification model can be an incremental model to existing system or total model. One-time source code change incorporates the IDEAS model into the existing simulation.

IDEAS has been applied to numerous aircraft including, S-3B, C-130MTT, PC-7 Mk II, F-18C, UH-1N, Vigilante, AH-1W and Guardian. The example presented was for the S-3 Operational Flight Trainer Flight Fidelity Upgrade Program. Flight test data analyzed included 360 degree heading changes, all axis doublets and 3-2-1-1manuvers. Analysis was completed and presented for instrumentation errors and aerodynamic coefficients. An example time history comparison was presented demonstrating improvements in simulation fidelity.

In summary, IDEAS been demonstrated to be flexible adapting to multiple aircraft/instrumentation systems and improving the fidelity of simulations.

4.2.1.9 Systems Technology Inc. – David Klyde

A number of improvements have been made to VDANL, STI's ground vehicle computer simulation application, primarily under a recent contract to the US Army TACOM. Improvements include: enhanced tire model with asymptotic fits of tire data; multi-axle vehicles and trailers – previously limited to 2 axles now up to 10 axles; multiple wheels/tires per axle side; brake thermal model; enhanced bump stop model; damper/bump stop track widths; and speed sensitive steering power assist model. In ongoing work for the Federal Highway Administration (under a subcontract to Battelle), many of these new features have been validated using a tractor-trailer model. The model was developed using parameters for a tractor-trailer combination that was fully instrumented and tested at the National Highway Traffic Safety Administration's (NHTSA) Vehicle Research and Test Center (VRTC). The parameter determination, conducted on behalf of NHTSA by several organizations, and the test results from the VRTC testing were used to develop a VDANL parameter set and to evaluate the model using a wide range of vehicle tests. The VRTC conducted this testing to develop a parameter set for and to evaluate the vehicle dynamics software for the National Advanced Driving Simulator. This software is called NADSdyna. The results of their evaluation have been published by the SAE and were thus used as basis for comparison for the VDANL evaluation. The STI pilot-in-the-loop flight simulator has been developed as an additional research tool to strengthen the capabilities of STI in the area of real-time flight simulation and pilot-vehicle system identification. The McFadden feel system is a key component in that it provides key proprioceptive cues that enhance the fidelity of the simulation. The McFadden Series 292A 2-axis (pitch and roll) fighter stick was selected for a number of reasons. First, the device can provide a wide range of control force characteristics that are encountered in real aircraft including; linear and nonlinear spring gradients, damping, breakout, deadband, coulomb friction, and travel limits. Second, these characteristics can be used in any combination and be changed "on the fly." McFadden Feel System Simulator Pilot Computer Projected Display

The simulator shown in Figure 1 is a win32 console application designed to interface with Matlab™ for data input and output. It is capable of simultaneously simulating the time response to arbitrary input of as many linear transfer function systems as computer memory will allow. Initialization data for this program is one or more Matlab™ files, each containing a state-space quadruple representation of a linear dynamic system. Included in this file is information the simulator uses to attach its input and output devices to the input and output states being simulated. The current PC-based simulator features: •

- Linear airframe equations of motion driven by state space input files;
- Multiple aircraft input files;
- Nonlinear software rate limits and actuator models;
- Data recording of unlimited output states;
- Vehicle dynamics that update at 120 Hz and graphics that update at a minimum of 30 Hz; and
- Texture-mapped PC graphics with a superimposed head-up display that supports pitch and roll axis tracking tasks.

Recent Activities at Systems Technology, Inc.

Figure 1: STI Simulator with McFadden Control Loader and Projected Display

During a run, the pilot is presented a HUD superimposed on a suitable 3-D environment (see Figure 2). At the end of a run, the input vectors and output time responses of all simulated systems are saved to a Matlab file for future analysis. The simulator uses tracking bars on the HUD to support sum-of-sines and step and ramp discrete tracking tasks. These tasks provide the high gain environment that is required to induce unfavorable pilot-vehicle interactions such as PIO. The discrete tracking task is particularly useful for investigating the effects of rate limiting. Changes to the controlled element dynamics can be introduced during a run to simulate system “failures” or unintended mode shifts.

