N94-25115

ADVANCED INFORMATION PROCESSING SYSTEM

AIPS

Felix L. Pitts

NASA Langley Research Center

Workshop on Guidance, Navigation, Controls, and Dynamics for Atmospheric Flight

March 19, 1993

OUTLINE

- Background and Description
- Program Accomplishments
- Current Focus
- Applications
- Technology Transfer
- FY92 Accomplishments
- Funding

NEED FOR VALIDATED ARCHITECTURES

A need exists for architectural concepts that have been validated such that their physical implementation in hardware and software will meet the quantitative missions requirements such as

- cost
- weight, volume, power
- throughput performance
- transport lag
- mission success probability
- mission availability
- •

and also be responsive to qualitative requirements such as

- expandability
- graceful degradation
- technology insertion
- damage tolerance
- •

AIPS IS

- A COMPUTER SYSTEMS PHILOSOPHY
- A SET OF VALIDATED HARDWARE BUILDING BLOCKS
- A SET OF VALIDATED SERVICES AS EMBODIED IN SYSTEM SOFTWARE

TO ACHIEVE

- DISTRIBUTED FAULT-TOLERANT SYSTEM ARCHITECTURES FOR A BROAD RANGE OF APPLICATIONS

GOAL

- PROVIDE THE KNOWLEDGEBASE which will allow achievement of VALIDATED fault-tolerant distributed computer system architectures, suitable for a broad range of applications, having failure probability requirements to 10E-9 at 10 hours

AIPS PROGRAM HISTORY

Phase I 1983-1984

Requirements Survey	(NASA, JPL, Airframers)
Technical Survey	(NASA, DoD, Industry, Academe)
Architecture Synthesis	(CSDL monitored by Peer Review Group)

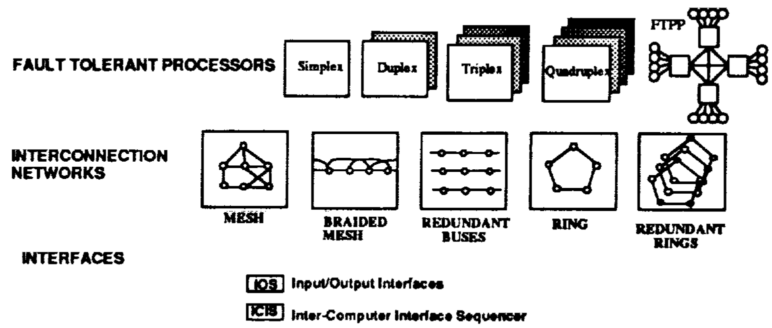
Phase II 1986-1986

Functional & Detailed Design of Building Blocks
Reliability & Performance Modeling of Building Blocks

Phase III 1986-1993

Emphasize Validation to Verify AIPS Attributes
Focus on: Engineering Model for ALS
High Throughput/Highly Reliable Army Fault Tolerant Architecture

AIPS BUILDING BLOCKS: HARDWARE



AIPS BUILDING BLOCKS: SOFTWARE

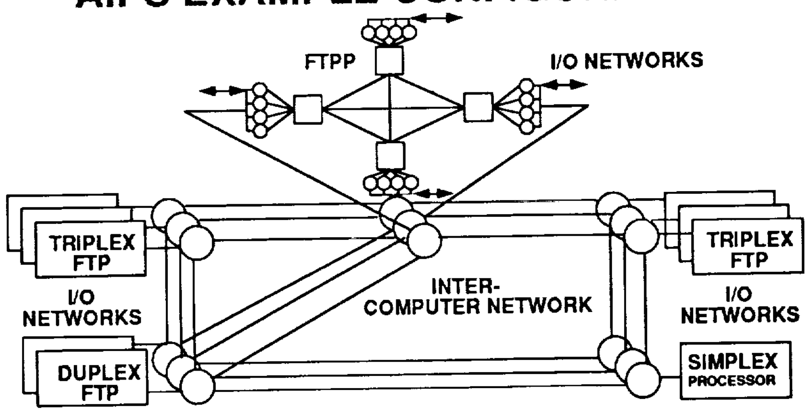
LOCAL SYSTEM SERVICES:
- Ada Real Time Operating System
- FTP Redundancy Management
- Local Time Management

INPUT/OUTPUT (I/O) SYSTEM SERVICES:
- I/O User Communications
- I/O Redundancy Management

INTERCOMPUTER (IC) SYSTEM SERVICES:
- Ada Distributed Synchronous Communications
- IC User Communications
- IC Redundancy Management

SYSTEM MANAGER:
- Function Allocation & Migration
- System Redundancy Management
- Global Time Management

AIPS EXAMPLE CONFIGURATION



FEATURES: APPROPRIATE FUNCTION RELIABILITY
LOW FAULT TOLERANCE OVERHEAD
GROWTH CAPABILITY
Ada OPERATING SYSTEM
REDUNDANCY TRANSPARENT TO USER

DISTRIBUTED SYSTEM CONTROL

- AIPS Operates in an overall framework that can be characterized as a limited form of a fully distributed multicomputer system
  - Each GPC has the Resources to Operate Autonomously
  - Each GPC in Steady State is Assigned to a Unique Set Of Functions
  - Local Operating System in Each GPC Provides Local System Services of Initialization, Task Scheduling and Dispatching, I/O Service, and Local Redundancy Management

SYSTEM COMPLEXITY MANAGEMENT

- AIPS Architecture Designed to Hide System Complexity from Applications
- System Services, as Implemented in Hardware and Software, Manage Distributed Resources and Hardware Redundancy
- Distributed Computation Deliberately Separated from Fault Tolerance
- Exact Consensus Between Processes and Exact Consensus Between Bus Transmissions Simplifies Fault Detection and Isolation
- Hardware Mechanization of Fault Detection and Isolation Simplifies Redundancy Management
- AIPS Architecture Designed to Facilitate Congruent Data Flow in Redundant Processors and Between GPCs

PROGRAM ACCOMPLISHMENTS

• Produced an Analytical and Empirical Knowledgebase for Validation of AIPS Architecture and Building Blocks

- Architecture Design Rules and Guidelines
- Analytical Reliability, Performance, Availability and Cost Models
- Empirical Reliability and Performance Data

• Developed and Demonstrated Distributed Engineering Model

-Validatability,Distributed computation, Mixed redundancy, Fault tolerance (processors, networks, interfaces), Damage tolerance, Graceful degradation, Expandability, Transparency of fault tolerance to applications programmer, Low fault tolerance overhead, Performed Laboratory Test and Evaluation

-Demonstrated AIPS Building Blocks

3 Triplex FTPs and 1 Simplex Processor

Triplex Intercomputer Network, Mesh I/O network

System Services Software (>100,000 Lines of Ada Code)

ACCOMPLISHMENTS (cont'd)

- COMPLETED MULTIPATH REDUNDANT AVIONICS SUITE MPRAS 2102 AIPS TASK FOR ADVANCED LAUNCH SYSTEM
  - AIPS ENGINEERING MODEL OPERATIONAL
  - GOVT/INDUSTRY REVIEW 10/89
  - 4 REPORTS PUBLISHED SEPT. 1991
  - SUBMITTED AIPS/ALS UPDATE FOR ALS/ADP REVISION D PLAN
  - PRODUCED A 20 MINUTE AIPS VIDEO

- COMPLETED "HANDS OFF" CASE / AIPS DEMO FOR CODE GENERATION AND EXECUTION OF ATOPS 737 AUTOPILOT

- PUBLISHED NUMEROUS REPORTS AND PAPERS
  - ATTACHED 29 REPORT BIBLIOGRAPHY

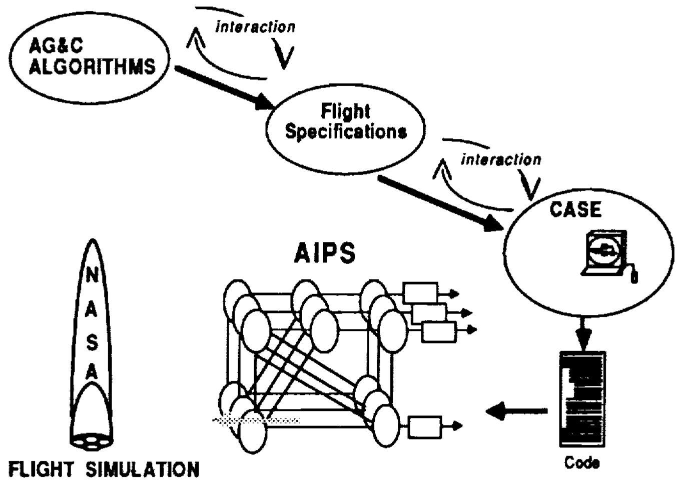
AIPS CURRENT FOCUS

- **Base Program**
  - **AG&C/CASE/AIPS Demo (NASA Funding)**
  - **Develop Authenticated Protocols for Inter-System Communication (SDI Funding)**

