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SSTAC/ARTS REVIEW OF THE DRAFT INTEGRATED TECHNOLOGY PLAN (ITP)

Volume VI: June 26-27

Controls and Guidance

Briefings from the
June 24-28, 1991 Conference
McLean, Virginia

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SSTAC/ARTS REVIEW OF THE DRAFT ITP
Mclean, Virginia
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Controls and Guidance

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Overview of Guidance and Controls Programs

NASA Headquarters
OAET/Code RC

June 26, 1991

John Di Battista

GUIDANCE AND CONTROL PROGRAM

OBJECTIVE:

Advance critical areas of enabling and enhancing transportation and spacecraft guidance and control technologies that support civil, commercial, science, and exploration missions for the 1990's and beyond. The technology program consists of research and technology development in:

- Guidance Technology
- Controls Technology
- Computational Controls Technology

GUIDANCE AND CONTROLS
RESEARCH AND TECHNOLOGY
PROGRAM BASIS

- **NATIONAL AERONAUTICS AND SPACE ACT OF 1958**

  ...Space activities...shall be conducted so as to contribute materially to...

  (4) The establishment of long-range studies of the potential benefits to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes;

  (5) The preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere;...

Space Technology to Meet Future Needs...Joe Shea Committee 1987

SPACECRAFT

....concepts such as adapatively controlled structures should be developed ......pg 104

TRANSPORTATION VEHICLES

There is a need for modern technology in future vehicles of all classes to enable new capabilities such as heavier lift capacity, to improve reliability, and to lower cost......pg 15

GUIDANCE AND CONTROLS PROGRAM HISTORY

- **1958 - 1980.................... RESEARCH AND TECHNOLOGY PROGRAM TO SUPPORT RIGID BODY SPACECRAFT CONTROL WITH FLEXIBLE APPENDAGES AND PROVIDE CONTROL SUBSYSTEM COMPONENT TECHNOLOGY**
- **1984.................................SDIO SUPPORT TO CONTROLS INITIATED**
- **1978 -1984......................DARPA ACTIVE CONTROL OF FLEXIBLE STRUCTURES (ACOSS) PROGRAM**
- **1980....................................PROGRAM INITIATED TO SUPPORT LARGE COMPLEX AND FLEXIBLE SPACECRAFT**
- **1982....................................CODE R CONTROLS STRUCTURES INTERACTION PROGRAM INITIATED**
- **1988....................................PROGRAM PLANNING INITIATED TO PROVIDE ADVANCED GUIDANCE TECHNOLOGY (ADVANCED LAUNCH SYSTEM TECHNOLOGY PROGRAM)--1989**
- **1989....................................COMPUTATIONAL CONTROLS PROGRAM IDENTIFIED**

GUIDANCE AND CONTROLS PROGRAM

HISTORY

CONTINUED)

1989 - 1991......................EXPLORATION TECHNOLOGY PROGRAMS IN AUTONOMOUS RENDEZVOUS AND DOCKING AND AUTONOMOUS LANDER

1990...................................LAUNCH VEHICLE AVIONICS PLANNING INITIATED BY STRATEGIC AVIONICS WORKING GROUP

GUIDANCE AND CONTROL PROGRAM

APPROACH:

- IDENTIFY TECHNOLOGY NEEDS THROUGH STUDIES, FUTURE MISSION REQUIREMENTS AND GUIDANCE FROM CODE M,S, OTHER GOVERNMENT AGENCIES AND COMMERCIAL PROVIDERS,THE SSTAC AND THE STRATEGIC AVIONICS WOKING GROUP, AND OTHERS.
- IDENTIFY THE CENTERS WITH THE BEST CAPABILITIES AND FACILITES FOR THE IDENTIFIED TECHNOLOGY AREAS
- DEVELOP A COORDINATED PROGRAM USING INPUTS FROM CENTERS AND NASA HEADQUARTERS
- ESTABLISH PARTNERSHIPS BETWEEN THE CENTERS, INDUSTRY, UNIVERSITIES, AND OTHER GOVERNMENT LABORATORIES
- BASE PROGRAM ELEMENTS CARRY OUT GENERIC RESEARCH AND TECHNOLOGY
- FOCUSED PROGRAM ELEMENTS HAVE ADVANCED BRASSBOARD DEMONSTRATION WHICH CONTRIBUTING TO TECHNOLOGY TRANSFER, AND WHEN APPROPRIATE, PARTICIPATE IN FLIGHT EXPERIMENTS
- TRANSFER TECHNOLOGY TO THE USER FOR USE IN DEVELOPMENT OF OPERATIONAL FLIGHT SYSTEMS

GUIDANCE AND CONTROLS PROGRAM

BENEFITS:

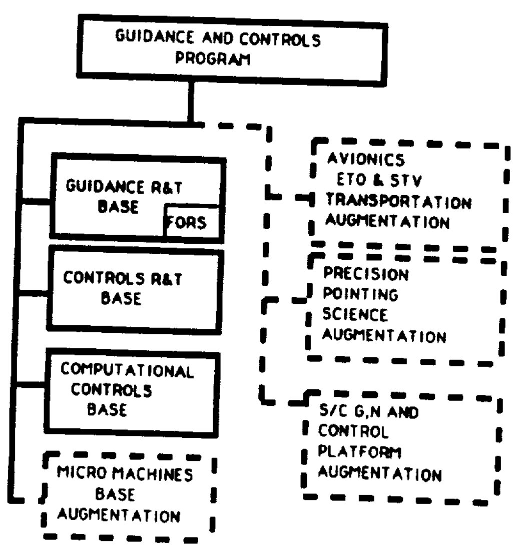
• CRITICAL ENABLING GUIDANCE AND CONTROLS TECHNOLOGIES ARE PROVIDED IN ACCORDANCE WITH THE NATION'S LONG RANGE GOALS TO MAINTAIN THE PREMANCE OF OUR SPACECRAFT AND TRANSPORTATION VEHICLES

AND ENABLE THE DEVELOPMENT OF THE FOLLOWING TECHNOLOGIES:

- PROVIDE NEW AND EFFICIENT ADAPTIVE GUIDANCE ALGORITHMS
- PROVIDE HIGHLY RELIABLE DISTRIBUTED FAULT TOLERANT CONTROL SYSTEMS TECHNOLOGY
- PROVIDE ROBUST CONTROLS TECHNOLOGY FOR LARGE COMPLEX SPACE SYSTEMS INCLUDING SYSTEM IDENTIFICATION, ADAPTIVE CONTROL, PRECISION METROLOGY, SENSORS AND ACTUATORS
- PROVIDE COMPUTATIONAL CONTROLS TECHNOLOGY ENABLING ORDERS OF MAGNITUDE INCREASES IN THE ABILITY TO DESIGN, SYNTHESIZE, ANALYSE AND SIMULATE LARGE COMPLEX SPACE SYSTEMS

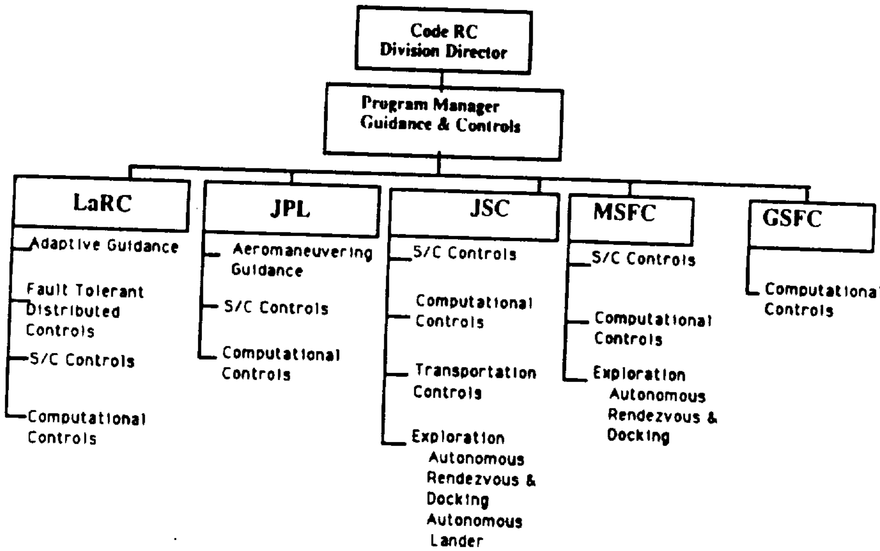
GUIDANCE AND CONTROLS PROGRAM

WORK BREAKDOWN STRUCTURE



GUIDANCE & CONTROLS PROGRAM

ORGANIZATIONAL CHART



GUIDANCE & CONTROLS PROGRAM

STATE OF THE ART:	Today	Goals
Guidance Technology ● Shuttle ● Planetary S/C and Probes	● Precalculated I loads / weather ballons ● Spinning Gyros/Image Dissectors Star Trackers ● Ballistic Planetary Entry with Aerodynamic Deceleration	● Day of Launch kI Loads/ Lidar Wind Sounders ● Fiber Optics Rotation Sensor Aeromaneuvering
Fault Tolerant Distributed Control ● Shuttle/Titan/ Atlas-Centaur/Delta	● Shuttle Triple Redundancy with Actuator Force Fight ● Titan/Delta Single String S- Level Parts ● Centaur Dual String Redundancy ● AIPS Fault Tolerant Architecture Technology	● AIPS Architecture Implementation with B-Level Parts ● Launch on Schedual with Fault ● Vehicle Health Management
Spacecraft Control ● Rigid Body Control Theory ● Gains Adjusted On Orbit toAccomodate Deployed Configuration Control	● Galelo Spun/Despun Control Hubble,Ulysses, & Mariner ● Flexible Appendage Thermal System /Control System Interaction ● Grond Based Large Space System Controls Testbeds	● Robust S/C Control with On Orbit System I.D and Adapt. Controls for Complex S/C including Growth SS,Multi-Instrument Platforms and Large Segmented Telescopes
Computational Controls ● Efficient Computational Algorithms ● Real Time H/W in the Loop Simulations ● Parrallel Processing User Friendly Interface	● Order N Algorithms/Symbolic Logic ● Discos, Treetops, Matrix X , etc ● Space Station Dynacs Simulation ● Craft Cassini Control Simulator Interface	● Parallized Order N Algorithms ● Parallel Processing on Super-computers with real time H/W in the loop simulations ● Mcintosh like interface

GUIDANCE AND CONTROLS PROGRAM FACILITIES

- PLS SIMULATOR
- AIRLABS
- ACES/CASES
- SCOLE
- CARL

GUIDANCE & CONTROLS PROGRAM

ACCOMPLISHMENTS:

- Developed Generic 100 Faster Space Station Controls Simulator with Order N Algorithms, Symbolic Equation Manipulator and Parallel Processing
- Demonstrated Navigational Grade Fiber Optics Rotation (FORS) Gyro
- Developed Treetop, Contops and Order N Discos Controls/Simulation Codes
- Developed SHAPES Sensor for Large 100 M Antenna Control
- Provided Controls Algorithms Technology to Hubble Space Telescope for Solar Array Thermal Pumping Problem Fix
- Provided Real Time PLS Controls Simulator
- Provided Adaptive Guidance LIDAR Winds Aloft Technogy
- Demonstrated distributed fault tolerant Advanced Information Processing System Breadboard
- Developed for demonstration Astro Solid State CCD Star Tracker Saving Mission
- Developed robust efficient adaptive control system identification and control algorithms technology for large complex systems

GUIDANCE & CONTROLS PROGRAM

PICTURES
OF
SS Workstation
FORS
HUBBLE
PLS
LIDAR
ASTRO
AIPS
ETC

GUIDANCE & CONTROLS PROGRAM

PROGRAM MILESTONES:

GUIDANCE PROGRAM

- PERFORM LIDAR WINDS PROFILE TESTS AT KSC --1991
- DEVELOP STOCASTIC ETO GUIDANCE ALGORITHMS AND TRAJECTORY DESIGN TOOLS-- 1992
- COMPLETE BEADBOARD OF A. I. BASED STAR TRACKER--1993
- COMPLETE FORS SINGLE AXIS ENGINEERING MODEL--1993

CONTROLS PROGRAM

- COMPLETE SPACECRAFT MCONTROL SYSTEM DESIGN GUIDELIE DOCUMENT --1992
- COMPLETE RMS CONTROL SYSTEM UPGRADE DESIGN PLAN--1992
- DEMONSTRATE PRECISION STRUCTURE (INTERFEROMETER) SHAPE MEASUREMENT--1992
- COMPLETE PRELIMINARY MICRO GYRO DESIGN--1993
- VALIDATE AIPS CHARACTER ARCHITECTURE--1995

COMPUTATIONAL CONTROLS

- UPGRADE DISCO WITH FLEXIBLE ORDER N DISCO --1992
- MBODY MODEL REDUCTION COMPONENT REP. S/W--1994
- 10 MSEC REALTIME SYSTEM SIMULATION (400 STATE CAPABILITY)--1996

GUIDANCE & CONTROLS PROGRAM

RELATED NASA PROGRAMS:

- CODE R CONTROLS STRUCTURES INTERACTION PROGRAM
- CODE M BRIDGING TASK IN ADAPTIVE GUIDANCE
- CODE R AERONAUTICS CONTROLS PROGRAM
- CODE R NASP GUIDANCE AND CONTROLS PROGRAM

RELATED GOVERNMENT PROGRAMS

- SDIO CONTROLS PROGRAMS IN COMPLEX SYSTEMS AND ADVANCED AVIONICS PROGRAM
- DOD ADVANCED LAUNCH SYSTEM (ALS) PROGRAMS IN ADAPTIVE GUIDANCE AND FAULT TOLERANT AVIONICS

GUIDANCE AND CONTROLS PROGRAM

RESOURCES ($,M)

	FY91	FY92	FY93	FY94	FY95	FY96	FY97
Existing Program							
GUIDANCE AND CONTROLS	4650	5205	5700	6450	7000	7900	8900
GENERIC HYPERSONICS	328	340	370	420	490	560	650

RESOURCES BREAKDOWN FY 92 ONLY	FY92
GUIDANCE TECHNOLOGY	1355
CONTROLS TECHNOLOGY	2990
COMPUTATIONAL CONTROLS	1200

NEW AREAS FOR AUGMENTATION REQUESTED:

- TRANSPORTATION VEHICLE AVIONICS - 1993
  - AUTONOMOUS RENDEZVOUS & DOCKING- 1994
  - AUTONOMOUS LANDER- 1994
  - PLATFORM G,N&C - 1994
  - PRECISION POINTING - 1994
- MICROMACHINES - 1995

Transportation Technology

Earth-To-Orbit Transportation

Earth-to-Orbit Vehicle Avionics

OBJECTIVES

- **Programmatic**

  Develop vehicle avionics which support minimization of life cycle costs; multi-program implementation; integrated flight and ground infrastructure; continuous customer driven requirements; effective technology utilization and evolution; minimization of life cycle costs; ability to recover and fly with failures; mudular, scalable, maintainable and robust; increased performance and long term safe operations; rapid prototyping, demonstration, and multi-test bed supportability

- **Technical**

  The specific areas of technology development are avionics architectures technologies and required advanced software; vehicle health management (VHM) advanced technology concepts; guidance, navigation, and control advanced algorithms and development environments; electrical actuators technology development; advanced power management and control systems; landing and recovery systems technology development

SCHEDULE

- Identify critical avionics technology requirements (1993-1996)
- Define avionics architecture concepts (1995-2002)
- Define VHM advanced technology concepts (1993-1996)
- Complete advanced power management architecture definition (1993)
- Define GN&C design tools for rapid prototyping (1994)
- Define GN&C advance algorithms (1993-1998)
- Define electrical actuation (ELA) power systems (1993)
- Advance recovery system Phase IIIA at MSFC (1993-1995)
- Define requirements for modeling and large scale test of advanc recovery system (1995-1997)

RESOURCES:

- 1993 $ 7.0 M
- 1994 $11.0 M
- 1995 $23.0 M
- 1996 $35.0 M
- 1997 $36.5 M

PARTICIPANTS

Avionics Architecture	ARC, JSC, & LaRC
Avionics Software	ARC, JSC, & LaRC
Vehicle Health Management	LeRC & MSFC
Guidance, Navigation, & Control	LaRC, JSC, & JPL
Electrical Actuation	LeRC & SSC
Landing/Recovery Systems	JSC & MSFC
Power Management & Control	LeRC

Transfer Vehicle Avionics

OBJECTIVES

- **Programmatic**

  Develop vehicle vehicle avionics which support minimization of life cycle costs; multi-program implementation; integrated flight and ground infrastructure; continuous customer driven requirements; effective technology utilization and evolution; minimization of life cycle costs; ability to recover and fly with failures; modular, scalable, maintainable and robust; increased performance and long term safe operations; rapid prototyping, demonstration, and multi-test bed supportability

- **Technical**

  The specific areas of technology development are avionics architectures technologies and required advanced software; vehicle health management (VHM) advanced technology concepts; guidance, navigation, and control advanced algorithms and development environments; electrical actuators technology development; advanced power management and control systems; landing and recovery systems technology development

SCHEDULE

- Identify critical technology areas for architecture development (1994-1996)
- Develop test bed concepts for architecture and software requirement definitions (1997-1999)
- Define operational and environmental requirements for VHM support to transfer vehicle (1993-1995)
- Define and develop VHM methods and concepts (1994-1998)
- Develop GN&C rapid prototyping requirements and test bed approach (1993-1995)
- Develop GN&C sensor requirements and algorithms for transfer vehicle (1994-1997)
- Identify key design concepts for tether control in support of micro-g management, power generation, etc. (1993-1995)
- Develop new control strategies for tethers and verify thru detail dynamic simulations (1995-1999)
- Support technology development and system design using magnetostrictive actuator servo values
- Complete requirements for ultra reliable, universal, modular smart power backbone system (1995)

RESOURCES

- 1993 $ 5.0 M
- 1994 $ 9.0 M
- 1995 $15.0 M
- 1996 $32.0 M
- 1997 $44.3 M

PARTICIPANTS

Avionics Architecture	-	ARC, JSC, & LaRC
Avionics Software	-	ARC, JSC, & LaRC
Vehicle Health Management	-	LeRC & MSFC
Guidance, Navigation, & Control	-	LaRC, JSC, & JPL
Electrical Actuation	-	LeRC & SSC
Landing/Recovery Systems	-	JSC & MSFC
Power Management & Control	-	LeRC

April 25, 1991
DRS QUAD12

Transportation Technology

Low-Cost Commercial Transport

Commercial Vehicle Avionics

OBJECTIVES

- **PROGRAMMATIC**

  Develop vehicle avionics which support minimization of life cycle costs, commercial implementation; integrated flight and ground infrastructure; continuous customer driven requirements, effective technology utilization and evolution; minimization of life cycle costs, ability to recover and fly with failures; increased performance and long-term safe operations; rapid prototyping, demonstration, and multitest bed supportability

- **TECHNICAL**

  The specific areas of technology development are avionics architectures technologies and required advanced software; vehicle health management (VHM) advanced technology concepts; guidance, navigation, and control advanced algorithms, and development environments; and advanced power management and control systems

TASK SCHEDULE/MILESTONES

- Identify critical avionics technology requirements (1993-96)
- Demonstrate avionics archirecture conceps (SW and HW) components (1995-2002)
- Define advanced VHM concepts (1993-96)
- Demonstrate advanced VHM applications (1995-2002)
- Complete power management architecture definition (1994)
- Power management test (1996)
- Power management system demonstration and ground checkout and definition flight modules (1998)
- Define GN&C design tools for rapid prototyping (1995)
- Demonstrate GN&C rapid prototyping (1996)
- Define GN&C advanced algorithms (1994-98)

RESOURCES

FY	$M
1993	1.0
1994	1.5
1995	3.1
1996	3.7
1997	3.1

PARTICIPANTS

Avionics Architecture	- JSC
Avionics Software	- JSC
Vehicle Health Management	- MSFC
Guidance, Navigation, & Control	- JSC, MSFC
Power Management & Control	- MSFC

Autonomous Landing

OBJECTIVES

- **Programmatic**
  Develop autonomous landing technology which supports technology that enables planetary exploration spacecraft to land safely in the face of surface hazards and close to areas of mission interest; autonomous GN&C technology; advanced sensor development

- **Technical**
  The specific areas of technology development are concept definition and analysis of technology to facilitate--navigation for precision landing; hazard detection and avoidance during terminal descent; sensor development modelling and algorithm development for Mars terrain navigation; Mars terrain definition

SCHEDULE

- Requirements definition (1993)
- Alternate sensor models and algorithms development at system and sensor levels (1994)
- Prototype of sensors, algorithms and computer simulations selected for implementation (1994); designed/development (1995); landing test bed simulation (1997)

RESOURCES

- 1991 $ 0.5 M
- 1992 $ ---- M
- 1993 $ 2.0 M
- 1994 $ 4.5 M
- 1995 $ 6.0 M
- 1996 $ 7.0 M
- 1997 $ 7.3 M

PARTICIPANTS

System Engineering	-	JSC & JPL
Precision Landing	-	JSC & JPL
Hazard Detection and Avoidance	-	JSC, JPL, & ARC
Sensor Development	-	JSC, JPL, & ARC

April 25, 1991
DRS-QUAD13

Autonomous Rendezvous & Docking

OBJECTIVES

- **Programmatic**
  Develop autonomous rendezvous and docking (AR&D) system technology for spacecraft in low geosynchronous Earth orbits and in planetary orbits in the discipline areas of; sensors, GN&C technology, and mechanisms

- **Technical**
  The specific areas of technology development are define user requirements; conduct mission studies and analyses to define performance requirements; identify and evaluate AR&D system conceptual designs against users requirements; define requirements for prototype hardware and software

SCHEDULE

- Define user requirements for AR&D technology (1992-1993)
- Conduct mission studies and analysis for performance requirements (1993-1994)
- Identify conceptual designs (1994-1996)
- Definition of requirements for prototype hardware and software (1996-1998)

RESOURCES

- 1991 $ 0.5 M
- 1992 $ ---- M
- 1993 $ 2.0 M
- 1994 $ 5.0 M
- 1995 $ 7.0 M
- 1996 $ 7.3 M
- 1997 $ 7.7 M

PARTICIPANTS

GN&C Radar Sensors & Mechanisms	-	JSC
Vision Processing	-	MSFC
Neural Networks and AI	-	ARC
Interplanetary AR&D Algorithm Requirements	-	JPL

April 25, 199[illegible]

SPACE PLATFORMS TECHNOLOGY
EARTH ORBITING PLATFORMS

CONTROLS

OBJECTIVES

PROGRAMMATIC
DEVELOP TOOLS AND METHODOLOGY FOR THE DESIGN AND ANALYSIS OF MULTI-INTEGRATED CONTROLS SYSTEMS

TECHNICAL
- POINTING ACCURACY (PLATFORM) ARCSECONDS
- POINTING ACCURACY (PAYLOAD) SUB-ARCSECOND
- LIFETIME 10+ YEARS

SCHEDULE

1994 SYSTEM MODELING
1995 DESIGN METHODOLOGY
1997 ON-ORBIT CHARACTERIZATION
1999 FEATURE-ASSISTED POINTING
2000 TESTBED EVALUATIONS

RESOURCES*

1994	$3.1 M
1995	$6.2 M
1996	$8.5 M
1997	$11.3 M

*THIS ELEMENT IS CLOSELY COORDINATED WITH DEVELOPMENT EFFORTS IN NASA/OSSA AND RELATED OTHER GOVERNMENT PROGRAMS. RESOURCES SHOWN ARE NASA OAET ONLY

PARTICIPANTS

LaRC
TOOL AND METHODOLOGY DEVELOPMENT AND EVALUATION, CONTROL ELEMENT DEVELOPMENT AND TEST

JPL
SENSOR DEVELOPMENT; SYSTEM IDENTIFICATION; CONTROL

GSFC
MODELING/SIMULATION TOOL DEVELOPMENT AND VALIDATION CONTROL ELEMENT DEVELOPMENT

MSFC
TESTBED DEVELOPMENT, CONTROL CONCEPT EVALUATIONS

SPACE PLATFORMS TECHNOLOGY
DEEP SPACE PLATFORMS

GUIDANCE, NAVIGATION AND CONTROL

OBJECTIVES

PROGRAMMATIC
DEVELOP AND VALIDATE KEY TECHNOLOGIES FOR THE GN&C OF DEEP SPACE PLATFORMS

TECHNICAL
- LIFETIME 15+ YEARS
- AUTONOMOUS OPERATIONS
- ADAPTIVE GUIDANCE
- ALGORITHM VERIFICATION

SCHEDULE

1994 ASSESS GN&C REQUIREMENTS
1995 ASSESS SOA IN GUIDANCE METHODOLOGY
1997 DEVELOP ADVANCED TRAJECTORY CONTROL ALGORITHMS
1998 COMPLETE DEVELOPMENT OF GN&C COMPONENTS
2000 DEVELOP SOFTWARE AND CONDUCT SYSTEM EVALUATIONS

RESOURCES*

1994	$3.1 M
1995	$4.6 M
1996	$5.0 M
1997	$5.2 M

*THIS ELEMENT IS CLOSELY COORDINATED WITH DEVELOPMENT EFFORTS IN NASA/OSSA AND RELATED OTHER GOVERNMENT PROGRAMS. RESOURCES SHOWN ARE NASA OAET ONLY

PARTICIPANTS

LaRC
TECHNOLOGY ASSESSMENTS, GN&C TOOLS AND METHODOLOGY DEVELOPMENTS/EVALUATIONS, HARDWARE DEVELOPMENTS

JPL
ATTITUDE AND METROLOGY SENSORS, CONTROL METHODOLOGY

PRECISION POINTING

OBJECTIVES

DEVELOP PRECISION POINTING TECHNOLOGY FOR INSTRUMENTS AND TELESCOPES

CRITICAL DRIVER MISISONS:

FOR MULTIPLE INSTRUMENT POINTING: NEXT EOS, GEOPLAT

FOR TELESCOPE POINTING: ST-NG, MOI

TECHNOLOGY CHALLENGE

INCREASE SPACE BASED TELESCOPE POINTING CAPABILITY BY TWO ORDERS OF MAGNITUDE BEYOND HST

INCREASE REMOTE SENSING INSTRUMENT POINTING CAPABILITY BY 2-ORDERS OF MAGNITUDE

INCREASE RELIABILITY, LIFETIME AND EFFICIENCY OF POINTING COMPONENTS

DELIVERABLES

1996	FINE GUIDANCE SENSOR FOR SMMM
1998	AUTONOMOUS FEATURE TRACKING SYSTEM DEMO FOR EOS-A2
2000	LINE OF SIGHT TRANSFER
2002	TARGET REFERENCE POINTING DEMO FOR GEOPLAT
2005	AUTONOMOUS POINTING SYSTEM EXECUTIVE FOR EOS-A3
2006	HIGH RELIABILITY/PERFORMANCE GYROS FOR ST-NG

PARTICIPANTS/RESOURCES

JPL, LARC, GSFC

0	0	0	0	0
0	2.0	4.0	7.0	12.5

INFORMATION SCIENCE & CONTROLS

MICROMACHINES AND SENSORS

THRUST(S) SUPPORTED

- SCIENCE
- EXPLORATION

OBJECTIVE:

Develop and demonstrate a new class of sensors/instruments using state-of-the-art micro machining technologies for in-situ measurements such as: surface characterization, sub surface characterization, planetary atmospheric analysis and far IR-atmospheric science.

PRODUCTS (FY 1993 - FY 1996)

- Micro gyros - FY '95
- *Micro seismometers. - FY '96*
- *Micro gas analyzer. - FY 97*
- *Vacuum micro electronics. - FY '97*
- *Micro science instrument systems. - FY '98*

PAYOFF

- Lightweight, small, economical instruments.
- Custom design.
- Ease & economy of duplication with VLSI fab. tech.
- Form critical in-house expertise.
- Science & exploration mission options are enabled with smaller instruments.

CENTERS: JPL, LaRC

RESOURCE INFORMATION

FUNDING	CURRENT	NET ($ K) AUGMENTATION	TOTAL
FY 1993	100		100
FY 1994	100		100
FY 1995	100	3000	3100
FY 1996	100	4000	4100
FY 1997	100	5000	5100

MAJOR FACILITIES: NONE

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SUMMARY

- TRANSPORTATION AVIONICS TECHNOLOGY HAS HIGHEST PRIORITY TO RESPOND TO CODE M REQUEST
- CODE S RECOGNITION OF NEED FOR S/C CONTROLS RESEARCH AND TECHNOLOGY NOT STRONG IMPACTING AUGMENTATIONS PRIORITY
- BASE PROGRAM HAS BEEN SUCCESSFULL SEED BED FOR AUGMENTATION TECHNOLOGY PROGRAMS
- INCREASED MANAGEMENT ATTENTION & FUNDING REQUIRED FOR TECHNOLOGY TRANSFER

NASA

STRATEGIC AVIONICS TECHNOLOGY PLANNING AND BRIDGING PROGRAMS

PRESENTATION
FOR

SSTAC CONTROLS COMMITTEE

NASA HEADQUARTERS

ALDO J. BORDANO
JOHNSON SPACE CENTER

NASA

SATWG BACKGROUND

O A NASA STRATEGIC TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM WAS HELD IN WILLIAMSBURG IN NOVEMBER 1989

O AS A SYMPOSIUM FOLLOW-ON, A STRATEGIC AVIONICS TECHNOLOGY WORKING GROUP (SATWG) WAS ESTABLISHED IN EARLY 1990 AND MEMBERSHIP INCLUDES:

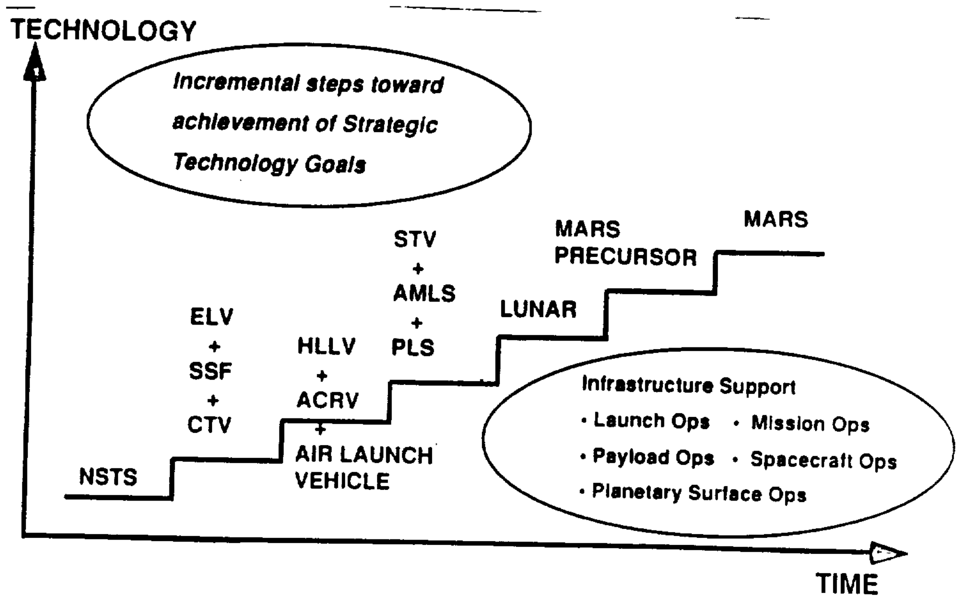
- AMES RESEARCH CENTER
- LEWIS RESEARCH CENTER
- JOHNSON SPACE CENTER
- MARSHALL SPACE FLIGHT CENTER
- KENNEDY SPACE CENTER
- STENNIS SPACE CENTER
- LANGLEY RESEARCH CENTER
- GODDARD SPACE FLIGHT CENTER
- JET PROPULSION LABORATORY

SATWG GOALS & OBJECTIVES

- O SUPPORT DEVELOPMENT OF A STRATEGIC SPACE AVIONICS TECHNOLOGY PLAN
  - AVIONICS TECHNOLOGY STRATEGIES AND GOALS
  - LONG-RANGE ELEMENTS TO SUPPORT FUTURE PROGRAMS
  - ELEMENTS TO SUPPORT EXISTING PROGRAMS INCLUDING OPERATIONAL INFRASTRUCTURE
- O PROMOTE AN EFFECTIVE COMMUNICATION, COOPERATION, AND TEAM BUILDING ENVIRONMENT IN SPACE AVIONICS BETWEEN NASA, INDUSTRY AND GOVERNMENT AGENCIES
- O DEVELOP COOPERATIVE PROGRAMS WITHIN ELEMENTS OF NASA
- O PROMOTE IMPROVED TECHNOLOGY TRANSFER PROCESSES, SUCH AS "BRIDGING," BETWEEN TECHNOLOGISTS, DEVELOPERS, CONTRACTORS, AND PROGRAM MANAGERS
- O DEVELOP INNOVATIVE IDEAS AND ACT AS A SUPPORT GROUP TO ALL NASA PROGRAMS

Strategic Avionics Technology Working Group

INCREMENTAL STRATEGIC TECHNOLOGY GOALS



Strategic Avionics Technology Wprking Group

NASA

KEY STRATEGIC AVIONICS TECHNOLOGY THEMES

O CUSTOMER FOCUSED EMPHASIS - UTILIZE AND BUILD UPON:

- SHUTTLE/SPACE STATION EXPERIENCE
- ALS TECHNOLOGY DEVELOPMENT
- COMMERCIAL TECHNOLOGY - - PRESENT AND FUTURE
- NASA ADVANCED TECHNOLOGY DEVELOPMENT
- EXPENDABLE LAUNCH VEHICLE EXPERIENCE
- DOD/DARPA TECHNOLOGY DEVELOPMENT

Strategic Avionics Technology Working Group

NASA

KEY STRATEGIC AVIONICS TECHNOLOGY THEMES

O SIGNIFICANT CHALLENGES

- BUILD FAULT - TOLERANCE AVIONICS CHEAPER, FASTER, AND SIMPLER
  - IMPROVED TECHNOLOGY INSERTION
  - CONSIDER HARDWARE / ARCHTECTURE DEVELOPMENT APPROACHES TO ADDRESS:
    - - COMMONALTY, SCALABILITY, MODULARITY, AND LONG-TERM OPERABILITY REQUIREMENTS
  - INVESTIGATE OPEN ARCHITECTURE CONCEPTS
- EXPLORATION DRIVERS
  - MANNED/UNMANNED COMPATIBLE AVIONICS DESIGNS
  - VEHICLE HEALTH MANAGEMENT (AUTOMATED & INTEGRATED)
  - SPACE-BASED CHECKOUT, SUPPORTING PHASED ASSEMBLY
  - REMOTE IN-FLIGHT & SURFACE-SITE TRAINING

Strategic Avionics Technology Working Group

KEY STRATEGIC AVIONICS TECHNOLOGY THEMES

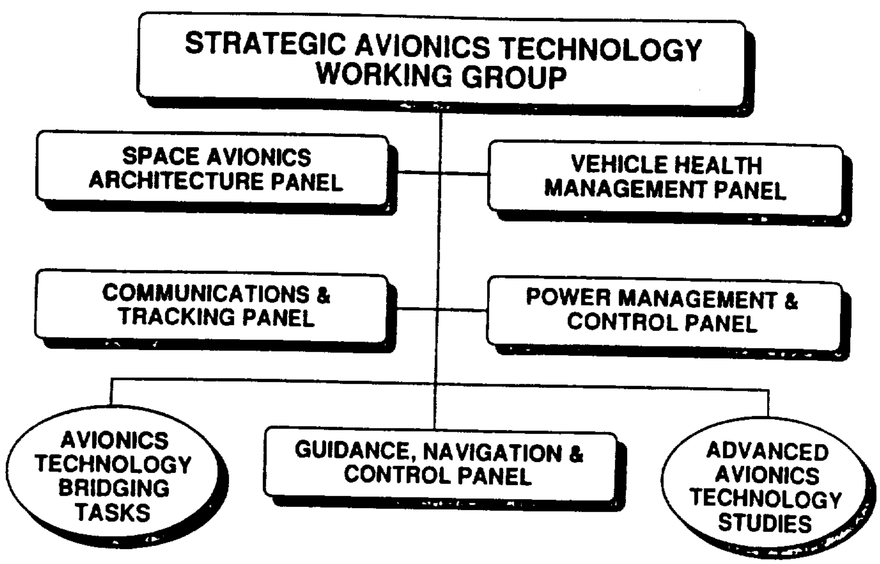
o FOCUS AREAS FOR THE FUTURE

- TECHNOLOGY TO ENABLE CONTINUOUS IMPROVEMENT OF OPERATIONAL SYSTEMS INCLUDING BOTH FLIGHT ELEMENTS AND GROUND INFRASTRUCTURE

- TECHNOLOGY TO ADDRESS SIGNIFICANT FUTURE PROGRAM REQUIREMENTS
  - SPACE-BASED & REMOTE SURFACE OPERATIONS
  - LONG DURATION MISSIONS
  - ASSEMBLY IN SPACE
  - INTERACTION OF FLIGHT VEHICLES/ELEMENTS

- DIFFERENT PLANNING PROCESSES ARE REQUIRED

SATWG STRUCTURE



NASA

SATWG ACTIVITIES & ACCOMPLISHMENTS

O INITIATED FY '91 TECHNOLOGY BRIDGING TASKS

- ADAPTIVE ASCENT GUIDANCE NAVIGATION & CONTROL
- ELECTRICAL ACTUATION / POWER SYSTEMS

O FIVE MAJOR PLANNING PANELS IN PLACE AND ACTIVE

O QUARTERLY INDUSTRY TECHNICAL INTERCHANGE MEETINGS ESTABLISHED

O STRATEGIES FOR CUSTOMER DRIVEN AVIONICS FACILITIES AND TEST BEDS BEING DEVELOPED

O COORDINATION OF CODE M AVIONICS TECHNOLOGY REQUIREMENTS INPUTS ACCOMPLISHED

Strategic Avionics Technology Working Group

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SATWG ACTIVITIES & ACCOMPLISHMENTS

O COORDINATION OF CODE R ADVANCED AVIONICS TECHNOLOGY REQUIREMENTS INPUTS ACCOMPLISHED

O SATWG INDUSTRY INTERFACE GROUP ESTABLISHED

- CONSOLIDATED INDUSTRY FEEDBACK / RECOMMENDATIONS

O ACTIVE COOPERATIVE TECHNOLOGY TASKS

- SPACE AVIONICS REQUIREMENTS STUDY
- INS/GPS ORBITER APPLICATION STUDY
  - INS/GPS FLIGHT TEST FOR AUTOMATIC LANDING
- ON-ORBIT RMS PERFORMANCE AND DYNAMICS
- PLS GN&C SIMULATION STUDY
- LIMITED FUNDING PRIME CONTRACTOR STUDIES -> "SEED PROJECTS"

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INNOVATIVE TECHNOLOGY & PROGRAM DEVELOPMENT PROCESSES

O THREE PROCESS PROJECTS ARE PROPOSED AS A NEW BUSINESS APPROACH

#1 - AVIONICS TECHNOLOGY AND ADVANCED DEVELOPMENT PROCESS
#2 - AVIONICS DESIGN, DEVELOPMENT, TEST, AND EVALUATION PROCESS
#3 - AVIONICS OPERATIONS PROCESS

O TRENDS FOR PROCESS #1

- BECOMING MORE CUSTOMER FOCUSED
- TECHNOLOGY NEEDS DEVELOPED TO ADDRESS MULTIPLE PROGRAMS
- BECOMING MORE INTERDEPENDENT WITH PROCESS #2 AND PROCESS #3 (EXAMPLE - MATERIALS, MANUFACTURING ND OPERATIONS COST)

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INNOVATIVE TECHNOLOGY & PROGRAM DEVELOPMENT PROCESSES

O IMPLEMENTATION MODEL

- A TOP-DOWN / BOTTOM-UP / MIDDLE-IN APPROACH IS PROPOSED
  - TOP-DOWN = PROGRAM MANAGERS
  - BOTTOM-UP = TECHNOLOGISTS

- TYPICAL MIDDLE-IN FUNCTIONS
  - DEVELOP STRATEGIES ACROSS PROGRAMS -> TECHNOLOGY UTILIZATION INCENTIVES TO PROGRAMS
  - CONNECT POCKETS OF TECHNICAL AND MANAGERIAL EXCELLENCE
  - IMPROVE NASA INSTITUTIONAL TECHNOLOGY, ENGINEERING, AND OPERATIONS ELEMENTS IN A TEAMWORK ENVIRONMENT
  - DEVELOP EARLY SPACE AVIONICS REC EMENTS AS A FOUNDATION FOR TECHNOLOGY AND ADVANCED DE OPMENT PLANNING
  - HORIZONTAL SE&I IS A PROPOSED TERM FOR THE MIDDLE-IN FUNCTION

Strategic Avionics Technology Working Group

NASA

INNOVATIVE TECHNOLOGY & PROGRAM DEVELOPMENT PROCESSES

O IMPLEMENTATION MODEL (CONT'D.)

- PLAN & IMPLEMENT PRIORITIZED AVIONICS TECHNOLOGY & ADVANCED DEVELOPMENT PROGRAMS
  - UTILIZE & BUILD UPON AVAILABLE TECHNOLOGY / EXPERIENCE
  - IDENTIFY & FORECAST TECHNOLOGY DEVELOPMENT PROGRESS
  - ESTABLISH "GAP" TECHNOLOGY RESEARCH & DEVELOPMENT

- SATWG TECHNOLOGY IMPLEMENTATION PROCESSES
  - TECHNOLOGY "BRIDGING" PROCESS
    -> JOINT USER / DEVELOPER TECHNOLOGY DEVELOPMENT EFFORT
  - TECHNOLOGY TRANSITION PROCESS
    -> GRADUAL PROGRESSION & TRANSFER OF DEMONSTRATED TECHNOLOGY
  - TECHNOLOGY UTILIZATION INCENTIVE PROCESS -> PROGRAMS
  - TECHNOLOGY INSERTION PROCESS -> IMMEDIATE APPLICATION

Strategic Avionics Technology Working Group

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OTHER SPACE AVIONICS DEVELOPMENT STRATEGIES

O NASA/CONTRACTOR TEAMING STRATEGIES

- INVOLVES LEVELS OF COOPERATION WITHIN COMPETITIVE BOUNDARIES
- TEAMING PROCESS MUST INCLUDE APPROPRIATE INCENTIVES
- NASP TEAMING INCLUDES CONCEPT OF:
  - EQUALITY, EQUITABILITY OF WORK, WORKING TOWARD A COMMON GOAL

O AVIONICS LABORATORY / WORK STATION STRATEGIES

- CONSIDER ALTERNATIVES TO NEW BRICK AND MORTAR
- AVIONICS WORK STATION CONCEPT
- GENERIC AVIONICS TEST BED CONCEPT
  - LINK INTEGRATED ENVIRONMENTS
  - SUPPORT MULTIPLE PROGRAMS
- REMOTE UTILIZATION OF CONTRACTOR AVIONICS LABORATORIES

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OTHER SPACE AVIONICS DEVELOPMENT STRATEGIES

- INFLUENCE THE DEVELOPMENT OF STANDARDS, INTERFACE SPECIFICATIONS, AND CHIP DEVICES, & OTHER INDUSTRY AVIONICS TRENDS

- CONSIDER A LIFE CYCLE PROCESS FOR DEVELOPMENT AND MAINTENANCE OF AVIONICS HARDWARE AND SOFTWARE

  - OPERATIONS COSTS <u>ARE</u> THE NUMBER ONE TOTAL PROGRAM COST DRIVER FOR EXTENDED DURATION SPACE PROGRAMS

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SATWG CALENDER

EVENT	DATE	HOST	FOCUS
ORGANIZATIONAL MEETING	4/ 5/90	NASA/HQ	COORDINATION
FAULT TOLERANCE & RM	4/25/90	MMC/DENVER	FT & RM
VEHICLE HEALTH MANAGEMENT	9/11/90	HARRIS/MELBORNE	VHM
SATWG MEETING	11/14-16/90	GDSS/SAN DIEGO	ARCHITECTURE
HEALTH MANAGEMENT CONF.	11/90	U. of CINCINNATI	PROP. VHM
SATWG MEETING	2/26-28/91	BOEING/SEATTLE	SE & I
VEHICLE HEALTH MANAGEMENT	6/10-13/91	NASA-MSFC	NLS VHM
SATWG MEETING	7/9-11/91	ROCKWELL/DOWNEY	POWER
VEHICLE HEALTH MANAGEMENT	9/91	NASA-KSC (JOINT JSC)	SSF/SS/ACRV
SATWG MEETING	11/5-7/91	LOCKHEED/NASHUA	C & T
VEHICLE HEALTH MANAGEMENT	11/91	NASA-SSC	SENSORS
SATWG MEETING	2/92	MDAC-HUNTINGTON BCH	GN & C
VEHICLE HEALTH MANAGEMENT	3/92	NASA-AMES	SOFTWARE
SATWG MEETING	6/92	MMC/DENVER	VHM

Strategic Avionics Technology Working Group

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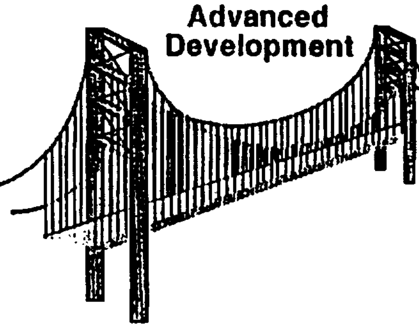
"BRIDGING THE GAP"



NASA

TECHNOLOGY BRIDGING

- "Technology Bridging" is a process that was spawned by the Strategic Avioincs Technology Working Group (SATWG)
- It is a technology development and demonstration process that "bridges" technology providers, users and customers
- It is a joint endeavor between government, industry and academia
- It employs the priciples of concurrent engineering
- It produces credible cost/benefits assessment
- Its objective is to facilitate the transition of technology from the lab to a customer's project
- Once the customer has incorporated the technology into his advanced development program the bridging project will either focus on other applications or terminate so that other technology area bridging projects may be initiated.

NASA

AUTONOMOUS GUIDANCE, NAVIGATION AND CONTROL

OBJECTIVE

- To develop and demonstrate autonomous guidance, navigation and control technologies in areas of:
  - New sensors and sensing devices
  - Ground and onboard guidance algorithms
  - Navigation and control algorithms
  - Vehicle monitoring systems for autonomous ascent GN&C systems

PAYOFFS

- Increased launch probability
- Improved ascent/entry wind measurement technology
- Improved abort planning and failure adaptability
- Reduced cost from improved operations

Office of Space Flight

NASA

ELECTRICAL ACTUATION
Bridging Activities

OBJECTIVES

- Develop and demonstrate a representative high power, cost effective electrical actuation system suited for secondary objectives, including flight / ground fluid control valves and surface systems applications.

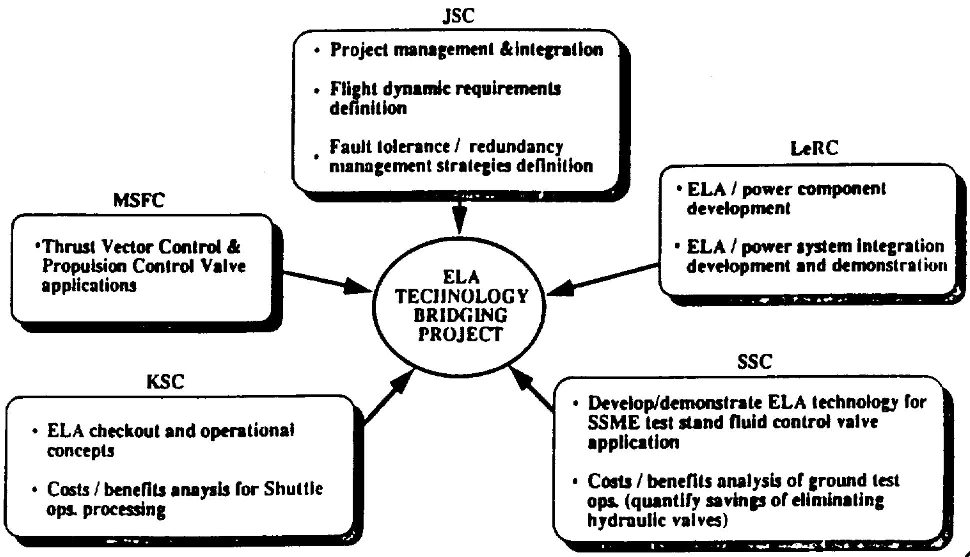
PAYOFFS

- Elimination of maintenance intensive high pressure hydraulic systems
- Elimination of central hydraulic APU's, hazardous / toxic fluids
- Reduction of labor intensive tests, preparation time, and operations costs
- Improved dispatch reliability, operability, and abort recovery
- Improved launch window (late hold capability)
- Reduced stand-down time, rapid change-out / retest

Electrical Actuation Technology Bridging

NASA

Electrical Actuation Technology Bridging Team



Electrical Actuation Technology Bridging

APPENDIX

STRATEGIC AVIONICS TECHNOLOGY WORKING GROUP AND SUB - PANEL CHARTERS

Johnson Space Center · Houston, Texas

NASA

SATWG CHARTER	
	KENNETH J. COX

- O PROVIDE A FORUM TO SUPPORT THE DEVELOPMENT OF A SPACE STRATEGIC AVIONICS TECHNOLOGY PLAN INCLUDING
  - O AVIONICS TECHNOLOGY STRATEGIES AND GOALS
  - O LONG-RANGE ELEMENTS TO SUPPORT FUTURE AND DEVELOPING PROGRAMS
  - O SUPPORT ELEMENTS FOR EXISTING PROGRAMS INCLUDING OPERATIONAL INFRASTRUCTURE
  - O GUIDELINES FOR FUNCTIONAL COMMONALTY OF AVIONICS ARCHITECTURES
- O DEVELOP COOPERATIVE PROGRAMS BETWEEN CODE R AND CODE M/S
- O PROVIDE FOR AVIONICS TECHNICAL INTERCHANGE BETWEEN NASA TECHNOLOGISTS, ADVANCED DEVELOPERS, PROGRAMS, OPERATORS, AND MAJOR AVIONICS CONTRACTORS
- O PROMOTE IMPROVED TECHNOLOGY TRANSFER PROCESSES, SUCH AS "BRIDGING," BETWEEN TECHNOLOGISTS, DEVELOPERS, CONTRACTORS, AND PROGRAM MANAGERS
- O DEVELOP INNOVATIVE IDEAS AND ACT AS A CONSULTING GROUP TO SUPPORT NASA NEW PROGRAMS

Johnson Space Center · Houston, Texas

NASA

SPACE AVIONICS ARCHITECTURE PANEL CHARTER	
	KENNETH J. COX

- O DEVELOP AN ADVANCED AVIONICS ARCHITECTURE TECHNOLOGY PLAN FOR SPACE TRANSPORTATION AND EXPLORATION PROGRAMS WITH EMPHASIS ON LOWER LIFE CYCLE COST AND MORE EFFICIENT DDT&E COST
  - O DEVELOP AN EARLY TOP-LEVEL IDENTIFICATION OF AVIONICS ARCHITECTURE REQUIREMENTS AND DESIGN DRIVERS
  - O DEFINE SYSTEM ARCHITECTURE, SOFTWARE, AND HARDWARE STANDARDS FOR DEVELOPMENT AND VERIFICATION
  - O ESTABLISH AN OPEN ARCHITECTURE APPROACH
  - O INCORPORATE TOP-DOWN CONCEPTS INVOLVING MODULARITY, COMMONALITY, SCALABILITY, AND INTERFACE STANDARDS
  - O INVESTIGATE AVIONICS COMMONALITY UTILIZATION STRATEGIES BETWEEN
    - O EARTH TO ORBIT LAUNCH VEHICLES
    - O ORBITAL VEHICLES
    - O TRANSFER AND EXCURSION VEHICLES
    - O MOBILE AND FIXED SURFACE SYSTEMS
- O FACILITATE SUPPORTABILITY AND LOGISTICS SUPPORT

ORIGINAL PAGE IS OF POOR QUALITY

NASA	SPACE AVIONICS ARCHITECTURE PANEL CHARTER (CONT'D)	
		KENNETH J. COX

- O PROVIDE A FORUM FOR AVIONICS ARCHITECTURE TECHNOLOGY INTERCHANGE BETWEEN NASA, AEROSPACE INDUSTRY PARTNERS, DOD, AND THE COMMERCIAL SECTOR
  - O SUPPORT IDENTIFICATION OF AVAILABLE AND FUTURE TECHNOLOGY
  - O IDENTIFY CRITICAL TECHNOLOGY AREAS FOR NASA
  - O ESTABLISH INITIAL TEST BED STANDARDS FOR PARTICIPATING CENTERS
- O DEVELOP AN IMPROVED TECHNOLOGY INSERTION PROCESS WITH A GOAL OF LOWER LIFE-CYCLE COST, FASTER PROJECT UTILIZATION, AND EVER-DECREASING OPERATIONAL COSTS
  - O FOCUS ATTENTION ON THE PROCESSES FOR THE DEVELOPMENT AND MAINTENANCE OF AVIONICS SOFTWARE OVER THE LIFE-CYCLE OF MAJOR SYSTEMS
  - O DEFINE CRITICALITY CATEGORIES BASED ON CREW SAFETY, MISSION SUCCESS, MISSION SUPPORT, AND ENGINEERING ANALYSIS THAT MAY PERMIT EARLY TECHNOLOGY ENHANCEMENT UPGRADES IN SELECTED AREAS
  - O EVALUATE METHODS FOR DEFINING EVOLVABLE REQUIREMENTS, DETERMINING REGRESSION TESTING POLICY AND ESTABLISHING REVERIFICATION CRITERIA
- O DEVELOP INNOVATIVE IDEAS AND CREATE A CORPS OF EXPERTISE TO ACT AS A CONSULTING GROUP TO SUPPORT PROGRAMS

NASA	VEHICLE HEALTH MANAGEMENT PANEL CHARTER	
		KENNETH J. COX

- O SERVE AS THE FOCUS FOR AUTOMATED VEHICLE HEALTH MONITORING AND CHECKOUT ACTIVITIES; PROVIDE TECHNICAL INTERCHANGE AMONG NASA, DOD, AND PRIVATE SECTOR EFFORTS AND ADVOCACY FOR FURTHERING THE STATE-OF-THE-ART
- O DEVELOP SYSTEM REQUIREMENTS AND ARCHITECTURAL CONCEPTS FOR AUTOMATED CHECKOUT AND MONITORING OF LAUNCH AND SPACE VEHICLES
- O DEVELOP INTEGRATION STRATEGIES FOR THE INCORPORATION OF AUTOMATED CHECKOUT AND MONITORING SYSTEMS INTO FUTURE EARTH-TO-ORBIT, CREW RETURN, AND SPACE TRANSFER VEHICLES
- O IDENTIFY AREAS FOR FUTURE RESEARCH AND TECHNOLOGY ACTIVITIES
- O SERVE AS A CONSULTANT GROUP IN SUPPORT OF NASA PROGRAMS
- O DEFINE AND PROVIDE FOR APPROPRIATE TEST AND DEMONSTRATIONS OF TECHNOLOGY AND SYSTEM CONCEPTS
- O DEVELOP REQUIREMENTS AND PLANNING FOR TEST FACILITIES AND EQUIPMENT
- O PUBLISH PERIODIC REPORTS PERTINENT TO ONGOING OR FUTURE PROGRAMS

NASA

COMMUNICATIONS AND TRACKING PANEL CHARTER

KENNETH J. COX

- O DEVELOP AN ADVANCED COMMUNICATIONS AND TRACKING SYSTEMS TECHNOLOGY PLAN FOR SPACE TRANSPORTATION AND EXPLORATION PROGRAMS WITH EMPHASIS ON LOWER DDT&E COSTS, AND LOWER LIFE-CYCLE COSTS
  - O DEVELOP AN EARLY DEFINITION OF TOP LEVEL COMMUNICATIONS AND TRACKING SYSTEM REQUIREMENTS AND DESIGN DRIVERS
  - O DEFINE SYSTEMS ARCHITECTURE REQUIREMENTS AND STANDARDS FOR HARDWARE/SOFTWARE DEVELOPMENT AND VERIFICATION
  - O ESTABLISH AN OPEN ARCHITECTURE APPROACH, WHICH INCORPORATES MODULARITY, COMMONALITY, AND INTERFACE STANDARDIZATION
  - O INVESTIGATE STRATEGIES FOR MULTIPROGRAM DEVELOPMENT OF COMMON AND NEAR-COMMON ELEMENTS, COMMUNICATIONS SERVICES STANDARDS, TRACKING AND NAVIGATION SENSOR STANDARDS
- O PROVIDE A FORUM FOR COMMUNICATIONS AND TRACKING SYSTEMS TECHNOLOGY INTERCHANGE BETWEEN NASA, AEROSPACE INDUSTRY PARTNERS, DOD, AND THE COMMERCIAL SECTOR
  - O SUPPORT IDENTIFICATION OF AVAILABLE TECHNOLOGY
  - O DEVELOP PROJECTIONS OF FUTURE TECHNOLOGY CAPABILITIES
  - O IDENTIFY CRITICAL TECHNOLOGY AREAS FOR NASA PROGRAMS
  - O IDENTIFY CURRENT AND PLANNED TEST BED CAPABILITIES AT PARTICIPATING CENTERS, AND ESTABLISH STANDARDS AND PROCEDURES FOR UTILIZATION

NASA

COMMUNICATIONS AND TRACKING PANEL CHARTER (CONT'D)

KENNETH J. COX

- O DEVELOP AND FOSTER INNOVATIVE IDEAS AND CREATE A CORPS OF EXPERTISE TO ACT AS A COMMUNICATIONS AND TRACKING SYSTEMS CONSULTING GROUP TO SUPPORT NASA PROGRAMS. PURSUE TECHNOLOGICAL ADVANCES WHICH WILL PROVIDE:
  - O GREATER SPECTRUM EFFICIENCY
  - O AUTOMATED SYSTEM MANAGEMENT AND CONTROL
  - O GRACEFUL SYSTEM DEGRADATION AS THE RESULT OF FAILURES
  - O GREATER RFI/EMI IMMUNITY
  - O VERY LOW POWER CONSUMPTION
  - O NEW AREAS OF SPECTRUM UTILIZATION
  - O HIGHER IMAGE PROCESSING RATES
  - O INCREASED MATURITY LEVELS OF SENSOR FUSION
  - O HIGHER LEVELS OF CAPABILITY FOR AUTONOMOUS OPERATIONS

Johnson Space Center - Houston, Texas

NASA

POWER MANAGEMENT AND CONTROL PANEL CHARTER	
	KENNETH J. COX

- O DEVELOP AN ADVANCED POWER MANAGEMENT AND CONTROL SYSTEM TECHNOLOGY PLAN FOR SPACE TRANSPORTATION AND EXPLORATION PROGRAMS INCLUDING:
  - O ADVANCED INTEGRATED ELECTRICAL POWER SYSTEM TECHNOLOGIES TO SUPPORT FUTURE AND DEVELOPING PROGRAMS
  - O LONG RANGE STRATEGIES AND GOALS TO ENSURE FAULT TOLERANT POWER FOR ALL MISSION SCENARIOS
  - O DEVELOP OPERATIONAL INFRASTRUCTURES TO SUPPORT FUTURE TRANSPORTATION AND EXPLORATION PROGRAMS
  - O PROVIDE GUIDELINES FOR FUNCTIONAL COMMONALTY OF ELECTRICAL POWER MANAGEMENT AND CONTROL ARCHITECTURES ACROSS PROGRAMS
- O PROVIDE A FORUM FOR ELECTRICAL POWER MANAGEMENT AND CONTROL TECHNOLOGY INTERCHANGE AMONG NASA, DOD, INDUSTRY AND THE COMMERCIAL SECTOR
  - O IDENTIFY AREAS FOR FUTURE RESEARCH AND TECHNOLOGY DEVELOPMENT ACTIVITIES
  - O DEFINE REQUIREMENTS FOR TECHNOLOGY DEVELOPMENT EFFORTS
  - O DEVELOP TEST FACILITIES AND EQUIPMENT
  - O DEVELOP AND PROVIDE FOR APPROPRIATE TESTS AND DEMONSTRATIONS OF TECHNOLOGY APPLICATIONS AND SYSTEMS CONCEPTS
- O DEVELOP AN IMPROVED TECHNOLOGY INSERTION PROCESS TO REDUCE PERCEIVED RISK, LOWER OPERATIONAL AND LIFE-CYCLE COSTS, AND MAXIMIZE SYSTEM OPERABILITY AND POWER AVAILABILITY

Johnson Space Center - Houston, Texas

NASA

GN & C PANEL CHARTER		
	KENNETH J. COX	6/21/91

- O THE GN & C PANELIS ESTABLISHED TO PROVIDE A FORUM TO FACILITATE THE EXCHANGE OF INFORMATION AMONG TECHNOLOGY DEVELOPERS, USERS, AND THE SPACE AVIONICS COMMUNITY, AS A WHOLE
- O THE PANEL WILL GATHER & DISSEMINATE USER NEEDS / REQUIREMENTS, AND IDENTIFY & CATALOG TECHNOLOGY STATUS VIA LIVING DOCUMENTS
- O FUTURE GN & C TECHNOLOGY PROJECTIONS & CAPABILITIES WILL BE RESEARCHED & MADE AVAILABLE
- O THE PANEL WILL BE RESPONSIBLE FOR FOSTERING TECHNOLOGY INTERCHANGE BETWEEN NASA, DoD, AND THE COMMERCIAL SECTOR
- O THE PANEL CHARTER DOES NOT INCLUDE THE DIRECTION OR MANAGEMENT OF TECHNOLOGY DEVELOPMENT

Avionics Technology Plan

Johnson Space Center - Houston, Texas

Integrated Technology Plan Overview

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

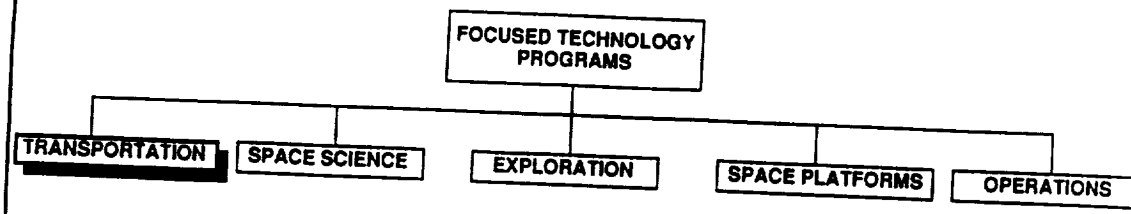
Integrated Technology Plan Elements

Work Breakdown Structure

Johnson Space Center - Houston, Texas

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

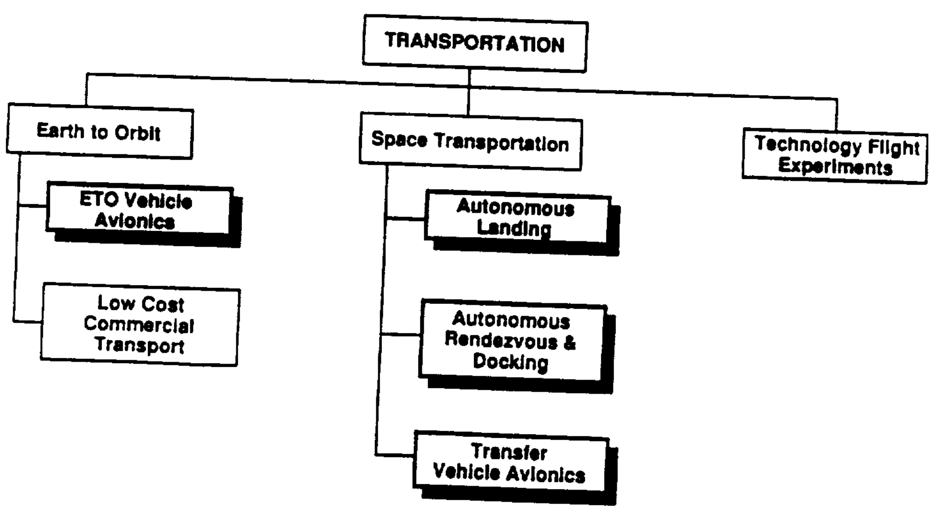


Work Breakdown Structure (Continued)

Johnson Space Center - Houston, Texas

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91



Generic Outline

Presentation will cover each identified Integrated Technology Plan Element and Subelement as follows

- ❑ **Overview** (at the element level 5.X.X)
- ❑ **Current & Related Programs** (at the subelement level 5.X.X.X)
- ❑ **Proposed Technology Program** (at the subelement level 5.X.X.X)
- ❑ **Program Benefits** (at the subelement level 5.X.X.X)

Note: The Integrated Technology Plan Report for these elements and subelements is over 100 pages. This presentation will be a high level summary of that report.