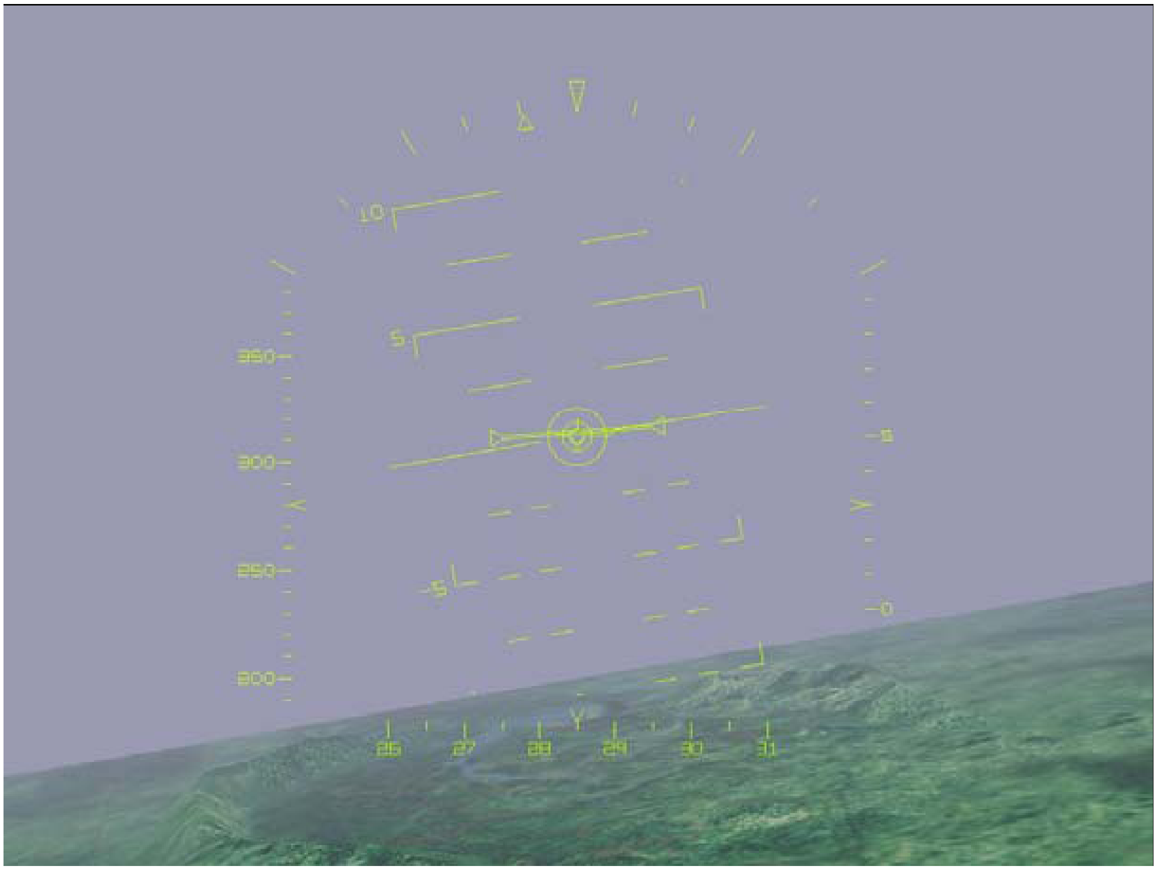


Figure 2: Projected Head-Up Display

4.2.2 Universities

4.2.2.1 John Hopkins APL – Uday Shankar

This presentation discusses the GNC research at the Guidance, Navigation, and Control Group at the Johns Hopkins University Applied Physics Laboratory.

Johns Hopkins University Applied Physics Laboratory (JHU/APL) is one of five institutions at the Johns Hopkins University. APL is a not-for-profit research organization with about 3600 employees (68% scientists and engineers). Our annual revenue is on the order of $670m. The Air and Missile Defense Department is a major department of APL involved with the defense of naval and joint forces from attacking aircraft, cruise missiles, and ballistic missiles.

The major thrust of the GNC group is the guidance, navigation, and control of missiles. Our mission is to integrate sensor data, airframe and propulsion capabilities to meet mission objectives. We are involved with GNC activities in the concept stage (design, requirements analysis, algorithm development), detailed design (hardware, software), and flight test (pre-flight predictions, post-flight analysis, failure investigation).

The Advanced Systems section within the GNC group is involved with several projects: boost-phase interception of ballistic missiles, discrimination-coupled guidance for midcourse intercepts, Standard Missile GNC engineering, Kill Vehicle engineering, integrated guidance control, swarm-on-swarm guidance, and rapid prototyping of GNC algorithms and hardware.

We discuss two examples. The first is the swarm-on-swarm guidance. This framework can be used to solve guidance problems associated with several missile defense scenarios. The second is the application of dynamic-game guidance solutions. This has applications in terminal guidance of a boost-phase interceptor and the discrimination-coupled guidance of terminal homing of a midcourse interceptor.

We discuss in more detail the problem of terminal guidance of a boost-phase interceptor. The problem is formulated and a closed-form solution is offered.

4.2.2.2 Texas A&M - Raktim Bhattacharya

The functionality of embedded systems is evolving from static dedicated systems to dynamic systems that adapt in real time to changes in the controlled system and its environment. The paradigm for system design and implementation is also shifting from a centralized, single processor framework, to a decentralized, distributed processor implementation framework.

Distribution and decentralization of services and components is driven by the falling cost of hardware, increasing computational power, increasingly complex control algorithms and development of new, low cost micro-sensors and actuators. Distributed, modular hardware architecture offers the potential benefit of being highly reconfigurable, fault tolerant and inexpensive. Modularity can also accelerate the development time of products, since groups can work in parallel on individual system components. These benefits come with a price; the need for sophisticated, reliable software to manage the distributed collection of components and tasks.