- **Army Fault Tolerant Architecture (Army Funding)**
  - **Fault Tolerant Parallel Processor Development**
  - **Common-Mode Fault Study**
  - **Optical Fault Tolerant Interconnection Networks**

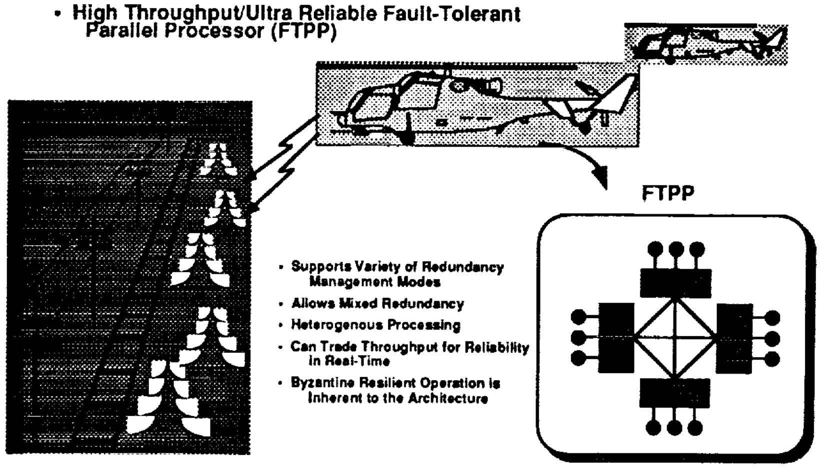
- **Terminate CSDL/ AIPS Contract**
  - **Contract Completed 9/30/92; All Tasks Completed by 9/30/93**

AG&C/CASE/AIPS DEMONSTRATION



Army Fault-Tolerant Architecture (AFTA)

- Helicopter Night-Time Nap of the Earth Operations
- Integrated Flight Controls and Image Processing
- High Throughput/Ultra Reliable Fault-Tolerant Parallel Processor (FTPP)



Fault Tolerant Parallel Processor

High Performance Voting Architecture. Fully connected fiber optic network between processor groups.

Tolerates arbitrary failure modes (Asymmetrical faults).

Uses many Processing Elements (PE's) for high throughput.

Uses redundant PE's for high reliability. Data Voting Architecture

Can trade Throughput for reliability or availability in real-time.

Uses Non Development Items (NDI) PEs, backplanes, power supplies, I/O for improved suportability

Allows mixed redundancy and heterogeneous processing resources.

AFTA Characteristics

- Processing Elements
  - Support for 3 to 40 PE's per Cluster (FTPP).
  - 680x0's, 80960's, MIPS R3000's, TMS320x0, etc...
  - PE's in the AFTA are grouped into redundant Virtual groups to achieve fault tolerance.
  - Virtual groups can be simplex, triplex, quadraplex, or quintuplex.
  - Static Virtual group configuration determined by reliability and availability analysis.
- Network Elements provides:
  - 100 Mbit/sec fiber optic interchannel links.
  - Standard bus interface to Processing Elements. (Mil-STD-344, Pi-bus, Futurebus, Safebus, etc...)
  - Time management primitives for architecture (synchronization).
  - Reliable data Communication services (Voting, Source congruency).
  - Maps physical processing sites into virtual groups (VIDs).

AFTA Characteristics cont'd

❑ Software main components:

XD Ada-based operating system with real-time extensions. Preemptive rate group scheduler.

Periodic task communication between Virtual groups. Pre-defined communication services.

Performance Penalties from Redundancy Management and Operating systems functions minimal. (10% - 15%)

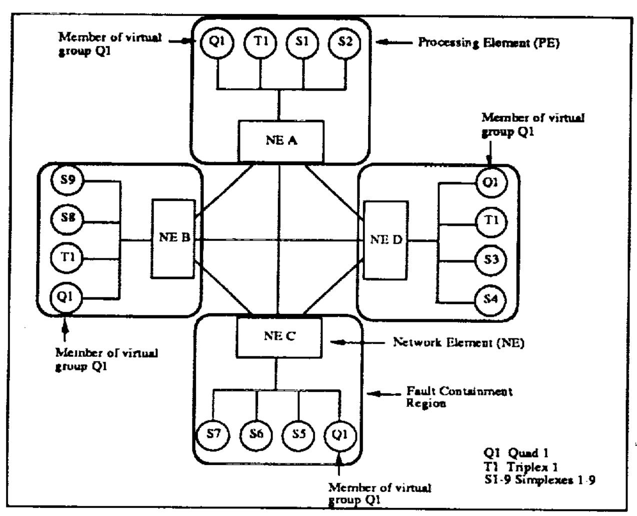
POSIX Real-time operating system interface standard (IEEE P1003). LynxOS Version being evaluated now (FY93).

❑ I/O controllers

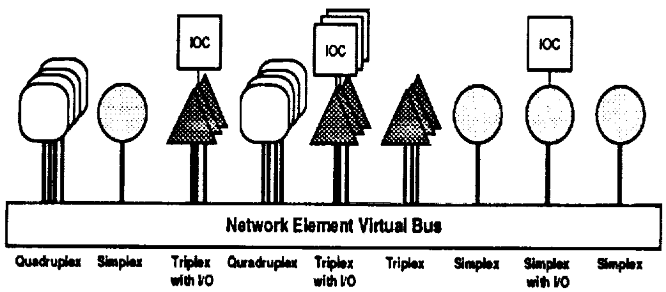
Fault-Tolerant Data bus (Auth. protocols)

1553, JIAWG FT data bus, VME, etc....

AFTA Physical Architecture



AFTA Virtual Architecture



AFTA Program Status

Three phase program:

I. Conceptual study - Completed in FY91. Analytical modeling, feasibility studies, requirements acquisition, preliminary design.

II. Detailed design. FY92. Design hardware and software architectures.

III. Detail design and evaluation. FY93. Complete HW and SW architecture designs, begin performance evaluation activities of AFTA in relation to TF/TA application.

Major deliverables:

1. All procured hardware and software.
2. All software and hardware documentation
3. Final written comprehensive report.
4. CECOM will receive an AFTA for evaluation in FY95. (Loan from CSDL)

SELECTED APPLICATIONS OF AIPS

- **Unmanned Undersea Vehicle (UUV) - DARPA**

  - Under DARPA sponsorship, Draper designed and built two UUVs, each of which is autonomously controlled by a triplex FTP based on the AIPS architecture

  - Both vehicles have undergone extensive sea trials without any significant FTP related problems

- **Seawolf SSN-21 Ship Control System - US Navy (NavSea)**

  - A quadruply redundant FTP, based on the AIPS architecture, has been militarized and packaged in SEM-E modules to perform the "swim-by-wire" functions onboard the SSN-21 Seawolf nuclear attack submarine

SELECTED APPLICATIONS OF AIPS (Cont.)

- **SDIO Battle Management / C3 - US Army (SDC)**

  - A quadruply redundant FTP with attached processors (FTP/AP) was delivered to Army Strategic Defense Command for evaluation as a Battle Management Computer

- **Army Fault Tolerant Architecture - US Army CECOM**

  - An AIPS-based Army Fault Tolerant Architecture (AFTA) has been developed for the helicopter terrain avoidance/terrain following flight control application for the Army Communications and Electronics Command

SELECTED APPLICATIONS OF AIPS (Cont.)

- GPALS Engagement Planner - US Army (SDC)

  - The brassboard of Army Fault Tolerant Architecture is being fabricated for the GPALS (Global Protection Against Limited Strikes) Engagement Planner application for the Army SDC

- MAGLEV Command and Control Computer - DOT

  - A fault-tolerant, fail-safe computer architecture using the AIPS-developed design for validation methodology was developed for the US Maglev (magnetically levitated) transportation system under DOT sponsorship

AIPS TECHNOLOGY TRANSFER

- Tech Aerojet FTP

  - Under a contract from NASA MSFC Tech Aerojet selected the AIPS Fault Tolerant Processor architecture for the engine control application on the National Launch System

  - Under a subcontract from Tech Aerojet, Draper helped them define an Intel i960-based triplex FTP's fault tolerance related hardware for fabrication by Tech Aerojet

- Martin Marietta Astronautics FTPP

  - A study was done by Draper to apply AIPS technology to Martin's aerospace needs under a contract from MM

  - Following the study, a quadruply redundant Fault Tolerant Parallel Processor (FTPP) was delivered to Martin for use in various IR&D and sponsored projects

FY92 ACCOMPLISHMENTS

During FY92, three major tasks were active:

- Army Fault Tolerant Architecture (AFTA)
  - Detailed design of the AFTA hardware and software was completed.
  - The Network Element, the only hardware development item in AFTA, which is responsible for fault tolerance related functions and message passing between processors, was designed and breadboarded.
  - Breadboard of the NE was fabricated and tested; the Scoreboard, one of the two NE cards which was designed using VHDL, worked the first time without any errors.
  - A 2-volume report documenting the conceptual study phase of AFTA was published.