5.2.7 ETO Vehicle Avionics Overview

- ❑ The next generation of space transports will need to have increased mission safety, more autonomy for reduced crew workload, and reduced operational costs.
  - Avionics Architecture - for increased avionics performance
  - Avionics Software - addresses mission and safety features in software operating systems kernel
  - Vehicle Health Management - for self diagnosing and self compensating integrated systems
  - Power Management and Control - for reliable, universal, modular, electrical power bus systems
  - Guidance, Navigation, and Control - offers efficient computational algorithms and sensors, software tools to analyze complex body dynamics, and enhanced launch and land on demand probability
  - Electrical Actuation Systems - replaces hydraulic systems to enhance system reliability, reduced operational cost
  - Advanced Landing & Recovery Systems - for enhanced booster recovery and landing technology
- ❑ The following advanced vehicles will all require some combination of these advanced technologies:
  - HLLV, NLS, PLS, CTV, ACRV, ALS, and ELV's
- ❑ ETO and Transfer Vehicle Avionics technology development share common goals which invites and in fact, for cost effectiveness, dictates collaboration and interfacing between the two areas of development.

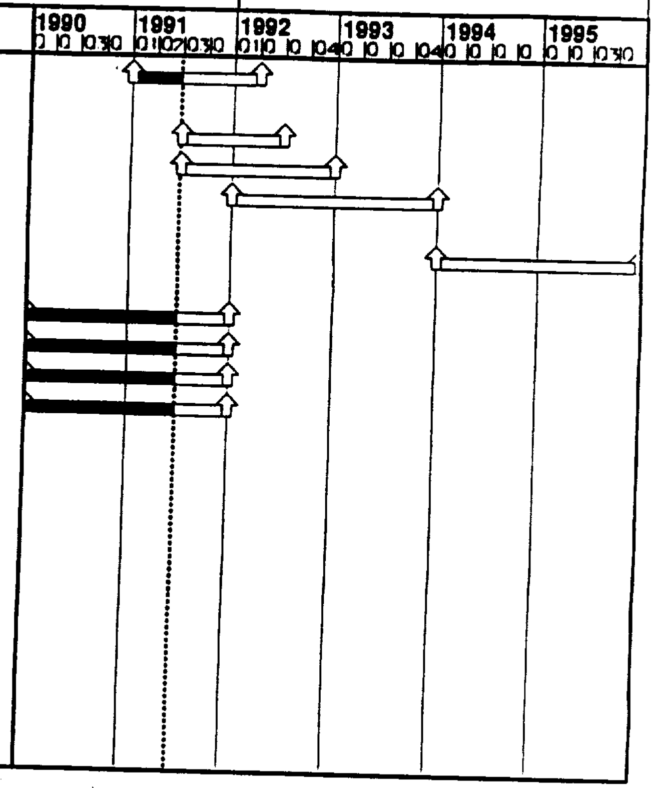
NASA

5.2.7.1 ETO Vehicle Avionics:
Avionics Architecture
Current & Related Programs

Navigation, Control & Aeronautics Division
A. J. Bordano/EG

Description

- Flight Data System Open Architecture Requirements Definition & Methodology Development
- Flight Data System Open Architecture Document
- Flight Data System System Profiles
- Flight Data System Open Architecture Performance Analysis and Trades
- Flight Data System Open Architecture Prototype Development
- Network Performance Model
- Bare 386 Real-time Kernel Investigation
- Station Flight-to-Ground Interoperability Evaluation
- Applications-to-RODB Data Type Analysis



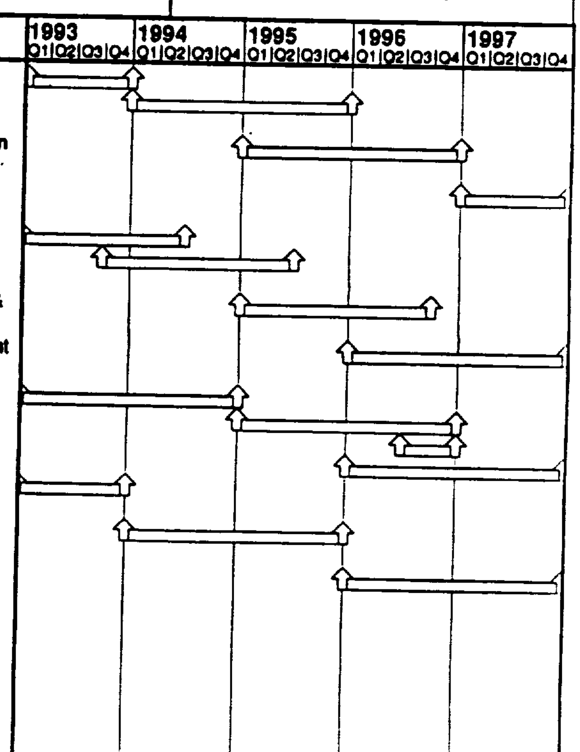
NASA

5.2.7.1 ETO Vehicle Avionics:
Avionics Architecture
Proposed Technology

Navigation, Control & Aeronautics Division
A. J. Bordano/EG

Description

- Real time distributed processing test bed development
- Real time distributed processing hetrogeneous processing & memory installation & operation in test bed
- Real time distributed processing network installation & operation in test bed
- Real time distributed processing hardware sensitivity factor determination
- High capacity processing requirements definition
- High capacity 32 and 64 bit processing component prototype development
- High capacity specialized coprocessor prototype development & integration
- High capacity multi-mega byte memory alternatives development and integration
- Non-Stop computing requirements definition
- Non-Stop computing system models development
- Non-Stop system reconfiguration demonstration
- Non-Stop computing test and verification technology definition
- Launch vehicle advanced human-tended avionics displays and controls interface and aids requirements definition
- Avionics human tended alternative sensory mechanisms and display prototype development
- Avionics Displays and Controls Advanced Human-Machine Test & Verification Technology Determination



5.2.7.1 ETO Vehicle Avionics: Avionics Architecture Program Benefits

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

TECHNOLOGY	BENEFITS	WHY
Architecture/ETO Technology • Real-Time Distributed processing - Develop and prototype via test beds advanced flight data system distributed and multiple heterogeneous processors, memory, buses and other key components operating in real-time. - Determine sensitivity factors governing real-time processing performance.	• Definition of interfaces and standards including performance criteria to establish and verify architecture concepts.	• Development of flexible architectures for reduced development and life cycle costs
• High Capacity Processing - Develop requirements and prototypes for 32 bit and 64 bit processing components, memories and buses; specialized high speed coprocessors such as I960 and R4000; and multi-megabyte memory alternatives and technologies.	• The transfer of commercial technologies into space rated components will enable onboard processing capabilities to accommodate increased complexity of the avionics suite.	• Compatibility with ground systems in both performance and architecture
• Non-Stop Computing - Develop, build and demonstrate system models exhibiting multi-fault tolerant system and component behavior and which exhibit reconfigurable capability to determine the issues, costs and requirements - Determine the technologies needed to test, verify and certify non-stop computing capabilities for space flight operations	• Non-stop requirements and multi-fault tolerant components can be used to test and evaluate concepts, their associated costs, and implementation difficulty.	• Development of more flexible launch commit criteria and increases in mission safety
• Avionics Displays and Controls - Define requirements for advanced human-tended display and control interfaces, aids and alternative sensory mechanisms - Develop prototype and demonstrate advanced total environment or holographic display and high fidelity voice control interfaces - Determine the technologies needed to test, verify and certify advanced human-machine interface capabilities for flight operations	• Definition of requirements for advanced displays and controls, and prototypes of such devices can be used to present more effective human interface mechanisms to astronauts for evaluation	• More effective use of data fusion to increase the machine processing of information for the manned interface.

NASA

5.2.7.2 ETO Vehicle Avionics: Avionics Software Current & Related Programs

Navigation, Control & Aeronautics Division
A. J. Bordano/EG

Description

• Space Applications GN&C Characteristics and Methods Defined

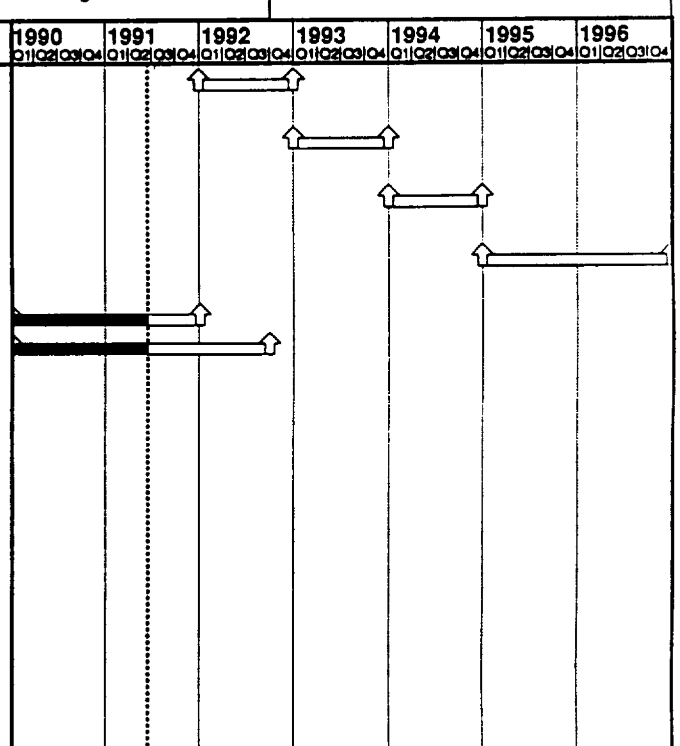
• Space Applications GN&C Family Generated and other Applications Identified

• Space Applications Characteristics and Methods Defined for additional Applications

• Space Applications Combined Demonstration with Target Avionics Platform

• Applications-to-RODB Data Type Analysis

• Matrix-X Simulation Development



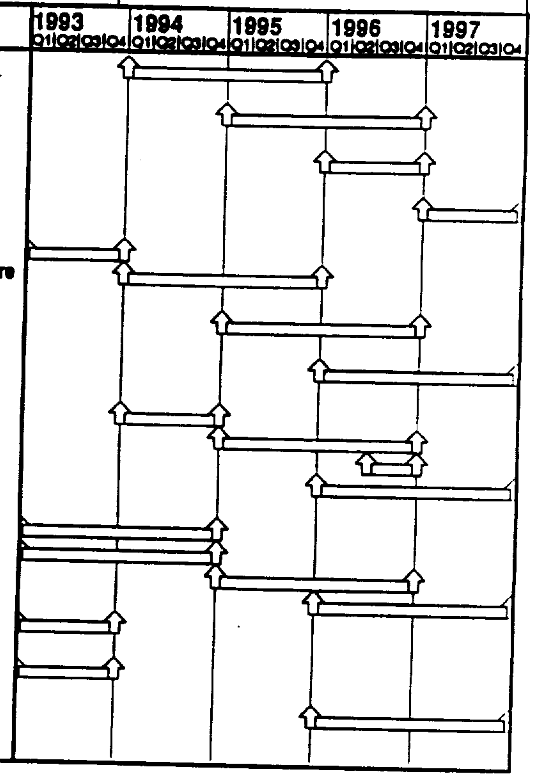
NASA

5.2.7.2 ETO Vehicle Avionics: Avionics Software Proposed Technology

Navigation, Control & Aeronautics Division
A. J. Bordano/EG

Description

- Real Time Distributed Processor Operating System and Services Prototype Development
- Real Time Distributed Network Operating System and Services Prototype Development
- Real Time Distributed Processing Computer and Network Integration and Demonstration
- Real time Distributed Processing Software Sensitivity Factor Determination
- High Capacity Processing Software Requirements Definition
- High Capacity 32 and 64 bit Processing Component Prototype Software Development
- High Capacity Specialized Coprocessor Prototype Software Development & Integration
- High Capacity Multi-mega byte Memory Alternatives Software Development and Integration
- Non-Stop Computing Software Requirements Definition
- Non-Stop Computing Software Models Development
- Non-Stop Software Reconfiguration Demonstration
- Non-Stop Computing Software Tests and Verification Technology Definition
- Reusable Requirements and Architectureal Alternatives Definition
- CASE Tool Data Repository Filter Development
- Reuseable Case Tool Component Development
- Reusable Prototype Component Development and Demo
- Launch Vehicle Advanced Human-Tended Avionics Displays and Controls Interface and Aids Requirements Definition
- Avionics Human-Tended Alternative Sensory Mechanisms and Display Prototype Development
- Avionics Displays and Controls Advanced Human-Machine Test & Verification Technology Determination



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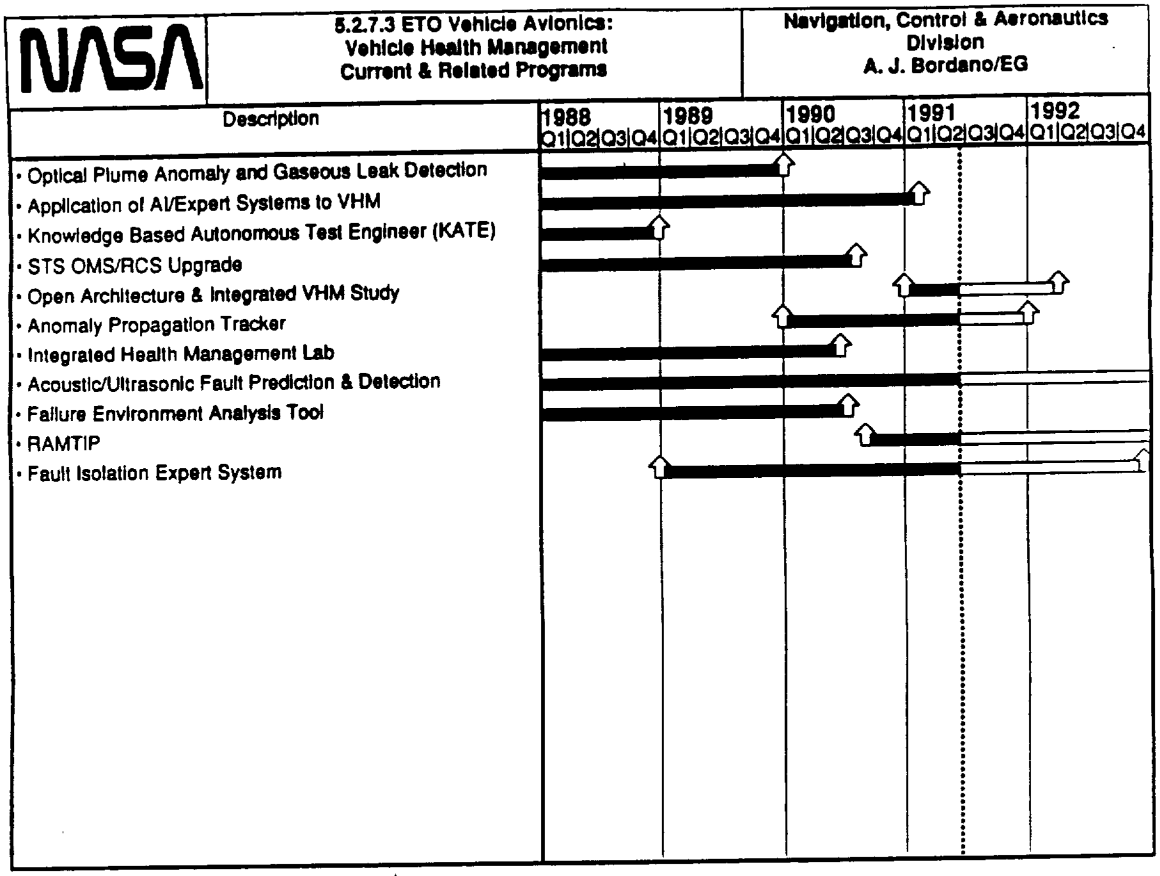
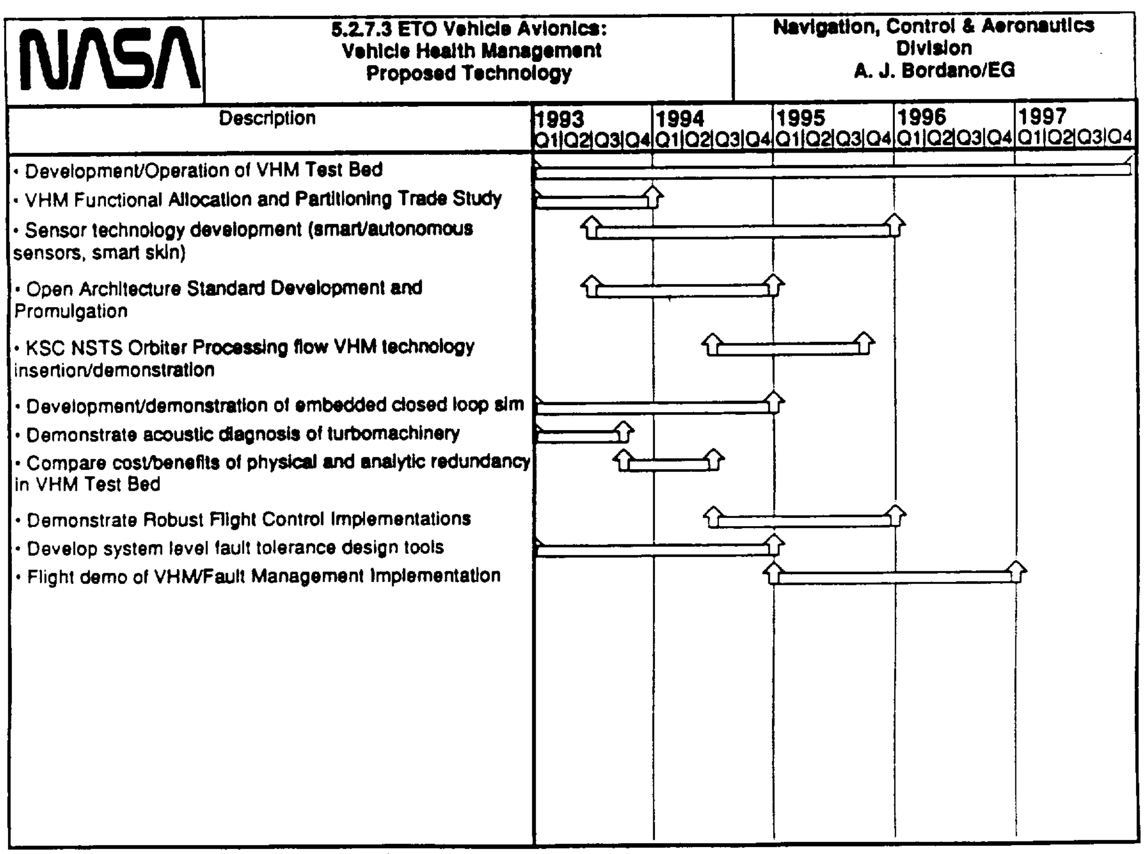
5.2.7.2 ETO Vehicle Avionics: Avionics Software Program Benefits

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

TECHNOLOGY	BENEFITS	WHY
Software/ETO Technology • Real-time Distributed Processing - Develop prototype and demonstrate distributed operating systems and services that operate in real-time over distributed and multiple processors. - Determine sensitivity factors governing distributed operating system and services for real-time processing performance.	• Establishes capability and performance of operating systems distributed across multiple buses, networks and vehicles	• Assessment of distributed operating system and services requirements
• High Capacity Processing: - Develop and prototype software for 32/64 bit processors, specialized coprocessors such as i960, R4000 and multi-megabyte memory alternatives associated with mass storage disk for space qualified components	• Additional processing capability and performance for the on-board data system.	• Compatibility with ground systems in both performance and architecture
• Non-Stop Computing - Develop and demonstrate software models exhibiting multi-fault tolerant system and component behavior and reconfigurable capability with and without human controls - Determine the technologies needed to test, verify and certify for flight operations	• Determination of requirements and components for fault resistant computing for evaluation of concepts, costs and implementation difficulty.	• More flexible launch commit criteria and increases in mission safety
• Software Reusability - Develop and build Computer Aided Systems Engineering (CASE) tool data repository filters for exchanging data between different CASE tools for flight software development - Define and test reusable software features for flight software specific operating systems, services and applications.	• Establishes generic flight software system elements for reuse across any program	• Lower development and life cycle costs for the software element
• Avionics Displays and Controls - Develop and prototype knowledge based visual, touch, voice and other sensory display and control aids to support human operation of complex systems - Determine the technologies needed to test, verify and certify advanced human-machine interface software	• Determination of effective human interface mechanisms as the complexity and amount of information increase	• Aids human data comprehension and response


NASA
5.2.7.3 ETO Vehicle Avionics:
Vehicle Health Management
Current & Related Programs
Navigation, Control & Aeronautics Division
A. J. Bordano/EG
Description
1988 Q1 Q2 Q3 Q4
1989 Q1 Q2 Q3 Q4
1990 Q1 Q2 Q3 Q4
1991 Q1 Q2 Q3 Q4
1992 Q1 Q2 Q3 Q4
• Optical Plume Anomaly and Gaseous Leak Detection
• Application of AI/Expert Systems to VHM
• Knowledge Based Autonomous Test Engineer (KATE)
• STS OMS/RCS Upgrade
• Open Architecture & Integrated VHM Study
• Anomaly Propagation Tracker
• Integrated Health Management Lab
• Acoustic/Ultrasonic Fault Prediction & Detection
• Failure Environment Analysis Tool
• RAMTIP
• Fault Isolation Expert System


NASA
5.2.7.3 ETO Vehicle Avionics:
Vehicle Health Management
Proposed Technology
Navigation, Control & Aeronautics Division
A. J. Bordano/EG
Description
1993 Q1 Q2 Q3 Q4
1994 Q1 Q2 Q3 Q4
1995 Q1 Q2 Q3 Q4
1996 Q1 Q2 Q3 Q4
1997 Q1 Q2 Q3 Q4
• Development/Operation of VHM Test Bed
• VHM Functional Allocation and Partitioning Trade Study
• Sensor technology development (smart/autonomous sensors, smart skin)
• Open Architecture Standard Development and Promulgation
• KSC NSTS Orbiter Processing flow VHM technology insertion/demonstration
• Development/demonstration of embedded closed loop sim
• Demonstrate acoustic diagnosis of turbomachinery
• Compare cost/benefits of physical and analytic redundancy in VHM Test Bed
• Demonstrate Robust Flight Control Implementations
• Develop system level fault tolerance design tools
• Flight demo of VHM/Fault Management Implementation

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5.2.7.3 ETO Vehicle Avionics: Vehicle Health Management Program Benefits

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

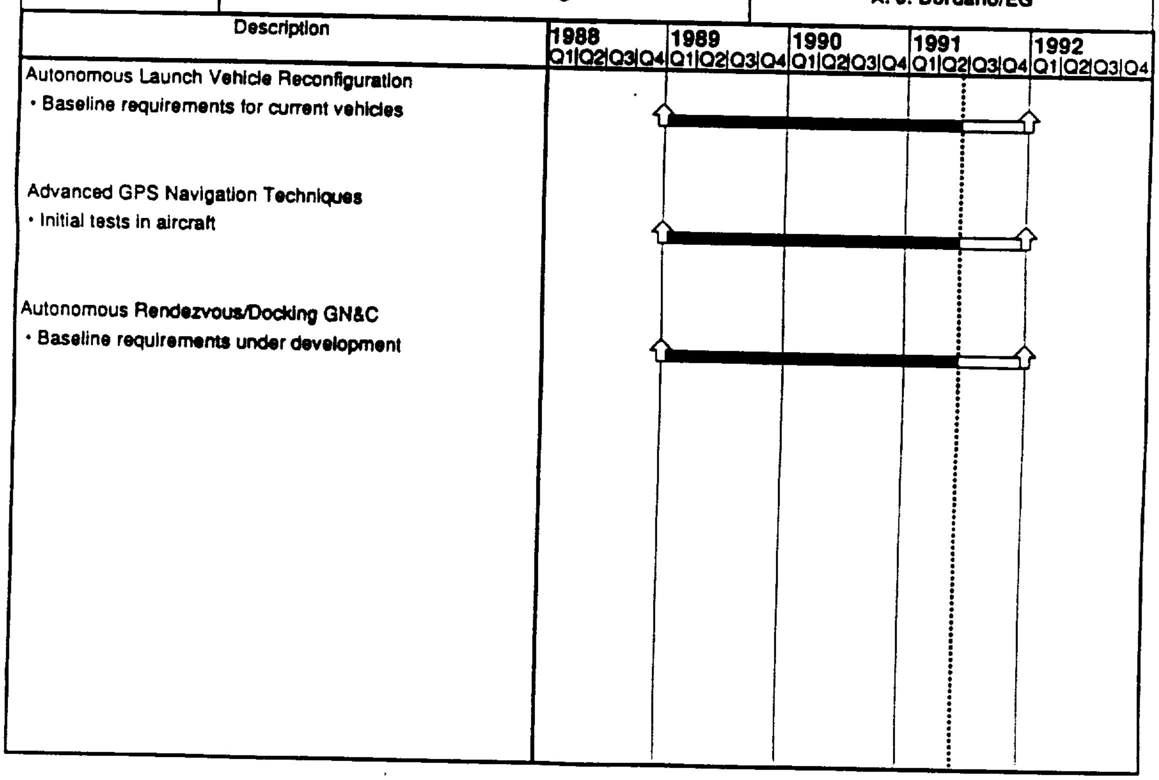
TECHNOLOGY	BENEFITS	WHY
• Automated vehicle checkout	• Expedite pre-launch operations; minimize personnel costs • Launch commit and Go/No Go decision process is expedited	• Delays, launch aborts and recycles are too expensive in direct & indirect costs; more efficient operations
• Autonomous vehicle health management	• Maximize mission capabilities, performance; enhanced mission success probability	• Alleviates and circumvents effects of in-flight failures and degradations • VHM techniques allow weight and power savings by substituting software intelligence for some physical redundancy
• VHM system architecture and software	• Enables incremental adoption of VHM concepts and new hardware; minimizes technical risks; improves efficiency and robustness	• Different systems, technologies and sensors will develop at different times
• VHM sensors	• Increased knowledge of complex equipment's health condition	• Prognosis and timely fault detection capabilities are required for complex equipment operating in extreme environments
• Residual lifetime estimation, dynamic health & status assessment	• Enhanced mission success • Impro· ·rformance margins • Improved cost effectiveness of processing and maintenance operations	• Component health is continuously monitored and incipient failures are detected perform they become acute • Performance redlines can be calculated dynamically and need not rely on statistical estimates of "beginning of life" (optimistic) or "end of life" (pessimistic) projections of system capabilities • System elements may be repaired when needed as opposed to following a periodic (overly conservative) schedule

NASA

5.2.7.4.1 ETO Vehicle Avionics: GN&C Algorithms Current & Related Programs

Navigation, Control & Aeronautics Division

A. J. Bordano/EG



NASA	5.2.7.4.1 ETO Vehicle Avionics: GN&C Algorithms Proposed Technology	Navigation, Control & Aeronautics Division A. J. Bordano/EG

Description

Autonomous Launch Vehicle Reconfiguration
- Baseline requirements for advanced vehicles
- GN&C Simulation
- Algorithm development
- Level C requirements development

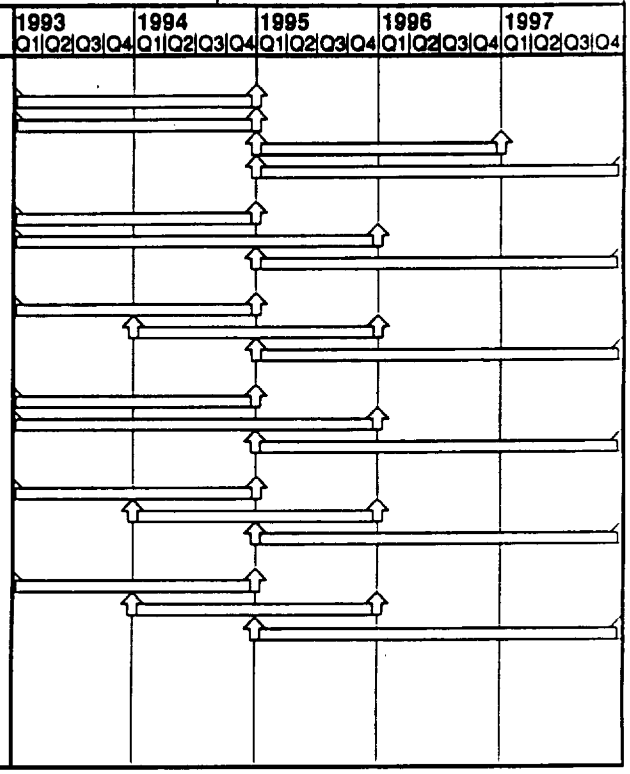
Atmospheric Adapative Entry GN&C
- Control concept development
- Environmental model development and simulation
- Algorithm development and simulation

Numeric/AI Guidance Techniques
- AI concept development
- Numeric Guidance/AI Integration
- Detailed algorithm development and testing

Parallel Processing GN&C Methods
- GN&C processing concept development
- Parallel GN&C architecture definition
- Algorithm development and simulation

Advanced GPS Navigation Techniques
- Advanced requirements baseline
- Advanced model development
- Detailed algorithm development and testing

Autonomous Rendezvous/Docking GN&C
- AR&D requirements development
- Algorithm concept development
- Algorithm testing and simulation



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5.2.7.4.1 ETO Vehicle Avionics: GN&C Algorithms Program Benefits	Navigation, Control & Aeronautics Division	A. J. Bordano/EG	6/26/91

TECHNOLOGY	BENEFITS	WHY
Autonomous Launch Vehicle GN&C Reconfiguration • Identify new approaches to current launch vehicle algorithms and processes that reduce or eliminate recurring engineering analysis, computer simulation and FRR activities	• Recurring launch operations costs can be reduced through automation and improvements to current GN&C algorithms and operations approaches	• Elimination of manpower intensive activities is needed for the next generation of launch vehicles
Atmospheric Adaptive Entry GN&C • Develop a GN&C system that can actively control heat rate, heat load or temperature while maintaining an accurate landing point	• Improved thermal protection margin and reduced sensitivity to atmospheric and system uncertainties	• Entry vehicle landing accuracy and thermal protection system requirements are driven by the ability of the GN&C system to adapt to dispersed atmospheric conditions
Numeric/AI Guidance Techniques • Utilize artificial intelligence techniques to provide assured convergence of numeric guidance algorithms	• Accurate, reliable guidance solutions using exact environment models	• Current numeric guidance schemes are not assured of always converging
Parallel Processing GN&C Methods • Develop new approaches and algorithms that can be effectively used on parallel processing computers	• Perform complex GN&C computations onboard using parallel processing	• Sequential computation limits today's GN&C processing
Advanced GPS Navigation Techniques • Develop new algorithms and environment models to improve GPS navigation accuracy for ETO vehicles	• Accurate, autonomous space vehicle navigation	• Changing environmental conditions can degrade doppler measurements
Autonomous Rendezvous/Docking GN&C • Develop algorithm concepts and approaches to support autonomous rendezvous	• Recurring costs reduced through automation and improvements to current GN&C algorithms and operations approaches	• Current AR&D operations rely heavily on ground based manual procedures

NASA

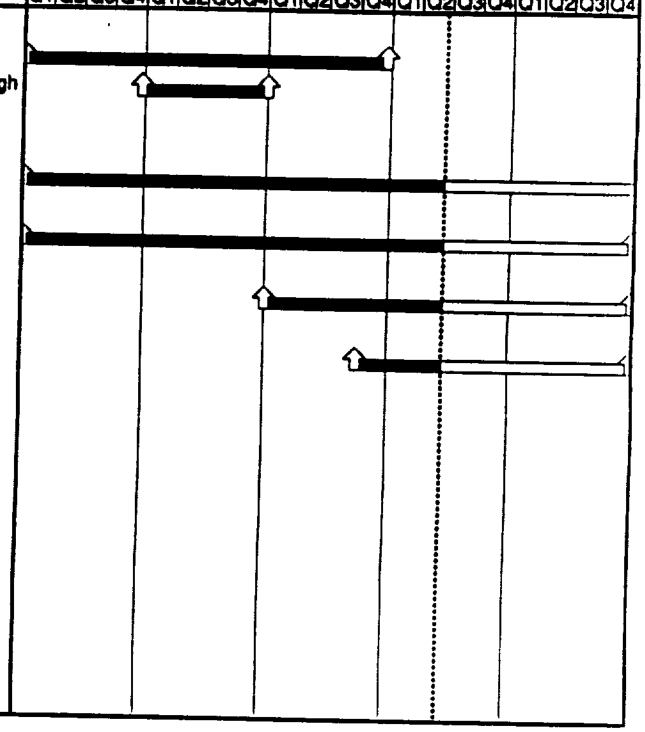
5.2.7.4.2 ETO Vehicle Avionics:
GN&C Sensors
Current & Related Programs

Navigation, Control & Aeronautics Division
A. J. Bordano/EG

Description — 1988 Q1 Q2 Q3 Q4 | 1989 Q1 Q2 Q3 Q4 | 1990 Q1 Q2 Q3 Q4 | 1991 Q1 Q2 Q3 Q4 | 1992 Q1 Q2 Q3 Q4

Optical Sensors for GN&C Applications
- Optical Sensors for GN&C Applications
- Set requirements and proof of concept testing for the High Resolution Attitude Rate Sensor

Inertial Components and Systems for GN&C Applications
- Evaluate inertial components for vendor specification compliance and vehicle applications
- Evaluate state-of-the-art inertial sensors for launch vehicle, orbital vehicles, and payload packages
- Develop inertial sensor packages for payload inertial measurements
- Maintain data base of state-of-the-art and proposed inertial sensor and system technologies



NASA

5.2.7.4.2 ETO Vehicle Avionics:
GN&C Sensors
Proposed Technology

Navigation, Control & Aeronautics Division
A. J. Bordano/EG

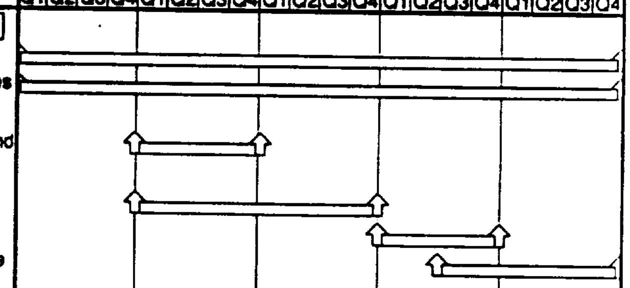
Description — 1993 Q1 Q2 Q3 Q4 | 1994 Q1 Q2 Q3 Q4 | 1995 Q1 Q2 Q3 Q4 | 1996 Q1 Q2 Q3 Q4 | 1997 Q1 Q2 Q3 Q4

Typical Schedule for GN&C Sensor Investigation

Specify requirements for sensor and system hardware
Specify requirements for software algorithms and databases

Reasearch the current technology for required hardware and software

Investigate and develop various algorithms
Design, build, and laboratory test of prototype system
Field test of prototype system in laboratories, and/or remote observatories and sites



GN&C Sensor Investigation

- Autonomous Attitude Determination System Development
- Optical Rate Sensor Development
- Horizon/Terrain Mapping/Feature Recognition Sensor Development
- Magnetorestive Sensor
- Fiber-Optic Gyro Research and Development
- Vibrating Beam Accelerometer
- Coriolis Accelerometer Inertial Measurement Unit (CAIMU)
- Capacitive, Magnetic Supension IMU (QUBIK)
- Multiple Receiver GPS IMU
- Gravity Wave/Lense Thirring Effec Detector (GWLTED)
- Electrostatic/Micromachined Accelerometer with Hybrid Electronics (EMA)
- Integrated Fiber-Optics Gyro GPS/Inertial Navigation System (FGPSINS)

5.2.7.4.2 ETO Vehicle Avionics: GN&C Sensors Program Benefits

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

TECHNOLOGY	BENEFITS	WHY
Optical Rate Sensor	• Precision vehicle attitude rates using optical techniques	• Provides reliable imaging real time navigation support for Earth orbit missions
Autonomous Attitude Determination System	• Precision vehicle attitude using optical imaging techniques	• Provides reliable real time attitude determination system for Earth orbit missions
Horizon Sensor	• Precision navigation capabilities using optical imaging techniques	• Provides reliable real time navigation support for Earth orbit missions
Terrain Mapping/Feature Recognition System	• Precision navigation capabilities using optical imaging and storage techniques	• Provides reliable real time support for Earth orbit missions
Magnetoresistive Sensor	• Azimuth determination in a smaller, lighter, less costly, less power package	• Provide light weight, low power consumption azimuth sensor for low earth orbit satellites
Interferometric Fiber-Optic Gyro (IFOG). Most mature	• High Mean Time Before Failure (MTBF) low power, angular rate sensor	• Provide highly reliable autonomous navigation and angular rate sensing
Resonator Fiber-Optic Gyro (RFOG). Least mature	• High MTBF, low power, RLG compatible angular rate sensor	• Provide highly reliable autonomous navigation and angular rate sensing
Fiber Optic Gyro Closed Loop	• High angular rate inertial sensor with improved rate linearity	• Provide highly reliable autonomous navigation and angular rate sensing
Vibrating Beam Accelerometer	• Precision, low power, small, reliable acceleration measurement	• Provide highly reliable autonomous navigation and linear acceleration measurement support
Coriolis Acceleration Inertial Measurement Unit	• Small, low power/part count IMU. Only accelerometer required for complete system	• Provide highly reliable compact autonomous navigation support
Capacitive, magnetic suspension IMU (QUBIK)	• Single sensor provides all inertial sensing requirements.	• Provide highly reliable compact autonomous navigation support
Multiple Receiver GPS IMU	• Calculate attitude from relative positions of GPS receivers on common vehicle	• Provide navigation for launch and low Earth orbit vehicles
Gravity Wave/Lense Thirring Effect Detector	• Calculate relativistic effects of massive bodies on trajectory and GPS time-keeping	• Provide more accurate navigation support for launch trajectories and for GPS navigation
Electrostatic/Micromachine accelerometer	• High sensitivity, small size, low power	• Provide compact autonomous navigation and acceleration measurement support
Integrated Fiber-Optic GPS/INS	• High MTBF, self calibrating Inertial Navigation System	• Provide highly reliable navigation support for low earth orbit missions

NASA

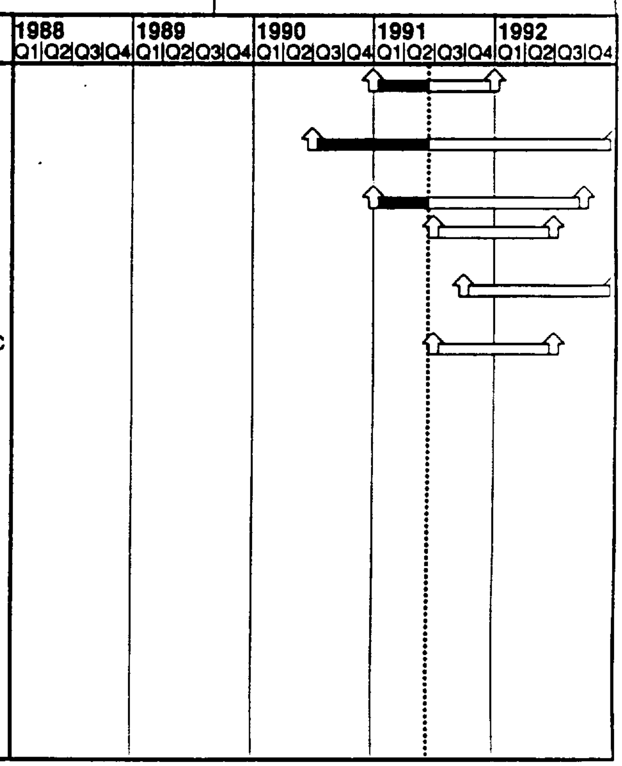
5.2.7.5 ETO Vehicle Avionics: Electrical Actuation Current & Related Programs

Navigation, Control & Aeronautics Division

A. J. Bordano/EG

Description

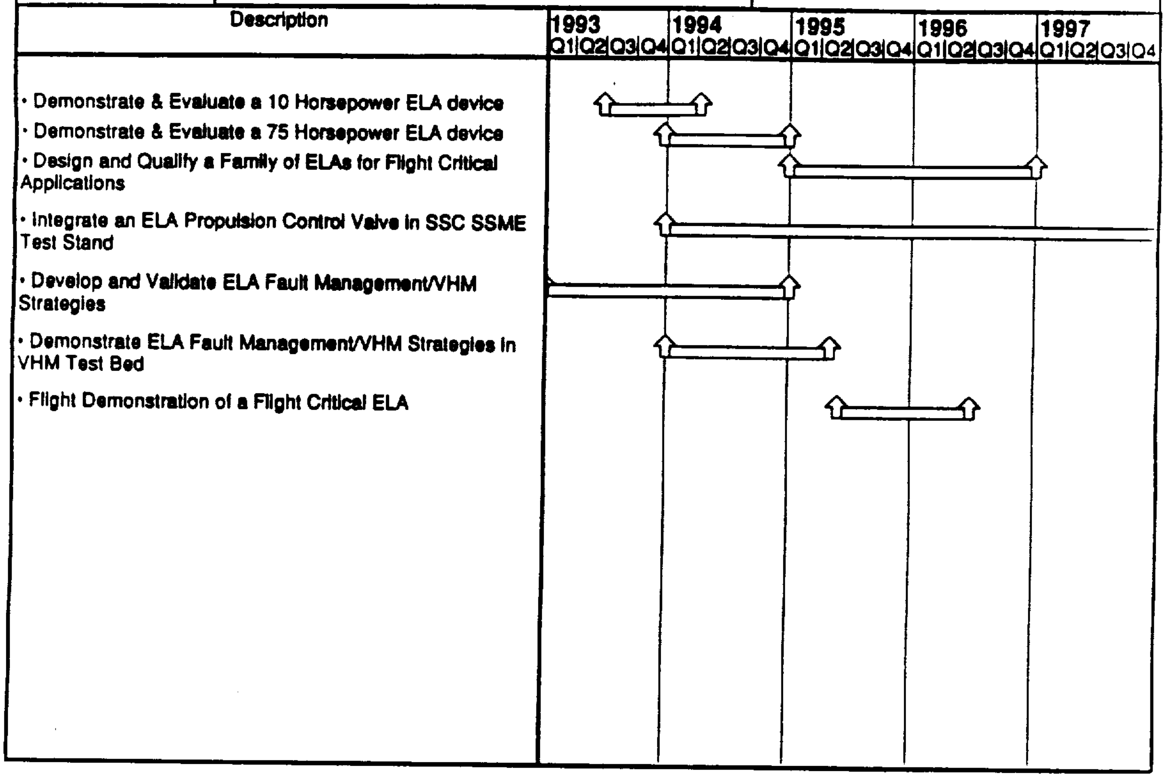
- General Dynamics 25-40 Horsepower EMA DDT&E Program (SATWG ELA Technology Bridging Program)
- JSC Actuator Test Set and Facility Development and Operation
- Honeywell TVC EMA Development Project
- Assessment of ETO actuation task requirements and ELA suitability
- System Engineering to identify design parameters and sensitivities; key trade criteria
- Evaluate Parker-Hannifin Nosewheel Steering EHA at JSC ATS



NASA

5.2.7.5 ETO Vehicle Avionics: Electrical Actuation Proposed Technology

Navigation, Control & Aeronautics Division
A. J. Bordano/EG



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5.2.7.5 ETO Vehicle Avionics: Electrical Actuation Program Benefits

Navigation, Control & Aeronautics Division
A. J. Bordano/EG
6/26/91

TECHNOLOGY	BENEFITS	WHY
• Electromechanical Actuation (EMA)	• Expedite pre-launch operations; minimize personnel costs • Operational safety increased • Distributed system is more fault/damage tolerant • Greatly reduced risk of system failures	• Hydraulic system eliminated; preflight control system checkout is expedited, does not entail hazardous operations • Hazardous fluids, stored energy systems, fluid replenishment operations eliminated • Distributed system elements; no central single point failures, no fluid couplings to burst or leak • Very low system part count
• Electrohydrostatic Actuation (EHA)	• Expedite pre-launch operations; minimize personnel costs • Operational safety increased • Distributed system is more fault/damage tolerant • Greatly reduced risk of system failures • Directly applicable to flight-critical applications	• Centralized hydraulic system eliminated; preflight control system checkout is expedited, does not entail periodic hazardous operations • Hazardous fluids, stored energy systems, fluid replenishment operations eliminated • Distributed system elements; no central single point failures, no external fluid couplings • Very low system part count • EHAs provide inherent load-sharing ability • Overload capacity is similar to conventional hydraulics • Actuator can be backdriven with adjustable impedance (variable damping capability)
• ELA (all technologies)	• Inherently supports basic constructs of VHM initiative • Expedites launch system processing and checkout operations • Allows system level functionality test at low cost in terms of manpower, time, and special configurations/test support equipment requirements	• Simple electrical and command interface with host vehicle • Obviates need for external hydraulic support carts • Long "shelf life" without need for constant servicing
• Magnetostrictive and other direct acting	• Increased reliability • Unit cost is reduced	• Extremely low parts count (for magnetostrictive, 1 moving part!) • Devices are mechanically relatively simple

NASA

5.2.7.6 ETO Vehicle Avionics: Landing/Recovery Systems Current & Related Programs

Navigation, Control & Aeronautics Division
A. J. Bordano/EG

Description

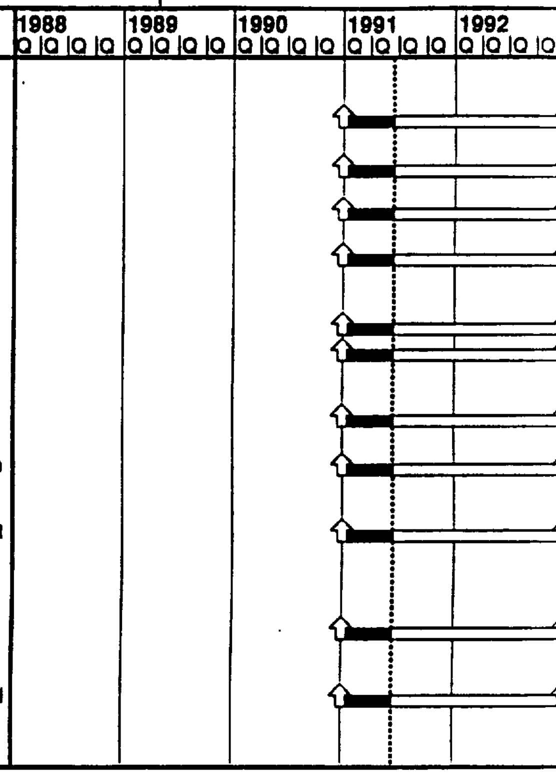
Parachute Aero Sciences
- Multi-Body Simulation
  - •• Baseline set of requirements for multi-body simulation
- Computational Fluid Dyanmics (CFD)
  - •• Baseline set of requirements for CFD code development
- Wind Tunnel Testing
  - •• Baseline set of requirements for wind tunnel testing
- Flight Demonstration
  - •• Baseline set of requirements for flight demonstration

Advanced Recovery System (ARS) Demonstration
- Flight Demonstration
  - •• Augmented ARS Phase IIIA Program
  - •• Baseline set of reqments for landing flare wind tunnel test

Parachute Guidance, Navigation & Control
- Simulation Development
  - •• Baseline set of requirements for simulation development
- Sensor/Avionics Configuration
  - •• Baseline set of requirements for sensor/avionics configuration
- GN&C Software Development
  - •• Baseline set of requirements for GN&C software development

Impact Systems Test Bed
- Test Planning & Testbed Design/Fabrication
  - •• Baseline set of requirements for impact systems test

Advanced Instrumentation
- System Development
  - •• Baseline set of requirements for instrumentation definition and development



NASA

5.2.7.6 ETO Vehicle Avionics: Landing/Recovery Systems Proposed Technology

Navigation, Control & Aeronautics Division
A. J. Bordano/EG

Description

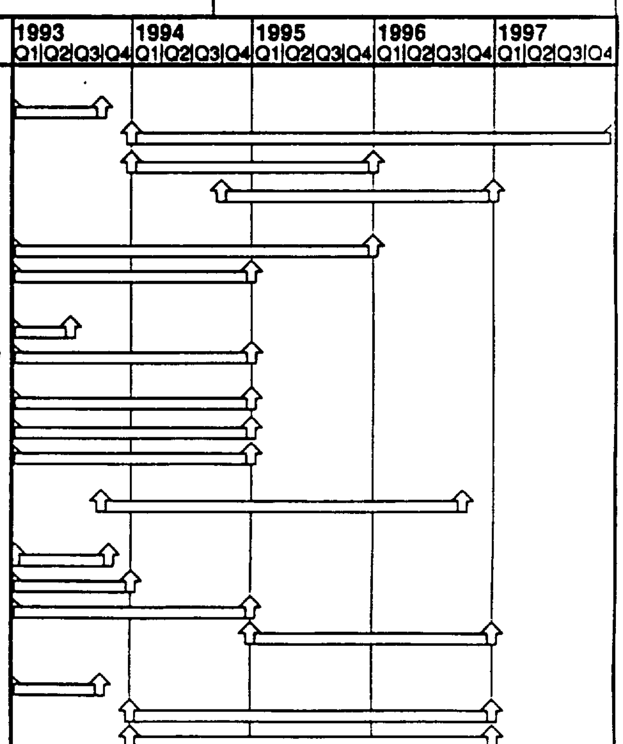
Parachute Aero Sciences
- Multi-body simulation development
- CFD code development/application
- Wind tunnel testing
- Flight demonstration

Advanced Recovery System (ARS) Demonstration
- Augmented ARS Phase IIIA Program
- Landing flare wind tunnel program

Parachute Guidance, Navigation, & Control
- Definition of simulation requirements
- Inertial simulation capability using primary aero data base
- Definition of representative sensor/avionics configuration
- Testing of representative sensors/actuators
- Definition of GN&C software requirements & code development
- Procurement/integration of sensor/effector hardware

Impact Systems Test Bed
- Test Planning
- Testbed design
- Testbed fabrication & preparation
- Landing system test

Advanced Instrumentation
- Definition of instrumentation requirements
- System development
- Experimental validation of measurement techniques



5.2.7.6 ETO Vehicle Avionics: Landing/Recovery Systems Program Benefits

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

TECHNOLOGY	BENEFITS	WHY
Parachute Aero Sciences • Multi-body simulation development for realistic modeling of parachute system dynamics • Computational fluid dynamics code development to model the unsteady flow physics • Wind tunnel testing to acquire database for conducting trade studies and assessing scaling effects • Flight demonstration to test integrated system performance	• Realistic modeling of parachute inflation, dynamics of multiple parachutes in a cluster and landing flare simulation • Provides improved understanding of parachute flowfields to assist in canopy structural design • Provides database for use in system simulation trade studies • Physical testing of integrated system	• Allows for systems trade studies to yield more optimum design and reduced flight testing requirements • Provides improved design process and reduced testing requirements • Provides validation of design tools and assessment of scaling parameters • Provides integrated system assessment and demonstration of procedures such as automatic landing flare
Advanced Recovery System (ARS) Phase IIIA • Augmented ARS Phase IIIA program for demonstration of flared landing capability • Landing flare wind tunnel program to acquire database for procedures development and assessment of scaling effects	• Further advance knowledge of large scale gliding parachute systems • Provides database for use in improving definition of flare and development of scaling parameters	• Demonstrates deployment, precision flared landing capabilities • Provides validation of design tools and assessment of scaling parameters
Parachute GN&C • Inertial simulation capability for realistic modeling of integrated system performance • Definition/testing of representative sensor/avionics configuration for assessing environmental effects • GN&C software requirements and code development for assessment of system performance	• Realistic modeling of integrated system to assess sensor and effector requirements, guidance and flight control algorithms and definition of avionics configuration • Provides realtime feedback of environmental effects such as winds and density variation to improve landing accuracies • Provides integrated GN&C system to support parachute landing systems development	• Allows for system trade studies to improve system design and improve landing accuracies • Reduces landing zone requirements by compensating for environmental effects • Provides integrated system assessment and demonstration of flare landing and targeting accuracies

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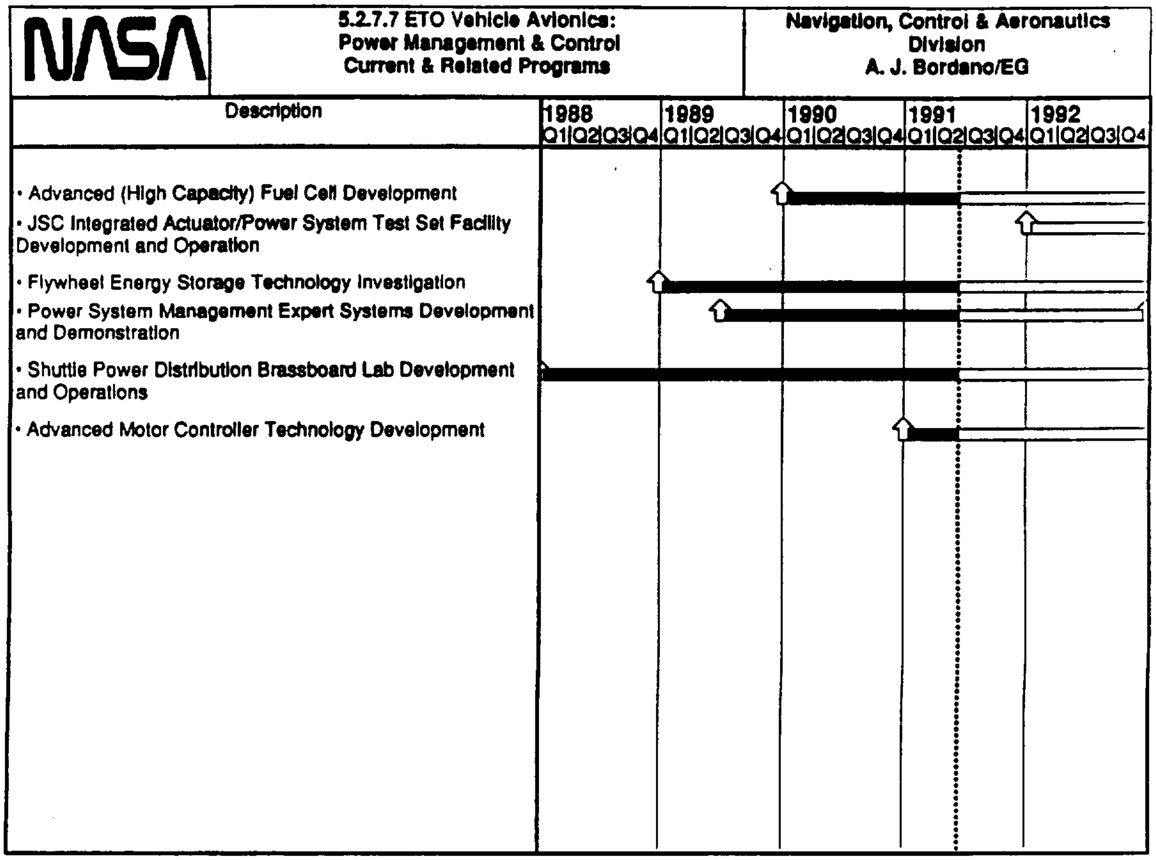
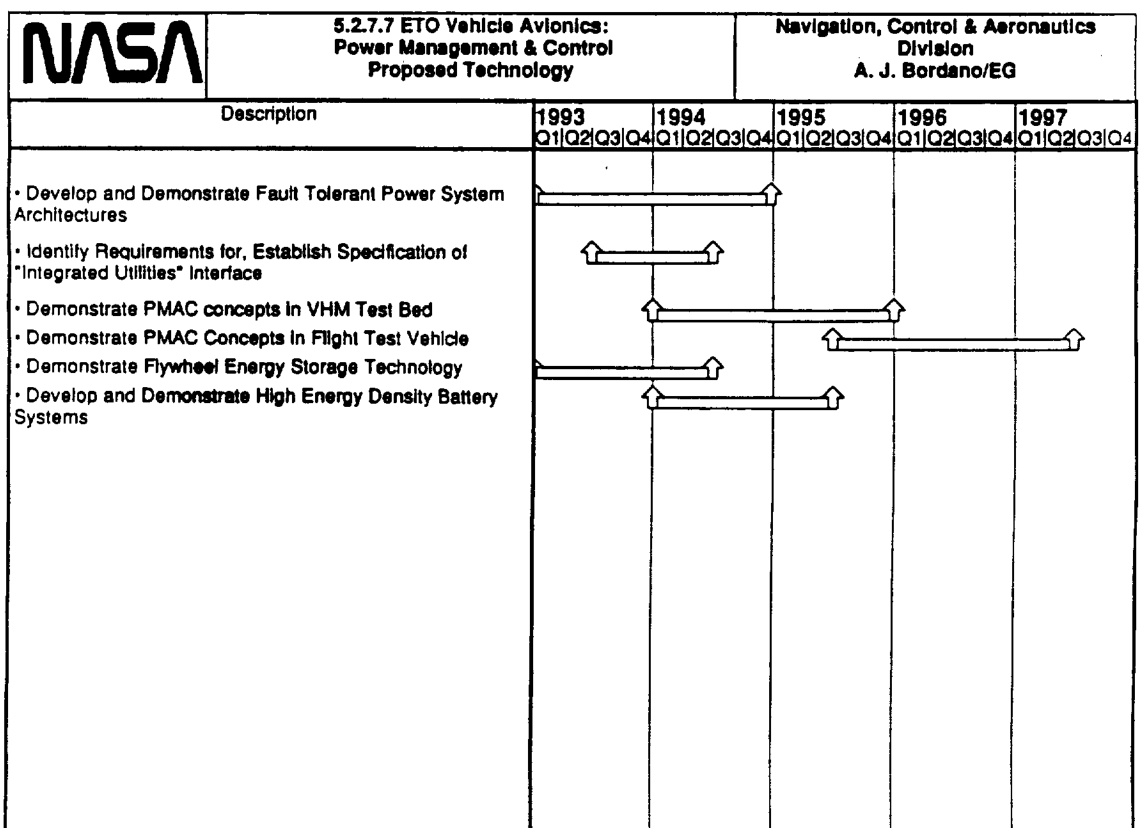
5.2.7.6 ETO Vehicle Avionics: Landing/Recovery Systems Program Benefits (Continued)

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

TECHNOLOGY	BENEFITS	WHY
Impact Systems Test Bed • Test bed design/fabrication to evaluate candidate impact attenuation systems • Landing system test to assess candidate impact attenuation system performance	• Provide capability to evaluate candidate impact attenuation system concepts • Provides physical testing of candidate systems and concepts	• Reduces impact conditions for variety of dispersed flight conditions and allows for land landings • Provides integrated system assessment of impact attenuation capabilities and system certification
Advanced Instrumentation • Measurement system development for enhancing system design and validation of design tools • Experimental validation of measurement techniques to assess instrumentation accuracies and capabilities to measure flow properties	• Provides system to measure local pressures on parachute canopy and loads in suspension lines • Provides assessment of instrumentation intrusion on local flow field	• Improve ability to validate new design tools and enhance confidence in system performance • Improved design process through better understanding of canopy shape and attitude sensitivities


NASA
5.2.7.7 ETO Vehicle Avionics:
Power Management & Control
Current & Related Programs
Navigation, Control & Aeronautics
Division
A. J. Bordano/EG
Description
1988 Q1 Q2 Q3 Q4
1989 Q1 Q2 Q3 Q4
1990 Q1 Q2 Q3 Q4
1991 Q1 Q2 Q3 Q4
1992 Q1 Q2 Q3 Q4
• Advanced (High Capacity) Fuel Cell Development
• JSC Integrated Actuator/Power System Test Set Facility Development and Operation
• Flywheel Energy Storage Technology Investigation
• Power System Management Expert Systems Development and Demonstration
• Shuttle Power Distribution Brassboard Lab Development and Operations
• Advanced Motor Controller Technology Development


NASA
5.2.7.7 ETO Vehicle Avionics:
Power Management & Control
Proposed Technology
Navigation, Control & Aeronautics
Division
A. J. Bordano/EG
Description
1993 Q1 Q2 Q3 Q4
1994 Q1 Q2 Q3 Q4
1995 Q1 Q2 Q3 Q4
1996 Q1 Q2 Q3 Q4
1997 Q1 Q2 Q3 Q4
• Develop and Demonstrate Fault Tolerant Power System Architectures
• Identify Requirements for, Establish Specification of "Integrated Utilities" Interface
• Demonstrate PMAC concepts in VHM Test Bed
• Demonstrate PMAC Concepts in Flight Test Vehicle
• Demonstrate Flywheel Energy Storage Technology
• Develop and Demonstrate High Energy Density Battery Systems

Johnson Space Center - Houston, Texas

5.2.7.7 ETO Vehicle Avionics: Power Management & Control Program Benefits

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

TECHNOLOGY	BENEFITS	WHY
•Autonomous reconfiguration among series/parallel circuit paths	• Expedite pre-launch operations; minimize personnel costs • Increased mission success probability	• PMAC implementation supports automated vehicle checkout • System is more robust and fault tolerant
•Integrated modular service backbone	• Vehicle integration task is simplified • Power, thermal, data capabilities are provided in a balanced fashion • Vehicle performance is improved	• All required services are provided across a unified interface • Integrated "utilities bus" characterized by high level of integration and multiplexing, saves weight
•High frequency power distribution and control	• Vehicle performance is improved	• System components are lighter; efficiencies are higher
•High energy density battery systems	• Enhanced mission success probability	• Eliminates requirements for more complex and technically risky dynamic power generation systems for launch vehicles
•Enhanced fuel cells	• Enhanced mission success • Vehicle performance is increased	• Fuel cell system reliability is increased • Advanced fuel cells have a higher net energy density; power system is lighter for the same capacity
•Advanced Energy storage and power conditioning devices (i.e. flywheels), advanced motor controllers	• Enhanced compatibility with electrical actuation (ELA) technology; improved system efficiencies	• Power supply, regulation, and conditioning technology is matched to the unique requirements of ELAs

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5.3.8 Transfer Vehicle Avionics Overview

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

- The next generation of transfer vehicles will need to have increased mission safety, more autonomy for unmanned operation or reduced crew workload, and reduced operational costs.
- Transfer Vehicle and ETO Avionics technology development share common goals which invites and in fact, for cost effectiveness, dictates collaboration and interfacing between the two areas of development.
- The goals of the NASA Transfer Vehicle Avionics Technology Development Program are:
  - Build on a foundation provided by similar work for the ETO Vehicle Avionics Technology Development Program.
  - Provide the capability to develop self contained transportation systems for long duration missions where ground support are not readily available.
  - Advance technologies in vehicle avionics architecture, software, health management, GN&C, electrical actuators, and power management and control for short and long duration missions.
- These technology goals are intended to improve efficiency and safety (reliability, robustness, failure tolerance), decrease crew workload, and reduce cost of production/operation in the next generation of Space Transportation Systems.
- A major technology challenge arises in the development of self contained space transportation systems necessary to operate without logistic supply lines, for protracted periods of dormancy, for long term exposures to charged particle/radiation and changing environment expected of the interplanetary space and planet surfaces.