Reliability is an important issue in real-time embedded systems. The rising complexity in real-time systems is causing the verification gap to expand exponentially. Verification gap is the gap between the testing that is conducted and the required testing that needs to be done. Consequence of the expanding gap is lower reliability of products. This limits ability to grow and innovate as resources are engaged in fixing errors in the field. This has high cost implications as it is more expensive to fix problems in the field.

The presentation addresses reliability of real-time systems by guaranteeing robustness with respect to system uncertainty, communication uncertainty, computational uncertainty and uncertainty associated with product development.

The presentation concludes with a summary of other research activities. This includes formulation of atmospheric re-entry problems as a receding horizon control problem, a toolbox in MATLAB that allows rapid development of nonlinear trajectory generation. Other research activities are listed at www.aero.tamu.edu/people/raktim.

4.2.2.3 UC Irvine – Ken Mease

Presentation was cancelled.

4.2.2.4 University of Colorado – Dave Schmidt

The MAE department has grown significantly since it was founded in January 1999, and now has about 150 undergraduate and 100 graduate majors. The faculty is currently comprised of six tenured or tenure track and two non-tenure track faculty, with another new faculty member to join this summer. Areas of research expertise include solid and fluid mechanics, aerodynamics, atmospheric modeling, dynamic systems and control, thermodynamics and energy conversion, and design. Two specific project were highlighted. The first was an Army-funded multidisciplinary study of the station-keeping performance of a large high-altitude airship. The second was a student project addressing autonomous navigation and guidance of UAVs, which includes the development and in-flight demonstration of a fully autonomous air vehicle.

4.2.2.5 University of Kansas – Richard Colgren

This summary report described the design of two aircraft. The first aircraft is a full-scale UAV intended to perform scientific missions in Polar Regions. The second aircraft is a half-scale stability and control demonstrator intended to prove the feasibility of the full-scale Polar UAV.0

The Polar UAV was developed and designed for a CReSIS research program. CReSIS (Center for Remote Sensing of Ice Sheets) is a national research program that intends to study the mass balance of polar ice sheets and its potential impact on global sea levels. CReSIS requested proposals for an air vehicle to perform the mission of observing the thickness and motion of the ice sheets. This mission necessitates long flights and substantial risk. These factors suggest that unmanned aircraft will be a good alternative to a human-piloted aircraft. Therefore, the aim of this project is to develop an UAV that will meet the mission requirements both in the Antarctic and Greenland.

Before the start of this project, The University of Kansas aerospace engineering students developed a conceptual design of a polar UAV in 2002. This design concept has been substantially modified using updated requirements then defined to a higher level of detail. This design project delivers a complete preliminary design of the full-scale Polar UAV and a complete detailed design of a half-scale demonstrator.

The design of the UAV concept for use by the CReSIS center has evolved significantly from its rough state at the beginning of this project. The Cryohawk design meets a well-defined mission statement and operational profile. The design was taken through a class 1 and class 2 weight sizing, a new performance matching, and a full set of aerodynamic calculations. Then a stability and control analysis was completed. The design meets the CReSIS center's needs.

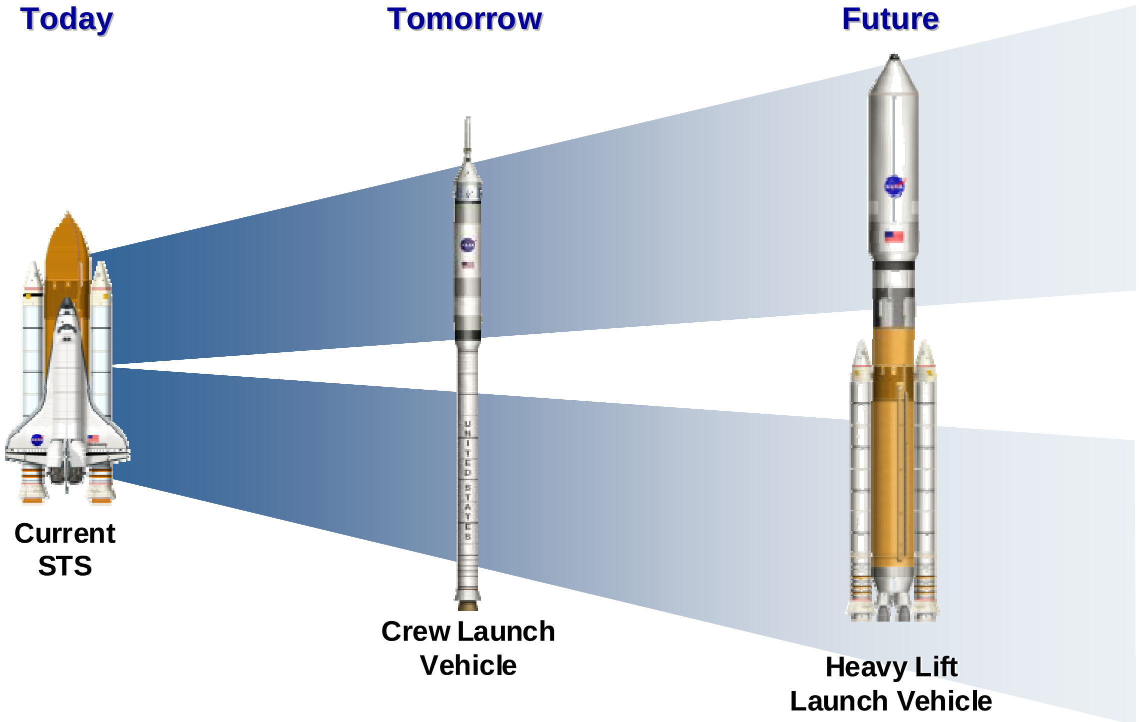
On top of the accomplishments made toward furthering the design of the full size UAV, a 50% scale flight test demonstrator was successfully designed. A design and AAA analysis was done on this scaled aircraft. This aircraft is being manufactured and will be completed before the end of the Spring 2006 school semester. This vehicle will serve as a useful tool in future academic endeavors.