FY92 ACCOMPLISHMENTS

- Authenticated Protocols-Based Inter-Computer and I/O Networks

- A detailed design of the Transport Layer, patterned after the Open Systems Interconnect (OSI) model, of the inter-computer communication software was completed.

- Key generation, signaturing and message authentication algorithms were produced, coded and optimized in C and Assembly languages.

- Hosting of AGN&C Algorithms using CASE on AIPS/FTPP

- Martin Marietta Astronautics, Denver produced Matlab scripts of advanced guidance algorithms designed at NASA LaRC.

- Draper Lab, in collaboration with Martin, chose a subset of Matlab scripts for interfacing with the CASE tool.

- Modification of the CASE tool to accept Matlab scripts was started.

FUNDING

	FY92 and Prior	FY93	TOTAL
• SDIO/ALS	$3.23 M		
• SDIO/BMC3	$1.22 M	$150 k (Authen Proto)	
• ARMY/AVRADA	$2.30 M $6.75 M		
• NASA RC FUNDING	$1.45 M	$50 k (AG&C Demo) $403 k (CASE)	
• TOTALS	$8.2 M	$830 k	$9.03 M

Automated Code Generation for GN&C Applications

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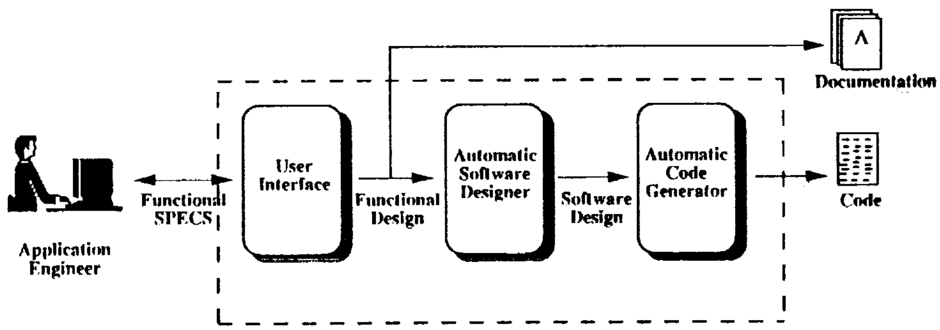
March 19, 1993

Outline

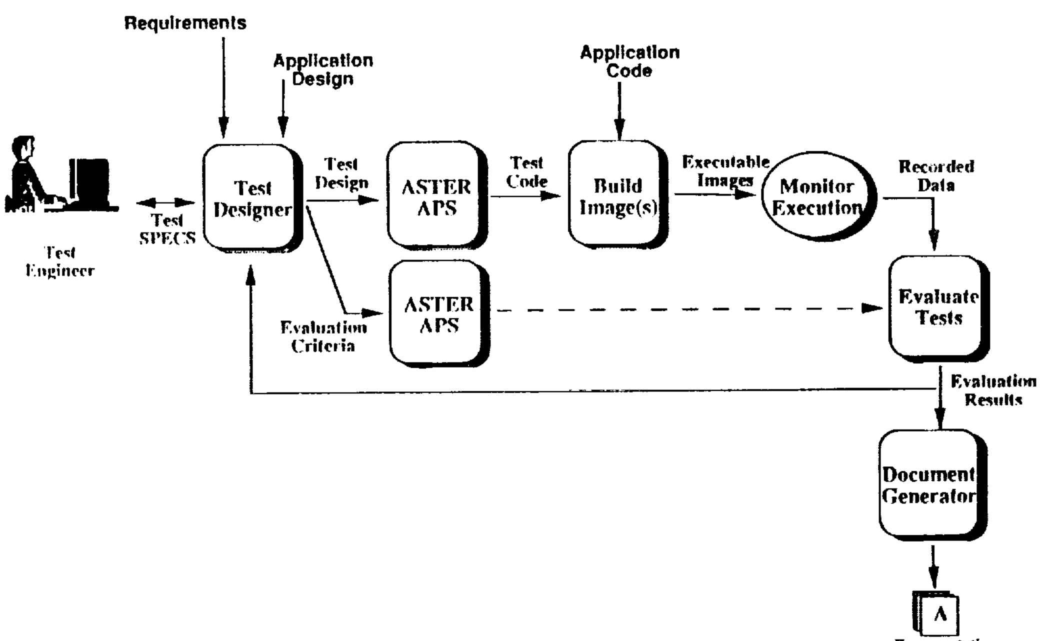
- ASTER
- Applications
- GN&C Demonstration
- Matlab Integration
- Summary

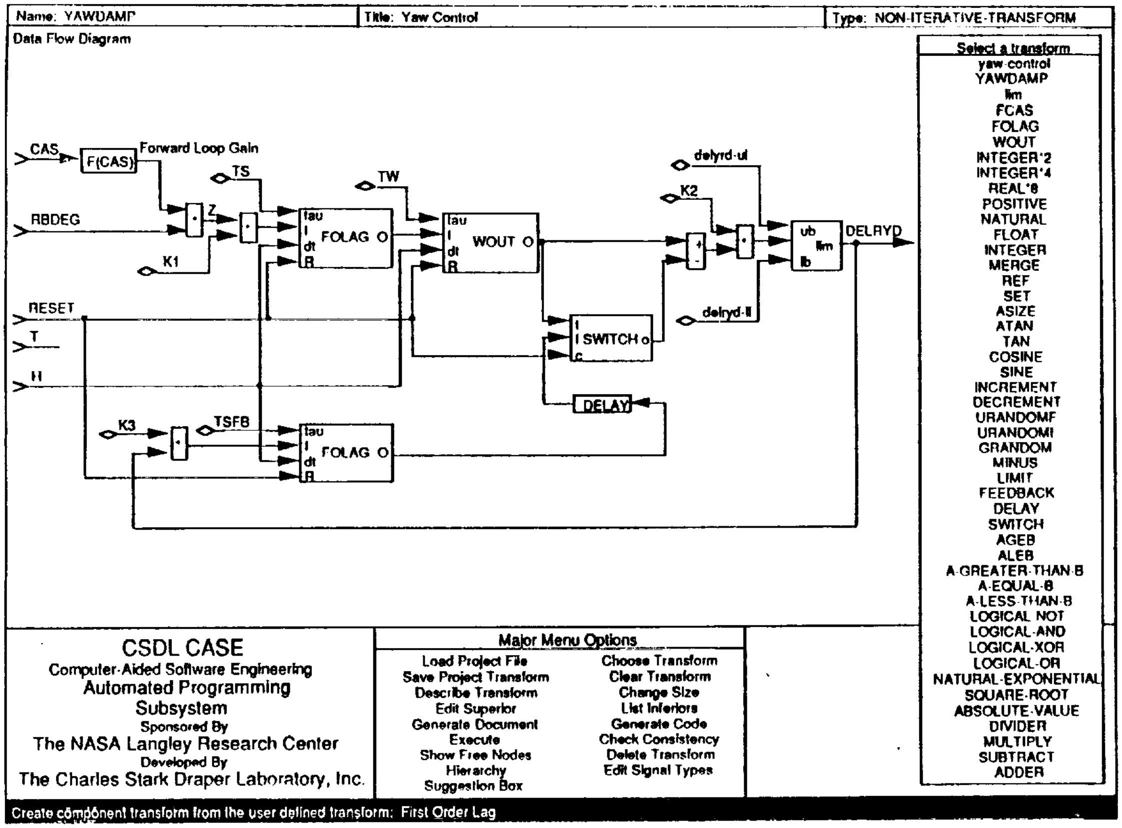
Automatic Programming Subsystem

- Accepts functional specifications
- Generates source code (Ada, C)
- Generates documentation
- System architecture:



Automatic Testing System





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FEEDBACK
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Computer-Aided Software Engineering
Automated Programming
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Sponsored By
The NASA Langley Research Center
Developed By
The Charles Stark Draper Laboratory, Inc.
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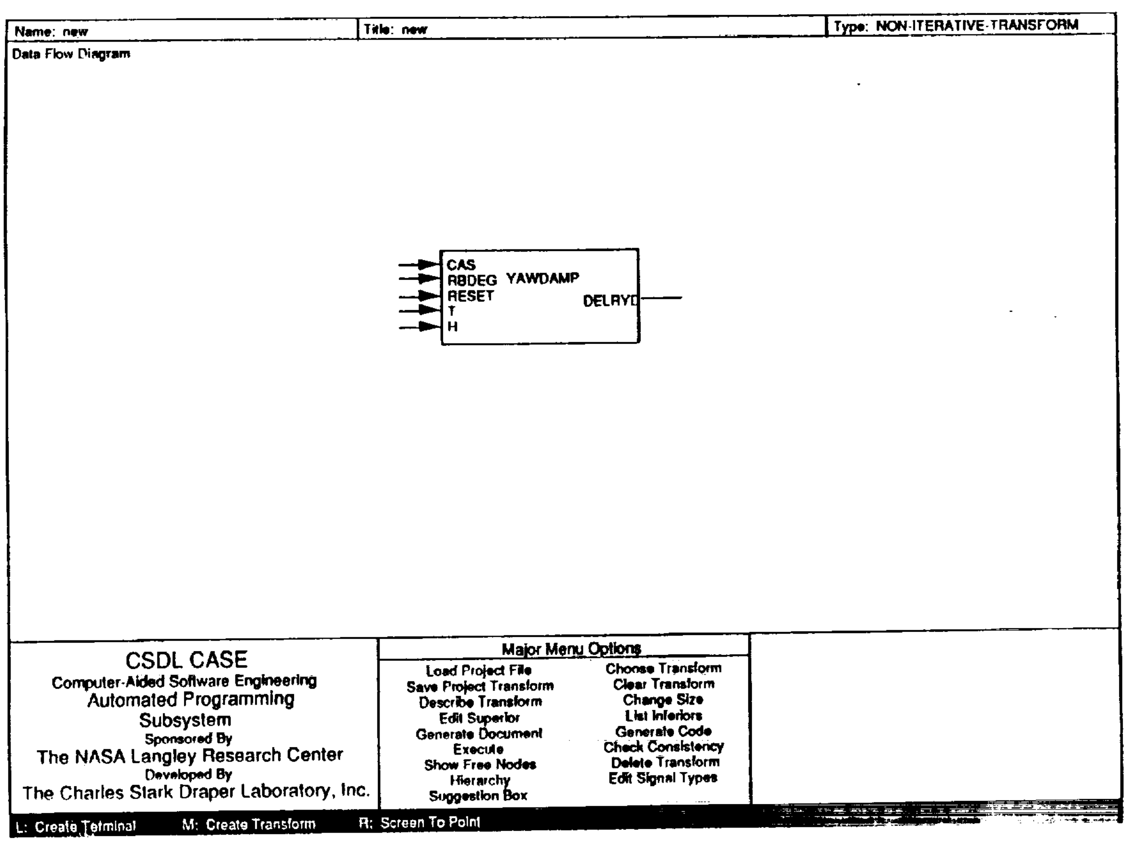

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Clear Transform
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List Inferiors
Generate Code
Check Consistency
Delete Transform
Edit Signal Types
L: Create Terminal
M: Create Transform
R: Screen To Point

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Benefits of the ASTER Approach

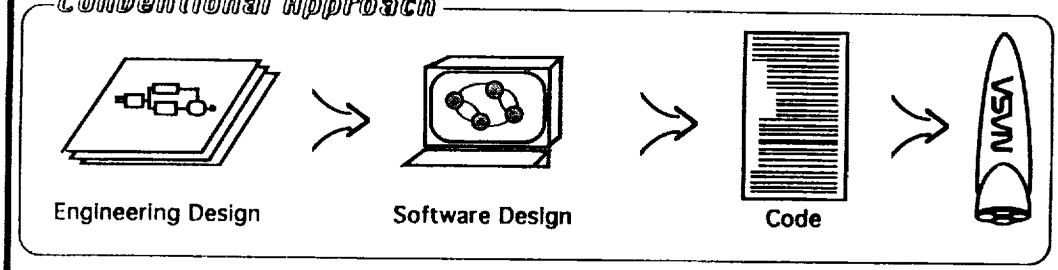
- Reduce development time
- Reduce errors
- Code and documentation always agree
- Decouple engineering design and software design
- Reuse engineering designs
- Facilitate and reduce testing
- Provide an open, extensible architecture

Systems Architecture Branch

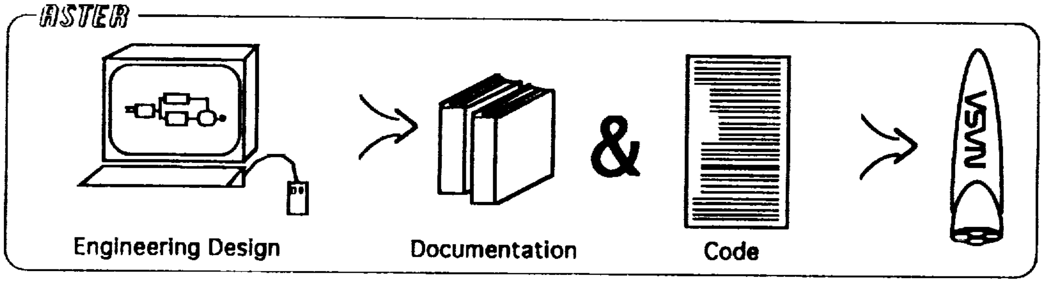
NASA Langley Research Center

Software Development Techniques

Conventional Approach



ASTER



Systems Architecture Branch

Demonstrations

- Large Gap Magnetic Suspension System (LGMSS)
  - C code running on an embedded Silicon Graphics workstation
  - Passed CDR and delivered to customer
- B737 Autoland Flight Control System
  - Ada running on Draper's Fault Tolerant Processor in conjunction with a FORTRAN simulator on a MicroVAX
  - Ada running on Draper's Fault Tolerant Parallel Processor in conjunction with a FORTRAN simulator on a MicroVAX
  - C currently being hosted on Draper's Transputer FTP
- Guidance and Control System for a Mars Lander
  - Ada running on VAX in conjunction with FORTRAN simulator
- Inertial Fiber Optic Gyro/Standy Attitude Indicator (IFOG/SAI)
  - Ada running on a MIPS R3000
- Inertial Reference System for Deep Submergence Rescue Vehicle
  - Model upgrade from FORTRAN to Ada on a VAX

Demonstrations (cont.)

- Space Station Control System
  - Applied for documentation purposes
  - Ada and C code generated
- General Dynamics Electromechanical Actuator
  - Ada and C code generated
- Martin Marietta Load Relief Filter
  - Ada code running on SUN and VAX
  - C code running on a variety of workstations, PC's & computers
- Boeing B737 Yaw Damping System
  - Ada running on Draper FTP for N-version software experiment
  - C running on Draper FTPP
- Autonomous Exploration Vehicle
  - Ada running on SUN workstation
  - C running on SUN workstation
- Shuttle's Ascent First Stage Guidance
  - Implemented by Martin Marietta under IR&D
  - Ada executed and tested on two environments, including a shuttle software simulator