NASA	5.3.8.1 Transfer Vehicle Avionics: Avionics Architecture Current & Related Programs	Navigation, Control & Aeronautics Division A. J. Bordano/EG

Description | 1990 Q1 Q2 Q3 Q4 | 1991 Q1 Q2 Q3 Q4 | 1992 Q1 Q2 Q3 Q4 | 1993 Q1 Q2 Q3 Q4 | 1994 Q1 Q2 Q3 Q4 | 1995 Q1 Q2 Q3 Q4

- Flight Data System Open Architecture document
- Flight Daya System system profiles
- Flight Data System Open Architecture performance analysis and trades
- Flight Data System Open Architecture prototype development
- Network Performance Model
- Bare 386 Real Time Kernel Inestigation
- Station Flight-to-Ground Interoperability Evaluation
- Applications-to-RODB Data Type Analysis

NASA	5.3.8.1 Transfer Vehicle Avionics: Avionics Architecture Proposed Technology	Navigation, Control & Aeronautics Division A. J. Bordano/EG

Description | 1993 Q1 Q2 Q3 Q4 | 1994 Q1 Q2 Q3 Q4 | 1995 Q1 Q2 Q3 Q4 | 1996 Q1 Q2 Q3 Q4 | 1997 Q1 Q2 Q3 Q4

- Long Duration Flight (LDF) Architecture and Simulation Requirements Definition
- LDF Architecture Predictive/Alternatives Simulation Development
- LDF Processing Embedded Simulation Architecture and Component Prototype Development for Inflight Health Monitoring and Training
- LDF Processing Inflight Mass Data Collection, Trend Analysis, and System Performance Prototype Development
- Multi-Systems and Multi-Vehicle (MS&MV) Processing Requirements Definition (including Robotics)
- MS&MV Operations Architecture Development (including integrated Robotics Architecture)
- MS&MV Off-Earth Processing Prototype Development
- MS&MV Earth-Based and MCC Concept/Prototype Development
- MS&MV Network LAN Prototype Development
- MS&MV Network WAN Prototype Development
- MS&MV Network Advanced Intelligent Knowledge Based Prototype Development
- Resynchronization Processing Software Requirements for Stopping, Recovery, and Resync Control
- Resynchronization Processing Software Requirements for Thread
- Avionics Displays and Controls Alternative Sensory Mechanism Prototype Development
- Avionics Displays and Controls Advanced Total Environment and High Fidelity Voice Control Prototype Development

5.3.8.1 Transfer Vehicle Avionics: Avionics Architecture Program Benefits

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

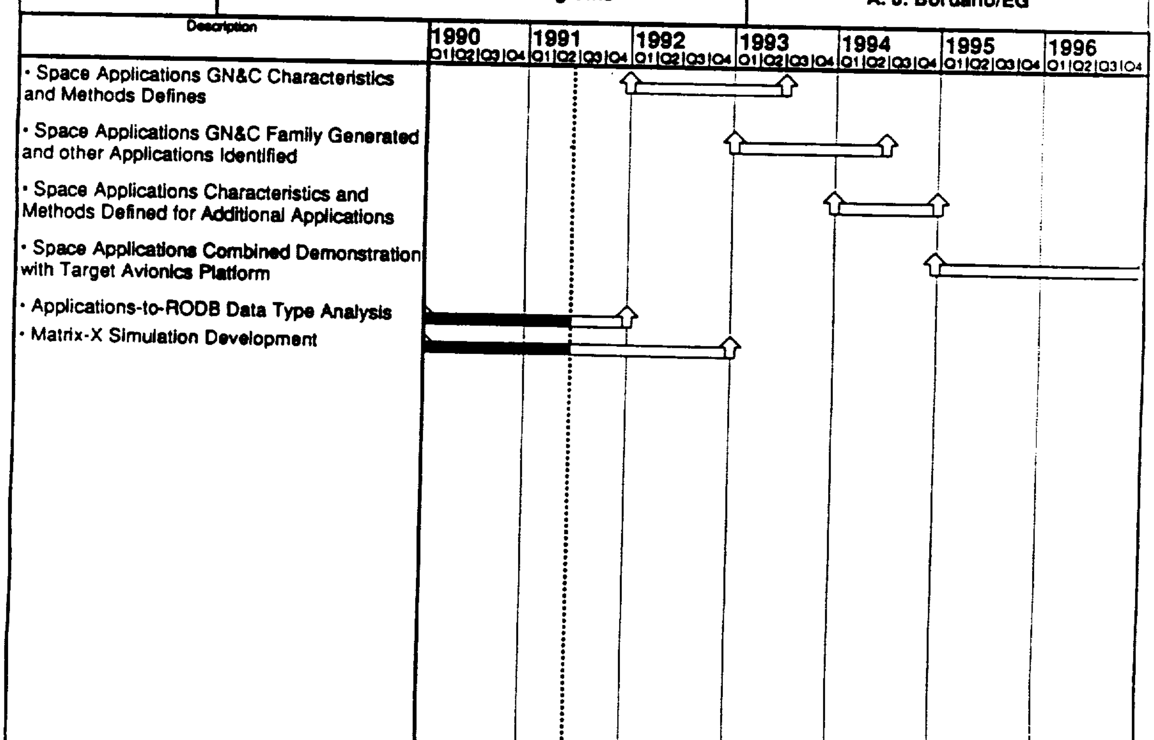
TECHNOLOGY	BENEFITS	WHY
Transfer Vehicle Architecture • Long Duration Flight Architecture - Develop predictive models which account for cumulative space effects and alternative response mechanisms - Prototype and demonstrate candidate architectures including embedded simulations for inflight health status monitoring and training - Prototype and demonstrate inflight mass data collection, trend analysis, and system performance forecasting	• Definition of architectures and standards to evaluate concepts and systems before design commitment	• Establish criteria for long duration flight stresses such as dormancy
• Multi-Systems and Multi-Vehicle Processing - Define architectures to use in multi-system and multi-vehicle operations, including advanced robotic architectures - Develop and prototype flight data systems of off-Earth systems, Earth-based data systems and alternative mission control center concepts	• Evaluation of the data systems with heterogeneous components and alternate combinations of humans and robotics	• Development of standards for operating at different levels of autonomy across multiple vehicles
• Multi-Systems and Multi-Vehicle Networks - Develop and prototype advanced inter-processor communication (local area networks) hardware and inter-vehicle communication (wide area networks) hardware - Investigate new test, certification, and verification technologies for advanced network hardware	• Efficient data communication in both local and wide area environment	• Effective data communication
• Resynchronization Processing - Define requirements for stopping and recovering from single and multiple processing failures for operating under fault conditions and for re-synchronizing processing threads in both single and multiple vehicles	• Realistic testing of time and data synchronization and fault recovery across single and multiple vehicles	• Satisfy mission performance and success criteria
• Avionics Displays and Controls - Define requirements for advanced human-tended display and control interfaces, aids and alternative sensory mechanisms - Develop, build, prototype and demonstrate advanced total environment or holographic display and high fidelity voice control interfaces	• Efficient data fusion processes to eliminate comprehension overload on the human senses	• Acceptability of advanced human-machine interfaces

NASA

5.3.8.2 Transfer Vehicle Avionics: Avionics Software Current & Related Programs

Navigation, Control & Aeronautics Division

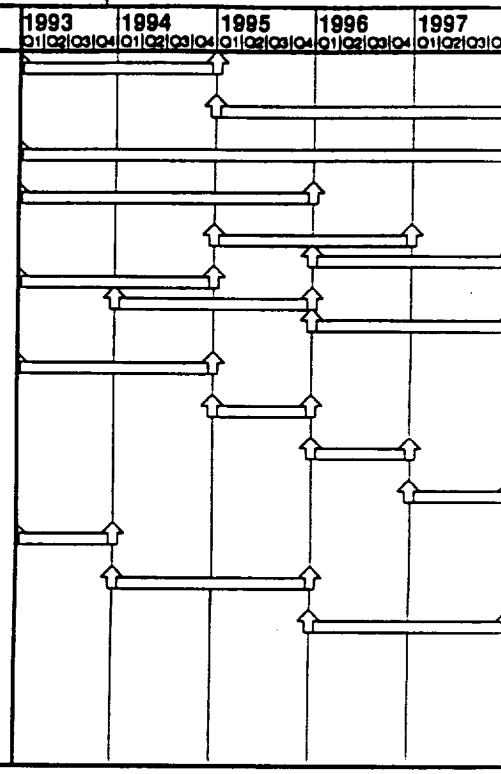
A. J. Bordano/EG



5.3.8.2 Transfer Vehicle Avionics: Avionics Software Proposed Technology	Navigation, Control & Aeronautics Division A. J. Bordano/EG

Description

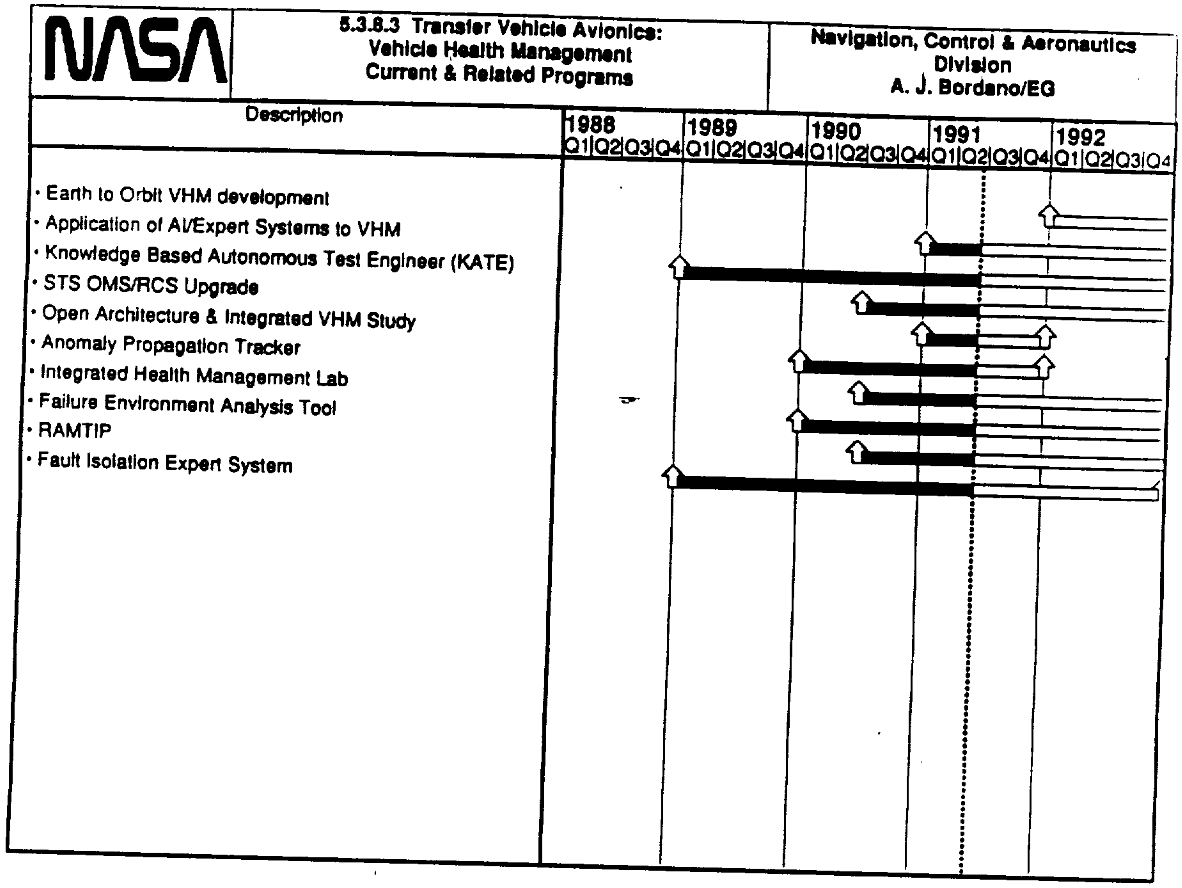
- Long Duration Flight Algorithm and Remote Control Model Requirements Definition
- Alternative Long Duration Algorithm and Remote Control Prototype Development
- Case Tool Development for Auto Code Prodn, Data Exchange, Config Mgnt, Reuseability and Traceability of Flight Software
- Multi-Systems/Vehicle (MS&MV) Interface and SW Requirements Definition (incl altern MCCs and Plentary surface vehicles)
- MS&MV Flight Data System Interface Development
- MS&MV Flight Data System Software Prototype Development
- MS&MV LAN Software Prototype Development
- MS&MV Networks WAN Software Prototype Development
- MS&MV Networks Advanced Intelligent Knowledge Based Prototype Development
- Resynchronization Processing Software Requirements for Stopping, Recovery, and Resync Control
- Resynchronization Processing Software Requirements for Thread Definition and Controls
- Resynchronization Processing Concurrency and Consistency Requirements Definition in one Vehicle
- Resynchronization Processing Concurrency and Consistency Requirements Definition in Multiple Vehicles
- Off-Earth Advanced Human-Tended Avionics Displays and Controls Software Requirements Definition
- Avionics Displays and Controls Advanced Intelligent Knowledge Based Human Operations Software Prototype Development
- Avionics Advanced Software Displays and Controls Prototype Development

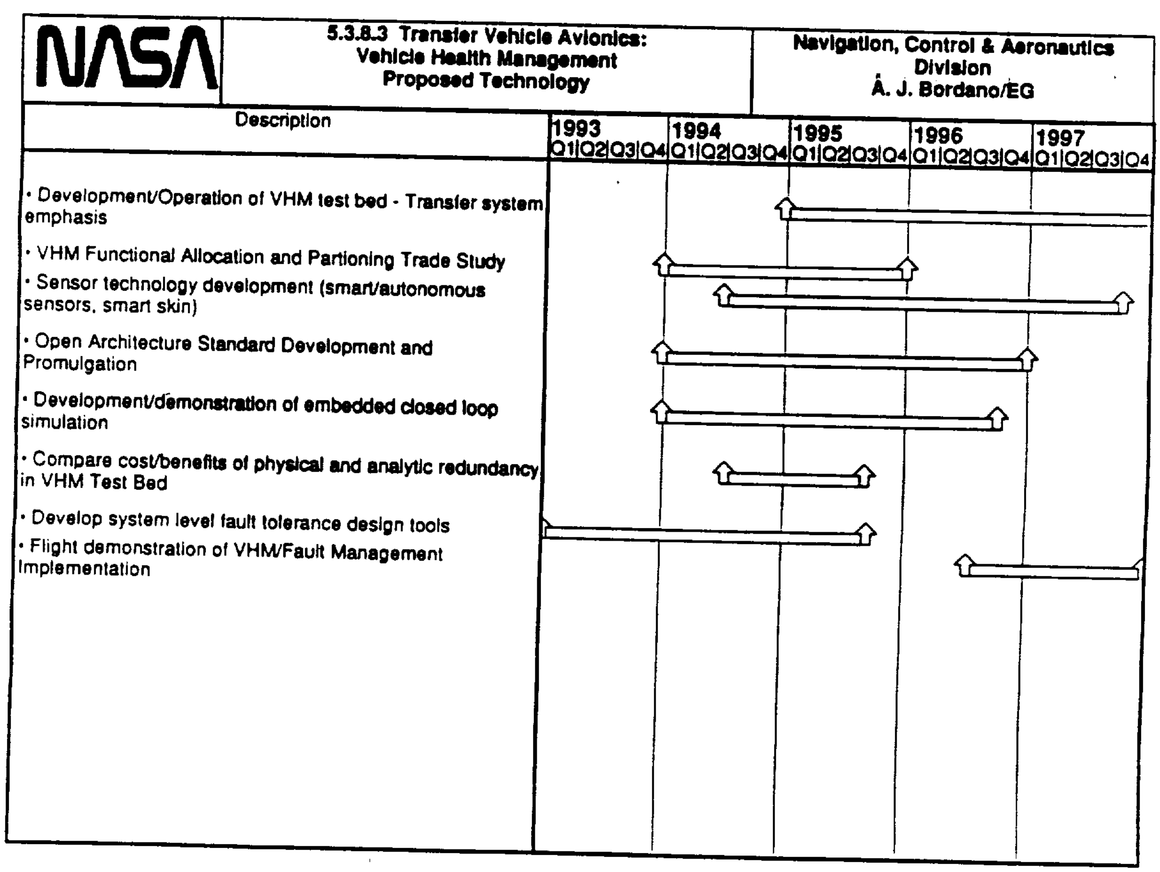


Johnson Space Center - Houston, Texas

5.3.8.2 Transfer Vehicle Avionics: Avionics Software Program Benefits	Navigation, Control & Aeronautics Division	
	A. J. Bordano/EG	6/26/91

TECHNOLOGY	BENEFITS	WHY
Transfer Vehicle Software • Long Duration Flight Software - Develop degradation algorithms and simulations of time delay models for remote control of flight data system elements - Develop and build Computer Aided Systems Engineering (CASE) tools which support code development, data exchange, configuration management, requirements traceability and reuseability for flight software elements.	• Better understanding of the software requirements operating under degrading or aging system components	• Software to support time degradation effects
• Multi-Systems and Multi-Vehicle Processing - Develop and demonstrate flight data system interfaces among off-Earth systems, Earth-based data systems, planetary surface vehicles, and alternate mission control center concepts	• Assessment of software features for operation across heterogeneous systems and vehicles	• Operations across a remote and diverse fleet
• Multi-Systems and Multi-Vehicle Networks - Develop and prototype inter-processor communication (local area networks) software and inter-vehicle communication (wide area networks) software for data communications - Develop and prototype advanced intelligent knowledge based control over networks	• Development of data communication for interacting non-Earth based mission	• Efficient data communication both inter and intra vehicle
• Resynchronization Processing - Define software requirements for stopping and recovering from single and multiple software failures in single and multiple vehicles and for re-synchronizing processing threads - Define requirements for data consistency and concurrent operation across multiple systems in one vehicle and in multiple vehicles	• Establish and demonstrate software recoverability for both inter and intra vehicles	• Support to long duration and remote missions
• Avionics Displays and Controls - Develop and prototype knowledge based display and control aids to support human operation of complex systems - Develop and prototype software controls for advanced visual, touch, voice and other sensory display and control interfaces	• Provides effective approaches for increasing software support to human data comprehension	• Human-machine interface evaluation and acceptance


NASA
5.3.8.3 Transfer Vehicle Avionics:
Vehicle Health Management
Current & Related Programs
Navigation, Control & Aeronautics
Division
A. J. Bordano/EG
Description
1988
1989
1990
1991
1992
Q1 Q2 Q3 Q4
• Earth to Orbit VHM development
• Application of AI/Expert Systems to VHM
• Knowledge Based Autonomous Test Engineer (KATE)
• STS OMS/RCS Upgrade
• Open Architecture & Integrated VHM Study
• Anomaly Propagation Tracker
• Integrated Health Management Lab
• Failure Environment Analysis Tool
• RAMTIP
• Fault Isolation Expert System


NASA
5.3.8.3 Transfer Vehicle Avionics:
Vehicle Health Management
Proposed Technology
Navigation, Control & Aeronautics
Division
A. J. Bordano/EG
Description
1993
1994
1995
1996
1997
Q1 Q2 Q3 Q4
• Development/Operation of VHM test bed - Transfer system emphasis
• VHM Functional Allocation and Partioning Trade Study
• Sensor technology development (smart/autonomous sensors, smart skin)
• Open Architecture Standard Development and Promulgation
• Development/demonstration of embedded closed loop simulation
• Compare cost/benefits of physical and analytic redundancy in VHM Test Bed
• Develop system level fault tolerance design tools
• Flight demonstration of VHM/Fault Management Implementation

5.3.8.3 Transfer Vehicle Avionics: Vehicle Health Management Program Benefits

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

TECHNOLOGY	BENEFITS	WHY
• Automated vehicle checkout - performed continuously and without human intervention	• Increased prospects of system survival and mission success in harsh environments	• VHM allows superior insight into system conditions; supports both human and machine-based decisions
• Autonomous vehicle health management	• Maximize mission capabilities, performance; enhanced mission success probability	• Alleviates and circumvents effects of in-flight failures and degradations • VHM techniques allow weight and power savings by substituting software intelligence for some physical redundancy
• VHM system architecture and software	• Enables incremental adoption of VHM concepts and new hardware; minimizes technical risks; improves efficiency and robustness	• Different systems, technologies and sensors will develop at different times
• VHM sensors (physical sensing devices, analytic and other synthetic redundancy techniques) - use of "smart skin" for structures and propellant system elements • Distributed sensor architecture	• Increased knowledge of complex equipment's health condition • System is physically and functionally redundant and can withstand large scale physical insult without total loss of functionality	• Prognosis and timely fault detection capabilities are required for complex equipment operating in extreme environments
• Residual lifetime estimation, dynamic health & status assessment - mission operations will not be compromised by being forced to rely on devices and systems of questionable reliability	• Enhanced mission success • Improved performance margins • Improved cost effectiveness of processing and maintenance operations	• Component health is continuously monitored and incipient failures are detected before they become acute • Performance redlines can be calculated dynamically and need not rely on statistical estimates of "beginning of life" (optimistic) or "end of life" (pessimistic) projections of system capabilities • System elements may be repaired when needed as opposed to following a periodic (overly conservative) schedule

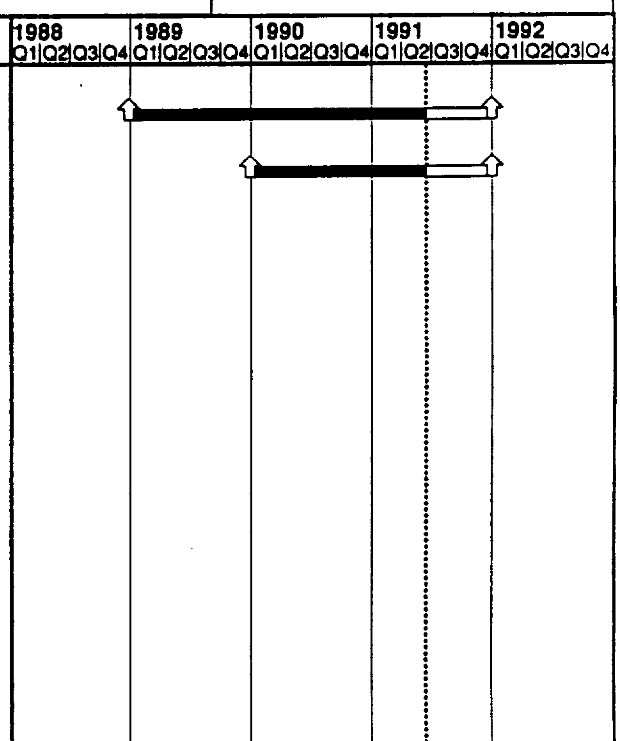
NASA

5.3.8.4.1 Transfer Vehicle Avionics: GN&C Algorithms Current & Related Programs

Navigation, Control & Aeronautics Division
A. J. Bordano/EG

Description

Autonomous Navigation in Interplanetary Space
• Preliminary concept development
Autonomous Rendezvous/Docking GN&C
• Baseline requirements under development



NASA

5.3.8.4.1 Transfer Vehicle Avionics: GN&C Algorithms Proposed Technology

Navigation, Control & Aeronautics Division
A. J. Bordano/EG

Description

Precision Orbit GN&C
- GN&C concept development
- Environment model development and simulation
- Algorithm development and simulation

Precision Orbit GN&C
- Optimal trajectory development
- Environmental model development and simulation
- Detailed algorithm development and testing

Advanced Analytical Propagators
- Analytic Technique Development
- Detailed requirements development
- Detailed algorithm development and testing

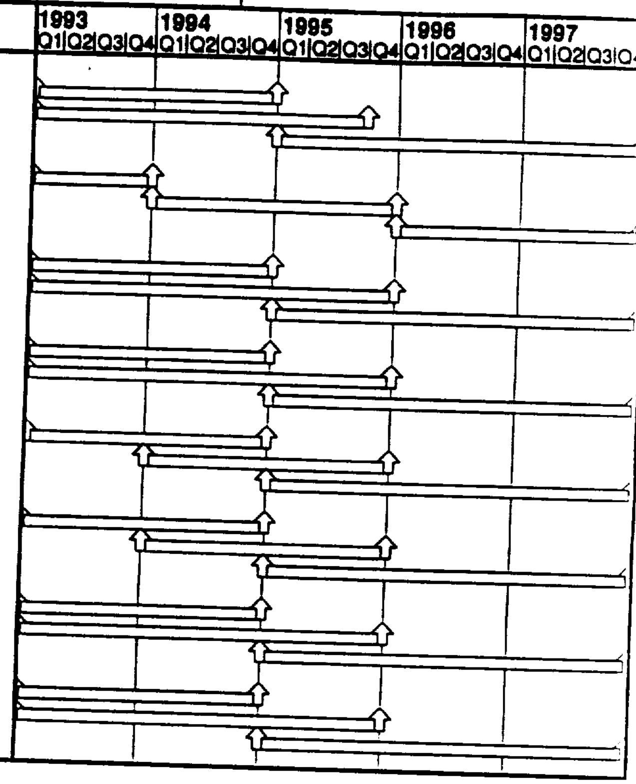
GN&C for Artificial Gravity Vehicles
- Artificial gravity approach assessment
- GN&C architecture definition
- Algorithm development and simulation

Autonomous Navigation in Interplanetary Space
- Autonomous approach development
- Concept trade studies
- Detailed algorithm development and testing

Numerical/AI Guidance Techniques
- AI conept development
- Numeric Guidance/AI Integration
- Detailed algorithm development and testing

Parallel Processing GN&C Methods
- GN&C processing concept development
- Parallel GN&C architecture definition
- Algorithm development and simulation

Autonomous Rendezvous/Docking GN&C
- AR&D requirements development
- Algorithm concept development
- Algorithm testing and simulation



Johnson Space Center - Houston, Texas

5.3.8.4.1 Transfer Vehicle Avionics: GN&C Algorithms Program Benefits

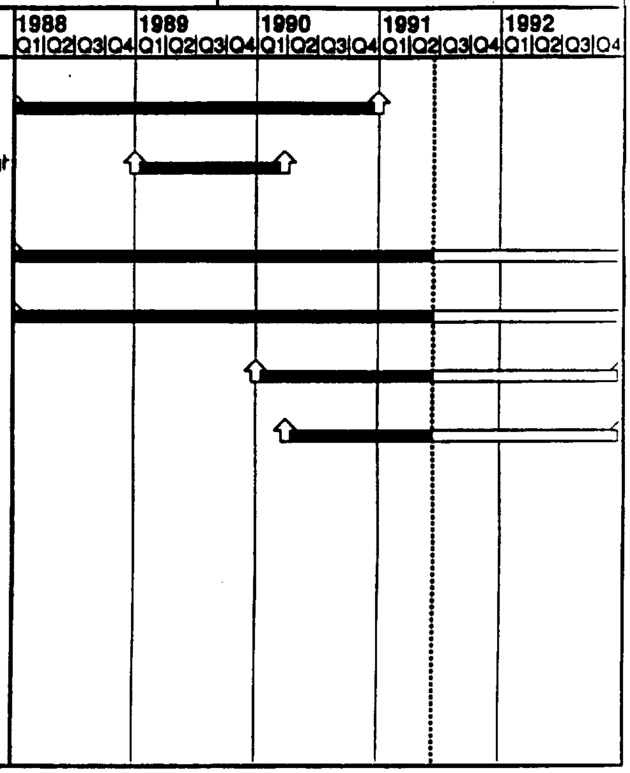
Navigation, Control & Aeronautics Division

A. J. Bordano/EG 6/26/91

TECHNOLOGY	BENEFITS	WHY
Precision Orbit GN&C • Develop new approaches and algorithms for maintaining extremely precise orbits	• Allows efficient use of geosynchronous orbits and Earth/Moon, Earth/Sun, Sun/Mars libration points	• Utilizing these unusual orbits requires precise maintenance of the vehicle position
Low Thrust Vehicle GN&C • Develop new GN&C algorithms for use on extremely low thrust to weight transfer vehicles	• Will allow effective use of advanced propulsion systems such as nuclear electric	• Current GN&C algorithms were developed for vehicles with relatively high thrust to weight
Advanced Analytic Propagators • Develop new analytic orbit propagator techniques for onboard use	• Analytic approaches are computationally more efficient than numeric approaches and have more assurance of convergence	• Current analytic propagators do not provide the accuracy necessary for the next generation of launch vehicles
GN&C for Vehicles Utilizing Artificial Gravity • Develop GN&C algorithms for vehicles which use spinning structures to provide artificial gravity for crew members	• Allow efficient operation of transfer vehicles while simultaneously providing a healthy crew environment	• Rotational dynamics necessary for artificial gravity has adverse effects on GN&C
Autonomous Navigation in Interplanetary Space • Develop autonomous navigation techniques and algorithms for use on deep space missions	• Reduce or eliminate requirement for Earth based navigation tracking	• Current deep space navigation is Earth based
Numeric/AI Guidance Techniques • Utilize artificial intelligence techniques to provide assured convergence of numeric guidance algorithms	• Accurate, reliable guidance solutions using exact environment models	• Current numeric guidance schemes are not assured of always converging
Parallel Processing GN&C Methods • Develop new approaches and algorithms that can be effectively used on parallel processing computers	• Complex GN&C computations can be performed with onboard parallel processing	• Sequential computation limits today's GN&C processing
Autonomous Rendezvous/Docking GN&C • Develop algorithm concepts and approaches to support autonomous rendezvous	• Recurring costs can be reduced through automation and improvements to current GN&C algorithms and operations approaches	• Current AR&D operations rely heavily on ground based manual procedures

NASA	5.3.8.4.2 Transfer Vehicle Avionics: GN&C Sensors Current & Related Programs	Navigation, Control & Aeronautics Division A. J. Bordano/EG

Description



Optical Sensors for GN&C Applications

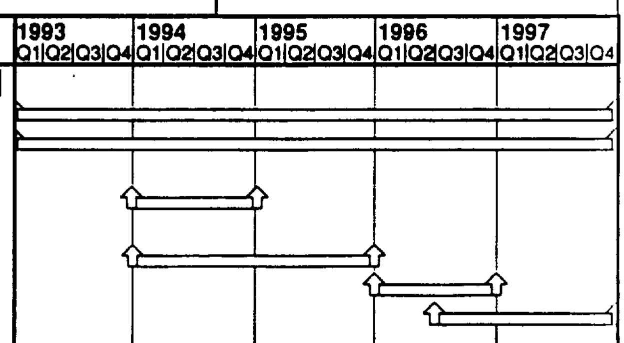
- Set requiremtns and proof of concept testing for the Continuous Stellar Tracking Attitude Reference (CSTAR)
- Set requirements and proof of concept testing for the High Resolution Attitude Rate Sensor

Inertial Componenets and Systems for GN&C Applications

- Evaluate inertial components for vendor specification compliance and vehicle applications
- Evaluate state-of-the-art inertial sensors for launch vehicle, orbital vehicles, and payload packages
- Develop inertial sensor packages for payload inertial measurements
- Maintain database of state-of-the-art and proposed inertial sensor and system technologies

NASA	5.3.8.4.2 Transfer Vehicle Avionics: GN&C Sensors Proposed Technology	Navigation, Control & Aeronautics Division A. J. Bordano/EG

Description



Typical Schedule for GN&C Sensor Investigation

- Specify requirements for sensor and system hardware
- Specify requirements for software algorithms and databases
- Reasearch the current technology for required hardware and software
- Investigate and develop various algorithms
- Design, build, and laboratory test of prototype system
- Field test of prototype system in laboratories, and/or remote observatories and sites

GN&C Sensor Investigation

- Autonomous Attitude Determination System Development
- Optical Rate Sensor Development
- Horizon/Terrain Mapping/Feature Recognition Sensor Development
- Magnetorestive Sensor
- Fiber-Optic Gyro Research and Development
- Vibrating Beam Accelerometer
- Coriolis Accelerometer Inertial Measurement Unit (CAIMU)
- Capacitive, Magnetic Supension IMU (QUBIK)
- Gravity Wave/Lense Thirring Effec Detector (GWLTED)
- Electrostatic/Micromachined Accelerometer with Hybrid Electronics (EMA)

5.3.8.4.2 Transfer Vehicle Avionics: GN&C Sensors Program Benefits

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

TECHNOLOGY	BENEFITS	WHY
Optical Rate Sensor	• Precision vehicle attitude rates using optical techniques	• Provides reliable imaging real time navigation support for extended Lunar and Mars missions
Autonomous Attitude Determination System	• Precision vehicle attitude using optical imaging techniques	• Provides reliable real time attitude determination system for extended Lunar and Mars missions
Horizon Sensor	• Precision navigation capabilities using optical imaging techniques	• Provides reliable real time navigation support for Lunar and Mars exploratory missions
Terrain Mapping/Feature Recognition System	• Precision navigation capabilities using optical imaging and storage techniques	• Provides reliable real time navigation support for Lunar and Mars exploratory missions
Magnetoresistive Sensor	• Provides azimuth determination in a smaller, lighter, less costly, less power package	• Provide light weight azimuth sensor for Earth and Mars orbit that requires little power for operation
Interferometric Fiber-Optic Gyro (IFOG) Most mature	• High Mean Time Before Failure (MTBF) low power, angular rate sensor	• Provide highly reliable autonomous navigation and angular rate sensing for Lunar and Mars missions
Resonator Fiber-Optic Gyro (RFOG) Least mature	• High MTBF, low power, RLG compatible angular rate sensor	• Provide highly reliable autonomous navigation and angular rate sensing for Lunar and Mars missions
Fiber Optics Gyro Closed Loop	• High angular rate inertial sensor with improved rate linearity over Open Loop FOG's	• Provide highly reliable autonomous navigation and angular rate sensing for Lunar and Mars missions
Vibrating Beam Accelerometer	• Precision, low power, small, reliable acceleration measurement	• Provide highly reliable autonomous navigation and linear acceleration measurement
Coriolis Acceleration Inertial Measurement Unit (IMU)	• Small, low power/part count IMU. Only accelerometers required for complete system.	• Provide highly reliable compact autonomous navigation support for Lunar and Mars missions.
Capacitive, Magnetic Suspension IMU (QUBIK)	• Single sensor provides all inertial sensing requirements.	• Provide highly reliable compact autonomous navigation support for Lunar and Mars missions.
Gravity Wave/Lense-Thirring Effect Detector	• Calculate the general relativistic effects of massive bodies on vehicle trajectories.	• Provide more accurate navigation support for interplanetary trajectories.
Electrostatic/Micromachined accelerometer with hybrid electronics	• High sensitivity, small size, low power	• Provide compact autonomous navigation and acceleration measurement for Lunar and Mars missions.

NASA

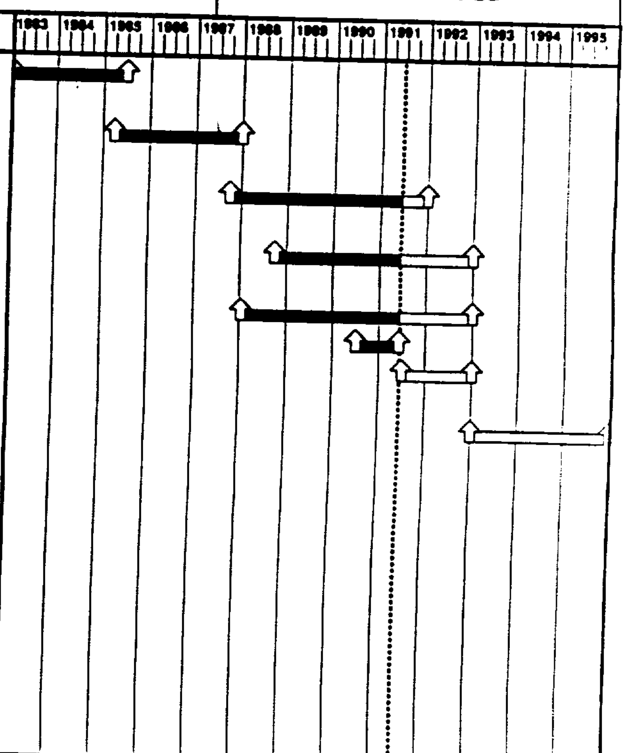
5.3.8.5 Transfer Vehicle Avionics: Tether Control Current & Related Programs

Navigation, Control & Aeronautics Division

A. J. Bordano/EG

Description

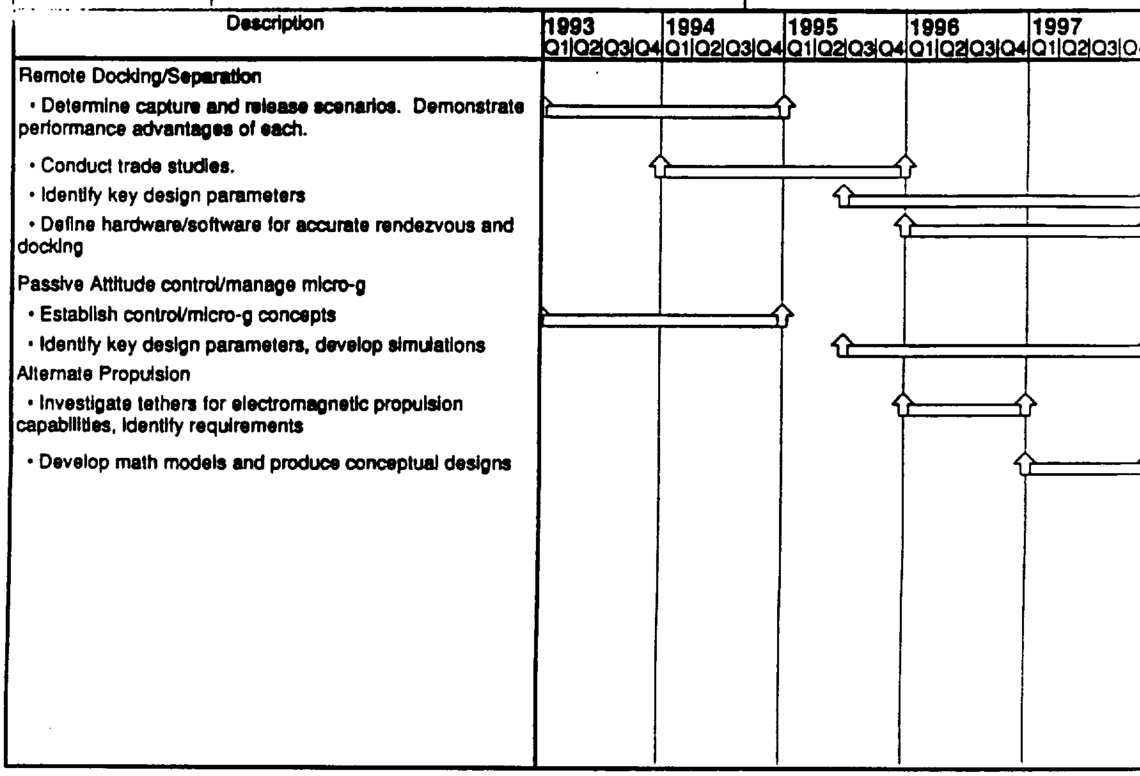
- Model and Tool Development resulted in an operational STOCS (engineering tool for Tether design and analysis).
- Tether/Space Shuttle Interference Problems/Control Interactions and Tether Dynamics Analysis.
- Pursue Flight Design Assessment engineering activity/reports/presentations
- Initiate/continue effort to model the System Engineering Simulator to accomodate Tether problems
- Modify/Update models in STOCS as required
- Initiate/complete STOCS rehost to Cray computer
- Initiate/complete checkout/validation of the first Tether Satellite System mission and analyze flight results.
- Prepare for Tether Flight 2 and 3 and perform post flight analyses



NASA

5.3.8.5 Transfer Vehicle Avionics: Tether Control
Proposed Technology

Navigation, Control & Aeronautics Division
A. J. Bordano/EG



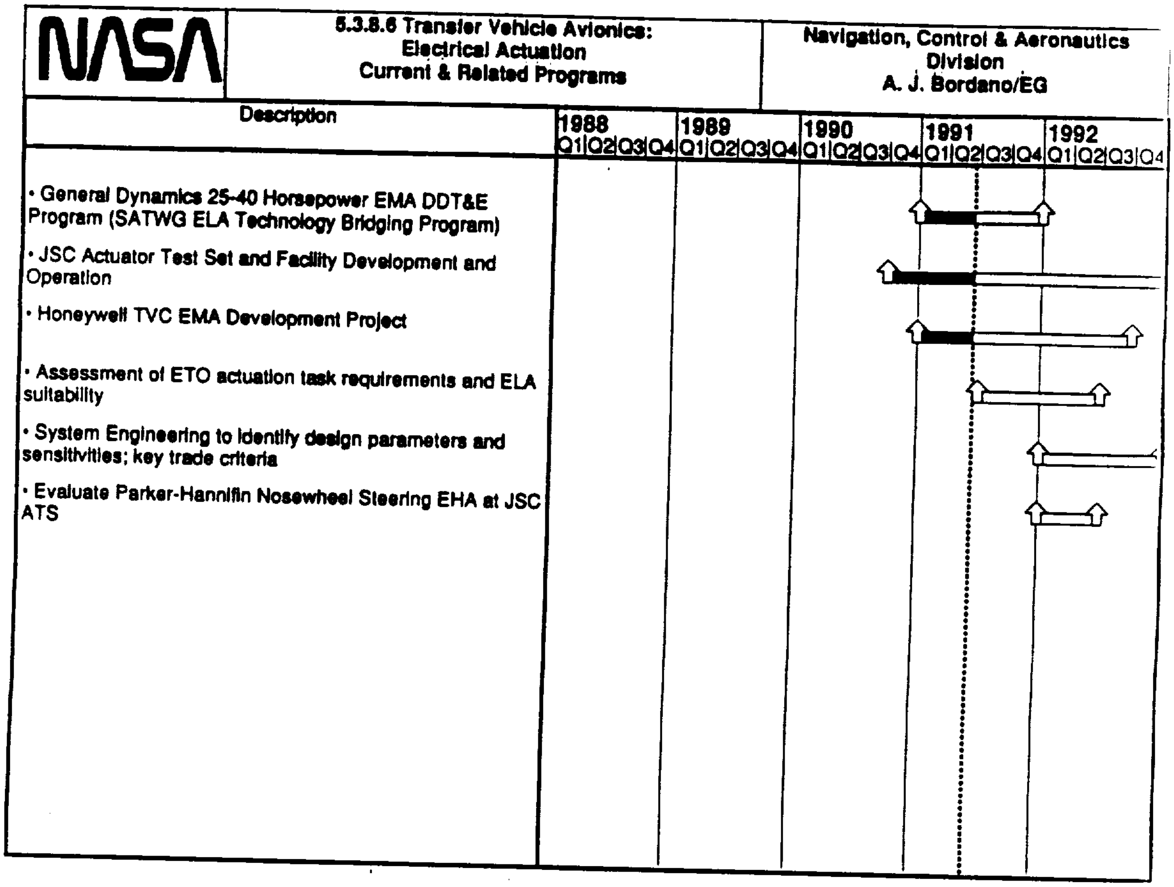
Johnson Space Center - Houston, Texas

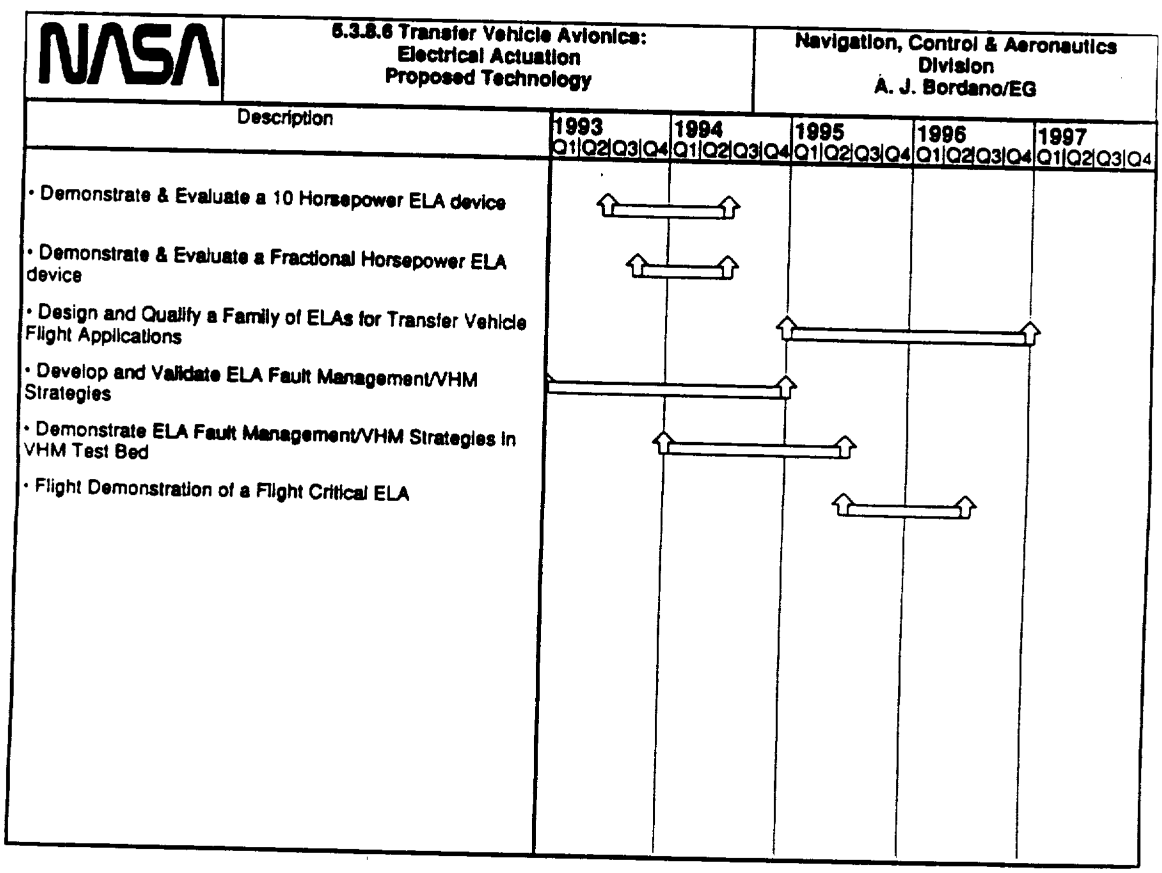
5.3.8.5 Transfer Vehicle Avionics: Tether Control Program Benefits

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

TECHNOLOGY	BENEFITS	WHY
Remote Docking /Separation • Determine capture and release scenarios for Space Station and Interplanetary Vehicle operations • Identify key design parameters characterizing designs • Define hardware/software requirements for accurate rendezvous and docking	• Demonstration of performance advantages of using tethers for docking and separation. Establish hardware/software requirements for accurate rendezvous/docking	• Potential for fuel saving and reduced contamination of solar arrays due to jet effluent impingement
Passive Attitude Control/Manage Micro-g • Establish control concepts/micro-g management concepts for various modes of operation of space platforms and interplanetary vehicles. • Identify key design parameters characterizing designs.	• Will establish tether systems versatile enough to accomplish micro-g management, and enable fuel/energy savings through passive tether attitude control	• Micro-g management is difficult to achieve, sometimes requiring elaborate mounting schemes. Tethers may offer a more feasible option. Fuel and energy savings for long duration vehicles are possible if tethers can be used for passive control.
Alternate Propulsion • Investigate the use of electrodynamic propulsion for orbital maneuvering using tethers • Produce conceptual designs that integrate tether propulsion into the vehicle control avionics	• Enable a means of producing orbit changes for space vehicles with minimum energy expenditure	• Space platforms in orbit for long periods require frequent resupply missions for refueling. Electrodynamic propulsion using tethers could minimize this requirement


NASA
5.3.8.6 Transfer Vehicle Avionics:
Electrical Actuation
Current & Related Programs
Navigation, Control & Aeronautics Division
A. J. Bordano/EG
Description
1988 Q1 Q2 Q3 Q4
1989 Q1 Q2 Q3 Q4
1990 Q1 Q2 Q3 Q4
1991 Q1 Q2 Q3 Q4
1992 Q1 Q2 Q3 Q4
• General Dynamics 25-40 Horsepower EMA DDT&E Program (SATWG ELA Technology Bridging Program)
• JSC Actuator Test Set and Facility Development and Operation
• Honeywell TVC EMA Development Project
• Assessment of ETO actuation task requirements and ELA suitability
• System Engineering to identify design parameters and sensitivities; key trade criteria
• Evaluate Parker-Hannifin Nosewheel Steering EHA at JSC ATS


NASA
5.3.8.6 Transfer Vehicle Avionics:
Electrical Actuation
Proposed Technology
Navigation, Control & Aeronautics Division
A. J. Bordano/EG
Description
1993 Q1 Q2 Q3 Q4
1994 Q1 Q2 Q3 Q4
1995 Q1 Q2 Q3 Q4
1996 Q1 Q2 Q3 Q4
1997 Q1 Q2 Q3 Q4
• Demonstrate & Evaluate a 10 Horsepower ELA device
• Demonstrate & Evaluate a Fractional Horsepower ELA device
• Design and Qualify a Family of ELAs for Transfer Vehicle Flight Applications
• Develop and Validate ELA Fault Management/VHM Strategies
• Demonstrate ELA Fault Management/VHM Strategies in VHM Test Bed
• Flight Demonstration of a Flight Critical ELA

5.3.8.6 Transfer Vehicle Avionics: Electrical Actuation Program Benefits

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

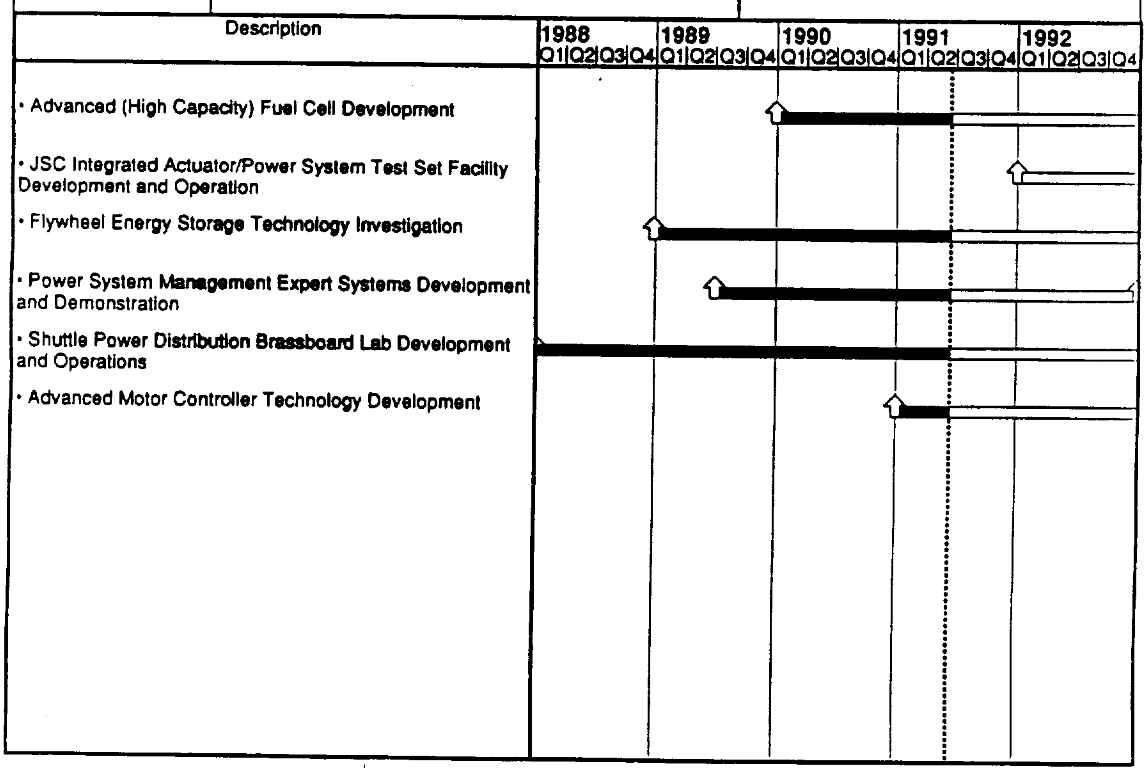
TECHNOLOGY	BENEFITS	WHY
•Electromechanical Actuation (EMA)	• Expedite system checkout operations; minimize personnel costs • Operational safety increased • Distributed system is more fault/damage tolerant • Greatly reduced risk of system failures • System performance margins are expanded	• Hydraulic system eliminated; system checkout does not entail hazardous operations • Hazardous fluids, stored energy systems, fluid replenishment operations eliminated • Distributed system elements; no central single point failures, no fluid couplings to burst or leak • Very low system part count • Actuation system weight is reduced
•Electrohydrostatic Actuation (EHA)	• Expedite test and verification opera tions; minimize personnel costs • Operational safety increased • Distributed system is more fault/damage tolerant • Greatly reduced risk of system failures • Directly applicable to flight-critical applications	• Centralized hydraulic system eliminated; checkout is expedited, does not entail periodic hazardous operations • Hazardous fluids, stored energy systems, fluid replenishment operations eliminated • Distributed system elements; no central single point failures, no external fluid couplings to burst or leak • Very low system part count • EHAs provide inherent load-sharing ability • Overload capacity is similar to conventional hydraulics • Actuator can be backdriven with adjustable impedance (variable damping capability)
•ELA (all technologies)	• Inherently supports basic constructs of Vehicle Health Management (VHM) initiative • Expedites launch system processing and checkout operations • Allows system level functionality test at low cost in terms of manpower, time, and special configurations/test support equipment requirements • Increases probability of mission success • Decreases reliance on logistics lifetime, requirements for repair	• Simple electrical and command interface with host vehicle • Obviates need for external hydraulic support carts • Long "shelf life" without need for constant servicing • Systems can withstand rigors of extended missions, long duty cycles, protracted dormant periods
•Magnetostrictive and other direct acting	• Increased reliability • Unit cost is reduced	• Extremely low parts count (for magnetostrictive, 1 moving part!) • Devices are mechanically simple

NASA

5.3.8.7 Transfer Vehicle Avionics: Power Management & Control Current & Related Programs

Navigation, Control & Aeronautics Division

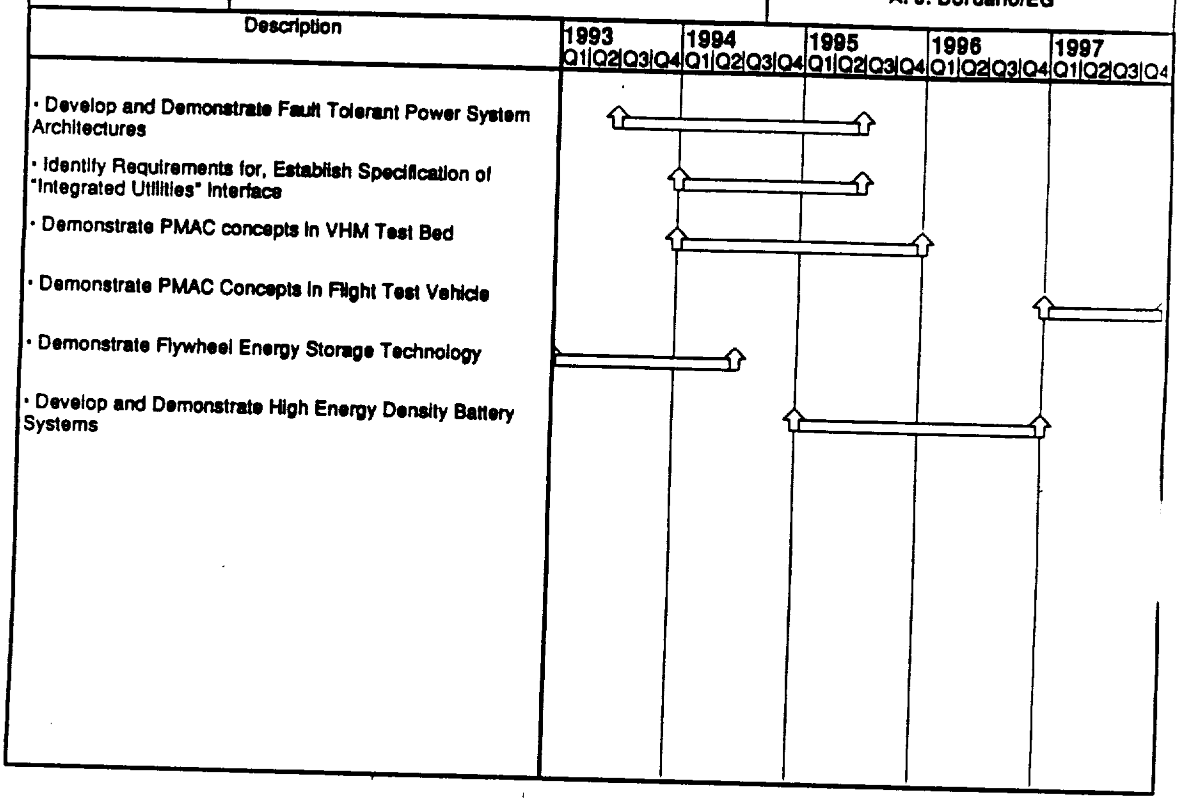
A. J. Bordano/EG



NASA

5.3.8.7 Transfer Vehicle Avionics: Power Management & Control Proposed Technology

Navigation, Control & Aeronautics Division
A. J. Bordano/EG



Johnson Space Center • Houston, Texas

5.3.8.7 Transfer Vehicle Avionics: Power Management & Control Program Benefits

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

TECHNOLOGY	BENEFITS	WHY
• Autonomous reconfiguration among series/parallel circuit paths	• Expedite system checkout and self-test opera tions; minimize support personnel costs • Increased mission success probability; especially for long duration missions	• PMAC implementation supports automated vehicle checkout • System is more robust and fault tolerant • Supports gradual degradation rather than sudden total loss of functions
•Integrated modular service backbone	• Vehicle integration task is simplified • Power, thermal, data capabilities are provided in a balanced fashion • Vehicle performance is improved	• All required services are provided across a unified interface • Integrated "utilities bus" characterized by high level of integration and multiplexing, saves weight
•High frequency power distribution and control	• Vehicle performance is improved	• System components are lighter; efficiencies are higher
•Multi-mode power generation systems	• Enhanced mission success probability	• Appropriate power generation method is available to match operational environment (low earth orbit, planetary surfaces, deep space)
•Enhanced fuel cells	• Enhanced mission success • Vehicle performance is increased • Supports requirements for closed loop vehicle systems	• Fuel cell system reliability is increased • Advanced fuel cells have a higher net energy density; power system is lighter for the same capacity • Regeneration capability allows cell to produce water or hydrogen/oxygen
•Advanced Energy storage and power conditioning devices (i.e. flywheels), advanced motor controllers	• Enhanced compatibility with electrical actuation (ELA) technology; improved system efficiencies	• Power supply, regulation, and conditioning technology is matched to the unique requirements of ELAs

5.3.9 Autonomous Landing Overview

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

- The goal of the NASA Autonomous Landing Technology Development Project is to enable safe, accurate, autonomous spacecraft landing using precision landing at a preselected safe location or on-board detection and avoidance of surface hazards to landing.
- Mars and Lunar landings must be achieved safely regardless of surface hazards such as large rocks and steep slopes, be close to the area of mission interest, and occur without real time ground control.
- Earth orbiting and return spacecraft, such as the PLS and ACRV, require landing to be achieved reliably and on short notice.
- There are three areas of technology thrust:
  - Systems Engineering: Systems engineering activities include - the evaluation of landing accuracy and the probability of safe landing for alternate landing approaches, and the development of detailed engineering models such as Lunar/Mars terrain models.
  - Precision Landing: The principal objective of the precision landing work is the development of methods of navigation with respect to the landing site. A second objective of the precision landing work is the development of guidance and flight control algorithms that can compensate for environmental anomalies such as atmospheric density and wind variations while steering to a preselected safe landing site.
  - Hazard Detection & Avoidance Landing: The objective of the autonomous hazard detection & avoidance work is to develop the sensors, algorithms, and operating strategy that will enable exploration spacecraft to detect during terminal descent a safe landing site.