Lastly, successful cooperative relationships have been established. This project successfully expanded the envelope for graduate design/build/fly class projects. There is now an established avenue for interaction with the AE 510 undergraduate manufacturing class and with the Engineering Technology Program at Pittsburg State. There are other relationships that need to be built further, such as those with Kansas State University and Embry-Riddle, as well as other classes and departments at The University of Kansas. All of these accomplishments have been combined into a successful and growing program.

5.0 SUBCOMMITTEE B – MISSILES AND SPACE

5.1 "Launch Vehicles for NASA's Exploration Program," Donald Sauvageau, ATK Thiokol

President George W. Bush set the bold vision and charter for NASA to take the next steps in the exploration of our solar system. This exploration initiative provides unique opportunities for the space community to work closely with NASA to accomplish tasks that have not been matched since the Apollo era. In order for the NASA exploration initiative to be successful, it must come up with approaches that are affordable and sustainable, within a realistic schedule and budget environment, and are consistent with the overall projections contained in the President's exploration vision announcement. In order to have a sustainable and affordable program, the aerospace industry team, which includes NASA and contractors, must concentrate their limited resources on developing hardware that specifically accomplishes the overall exploration mission and minimizes the investment in the launch vehicle by using hardware that already exists or can be easily adapted to support the overall exploration vision.



Launch vehicles with significant lift capability can be configured using elements from the current Space Transportation System (STS). By taking advantage of the current STS propulsion elements, capabilities can be provided to deliver up to 300,000 lb of cargo to low earth orbit. There is also the potential to configure STS elements into a complimentary crew launch vehicle (CLV) that could lift a Crew Exploration Vehicle in excess of 40,000 lbm to low earth orbit. All STS-derived launch vehicles take advantage of the flight proven, human rated propulsion elements, thus ensuring early successful demonstrations of highly reliable launch vehicles. The STS-derived configurations offer a logical evolutionary path of increasing capabilities that could support and enable the

NASA Exploration Initiative, providing significant flexibility in the formulation of architectural approaches.

5.2 “Autonomous Navigation for Deep Space Missions,” Shyam Bhaskaran, JPL

Standard navigation for deep space missions uses a combination of radiometric (Doppler and range), interferometric (Delta Differential One-way Range) and optical data types to achieve mission objectives. These data are processed on the ground to obtain orbit solutions which are then used to plan maneuvers which are sent up to the spacecraft. For various reasons (e.g., increasing science return, more challenging mission concepts, decreasing cost), it is desirable to automate some or all of the navigation functions and place them on the spacecraft. Such a system, based on optical data types, has been developed and used for limited applications on several missions. The basic elements of the optical autonomous navigation (Autonav) system are: image processing to reduce image frames to get the basic angular information, orbit determination to combine the data using a batch sequential processor and estimate the spacecraft’s trajectory, maneuver planning to compute and execute course corrections to achieve mission targets, and an executive which interfaces Autonav with the rest of the spacecraft. The three missions which used this system are Deep Space 1, STARDUST, and Deep Impact. Deep Space 1 used Autonav for the cruise and comet flyby phases of the mission. STARDUST used it primarily to track the comet Wild 2 during its flyby. Finally, Deep Impact used Autonav to impact the comet Tempel 1 using one spacecraft while imaging the resultant impact crater using another.