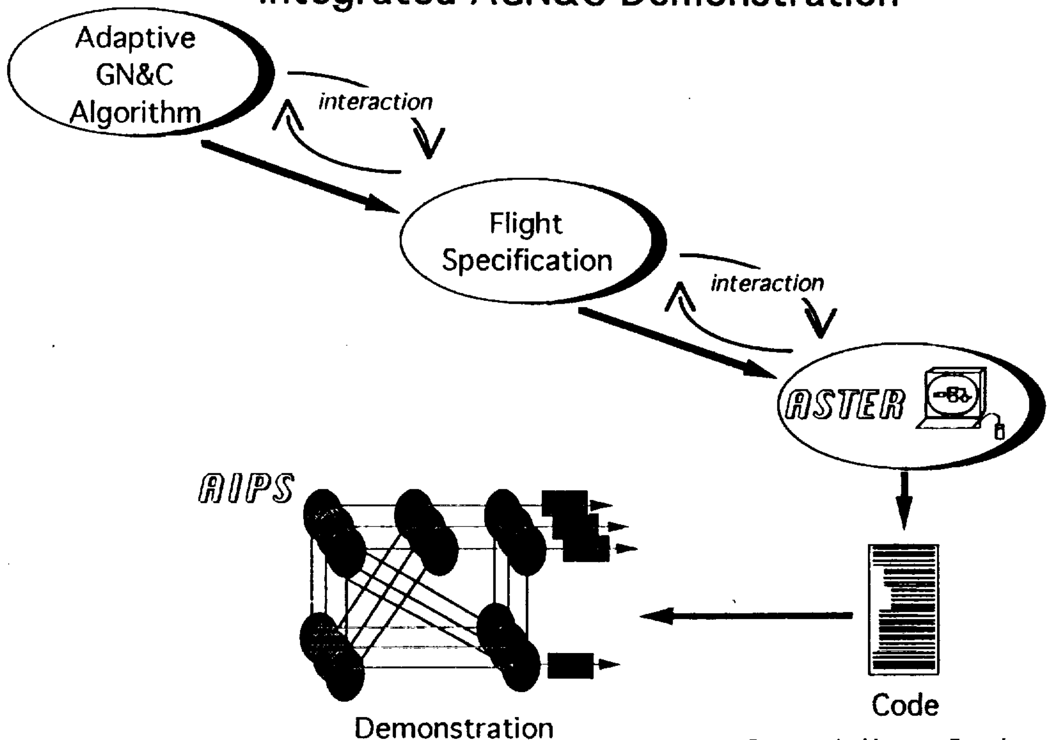
Objectives of AGN&C Demonstration

- Demonstrate the cooperative use of complimentary technologies within the Flight Systems Directorate
- Drive the development of ASTER
  - Vector/Matrix/Quaternion Operations
  - MATLAB™ Integration
  - Libraries

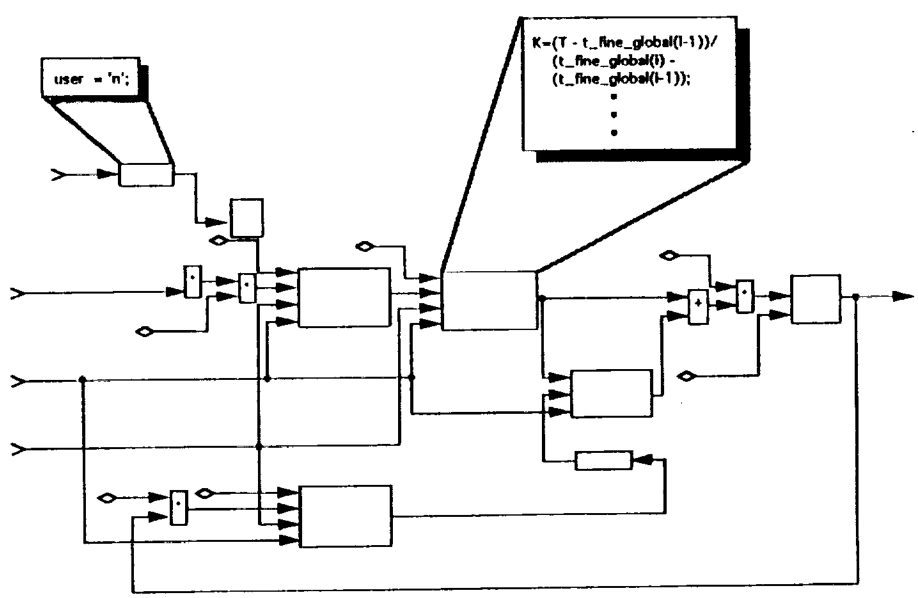
Approach

- Develop Finite Element Numerical Optimal Control (FENOC) Algorithm
- Develop flight software specification (MATLAB)
- Input specification into ASTER
- Generate Ada code
- Test code
- Execute on target architecture

Integrated AGN&C Demonstration



MATLAB Integration



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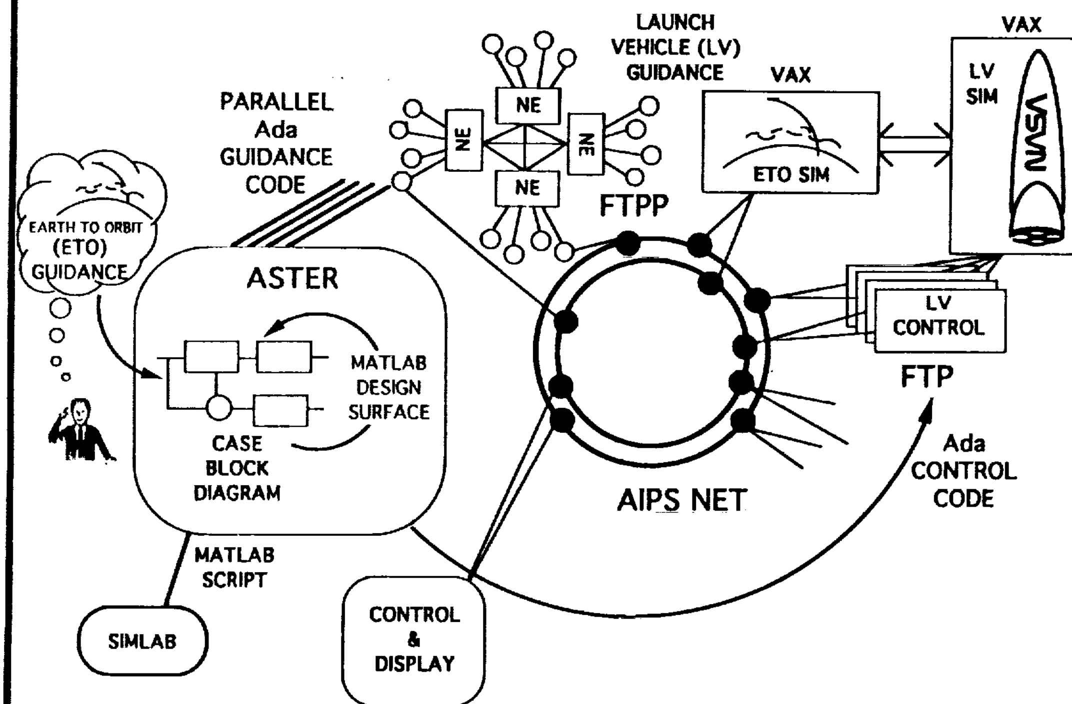
Integrated AGN&C Demonstration



Systems Architecture Branch

NASA Langley Research Center

Summary

- ASTER is a production quality code generation system.
- ASTER has been demonstrated on a variety of "real" applications.
- The AGN&C demonstration has identified ASTER enhancements.
- The AGN&C demonstration will illustrate the cooperative use of complimentary technologies within the Flight Systems Directorate.

Systems Architecture Branch

Related Publications

1. McDowell, M. E.: *Computer-Aided Software Engineering at The Charles Stark Draper Laboratory*. CSDL-P-2802, The Charles Stark Draper Laboratory, Inc., April 1988.

2. Walker, Carrie K.; and Turkovich, John J.: Computer-Aided Software Engineering: An Approach to Real-Time Software Development. *AIAA Computers in Aerospace 7*, October, 1989.

3. Turkovich, John J.: Automated Code Generation for Application Engineers. *AIAA/IEEE 9th Digital Avionics Systems Conference*, October, 1990.

4. *ALS CASE User's Guide*. The Charles Stark Draper Laboratory, Inc., Cambridge, MA, June, 1991.

5. Walker, Carrie K.; Turkovich, John J.; and Masato, T.: Applications of an Automated Programming System. *AIAA Computers in Aerospace 8*, October, 1991.

6. Jones, Denise R..; Walker, Carrie K.; and Turkovich, John J.: Automated Real-Time Software Development. *Technology 2002 Conference*, December, 1992.

7. *ASTER User's Guide*. The Charles Stark Draper Laboratory, Inc., Cambridge, MA, March 1993.

PANEL DISCUSSION

Howard Stone

I would like to have the panelists come up and be seated. While the panelists are coming let me add that we [the GNCTC] are going to be compiling the presentation material of this workshop into a NASA CP [conference publication]. We plan to send a copy of that CP to all who are interested in receiving a copy. If you are interested in receiving that publication please sign in on one of the yellow pads out in the lobby. We will also attempt to pick up the essence of this panel discussion for inclusion in the CP. To do that we are going to be videotaping the panel discussion. We do invite audience participation and to facilitate the taping process, we need to have everybody use a mike. If you have a question or a comment, wait for a mike to get to you. These mikes that are on the table are portable and we can move them around the room. Also, we have invited people to feel free to come up and use the view graph projectors in this discussion. If you do that, then please put on the lapel mike.