NASA

5.3.9 Autonomous Landing Current & Related Programs

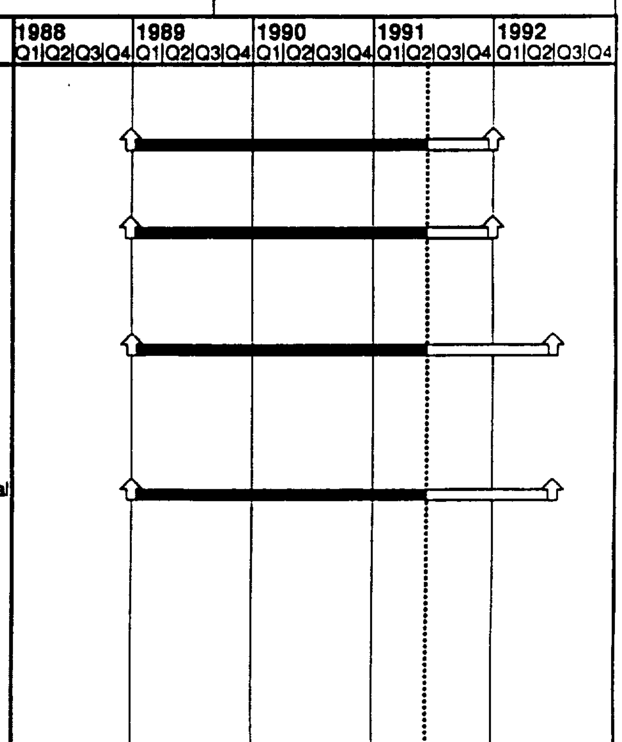
Navigation, Control & Aeronautics Division
A. J. Bordano/EG

Description

System Engineering
- System Analysis
  - Baseline set of landing requirements for Mars Rover Sample Return (MRSR) class missions
- Planetary Surface Models
  - An initial version of a Mars Surface Model

Precision Landing
- Image Matching Navigation
  - A baseline set of requirements plus an initial approach to & test of Hybrid Optical Image Matching Navigation

Hazard Detection & Avoidance
- Imaging Laser Radar
  - A baseline set of requirements for a detailed conceptual design of an Imaging Laser Radar



NASA	5.3.9 Autonomous Landing Proposed Technology	Navigation, Control & Aeronautics Division A. J. Bordano/EG

Description — 1993 Q1 Q2 Q3 Q4 | 1994 Q1 Q2 Q3 Q4 | 1995 Q1 Q2 Q3 Q4 | 1996 Q1 Q2 Q3 Q4 | 1997 Q1 Q2 Q3 Q4

System Engineering
- System Analysis
  - •• Develop a set of autonomous landing requirements for a range of planetary exploration missions
  - •• GN&C Simulation enhancements
  - •• Closed loop simulation of G&C, navigation/hazard detection sensor models, terrain and atmospheric models
  - •• Develop concepts and workstation level prototype of man-machine interface
- Planetary Surface Models
  - •• Development and testing of a Mars surface model
  - •• Collection of high resolution digital terrain maps for Earth analogs of Martian terrain types
- Sensor Field Test
  - •• Conceptional Design of Sensor Field Tests
  - •• Perform Sensor Field Tests

Precison Landing
- Image/Terrain Matching Navigation
  - •• Landing navigation requirements definition
  - •• Concept definition and simulation of alternate image/terrain matching algorithms & processors
  - •• Design, build and laboratory test of prototype for selected image/terrain matching approach
  - •• Field Test of protoype for selected image/terrain matching navigation approach
- GN&C for Landing from Earth Orbit
  - •• Guidance requirements definition
  - •• Investigation and prototyping of various guidance algorithms

NASA	5.3.9 Autonomous Landing Proposed Technology	Navigation, Control & Aeronautics Division A. J. Bordano/EG

Description — 1993 Q1 Q2 Q3 Q4 | 1994 Q1 Q2 Q3 Q4 | 1995 Q1 Q2 Q3 Q4 | 1996 Q1 Q2 Q3 Q4 | 1997 Q1 Q2 Q3 Q4

- •• Simulation testing of promising guidance algorithms with GPS navigation and Lidar derived wind profile
- •• Field test of protoype guidance algorithm

Hazard Detection & Avoidance
- Laser Radar
  - •• Develop a set of sensor and system requirements for a range of Mars and Lunar exploration landing missions
  - •• Specifications for prototype imaging laser radar
- Alternate Hazard Detection Sensors
  - •• Develop concepts for alternate hazard detection approaches and evaluate via simulation
- Field Test
  - •• Design, build and laboratory test of protoype sensor, algorithms and processor for selected hazard detection approach
  - •• Field test prototype of selected hazard detection approach from a helicopter over Earth analogs of Martian terrain types

5.3.9 Autonomous Landing Program Benefits

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

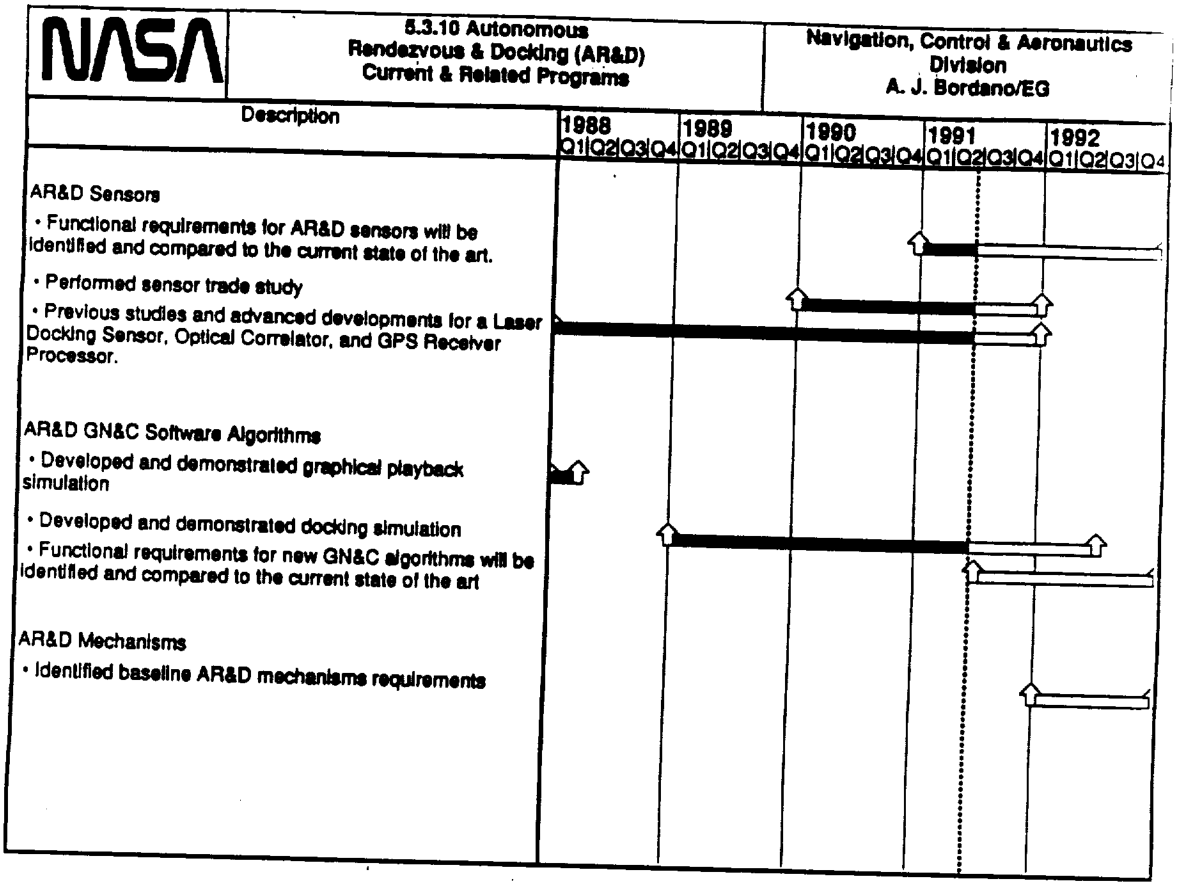
TECHNOLOGY	BENEFITS	WHY
System Engineering • Systems Analysis: - Simulation of landing accuracy vs. performance of navigation, guidance & control – Simulation of probability of safe landing vs. hazard detection sensor & vehicle performance - Develop workstation prototype of man-machine interface for autonomous landing system • Planetary Surface Models : - Develop Mars terrain model based on Viking, Mars Observer & Earth analog data - Collect high resolution terrain maps for Earth analogs of Martian terrain types • Field test of prototype Navigation & Hazard Detection sensors over Earth analogs of Mars terrain types	• Tools to assess performance of alternate approaches to & prior information requirements for alternate approaches to autonomous landing • Tool to evaluate alternate man-machine interface for autonomous landing GN&C system. • Generate test cases for sensor & system simulation of image & terrain matching navigation and hazard detection & avoidance • Realistic images/terrain models for development of Mars terrain model • Demonstrate sensor performance under realistic field conditions	• Allow selection of autonomous landing approach that meets the requirements and is affordable • High resolution images & terrain elevation maps of Mars not yet available • Flight tests in Lunar/Mars environment expensive
Precision Landing • Hybrid Optical Image Matching Navigation • Radar Image Matching Navigation • Terrain Map Matching Navigation • GN&C for Landing from Earth Orbit: – Prototype GN&C algorithms for PLS using GPS navigation & Lidar based wind profiles	• Image/Terrain matching navigation with respect to the landing site enables accurate landing • Increased robustness of entry & landing GN&C to atmospheric variability	• Allows trade-off between lander robustness & landing site selection while preserving required prob. of safe landing in area of mission interest • Enables landing from Earth orbit to be carried out on short notice
Hazard Detection & Avoidance • Imaging Laser Radar • Hybrid Interferometric Imager	• Provides capability for detecting a safe landing site in an area that contains some surface hazards	• Allows trade-off between lander robustness and level of prior information while maintaining required prob. of safe landing for the area of mission interest

5.3.10 Autonomous Rendezvous & Docking Overview

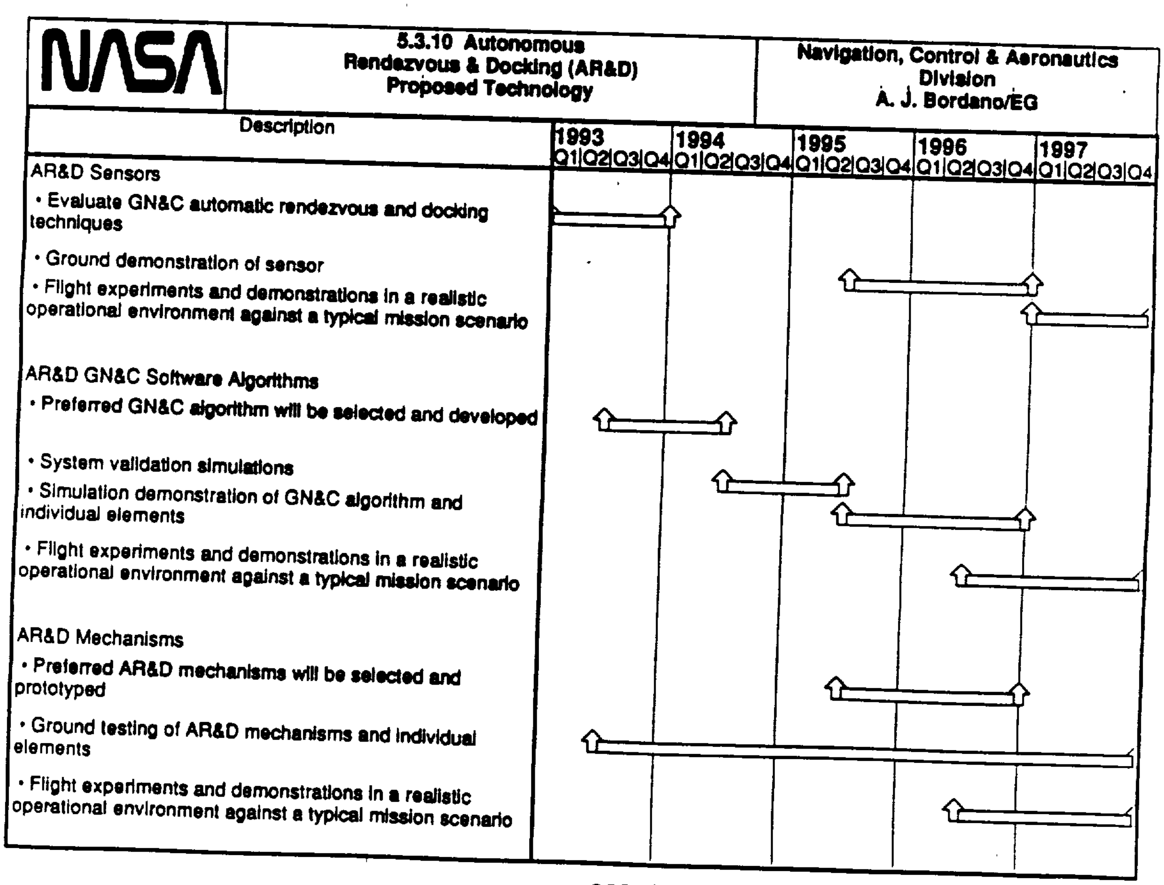
Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

- The goal of the NASA Autonomous Rendezvous & Docking Technology Development Project is to develop and integrate the technologies that provide the capabilities to perform autonomous rendezvous and docking operations in space.
- Rendezvous & docking operations in U. S. space programs to date have been in manned vehicles only, and with direct crew participation with heavy ground support.
- Development and demonstration of Autonomous Rendezvous & Docking Technologies will:
  - Permit unmanned spacecraft in Earth, Lunar and planetary orbits to operate without large ground support staffs for mission planning, training and conduct
  - Support manned spacecraft operations by augmenting the capabilities of the crew to perform rendezvous and docking without ground support.
- Autonomous Rendezvous & Docking capability is needed for:
  - Cargo Transfer Vehicle (CTV) operations in support of further SSF build-up
  - Spacecraft retrieval / servicing
  - Unmanned upper stage operations
  - In-space build-up and operations of Lunar/Mars exploration vehicles
  - In-space supporting facilities.



NASA
5.3.10 Autonomous
Rendezvous & Docking (AR&D)
Current & Related Programs
Navigation, Control & Aeronautics
Division
A. J. Bordano/EG
Description
1988 Q1 Q2 Q3 Q4
1989 Q1 Q2 Q3 Q4
1990 Q1 Q2 Q3 Q4
1991 Q1 Q2 Q3 Q4
1992 Q1 Q2 Q3 Q4
AR&D Sensors
• Functional requirements for AR&D sensors will be identified and compared to the current state of the art.
• Performed sensor trade study
• Previous studies and advanced developments for a Laser Docking Sensor, Optical Correlator, and GPS Receiver Processor.
AR&D GN&C Software Algorithms
• Developed and demonstrated graphical playback simulation
• Developed and demonstrated docking simulation
• Functional requirements for new GN&C algorithms will be identified and compared to the current state of the art
AR&D Mechanisms
• Identified baseline AR&D mechanisms requirements



NASA
5.3.10 Autonomous
Rendezvous & Docking (AR&D)
Proposed Technology
Navigation, Control & Aeronautics
Division
A. J. Bordano/EG
Description
1993 Q1 Q2 Q3 Q4
1994 Q1 Q2 Q3 Q4
1995 Q1 Q2 Q3 Q4
1996 Q1 Q2 Q3 Q4
1997 Q1 Q2 Q3 Q4
AR&D Sensors
• Evaluate GN&C automatic rendezvous and docking techniques
• Ground demonstration of sensor
• Flight experiments and demonstrations in a realistic operational environment against a typical mission scenario
AR&D GN&C Software Algorithms
• Preferred GN&C algorithm will be selected and developed
• System validation simulations
• Simulation demonstration of GN&C algorithm and individual elements
• Flight experiments and demonstrations in a realistic operational environment against a typical mission scenario
AR&D Mechanisms
• Preferred AR&D mechanisms will be selected and prototyped
• Ground testing of AR&D mechanisms and individual elements
• Flight experiments and demonstrations in a realistic operational environment against a typical mission scenario

5.3.10 Autonomous Rendezvous & Docking Program Benefits

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

TECHNOLOGY	BENEFITS	WHY
AR&D Sensors • Sensor Selection and Prototyping: - Development of active and passive, point-target and image-based, cooperative and non-cooperative, optical and radio frequency navigation components	• New light weight, low power, and reliable sensors	• Required to required to support autonomous rendezvous and docking proximity operations .
• Ground Demonstrations / Flight Experiments - Sensor field test of active and passive, point-target and image-based, cooperative and non-cooperative, optical and radio frequency navigation components	• Physical testing of active and passive, point-target and image-based, cooperative and non-cooperative, optical and radio frequency navigation sensor components	• Final testing phase for required AR&D navigation sensor components
GN&C Algorithms and Systems Simulation Development • Develop algorithm concepts and approaches to support autonomous rendezvous	• Recurring costs can be reduced through automation and improvements to current GN&C algorithms and operations approaches	• Current AR&D operations rely heavily on ground based manual procedures
• Develop concepts & workstation level prototype of man-machine interface for autonomous navigation	• Assessment of man-machine interfaces for autonomous rendezvous/docking . Construction of support materials for future missions.	• Better understanding of man-machine advanced navigation systems interfaces for future missions
• Ground Demonstrations / Flight Experiments:	• Integrated AR&D system suite	• Assessment of new sensor interfacing with other AR&D system components
AR&D Mechanisms • Mechanism Selection and Prototyping: - Development of AR&D support mechanisms	• Highly reliable,lightweight latches and low power latches, attenuators,etc.	• Support of AR&D
• Ground Demonstrations / Flight Experiments:	• Integrated AR&D system suite	• Assessment of individual mechanisms and integrated AR&D system.

NASA

AVIONICS TECHNOLOGY PLAN

PRESENTATION

FOR

SSTAC CONTROLS COMMITTEE

NASA HEADQUARTERS

ALDO J. BORDANO
JOHNSON SPACE CENTER

NASA

AVIONICS TECHNOLOGY PLAN

- BACKGROUND
- CUSTOMER REQUIREMENTS
- TECHNOLOGY PLAN
- CONCLUDING REMARKS

BACKGROUND

- HARDWARE
  - COMPUTER PROCESSORS. BUSES, NETWORKS, TRANSMITTERS/RECEIVERS INPUT/OUTPUT DEVICES, SENSORS, DISPLAYS AND CONTROLS . . . .
- SOFTWARE
  - DATABASES, ARTIFICIAL INTELLIGENCE, LANGUAGES, OPERATING SYSTEMS, APPLICATION SOFTWARE . . . .
- PACKAGING
  - MATERIALS, CONTAINERS, CONNECTORS, HEATING/COOLING COMPONENTS INSTALLATION METHODS . . . .
- POWER MANAGEMENT
  - CONVERTERS, SWITCHING, MATERIALS . . . .
- CHECKOUT AND TESTING
  - HEATH MONITORING, BUILT IN TEST, EQUIPMENT, REDUNDANCY . . . .

2

BACKGROUND
(CONCLUDED)

- VERIFICATION AND VALIDATION
  - METHODOLOGIES, SIMULATIONS, FACILITIES . . . .

3

BACKGROUND

- SUBSYSTEM ELEMENT TECHNOLOGIES
  - HARDWARE COMPONENTS TO SUPPORT CURRENT AND FUTURE SPACE VEHICLE DEVELOPMENTS AND MISSION REQUIREMENTS (FIBER-OPTIC GYROS, VIBRATING BEAM ACCELEROMETER, LIDAR'S- - - -)
  - APPLICATION SOFTWARE TO SUPPORT CURRENT AND FUTURE SPACE VEHICLE DEVELOPMENTS AND MISSION REQUIREMENTS (ADAPTIVE GN&C, AUTOMATIC RENDEZVOUS AND DOCKING, AUTOMATIC LAND LANDING - - - -)
- SYSTEM TECHNOLOGIES
  - ARCHITECTURES, VEHICLE HEALTH MONITORING, POWER MANAGEMENT - - - -
  - FACILITIES, METHODOLOGIES, PROCEDURES - - - -
    - PROTOTYPING, MODELS, SIMULATIONS, LABS, TOOLS- - - -
    - VERIFICATION
    - CERTIFICATION
    - CHECKOUT

4

BACKGROUND

- GOAL
  - DEVELOP INTEGRATED AVIONIC TECHNOLOGY PLAN FOR SPACE TRANSPORTATION VEHICLES BASED ON NASA AND COMMERCIAL SECTOR NEEDS
    - IDENTIFY CRITICAL TECHNOLOGIES (ELEMENTS, SYSTEMS AND PROCESSES)
    - DETERMINE TECHNOLOGY GAPS
    - RECOGNIZE TRENDS
    - IDENTIFY TRADES
    - DEVELOP ROAD MAPS, SCHEDULES

5

CUSTOMER REQUIREMENTS

- AVIONIC ARCHITECTURES
  - MODULAR, STANDARDIZED, OPEN, SCALABLE, ROBUST, FAULT TOLERANT, MULTI VEHICLE
  - MINIMIZE DDT&E COSTS
  - SIGNIFICANTLY REDUCE OPERATIONS COST
- SENSORS
  - FOR THE MOST PART BEING DEVELOPED NEAR TERM OR EXIST TODAY
- FAULT TOLERANT METHODOLOGIES
  - SYSTEM ARCHITECTURES
  - VOTING ALGORITHMS
  - BUILT-IN TEST
  - FAULT RECOVERY (- - - - e.g., SPARES)

6

CUSTOMER REQUIREMENTS

- DESIGN VERIFICATION AND VALIDATION METHODOLOGIES
  - CONCEPTS, APPROACH, TOOLS, FACILITIES
  - RAPID PROTOTYPING
  - APPLICATION SOFTWARE ARCHITECTURES (e.g., CORE GN&C)
  - AUTOMATED CODE GENERATION
  - TESTING METHODS
- SOFTWARE TECHNOLOGY
  - REAL TIME DISTRIBUTED OPERATING SYSTEMS
  - REDUNDANCY MANAGEMENT (FAULT DETECTION, ISOLATION, RECOVERY AND RECONFIGURATION)
  - MULTI PROCESSOR TASK SCHEDULING
  - MISSION MANAGERS
- AVIONICS PACKAGING TECHNOLOGIES ARE BEING DEVELOPED

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CUSTOMER REQUIREMENTS

- POWER MANAGEMENT AND DISTRIBUTION TECHNOLOGIES ARE BEING DEVELOPED
  - NEW APPROACHES, ARCHITECTURES ARE PROPOSED
- SOFTWARE APPLICATION TECHNOLOGIES
  - ADAPTIVE GN&C
  - AUTOMATIC RENDEZVOUS AND DOCKING
  - AUTONOMOUS LANDING
- GROUND/SPACE BASED CHECKOUT TECHNOLOGIES
  - FAULT/TREND ANALYSIS
  - ON-LINE BUILT IN TEST
  - AUTONOMOUS CHECKOUT

8

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CUSTOMER REQUIREMENTS

- AVIONIC ARCHITECTURES
  - CUSTOMIZED OPTIMIZED FOR SIZE, WEIGHT, POWER, PERFORMANCE VS OPEN MODULAR, SCALABLE, STANDARDIZED*
  - DISTRIBUTED VS SEMI DISTRIBUTED
  - FAULT DETECTION AND REDUNDANCY MANAGEMENT (HARDWARE VS SMART SOFTWARE METHODS)
  - PARTS (S LEVEL VS B LEVEL); SENSOR CONFIGURATIONS
- SENSOR AUGMENTATION
  - SUN SENSORS, STAR TRACKERS VS GPS
- DATA MANAGEMENT
  - COMPUTER PROCESSOR OPTIONS, MEMORY, SIZE, ETC.
  - LOCAL DATA BUS AND HIGH SPEED GLOBAL DATA BUS ISSUES
  - I/O INTERFACES
  - STANDARDS

* JIAWG, MASA, MPRAS & AIPS

9

NASA

CUSTOMER REQUIREMENTS
(CONCLUDED)

- POWER SOURCES
  - BATTERY TYPES (SILVER ZINC, LITHIUM, ETC.)
- PACKAGING
  - AIRCRAFT STANDARDS, SPACE UNIQUE REQUIREMENTS
- TESTABILITY
  - OPERATIONAL COSTS AND FLEXIBILITY, AUTONOMOUS

10

Integrated Technology Plan Overview	Johnson Space Center - Houston, Texas Navigation, Control & Aeronautics Division	
	A. J. Bordano/EG	6/26/91

Avionics Technology Plan

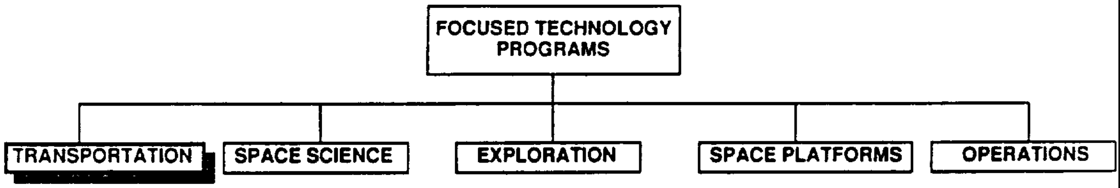
Johnson Space Center - Houston, Texas

Work Breakdown Structure

Navigation, Control & Aeronautics Division

A. J. Bordano/EG

6/26/91



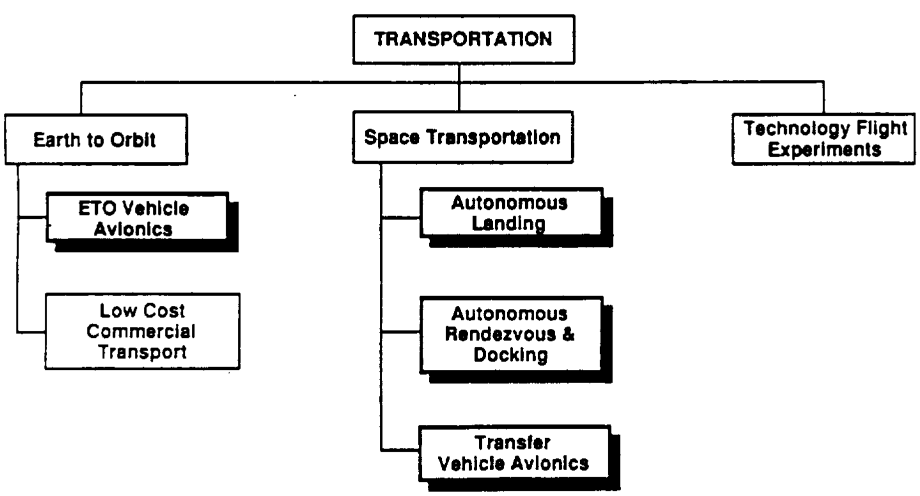
Johnson Space Center - Houston, Texas

Work Breakdown Structure (Continued)

Navigation, Control & Aeronautics Division

A. J. Bordano/EG

6/26/91



Integrated Technology Plan Overview

Integrated Technology Plan Elements

5.2.7 ETO Vehicle Avionics
5.2.7.1 Avionics Architecture
5.2.7.2 Avionics Software
5.2.7.3 Vehicle Health Management
5.2.7.4 GN&C
5.2.7.5 Electrical Actuators
5.2.7.6 Landing/Recovery Systems
5.2.7.7 Power Management & Control

5.3.8 Transfer Vehicle Avionics
5.3.8.1 Avionics Architecture
5.3.8.2 Avionics Software
5.3.8.3 Vehicle Health Management
5.3.8.4 GN&C
5.3.8.5 Tether Control
5.3.8.6 Electrical Actuators
5.3.8.7 Power Management & Control
5.3.9 Autonomous Landing
5.3.10 Autonomous Rendezvous & Docking

Johnson Space Center - Houston, Texas

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

Generic Outline

Presentation will cover each identified Integrated Technology Plan Element and Subelement as follows

- ❑ **Overview** (at the element level 5.X.X)
- ❑ **Current & Related Programs** (at the subelement level 5.X.X.X)
- ❑ **Proposed Technology Program** (at the subelement level 5.X.X.X)
- ❑ **Program Benefits** (at the subelement level 5.X.X.X)

Note: The Integrated Technology Plan Report for these elements and subelements is over 100 pages. This presentation will be a high level summary of that report.

Johnson Space Center • Houston, Texas

5.2.7 ETO Vehicle Avionics Overview

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

- The next generation of space transports will need to have increased mission safety, more autonomy for reduced crew workload, and reduced operational costs.
  - Avionics Architecture - for increased avionics performance
  - Avionics Software - addresses mission and safety features in software operating systems kernel
  - Vehicle Health Management - for self diagnosing and self compensating integrated systems
  - Power Management and Control - for reliable, universal, modular, electrical power bus systems
  - Guidance, Navigation, and Control - offers efficient computational algorithms and sensors, software tools to analyze complex body dynamics, and enhanced launch and land on demand probability
  - Electrical Actuation Systems - replaces hydraulic systems to enhance system reliability, reduced operational cost
  - Advanced Landing & Recovery Systems - for enhanced booster recovery and landing technology
- The following advanced vehicles will all require some combination of these advanced technologies:
  - HLLV, NLS, PLS, CTV, ACRV, ALS, and ELV's
- ETO and Transfer Vehicle Avionics technology development share common goals which invites and in fact, for cost effectiveness, dictates collaboration and interfacing between the two areas of development.

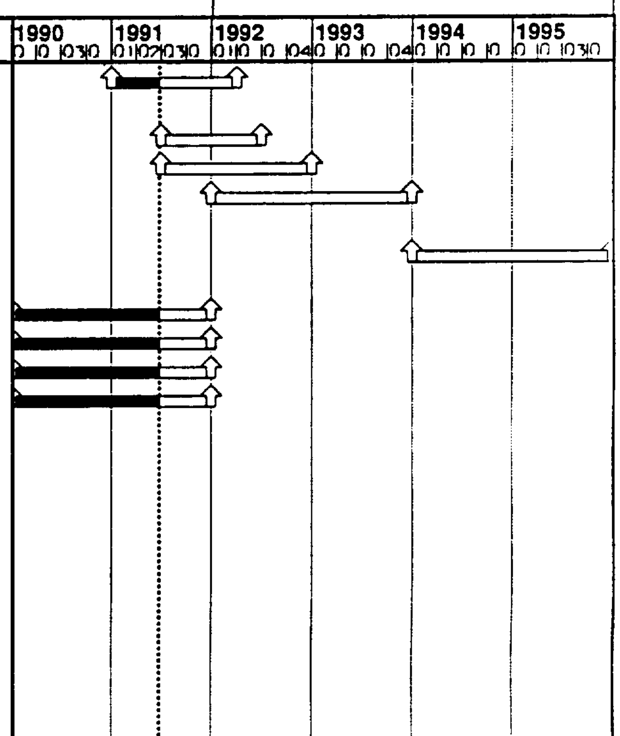
NASA

5.2.7.1 ETO Vehicle Avionics: Avionics Architecture Current & Related Programs

Navigation, Control & Aeronautics Division
A. J. Bordano/EG

Description

- Flight Data System Open Architecture Requirements Definition & Methodology Development
- Flight Data System Open Architecture Document
- Flight Data System System Profiles
- Flight Data System Open Architecture Performance Analysis and Trades
- Flight Data System Open Architecture Prototype Development
- Network Performance Model
- Bare 386 Real-time Kernel Investigation
- Station Flight-to-Ground Interoperability Evaluation
- Applications-to-RODB Data Type Analysis



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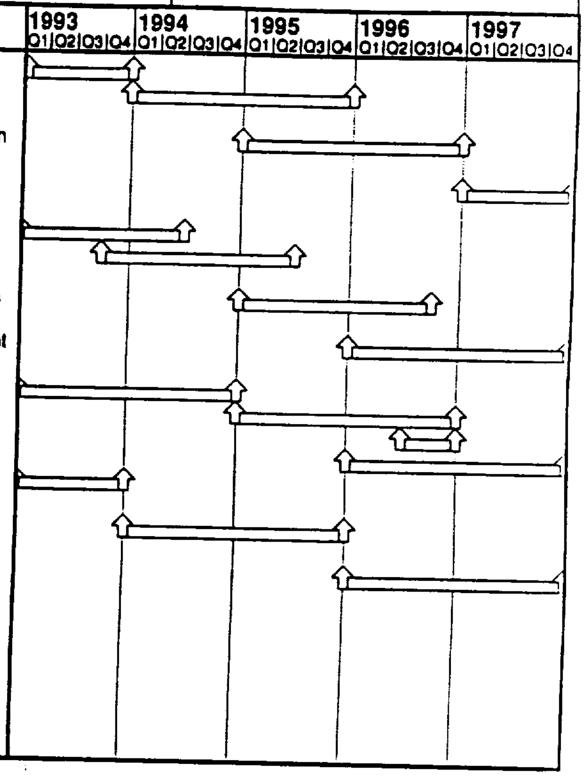
**5.2.7.1 ETO Vehicle Avionics:
Avionics Architecture
Proposed Technology**

Navigation, Control & Aeronautics Division
A. J. Bordano/EG

Description

- Real time distributed processing test bed development
- Real time distributed processing hetrogeneous processing & memory installation & operation in test bed
- Real time distributed processing network installation & operation in test bed
- Real time distributed processing hardware sensitivity factor determination
- High capacity processing requirements definition
- High capacity 32 and 64 bit processing component prototype development
- High capacity specialized coprocessor prototype development & integration
- High capacity multi-mega byte memory alternatives development and integration
- Non-Stop computing requirements definition
- Non-Stop computing system models development
- Non-Stop system reconfiguration demonstration
- Non-Stop computing test and verification technology definition
- Launch vehicle advanced human-tended avionics displays and controls interface and aids requirements definition
- Avionics human tended alternative sensory mechanisms and display prototype development
- Avionics Displays and Controls Advanced Human-Machine Test & Verification Technology Determination



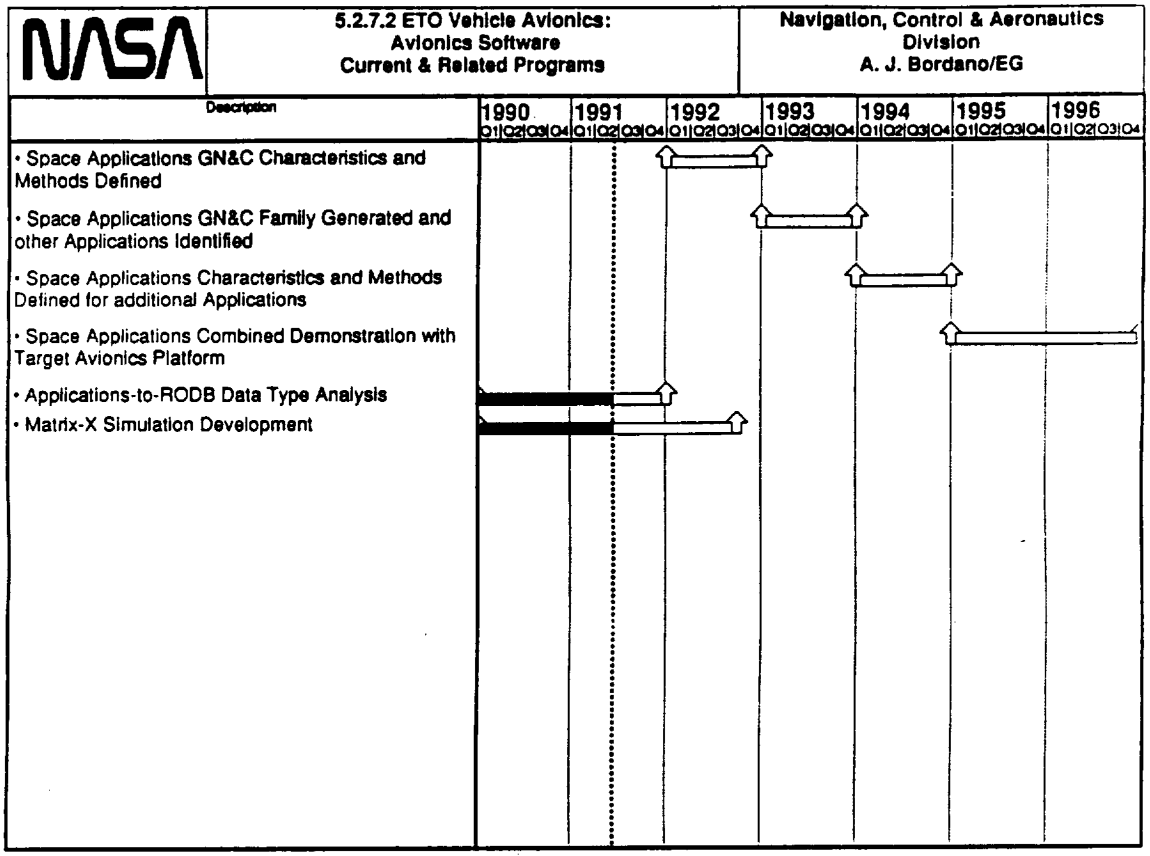
Johnson Space Center - Houston, Texas

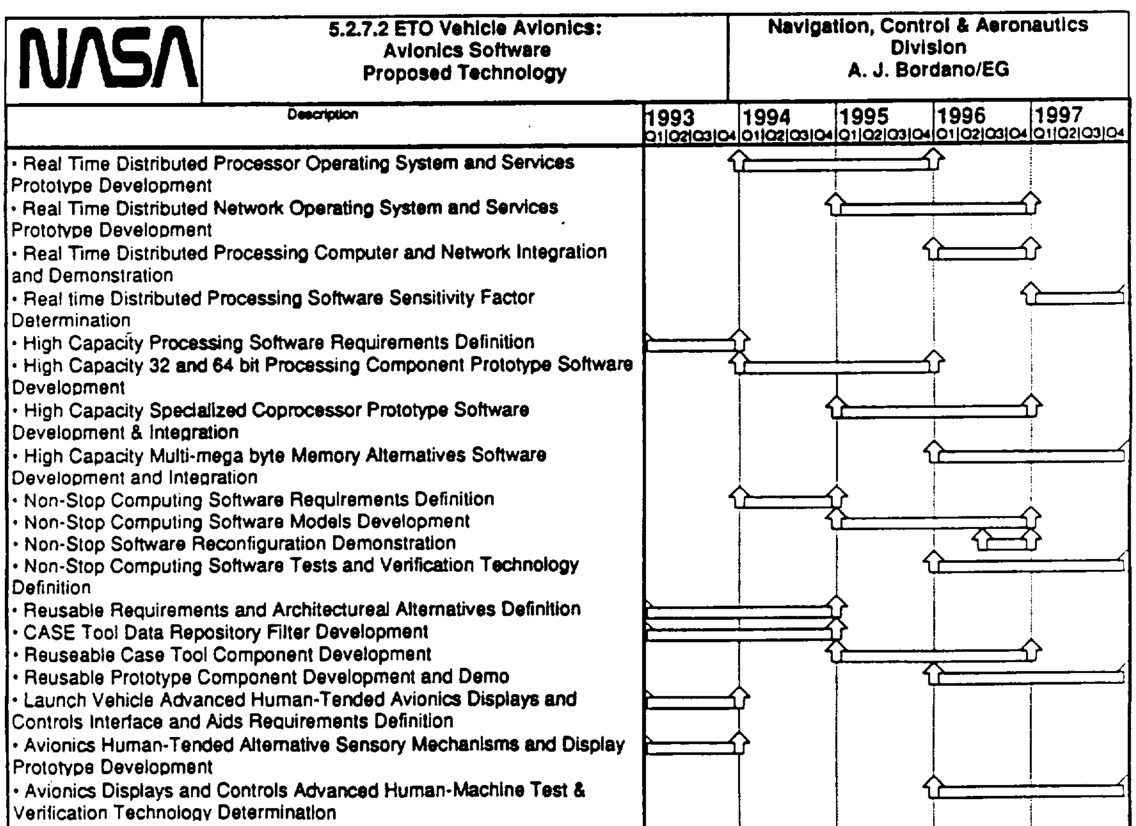
5.2.7.1 ETO Vehicle Avionics: Avionics Architecture Program Benefits

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

TECHNOLOGY	BENEFITS	WHY
Architecture/ETO Technology • Real-Time Distributed processing - Develop and prototype via test beds advanced flight data system distributed and multiple heterogeneous processors, memory, buses and other key components operating in real-time. - Determine sensitivity factors governing real-time processing performance.	• Definition of interfaces and standards including performance criteria to establish and verify architecture concepts.	• Development of flexible architectures for reduced development and life cycle costs
• High Capacity Processing - Develop requirements and prototypes for 32 bit and 64 bit processing components, memories and buses; specialized high speed coprocessors such as i960 and R4000; and multi-megabyte memory alternatives and technologies.	• The transfer of commercial technologies into space rated components will enable onboard processing capabilities to accommodate increased complexity of the avionics suite.	• Compatibility with ground systems in both performance and architecture
• Non-Stop Computing - Develop, build and demonstrate system models exhibiting multi-fault tolerant system and component behavior and which exhibit reconfigurable capability to determine the issues, costs and requirements - Determine the technologies needed to test, verify and certify non-stop computing capabilities for space flight operations	• Non-stop requirements and multi-fault tolerant components can be used to test and evaluate concepts, their associated costs, and implementation difficulty.	• Development of more flexible launch commit criteria and increases in mission safety
• Avionics Displays and Controls - Define requirements for advanc. human-tended display and control interfaces, ... and alternative sensory mechanisms - Develop prototype and demonstrate advanced total environment or holographic display and high fidelity voice control interfaces - Determine the technologies needed to test, verify and certify advanced human-machine interface capabilities for flight operations	• Definition of requirements for advanced displays and controls, and prototypes of such devices can be used to present more effective human interface mechanisms to astronauts for evaluation	• More effective use of data fusion to increase the machine processing of information for the manned interface.


NASA
5.2.7.2 ETO Vehicle Avionics:
Avionics Software
Current & Related Programs
Navigation, Control & Aeronautics
Division
A. J. Bordano/EG
Description
1990
1991
1992
1993
1994
1995
1996
Q1 Q2 Q3 Q4
• Space Applications GN&C Characteristics and Methods Defined
• Space Applications GN&C Family Generated and other Applications Identified
• Space Applications Characteristics and Methods Defined for additional Applications
• Space Applications Combined Demonstration with Target Avionics Platform
• Applications-to-RODB Data Type Analysis
• Matrix-X Simulation Development


NASA
5.2.7.2 ETO Vehicle Avionics:
Avionics Software
Proposed Technology
Navigation, Control & Aeronautics
Division
A. J. Bordano/EG
Description
1993
1994
1995
1996
1997
Q1 Q2 Q3 Q4
• Real Time Distributed Processor Operating System and Services Prototype Development
• Real Time Distributed Network Operating System and Services Prototype Development
• Real Time Distributed Processing Computer and Network Integration and Demonstration
• Real time Distributed Processing Software Sensitivity Factor Determination
• High Capacity Processing Software Requirements Definition
• High Capacity 32 and 64 bit Processing Component Prototype Software Development
• High Capacity Specialized Coprocessor Prototype Software Development & Integration
• High Capacity Multi-mega byte Memory Alternatives Software Development and Integration
• Non-Stop Computing Software Requirements Definition
• Non-Stop Computing Software Models Development
• Non-Stop Software Reconfiguration Demonstration
• Non-Stop Computing Software Tests and Verification Technology Definition
• Reusable Requirements and Architectureal Alternatives Definition
• CASE Tool Data Repository Filter Development
• Reuseable Case Tool Component Development
• Reusable Prototype Component Development and Demo
• Launch Vehicle Advanced Human-Tended Avionics Displays and Controls Interface and Aids Requirements Definition
• Avionics Human-Tended Alternative Sensory Mechanisms and Display Prototype Development
• Avionics Displays and Controls Advanced Human-Machine Test & Verification Technology Determination

Johnson Space Center - Houston, Texas

5.2.7.2 ETO Vehicle Avionics: Avionics Software Program Benefits

Navigation, Control & Aeronautics Division

A. J. Bordano/EG

6/26/91

TECHNOLOGY	BENEFITS	WHY
Software/ETO Technology • Real-time Distributed Processing - Develop prototype and demonstrate distributed operating systems and services that operate in real-time over distributed and multiple processors. - Determine sensitivity factors governing distributed operating system and services for real-time processing performance.	• Establishes capability and performance of operating systems distributed across multiple buses, networks and vehicles	• Assessment of distributed operating system and services requirements
• High Capacity Processing: - Develop and prototype software for 32/64 bit processors, specialized coprocessors such as i960, R4000 and multi-megabyte memory alternatives associated with mass storage disk for space qualified components	• Additional processing capability and performance for the on-board data system.	• Compatibility with ground systems in both performance and architecture
• Non-Stop Computing - Develop and demonstrate software models exhibiting multi-fault tolerant system and component behavior and reconfigurable capability with and without human controls - Determine the technologies needed to test, verify and certify for flight operations	• Determination of requirements and components for fault resistant computing for evaluation of concepts, costs and implementation difficulty.	• More flexible launch commit criteria and increases in mission safety
• Software Reusability - Develop and build Computer Aided Systems Engineering (CASE) tool data repository filters for exchanging data between different CASE tools for flight software development - Define and test reusable software features for flight software specific operating systems, services and applications.	• Establishes generic flight software system elements for reuse across any program	• Lower development and life cycle costs for the software element
• Avionics Displays and Controls - Develop and prototype knowledge based visual, touch, voice and other sensory display and control aids to support human operation of complex systems - Determine the technologies needed to test, verify and certify advanced human-machine interface software	• Determination of effective human interface mechanisms as the complexity and amount of information increase	• Aids human data comprehension and response

NASA

5.2.7.4.1 ETO Vehicle Avionics: GN&C Algorithms Current & Related Programs

Navigation, Control & Aeronautics Division

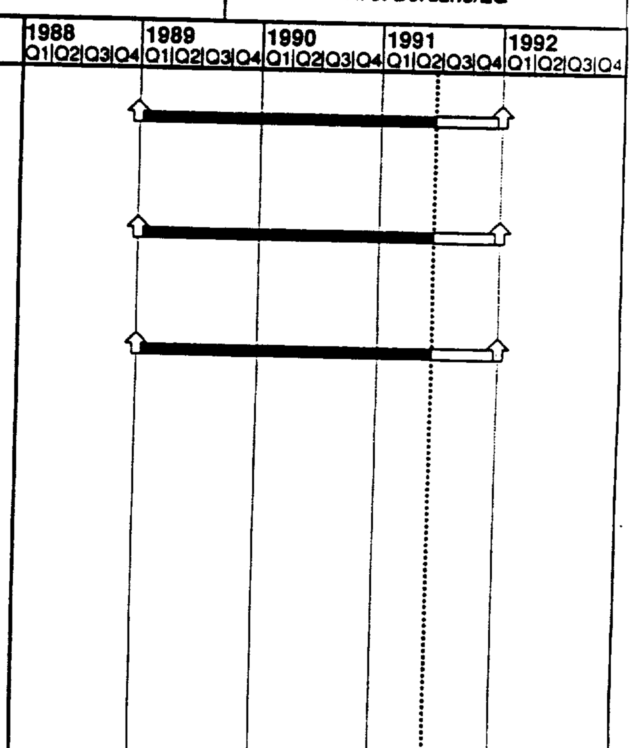
A. J. Bordano/EG

Description

Autonomous Launch Vehicle Reconfiguration
- Baseline requirements for current vehicles

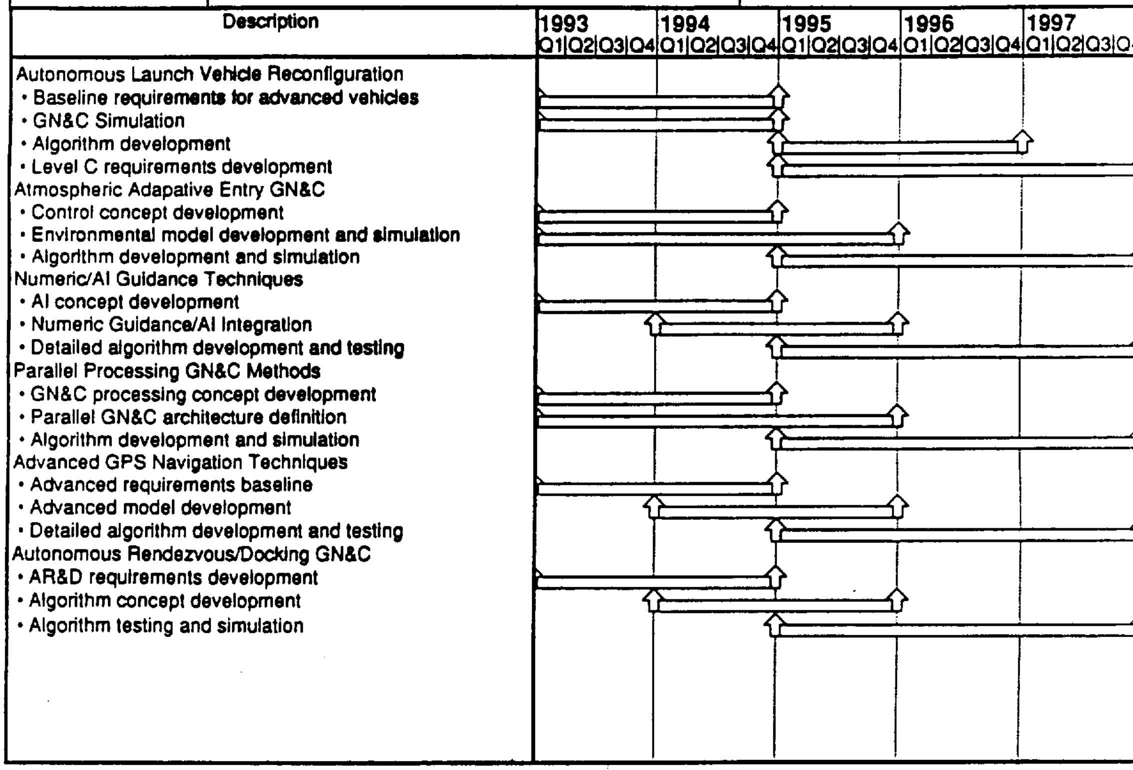
Advanced GPS Navigation Techniques
- Initial tests in aircraft

Autonomous Rendezvous/Docking GN&C
- Baseline requirements under development



5.2.7.4.1 ETO Vehicle Avionics:
GN&C Algorithms
Proposed Technology

Navigation, Control & Aeronautics Division
A. J. Bordano/EG



Johnson Space Center - Houston, Texas

5.2.7.4.1 ETO Vehicle Avionics: GN&C Algorithms Program Benefits

Navigation, Control & Aeronautics Division

A. J. Bordano/EG | 6/26/91

TECHNOLOGY	BENEFITS	WHY
Autonomous Launch Vehicle GN&C Reconfiguration • Identify new approaches to current launch vehicle algorithms and processes that reduce or eliminate recurring engineering analysis, computer simulation and FRR activities	• Recurring launch operations costs can be reduced through automation and improvements to current GN&C algorithms and operations approaches	• Elimination of manpower intensive activities is needed for the next generation of launch vehicles
Atmospheric Adaptive Entry GN&C • Develop a GN&C system that can actively control heat rate, heat load or temperature while maintaining an accurate landing point	• Improved thermal protection margin and reduced sensitivity to atmospheric and system uncertainties	• Entry vehicle landing accuracy and thermal protection system requirements are driven by the ability of the GN&C system to adapt to dispersed atmospheric conditions
Numeric/AI Guidance Techniques • Utilize artificial intelligence techniques to provide assured convergence of numeric guidance algorithms	• Accurate, reliable guidance solutions using exact environment models	• Current numeric guidance schemes are not assured of always converging
Parallel Processing GN&C Methods • Develop new approaches and algorithms that can be effectively used on parallel processing computers	• Perform complex GN&C computations onboard using parallel processing	• Sequential computation limits today's GN&C processing
Advanced GPS Navigation Techniques • Develop new algorithms and environment models to improve GPS navigation accuracy for ETO vehicles	• Accurate, autonomous space vehicle navigation	• Changing environmental conditions can degrade doppler measurements
Autonomous Rendezvous/Docking GN&C • Develop algorithm concepts and approaches to support autonomous rendezvous	• Recurring costs reduced through automation and improvements to current GN&C algorithms and operations approaches	• Current AR&D operations rely heavily on ground based manual procedures

CONCLUDING REMARKS

- TECHNOLOGY PLAN IS BASED ON "UNCONSTRAINED" INPUTS
- PRIORITIES WILL BE ESTABLISHED BASED ON USER REQUIREMENTS AND TECHNOLOGY GAPS
- HOWEVER, SOME THEMES HAVE CLEARLY EMERGED
  - "TODAY'S AVIONICS SYSTEMS ARE CUSTOMIZED TO MAXIMIZE THE PERFORMANCE AND EFFICIENCY FOR A SPECIFIC VEHICLE APPLICATION. - - - - TODAY, IN THE AIRCRAFT INDUSTRY, A COMMON MODULE APPROACH IS BEING STANDARDIZED IN ORDER TO ACHIEVE HIGH PRODUCTION RATES WHICH NOT ONLY LOWERS COST BUT ALLOWS COST TO BE AMORTIZED OVER MANY DIFFERENT AIRCRAFT WHICH CAN UTILIZE THE SAME COMMON MODULES. THIS APPROACH PROVIDES THE FLEXIBILITY, SCALABILITY, AND LOW COST CHARACTERISTICS NOW BEING SOUGHT IN THE SPACE INDUSTRY. A COST EFFECTIVE APPROACH FOR THE SPACE INDUSTRY WOULD CONSIDER USING A MODULAR SYSTEM WITH COMMON BUILDING BLOCKS SO THAT THE COST CAN BE SHARED OVER MANY VEHICLES AND PROGRAMS."