5.3 “The Inertial Stellar Compass,” Tye Brady and Sean Buckley, Draper Laboratory

Draper’s Inertial Stellar Compass (ISC) is a real-time, miniature, low power stellar inertial attitude determination system, composed of a wide field-of-view active pixel sensor (APS) star camera and a microelectromechanical system (MEMS) gyro assembly, with associated processing and power electronics. The integrated APS and MEMS gyro technologies provide a 3-axis attitude determination system with an accuracy of 0.1 degree at very low power and mass. The attitude knowledge provided by the ISC is applicable to a wide range of Space and Earth science missions that may include the use of highly maneuverable, stabilized, tumbling, or lost spacecraft. Under the guidance of NASA’s New Millennium Program’s ST-6 project, Draper is developing the ISC. Its completion and flight validation will represent a breakthrough in real-time, miniature attitude determination sensors. The presentation describes system design, development, and validation activities in progress at Draper.

5.4 “Discrete Thruster Control of Precision Guided Munitions,” Gary Balas, University of Minnesota

Side-directed discrete thrusters are an attractive maneuver mechanism for several projectile applications. They provide quick reaction capability for terminal guidance where acquisition is delayed until very short ranges. They also provide significant maneuver authority in low velocity trajectories where the equivalent size of aero control surfaces would have to be unrealistically large. But along with their inherent advantages for projectile guidance come several design challenges.

This talk describes two discrete side-directed thruster systems, the Saab-Bofors STRIX terminally guided mortar munition and the ATK PGMM precision guided mortar munition, and the control challenges associated with them. A brief overview of the projectile equations of motion are presented and parameters associated with an example system. The issue of controllability of these discrete thrust munitions is discussed in relationship to bang-bang minimum fuel optimal control and impulsive dynamical systems. Due to the theoretical challenges associated with determining the controllability of these systems, initial investigations focussed on a naive control strategy. Simulation results are shown for di®erent numbers and magnitude of the discrete thrusters. The presentation concludes with a list of references on the topic.

6.0 SUBCOMMITTEE C – AVIONICS AND SYSTEM INTEGRATION

6.1 “Fail-Passive Electronics for Safety Critical avionics,” Bob Yeh, Boeing

The concept for Fail-Passive Electronics for Commercial Airplane Avionics systems is illustrated by the 777 Fly-By-Wire (FBW) computers. This presentation begins with the fundamental concept of dependability developed by the dependability and fault-tolerance technical community. It is followed by the 777 FBW design philosophy for safety covering the common mode failure/single point failure, and the dissimilarity.

The command/monitoring concept for the self-monitoring computing channel of 777 Primary Flight Computer (PFC) is elaborated. The closed loop (monitoring) concept of 777 Actuation Control Electronics (ACE) is depicted. It is concluded by the concept and feature for fail-passiveness of the 777 PFC-ACE data paths.

6.2 “Flight Demonstration of Next Generation Air Transportation System Capabilities,” Carl Jezierski

The integrated architecture for 2025, the Next Generation Air Transportation System (NGATS), is envisioned to be “One in which pilots fly 4-D de-deconflicted trajectories that ensure safety separation standards are achieved; where distributed decision-making, based on complete situational awareness, provide vast user flexibility; and allowing the injection of emerging concepts to be easily integrated with existing elements.” (“NGATS ATM Enterprise Architecture Report”, Crown Consulting, June 2005). Transitioning to space-based communication, navigation and surveillance subsystems offers increased capabilities while at the same time presenting opportunities to reduce ground-based infrastructure cost.

This presentation briefly describes several of the airborne technologies which will provide some of these capabilities and the testing/demonstration activities that will be conducted in the near future at the FAA William J Hughes Technical Center.

6.3 "Some Issues in Autonomous Vehicle Control Management,” Mario Innocenti, University of Pisa

The presentation describes some of the research activities carried out in the Department of Electrical Systems and Automation, in the general area of management and control of autonomous vehicles. In particular, areas of formation flight, path assignment, and vision-based algorithms will be described, as applied to autonomous flight and ground vehicles. In the area of formation flight, the activity deals primarily with aspects such as formation flexibility in terms of geometry and reconfiguration to communications failures. Path and task assignment is studied with the primary objective of computational load, and decentralized clustering. Vision-based algorithms are analyzed, with particular application to formation control, aerial refuelling, and ground motion safety with respect to obstacle avoidance.

6.4 "FAA Safety Initiatives," Joe Schanne, FAA

In this presentation, the development and implementation of a Safety Management System (SMS) by the FAA's Air Traffic Organization (ATO) will be briefly described. The context of this implementation, as compared to other international air navigation service providers will be discussed. Several real world examples will then be explored. The first example is a brief overview of the Safety Risk Management (SRM) process now being used by the FAA's ATO when changes to the National Airspace System (NAS) are made. Specifically we will look at the process being followed to allow the introduction of Unmanned Airborne Systems (UAS's) in NAS airspace. The second example focuses on the measurement and improvement of Safety Culture within the FAA's ATO. A recreation of an international aircraft accident (Überlingen, 2002) provides a strong example of the importance in insuring the safety risks are identified between engineering and operational disciplines

7.0 SUBCOMMITTEE D – DYNAMICS, COMPUTATIONS AND ANALYSIS

7.1 "Autonomous Aerial Refueling," Jake Hinchman

AFRLA critical aspect of military aircraft operations is the ability to refuel in flight. Aerial refueling increases an aircraft's effectiveness by extending its range and endurance (amount of time spent in the air), thus enabling it to travel anywhere on the globe, if needed. In addition, by being able to refuel, military aircraft are able to carry their maximum payload of weapons without reducing their range due to the extra weight. In effect, this enables the aircraft to be more effective in attacking and destroying enemy air and ground assets.