Let me now introduce our panel. Your participation is very much appreciated and the GNCTC at LaRC would like to thank each one of you [the panelists] for coming and being willing to participate.

From right to left, our first panelist is Tom Richardson from Boeing Defense and Space Group in Seattle. Tom has worked in control systems synthesis, aircraft stability and control, aeroelastic modeling, and flight control architecture designs. He has been responsible for developing techniques to achieve highly reliable digital flight control systems using advanced architectures, fault detection, and redundancy management techniques. He is currently manager of Boeing's Defense and Space Group flight control technology organization and is the program manager for the Air Force Strategic Flight Management Contract and the NASA fly-by-wire contract that Felix [Pitts] discussed earlier. Tom we appreciate you coming.

Our second panelist is Clint Browning from Honeywell in Clearwater, Florida. He is the Head of the Engineering Department for Space Shuttle Flight Control and is technical director for Honeywell on the ACRV program. Clint started out at Vought years ago. He worked Scout, something near and dear to us at Langley. He worked on the Small Spinning Upper Stage and the shuttle program. Also he worked with Boeing on a roll channel automatic landing system for the Boeing 727. Clint, we do appreciate you coming very much.

Next to Clint is John Hodgkinson from McDonnell Douglas Aerospace West in Long Beach. He is currently manager of Stability, Control, and Flying Qualities Technology and is responsible for methods development and research in these areas. Formerly he managed the YF-23 flight controls development at Northrop and was Director of Engineering Technology at Eidetics. He has served on two AGARD G&C working groups and the AIAA Atmospheric Flight Mechanics and GN&C technical committees. He teaches flying qualities at Northrop University where he is an Adjunct professor and is a lecturer in flight mechanics and stability and control at UCLA. Thank you, for taking time to be here.

Our final panel member is Dave Leggett from Wright Laboratory. Dave graduated from Georgia Tech and the Air Force Institute of Technology where he got his masters degree. He has been with the Flying Qualities Group for the last twelve years and has worked on aircraft projects such as the NT-33, F15/STOL, the Maneuver Technology Demonstrator, and the Variable In-Flight Stability Test Aircraft (VISTA). He now has the awesome task of directing the research supporting the revision of MIL-STD-1797. Dave, we thank you for being here and I will go ahead and turn the session over to you now.

Dave Leggett

The subject of this discussion is the direction of guidance navigation, and controls research needed to insure US competitiveness and leadership in aerospace technologies. I want to start off by saying one of our biggest challenges right now is the fact that research budgets are shrinking for absolutely everyone. One of the good things I heard in the last two days is talk of exchanging information and trying to set up channels of communication between different organizations. I think that we need to do more than just talk to one another. We are going to have to find ways to pool our resources and do joint research programs together -- that is the only way we are going to be able to put enough resources, enough mass on a given problem to solve it. I am going to focus just on the Air Force, I will let some of my compatriots here talk about the civil side of things.

I will start with where I think flying qualities needs some research. One of the areas we are particularly interested in is the development of standardized evaluation maneuvers for evaluating aircraft handling qualities. The lack of a standard set of evaluation maneuvers is part of the reason we have some discrepancies in our different flying qualities criteria and analysis methods. Another reason to develop standardized evaluation maneuvers was discovered by the review team during the digital flight control system development process review. We found out that, in a lot of cases, handling qualities testing has basically just become parameter ID. They just go up and do parameter ID and compare the numbers to the numbers in the spec. That was never the intent of the spec. We still intended aircraft handling qualities evaluation to be done using closed-loop evaluation by getting the pilot to really do some tasks and evaluate the aircraft for those tasks. In order to put that into the spec., as it seems now we are going to have to, we have to have some means of defining a standard task that we can use to compare all aircraft against. I think in the next few years we are going to be interested in developing a list of possible tasks to use as well as guidance to the SPO's on how to do those tasks.

Another area we are going to be interested in is in resolving a lot of the discrepancies in the current handling qualities criteria and the handling qualities analysis methods. Although there is a good bit of agreement among a many of the different criteria and analysis methods, there are also areas where they disagree. It seems like everybody has their favorite criteria and that leads to a lot of people mistrusting the other criteria. I think we need to resolve that to make a better flying qualities spec.

I will now move on to some other areas the Air Force is interested in. We seem to be expanding the envelopes of flight here and the Air Force is interested in what kind of capabilities those things will give them. A hot buzz word in recent years has been agility. I think Air Force interest in agility per se is kind of waning, there are a lot of reasons for that; however, I am not going to go into those now. There is one area of agility I think the Air Force is still very much interested in and that is high angle of attack. I think we are interested in trying to find out what we can do in that regime, how we can do it, and how we can control the airplane at high angles of attack. Another region of the expanding envelope that the Air Force is interested in is high-speed flight, or hypersonic flight. That is an area where if you just look at the budget, the Air Force budget for doing hypersonic research is shrinking. I do not think that is because of lack of interest, it is largely because of priorities and the overall budget is shrinking. That is an area where we have little data and we would like to know what can we do with that capability, how do we get it [the capability], and how do we control it.

Another area of interest which is not really a flight regime, is new control responses and unconventional flight modes. Examples are a direct speed control or a speed hold mode, or a level turn mode. When the AFTI F-16 or the F-16 CCV flew, we tried a bunch of unconventional modes and in the case of several of them, the pilots could not find any particular need for them at the time. Interestingly, some F-117 pilots came to talk to us about a year ago and mentioned that they'd love to be able to turn without banking the airplane so I think there are opportunities for these kind of unconventional modes opening up.

Another area that the Air Force is definitely interested in is application of multi-input/multi-output control design methods and other modern control methods. All those things go over my head so I do not think I will say too much about them other than to say that I know there are several offices in the Air Force that are definitely interested in pursuing these kinds of design methods.

The Air Force is definitely interested in areas of research to reduce pilot workload. I saw a lot of things here in the last two days that were looking in that area, in particular the use of displays to help reduce the pilots workload. One of the things the Air Force is working on getting some standardization in display symbols and in display formats -- we have been sponsoring some research in that area. I think it would help pilots as they transition from one aircraft to another if they did not have to learn a whole new HUD whenever they go to another airplane.

Another area in displays that I think might be being overlooked is display dynamics. If we are going to use displays to help the pilots do the tasks, if he is going to be depending on that display to do the job, then display dynamics are going to play a role in here too. In a lot of cases the displays depend on data from sensors which is filtered and that filter introduces dynamics that we are going to have to deal with.

Another item in the area of reducing pilot workload is automatic flight modes. More and more of what the airplane is going to be doing in the future is going to be done automatically. We have had automatic landing systems for some time, though the Air Force is even interested in making them autonomous automatic landing systems. There are other automatic systems that we are putting the aircraft now too: automatic collision avoidance systems and so forth. Those help in one way, to reduce pilot workload, but I think we also need to give some consideration on what is going to be the pilot's role in a system where he is less and less the pilot and more and more the system manager. I think there is some things we are going to have to deal with and explore about how the pilot is going to interface with this system.

Another thing the Air Force is interested in is new means and methods of generating forces and moments on the aircraft. Forebody vortex control is an example of that sort of thing. That is an area I do not know too much about but I do know that there are offices in the Air Force, particularly at Wright Lab, that are interested in that area.

Finally, I think virtually every combat aircraft from here on out is going to pay a lot of attention to stealth technology, and for the guidance and control folks that is a new challenge. A lot of these Stealth airframes have some really nasty aerodynamic characteristics and yet at the same time they put restrictions on control surfaces: how many, the shape, the size, and how much we can move them. We are being asked to do a lot more with a lot less with these configurations and I think that is another challenge for us.

At this point I think I will pass it onto you, John. I did manage to fill up the five minutes, did I not?

John Hodgkinson

We have a saying where I work that when, for example, we have to give a briefing to the vice president or something, it is time to raise the level of ambiguity of the discussion. That is really what I'm going to do for a minute. I'm going to talk on very ambiguous terms.

In asking what the direction of our research should be, we need to recognize that we [the aerospace industry] are a small analogue of what is happening in this country. So when you look at what comprises U.S. competitiveness and what is U.S. leadership, you think of certain categories of things that we do well, and things that we do not do so well. The things that we do not do so well are the things that are the focus of total quality management, such as cranking out products that are good, reliable, and on schedule, and talking to the customer. That kind of scheduled activity is one thing that, we are working very hard to do better and to compete better on.