11

CONCLUDING REMARKS

- CRITICAL TECHNOLOGIES REQUIRED
  - AVIONICS ARCHITECTURES (PROTOTYPING, SYSTEM TRADES, TEST, ETC.) WHICH ARE MODULAR, STANDARDIZED, OPEN AND HAVE THE ABILITY TO CONFIGURE NEW OR REVISED SYSTEMS QUICKLY AND EFFICIENTLY WITH MINIMUM IMPACT ON COST AND SCHEDULE
  - ADVANCED SOFTWARE FOR REDUNDANCY MANAGEMENT (FAULT DETECTION, ISOLATION, RECOVERY - - - -) WHICH IS RELIABLE, FLEXIBLE WITHOUT HIGH OVERHEAD
  - ADVANCED SOFTWARE FOR DEVELOPMENT, VERIFICATION AND VALIDATION OF FLIGHT CODE WHICH UTILIZE NEW TEST METHODS AND SIGNIFICANTLY REDUCE LIFE CYCLE COSTS
  - ADVANCED SOFTWARE FOR AUTONOMOUS CHECKOUT
  - ADAPTIVE GUIDANCE, NAVIGATION AND CONTROL ALGORITHMS WHICH SUPPORT SAFE MISSION COMPLETION DURING NON NOMINAL CONDITIONS AND REQUIRE MINIMUM GROUND SUPPORT

12

VEHICLE HEALTH MANAGEMENT

ROBERT L. MCKEMIE
MSFC/EL43
JUNE 26, 1991

VEHICLE HEALTH MANAGEMENT

AGENDA

- DEFINITION/SCOPE
- TECHNOLOGY NEEDS
- CURRENT ACTIVITIES/FUTURE PLANS
- SUMMARY

VHM OVERVIEW

DEFINITION - Vehicle Health Management: The ability to verify and monitor vehicle health and to take appropriate corrective actions necessary to maintain the vehicle in a functional and/or safe state.

- vehicle checkout
- failure detection
- data processing
- system reconfiguration

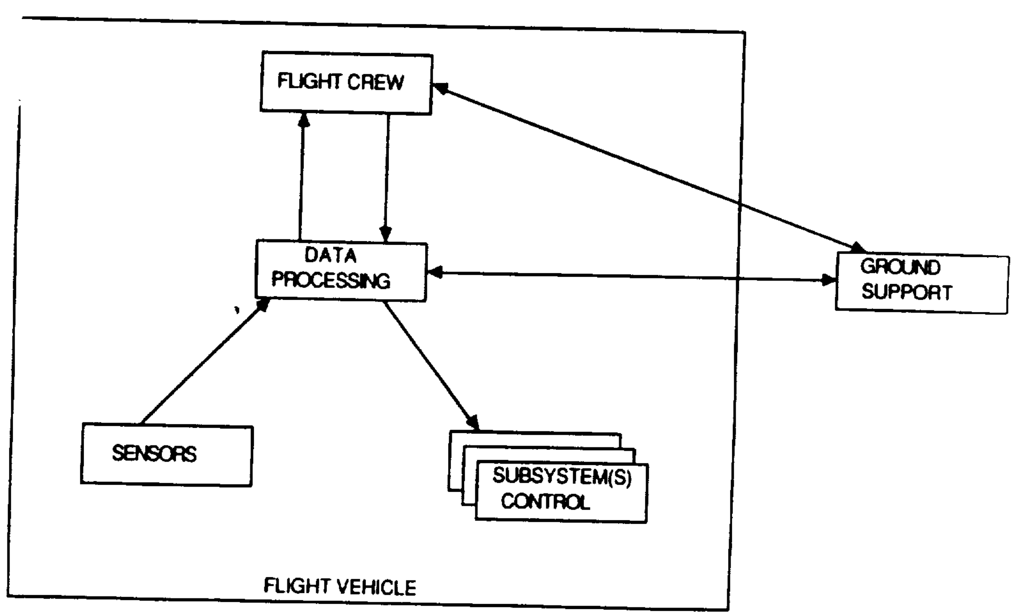
ELEMENTS - Vehicle Health Management System includes:

Sensors
Data Collection and Processing Elements
Algorithms/Decision Models

Totally autonomous vehicle or containing ground based elements.

Component/subsystem/system level elements

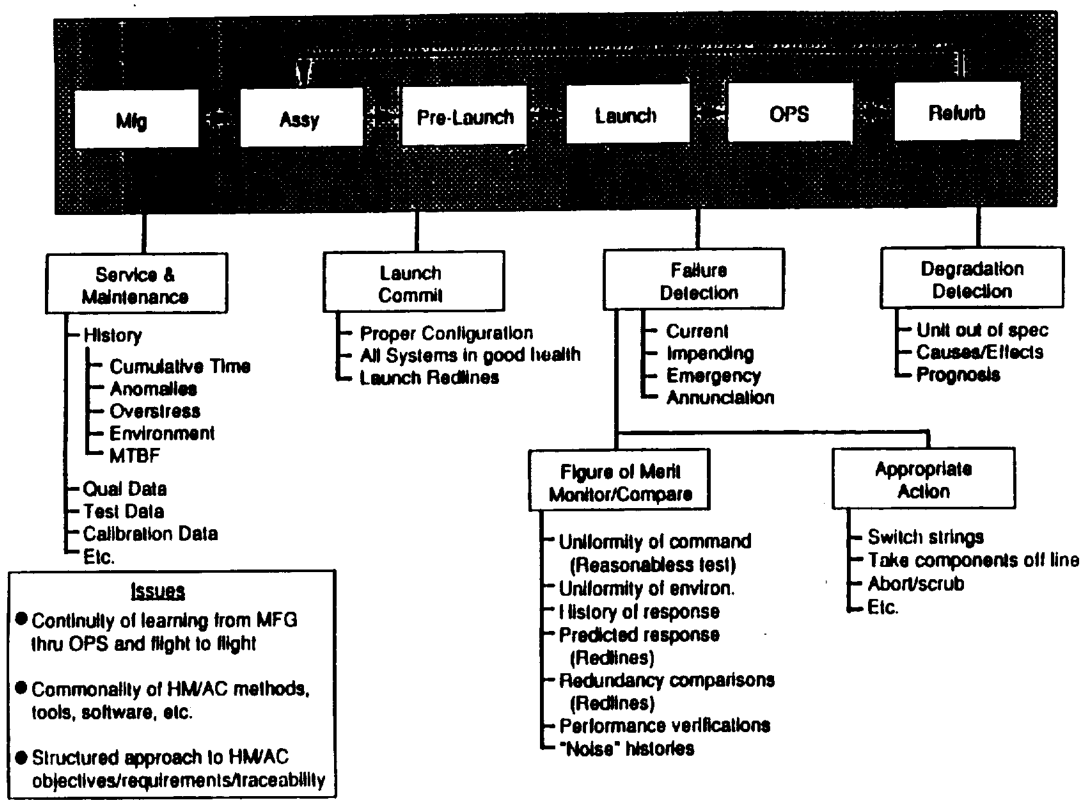
VHM OVERVIEW



SIMPLIFIED VHM SYSTEM

1-1475-0-30D

HM/AC Objectives/Requirements



VHM OVERVIEW

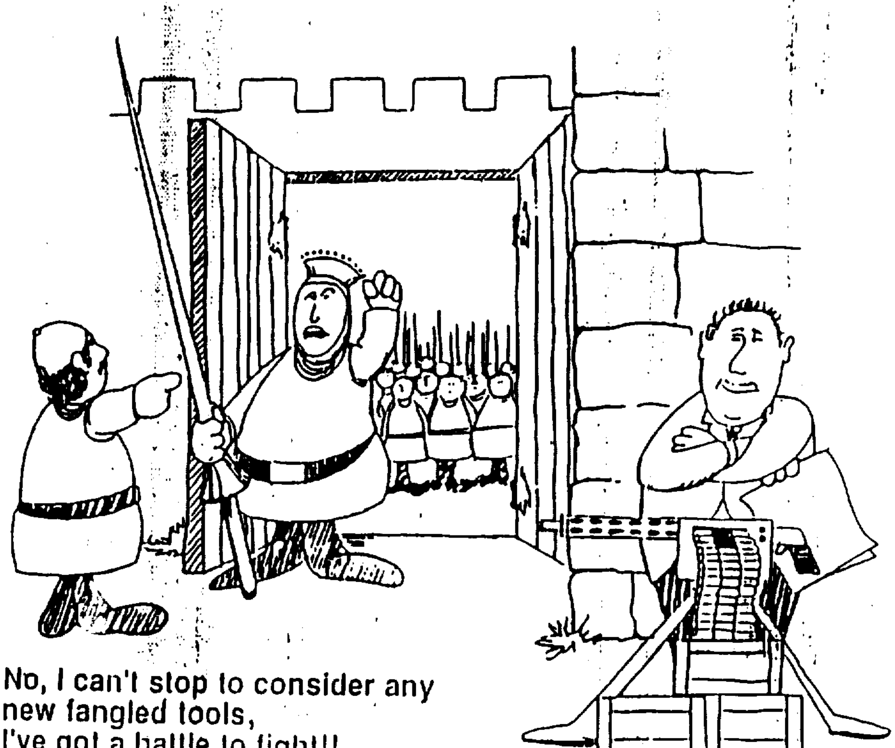
- VHM is not new, but must take advantage of new technologies.
  - Increased Automation
    - streamline vehicle checkout
    - reduce ground/flight crew requirements
  - Better Detection/Prediction Methods
    - enhance troubleshooting
    - reduce hardware costs
    - improve probability of mission success
    - reduce maintenance costs
  - Improved Decision Making
    - quicken response time
    - provide consistent, reliable decisions
    - improve probability of mission success
  - Improved Reliability
    - reduce hardware costs
    - improve probability of mission success

ETO VEHICLE AVIONICS - (TRANS.) 1

TECHNOLOGY PERFORMANCE OBJECTIVES

OAET

PERFORMANCE PARAMETER	CURRENT SOA	OBJECTIVE/REQUIREMENT
VEHICLE HEALTH MANAGEMENT		
COST	HIGH RECURRING	LOW RECURRING
SAFETY/RELIABILITY	REDLINES	SAFE SHUTDOWN/AUTOMATED SYSTEM MANAGEMENT
GROUND CHECKOUT	LABOR INTENSIVE/TIME CONSUMING	INCREASED AUTOMATION/FASTER PROCESSING
MISSION OPERATIONS	MAN-IN-LOOP	INCREASED AUTONOMY
TECHNOLOGY INSERTION	REQUIRES REDESIGN	PLUG-IN
FAULT DIAGNOSIS	MANUAL	AUTOMATED
APPX NEED DATE		1996 (HLLV)



No, I can't stop to consider any
new fangled tools,
I've got a battle to fight!!

ADVANCED AVIONICS TECHNOLOGY REQUIREMENTS

VEHICLE HEALTH MANAGEMENT

GENERAL REQUIREMENTS:

•DEVELOP FLIGHT AND GROUND AVIONICS SYSTEMS THAT ENABLE AUTOMATED VEHICLE CHECKOUT AND MONITORING TO REDUCE LAUNCH PROCESSING AND MISSION OPERATIONS COSTS.

ELEMENTS:

•INVESTIGATE SYSTEM ARCHITECTURES TO DETERMINE OPTIMAL CONFIGURATION TO SUPPORT AUTOMATED VEHICLE HEALTH MANAGEMENT. ARCHITECTURE MUST BE SUPPORTIVE OF NEW TECHNOLOGY INTEGRATION AS IT BECOMES AVAILABLE WITH A MINIMUM IMPACT TO THE FLIGHT VEHICLE OR GROUND SYSTEM.

•INVESTIGATE POTENTIAL SENSOR TECHNOLOGIES TO ENABLE THE MONITORING OF CRITICAL VEHICLE HEALTH PARAMETERS. BY SENSING CRITICAL PARAMETERS EFFECTIVELY, "GO/NO-GO" DECISIONS, FAULT DETECTION, AND HARDWARE LIFE PREDICTIONS CAN BE MADE IN A TIMELY, RELIABLE, AND CONSISTENT MANNER.

•DEVELOP SYSTEMS ENGINEERING METHODOLOGIES APPROACHES AND TOOLS TO SUPPORT DEVELOPMENT OF AN AUTOMATED HEALTH MANAGEMENT SYSTEM.

ADVANCED AVIONICS TECHNOLOGY REQUIREMENTS

VEHICLE HEALTH MANAGEMENT

ELEMENTS (CONT'D):

•DEVELOP SOFTWARE TECHNOLOGIES (E.G., EXPERT SYSTEMS) TO ALLOW DELEGATION OF DECISION MAKING FROM CHECKOUT PERSONNEL TO AUTOMATED HEALTH MANAGEMENT SYSTEM. THIS WILL ALLOW VEHICLE PROCESSING WITH A SMALLER TEST TEAM AND REDUCE THE CHANCE OF HUMAN ERROR.

•DEVELOP SIMULATION/DEMONSTRATION TECHNIQUES TO VERIFY PERFORMANCE OF THE HEALTH MANAGEMENT SYSTEM AND TO ESTABLISH CONFIDENCE IN AUTOMATED CHECKOUT AND CONTROL. TOTAL CONFIDENCE IS REQUIRED PRIOR TO ITS FULL IMPLEMENTATION ON A FLIGHT VEHICLE.

REPRESENTATIVE TECHNOLOGIES

- SENSORS
  - PLUME OPTICAL ANALYSIS
  - HYDROGEN LEAK DETECTION
  - REMOTE OPTICAL INSPECTION
  - BIT
- SOFTWARE
  - DATA TRENDING ALGORITHMS
  - NEURAL NETS
  - PARITY SPACE ALGORITHMS
  - MODEL BASED DIAGNOSTICS
- SYSTEMS TOOLS
  - COST/BENEFIT MODELLING
  - DIGRAPH TOOLS
  - SYSTEM SIMULATION

VHM ACTIVITIES/PLANNING

- ESTABLISHED AS A SATWG (STRATEGIC AVIONICS TECHNOLOGY WORKING GROUP) PANEL
  - MSFC/LeRC CO-CHAIR
  - EXTENSIVE NASA/INDUSTRY PARTICIPATION
- NASA/INDUSTRY MEETING, SEPT., 1990, INDIATLANTIC, FL
- VHM WORKSHOP, LeRC, DEC., 1990 (SPACE BASED VEHICLES)
- VHM WORKSHOP, MSFC, JUNE, 1991 (E-T-O LAUNCH SYSTEMS)
- DEVELOP AND MAINTAIN VHM TECHNOLOGY REQUIREMENTS (ON-GOING)
- JSC/KSC WORKSHOP (ORB/SSF), SEPT. 1991
- SENSOR WORKSHOP (SSC), FALL, 1991
- SOFTWARE WORKSHOP (ARC), SPRING, 1992

SUMMARY

•VHM PANEL ACTIVITIES PROVIDE NASA FOCUS FOR VHM TECHNOLOGY NEEDS/PLANS

- -ESTABLISH JOINT NASA/INDUSTRY DIALOGUE
- -IDENTIFY AND PRIORITIZE TECHNOLOGY NEEDS
- -SUPPORT TECHNOLOGY DEVELOPMENT EFFORTS
- -IDENTIFY/SUPPORT BRIDGING TASKS

•EFFORT WILL BE ON-GOING, LONG TERM ACTIVITY

•ENHANCED VHM IS A KEY TO COST-EFFECTIVENESS AND MISSION SUCCESS OF FUTURE PROGRAMS

SPACECRAFT GUIDANCE RESEARCH AT LANGLEY

Douglas B. Price
Head, Spacecraft Controls Branch
Langley Research Center

June 26, 1991

Briefing Contents

- Spacecraft Guidance Technology at LaRC
- Guidance Group Mission Statement
- Mission Statement Implementation
- Technical Program Summary
- Summary

SCB Guidance Group Mission

- To develop algorithmic technology for guidance of aeromaneuvering spacecraft subject to uncertainties

- To identify and advocate technology for sybsystems needed by guidance algorithms; e.g. electro-optical sensors

- To actively interchange technology and requirements with industry

How the Mission is Accomplished

- "Program requirements" are imposed by characteristics of a proposed mission/system, e.g. ALS

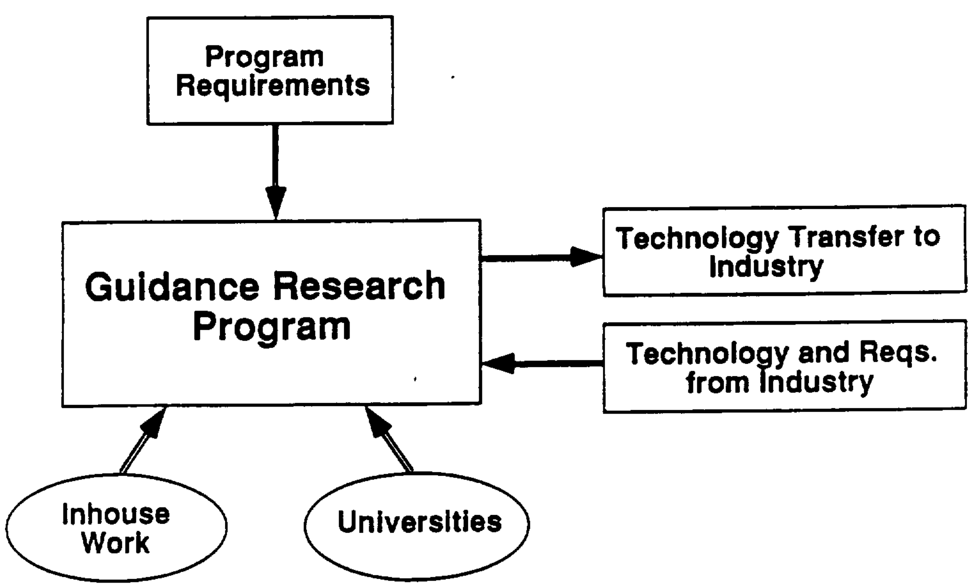
- Guidance group focusses inhouse and grant-based academic research on program requirements

- Resulting technology is shared with industrial partners via Technology Interchange Tasks

Technology Interchange Tasks

- Industrial researchers exercise and demonstrate new technology with guidance group support
- "Lessons learned" and refined concepts and requirements feed back to guidance group
- Guidance group works with academics to enhance university research focus

Research Implementation Flow



Technical Program Summary

- Issues
- Algorithmic technology activity
  - goals
  - guidance synthesis techniques
    - discrete time methods
    - perturbation methods
    - neural methods
  - globally convergent algorithms
- Validation/modelling support
- Technology interchange

Issues in Aeromaneuvering Spacecraft Guidance

- Highly constrained trajectories
- Limited control authority/sluggish rotational response
- Energy and/or constraint performance dominated by uncertain atmospheric effects
- Above issues are shared by:
  - launch systems
  - aerobrakes
  - aerospace planes

Algorithmic Technology Goal: Direct Statistical Guidance Synthesis (DSGS)

- Statistics of process uncertainties are direct inputs to a formal guidance synthesis algorithm
  - winds
  - hardware failures
  - plant uncertainties
- Benefits:
  - design directly for probability of achieving mission goals
  - reduce design/testing cycles for guidance design

Steps Toward DSGS

1. Develop technology for reliable, accurate deterministic optimal and suboptimal control synthesis

2. Extend problem formulations to include random process statistics

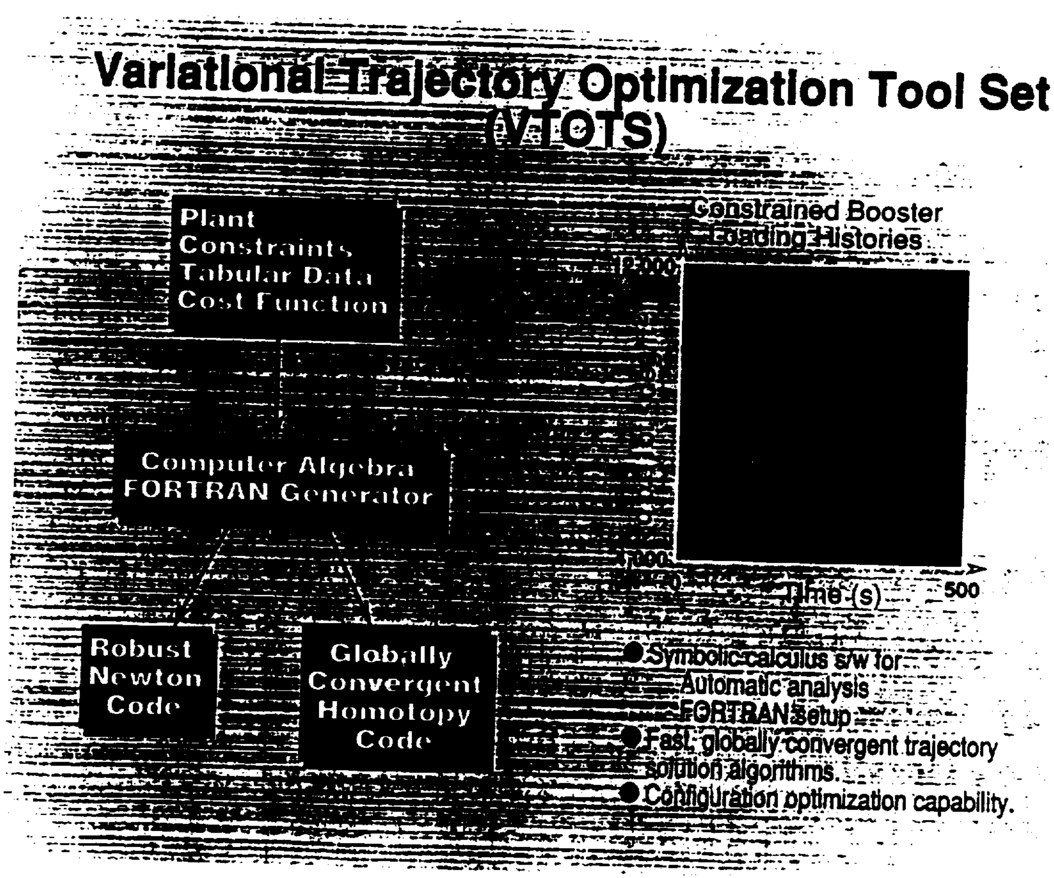
3. a. Validate in test bed

   b. Ensure that results have industrial applicability

Trajectory Optimization Techniques

- Focus is on numerical solution of optimal control necessary conditions in discrete time

- Inhouse, grant-based and contract work is implemented in "Variational Trajectory Optimization Tool Set" (VTOTS)



VTOTS Trajectory Prototyping Tool

GOAL:

- Fast, accurate solution of Variational Optimal Control Boundary Value Problems for:
  - trajectory/configuration optimization
  - guidance synthesis

- Very simple user interface: "OTIS-like" ease of use

VTOTS Participants

- NASA LaRC/Ga. Tech.
  - joint development of algorithmic theory and problem solution code
- McDonnell Douglas Space Systems Co.
  - OTIS to VTOTS adaptation
  - aeroheating capability
  - automatic mesh generation issues
- Cornell University
  - parallel Newton code for solving necessary conditions

Impediments to "OTIS-Like" Ease of Use

- Derivation of necessary conditions
- State inequality constraints
- Boundary conditions
- Numerical stability
- Lack of "OTIS-like"user community

Derivation of Necessary Conditions

- Problem
  - derive costate ODEs by differentiating Hamiltonian
  - solve nonlinear equations for controls
- Solution
  - symbolic computation front end; user merely inputs plant and cost function
  - control equations represented as functions to be zeroed (solved) at discrete time steps

State Inequality Constraints

- Problem
  - pre-assume structure of active constraint arcs
  - construct trajectory structure using internal boundary conditions and conditions on time derivatives of constraints
- Solution
  - demonstrations and trades on several discrete time problem representations, with constraint necessary conditions represented by Mangasarian functions

  ⟶ no apriori imposition of structure on problem

Boundary Conditions

- Problem
  - costate boundary conditions obtained via solution of nonsquare linear system for "undetermined multipliers"
- Solution
  - state and costate necessary conditions represented as an equivalent square nonlinear system in states and costates

  ⟶ no analysis necessary for implementation

Numerical Sensitivity

- Problem
  - traditional methods for solution of necessary conditions highly nonconvergent
- Solution
  - discrete time representations converge robustly
  - globally convergent methods under development for initial guesses
  - analytic differentiation where possible; high-accuracy numerical differentiation techniques else

Lack of OTIS-Like User Community

- Problem
  - OTIS is an excellent package with strong following
- Solution
  - working with industrial partner to give VTOTS
    - similar "taste and feel" to OTIS
    - features for industrial utility
  - pending successful VTOTS development, conduct an OTIS/VTOTS flyoff
  - possibly seek co-sponsorship arrangement with Air Force

Examples of Perturbations

Singular Perturbations

$$\dot{x} = f(x,y,u)$$
$$\varepsilon \dot{y} = g(x,y,u)$$

Regular Plant Perturbations

$$\dot{x} = f(x,u) + \varepsilon g(x,u)$$

Regular Trajectory Perturbations (Linearization)

$$x = \bar{x} + \delta x \qquad u = \bar{u} + \delta u$$
$$\dot{\bar{x}} = f(\bar{x},\bar{u})$$
$$\delta\dot{x} = \frac{\partial f}{\partial \bar{x}}\delta x + \frac{\partial f}{\partial \bar{u}}\delta u$$

Important Limitation of Discrete-Time Methods

BANDWIDTH:

- frequency content of optimal trajectory limited by discretization mesh density

- disturbances outside Nyquist frequency not represented

  $\longrightarrow$ these may be important for constraint performance

Perturbation Methods

Exploit alternate plant representations for guidance synthesis

VTOTS:

Solve optimal control problem via more tractable trajectory representation

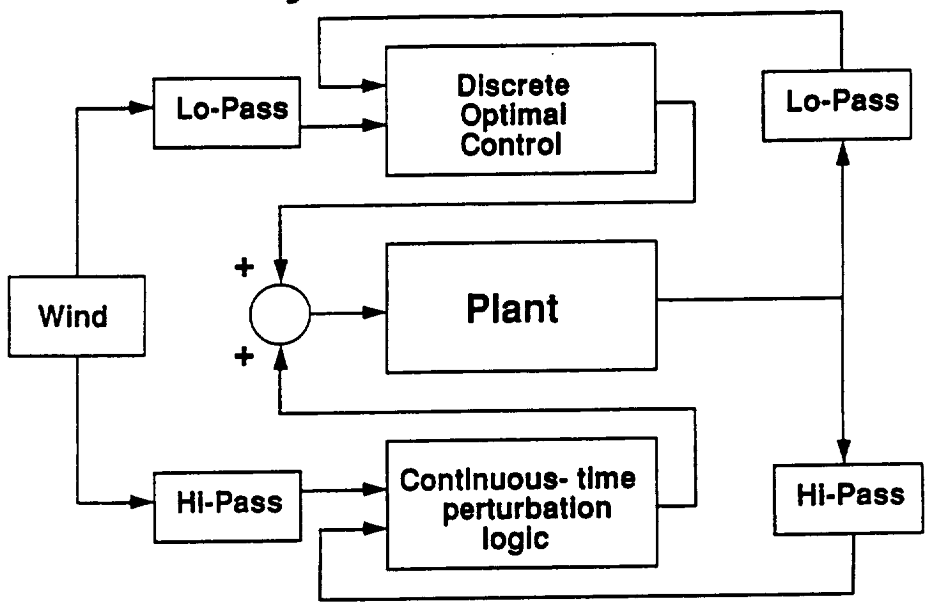
PERTURBATION METHODS:

Approximate optimal control problem by expanding about solution of a convenient "neighboring" problem

Comments

- Guidance group supports research in all three perturbation categories; inhouse activity in regular perturbations
- Regular perturbations are applicable to launch vehicles
- Regular perturbation schemes can be exploited to restore high-frequency effects (e.g. wind gusts) to guidance schemes based on discrete-time optimal control

Candidate Hybrid Guidance Architecture



Neural Methods

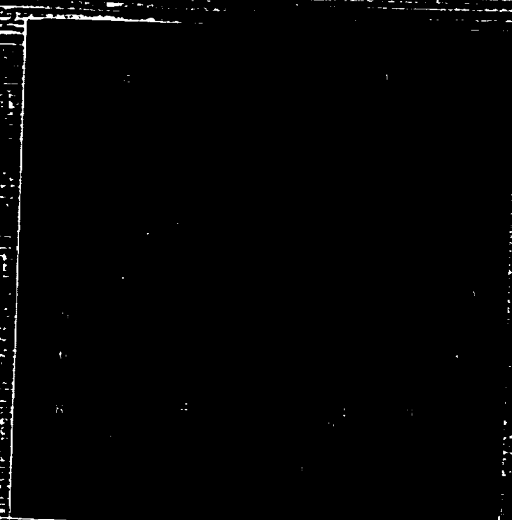
- Current activity entirely contracted out
  - 2 universities (joint activity)
  - 1 SBIR Phase II contract
- Both efforts stress use of neural net as rapid interpolation system, but
  - different guidance architectures
  - different training methods

Globally Convergent Algorithms

- **Activity supports**
  - initial guess generation in VTOTS
  - calculation of global minima in direct optimization problems

- **Two approaches under investigation**
  - extensions to Chow-Yorke homotopy techniques
  - "genetic" minimization algorithms

GLOBALLY CONVERGENT EQUATION SOLVER



[illegible]

- Guaranteed convergence from arbitrary starting guess for smooth systems of equations
- Applications to:
  - Optimal control boundary value problems
  - Global minima for multidisciplinary optimization

Solution curve joining initial guess to a zero of Watson's [illegible] Exponential Function

Chow-Yorke Homotopy Techniques

- Extension of "continuation" method
  - avoids singularities which can destroy progress of calculations
  - failure can occur when calculations become smoothly unbounded
- Inhouse activity centers on procedures for preserving boundedness
- FORTRAN implementations for general functions and for VTOTS finite element discretization

Genetic Algorithm

- Non-derivative procedure for functional minimization
- At each iteration, a random population of solution candidates is modified by "reproduction, crossover and mutation" operations
- The "fittest" - lowest cost - population elements dominate "less fit" higher cost elements
- We're not sure how it works, but it performs impressively

Validation/Modelling Support

- Evaluation of candidate guidance schemes via Monte Carlo simulation

- Development of high quality simulations of pertinent random atmospheric phenomena for guidance validation

Stochastic Atmosphere Simulation

- Constructed and analyzed fidelity of Gaussian random model for synthetic KSC launchsite winds

- Procedure for controlling spatial frequency bandwidth of atmospheric variations in an inhouse trajectory simulation implementation of the GRAM model

Monte Carlo Guidance Evaluations

Two studies underway

- performance evaluation of a suboptimal analytic aerospace plane guidance rule for ascent

- optimal control-based launchsite wind profiler requirements study for Shuttle

Generic Hypersonics (GH) Guidance & Optimization Program at Langley

Technical Focus:

- Technology for trajectory and system optimization and synthesis of suboptimal aerospace plane guidance laws

Approach:

- Combined program of grant/contract/inhouse research and development
- Exploit leveraging opportunities from other Langley guidance activities

GH Guidance and Optimization Foci (I)

- Simplified procedures for solving variational optimal control problems
- Finite element discretizations of optimal trajectory boundary value problems (spinoff from Advanced Launch System)
- Use of variational optimal control formulations for system configuration optimization

GH Guidance and Optimization Foci (II)

Motivations for emphasis on variational methods

- direct treatment of sensitivity functions
  - useful for system optimization
- numerical schemes lead to solution of equations, rather than search for minima

System Optimization Studies

- Comparison of static and variational optimal control formulation of a system parameter optimization problem

TASK: choose thrust angle for max performance

a) direct optimization of energy rate at points along a fixed trajectory

b) optimal control of thrust angle for payload to orbit along identical trajectory

System Optimization Studies (II)

Exact calculation of state constraint sensitivity functions

- Constraint sensitivities obtained via quadrature of Lagrange multipliers on state constrained trajectory arcs
- Concept demonstration for dynamic pressure constraint on fuel optimal ascent of Langley Accelerator
- Results to be obtained via Variational Trajectory Optimization Tool Set (VTOTS)

Other Technology Interchange Activities

Active:

- Codevelopment of VTOTS with MDSS

Pending:

- Launch vehicle guidance exploiting regular perturbation of optimal return function
- Aerobrake performance sensitivity to guidance and atmospheric knowledge assumptions

Summary

- Guidance group develops technologies for guidance of aeromaneuvering spacecraft
- Guidance group's program focusses inhouse and academic resources on industrial requirements
- Group implements technology interchange with industry by constructing opportunities for technology demonstration by industrial research groups

Autonomous

Rendezvous & Docking

Technology Development

Status & Plans

Why AR&D?

<u>Leadership and America's Future in Space: The Sally Ride Report (August 1987)</u>

"...this initiative (Mars Rover/Sample Return) places a premium on advanced technology ... to maximize the scientific return. It requires ... a high level of sophistication in automation..."

<u>Report of the NASA 90-Day Study (Nov 1989)</u>

"Elements needing technology development include ... autonomous rendezvous and docking. ...[Which is] essential to the cost-effective return of samples from Mars as part of the robotic missions."

<u>Advisory Committee on the Future of the U.S. Space Program (December 1990)</u>

"Among the more critical technology topics that must be pursued are ... automation and robotics, ... sensors..."

<u>Report of the Synthesis Group, Executive Summary (May 1991)</u>

"At Mars, we need Earth-independent operations, since round trip communications times will vary from seven to 40 minutes."

"Technology development is required in the following areas:

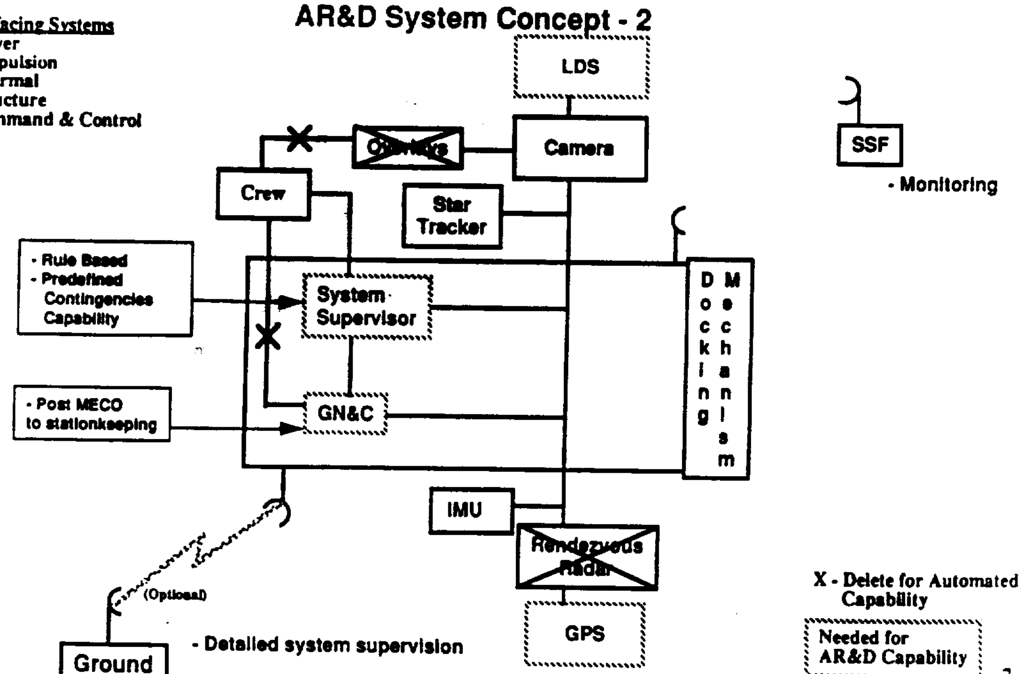
... (6) Automated rendezvous and docking of large masses"

Background

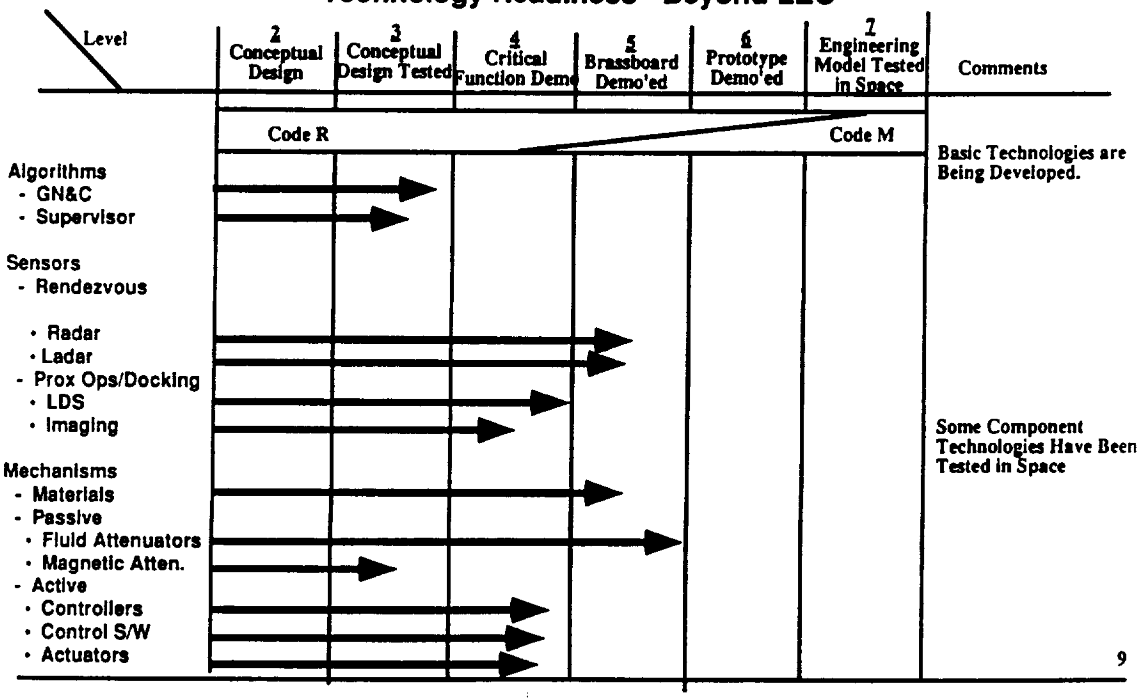
- Exploration Technology Program AR&D (Previously Pathfinder)
  - Identified Subtask Technology Requirements
  - Developed Preliminary System Requirements
  - Docking Ground Demo (Sensor & Mechanism Hardware, GN&C) in FY91
  - AR&D Graphics Demo (Hardware Math Models, GN&C) in FY 90 & 91
- Conducted Rendezvous, Proximity Operations, & Docking (RPOD) Quality Function Deployment (QFD)
  - Team Members Include JSC Engineering & Operations Organizations plus Industry (General Dynamics, Martin Marietta, Lockheed, McDonnell Douglas, TRW, Draper Labs)
  - Conducted Customer Needs Survey, both Programmatic (LMEPO, CTVPO) & Technological (Code R, JSC, MSFC)
  - Results will Support Development of NASA Strategic & Tactical Plans in this Technology Area

AR&D System Concept - 2

Interfacing Systems
- Power
- Propulsion
- Thermal
- Structure
- Command & Control



Technology Readiness - Beyond LEO



Issues & Trades

- Functional Partitioning (Ground, Transfer Vehicle, SSF)
- System Acceptability/Mission Success/Safety
- Level of Independence
- Modularity/Flexibility
- Performance Requirements vs Mission Constraints (Sensors, Mechanisms, Control Effectors)
  - •• Fuel
  - •• Plume Effects
  - •• Mechanism Intelligence
  - •• Lighting
  - •• Sensor Handover Zones
  - •• Sensor Accuracy vs Mechanism Robustness
  - •• Environmental Effects (Thermal, Duration, Solar Radiation)

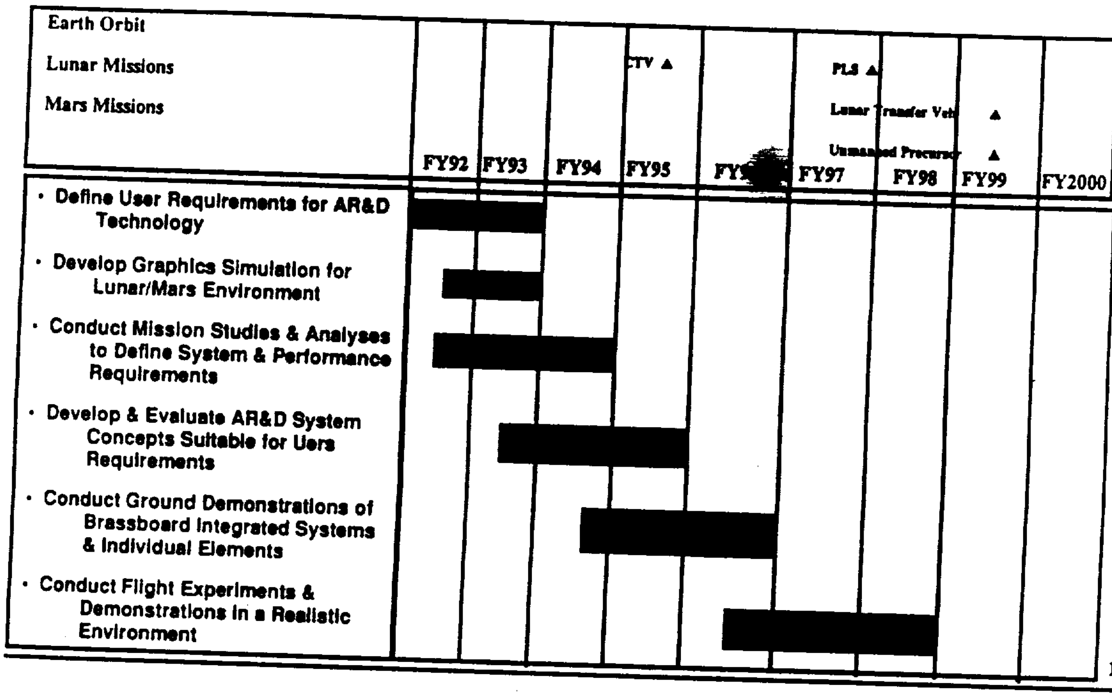
NASA

Autonomous Rendezvous and Docking Technology Development

Navigation, Guidance & Aeronautics Division

Stephen Lamkin | June 26, 1991

Milestones



13

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INTEGRATED TECHNOLOGY PLAN
for the
CIVIL SPACE PROGRAM

AUTONOMOUS LANDING

Controls Committee Review

McLean, VA
June 26-27, 1991

Ken Baker
ER2/Intelligent Systems Branch
Automation & Robotics Division
Engineering Directorate
Johnson Space Center

OBJECTIVES

Develop Technology to Enable Landing of Planetary Exploration Spacecraft:

- *Safely* in the Face of Surface Hazards Presented by Rough Terrain
- *Accurately*, i.e. Close to the Area of Mission Interest
- *Autonomously*, i.e. Without Real-Time Ground Control

BENEFITS

- Increased Probability of Safe Landing
- Reduced Structural Mass Needed to Make the Lander *Robust* Enough to Survive Touchdown
- Reduced Resources Needed to Survey Area of Mission Interest from *Orbit* Until *Safe* Landing Site Is Found

BASIC TECHNICAL APPROACH

Precision Landing

- *Scenario:*
  - Select, Prior to Deorbit, a Safe Landing Site Using High Resolution Orbital Imagery
  - During Descent, Maneuver Accurately Enough to Land Within That Site
- *Technology Need:* Sensor, Algorithm & On-Board Computer to Provide Navigation Measurements With Respect to the Surface of the Planet That Are:
  - Accurate and
  - Robust to Variations in Operating Conditions Such As: Observing Geometry, Illumination Geometry, etc.

On-Board Hazard Detection & Avoidance

- *Scenario:*
  - Aim the Lander At an Area That Is *Expected* A Priori to Contain Small, Safe Landing Sites Within Its Maneuver Range
  - In Real-Time Detect a Safe Site & Maneuver to Land There
- *Technology Need:* Sensor, Algorithm & On-Board Computer That Provide Reliable Detection of Landing Hazards Within the Current Terminal Maneuver Footprint

PATHFINDER STUDY RESULTS

Image Matching Navigation Using Visible Images (JPL, JSC)

- *Template Matching of Optical Images (JPL):*
  - Position *Error* on Simulated Mars Terrain: 0-50 Pixels[11]
  - Possible Source of Errors;

    Distortion of On-Board Image vs. Reference Due to Lander Trajectory Dispersion

    Size and *Resolution* of Reference Image[12]
- *Hybrid Optical Image Matching (JSC):*
  - Synthetic Estimation Filters[13, 14] for *Robust* Detection of Landmarks
  - Taking Into Account Practical Limits of Real Optical Computing Devices
  - Being Tested on Images of Lab./Simulated Mars Terrain

Hazard Detection (JSC/ARC)

- Sensor Surveys[15] That Included Laser Radar, Passive Computer Vision, Hybrid Interferometric Imaging & SAR, Identified Imaging Laser Radar as the First Choice, But:
  - Arrays of GaAlAs Laser Diodes & Si Avalanche Photo-Diode Detectors with Pre-Amps Need Improvement
  - Best Performance from LADAR/Mars Terrain Simulations Is

    Pr {Correct Detection of Hazard} = 0.95 → Pr {False Alarm} = 0.12[16]

WORK BREAKDOWN STRUCTURE	
WBS CATEGORY	ACTIVITIES
Systems Engineering	Determine Requirements Develop Mars/Lunar Surface Models Identify Candidate Approaches & Associated Technology Development Needs Collect Terrain Elevation Maps & Images for Earth Analogs of Mars Terrain Closed Loop Sim. of Precision Landing and of Hazard Detection & Avoidance Select Most Promising Approaches for Development & Field Test of Prototypes
Precision Landing	Develop & Evaluate Selected Techniques Such As: Track Orbital/Surface Beacon from Lander for Navigation Updates Surface Image/Feature Matching for Navigation Updates Using Visible Images, Radar Images or Digital Terrain Maps Develop Prototype Instruments, Such As: Hybrid Optical Image Correlator Imaging Radar On-Board Digital Computer
Hazard Detection & Avoidance	Develop & Evaluate Selected Techniques Such As: Active Detection via Imaging Laser Radar Passive Computer Vision (Slope via Shape from Motion, Rock Detection via Shadows) Hybrid Interferometric Imaging Develop Prototype Instruments, Such As: Imaging Laser Radar Hybrid Interferometric Imager

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4. Anon., *MRSR Flight System Requirements*, Jet Propulsion Laboratory/Johnson Space Center, Pasadena, CA/Houston, TX (June 9, 1989).

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7. A. Engel, T. Bogner, T. Dierlam, and K. Spratlin, *Autonomous Landing Study: Probability of Safe Landing*, Draper Laboratory, Cambridge, MA (July 20, 1989). Briefing to MRSR MDT/SDT on July 20, 1989, NASA Contract NAS9-18147

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CODE RC CONTROLS PROGRAM

OVERVIEW BRIEFING

FOR

CONTROLS COMMITTEE

OF THE

SPACE SYSTEMS & TECHNOLOGY ADVISORY COMMITTEE

CLAUDE R. KECKLER

NASA - LANGLEY RESEARCH CENTER

JUNE 27, 1991

OVERVIEW CONTENT

CONTROLS RESARCH, AND DEVELOPMENT OF ANALYTICAL TOOLS, SOFTWARE PACKAGES, AND HARDWARE COMPONENTS AT:

- ARC
- GSFC
- JPL
- JSC
- LaRC
- MSFC

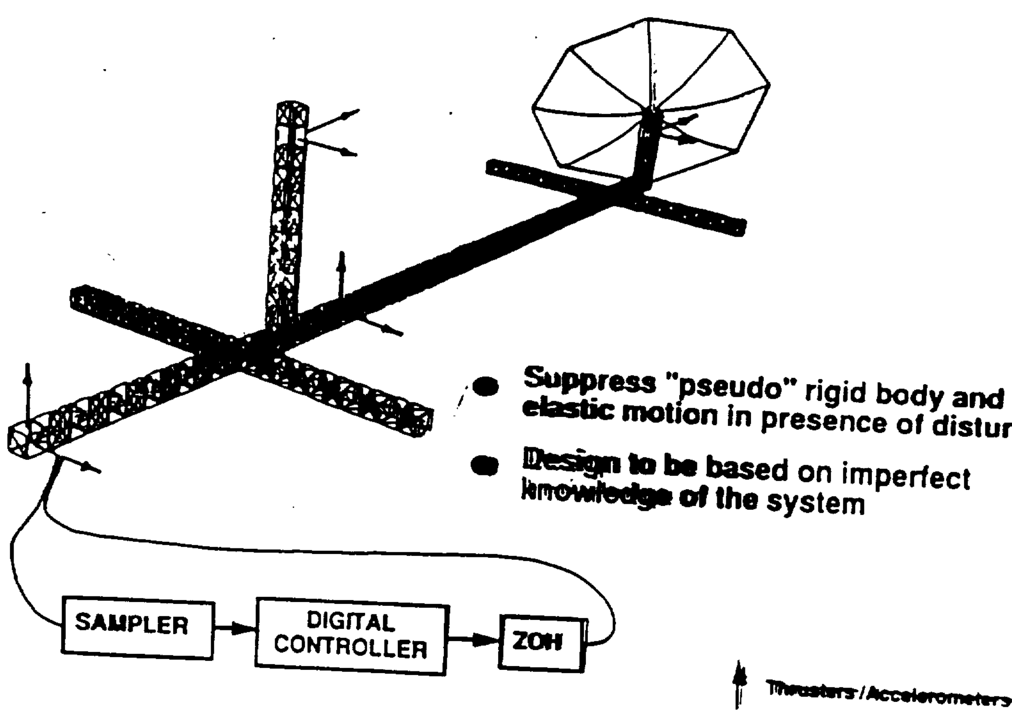
GOALS

- Design & validate controllers for rigid-body control and vibration supressio of the CSI Phase Zero Evolutionary model.

APPROACH

- Apply advanced control design techniques:
  - Linear-Quadratic-Gaussian (LQG)
  - Dissipative
  - H_∞
  - Dissipative augmented LQG (HAC/LAC)
- Incorporate robustness in the designs
- Evaluate via simulation and actual testing
- Compare results

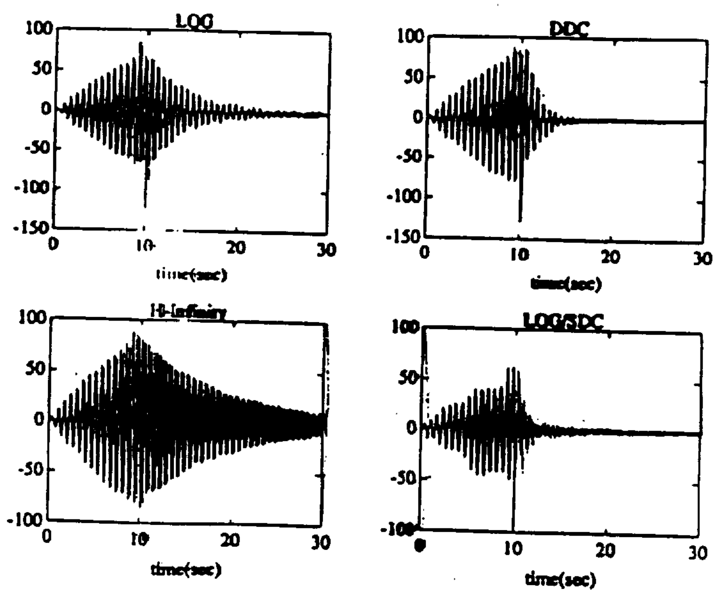
SCHEMATIC OF CONTROL PROBLE



- Suppress "pseudo" rigid body and elastic motion in presence of disturb
- Design to be based on imperfect knowledge of the system

CONTROLLER COMPARISONS

CLOSED-LOOP: EXPERIMENTAL TIME HISTORIES
ACCELERATION #8 (IN/S^2)



CLOSED-LOOP DAMPING

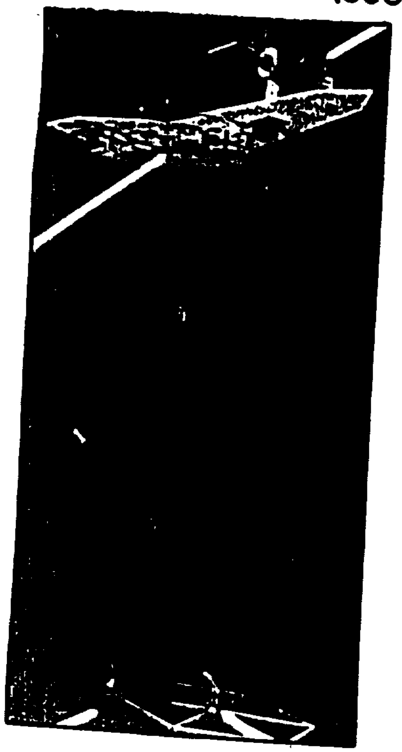
EXPERIMENT VS ANALYSIS

	EXPERIMENT		ANALYSIS	
	MODE 7	MODE 8	MODE 7	MODE 8
LQG	3 %	3.5 %	2.9 %	2.7 %
DDC	8.5 %	14 %	7.0 %	23.9 %
H_∞	1 %	2 %	1.6 %	2.4 %
LQG/SD	12 %	16 %	15 %	15 %

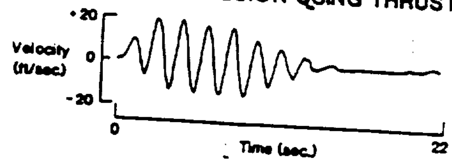
89-3395

SPACECRAFT CONTROL LABORATORY EXPERIMENT

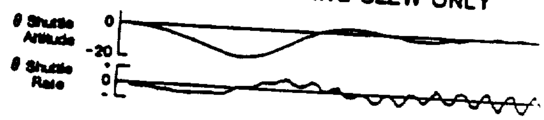
(SCOLE) CONTROL LAWS



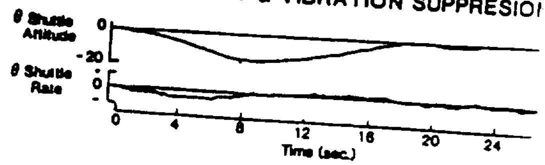
VIBRATION SUPPRESION USING THRUSTERS



RIGID BODY BANG-BANG SLEW ONLY



BANG-BANG SLEW & VIBRATION SUPPRESIO



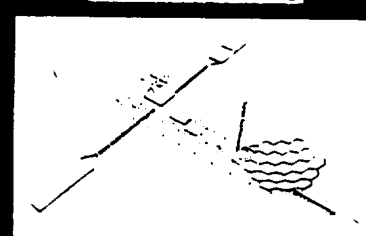
NASA L-89-10136

APPLICATION OF HOLOGRAPHIC STORAGE DEVICE

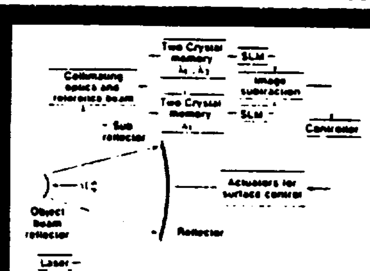
Sensing

Mission to planet Earth

Distributed sensing



Block diagram of distributed sensor applied to control of a flexible reflector



GRANTS

* MIT -

  Develop faster photorefractive materials

* Johns Hopkins

  Develop photorefractive thin films for large focal planes

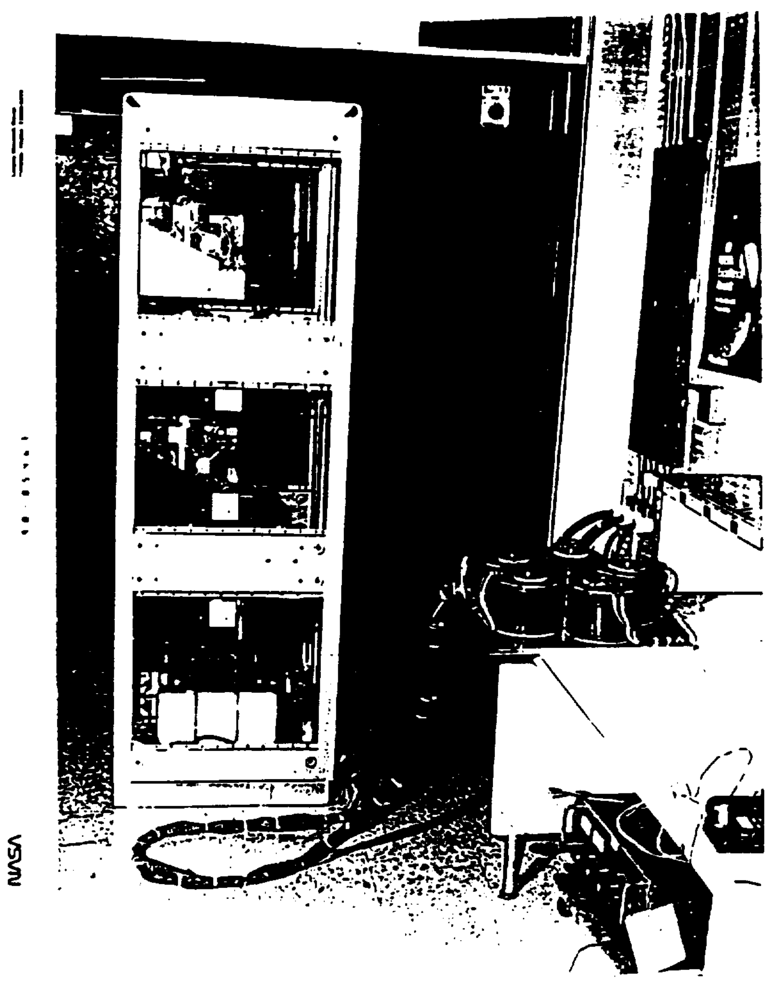
* VPI

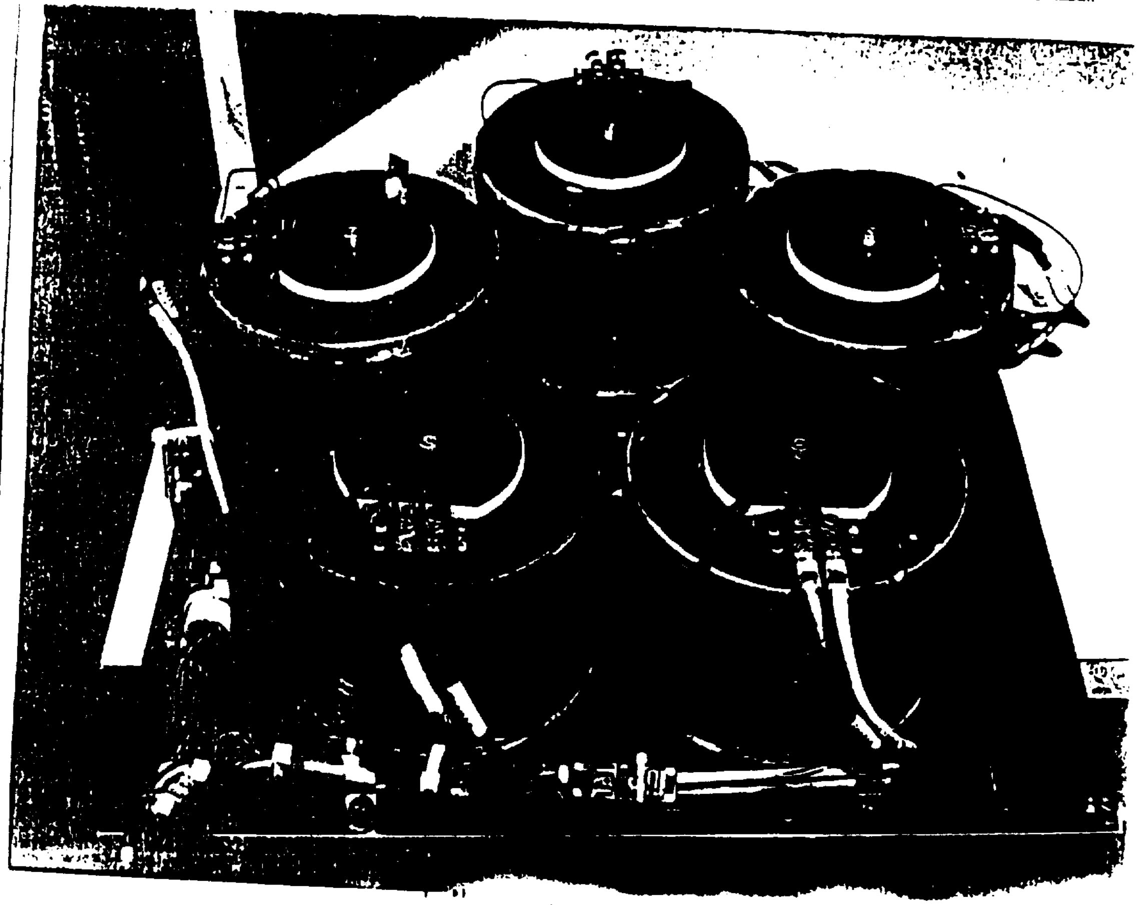
  Analyse performance of interferometric sensor versus incoherent sensor for control of large reflector