However, what has been described thus far applies to piloted or manned airplanes. A new class of vehicle, the Unmanned Air Vehicle (UAV), is now becoming an important asset in military operations. Its role will be similar to the manned aircraft in that it will be required to per-form reconnaissance, target identification, target attack, and battle damage assessment. Consequently, if a UAV is expected to perform the same functions as a manned aircraft, it must also have an aerial refueling capability. The Automated Aerial Refueling (AAR) Program, a joint program between the Air Force Research Laboratory (AFRL) and the Defense Advanced Re-search Projects Agency (DARPA), will develop technologies that will allow a UAV to refuel with a limited amount of controller interaction. The purpose of this paper is to provide a top level description of this program, the technologies being developed, and the role of both flight test and simulation in the technology development and validation process.

7.2 "Aircraft Handling Qualities and Control Response Types," Tony Lambregts, FAA

This presentation examines various Fly-By-Wire (FBW) augmented manual control design options and criteria for achieving desired handling qualities. Design concepts with different "response types" will be reviewed. The author re-interprets some of the classical Handling Qualities criteria in light of desired response characteristics in the time domain, which can then be evaluated through simulation time histories. A design methodology is discussed that can provide the same aircraft responses to pilot control inputs for different response types, e.g., Pitch-Rate Command/ Attitude Hold and Flight Path Angle (FPA) Rate Command/FPA Hold designs. The role of various feedback and feed-forward signal paths and ways to minimize the need for gain scheduling is discussed.

7.3 "Problems in Validating Control Feel in Simulators" by T. Scott Davis, SAIC

This presentation reports on how structural deformation of control linkages significantly affects control loading system validation in simulators. The presentation covers

- C-130 simulator test data, including control deformation
- lessons learned on testing
- insight into the actual control feel in a reversible system
- the manner in which mechanical deflection of systems in the aircraft and the mechanical system deflection in the simulator are both much more considerable factors in control feel than previously understood.

The flexing of even very stiff simulator controls needs to be carefully measured in static force versus deflection data. In addition, the flexing of actual aircraft controls, which generally flex more than simulator controls, is a very significant factor that must be considered in control loading criteria data. The results in this study document the necessity of knowing the mechanical characteristics (stiffness) in both the simulator and aircraft control systems, even in those components normally considered "stiff" and therefore often neglected in the past.

7.4 "Man/Machine Interface Design for Transport Aircrft" Rene van Paassen, Delft University of Technology

Demands on the capability of aircraft to be able to operate in busier airspace than before, operate with all-weather capability and at an increased safety level. To cope with such demands, the crew at the flight deck needs support from advanced automation and advanced displays. Computer technology and interface hardware allow great freedom in the choice of display presentations. Most constraints imposed by technology on the display presentation format are now lifted. The challenge for the display designer is now to find presentation formats that optimally support the pilot's (mostly cognitive) tasks. Three levels of display design can be distinguished:

- Physical ergonomics; attention to colors, readability, clarity, unambiguous symbols, etc.
- Integration and configuration; integrated presentations, such as primary flight displaypresentations, where all necessary variables for the control task can be observed with minimal effort, and also the application of configural displays, that not only efficiently present parameters, but also, e.g.,. through alignment of engine display parameters, allow checks at a more global level.
- Effective support of cognitive work; the display presentation should become a "spreadsheet" for performing the cognitive work of the crew. Constraints on the operation of the aircraft, whether arising from the vehicle's limitations or from the environment should be shown in such a manner that a strategy for control of the vehicle can be found.

Ecological Interface Design

Ecological Interface Design (EID) is an approach to the design of interfaces for cognitive work. It starts by considering the work domain; the purpose of the work and the set of tools that is available for accomplishing this purpose. The work domain and its constraints are first mapped in the Abstraction Hierarchy (AH), a stratified hierarchy that describes the multiple layers of means and ends in the work domain. Starting from the AH, the work situation is further "designed", by devising possible paths along which the work may performed (tasks) and by factoring in the personnel and environment in which these tasks must be performed. In a last step, which still requires considerable creativity, an interface is designed that takes the constraints identified with the AH and visualizes these to the operators. Obviously, the design is not only about the interface, but more about the work and work domain. A more encompassing term for this approach is "Cognitive Systems Engineering" (CSE). EID and CSE started for process control plants. The application to vehicle systems, such as aircraft, required careful re-consideration of the basic premises for EID. The differences between the two domains are analyzed, and an adapted approach is proposed.