In the other category of things that we well, and which we do not focus sufficiently on, because it is much more difficult to quantify, is the unforeseen breakthrough research that proceeds from a brilliant insight. This nation, by virtue of its culture, has repeatedly provided such breakthroughs over the decades. It is a very difficult thing to manage, and it is a very difficult thing to fund. I know we all draw research schedules. We have five year plans - and I think my friends at St. Louis have ten year plans - for the research we are doing. It is very hard to imagine any breakthroughs happening on a ten year plan of that kind. However, *the inspirational, exploratory research is something that we -- and I believe this very, very strongly -- should preserve in this country.*

Okay, I will be a little more specific now. Some statistics that I heard from Bruce Holmes really interested me. I think one of the statistics was that 83.7 percent of general aviation accidents had human factors as a contributing factor. I think that was the number -- I wrote it down. It is certainly a very dramatic one [number]. We look very carefully at the statistics where I work and in the last thirty years of commercial airplane operations fifty percent of airplane losses have involved primary flight crew error. So it seems to me that we are doing an excellent job of making sure that control systems, structures, and so on are safe. Fail-safe technology twenty-or-so years ago dramatically improved airplane safety. I know we have experts here (at LaRC) on redundancy management and work is needed to insure that kind of thing continues. It seems to me, however, that the *human element is the one area where the real pay dirt is in assuring further advances.* Furthermore, we are fortunate in this country, because of a culture that encourages people to speak out, to have the kind of excellent test pilots (like Lee Person and Rob Rivers here, for example) that could be a big help to us. *We [the engineers] need to listen to those folks and they need to continue talking to us.*

Bottom line -- NASA and its partners need to focus on the inspirational kinds of research, the exploratory kinds of research and, furthermore, I'd suggest that we look at the human interfaces being an area that has a lot of payoff.

Clint Browning

I really appreciate the opportunity to be here and participate with these distinguished panel members and to be a part of this workshop program. I have just a few charts that I want to use to emphasize the area that we are addressing. I want to present the priority needs from the space standpoint and our overall aerospace industry [see figure 1]. I realize this list is not complete and the more people I talk to within my company, the longer the list kept getting. I'm sure you can think of others that are important to competitiveness and leadership. The first item, which Howard mentioned this in his opening talk, is *the need to reduce launch operations cost.* About this there can be no doubt. There is also, I think a great pay back to be gained from applying the so-called dual use technologies, the kinds of things that the military and commercial industry are working, that have application in space and sometimes vice versa. Shortening the design cycle is a critical area that we are all facing; the kind of time lines that we have been dealing with in the past, from both the schedule and resources standpoint just cannot continue. We have got to find ways to do it faster, quicker, and cheaper as well as with increased quality. [We need to] increase fault tolerance. [We need to] promote cooperative government /industry joint research -- which we heard some of these gentlemen already refer to.

Space Vehicle GN&C - Priority Needs

- Reduce Launch Operations Cost
- Apply "Dual Use" Commercial and Military Technologies
- Shorten the Design Cycle
- Increase the Fault Tolerence
- Promote Cooperative Govt/Industry Joint Research

Figure 1 - First Vu-Graph of Clint Browning's Talk

To insure U. S. aerospace leadership, we must focus technology dollars to reduce the operations cost. One area that I believe would have benefits is to reduce the complexity. Systems like the space shuttle have a tremendous amount of complexity to them. On a system like the shuttle there may be sixty or eighty subcontractors providing LRU'S for the avionics. Reducing the actual number of LRU'S, the interfaces, simplifying the certification/verification/check out process, and improving the system reliability and availability all potentially reduce launch delays due to system complexity. We need to make avionics cheaper. Using commercial off the shelf components may be the way to go. One area for space that has to be a concern is the radiation effects, the SEU tolerance has to be considered. I might also mention an area that needs, I believe to be seriously looked at, is the S level parts requirement that has been imposed upon space avionics components. With today's total quality management, perhaps the thing that needs to be done is to certify a process and a company that is producing very high quality parts and not impose the S level in all areas. Also lets get vehicle health management out of the talking stage, integrate and demonstrate the use of sensors, the diagnostics, and the processing for self monitoring. The expected pay-off is to reduce the army that required to launch these vehicles. These areas are not new to anyone but I think they are certainly areas that need dollars and technology research applied.

In navigation a lot of work is being done in integrated autonomous navigation, particularly related to the GPS inertial navigation systems and particularly in the terminal phases of the missions where the differential mode has added high accuracy to the GPS approach. There is a lot of work going on in avionics companies with highly fault tolerant INS/GPS combinations. I think these are areas that navigation can help in terms of competitiveness, and even the part that the GPS might play in the attitude determination.

I might just break right here and say, personally, and I think from our standpoint at Honeywell, I'm very impressed with the research this is going on throughout this organization from what we heard over the last two days and we are relating to some of what has been said here.

In automation, the cockpit displays and hand controls is an important area. Do you go on up to the six degree of freedom hand controls? This whole area of the role of the crew versus automation has been mentioned, and that applies not only to the cockpit crew but to the ground crews. What is the role of those that are working on the preparation for the launch? What is the role of those that are on board the vehicle and the impact on autoland and safety. Due to physical deterioration in space, autoland becomes more and more critical the longer people stay in space. It will be more of a consideration for the sixteen day orbiter, moving on up to a twenty eight day orbiter, and perhaps longer for moon and Mars missions. It is generally felt that autoland is an absolute necessity. Advanced guidance concepts are required to expand flight envelopes, and therefore not be so dependent upon the weather, both for launch and return.

A high level of functional integration and fewer boxes has been a focus in the military arena. Flight control, navigation, the processors, air data, radar altimeter, and perhaps terrain following can be combined into a single small avionics box. I think there is a lot of promise there, in terms of reducing the complexity and the number of interfaces to be dealt with. A lot of good work is going on in these areas. We do need a practical application and demonstration in some real life examples.

Reducing the design, test, verification, and integration cycle is very important. Integrated product development using integrated product teams can be cost effective by bringing different disciplines together, cutting down the time for serial functions, and performing parallel functions. I this believe ought to be encouraged and has great potential and we see many companies beginning to adopt this approach. Rapid prototyping, going all the way from the requirements/specifications through the analysis and design and the automatic code generation to the hardware and the integration, testing, and check out, has a tremendous opportunity to offer a competitiveness advantage which ought to all be encouraged. We have seen some indications of a three to five hundred percent productivity increase. What normally might take two hundred dollars as an industry standard to generate a line of ADA code is reduced to the twenty dollar range, which I think ought to continually be explored.

The Tagutchi design of experiments approach should be applied not only to the front end of the development process but as the systems analysis progresses application to the production manufacturing area and tests will reduce the test matrices associated with all the combinations and the parameters that have to be tested. Even application into the wind tunnel testing should reduce the amount of tunnel time required.

The need for increased fault tolerance in some ways flies in the face of the need to reduce complexity. The Space Shuttle quad system is tremendously complex and expensive, yet many of the unmanned launch vehicles have had a single string failure point in which a single failure will ruin the mission. Now we are seeing more and more of the launch vehicle companies begin to look at the increased fault tolerance because the cost of the payloads is becoming prohibitive to lose. There is a balance that must be found. The use of the standard buses and the open architecture's using modular approaches to help make the avionics easier to integrate.

The last direction is to actively promote joint government research where government in many cases does provide some study funds or in the cases of memorandums of understanding where both put up some funds for proof of concept . We had an excellent cooperative arrangement with NASA/Langley on the 737 INS/GPS autoland test. This helps get some things started that if industry or just the government kept them to themselves, it might not flourish. I must say on the other side of that coin though that industry is in business to make money and if this is all that ever happens, there is no pay back and there is no way that we can survive. There has to be some hope of a program or project, a way to sell something and to make some money. Many times companies are penalized for doing this. It might be best, from a business standpoint, to stand back and let somebody invest their money waiting for the proof of the concept and then step in and build something. There is another side of this that we really must watch and be careful because by the time the government gets ready to deploy a system, anybody could come and figure out how to do it and build it. Many companies started out on the INS/GPS research years ago. By the time that it is deployed or certified for flight, there is fifty competitors out there that can build and market the system. How do you help make it attractive for companies to do this kind of research? It is not the subject for a technical audience but you may find some companies are reluctant to engage in this research so I raise it as an issue. Thank you very much.