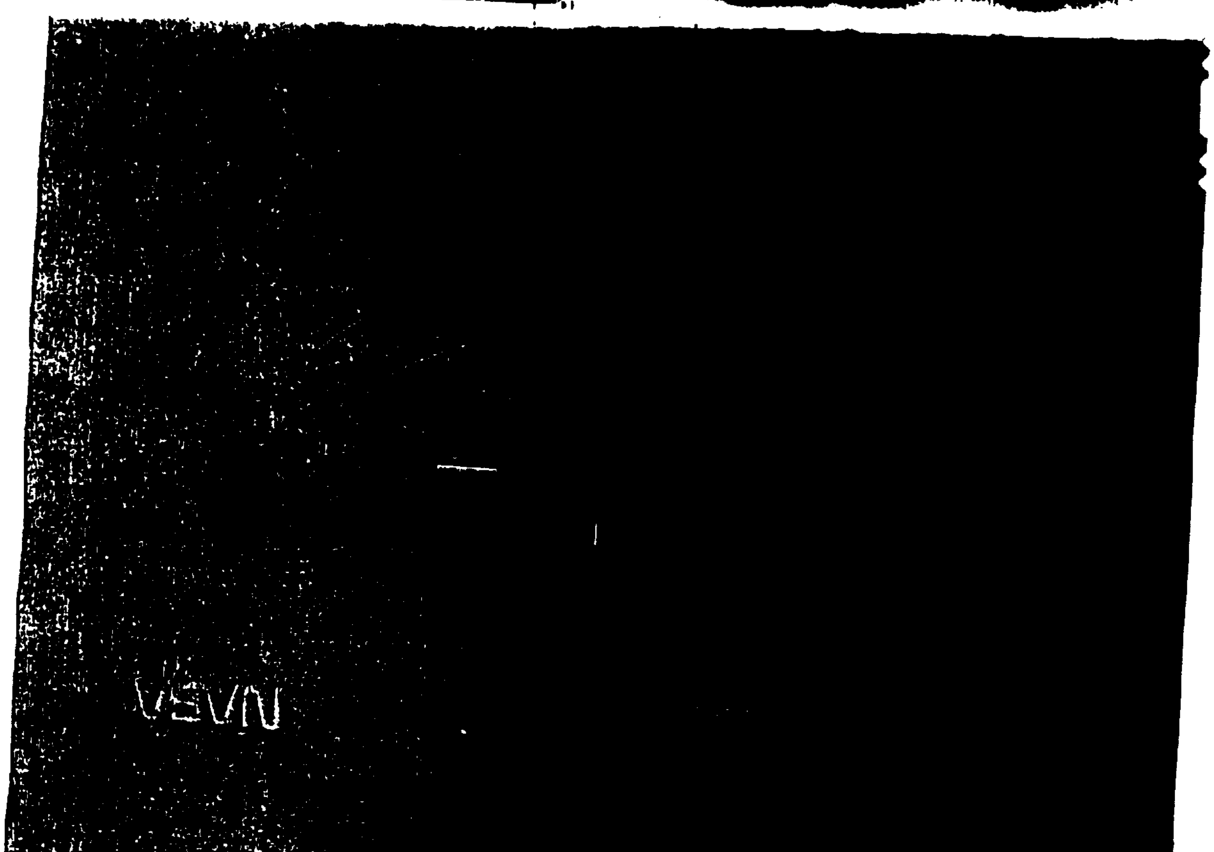
  Develop control laws for distributed sensing and processing

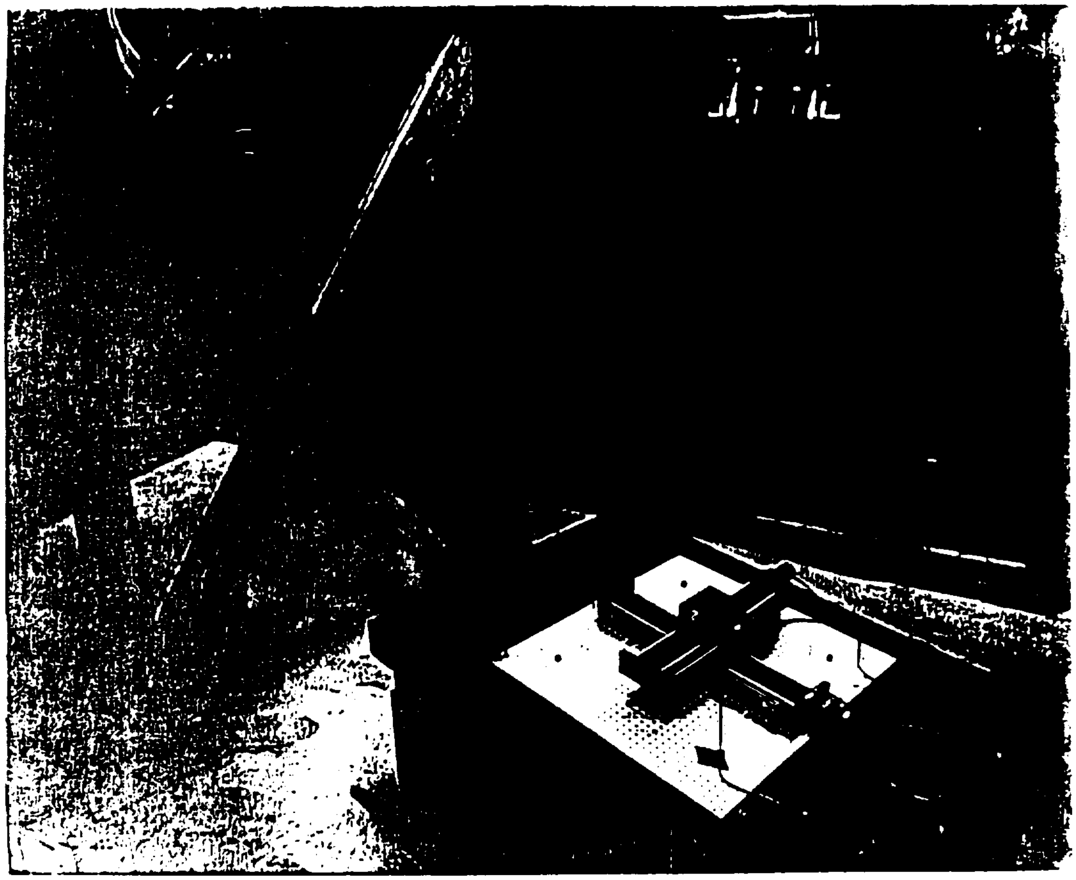
* UCLA

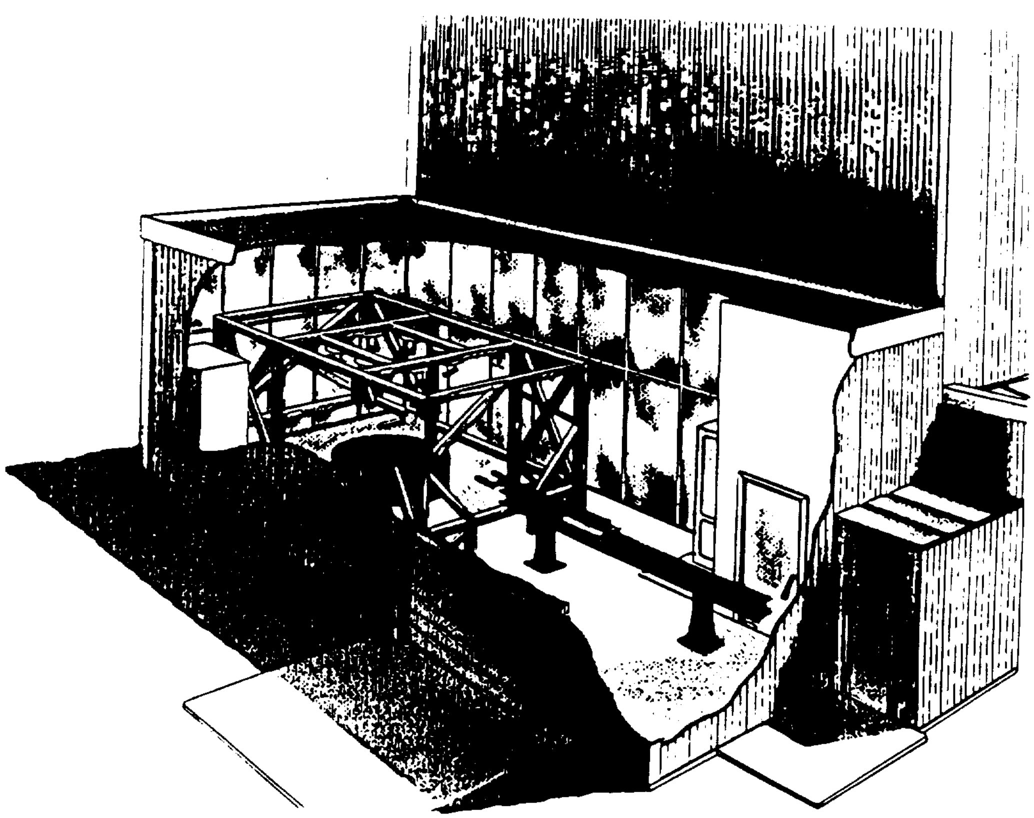
  Develop optical processing for implementing control



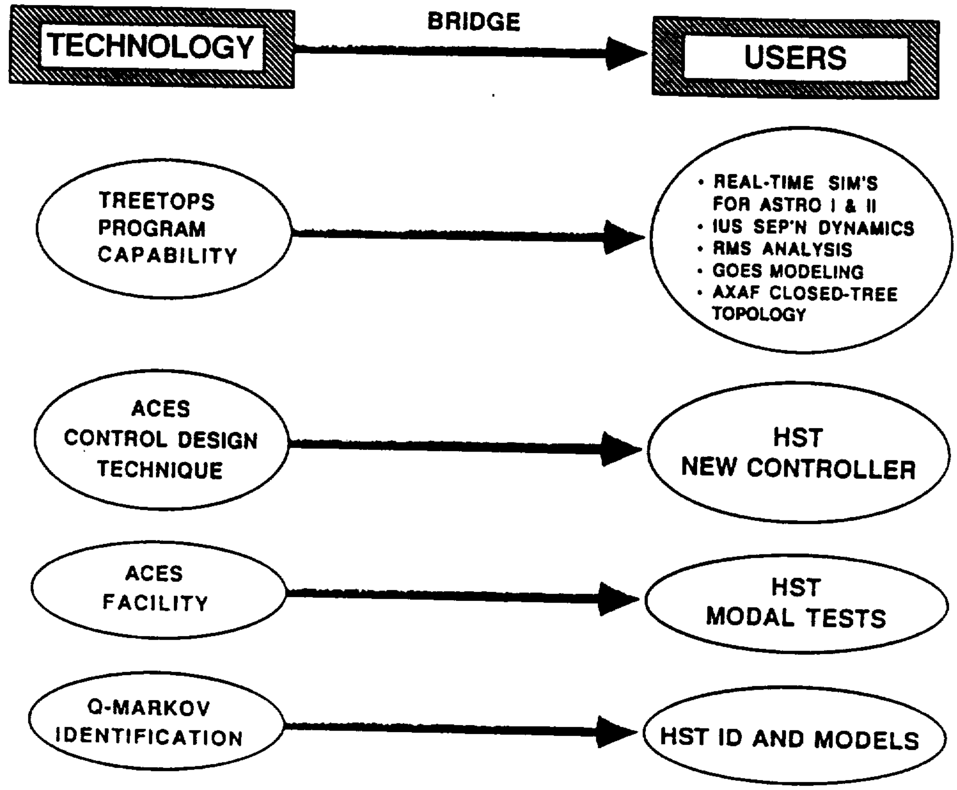








BRIDGING 506 RTOP TECHNOLOGY TO THE USER COMMUNITY



NC/OC Pointing Performance Comparison Based on March 30 SAGA Test Data

	EON		EOD		DAY		NIGHT	
	NC	OC	NC	OC	NC	OC	NC	OC
GYRO HOLD	21.0 18.3 11.1	33.0	31.1 24.2 15.3 10.5	77.3 24.3 28.5	5.9(53)	13.0(42)	4.1(29) 3.1(27) 9.4(15)	7.6(29)
FINE LOCK	12.8	29.3	ND	ND	6.4(39)	11.3(45)	ND	7.5(4)
COARSE TRACK	9.9	26.1	ND	ND	6.4(21)	9.4(42)	5.0(4)	12.5(4)

ND - No Data, ( ) Duration of the Measurement in Minutes
All Numbers are RMS pointing errors in milli-arcseconds (RSS of V2 & V3)
EON - END OF NIGHT, EOD - END OF DAY
OC - ORIGINAL CONTROLLER (LOCKHEED)
NC - NEW CONTROLLER (DC CONTROL TECHNOLOGY FROM 506 RTOP)

ACES III

PROGRAM ELEMENTS

- H-INFINITY CONTROLLER DESIGN AND IMPLEMENTATION BY OHIO UNIVERSITY INVESTIGATOR DR. DENNIS IRWIN

- ONE-CAT CONTROLLER IMPLEMENTATION BY CONTROL DYNAMICS COMPANY -- WORK COMPLETED AND FULLY REPORTED IN PREVIOUS PRESENTATIONS

- ADDITION OF THE BIDIRECTIONAL LINEAR THRUSTERS AND THE ROLL TORQUE MOTORS TO THE ACES FACILITY

  ... THIS WORK PREEMPTED BY THE USE OF THE FACILITY FOR THE...

- GUEST INVESTIGATOR PROGRAM

H-INFINITY CONTROLLER DESIGN, IMPLEMENTATION, & TEST

- GOAL: DESIGN AND IMPLEMENT AN H-INFINITY CONTROLLER DESIGN ON THE ACES FACILITY AND TEST IT FOR ROBUSTNESS AND PERFORMANCE

- H-INFINITY DESIGN WAS PERFORMED; HOWEVER, THE PERFORMANCE WAS POOR BECAUSE OF THE REQUIREMENT FOR AN EXTREMELY RELIABLE SYSTEM MODEL

  → MODEL OF SUFFICIENT FIDELITY IS NOT AVAILABLE FOR ACES

- EFFORT REFOCUSED ON REFINING MULTIVARIABLE MODELS (SYSTEM ID) AND ON PERFORMING CONTROLLER DESIGN USING EXPERIMENTAL FREQUENCY RESPONSE DATA

- INNOVATIVE MODELING TECHNIQUE HAS BEEN DEVELOPED FOR MULTI-INPUT MULTI-OUTPUT (MIMO) SYSTEMS

  - - DETERMINANTAL MODELING

  - - RESIDUE MATRIX IDENTIFICATION

TREETOPS ENHANCEMENT

GOAL: SIGNIFICANTLY UPGRADE TREETOPS CAPABILITY, EXPAND IT TO INCLUDE MODEL REDUCTION AND CONTROLLER DESIGN FUNCTIONS, AND INCREASE THE COMPUTATIONAL EFFICIENCY

PURPOSE: A USER-FRIENDLY ANALYSIS AND DESIGN TOOL IS NEEDED TO ANALYZE AND DEVELOP CONTROLLER METHODOLOGIES FOR COMPLEX MULTIBODY SYSTEMS

METHODOLOGY: ENHANCE THE TREETOPS CODE TO INCLUDE

- MODEL REDUCTION
- ORDER-N FORMULATION
- EQUILIBRIUM AND TRIM
- SENSITIVITY ANALYSIS
- INVERSE DYNAMICS
- SYMBOLIC REPRESENTATIONS
- THERMAL ANALYSIS
- SYSTEM IDENTIFICATION
- GRAPHICAL USER INTERFACE
- CONTROLLER DESIGN

TREETOPS

- THE TREETOPS SUITE OF PROGRAMS HAS BEEN USED EXTENSIVELY IN THE ANALYSIS OF SPACECRAFT AND STRUCTURES INCLUDING
  - EFFECTS OF THE MOBILE TRANSPORTER AND MOBILE SERVICE CENTER MOTION ON SPACE STATION ATTITUDE CONTROL
  - SHUTTLE DOCKING AND BERTHING TO SPACE STATION USING THE REMOTE MANIPULATOR SYSTEM
  - SIMULATIONS OF ASTRO I AND ASTRO II, AXAF, GOES, & IUS
- THERE ARE 47 UNIVERSITIES, CORPORATIONS, AND GOVERNMENT AGENCIES CURRENTLY USING TREETOPS
- TREETOPS HAS BEEN EXTENDED FOR PARALLELIZATION AND VECTORIZATION ON THE COMPUTATIONAL CONTROLS WORKSTATION DELIVERED TO JSC

A SIMULATION EXAMPLE WITH 11 BODIES, 85 FLEX DOF'S, 16 RIGID DOF'S, INTEGRATED CONTROLLERS, AND ORBITAL ENVIRONMENT SHOWED A RUN TIME REDUCTION FROM 18900 TO 225 MINUTES VIA VECTORIZATION.

CONTROL SYSTEM DESIGN ANALYSIS
CURRENT RESEARCH THRUSTS

- INteractive Controls Analysis (INCA) Program
- Windowed Observation of Relative Motion (WORM) Program
- Analysis and Simulation Tools for Engineering Controls (ASTEC)
- System Identification (FY90 Code RC)
- Robust Control of Flexible Structures (FY91 Code RC)

INCA OVERVIEW

- Comprehensive Control System Design Analysis Package
- Developed in Close Coordination with GSFC Controls Analysts
- For Large (100th Order) or Small Order Systems
- Runs on VAX Computers with VMS Operating System
- Version 3.13 Available Through COSMIC

WORM OVERVIEW

- 2 and 3 Dimensional Plotting Package
- INCA-derived Interface
- Used as Simulation and On-orbit Telemetry Output Device and as a Quick Means to Massage Data via Functional Relations
- Runs on VAX Computers with VMS Operating Systems
- Version 2.32 Available Through COSMIC

ASTEC OVERVIEW

- Multi-platform Control System Design, Analysis and Simulation Package
- Window/Mouse Environment
    - Microsoft Windows 3.0 for PC
    - Macintosh
    - X-Windows for Unix Systems
- Common Portable Math Library for all Versions
- C++ Programming Language
- INCA-based Algorithms

MULTIBODY APPLICATION TECHNOLOGY

Biomechanics	Inverse Dynamics Rolling/Sliding Joints Generalized Joint Constraints
Molecular Dynamics	Non-linear Stability Very Large Order Problems (100-500 DOF's) Clustering Concepts Generalized Bodies Massively Distributed Sensors/Actuators
Automotive	Real-time Man-in-the-Loop (50Hz goal) Real-time Hardware-in-the-Loop Visualization of Dynamic Systems Parallel Processing Load Apportionment
Human Factors	Man/Machine Interaction Dynamics & Performance
Robotics	Intermittant Loop Closure with Impact Inertial Contact through Seating Geared Joints
Spacecraft	Modal SynthesisMethods for Noncollacation Problems Discos callable by INCA for Nonlinear Simulation Recursive Linearization for Multibody Systems Discos Provided Linear Plant Model for INCA

JPL

ADVANCED GN&C ARCHITECTURE CONCEPTS

OBJECTIVE:

DEVELOP NEW GN&C SYSTEM ARCHITECTURES TO ENABLE GREATER ON-BOARD AUTONOMOUS ROBUST CONTROL, STABILITY AND PERFORMANCE

APPROACH:

- ADAPTIVE CONTROL FOR ROBUST STABILITY/PERFORMANCE OF SPACECRAFT OPERATING UNDER RAPID CHANGING CONFIGURATION OR ENVIRONMENT CONDITIONS
- IN-SPACE SYSTEM IDENTIFICATION FOR AUTONOMOUS ROBUST CONTROL SYSTEM SELF-TUNING AND SYSTEM AND/OR ENVIRONMENT CHARACTERIZATION
- REAL-TIME G&C ARCHITECTURE FOR ACCURATE FLIGHT PATH CONTROL OF AEROMANEUVERING VEHICLES FOR ORBIT CAPTURE AND LANDING APPLICATIONS
- EXPERIMENTALLY EVALUATE NEW CONTROL METHODOLOGIES AND DEMONSTRATE THEM AT A LEVEL OF MATURITY FOR FLIGHT APPLICATIONS

JPL

STABILIZATION & IDENTIFICATION

APPLICATION:

IN-SPACE SYSTEM IDENTIFICATION AND CONTROL TUNING TO ENABLE **RELIABLE PRECISE STABILIZATION** OF FUTURE SPACECRAFT

- MULTI-INSTRUMENT PLATFORMS
- LARGE ANTENNAS
- MULTI-APERTURE REFLECTORS
- INTERFEROMETER OBSERVATORIES

DESCRIPTION OF EFFORT:

ADVANCES NEW IN-SPACE ID TECHNOLOGY THROUGH

- CONCEPTUAL INNOVATIONS
- THEORETICAL DEVELOPMENT
- COMPUTER SIMULATION/VERIFICATION
- PHYSICAL GROUND EXPERIMENTS
- APPLICATION METHODS AND SOFTWARE DELIVERABLES
- FLIGHT EXPERIMENTS

JPL

STABILIZATION & IDENTIFICATION

PLANNED DEVELOPMENTS (FY'91-95)

- DEVELOP **REDUCED VARIANCE SPECTRAL ESTIMATION** OF THE PLANT TRANSFER FUNCTION
- DEVELOP THE ROBUSTNESS TO SYSTEM **NOISE AND UNMODELED PLANT DYNAMICS**
- DEVELOP THE **CAPABILITY TO HANDLE LARGE DATA SETS**
- **EXTEND** THE CAPABILITY OF THE NEW ID METHODS **TO LARGER MULTIVARIABLE SYSTEMS**
- DEVELOP THE **FIRST GENERATION** APPLICATION METHODS AND SOFTWARE TOOLS FOR **MULTIVARIABLE ID/ROBUST CONTROL**
- DESIGN, BUILD AND DEMONSTRATE A PROOF-OF-CONCEPT **NEURAL NET MIMO ID/ROBUST CONTROLLER**

JPL ADAPTIVE POINTING AND TRACKING CONTROL

APPLICATION:

ADAPTIVE CONTROLLERS ARE NEEDED FOR THE NEXT GENERATION SPACE SYSTEMS WHICH HAVE ANY OR ALL OF THE FOLLOWING ATTRIBUTES:

- HAVE SIGNIFICANT TIME-VARYING MASS PROPERTIES AND CHANGING DISTURBANCE ENVIRONMENT
- CANNOT BE TESTED FULLY ON THE GROUND DUE TO LOGISTIC CONSTRAINTS
- FLEXIBLE MODES AND/OR NON-COLLOCATED ACTUATOR/SENSOR CONFIGURATIONS
- UNCERTAINTIES DUE TO LARGE ANGLE ARTICULATION, FAST SLEW OR OTHER NONLINEAR EFFECTS

JPL ADAPTIVE POINTING AND TRACKING CONTROL

DESCRIPTION OF EFFORT:

DEVELOP ON-BOARD STABLE MULTIVARIABLE ADAPTIVE REGULATION AND TRACKING SYSTEM (SMARTS) CAPABILITY WHICH CAN CONTROL SPACECRAFT WITH

- VERY HIGH ORDER OF STATE VARIABLES (E.G. 100'S)
- MANY SENSORS AND ACTUATORS
- UNCERTAIN AND/OR CHANGING SPACECRAFT DYNAMICS, ENVIRONMENT AND MISSION SCENARIOS

SMARTS I: FOR SPACECRAFT WITH COLLOCATED SENSORS AND ACTUATORS

SMARTS II: FOR SPACECRAFT WITH SENSORS AND ACTUATORS THAT CANNOT BE COLLOCATED

SMARTS III: NEURAL BASED WITH LEARNING CAPABILITY

TASK 1. CONTROL OF SPACECRAFT

- ADVANCED CONTROL THEORY
  - DEVELOPMENT OF ROBUST CONTROL SYSTEM DESIGN TECHNIQUES FOR DISTURBANCE REJECTION IN FLEXIBLE SPACE STRUCTURES
  - DEVELOPMENT OF ADAPTIVE SYSTEM IDENTIFICATION AND CONTROL TECHNIQUES BASED ON ARTIFICIAL NEURAL NETWORKS.

- ADAPTIVE CONTROL
  - TESTING OF STATE SPACE SELF TUNING ADAPTIVE CONTROL ON SPACE STATION ATTITUDE CONTROL SIMULATOR

REVIEW OF CONTROLS TECHNOLOGY PROGRAM

Johnson Space Center - Houston, Texas

NAVIGATION, CONTROL, AND AERONAUTICS DIVISION

JOHN W. SUNKEL | MAY 29, 1991

- INFLIGHT EVALUATION OF THE STRUCTURAL INTEGRITY OF SPACECRAFT
  - DEMONSTRATE FREQUENCY BASED LOCALIZATION TO SUPPORT STRUCTURAL HEALTH MONITORING OF FLEXIBLE SPACECRAFT.

- ADVANCED RCS LOGIC FOR FLEXIBLE MULTI-BODY SPACE VEHICLES
  - DEVELOP ADVANCED RCS LOGIC FOR FLEXIBLE MULTI-BODY SPACECRAFT INCLUDING SPACE STATION DURING ORBITER BERTHING
  - DEVELOP NEW RCS PHASE PLANE LOGIC TO ACCOMMODATE SIGNIFICANT STRUCTURAL MODE INTERACTION

Hardware:

- The front end processor is a Silicon Graphics machine.
- The high speed parallel processing unit uses 4 Intel 860 boards.
- Intel 860 benchmark numbers:

	SUN 68020	Data General 88000	SUN Sparc	Silicon Graphics R3000/3010	Intel 80860
(1)	1.0	11.7	8.6	18.5	47.1
(2)	1.0	4.5	5.4	18.0	55.5

(1) Inversion of a 100x100 matrix

(2) Two-body dynamics simulation (approximately 10.8 MFLOPS)

Johnson Space Center- Houston, Texas

REVIEW OF CONTROLS TECHNOLOGY PROGRAM

NAVIGATION, CONTROL, AND AERONAUTICS DIVISION

JOHN W. SUNKEL | MAY 29, 1991

Performance:

- Space Station Example is for the assemble complete configuration that includes the following:
  - 11 flexible bodies with flex modes up to 5Hz for 11 independently articulating flexible body configuration
  - Total of 101 system degrees of freedom (85 flex and 16 rigid) including core body (9 modes), 2 Alpha booms (6 modes), and 8 solar panels (8 modes each)
  - SSF PDR RCS and CMG controllers running at 5 Hz
  - Joint controllers for the solar panels
  - Complete orbital environment

- Flex body data obtained from NASTRAN for each body.

- Space Station dynamics simulated for one orbit (90 min) with the RCS control system in the attitude hold mode

- Computational performance (all times in min)

SSCOMP	SGI	SUN-4	VAX-8850
90	675	2025	235

REVIEW OF CONTROLS TECHNOLOGY PROGRAM

Johnson Space Center- Houston, Texas

NAVIGATION, CONTROL, AND AERONAUTICS DIVISION

JOHN W. SUNKEL | MAY 29, 1991

- Current ongoing and future work involves

  - Upgrading the parallel controller

  - Completing the model database

  - Developing and completing the interface to IGES graphics

  - Enhancing the user interface as well as the simulation capabilities

Overview

Knowledge-based Control Technologies

- Adds enhanced robustness to RT fault management and control
- Provides graceful system degradation in fault-detected environment with minimum compromise to safety and reliability
- Provides automated monitoring of vehicle health and system status including trend analysis
- Integrates symbolic knowledge with numeric (algorithmic) knowledge

Elements of knowledge-based systems control technologies:

- **Fault Diagnosis & Planning** - - > Symbolic or model-based controllers
- **Neural Nets & Fuzzy Control** - - > Advanced Adaptive (Learning) Controls
- **Model-based Reasoning** - - > "Smart" Structures & Optimal Adaptive Controls

Fuzzy Logic Control

Automatic Train Control

- Has been in successful application since July 1987 in Sendai, Japan
- Uses rules of the form,

If speed of the train exceeds the speed limit,

Then the maximum brake notch is selected -

Space Shuttle attitude control

- Under study at NASA JSC and NASA Ames, preliminary results show significant fuel savings over the conventional On-orbit digital autopilot
- Uses rules of the form,

If attitude error is Negative Medium and attitude rate error is Negative Small,

Then Acceleration (converted to Jet on / off command) is Negative Small

SUMMARY

- COMPREHENSIVE, DIVERSIFIED RESEARCH PROGRAM
- OBJECTIVES AIMED AT RELEVANT NATIONAL GOALS
- SIGNIFICANT MILESTONES/PROGRESS BEING ACHIEVED
- RESOURCES LIMITING PACE OF ACHIEVEMENTS

OVERVIEW OF JPL ACTIVITIES IN TRANSPORTATION GUIDANCE, NAVIGATION, AND CONTROL

LINCOLN J. WOOD

29 MAY 1991

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

PROGRAM ELEMENTS TO BE DISCUSSED

AEROMANEUVERING GUIDANCE, NAVIGATION, AND CONTROL (506-46-1 AND 506-46-2)

PATHFINDER/ETP AEROBRAKING GN&C (591-42-3 AND 593-11-3)

PATHFINDER/ETP AUTONOMOUS LANDING (591-13-1 AND 591-13-2)

PATHFINDER/ETP AUTONOMOUS RENDEZVOUS AND DOCKING (591-21-2)

FY89/90 PRODUCTS - SUMMARY

- ONBOARD, REAL-TIME GUIDANCE AND CONTROL ALGORITHMS
  - SEVERAL NEW GUIDANCE ALGORITHMS FOR AEROASSISTED ORBIT TRANSFER, INCLUDING SIMPLE, NEAR-OPTIMAL SCHEMES
  - PERTURBATION GUIDANCE ALGORITHMS WITH BOUNDED CONTROL
  - RE-ENTRY VEHICLE MODELING
  - ADAPTIVE AND NONADAPTIVE CONTROL ALGORITHM DEVELOPMENT
- GUIDANCE AND NAVIGATION ALGORITHMS FOR AEROMANEUVERING ENTRY TO LANDING
- MARS APPROACH NAVIGATION ACCURACY ASSESSMENT
- CHARACTERISTICS OF OPTIMAL AEROASSISTED TRAJECTORIES
  - MINIMUM-FUEL PROPULSIVE AND AEROASSISTED TRANSFERS BETWEEN ARBITRARY ELLIPTICAL ORBITS
  - OPTIMAL AEROMANEUVERING PLANE CHANGE TRAJECTORIES USING MULTIPLE ATMOSPHERIC PASSES
  - MAXIMUM AEROMANEUVERING ORBIT PLANE CHANGES SUBJECT TO HEATING RATE CONSTRAINT
  - COMPARISON OF COST FUNCTIONS FOR AEROMANEUVERING TRAJECTORY OPTIMIZATION PROBLEMS

LJW-2

PARTICIPANTS DURING FY89 AND FY90

- JPL
  - LINCOLN J. WOOD - TASK LEADER
  - WILLIAM M. McENEANEY/ALEX S. KONOPLIV/VIJAY ALWAR - GUIDANCE AND NAVIGATION
  - DHEMETRIOS BOUSSALIS/ASIF AHMED/DON WANG - CONTROL SYSTEMS
- UNIVERSITY OF MICHIGAN - PROFESSOR NGUYEN X. VINH (TRAJECTORY OPTIMIZATION)
- UNIVERSITY OF TEXAS AT AUSTIN - PROFESSORS DAVID G. HULL AND JASON L. SPEYER (GUIDANCE)
- RICE UNIVERSITY - PROFESSOR ANGELO MIELE (TRAJECTORY OPTIMIZATION AND GUIDANCE)

FY89 PRODUCTS: JPL IN-HOUSE - GUIDANCE AND NAVIGATION (506-46-2)

- O THREE NEW GUIDANCE ALGORITHMS DEVELOPED FOR AEROASSISTED ORBITAL TRANSFER
  - O BASED ON APPROXIMATE SOLUTION OF OPTIMAL CONTROL PROBLEM - LOH'S TERM ASSUMED DEPENDENT ON INDEPENDENT VARIABLE ONLY
  - O APPLICABLE TO BOTH COPLANAR AND NON-COPLANAR ORBIT TRANSFERS
  - O TWO ALGORITHMS MAXIMIZE EXIT SPEED FOR FIXED HEADING ANGLE, ALTITUDE, AND FLIGHT PATH ANGLE AT EXIT - MOST USEFUL FOR PRE-FLIGHT TRAJECTORY OPTIMIZATION
  - O THIRD ALGORITHM MINIMIZES CONTROL EFFORT FOR FIXED VELOCITY, HEADING ANGLE, ALTITUDE, AND FLIGHT PATH ANGLE AT EXIT
    - O INTENDED FOR ONBOARD, REAL-TIME GUIDANCE
    - O SIMPLE ENOUGH TO BE IMPLEMENTED ONBOARD
    - O PERFORMED WELL IN PRESENCE OF ATMOSPHERIC MODELING ERRORS IN PRELIMINARY TESTS

- O THREE UNIVERSITY CONTRACTS MONITORED

LJW-4

FY89 PRODUCTS: JPL IN-HOUSE - CONTROL SYSTEMS (506-46-1)

- O ADAPTIVE AND NONADAPTIVE CONTROL LAWS EVALUATED
  - O FOR COPLANAR SKIP TRAJECTORY
  - O USING BANK MODULATION FOR LIFT VECTOR CONTROL
  - O USING AERODYNAMIC FORCES AS WELL AS THRUSTERS FOR ROLL CONTROL

- O SIMULATION SOFTWARE EXPANDED TO INCLUDE OUT-OF-PLANE DYNAMICS
  - O FOR CONTROL LAW EXPANSION TO INCLUDE BOTH ROLL AND PITCH AXIS CONTROL

- O STUDY ON LEARNING AND DECISION-MAKING MODEL FOR HIGHER-LEVEL ADAPTATION COMPLETED
  - O METHODS TO COPE WITH GREATER RANGE OF UNCERTAINTY AND UNMODELED CHANGES, ESPECIALLY IN AUTONOMOUS OPERATIONS

FY90 PRODUCTS: JPL IN-HOUSE - CONTROL SYSTEMS (506-46-1)

RE-ENTRY VEHICLE MODELING

- 0 DEVELOPED DYNAMIC AND KINEMATIC EQUATIONS OF MOTION FOR USE IN DESIGN AND ANALYSIS OF CONTROL ALGORITHMS AND DEVELOPMENT OF SIMULATION TOOLS
- 0 DERIVED AERODYNAMIC COEFFICIENTS AND STABILITY DERIVATIVES FOR BICONIC AEROSHELL
- 0 DEVELOPED AEROMANEUVERING CONTROLS SIMULATION PROGRAM

CONTROL ALGORITHM DEVELOPMENT

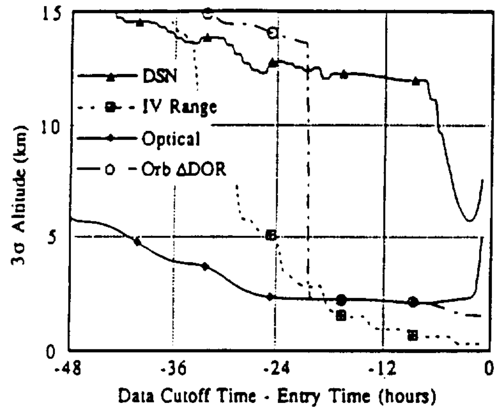
- 0 CONDUCTED OPEN-LOOP SIMULATIONS TO EVALUATE VEHICLE AERODYNAMIC PERFORMANCE AND STABILITY CHARACTERISTICS
- 0 CONDUCTED PRELIMINARY INVESTIGATION OF EFFECT OF LONGITUDINAL NORMAL MODES OF OSCILLATION ON HYPERSONIC VEHICLE PERFORMANCE
- 0 EXTENDED PLANAR CONTROL LAWS TO 3-D VEHICLE DYNAMICS AND CONTROL
- 0 DEVELOPED CONTROL LAW FOR SUPPRESSION OF DOMINANT SHORT-PERIOD NORMAL MODE OF OSCILLATION
- 0 QUALITATIVELY DEMONSTRATED PITCH OSCILLATION SUPPRESSION VIA SIMULATION

LJW-7

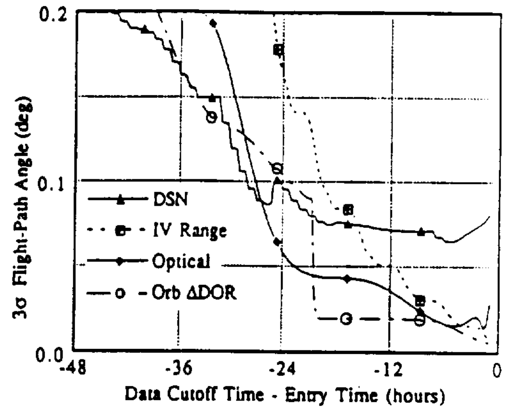
FY89/90 PRODUCTS: JPL IN-HOUSE - MARS APPROACH NAVIGATION (591-42-3)

- 0 ACCURACY OF APPROACH NAVIGATION HAS MAJOR IMPACT ON ABILITY TO PERFORM AEROCAPTURE AT MARS
- 0 ESTIMATES MADE OF TRAJECTORY KNOWLEDGE ACCURACY AT ENTRY INTERFACE, ASSUMING VARIOUS DATA TYPES (FUNDED JOINTLY WITH JPL's EXPLORATION INITIATIVE STUDIES OFFICE - CODES SL AND RZ)
  - 0 EARTH-BASED RADIO METRIC DATA ONLY (DOPPLER, RANGE, AND DELTA-DOR AT ANTICIPATED ACCURACY LEVELS OF LATE 1990s)
  - 0 EARTH-BASED PLUS VEHICLE-TO-VEHICLE RADIO METRIC DATA (MARS ORBITER IN EITHER 1/5-SOL OR AREOSYNCHRONOUS ORBIT)
  - 0 EARTH-BASED RADIO DATA PLUS ONBOARD OPTICAL DATA (IMAGES OF DEIMOS AND PHOBOS)
  - 0 EARTH-BASED TRACKING OF BOTH APPROACH VEHICLE AND MARS ORBITER
- 0 REPRESENTATIVE ACCURACY REQUIREMENTS AT NOMINAL ENTRY TIME (L/D = 0.7, V-INFINITY = 3.4 KM/S, 500-KM CIRCULAR TARGET ORBIT)
  - 0 40 KM IN ALTITUDE
  - 0 0.5 DEG IN FLIGHT PATH ANGLE

LJW-9



Summary for Altitude Error



Summary for FPA Error

FY91 PLANS

- O CONTINUE DEVELOPMENT OF ONBOARD, REAL-TIME, NEAR-OPTIMAL GUIDANCE ALGORITHMS AND TEST WITH REALISTIC ERROR MODELS
- O EXTEND AEROCAPTURE GUIDANCE AND NAVIGATION S/W TO INCLUDE NAVIGATED STATE AS WELL AS REAL STATE FOR EVALUATING GUIDANCE ALGORITHM PERFORMANCE
- O PLANETARY APPROACH NAVIGATION AND GUIDANCE
  - O CONTINUE WORK IN PROGRESS WITH IMPROVED ERROR MODELING AND FURTHER VARIATION OF KEY PARAMETERS
  - O PERFORM PRELIMINARY ASSESSMENT OF RELATIVE MERITS OF VARIOUS DATA TYPES
- O COMPLETE UNIVERSITY RESEARCH
  - O DETERMINATION OF CHARACTERISTICS OF OPTIMAL AEROASSISTED TRAJECTORIES
  - O DEVELOPMENT OF GUIDANCE ALGORITHMS

PLANS FOR FY92 AND BEYOND (593-11-3)

FY92	IDENTIFY CANDIDATE GUIDANCE/ATMOSPHERIC SENSOR ARCHITECTURES
FY93	DEFINE NAVIGATION TECHNOLOGY
FY94	PERFORM CONCEPTUAL DEMONSTRATION OF GUIDANCE/NAVIGATION SYSTEM
FY96	BEGIN TESTBED VALIDATION OF LUNAR RETURN GN&C SYSTEM
FY97	DEFINE GN&C FOR FLIGHT TEST
FY98	BEGIN TESTBED VALIDATION OF GN&C SYSTEM FOR MARS

TASKS TO BE PERFORMED JOINTLY WITH LaRC

LJW-13

GSFC JPL LaRC
JSC MSFC

A NASA PROGRAM AUGMENTATION:
COMPUTATIONAL CONTROL

G. K. MAN

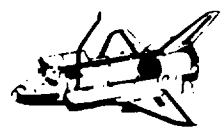
BRIEFING TO SSTAC - 6/27/91

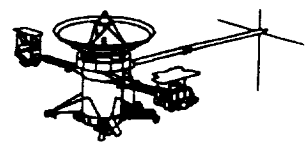
AGENDA

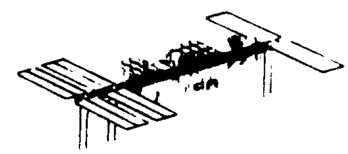
- OBJECTIVE
- MOTIVATION
- CURRENT LIMITS
- NASA TOOL DEVELOPMENT EXPERTISE
- TECHNICAL APPROACH
- RECENT ACCOMPLISHMENTS
- FOREIGN CAPABILITIES
- TECHNOLOGY TRANSFER
- PLAN
- SUMMARY

USERS

- COMPUTATIONAL CONTROL IS UPGRADING INFRASTRUCTURE TOOLS NEEDED FOR DESIGN AND PERFORMANCE TESTING OF <u>ALL</u> MAJOR CURRENT AND FUTURE NASA MISSIONS
- NEW TOOLS WILL PROVIDE RISK REDUCTION AND PRODUCTIVITY ENCHANCEMENT TO ALL FLIGHT SYSTEMS







CRAF/CASSINI
MARS OBSERVER
SIRTF

EXPLORATION TRANSPORTATION SPACE SCIENCE SPACESTATION

INTRODUCTION

OBJECTIVE

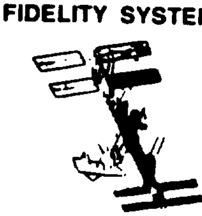
TO DEVELOP A NEW GENERATION OF ARTICULATED MULTIBODY MODELING, CONTROL DESIGN AND SIMULATION ALGORITHMS, AND PROTOTYPE SOFTWARE TOOLS FOR SPACECRAFT AND ROBOTS

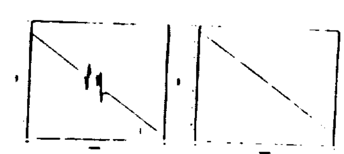
- FOR DESIGN, FUNCTIONAL AND PERFORMANCE TESTING
- TO HANDLE HIGH FIDELITY MODELS (>100 STATES)
- TO REDUCE MISSION RISK AND ENCHANCE PRODUCTIVITY

MOTIVATION

CURRENT TOOLS SEVERELY LIMIT COMPREHENSIVE CONTROL DESIGN AND VERIFICATION AND ARE INADEQUATE FOR FUTURE NEEDS

- CANNOT HANDLE HIGH FIDELITY SYSTEM
- EXCESSIVE RUN TIME
- NOT USER FRIENDLY



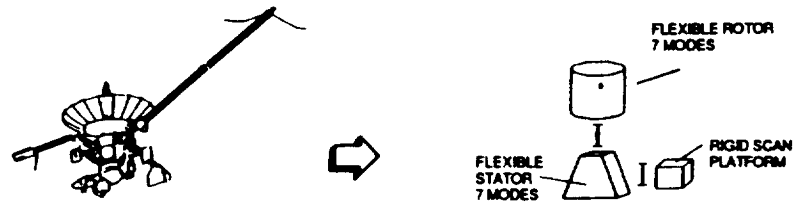


40 STATES

60 STATES
TOOL BREAKS DOWN

LIMITATION OF CURRENT TOOLS - GALILEO CASE STUDY

GALILEO SCAN PLATFORM POINTING CONTROL EXAMPLE



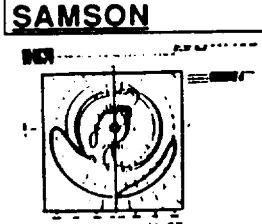
SPACECRAFT CONFIGURATION — HIGHLY SIMPLIFIED MODEL (20 DOF)

- CRAY X-MP CANNOT SIMULATE HIGHLY SIMPLIFIED GALILEO MODEL IN REAL-TIME (FALLS SHORT BY A FACTOR OF 10)
- CURRENT SIMULATION TECHNOLOGY LIMITS NASA'S ABILITY TO VERIFY SPACECRAFT DESIGN (REAL-TIME HARDWARE-IN-THE-LOOP TESTING IS LIMITED TO HIGHLY SIMPLIFIED RIGID BODY SIMULATIONS)
- NEED FOR NEW INFRASTRUCTURE TOOLS HAS REACHED A CRITICAL POINT. NEW TOOLS ARE NECESSARY TO SUPPORT CURRENT AND FUTURE AGENCY MISSIONS.

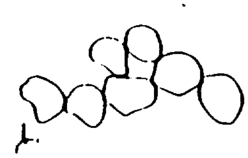
SPACECRAFT COMPUTATIONAL CONTROL TOOL DEVELOPMENT EXPERTISE

___ NASA TECHNICAL CONTRIBUTIONS

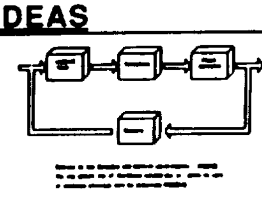
CONTROL DESIGN & ANALYSIS	MULTIBODY SIMULATION	COMPUTER AIDED ENGINEERING SHELL
CONTROL C	MBODY	CASCADE
INCA	DISCOS	IAC
$MATRIX_X$	TREETOPS	ISM
SAMSON	SDEXACT	IDEAS



INCA



DISCOS



CASCADE

TECHNICAL APPROACH

- SPATIAL RECURSION ALGORITHMS (FACTOR OF N INCREASE IN SPEED)
- PARALLEL COMPUTING (SPEED INCREASE ~ # OF PROCESSORS)
- SYMBOLIC MANIPULATION (> FACTOR 5 IMPROVEMENT IN SPEED)
- OBJECT-ORIENTED ENVIRONMENT FOR NEW ALGORITHM DEVELOPMENT & IMPLEMENTATION
- PROBLEM-SPECIFIC ALGORITHMS AND SOFTWARE TO PROVIDE GOOD NUMERICAL CONDITIONING & COMPUTATIONAL EFFICIENCY
- STATE-OF-ART SOFTWARE & HARDWARE (E.G. LAPACK)

KEY PRODUCTS

REAL-TIME SIMULATION SYSTEM FOR SPACECRAFT HARDWARE-IN-THE-LOOP TESTING

INTEGRATED ANALYSIS & SIMULATION WORK-STATION

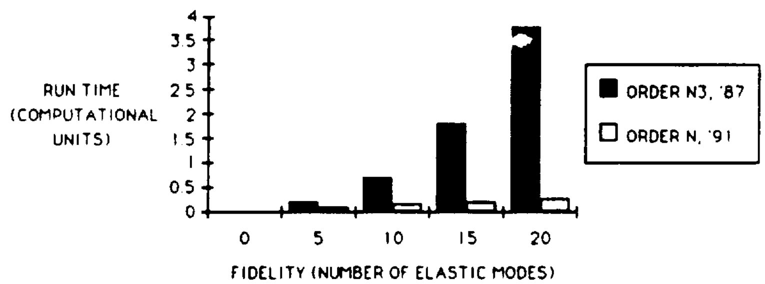
MODERN CONTROL DESIGN & ANALYSIS SOFTWARE

SELECTED RECENT ACCOMPLISHMENTS

- GSFC HAS ENHANCED DISCOS BY REPLACING THE ORDER N^3 ENGINE BY AN ORDER N ENGINE FOR RIGID AND ELASTIC SYSTEMS. THE UPGRADED DISCOS IS UNDER BETA TESTING.
- JPL HAS DEVELOPED NEW HIGHLY EFFICIENT DYNAMICS ALGORITHMS FOR REAL-TIME SIMULATION (DARTS), BASED ON SPATIAL OPERATOR ALGEBRA, FOR SPECIALIZED COMPUTER ARCHITECTURES (E.G. PARALLEL COMPUTERS). CRAF/CASSINI HAS ADOPTED THIS NEW ALGORITHM FOR THE DEVELOPMENT OF A REAL-TIME SIMULATION CAPABILITY FOR SPACECRAFT TESTING.
- JSC AND LaRC HAVE DEVELOPED A NEW SPACE STATION COMPUTATIONAL CONTROL WORKSTATION (SSCOMP) FOR CONTROL DESIGN, ANALYSIS AND SIMULATION. THE SIMULATION CAPABILITY IS 120 TIMES FASTER THAN 1987 TECHNOLOGY FOR A 140 STATES SPACE STATION.
- MSFC HAS UPGRADED TREETOPS WITH A NEW ORDER N ALGORITHM. THE NEW CODE IS BEING USED BY JSC FOR THE SHUTTLE RMS.

IMPROVEMENT IN TECHNOLOGY FROM 1987

DEVELOPMENT OF ORDER N MULTIBODY SIMULATION CAPABILITY



NEW/EMERGING CAPABILITIES

- ORDER-N DISCOS
- √ DARTS
- √ SSCOMP
- ORDER-N TREETOPS

FEATURES OF THE DARTS ALGORITHM

GENERAL EQUATIONS OF MOTION FOR A SPACECRAFT:

$$M(q)\ddot{q}+C(q,\dot{q})=T$$

CONVENTIONAL ALGORITHM

- REQUIRE ORDER N^3 COMPUTATION
- COMPUTE THE MASS MATRIX M
- COMPUTE THE CORIOLIS AND CENTRIFUGAL FORCES C
- SOLVE THE LINEAR EQUATION

  $M\ddot{q}=T\text{-}C$ FOR $\ddot{q}$

DARTS ALGORITHM

- REQUIRE ORDER N COMPUTATION
- DOES NOT REQUIRE M, OR C OR SOLVING THE LINEAR EQUATION
- BASED UPON A SPATIAL OPERATOR EXPRESSION FOR M^{-1}
- RECURSIVELY COMPUTE $\ddot{q}$

THE DARTS ALGORITHM

- REDUCES COMPUTATIONAL TIME (FROM CUBIC TO LINEAR COMPUTATIONAL COMPLEXITY)
- IS HIGHLY PARALLELIZABLE
- IS RECURSIVE AND MODULAR RESULTING IN REDUCED SOFTWARE COSTS

ARCHITECTURE OF THE DARTS ALGORITHM

EXTERNAL AND ACTUATOR FORCES

↓

1. RECURSION FROM EACH APPENDAGE TOWARDS BUS ONE AT A TIME

↓ *EFFECTIVE FORCES ON THE BUS*

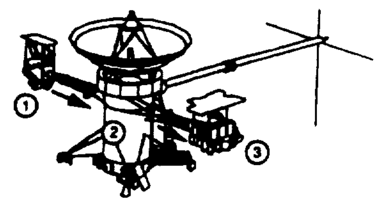
2. COMPUTE BUS ARTICULATED INERTIA

↓ *BUS ACCELERATION*

3. RECURSION FROM BUS TOWARDS EACH OF THE APPENDAGES

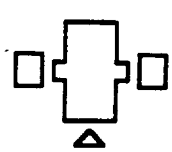
↓

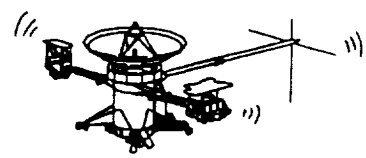
MODAL AND HINGE ACCELERATIONS $\ddot{q}$



CRAF/CASSINI APPLICATION

REDUCES RUN TIME & HANDLES HIGH FIDELITY IN REAL-TIME





- LIMITED TO 4 RIGID BODIES

CONVENTIONAL ALGORITHM

- 8-BODY SPACECRAFT
- FLEXIBLE BUS, BOOMS & ANTENNA
- PROPELLANT SLOSH FOR 3 TANKS

DARTS ALGORITHM

- NEW CAPABILITY INCLUDES IMPORTANT AND DIFFICULT TO MODEL EFFECTS SUCH AS PROPELLANT SLOSH AND SPACECRAFT FLEXIBILITY (PREVIOUSLY UNABLE TO INCORPORATE) FOR SPACECRAFT TESTING
- ALLOWS ANSWERING THE SAME DESIGN QUESTION IN LESS THAN 1/10 OF THE TIME
- A LARGE INCREASE IN MODEL FIDELITY IS OBTAINED WITH ONLY A SMALL INCREASE IN RUN TIME (THE RATE OF INCREASE OF RUNTIME IS REDUCED BY AN ORDER OF MAGNITUDE)

FEATURES OF SSCOMP

- THE PROTOTYPE SSCOMP IS AN INTEGRATED SELF-CONTAINED CAD PLATFORM FOR SPACE STATION G,N & C ANALYSIS
  - ORDER-N ALGORITHM FOR FLEXIBLE MULTI-BODIES SPACECRAFT
  - SYMBOLIC CODE GENERATOR
  - OBJECT ORIENTED INTERFACE
  - 3-D SOLID MODELING FOR ANIMATION
  - SILICON GRAPHICS COMPUTER WITH 4 I-860 BOARDS

- COMPUTATIONAL PERFORMANCE FOR ONE (90 MIN) ORBIT SIMULATION WITH RCS CONTROL SYSTEM IN ATTITUDE HOLD MODE (101 DEGREES OF FREEDOM)

SSCOMP	SGI	SUN-4	VAX-8850
90(MIN)	675	2024	235

- SIGNIFICANCE
  THIS HIGH PERFORMANCE (A ORDER OF MAGNITUDE INCREASE IN SPEED) WORKSTATION IS THE MODEL FOR A FUTURE CONTROL ANALYSIS AND SIMULATION PLATFORM

FOREIGN CAPABILITY ISSUES

MAJOR FOREIGN MULTIBODY CAD PROGRAMS

NUBEMN-	GERMANY	SYM-	YUGOSLAVIA
NEWEUL-	GERMANY	SPACAR-	NETHERLANDS
MEDYNA-	GERMANY	AUTODYN-	BELGIUM
MESA VERDE-	GERMANY	PLEXUS-	FRANCE
DECAP-	ITALY	DAPHNE-	JAPAN

EMPHASIS - AUTOMOBILS, TRAINS, HELICOPTERS, SPORTS, ROBOTS, SPACECRAFT

- FOREIGN TECHNOLOGIES ARE ADVANCING AT A RAPID PACE:
  - EUROPEANS ARE BUILDING POWERFUL TOOLS BASED ON U.S. TECHNOLOGY
  - JAPAN IS ENTERING THE FIELD IN THE LAST 2 YEARS WITH AMBITIOUS GOALS

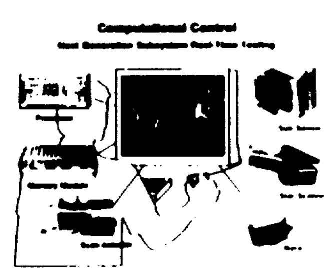
- U.S. IS UNIQUELY QUALIFIED TO MAINTAIN THE LEADERSHIP ON <u>HIGH PERFORMANCE COMPUTING AND SIMULATIONS</u> BY BUILDING ON OUR NEW HARDWARE AND SOFTWARE TECHNOLOGIES

TECHNOLOGY TRANSFER

- MULTIAGENCY, UNIVERSITY AND INDUSTRY WORKING AND ADVISORY COMMITTEE TO FACILITATE COMMUNICATION
- EARLY RELEASE OF TECHNOLOGY TO U.S. INDUSTRY
- UNIVERSITY OF IOWA/NSF VERIFICATION LIBRARY FOR REQUIREMENTS AND BENCHMARK PROBLEMS
- ANNUAL TECHNOLOGY TRANSFER WORKSHOP/ CONFERENCE TO DESEMINATE RESEARCH FINDINGS

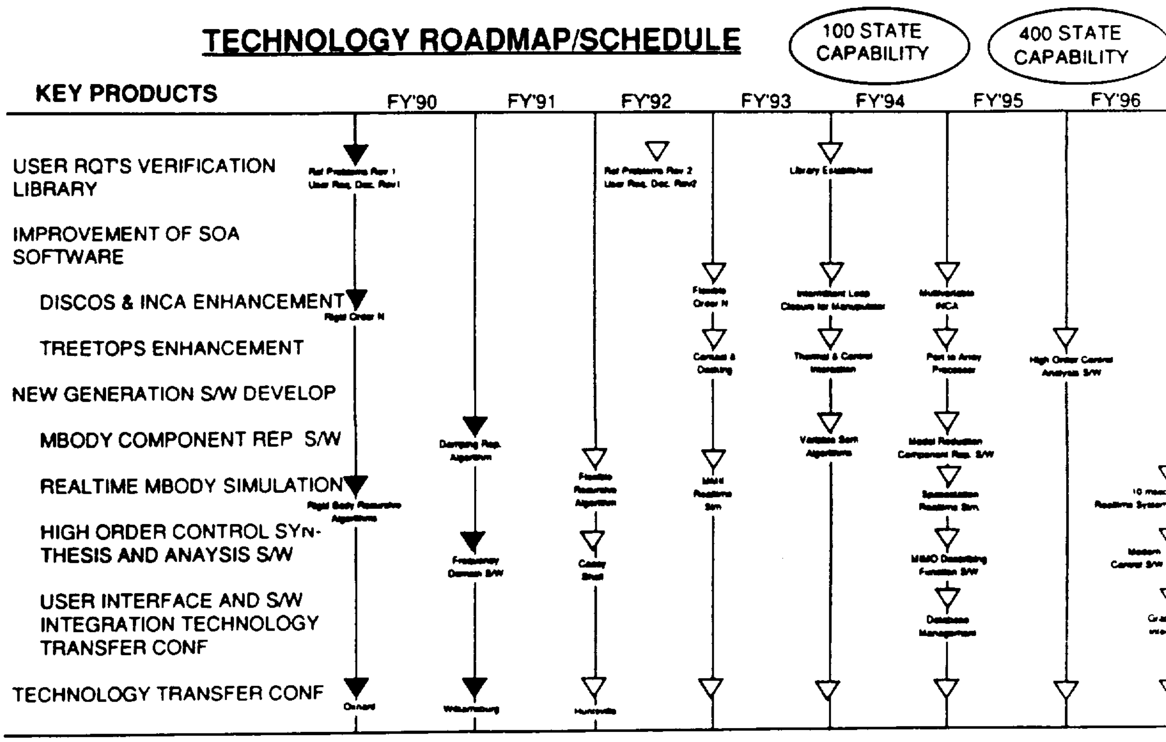
PERFORMANCE OBJECTIVE & RESOURCE

KEY PARAMETERS	PERFORMANCE OBJECTIVES		
• APPROXIMATE NEED DATE	1991	1994	1996
•SYSTEM FIDELITY FOR CONTROL DESIGN (# OF STATES)	10	100	400
•RUN-TIME FOR REALTIME HARDWARE-IN-THE-LOOP TESTING OF A 150 STATES SYSTEM (MSEC)	100	10	<10
•USER FRIENDLINESS (TIME TO SETUP A 100 STATES SIMULATION)	DAYS	HOURS	MINUTES



FUNDING REQUIREMENT FOR ALL CENTERS ($K)	FY92	FY93	FY94	FY95	FY96
	3600	3600	3600	3600	3600

LONG RANGE PLAN



SUMMARY

- NEED FOR NEW GENERATION TOOLS HAS HIT CRITICAL LEVEL
- NASA UNIQUELY QUALIFIED TO LEAD DEVELOPMENT OF NEW TOOL
- NASA HAS MADE SIGNIFICANT TECHNICAL PROGRESS IN KEY AREAS
  - FAST ALGORITHMS FOR HARDWARE-IN-THE-LOOP SIMULATION
  - NEW ANALYSIS WORKSTATION
- PRELIMINARY PROGRAM PLAN DEFINED
- NASA READY FOR PROGRAM START NOW

Fiberoptic Rotation Sensors (FORS) : Technology Development and Transfer

Presentation to the Space Science Technology Advisory Committee

Tysons Corner, Virginia
June 27, 1991

Randy Bartman
Optoelectronic Sensor Systems and Technology Group
Guidance and Control Section (343)
JPL

Overview

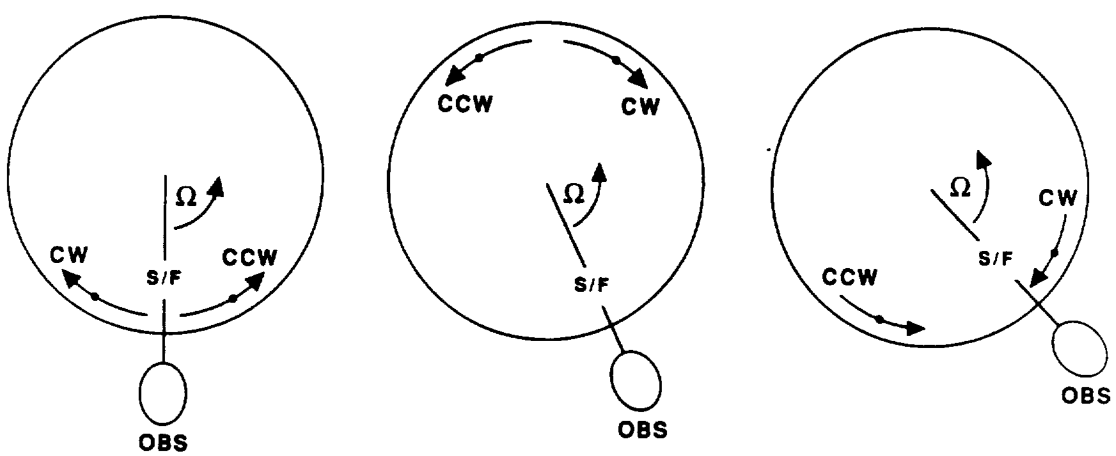
- Background Material
  - What is FORS?
  - Why are we pursuing it?
  - Brief history of FORS development
- FORS Engineering Model Development and Technology Transfer
  - Goal / Objectives / Assumptions
  - Schedule / Resources
  - Responsibilities
- Summary

What is FORS?