Example case 1: Airborne conflict avoidance

In this case, the potential for distributed airborne conflict avoidance is considered with CSE. It appears that the choice made for formulation of the basic mechanism of locomotion significantly influences the resulting display design. This design shows the work domain in such a manner that conflict avoidance maneuvers that combine speed and heading changes can be easily implemented by the flight crew.

Example case 2: Visualization of energy

This case adds an energy visualization to a synthetic vision primary flight display. The key in this case was the expression of the work domain purpose in terms of energy. Energy visualization provides a better link between the aircraft's control inputs and the purpose of the control tasks. Reformalizing these purposes in the form of potential and kinetic energy, instead of speed and altitude, enables the integration of these parameters in a single display dimension.

Conclusions

Cognitive Systems Engineering and Ecological Interface Design provide major new opportunities in the design of flight deck interfaces. Beyond the optimization of displays for legibility, and the optimization in terms of integration of the presentation, displays can now be improved to support the cognitive work of the flight deck crew. In recent work, we have been exploring additional flight crew tasks, and have also been applying this method to the maritime domain. We have recently started several projects to validate the designs created with EID. Recommended Literature On Abstraction Hierarchy and Ecological Interface Design:

Recommended Literature

On Abstraction Hierarchy and Ecological Interface Design:

Cognitive Work Analysis : Toward Safe, Productive, and Healthy Computer-Based Work
by Kim J. Vicente

A “gentle” introduction:

The Human Factor; Revolutionizing the Way People Live with Technology by Kim Vincente
(Hardcover - Feb 20, 2004)
On interface example 1:
EID of a Pilot Support System for Airborne Separation Assurance (2005)
Van Dam, S. B. J., Abeloos, A. L. M., Mulder, M. and van Paassen, M. M.,
Proceedings of the 13th International Symposium on Aviation Psychology
pp 585—591, Oklahoma, April 2005

On interface example 2:
Theoretical Foundations for a Total Energy-Based Perspective Flight-Path Display
Matthijs H. J. Amelink, Max Mulder, M. M. (Rene) van Paassen, John Flach
International Journal
of Aviation Psychology, Vol. 15, No. 3: pages 205-231.

Abstract | Printable PDF (214 KB) | PDF with links (230 KB)

8.0 SUBCOMMITTEE E – FLIGHT, PROPULSION AND AUTONOMOUS VEHICLE CONTROL SYSTEMS

8.1 "Vision-Based Navigation of a Small Unmanned Air Vehicle,” Raja Sengupta, UC Berkeley

Our aim is to make UAV’s a ubiquitous technology by enabling their use for commercial activities and enhancing their autonomy so they can be operated without advanced training. There is a thriving aerial inspection industry imaging infrastructure such as oil pipelines or powerlines for defects or road traffic for accidents. To advance UAV’s to a technology usable by this industry, we have developed a vision-based tracking technology to track locally linear structures. Using small UAV’s and cheap COTS cameras, at altitudes between 100 and 200 meters, we have tracked roadways and the California aqueduct, keeping the lateral tracking error to an average of 10 meters. Simultaneously we have been exploring an approach for obstacle avoidance that is computationally simpler than structure from motion, but may nevertheless be adequate for autonomous flight at altitudes of 200 meters and above where obstacles are sparse.

8.2 “Active-Vision Control Systems for Aircraft, Eric Johnson, Georgia Tech

Precision guided munitions, cruise missiles, Unmanned Aerial Vehicles (UAVs), and similar platforms currently perform guidance and flight control largely based on traditional navigation sensor information (e.g., GPS, inertial measurement, radio navigation) or the traditional plus the addition of 2D/3D imagery (radar, IR). Examples of the latter include radar guided missiles that are capable of operation in a very "structured" environment (lock onto target, and then provide terminal homing), and terrain matching in cruise missiles. We know from nature that far more is possible with even 2D imagery: birds and pilots can find their way to their destination without precise inertial sensor information, birds and pilots avoid colliding with terrain without a radar altimeter, and the list goes on. Imaging sensor data is currently available on many of these platforms, in the case of UAVs usually to provide human eyes with reconnaissance information. However it is not normally used for flight control.

Furthermore, some of these sensors are becoming an inexpensive source of rich information that could be added to many additional classes of vehicles. The Georgia Institute of Technology (GIT), the University of California at Los Angles (UCLA), the Massachusetts Institute of Technology (MIT), and the Virginia Polytechnic Institute and State University (VPSU) are working with industry and government partners to develop sound methods that utilize 2D and 3D imagery to enable aerial vehicles to autonomously detect and prosecute targets in uncertain complex 3D adversarial environments: the use of visual information to complement or replace tradition flight control sensors; the use of visual information for tracking air and ground targets, either to attack or to avoid; and the use of visual information to prevent collisions with terrain or obstacles.

This talk includes a summary of this work, with emphasis on recent flight test results in vision-aided navigation and air-to-air tracking.