Tom Richardson

First of all, I want to thank you for inviting me. This has been very interesting and illuminating to see the whole of guidance/navigation/control at NASA/Langley and some the Air Force effort. Second of all, I want to thank all of you hard-core attendees for staying around on a Friday afternoon. I looked at panel discussion on the program and I thought, well my goodness, there is going to be about five people out there on Friday afternoon -- so thanks for sticking in. I think it is worthwhile. None of us [on the panel] collaborated on what we were going to say but a lot of the themes are similar and I think the big drivers are the shrinking budgets and also the need to do better. These two factors are somewhat at odds, but I think we (in the research community) have got to do better and can do better. We do that by improving efficiency and by focusing our research.

One of the things I want to hit on in particular is focusing our research. We saw a lot of tremendous papers today and it is good to see all this basic research going on and I think that it ought to continue. When I look at the way aerospace research is defined, I see two basic varieties. There is basic research, which is far term, and applied research, which always has a near term payoff and has some other attributes. It is kind of gray as to where near term and far term is, but some things people at LaRC work with are clearly far term. Often you can't see where the research is going and maybe only twenty five percent of those efforts will be successful. But that basic research should go on -- because of that twenty five percent. I'd like to direct my subsequent comments more to what I would call *applied research*, things that have more of a near term payoff and that are going to be applied to our critical national needs. The application could be military or civilian.

I made a list! I made a list [see figure 2] of some of the big things. I may have missed some things, but I think it is important to develop a list to kind of categorize things. You have to market the research we do to the folks that control the money and I do not see how you can do it without prioritizing things.

GN&C - Priority Needs

- PIO
- FBL/PBW
- Design Process
- Airplane sizing and concept development
- Development of the airplane database
- Rapid prototyping of simulations
- Testing Methods
- Multivariable Nonlinear Control Design Methods
- Real Time Trajectory Generation

Figure 2 - First Vu-Graph of Tom Richardson's Talk

<u>Pilot Induced Oscillation (PIO)</u>

It keeps coming up. It has been known for years and my feeling is, the reason it is never solved, is that every time it happens the program manager gets by it somehow and says "Well, that is it, we have gotten that out of the way," and hopes that it will never happen again. Of course it does happen again and it is a big thing. *It is probably one of the biggest problems we have in flight controls.* If you want to focus problems in the controls area, pilot induced oscillation is a choice with which I agree wholeheartedly. We need some standards, we need to agree on what the criteria is that we are working towards, and we need to agree on some kind of design process. If you are talking PIO, then pretty soon you see the need for a better simulation of a pilot and their dynamic response. There is a lot to be done in this area (PIO) but it is a very important area.

Fly by Light/Power by Wire

This term may be a little bit constrictive, as it really should be something like *Advanced Vehicle Management Systems*. That is the title the Air Force gives it. There is a real need for research in this area, which addresses the question of how do you implement these complex systems that are feasible now. The guidance/navigation/control function at NASA Langley is kind of the way we organize thing. In my area, we focus more the algorithm development. However we work very closely with the people that do the actual implementations and are concerned with system architecture aspects. I think that is important, so I look along this Fly by Light/Power by Wire task as addressing the overall system architecture. There are many issues. What is the best way to blend photons and electricity? How do you best do it, how do you get by with the minimum amount of equipment to achieve redundancy or are you just going to go QUAD every time? There is a lot of weight involved and there is a lot of cost. In fact, one of the big drivers now in the work we do is cost.

Design Process

Everybody is mentioning the design process. It is very important that we have a good understanding of what our process is. It is hard to quantify. The reason it is hard [to quantify] is because it is not only events that happen, it is they happen in certain times in the design process and there is a lot of feedback. Getting that [the design process] nailed down where everybody understands what is to happen is crucial. It is got to be done faster. We have to figure out ways to automate things. Things like automatic code generation will help.

Airplane sizing and concept development

There is lots of other issues in airplane sizing and concept development. We have mentioned agility. I do not know if everybody appreciated what they are talking about in the agility study but what is important is more of the up front work when you are sizing the airplane, that you do not just size it to performance. You should size it for maneuvering and I think that is very important. Even if it is done very simplistically, it needs to be done up front. Otherwise they are going to give you an airplane and say, "Okay there it is, go make it fly, ... by the way we want to go zero to ninety degrees bank angle in a quarter of a second." So, there is a lot of work, there is a lot of activity that is done in the early sizing and concept development. *If the flight controls people do not participate in that, or if we are too slow, we get left in the dust.* I have been on a lot of programs where you just got a new program, you are all happy and settling in and they say "Oh, the flight control systems spec. has to be out in three weeks" and you barely have time to type it in that time and they say "Well, put it out and we'll fix it later on when we get a little bit smarter" and you know how that goes.

Development of the Airplane Database

This is very critical and it kind of goes in with airplane concept development [,which is discussed above]. I think we need more analytical methods and less dependence on a wind tunnels. We have some very good panel methods. There is the PANAIR code [at Boeing], there is vortex lattice, there is things can give you a quick answer -- not the best answer maybe, but codes that can give you a quick answer to get you going. We have to think about ways to do database development more quickly and have less reliance on the big ticket items. Wind tunnel testing is still a big ticket item. In a major program like the F22, the relative cost of wind tunnel testing is not so high. Testing is especially a big ticket item when you are in the some R&D program where you have got some limited funds to put some things together. Here, the cost of wind tunnel testing can wipe out your entire program.

Rapid Prototyping
This is important in all areas, and in simulation in particular, There is a lot of comment about the portability of software, and I strongly feel that we ought to be able to run our simulations at our work bench and have that same code run in the real time environment. That give is you two things. One, it gives you speed. You can transition more quickly, you do not have to go back and recheck the thing out in real time, with everybody sitting around watching you. Two, it lets you control the database. You have got the database in your area, and you do not have to worry because you have one [database] and somebody else has another and you can never figure out who has the right one. Code portability puts more of the focus [of database control] on the people doing the work. This is critical. All of the technology for creating this good situation is there. It is a matter of organizing it [the technology] and figuring out how to make it work. There is a lot of near term payoff here. We have done a lot of work in this area at Boeing and it has been very fruitful.

Testing Methods
A paper presented earlier described flutter testing and procedures used to come up on the flutter point, an unstable situation. The techniques described in that presentation can be applied to any test situation, particularly of something that has conditional stability. The investigation of PIO comes to mind. We need more formalized methods. This is an area that can have important near term payoffs if worked.

Multivariable Nonlinear Control Design methods
Many of the methods at technologies in this area are mature. We have some excellent methods. For the near term, they [the methods] need to be packaged. I am excited about an Air Force program , "Design Guidelines for Multivariable Control", that will attempt to systematize this area. They [the Air Force] are going to apply modern methods to some Air Force aircraft.

Real Time Trajectory Generation
We need real fast algorithms that work reliably and automatically. They [the algorithms] need to be robust. They really need to work in real time. The need occurs all the time, particularly in military aircraft. Something happens on a mission and the pilot must replan. This is a big problem. The pilot is faced with a 4D navigation and optimization problem with N constraints. The constraints may be involve survivability, fuel state, and wind conditions. Something to give a quick, not necessarily completely optimal, answer is required. Genetic algorithms may be fruitful here.

Well, that is my list. It is not an exhaustive list, it just the ones I know about. I should mention that the order of the list is not intended to reflect priority. The order is simply the order that these issue occurred to me.

The final chart [figure 3] I have labeled "Panel Action", but the action is really for everyone. Come up with a [prioritized] list of the applied research to be done.

Panel Action

- Priority list of applied research - problem statement
- Objective - vision of the future
- Plan for validating technology

Figure 3 - Second Vu-Graph of Tom Richardson's Talk

Problem Statement

Creating the list must proceed from the problem statement. One should start with the question, "What are the problems we have with aerospace vehicle design?"

Objective - vision of the future

We need to ask: "What is the objective? What are we trying to get out of all this?" We need to have some vision of the future, of what we want to exist 3-5 years from now. We might say, "We want to have the ability to quickly do these simulations and not have to fool around with these ways that we have always done them in the past."

Plan for validating technology.

We need a plan for validating the technology developed. Some of the work required here is in place, some needs help.

That is pretty much all I had. Thank you very much.

[The panel then moved to a question and answer period that was not readily transcribed. However, the videotape of the entire panel discussion, including the question and answer period, is easily followed by someone with a technical background and a copy may be obtained from the LaRC GNCTC. - Editor]

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A highlight of the workshop was the panel discussion which addressed the following issue: "Direction of Guidance, Navigation and Controls research to insure U.S. competitiveness and leadership in aerospace technologies." The panel consisted of representatives from Wright Labs, Honeywell, Boeing, and McDonnell Douglas that are respected in the GNC&D field. A transcript of the discussion is included in these proceedings.

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