- All solid state optical gyro, based on the Sagnac effect
- Unique (NASA patent #4,662,751) optical processing technique is used to convert gyro rotation rate into an optical beat frequency
  - Angular position is read by counting beats
- Implemented through the use of
  - Integrated optical circuits (AT&T Bell Labs, UTP)
  - Polarization-maintaining, low loss optical fiber
  - Semiconductor optical source, detectors operating at a wavelength of 1.3 μm

  Note: Much of this technology is being developed by and for the telecommunications industry

FORS Principle of Operation - The Sagnac Effect



Two light beams (CW and CCW) start at the same time but race in opposite directions around a waveguide.

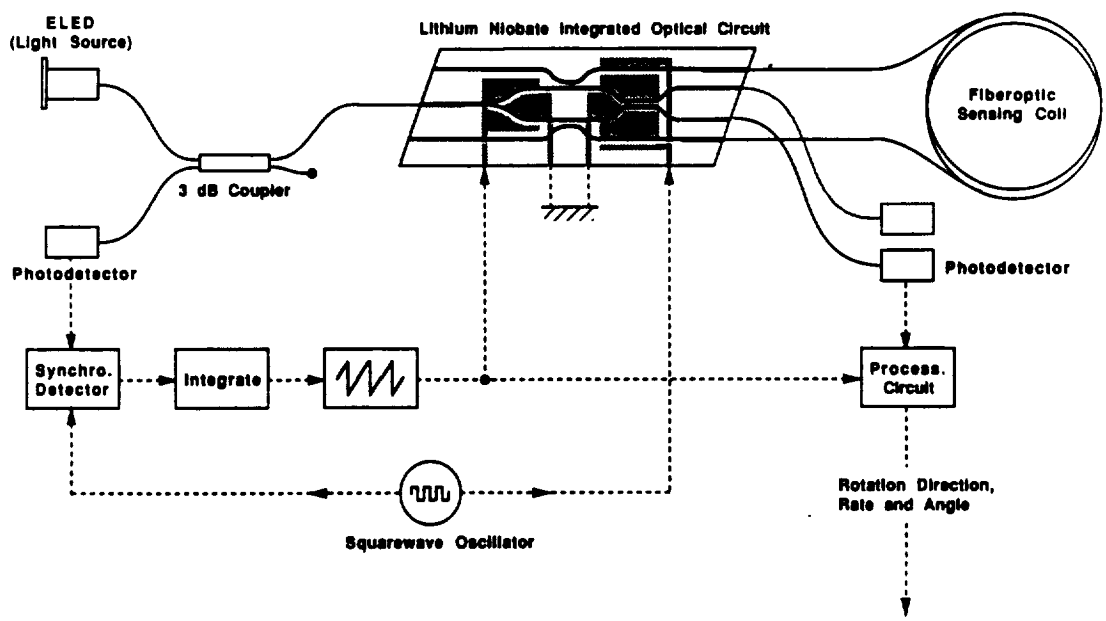
As the physical waveguide rotates, the attached "observer" (OBS) and the "start / finish line" (S/F) rotate with it ...

... Giving an "unfair advantage" to CW in the race for S/F: although it travels no faster than CCW, CW arrives at S/F first because of S/F's rotation.

This "unfair advantage" manifests itself as a relative or "non-reciprocal" phase shift, Φ_s , between the CW and CCW beams. Suppose CW and CCW are light beams of wavelength λ and the waveguide is an optical fiber of length L wound on a spool of diameter D: then Φ_s is given by

$$\Phi_s = 2\pi \frac{LD}{\lambda c} \Omega$$

Fiberoptic Rotation Sensor Schematic



Why FORS ?

- Navigational grade performance with improved lifetime, power, mass, cost, availability, flexibility
- All solidstate strapdown rotation sensor
  - No moving parts
  - Modular construction
- Optoelectronic technology →
  - Leverage telecommunications industry investments
  - Non-obsolescent
  - Potentially expanded vendor base

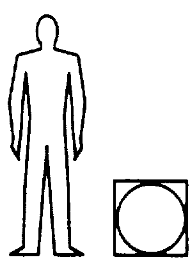
Inertial Sensors Comparison
DRIRU II vs. FORS

- **Characteristics**

	DRIRU II	FORS (equiv. perf.)
• Long term drift	0.003 deg/hr	< 0.003 deg/hr (goal)
• Max. input rate	< 4 deg/s	> 100 deg/s
• Operational life	4 - 5 years	≥ 12 years
• Mass	17 kg	< 10 kg
• Power (low rate)	15 W	< 10 W
• Power (high rate)	23 W	< 10 W
• Unit cost	$ 2.1- $ 3.5 M	$ 1.3 M

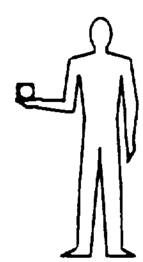
- **Advantages of FORS and their implications**
  - **Greater lifetime:** Allows extended (continuous) gyro operation during mission. This simplifies mission planning and/or increases operational flexibility.
  - **Reduced mass:** Reduced launch cost (7 kg x $ 100 K/kg) and/or increased science payload
  - **Reduced power:** Reduced power system cost (13 W x $ 80 K/W) and/or more power available for science payload
  - **Lower unit cost:** Reduced by $ 0.8 M - $ 2.2 M / IRU

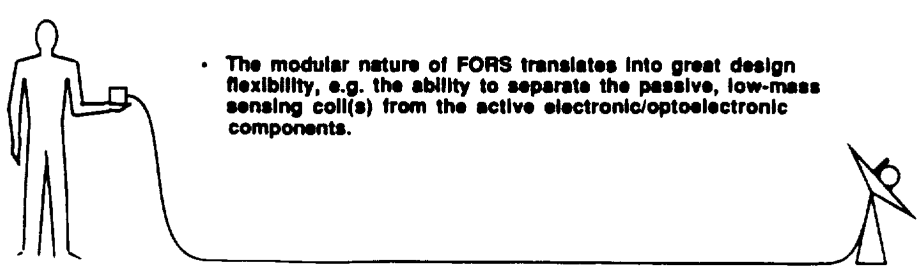
FORS Scaling and Design Flexibility



- Increasing the diameter of the coil and/or the length of fiber wound on it provides a straightforward means of improving FORS performance
- Take
  - Coil diameter D = 50 cm,
  - Fiber length L = 10 km,
  - Wavelength λ = 1.3 μm, and
  - "NEPS" ϕ = 1E -7 rad ;
- Then
  - "NERR" → Ω = 0.00025 deg/hr

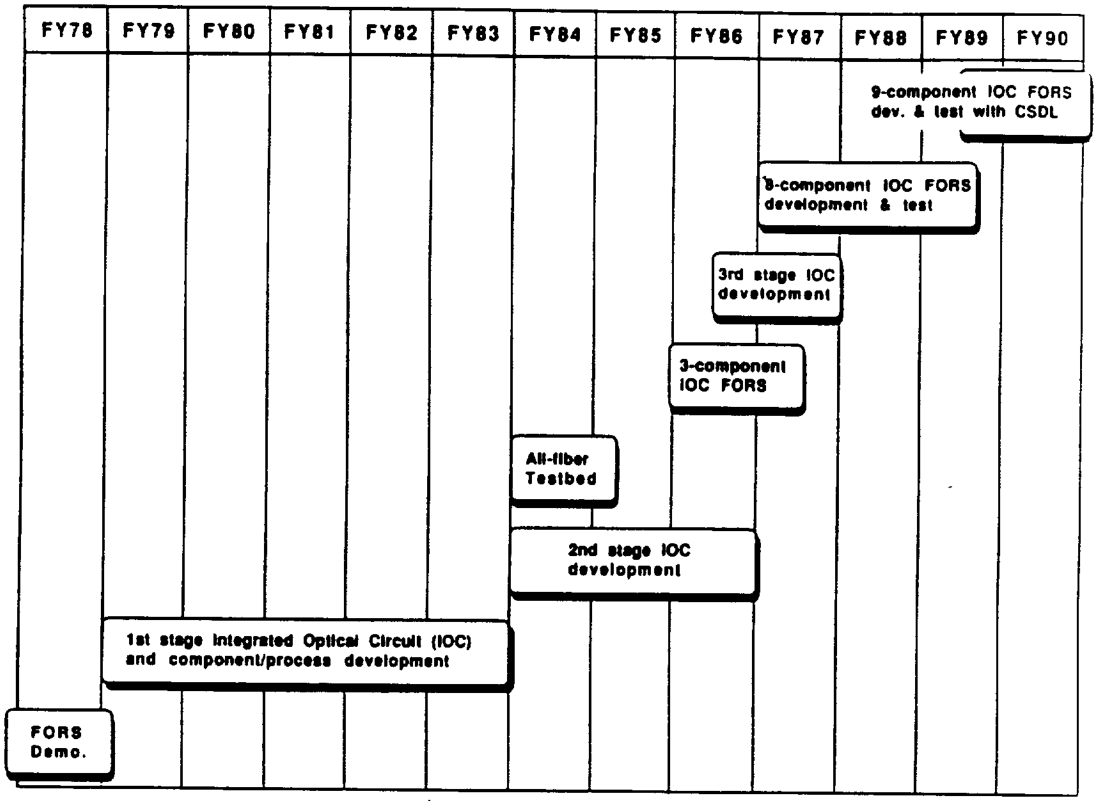
- Conversely, FORS performance can be traded for reduced size, mass and/or cost
- Take
  - Coil diameter D = 8 cm,
  - Fiber length L = 1 km,
  - Wavelength λ = 1.3 μm, and
  - "NEPS" ϕ = 1E -6 rad ;
- Then
  - "NERR" → Ω = 0.16 deg/hr





- The modular nature of FORS translates into great design flexibility, e.g. the ability to separate the passive, low-mass sensing coil(s) from the active electronic/optoelectronic components.

FORS Development - FY78 to FY90

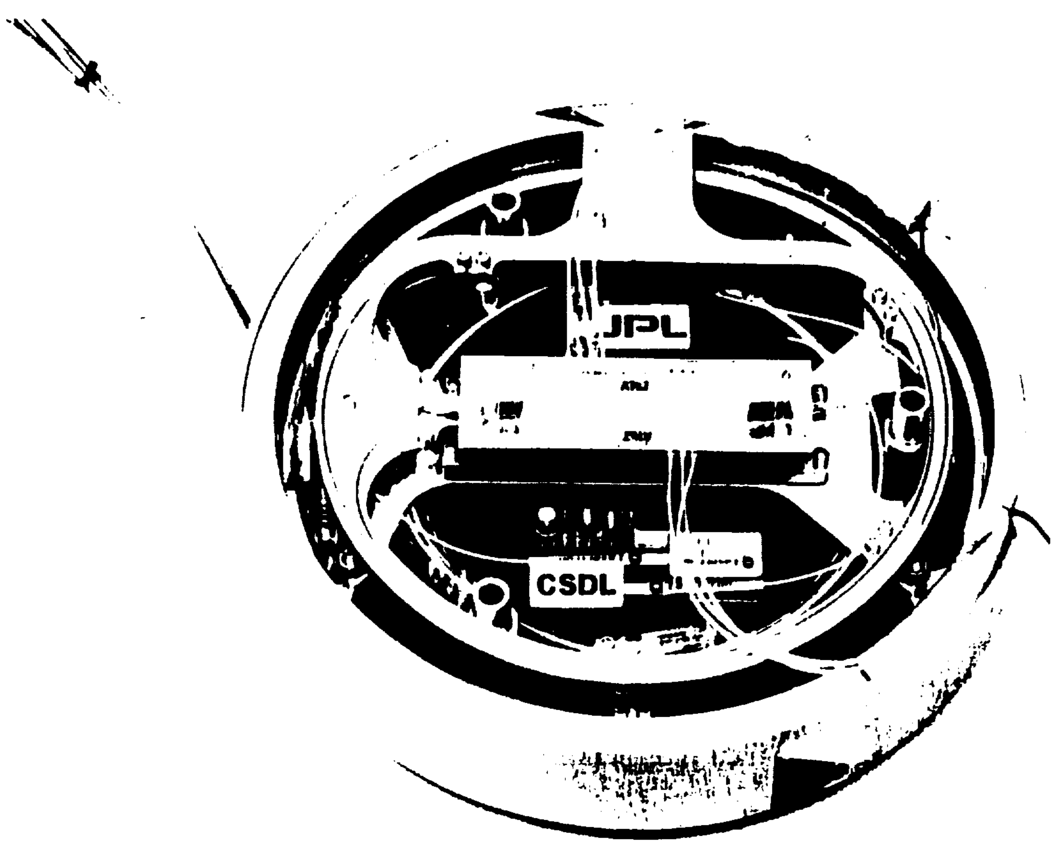


JPL / CSDL Cooperative Development Effort

- MOU / MOA between JPL and Charles Stark Draper Laboratory for cooperative development of JPL's FORS technology
  - Goal 1: Demonstrate FORS technology readiness for use on CRAF/Cassini
  - Goal 2: Develop and build first FORS EM and flight units
  - Goal 3: Transfer FORS technology to American industry

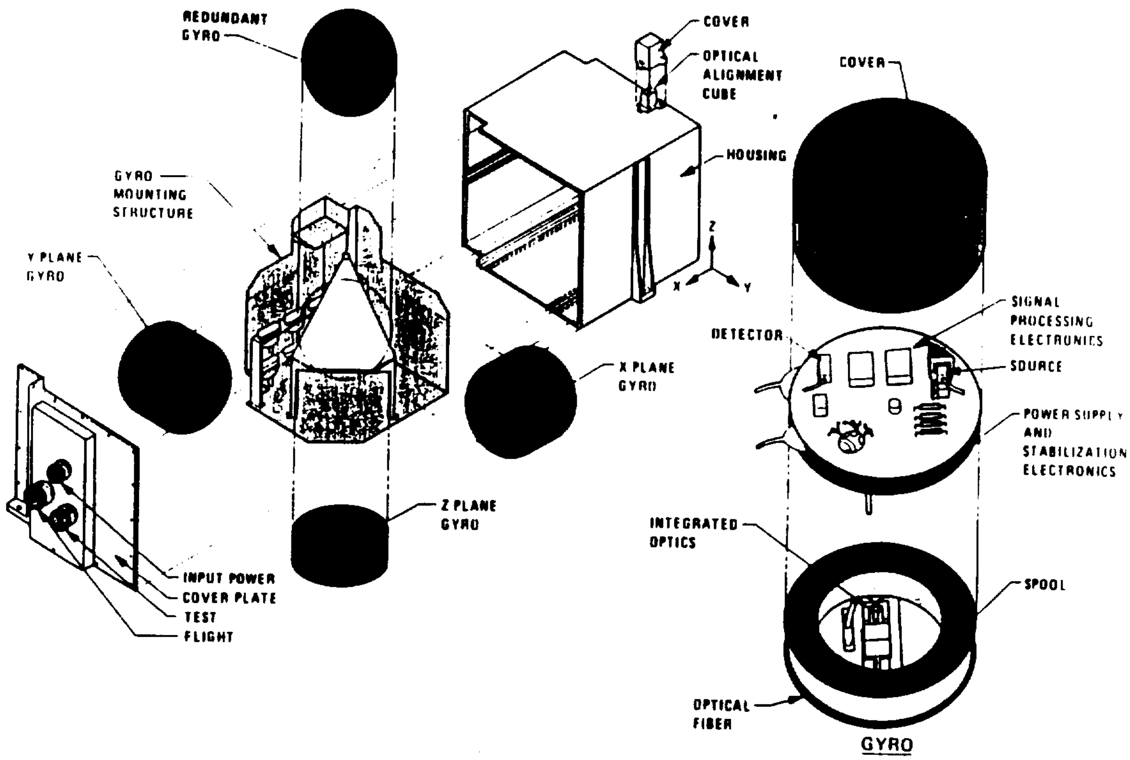
Key JPL/CSDL Accomplishments 1989 - 1991

- MOU / MOA between JPL / CSDL signed (8/89)
- JPL FORS technology transfer to CSDL
- Design, fabrication of 3 FORS brassboards
- Static & dynamic tests of brassboards
- IRU design / packaging studies initiated
- Successful FORS Technology Readiness Review (9/90)
- Additional funding commitments from Codes Q&R (~2/91)
- Preliminary review of FORS EM Development Plan (5/91)



JPL

NASA-JPL HIGH PERFORMANCE INERTIAL REFERENCE UNIT (FORS)



FORS: Demonstrated "nav-grade" performance

Time interval	Pointing error req.* (3σ)	Pointing error act. (3σ)
0.5 sec	2.3 μrad	0.15 μrad
100 sec	43 μrad	3.1 μrad
2 hours	0.5 mrad	0.5 mrad **

* CRAF / Cassini requirement

** Corresponds to rotation rate of 0.005°/hr

FORS Engineering Model Development Program

Goal

- Make available to NASA users a space-qualifiable Fiberoptic Rotation Sensor (FORS) Inertial Reference Unit (IRU)
- A FORS IRU will possess navigational grade performance and will offer significant advantages over current IRUs :
  - Improved lifetime
  - Lower power
  - Lower mass
  - Lower cost
  - Greater design flexibility

Objectives

- Develop, demonstrate engineering model* FORS four-axis IRU
  - Develop, demonstrate FORS single-axis EM
  - Develop, demonstrate flight-packaged, high reliability FORS optoelectronic components and interconnects
  - Fabricate additional single-axis FORS units
    - Conduct reliability, acceptance & long-term trend tests

- Transfer FORS technology to industry
  - Multi-vendor base

* **Engineering model:** Full flight functionality.
Capable of being environmentally tested to flight environments.
Same hardware, assembly techniques as flight hardware.
Flight or nearly flight form factor.

Assumptions

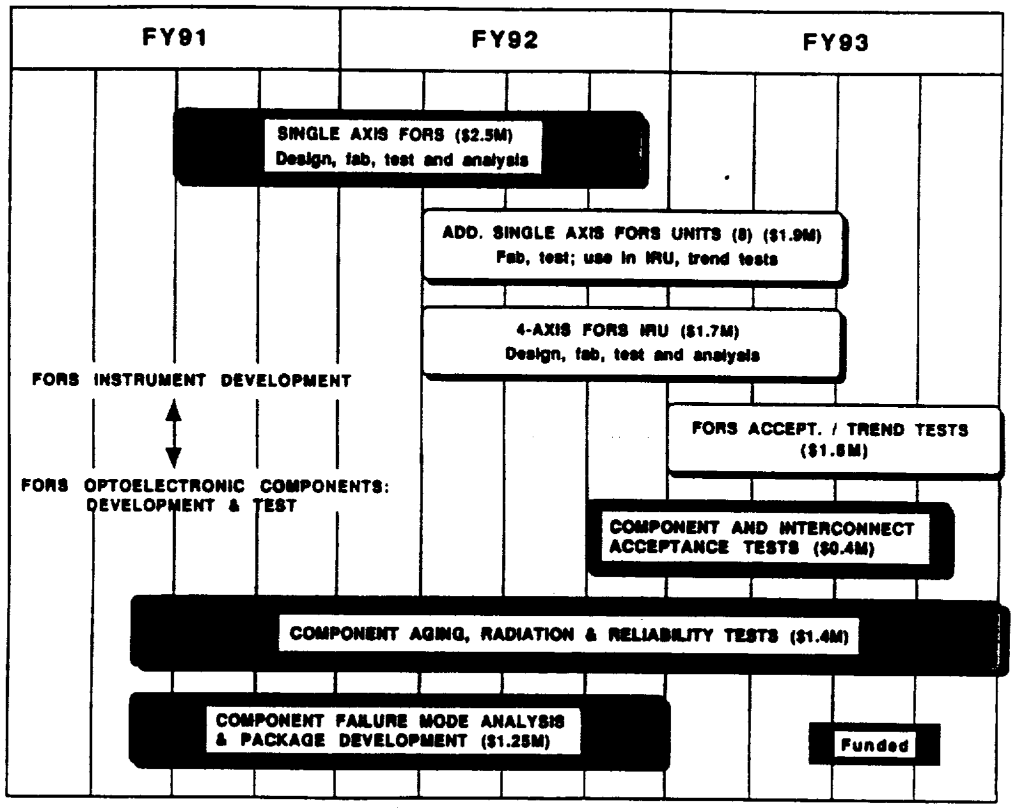
- Time frame
  - Four-axis IRU EM by end of FY93
  - Earliest users: AXAF, SIRTF, EOS, HST

- Funding
  - Total cost: $ 10.7 M over FY91-93
  - Expected sources: NASA Codes Q, R, S(?), CSDL CSR

- One integrated program with two major activity areas
  - FORS instrument development ("system design")
  - FORS optoelectronic component development

- Cooperative effort with industry: JPL-led, industry-performed
  - FORS instrument: JPL / Charles Stark Draper Lab
  - FORS components: JPL / vendors

FORS Engineering Model Development Program



FORS Engineering Model Development

Responsibilities Matrix

	JPL	CSDL	Vendors
FORS Instrument Development	• Overall management • Mission / IRU reqs. • Reliability / QA stds. • Environmental test • Full tech support	• Instrument design • Instrument fab • Functional test • Tech transfer • Tech / mgt. support	Indirect
FORS Optoelectronic Component Development	• Failure modes • Component reqs. • Reliability / QA stds. • Function / Env. tests • Tech support	• Component reqs. • Functional tests • Specific components Indirect	• Failure modes • Comp. p[illegible] develop. • Reliabil[illegible] QA stds. • Functio[illegible] Env. tests • Mgt. support

Summary

- Why FORS?
  - 0.01-0.001°/hr gyro for space applications
  - Reduced mass, power, cost and increased lifetime, reliability, design flexibility vs. spinning mass gyros
- Successful development program to date
  - Brassboards designed, fabricated and under test
  - Demonstrated 0.005°/hr performance
- Proceeding with development of Engineering Models
  - JPL-led, industry-performed
  - Single-axis FORS EM by end of FY92
- Model for technology transfer
  - Multi-code funding (Codes R,Q,S)
  - Joint effort with industry (CSDL, others)

PRECISION
INSTRUMENT & TELESCOPE
POINTING

OBSERVATION SYSTEMS PROGRAM AREA
OF THE
SPACE SCIENCE TECHNOLOGY PROGRAM

F. Hadaegh
F. Tolivar

Integrated Technology Plan for the Civil Space Program Review
Tysons Corner, Virginia, June 24-28, 1991

PRECISION INSTRUMENT & TELESCOPE POINTING

AGENDA

- TECHNOLOGY NEEDS
  - APPLICATION THRUSTS
  - INSTRUMENT POINTING
  - TELESCOPES AND INTERFEROMETERS
- INTEGRATED TECHNOLOGY DEVELOPMENT PLAN
  - CHALLENGES
  - APPROACH
  - DEVELOPMENT PROGRAM
  - SCHEDULE
- RECOMMENDATIONS

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TECHNOLOGY NEEDS

THE PRECISION INSTRUMENT & TELESCOPE POINTING PROGRAM WILL PROVIDE THE 1-2 ORDER-OF-MAGNITUDE INCREASE IN PRECISION POINTING CAPABILITY (IE, POINTING CONTROL, STABILITY, AND KNOWLEDGE) REQUIRED BY NUMEROUS OSSA FUTURE MISSIONS

- ASTROPHYSICS MISSION
  - Moderate Optical Interferometer (MOI)
  - Imaging Interferometer (II)
  - Next Generation Space Telescope (ST-NG)
  - Large Deployable Reflector (LDR)
  - Lunar Based Interferometers and Segmented Reflectors
- EARTH SCIENCE MISSIONS
  - Advanced LEO/GEO Instruments
- SOLAR SYSTEM EXPLORATION
  - Toward Other Planetary Systems (TOPS 1 & 2)

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APPLICATION THRUSTS

PRECISION INSTRUMENT & TELESCOPE POINTING

SCIENCE INSTRUMENT POINTING

- ADVANCED LEO/GEO EARTH OBSERVATIONS
- SOLAR SYSTEM EXPLORATION POINTING

TELESCOPE/ INTERFEROMETER POINTING

- ADVANCED ASTROPHYSICS MISSIONS
  - SPACE INTERFEROMETERS
  - NG-ST
  - SUBMM-IR (SMMM, LDR)

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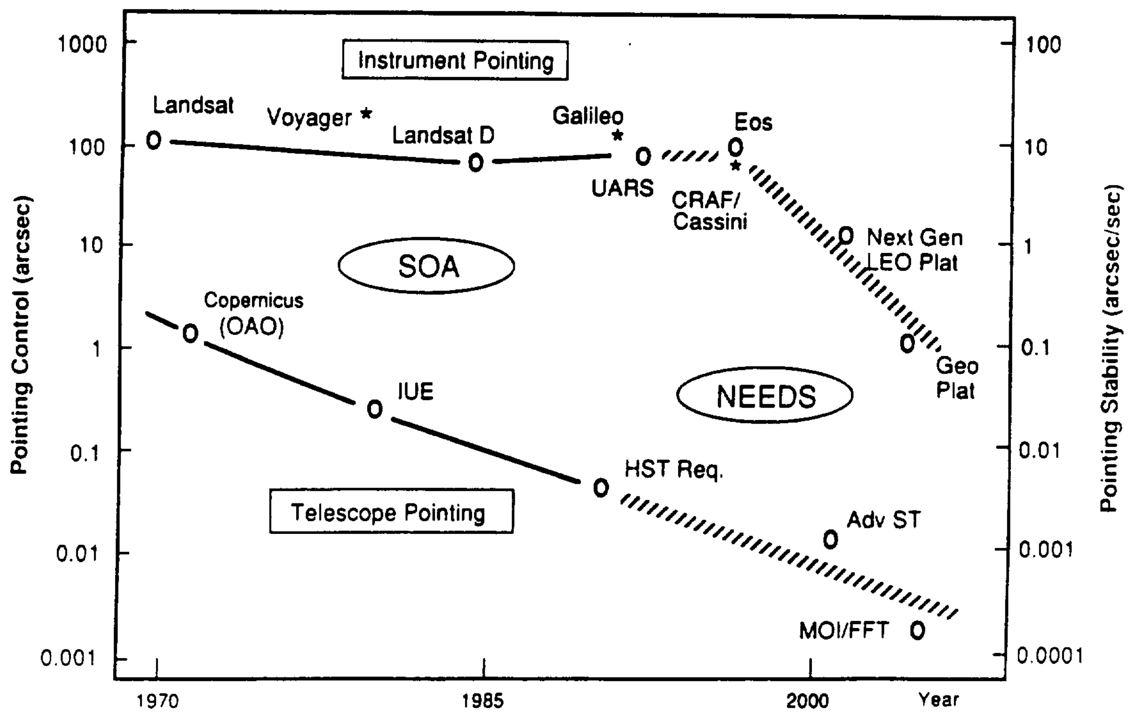
POINTING NEEDS vs SOA



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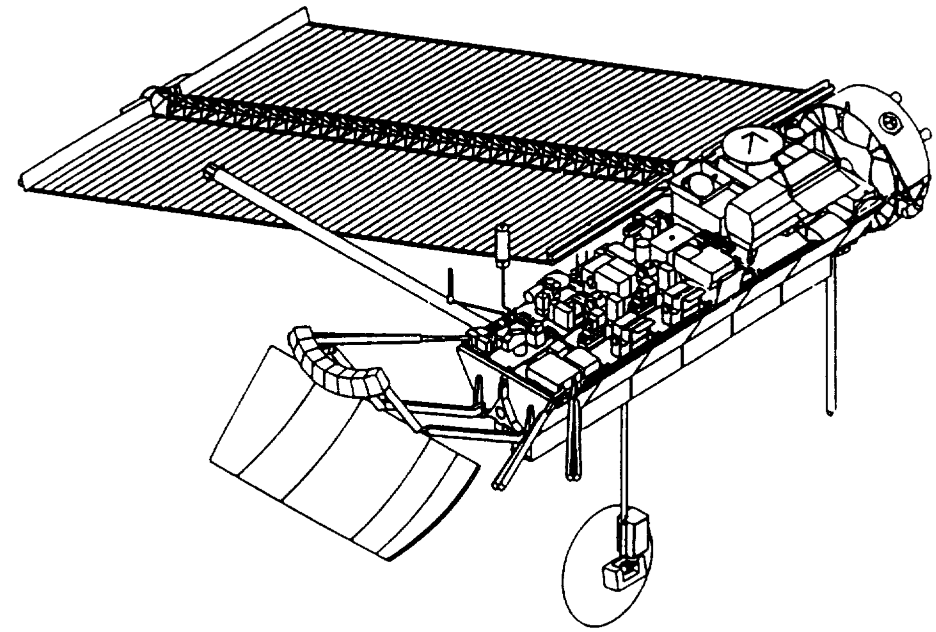
INSTRUMENT POINTING NEEDS

Eos POLAR ORBITING PLATFORM



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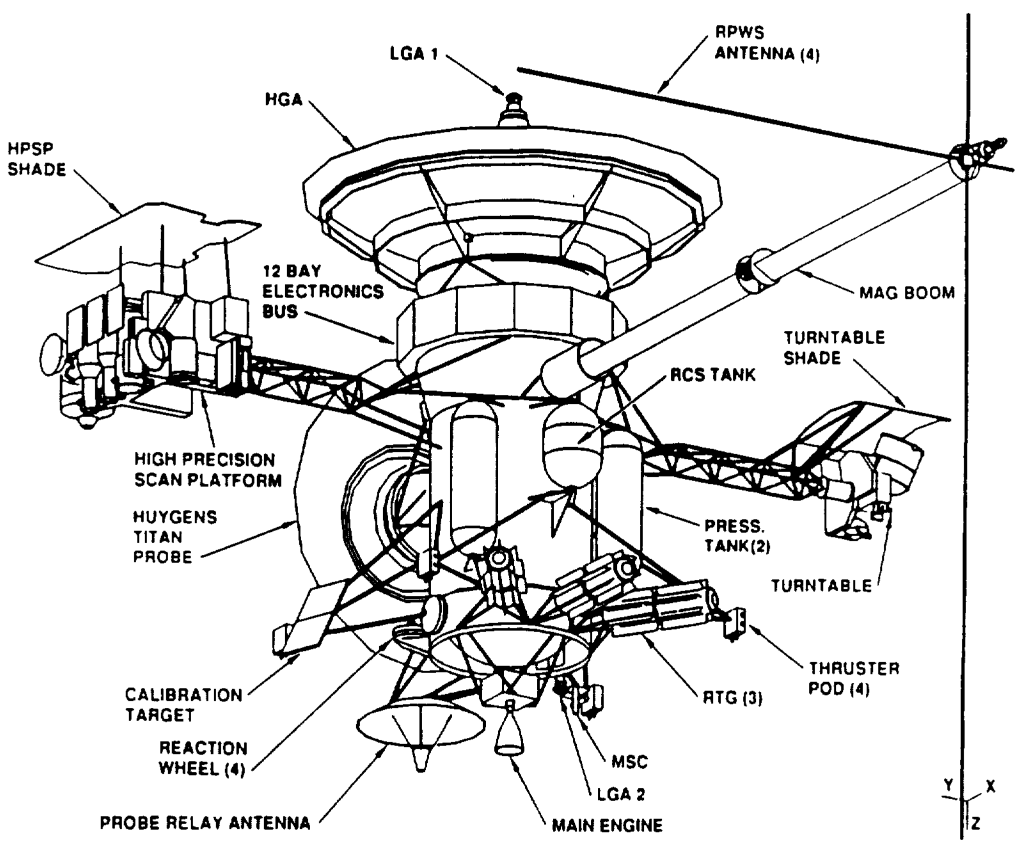


CASSINI DEPLOYED REAR TRIMETRIC VIEW

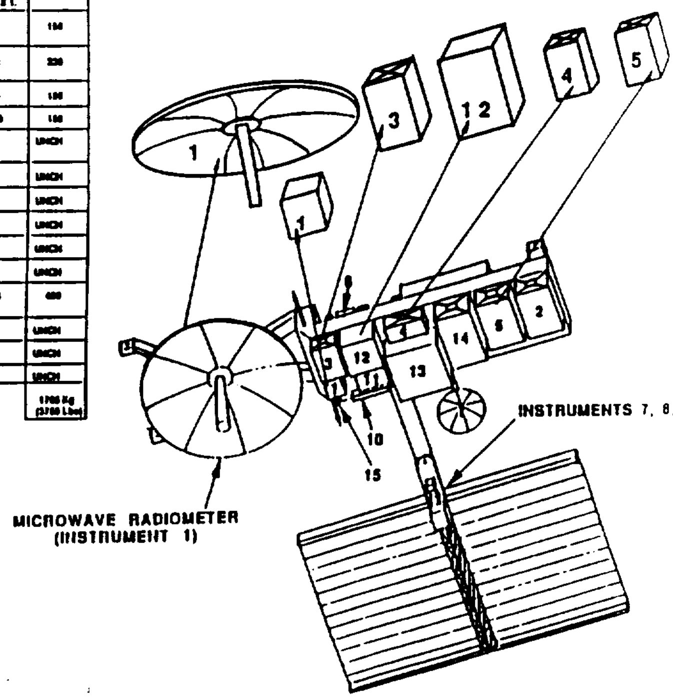
11 30 90

GEOPLAT

Class	No	Instrument Name	February 28, 1989 Dimensions (L X W X H) (M)	February 28, 1989 Mass (Kg)	October 4, 1989 Dimensions (L X W X H) (M)	October 4, 1989 Mass (Kg)
F	1	High-frequency Passive Microwave Radiometer	Ant: 4.4 Dia; Rad: .3 X .5 X .6	150	Ant: 4.4 X 4.4; Rad: 1. X 1. X 1.	350
F	2	High-resolution Infrared Interferometer	1.8 X 1.0 X .6	140	UNCH	150
F	3	Medium-resolution Imaging Spectrometer	1.14 X .76 X .66	110	2.1 X .9 X 1.2	220
O	4	Improved NOAA Imager	1.1 X .8 X .7	110	1.5 X 1.0 X .8	150
O	5	Improved NOAA Sounder	1.0 X 1.0 X .6	75	1.5 X 1.0 X 1.0	150
O	6	Improved NOAA Space Environment Monitor	2 X .3 X .3*	30	UNCH	UNCH
O	7	Solar X-ray Imager	.73 X .47 X .44*	30	UNCH	UNCH
PI	8	Solar Constant Monitor	.3 X .35 X .6*	50	UNCH	UNCH
PI	9	Solar Spectrum Monitor	.5 X .4 X .5*	40	UNCH	UNCH
F	10	Lightning Mapper	1.0 X .2 X .3	30	UNCH	UNCH
PI	11	Climate Radiation Radiometer	.5 X .7 X .40*	50	UNCH	UNCH
F	12	High-resolution Imaging Spectrometer	1.0 X 1.0 X 1.0	100	2.4 X 1.0 X 1.5	400
PI	13	Geodynamics Laser Ranger	1.5 X 1.0 X 1*	100	UNCH	UNCH
PI	14	Trace Gas Imager	1.7 X 1 X 1*	30	UNCH	UNCH
O	15	Advanced Data Collection Platform	.2 X .3 X .3*	30	UNCH	UNCH
			Total	1066 Kg (2351 Lbs)		1700 Kg (3750 Lbs)

* ——► Lockheed Final Report Values

Instrument Changes As of Oct. 4, 1989

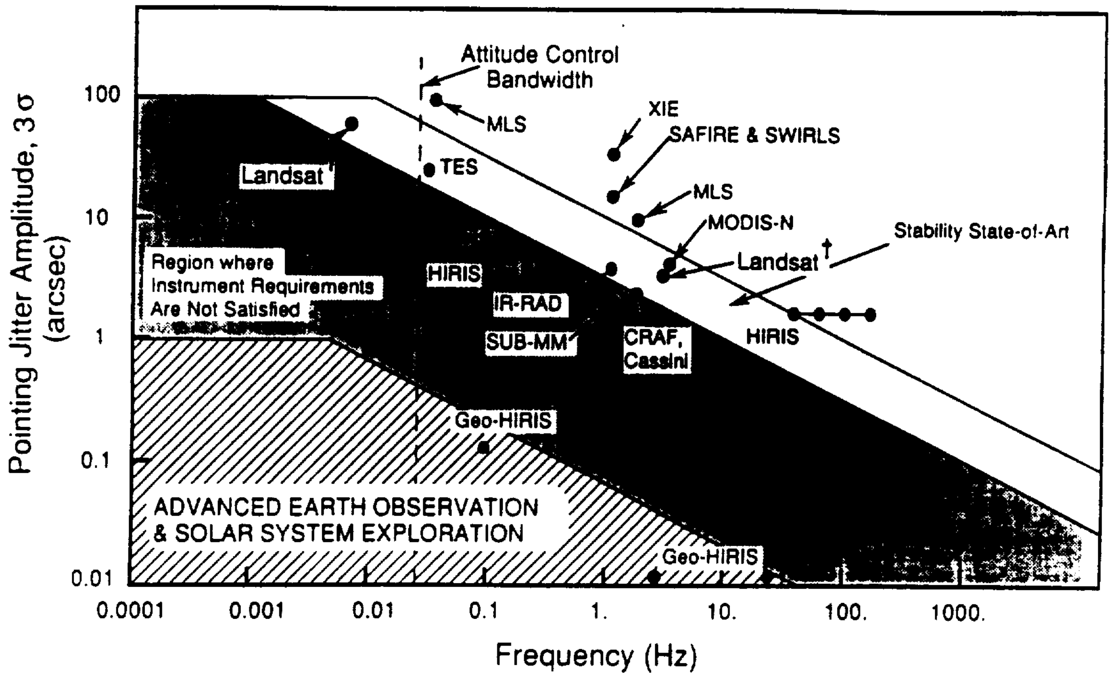


- INSTRUMENTS LARGER & MORE MASSIVE
- MORE STRINGENT POINTING REQUIREMENTS
- MORE ELECTRICAL POWER & COOLING AREA
- STILL HIGH DATA RATES

INSTRUMENT POINTING TECHNOLOGY REQUIREMENTS vs SOA

	EOS, C/C STATE-OF-ART (1991) LEO (1 arcsec = 3 m)	ADVANCED EOS/GEOPLAT/SOLAR SYS EXPL NEEDS LEO (1 arcsec = 3 m)	GEO (1 arcsec = 160m)
PIXEL SIZE	30 m	3 m	30 m
POINTING TECHNOLOGY	Core Attitude/Nav Reference Static Structure Fixed Instrument Mounts Pre-launch Alignment Limited Autonomy/Servicing	Precision Trackers & GPS Active Structure Alignment Precision Pointing and Isolation On-board Attitude Transfer System Extensive Autonomy	
CONTROL 3σ	108 arcsec	10 arcsec	1 arcsec
KNOWLEDGE 3σ	50 arcsec	5 arcsec	0.5 arcsec
STABILITY 3σ	100 arcsec/100 sec 10 arcsec/1 sec 1 arcsec/0.01 sec	10 arcsec/100 sec 1 arcsec/1 sec 0.1 arcsec/0.01 sec	1 arcsec/100 sec 0.1 arcsec/1 sec 0.01 arcsec/0.01 sec
DATASET COREGISTRATION	Via Ground Processing of Image Data Registration to $\frac{1}{4}$ Pixel Best Case	Via On-board Boresight Alignment Sensing Autonomous Registration to $\frac{1}{4}$ Pixel	

INSTRUMENT POINTING STABILITY STATE-OF-THE-ART vs FUTURE NEEDS



† Sudley, J and J.R. Schulman, " In-Orbit Measurements of LANDSAT-4 Thematic Mapper Dynamic Disturbances," NASA/Goddard Space Flight Center.

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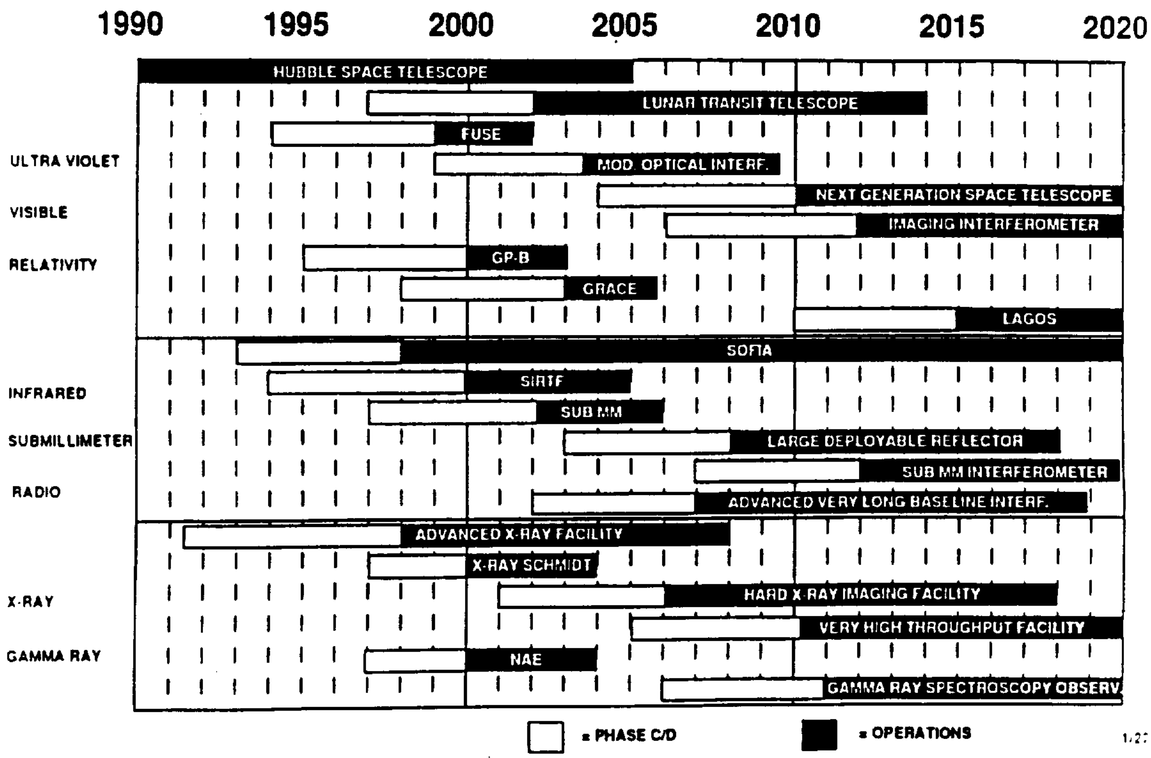
TELESCOPE & INTERFEROMETER POINTING NEEDS

NEXT CENTURY ASTROPHYSICS PROGRAM: CANDIDATE MAJOR AND MODERATE MISSIONS: 1995 - 2020 (FOR TECHNOLOGY PLANNING PURPOSES)



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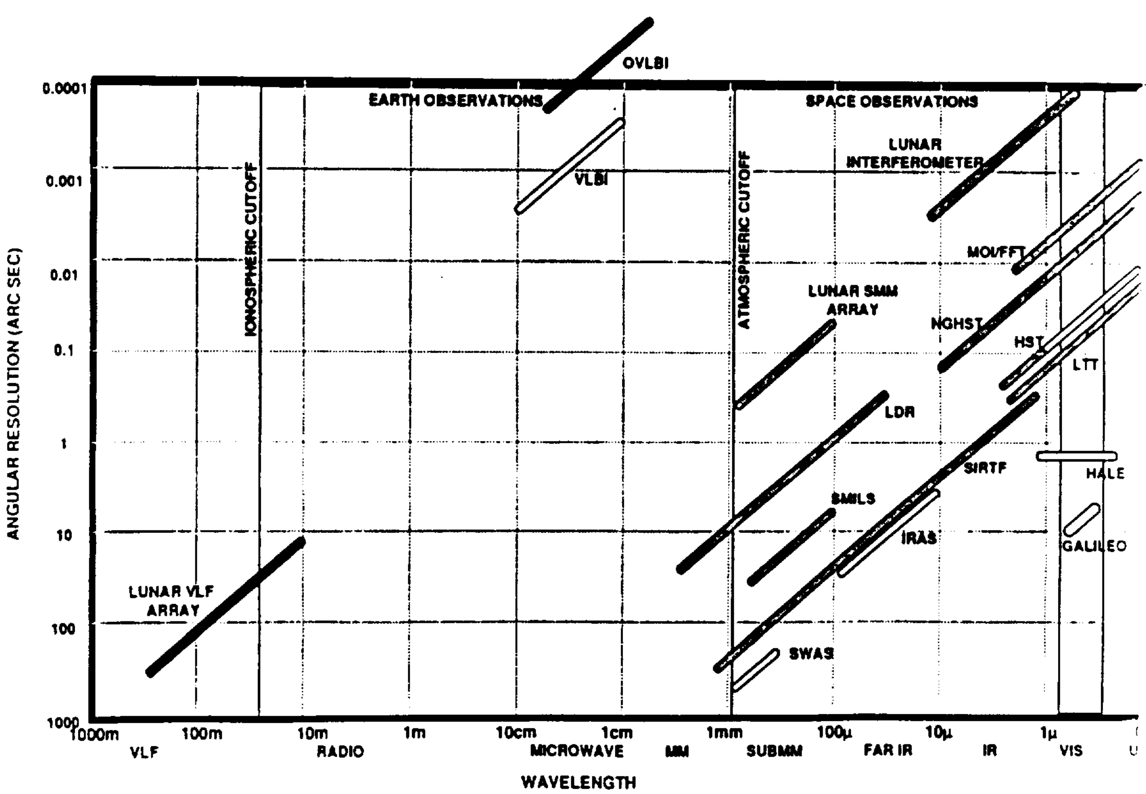
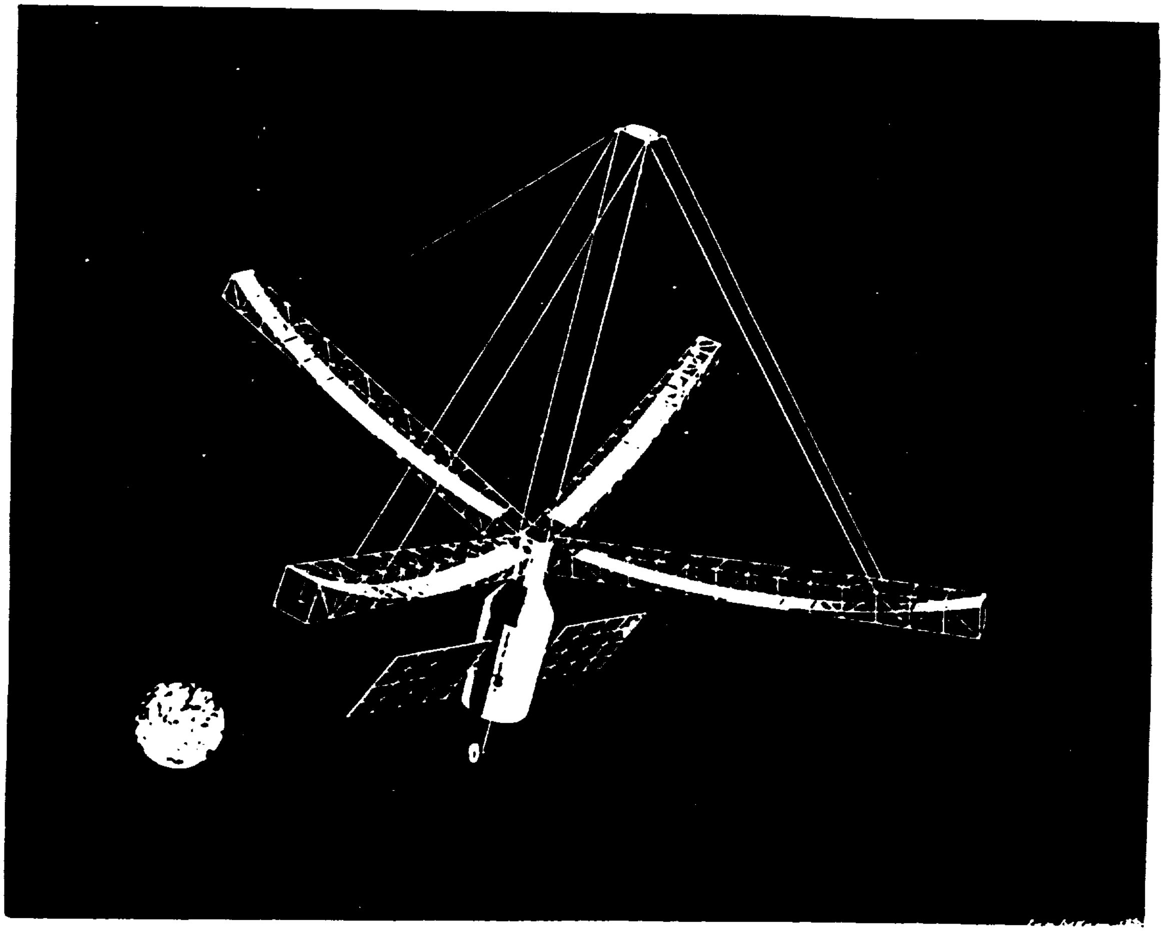
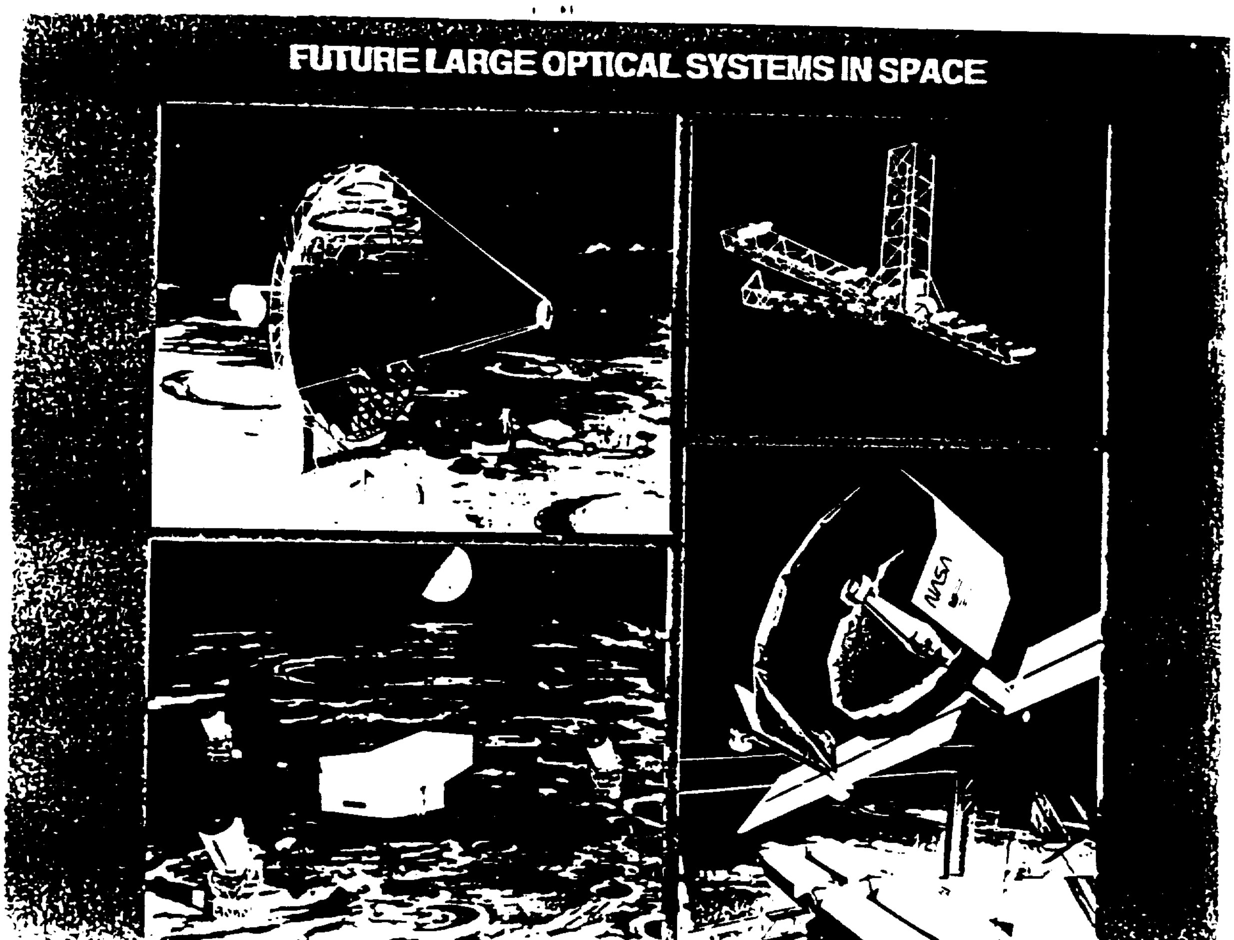
ANGULAR RESOLUTION VERSUS WAVELENGTH FOR FUTURE ASTRONOMICAL SPACE INSTRUMENTS







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PRECISION INSTRUMENT & TELESCOPE POINTING

MISSION REQUIREMENTS

MISSION	TECHNOLOGY FREEZE DATE	APERTURE/ BASELINE	POINTING ACCURACY	POINTING STABILITY	MISSION DURATION
NGST	2004	10 m	50 nrad	5 nrad	15 YEARS
LTT	1995	2 m	TBD	TBD	10 YEARS
LAGOS	2009	10^7 km	TBD	0.3 prad	10 YEARS
MOI	1997	20 m	0.3 nrad	0.3 nrad	5 YEARS
SIRTF	1994	1 m	300 nrad	300 nrad	3 YEARS
LDR	2006	20 m	250 nrad	125 nrad	10 YEARS
NGOVLBI	2000	TBD	500 nrad	500 nrad	10 YEARS
FFT	1997	30 m	0.8 nrad	0.8 nrad	10 YEARS
SMMM	1996	3.65 m	2.5 mrad	1.25 mrad	2 YEARS
FUSE	1993	1 m	2.5 nrad	1.25 nrad	4 YEARS
SMMI	2006	1 km	TBD	TBD	10 YEARS
LI	2003	10 km	TBD	TBD	10 YEARS
HXIF	1999	TBD	TBD	TBD	10 YEARS

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PRECISION INSTRUMENT & TELESCOPE POINTING

INTEGRATED TECHNOLOGY DEVELOPMENT PLAN

PRECISION INSTRUMENT & TELESCOPE POINTING

TECHNOLOGY CHALLENGES

- **INCREASE SPACE BASED TELESCOPE POINTING CAPABILITY BY 1-ORDER OF MAGNITUDE BEYOND HST**
  - 10 FOLD IMPROVEMENT IN PRECISION/STABILITY
  - PROVIDE NEW CAPABILITIES FOR LINE-OF-SIGHT TRASFER, TELESCOPE NODDING AND MULTI-APERTURE POINTING

- **INCREASE REMOTE SENSING INSTRUMENT POINTING CAPABILITY BY 2-ORDERS OF MAGNITUDE**
  - 100 FOLD IMPROVEMENT IN PRECISION/STABILITY
  - INCREASE SCIENCE THROUGHPUT AND OPERATIONAL EFFICIENCY VIA ON-BOARD POINTING AUTOMATION
  - PROVIDE NEW CAPABILITIES IN TARGET REFERENCED POINTING, ATTITUDE TRANSFER AND INSTRUMENT CO-BORESIGHTING

- **INCREASE RELIABILITY, LIFETIME AND EFFICIENCY OF POINTING COMPONENTS**
  - 3 FOLD IMPROVEMENT IN RELIABILITY AND LIFE OF CRITICAL COMPONENTS

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PRECISION INSTRUMENT & TELESCOPE POINTING

TECHNOLOGY DEVELOPMENT APPROACH

- FOCUSED DEVELOPMENT OF
  - ADVANCED POINTING SYSTEM ARCHITECTURE
  - SENSOR AND ACTUATOR BRASSBOARDS
  - HARDWARE AND SOFTWARE TESTBED DEMONSTRATIONS

- COORDINATE PLANNING AND IMPLEMENTATION WITH OSSA ADVANCED DEVELOPMENT

TECHNOLOGY DEVELOPMENT PROGRAM

INSTRUMENTS

- SENSORS/ACTUATORS
  - EXTENDED IMAGE/FEATURE TRACKERS
  - AUTONOMOUS STAR TRACKERS
  - ATTITUDE TRANSFER SYSTEMS
  - REACTIONLESS ACTUATORS
  - IMAGE MOTION COMPENSATION
- TARGET-REFERENCED POINTING TRACKING
  - EARTH/FEATURE BASED
  - EARTH COORDINATES (LONGITUDE/LATITUDE)
- INSTRUMENT CO-BORESIGHTING
  - MULTIPLE INSTRUMENTS
  - MULTI-SPECTRAL IMAGE REGISTRATION
- AUTONOMOUS POINTING EXECUTIVE
  - HIGH LEVEL COMMAND CAPABILITY
  - ON-BOARD SEQUENCE GENERATION/EXECUTION
  - SEQUENCE INTERRUPT/RESTART
- SYSTEMS DESIGN, ANALYSIS, INTEGRATION, AND TESTING

TELESCOPES

- ADVANCED OPTICAL SENSORS
  - FINE GUIDANCE SENSORS
  - AUTONOMOUS STAR TRACKERS
  - LINE-OF-SIGHT TRANSFER SYSTEMS
- INERTIAL ROTATION SENSORS/IRU'S
- PRECISION ACTUATORS
  - SUPERQUIET HIGH-CAPACITY REACTION WHEELS AND CONTROL MOMENT GYROS
  - MOMENTUM COMPENSATED POINTING/ BEAM STEERING DEVICES
- SYSTEM DESIGN, ANALYSIS, INTEGRATION AND TESTING

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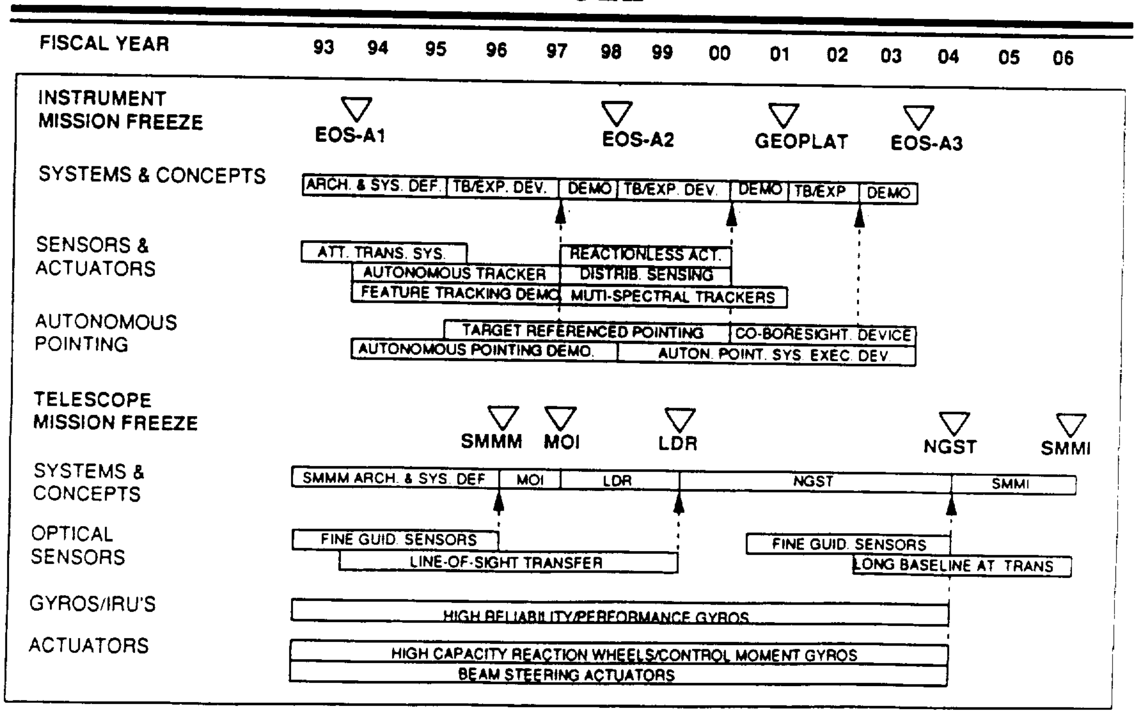
SCHEDULE



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RECOMMENDATIONS

- PROCEED WITH PROGRAM PLANNING AT 10-12 M$/YEAR LEVEL
- CONTINUE STRONG COORDINATION BETWEEN TECHNOLOGY DEVELOPERS AND USERS
  - FORM INTERCENTER TECHNOLOGY DEVELOPERS AND USERS WORKING GROUP
  - REVIEW OF GOVERNMENT/INDUSTRY CAPABILITIES
  - OSSA UPDATE OF MISSION REQUIREMENTS
- START EARLY (i.e., FY 93) TO INSURE AVAILABILITY OF TECHNOLOGY PRODUCTS TO NEAR TERM USERS (i.e., EOS, SMMM, and MOI)

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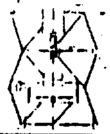
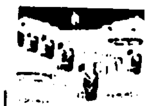
APPENDIX

NAME	HUBBLE SPACE TELESCOPE	LUNAR TRANSIT TELESCOPE	MODERATE OPTICAL INTER-FEROMETER	NEXT GENERATION HST	LUNAR IMAGING INTER-FEROMETER	FILLED FIZEAU TELESCOPE	LAGOS
LOCATION	LOW EARTH ORBIT	MOON	900 KM EARTH ORBIT	EARTH ORBIT OR MOON	MOON	900 KM EARTH ORBIT	SOLAR ORBIT AT L5 POINT
MISSION DURATION	15 YEARS WITH SERVICING	10 YEARS	5 -10 YEARS	15 YEARS	10 YEARS	10 YEARS	10 YEARS
WAVELENGTH	0.1 - 1 MICRON (2.5 MICRON WITH UPGRADE)	0.1 - 2.5 MICRONS	0.1 - 2.5 MICRONS	0.1 - 10 MICRONS	0.1 - 10 MICRONS	0.1 - 1 MICRON	<< 1 Hz GRAVITY 1.6 MICRON SENSOR
APERTURE SIZE	2.4 M	1 - 2 M	50 CM APERTURES 10 - 30 M BASELINE	10 - 16 M	.5 M APERTURES 1 KM BASELINE	30 M CROSS, DILUTE APERTURE	30 CM APERTURE 10^7 KM BASELINE
OPTICS TEMPERATURE	AMBIENT	100 K	AMBIENT	< 100 K	AMBIENT	AMBIENT	ULTRA STABLE

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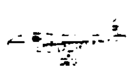
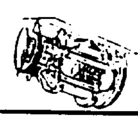
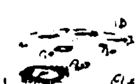
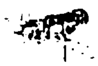
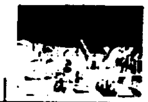
IR-SUBMM-RADIO MISSIONS

NAME	SOFIA	SIRTF	SMILS	LARGE DEPLOYABLE REFLECTOR	LUNAR SMM INTER-FEROMETER	ADVANCED ORBITING VLBI
LOCATION	C 141 AIRCRAFT	HIGH EARTH ORBIT	70,000 X 1,000 KM EARTH ORBIT	100,000 KM EARTH ORBIT	MOON	HIGHLY ELLIPTICAL EARTH ORBIT AND EARTH
MISSION DURATION	10 YEARS	3 - 6 YEARS	2 - 4 YEARS	10 - 15 YEARS	10 YEARS	10- YEARS
WAVELENGTH	IR THROUGH SUBMILLIMETER	1.4 - 1200 MICRONS	100 - 800 MICRONS	30 -3000 MICRONS	100 - 800 MICRONS	3 CM - 1.5 MM
APERTURE SIZE	2.5 M	1 M	3.6 M	10 - 20 M	4 -5 M APERTURES 1 KM BASELINE	25 M
OPTICS TEMPERATURE	AMBIENT	LIQUID HELIUM COOLED	AMBIENT	AMBIENT	AMBIENT	AMBIENT

X-RAY, γ-RAY MISSIONS

NAME	AXAF	NUCLEAR ASTROPHYSICS EXPLORER	HARD X-RAY IMAGING FACILITY	VERY HIGH THROUGHPUT FACILITY	GAMMA RAY SPECTROSCOPY OBSERVATORY		
LOCATION	600 KM EARTH ORBIT	LOW EARTH ORBIT	SPACE STATION ATTACHED OR FREE FLYER	MOON	MOON		
MISSION DURATION	15 YEARS WITH SERVICING	2 -4 YEARS	10 YEARS	20 YEARS	10 YEARS		
WAVELENGTH	0.09 - 10 KeV	10 KeV - 10 MeV	20 KeV - 2 MeV	0.15 - 40 KeV	10 KeV - 10 MeV		
APERTURE SIZE	1,700 CM^2 GRAZING INCIDENCE MIRRORS	325 CM^2 AREA, 2600 CM^3 VOLUME	20 X 20 M, 30 M^2 CODED APERTURE	20 X20 M 30 M^2 GRAZING INCIDENCE	1000 CM^2 AREA 7640 CM^3 VOLUME		
OPTICS TEMPERATURE	AMBIENT	AMBIENT	AMBIENT	AMBIENT			

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Microsensors and Microinstruments

W.J. Kaiser and T.W. Kenny

Center for Space Microelectronics Technology
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

Outline

Motivation for work on Micro-sensors and Micro-instruments.