8.3 “Optimization Based Approaches to Autonomy,” Cedric Ma, Northrop Grumman

The main benefit of using a numerical optimization based approach for vehicle autonomy applications is its ability to combine vehicle dynamics, environmental constraints, and mission objectives into a mathematical programming problem, which can be optimally solved on-line using powerful commercial solver tools created and supported by the operations research community. In this talk we introduce the concept of optimization-based autonomy, and present two potential real-time autonomy applications based on this approach – MILP path planning and OTG trajectory generation. We also present a broader survey of the area including the concept of autonomy, levels of autonomy, and the classes of autonomy applications. We conclude with a discussion on the benefits and challenges of using the optimization approach.

8.4 “DARPA Grand Challenge: Red Team Overview and Results,” Phillip L. Koon, The Boeing Company, Phantom Works

This presentation describes Boeing’s experiences on Carnegie Mellon University’s Red Team, a DARPA Grand Challenge competitor. Boeing was a prime sponsor and partner on Red Team embedding engineers on the team starting in September of 2003. The presentation will provide an overview of Red Team autonomous ground vehicle technology, race strategy and race results. Many videos and images taken during vehicle development, testing, qualifying and the 2005 race will be shown.

9.0 SUBCOMMITTEE A – AERONAUTIC AND SURFACE VEHICLES

9.1 "Feel System Characteristics," Brian Lee, Boeing Commercial

Feel systems represent very important elements of airplane design in that they are the man-machine interface in manual flight. At the same time, their detailed specification has not received much attention in either civilian certification regulations or military standards. Boeing has recently undertaken joint collaborative research with a team at the Central Aero- Hydro-dynamic Institute of Russia to define optimum and flying qualities level boundaries for various feel system parameters. This work was done in the presence of typical large jet transport aircraft characteristics, typical of modern wide-body aircraft. The work consisted of development of a theoretical basis for pilots' selection of optimum, desired, and adequate characteristics. This construct was then validated by and populated with results from large scale pilot-in-the-loop simulation experiments, conducted both in the US and in Russia by both Boeing and Russian test pilots. The results indicate that the theoretical basis is sound. This paper reviews the constructs, discusses the experiment designs, and reviews the results.

9.2 "Wright Experience," Kevin Kochersberger, RIT

This presentation provides a modern perspective to the accomplishments of the Wright brothers by combining recent scientific observations with a story of engineering genius. Using full-scale wind tunnel data acquired on the 1901, 1902 gliders and the 1903 powered machine, this presentation examines the evolution of the aerodynamic characteristics of Wright aircraft. In addition, several flights of a reproduction 1902 glider and two successful flights of a reproduction 1903 Flyer have provided invaluable experimental data on these historic aircraft. Using a custom-built flight data recorder, 15 parameters were recorded to reveal details about the aircraft's dynamics during a 97' and 115' flight. These flights are discussed in detail.

9.3 "Lessons Learned and Flight Results from the F-15 Intelligent Flight Control System Project," John Bosworth, NASA Dryden

The F-15 IFCS project was a joint effort with NASA Dryden and Ames, Boeing Phantom Works, the Institute for Scientific Research as well as participation from academia. The project overall goal is to advance neural network-based flight control technology. This technology has the potential to greatly increase the robustness to failures and provide a control technology that enables a new class of radically morphing vehicles. The effort included work in indirect adaptive systems that identify changes in vehicle behavior and adjust the flight control system to account for that change. Also a direct adaptive approach was demonstrated. This approach adjusts the flight controller based on feedback errors without directly identifying the behavioral change. The adaptation goals were to reduce the transient due to a failure, re-establish model following, and minimize longitudinal / lateral directional couple due the failure. Simulated failures were demonstrated using a destabilizing gain change and by freezing a single control surface.

Flight results and lessons learned are presented. The F-15 IFCS project is currently collecting valuable “real world” flight test data. Adaptive systems face some significant challenges in the area of structural / control system interaction. The area of adaptive control system technology is a fruitful area for research and the F-15 IFCS project is providing valuable information that will promote the technology to a higher readiness level.

9.4 “Torque Limit Cueing via Rotorcraft Collective,” Vineet Sahasrabudhe, Sikorsky

A collective axis cueing system has been developed for helicopters that cues the pilot to a variety of envelope limits associated with the engine and drive systems including transient and continuous transmission torque limits, rotor RPM limits, and the optimal RPM following an OEI emergency. The cueing system uses neural network and linear model based algorithms to predict approaching limits and then estimates the constraints on the collective control position to ensure that the limits are not exceeded. The constraints are relayed to the pilot through a combination of soft stop and stick shaker cues. This collective cueing system has been tested using a real-time piloted simulation of a UH-60 Black Hawk. The results of the simulation show that collective cueing leads to a significant reduction in pilot workload, decreases time required to conduct a specific task, and improves task accuracy for aggressive maneuvers. In addition, it allows the pilot to fly in true “heads up, out-the-window” fashion following a single engine failure. Finally, the study shows that with the judicious use of different types of cues (soft stops and stick shakers) and intuitively chosen stick shaker frequencies, multiple limits can be cued through the collective without confusion.