Some examples of miniature sensors for in-situ measurements.

Research and development of the Electron Tunneling Sensor.

Application to Infrared Detection.

Conclusions

JPL

Motivation

Conventional Instruments often impose Mass, Volume and Power consumption which are incompatible with mission requirements.

Recent improvements in fabrication technology through 'Micro-machining' of silicon enable the construction of micro sensors and actuators. This technology offers :

- Large potential reductions in mass, volume, and power consumption of sensing instruments.
- High degree of flexibility in device design for optimization of performance characteristics.
- Array compatibility for multiple functions and redundancy.

Examples of successful commercial implimentation of this technology exist.

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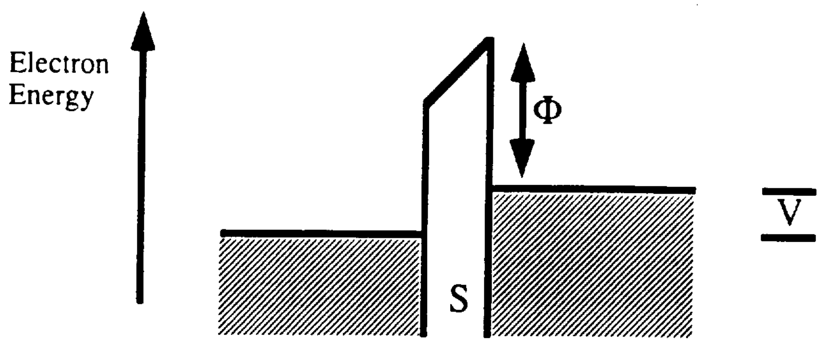
Conventional Sensors

- Conventional sensors operate by converting the Signal to a displacement of one sensor component relative to the rest of the sensor. The sensor then uses a capacitive, inductive, or optical transducer to directly measure the relative displacement.
- Conventional sensors are often limited by noise in the transducer or the following electronics. The sensitivity of existing transducers is improved by increasing the volume, mass, or power consumption of the transducer.
- A more sensitive transducer would allow the design of smaller, lighter, or more sensitive devices.

Vacuum Tunneling Concept



$$I \,\alpha\, V \exp[-a\sqrt{\Phi}\; S]$$

- The current typically increases by one order of magnitude for each 1 Å reduction in electrode separation.

Transducer Sensitivity Comparison

Transducer Type	Capacitive	Tunneling
Active Area	10 μm x 10 μm	10 Å x 10 Å
Electrode Separation	1 μm	5 Å
Bias Voltage	1 Volt	100 mV
Measurement Frequency	200 kHz	DC - 10 MHz
Measurement Current	1.1 nA	1 nA
1 % Transducer Signal	90 Å	0.004 Å

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Advantages of the Electron Tunneling Position Sensor

- Improved sensitivity.
  Approximately 20,000 x more sensitive than conventional transducers.
  Allows use of less sophisticated electronics.
  Sensitivity can be traded off to improve other characteristics, such as bandwidth, linearity, ...
- Microscopic active area.
  Less sensitive to contamination
  Allows construction of micron-scale sensors
- Low power consumption.
- Simple electronic control system.
- Compatible with silicon micromachining technology.

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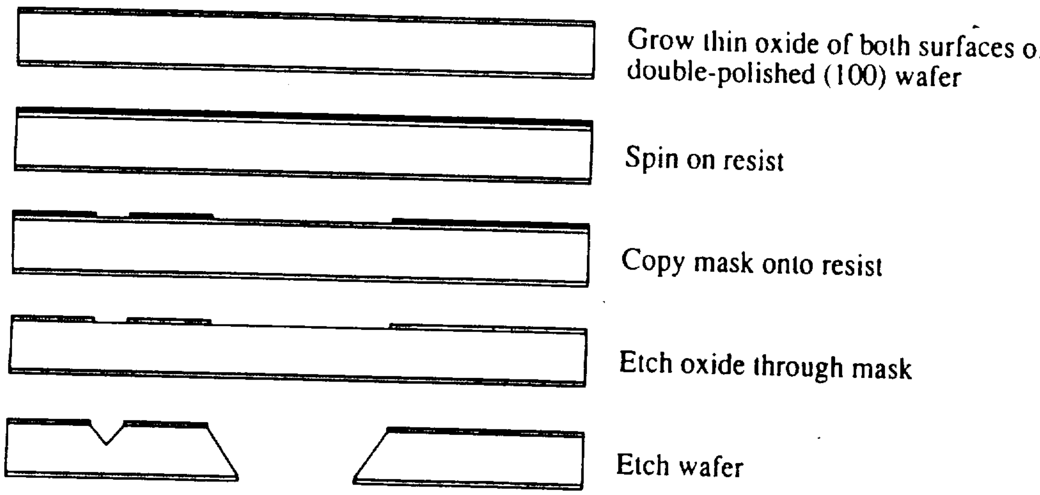
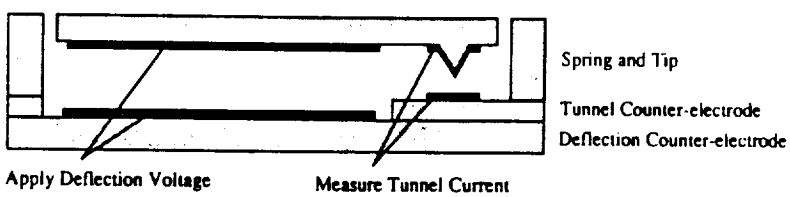
Tunnel Sensor Prototypes

- Piezoelectric bimorph as actuator with gold film and wire as tunneling electrodes. Featured sensitivity of ~ 10^{-5} g. Demonstrated use of tunneling as displacement transducer in a useful device. Suffered from temperature sensitivity and complicated fabrication.
- Large micromachined folded cantilever with electrostatic deflection to control separation and indium tip for tunneling. First demonstration of electrostatic deflection in a tunneling device.
- Small micromachined cantilevers with integral tips for use as generic transducer components. Characterization as accelerometer gives sensitivity of 10^{-8} g/ $\sqrt{\text{Hz}}$ at 1 kHz. Use in broad class of sensors under investigation.

Micromachining Process

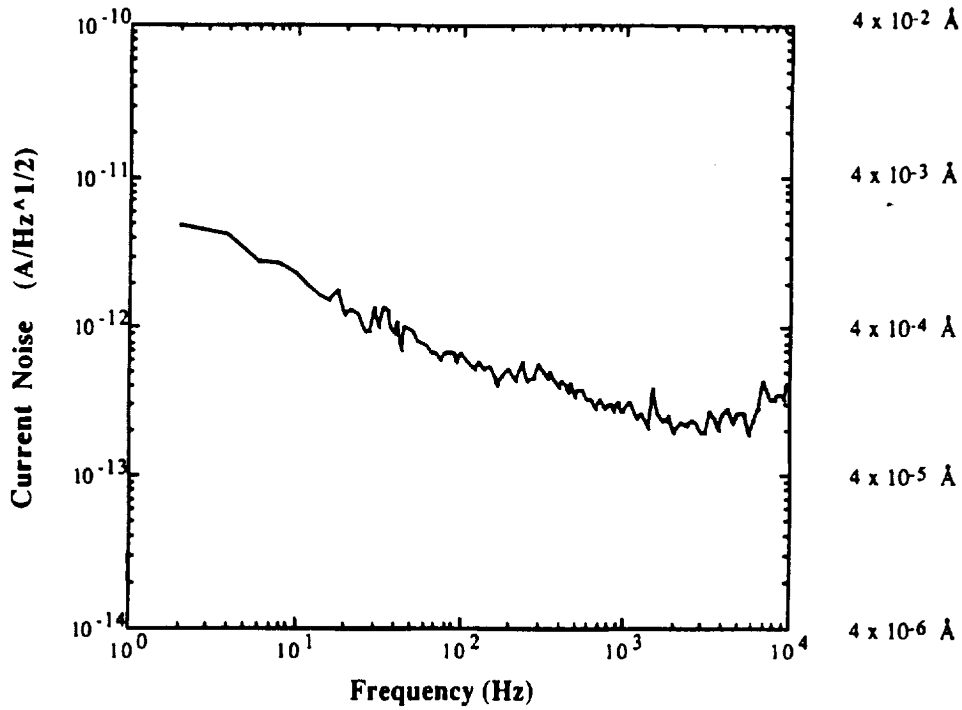


Tunnel Sensor Operation

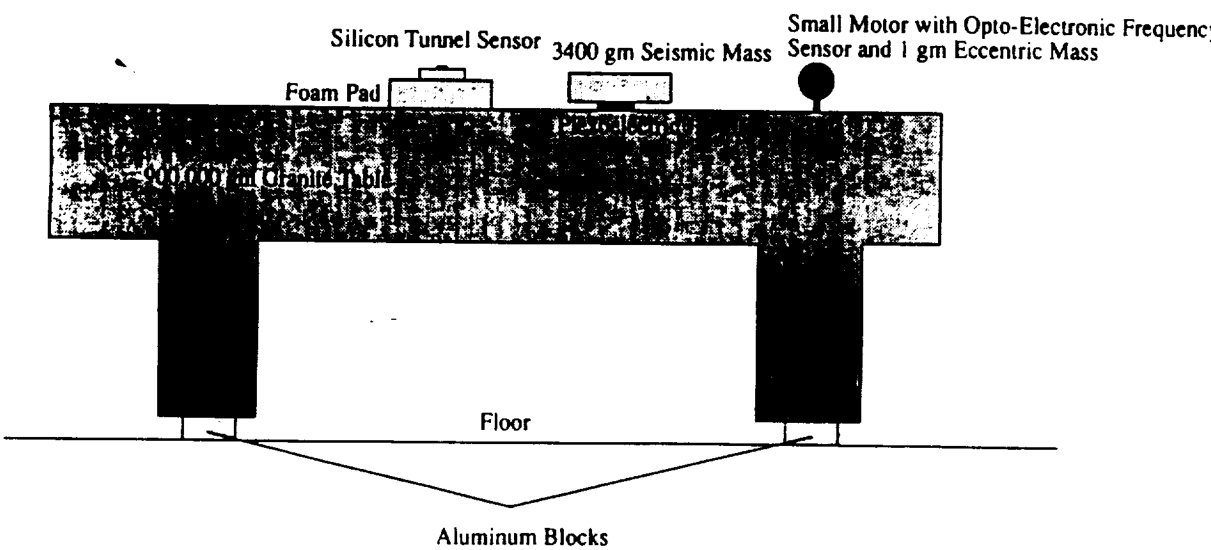


- Apply a deflection voltage until tunnel current appears.
- Activate Feedback Loop to maintain constant tunnel current
- If device experiences acceleration, spring will flex, producing a change in tunnel current.

Measured Current Noise



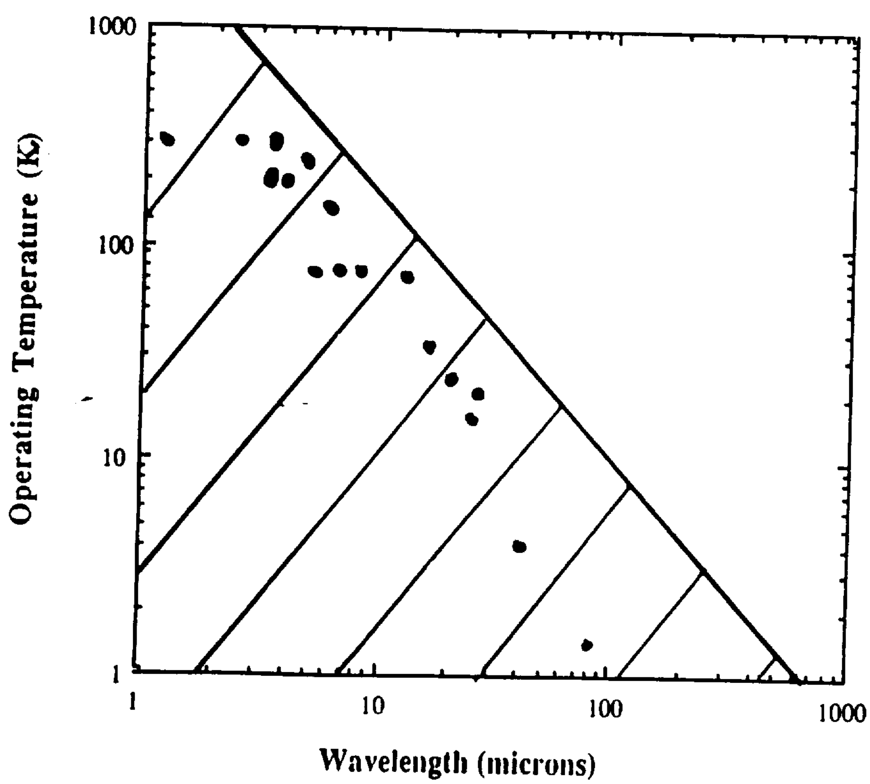
Accelerometer Demonstration



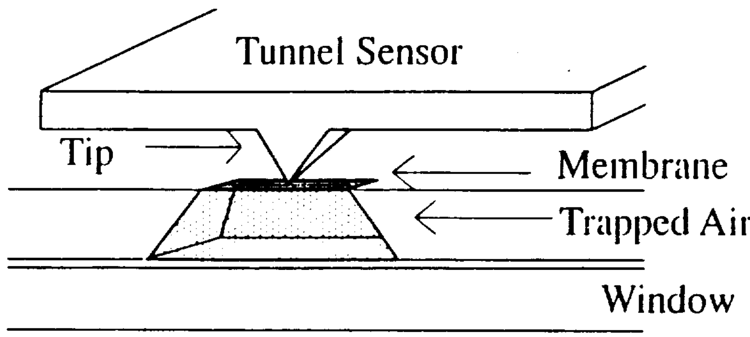
Applications of the Electron Tunneling Transducer

- Accelerometers and Seismometers
- Force and Strain Sensors
- Magnetometers
- Infrared Detectors
- Pressure Sensors
- Microphones and Hydrophones
- Microscopic Particle Detectors

Operating ranges of Quantum IR Detectors



Infrared Detectors



- Radiation absorbed by metallic film and converted to heat.
- Conduction of heat to gas causes thermal expansion which deflects membrane.
- Membrane deflection measured by tunnel sensor.

Features of the Infrared Tunnel Sensor

• Speed	Response to 10 kHz at peak sensitivity. Response beyond 10 kHz with sensitivity decreasing as 1/f.
• Size	Active area of single element from 1 mm to less than 50 microns
• Operating Temperature	Can operate at any temperature above 20 K
• Sensitivity	Approximately 10X more sensitive than Pyroelectric Detector at 300 K.
• IR Bandwidth	Thin metallic film absorbs radiation throughout the Infrared with 50% efficiency.
• Array Compatible	Elements feature low power dissipation and can be microfabricated into 1-D and 2-D arrays.

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Micromachined Instruments for In-Situ Science

Micro-Weather Stations for in-situ measurements in the planetary boundary layer.

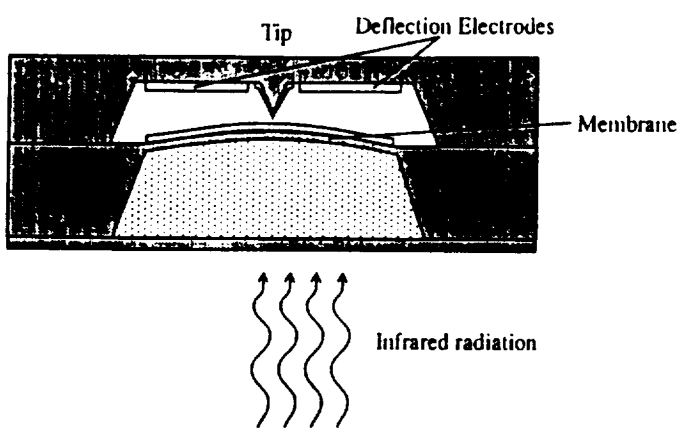
- System needs include low mass, volume, and power consumption.
- Devices under development for measurement of pressure, wind velocity and direction, temperature, humidity and atmospheric aerosols.
- Goal: To integrate a set of sensors into a miniature package suitable for widespread deployment.

Micro-Seismometry Instrumentation

- System needs include low mass, volume, power consumption and high sensitivity.
- Devices under development for measurement of seismic signals.
- Goal: To produce sensitive, miniature seismometers.

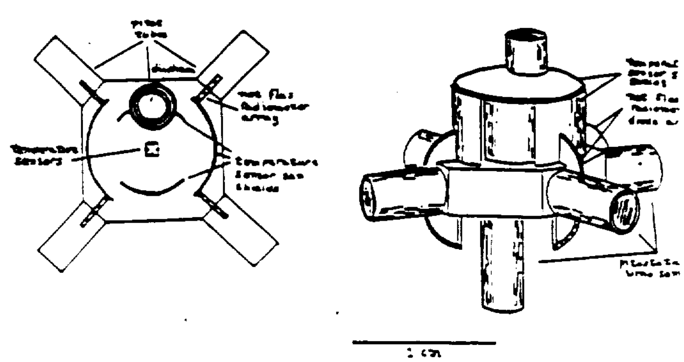
Plans : Infrared Sensor

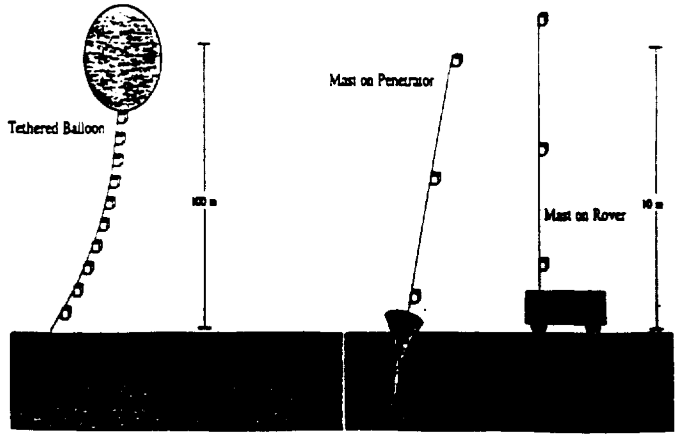
- The improved sensor is operated in the following manner :



- Apply deflection voltage until tunneling current is observed.
- Activate feedback loop to maintain constant tunneling current.
- If radiation is applied, feedback loop applies correction to deflection electrodes. Variations in deflection voltage are processed as signal.

- Micro Weather Stations for in-situ measurements in the Martian planetary boundary layer (PBL)
    - System need: Compact, low mass and low power stations for widely distributed measurements of PBL meteorology.
    - Devices currently under development for measurement of pressure, temperature, wind velocity and direction, humidity, and atmospheric aerosols.
    - Low power instrument, on-board processor.
    - Development directed to fabrication of sensors for initial testing in environmental chamber
- Micro seismometry instrumentation.
    - System needs: Compact, low mass, and low power seismometers for wide distribution.
    - Currently available seismometer systems are excessively massive. (Approximately 4kg per measurement axis).
    - Develop compact, single crystal silicon seismometer system.
    - Extend current technology to include active electronic suspension of seismometer elements.



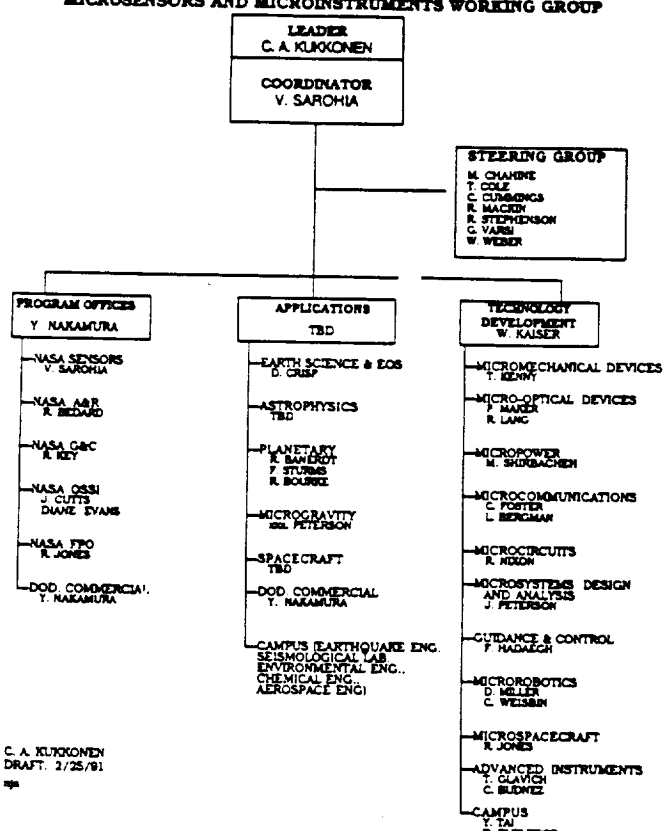


Micromachined Sensors, Actuators, and Instrument Examples

Instrument	Applications
Micro instruments for meteorology o Temperature o Pressure o Wind Velocity o Humidity o Aerosol detection	In-situ monitoring
Micro inertial guidance and control	Compact vehicle navigation
Micro seismometers	Planetary science Resource mapping Wide sensor deployment
Compact analytical spectroscopy instruments for in-situ science	Photoemission Auger SEM
Micro instruments for gas monitoring	In-situ measurements Environmental monitoring Planetary in-situ scienc
ir/vis/uv sensors and instruments	Infrared imaging Atmospheric science In-situ monitoring
Micro optical systems	Compact spectrometers Gas detection In-situ monitoring
Compact communication systems	Multi-node rf fiber-optic network

D R A F T

MICROSENSORS AND MICROINSTRUMENTS WORKING GROUP



C. A. KUKKONEN
DRAFT 2/25/91
mja

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Conclusions

- Electron tunneling represents the first new transducer technology in recent history. The sensitivity of electron tunneling to changes in relative position exceeds that of all currently available motion transducers.
- Tunnel sensors can be constructed which are robust, operate in air, and in the presence of environmental noise sources.
- Silicon micromachining has been used to fabricate tunnel sensors which incorporate electrostatic deflection.
- Tunnel sensor components have been built for incorporation into a novel infrared detector that is expected to be important for many applications.
- Applications of the tunnel sensor to other types of measurement are being explored. Measurement of acceleration, pressure, temperature, magnetic fields and other signals with devices based on the tunnel sensor may be important.

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MICRO GUIDANCE & CONTROL INITIATIVE

Fred Y. Hadaegh

June 27, 1991

SSTAC ITP - OAET/RC

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MICRO GUIDANCE & CONTROL TECHNOLOGY INITIATIVE

TOPICS

- OVERALL PURPOSE AND OBJECTIVES
- MICRO G&C APPLICATION
- PAYOFFS
- SELECTED TASK THEMES & TECHNOLOGIES
- TECHNOLOGY DEVELOPMENT PLAN
- SUMMARY
- ISSUES

MICRO GUIDANCE & CONTROL TECHNOLOGY

APPLICATIONS

THE APPLICATION NEEDS FOR FUTURE SPACE SYSTEMS HAVE BEEN IDENTIFIED AS FOLLOWS:

• NEW GUIDANCE AND CONTROL CAPABILITIES
- DISTRIBUTED MICRO-SENSOR SYSTEM IDENTIFICATION
- MULTIVARIABLE CONTROL OF STRUCTURAL DYNAMICS
- DISTRIBUTED SHAPE & POSITION CONTROL OF MIRROR ARRAYS
- EMBEDDED STABILIZATION OF TELESCOPE & INSTRUMENT OPTICS
- DISTRIBUTED MICRO-INTERTIAL REFERENCES
- EMBEDDED HEALTH MONITORING OF G&C EFFECTORS

TYPICAL APPLICATION:
REMOTE SENSING PLATFORMS, INTERFEROMETERS & DEPLOYABLE REFLECTORS

•MINIATURIZE EXISTING CAPABILITIES
- ATTITUDE & MANEUVER CONTROL SYSTEM
- MICRO-INERTIAL REFERENCES
- MICROELECTRO-OPTICS FOR MINIATURE CAMERAS & REMOTE SENSORS
- INERTIAL NAVIGATION SYSTEMS
- HEADING REFERENCE UNITS
- MINI-CAMERA POINTING & STABILIZATION
- ANTENNA POINTING & STABILIZATION

TYPICAL APPLICATION:
MICRO-SPACECRAFT, MICRO-LANDERS, MICRO-ROVERS

MICRO GUIDANCE & CONTROL TECHNOLOGY

- **OVERALL PURPOSE:** DEVELOP NEW MICRO-MINIATURIZED G&C SYSTEM ARCHITECTURES AND FUNCTIONS THAT MEET THE NEEDS OF FUTURE SPACE SYSTEMS
  - CONDUCT ADVANCED DEVELOPMENT THROUGH PROOF-OF-CONCEPT DEMONSTRATIONS
  - TRANSFER NEW TECHNOLOGIES TO NASA ADVANCED DEVELOPMENT SPACE PROGRAMS

- **KEY OBJECTIVES:** DEVELOP THE G&C MICRO-SENSING, COMPUTATION, AND CONTROL ARCHITECTURES AND FUNCTIONS THAT WILL ENABLE:
  - 100/1 OR MORE REDUCTION IN SIZE, MASS, AND POWER
  - 10/1 OR MORE RECURRING COST REDUCTION AND LOWER COST GROWTH RATES
  - SOLID STATE RELIABILITY AND REDUCED PERFORMANCE RISK
  - ROBUST PERFORMANCE OVER TEMPERATURE, VIBRATION, RADIATION
  - EMBEDDED HEALTH MONITORING
  - VIABLE DISTRIBUTED FAULT TOLERANT G&C ARCHITECTURES

MICRO GUIDANCE & CONTROL TECHNOLOGY INITIATIVE

PAYOFFS

- 100/1 OR MORE REDUCTION IN SIZE, MASS, AND POWER
- 10/1 OR MORE RECURRING COST REDUCTION AND LOWER COST GROWTH RATES
- SOLID STATE RELIABILITY AND REDUCED PERFORMANCE RISK
- ROBUST PERFORMANCE OVER TEMPERATURE, VIBRATION, RADIATION
- EMBEDDED HEALTH MONITORING
- VIABLE DISTRIBUTED FAULT TOLERANT G&C ARCHITECTURES
- MASSIVELY DISTRIBUTED CONTROL CAPABILITY

MICRO GUIDANCE & CONTROL TECHNOLOGY

SELECTED TASK THEMES

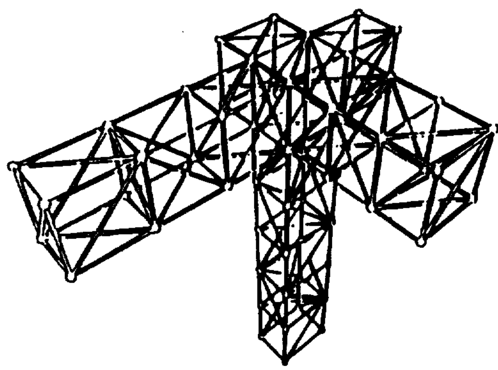
MAJOR ADVANCES IN MICRO G & C WILL BE INCORPORATED IN DEVELOPMENT PRODUCTS PLANNED UNDER SIX TASK THEMES:

- **MASSIVELY DISTRIBUTED MICROSENSING FOR SYSTEM ID & CONTROL**
  TO ENABLE SPACE INTERFEROMETERS/LARGE REFLECTORS
- **LIGHT POWERED REMOTE PROCESSING NETWORK FOR G&C MICROSENSING**
  TO ENABLE VIABLE DISTRIBUTED ID/CONTROL ARCHITECTURES
- **MICRO G&C FOR MICRO-SPACECRAFT AND MICRO-ROVERS**
  TO PROVIDE ESSENTIAL SYSTEM FUNCTIONS
- **SIX-DEGREE-OF-FREEDOM MICRO-INERTIAL MEASUREMENT UNIT FOR MICRO-SPACECRAFT AND MICRO-ROVERS**
  TO ENABLE G&C NAVIGATION SUBSYSTEMS
- **ACTIVELY CONTROLLED MICROMACHINED DEFORMABLE MIRRORS FOR ADAPTIVE REFLECTORS**
  TO PROVIDE OPTICAL PERFORMANCE NOT OTHERWISE FEASIBLE
- **EMBEDDED HEALTH SENSING FOR G&C EFFECTORS**
  TO PREDICT/MANAGE MISSION EFFECTIVENESS & LIFETIME

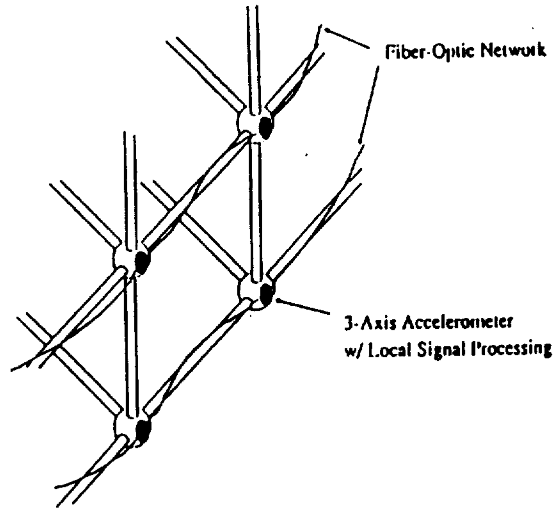
3-AXIS LIGHT POWERED SENSING SYSTEM

ENABLES

MASSIVELY DISTRIBUTED SENSING FOR I/D CONTROL



LARGE SPACE TRUSS STRUCTURE



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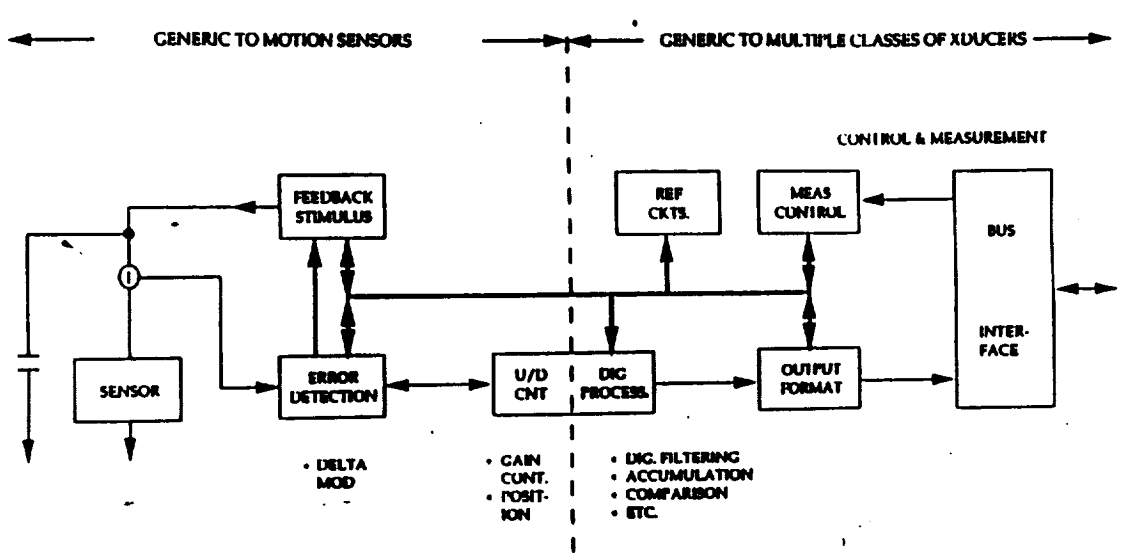
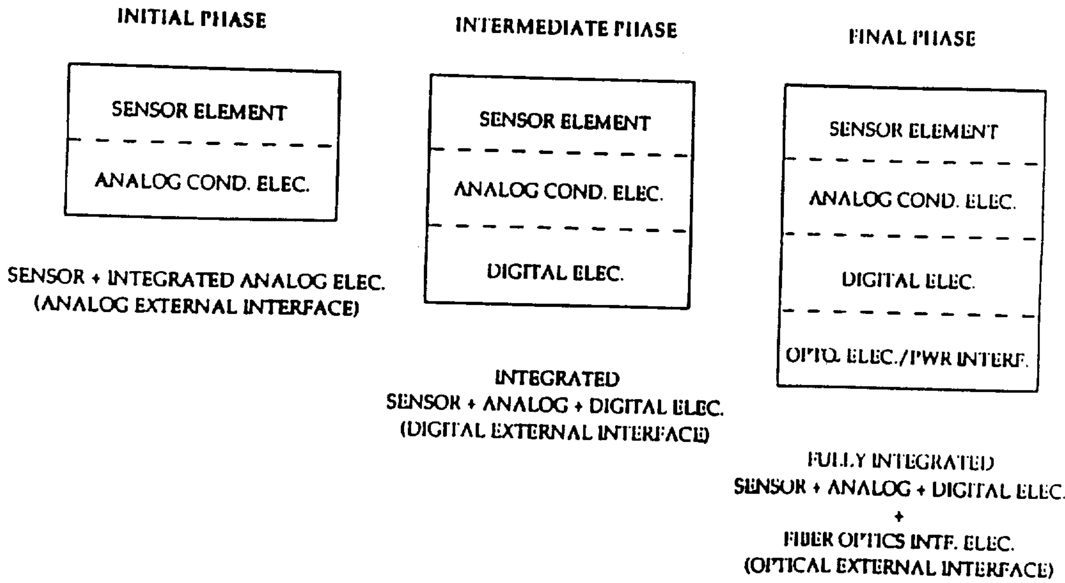


REMOTE SIGNAL PROCESSOR FOR MOTION SENSORS

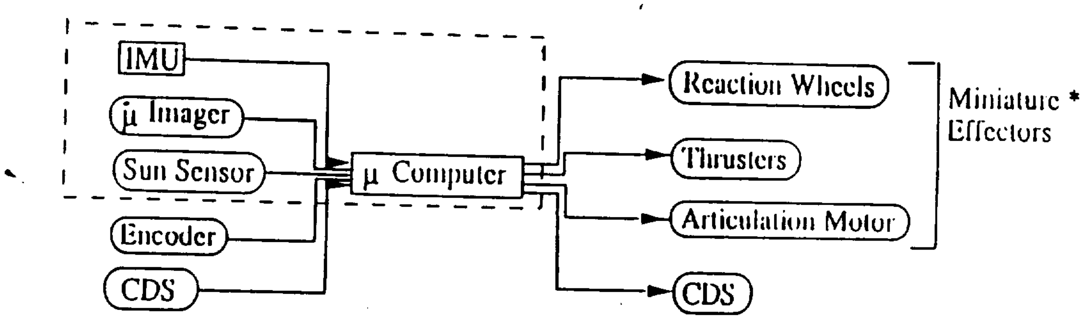
FEATURES:
1. Single chip implementation
2. Programmable measurement
   • Resolution, gain, offset
3. Low power, <10 ua for most measurements

MASSIVELY DISTRIBUTED MICRO SENSING FOR ID/CONTROL

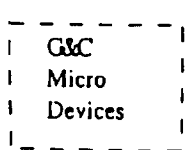
REMOTE PROCESSING NETWORK/STRUCTURE PHASED INTEGRATION AND TEST



MICRO-SPACECRAFT G&C

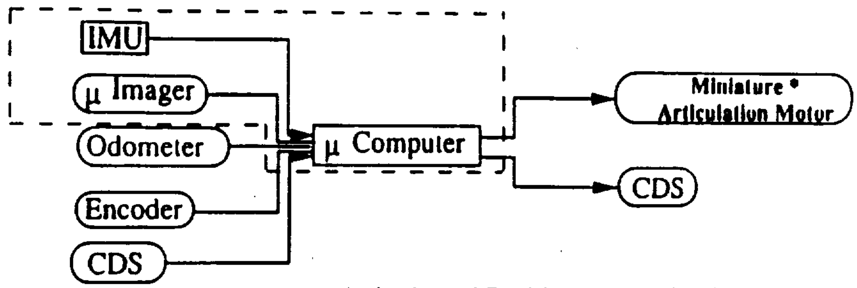


- Attitude Determination
- Attitude Control
- Articulation Control



* Scaled down from conventional size, not silicon micromachined

MICRO-ROVER G&C

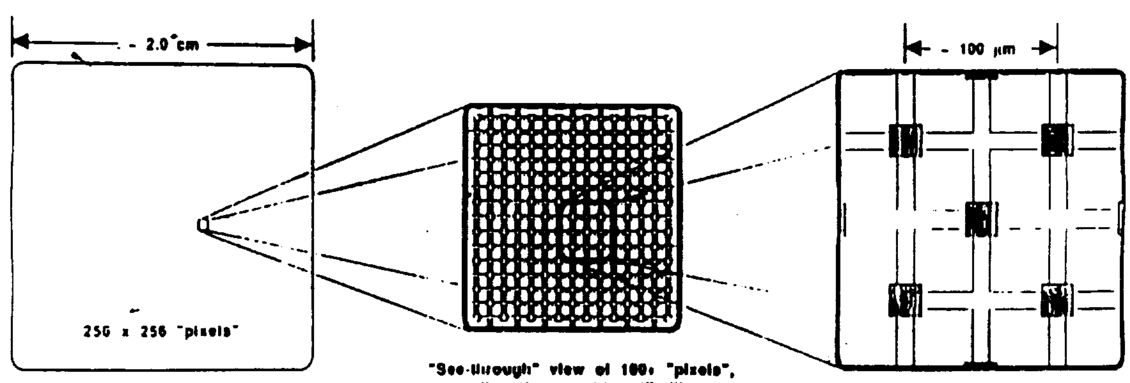


- Attitude and Position Determination
- Path Guidance
- Articulation Control

G&C Micro Devices

* Scaled down from conventional size, not silicon micromachined

Micromachined Deformable Mirror



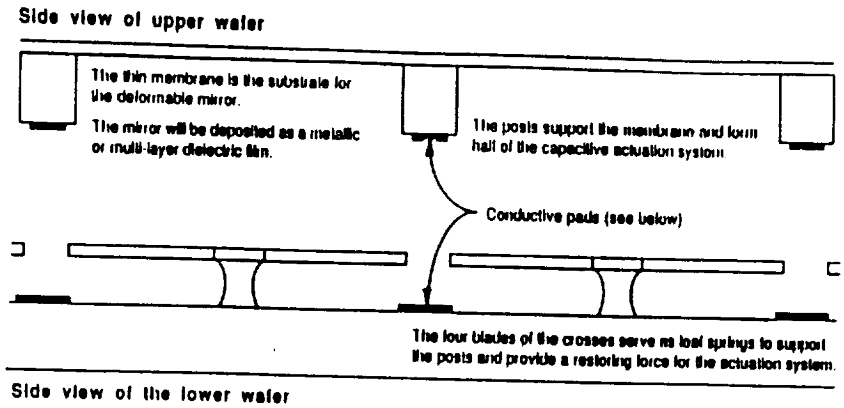
Top view of deformable mirror assembly

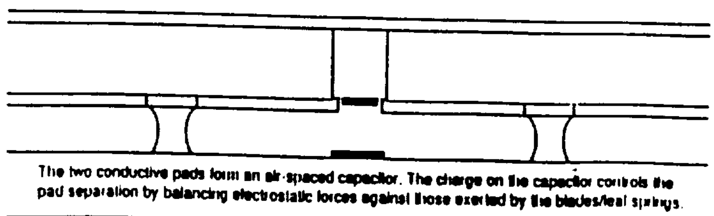
Assembly consists of two micromachined silicon wafers mounted face-to-face and bonded together around their peripheries

"See-through" view of 100+ "pixels", revealing the repetitive, tile-like geometry of the mirror assembly

Magnified view of several pixels showing the overlapping "cross-and-post" pattern of the actuator / mirror support structure

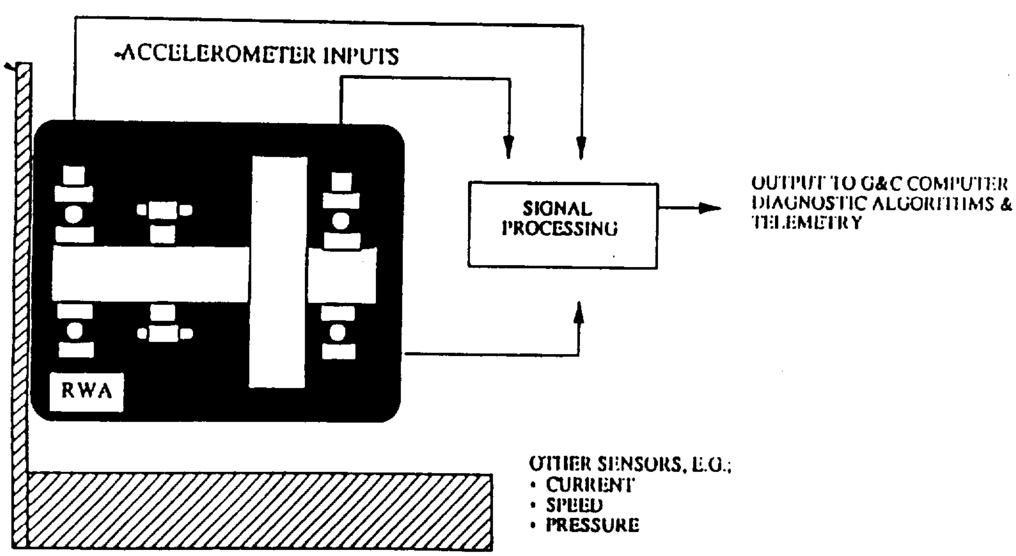
Micromachined Deformable Mirror





Side view of the mirror assembly

EMBEDDED HEALTH MONITORING OF G&C EFFECTORS



Reaction Wheel Test Bed

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A Micromachined Silicon Electron Tunneling Sensor

Center for Space Microelectronics Technology
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

- **Tunnel Sensor Characteristics**
- **Applications**

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Electron Tunneling Sensors

A New Class of Position Transducer With Potential Application to Measurement of

- Acceleration
- Infrared Radiation
- Pressure
- Temperature
- Magnetic Fields
- Particle Flux

All with Similar Electronic Requirements.

In many cases, arrays of sensors will be fabricated on single chip for Redundancy, Signal Identification, Focal-Planes, and for Multiple-Function Packages.

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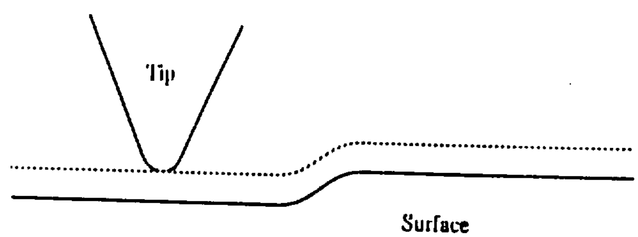
Electron Tunneling

- In the early 1980's, Binnig and Rohrer at IBM invented a new technique, Scanning Tunneling Microscopy (STM), for studying the structure of surfaces with atomic-scale resolution.

- In STM, a 'Tip' is positioned several Angstroms above the surface of interest. With the application of a voltage bias between the tip and the surface, a small tunneling current is observed.



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Advantages of the Electron Tunneling Position Sensor

- Improved sensitivity.
  Approximately 20,000 x more sensitive than conventional transducers.
  Larger signals allow use of less sophisticated electronics.
  Sensitivity can be traded off to improve other characteristics, such as bandwidth, linearity, ...

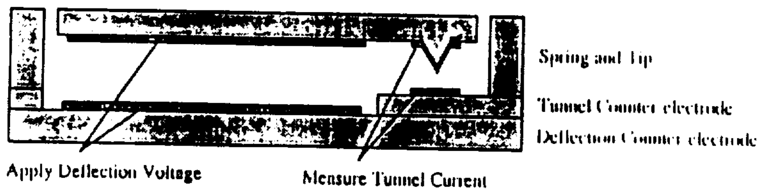
- Microscopic active area.
  Less sensitive to contamination
  Allows construction of micron-scale sensors

- Low power consumption.

- Simple electronic control system.

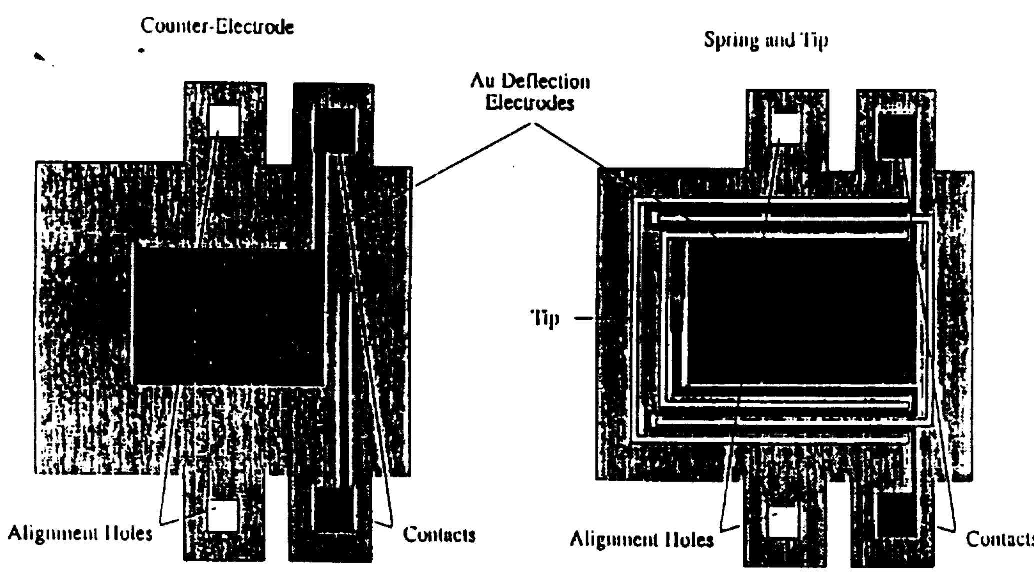
- Compatible with silicon micromachining technology.

Tunnel Accelerometer Operation



- Apply a deflection voltage until tunnel current appears.
- Activate Feedback Loop to maintain constant tunnel current
- If device experiences acceleration, spring will flex, producing a change in tunnel current.

Accelerometer Components



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Transducer Sensitivity Comparison

Transducer Type	Capacitive	Tunneling
Active Area	10 µm x 10 µm	10 Å x 10 Å
Electrode Separation	1 µm	5 Å
Bias Voltage	1 Volt	100 mV
Measurement Frequency	200 kHz	DC - 10 MHz
Measurement Current	1.1 nA	1 nA
1 % Transducer Signal	90 Å	0.004 Å

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Electron Tunneling Sensors

Present Proof-of Concept demonstrations rely upon off-chip electronics for simplicity and ease of modification.

Future completed devices will require integration of sensor and electronics.

Use of micromachined silicon for sensor structure will allow integration of sensor and electronics in the same silicon crystal.

Integrated sensors will be important for a broad class of NASA applications and will be candidates for technology transfer to industry.

Electron Tunneling Sensors

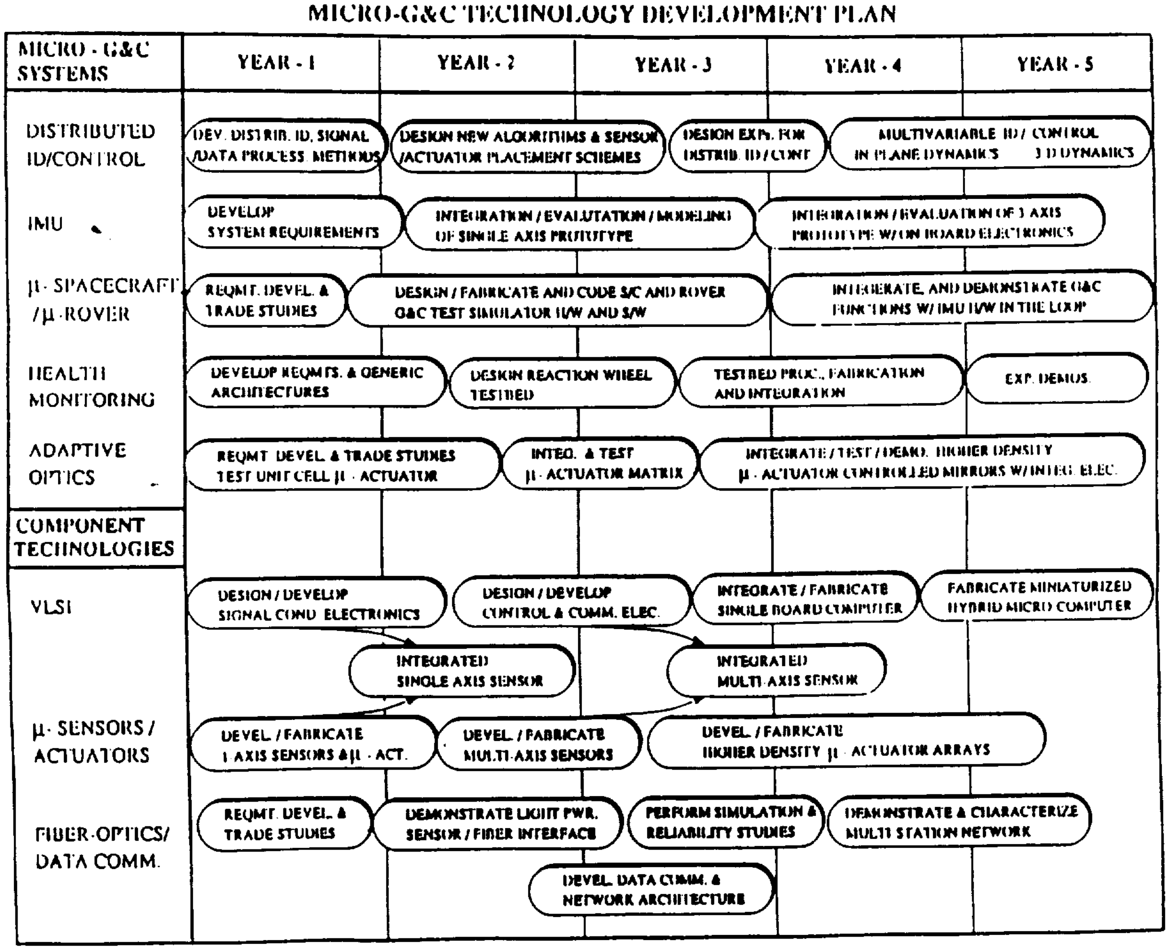
Generic Requirements for Tunnel Sensor Operation :

- Analog or Digital Feedback Loop for Control of Tunneling Current

  Operational Amplifiers for Amplification of 1 nA Current Located Near Transducer.
  Comparator Circuit for Sensing Force Applied to Transducer.
  Output Circuit for Applying Correction To Controlling Capacitor.

- Muiltiplexer for Selecting Individual Sensor
- Digital Signal Processor for Pre-Processing and Compression of Data.
- Interface Electronics

MICRO-G&C TECHNOLOGY DEVELOPMENT PLAN



SUMMARY

THIS INITIATIVE IS PLANNED TO:

- DEVELOP MICRO-G&C TECHNOLOGIES THAT MEET THE NEEDS OF FUTURE SPACE SYSTEMS
- ENABLE NEW CAPABILITY IN DISTRIBUTED CONTROL
- MAJOR REDUCTION IN G&C MASS, SIZE, POWER, PERFORMANCE RISKS, COSTS AND COST GROWTH
- HAVE SELECTED TASK THEMES WITH TIME-PHASED DEVELOPMENT PRODUCTS OVER FIVE YEARS
- HAVE TASKS AND PRODUCTS THAT ARE SYNERGISTIC IN SUPPORTING NEW G&C SYSTEM FUNCTIONS AND ARCHITECTURES

INTEGRATED TECHNOLOGY PLAN FOR THE CIVIL SPACE PROGRAM

CONTROLS-STRUCTURES INTERACTION (CSI) TECHNOLOGY PROGRAM SUMMARY

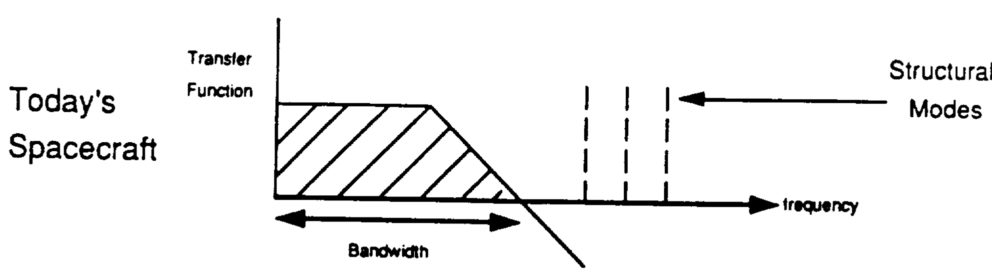
EARTH ORBITING PLATFORMS PROGRAM AREA OF THE SPACE PLATFORMS TECHNOLOGY PROGRAM

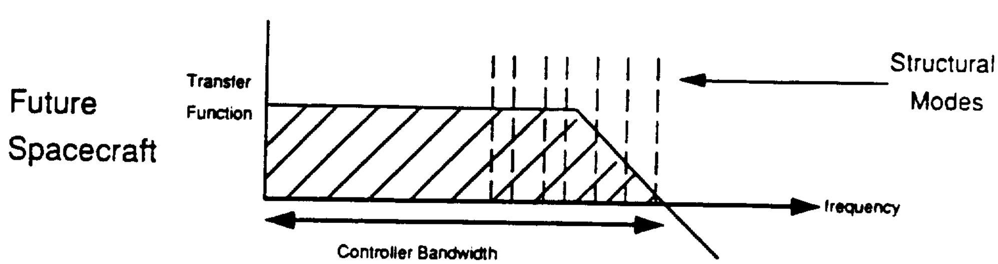
Jerry R. Newsom
NASA LaRC

June 26, 1991

CONTROLS- STRUCTURES INTERACTION

- CSI technology embraces the understanding of the interaction between the spacecraft structure and the control system, and the creation and validation of concepts, techniques and tools for enabling the interdisciplinary design of an integrated structure and control system, rather than the integration of a structural design and a control system design. (SSTAC 1987)





CONTROLS-STRUCTURES INTERACTION (CSI) TECHNOLOGY

GOAL:

DEVELOP VALIDATED CSI TECHNOLOGY FOR INTEGRATED DESIGN/ANALYSIS AND QUALIFICATION OF LARGE FLEXIBLE SPACE SYSTEMS AND PRECISION SPACE STRUCTURES

OBJECTIVES:

- To provide spacecraft dynamic response amplitude reductions of 50 percent, for any input or maneuver, with minimum increase in system mass.
- To enable the use of wide-bandwidth CSI control systems to achieve several orders of magnitude improvement in control and pointing capabilities.
- To predict the on-orbit performance of CSI systems within 10 percent of all amplitude, frequency, time and stability requirements based on the results of integrated analyses tuned/corrected by closed-loop ground and/or flight test data.
- To develop unified controls-structures modeling, analysis and design methods which allow a complete iteration on all critical design variables in a single integrated computational framework.
- To develop the capability to validate the performance of flight systems by analysis/ground tests.

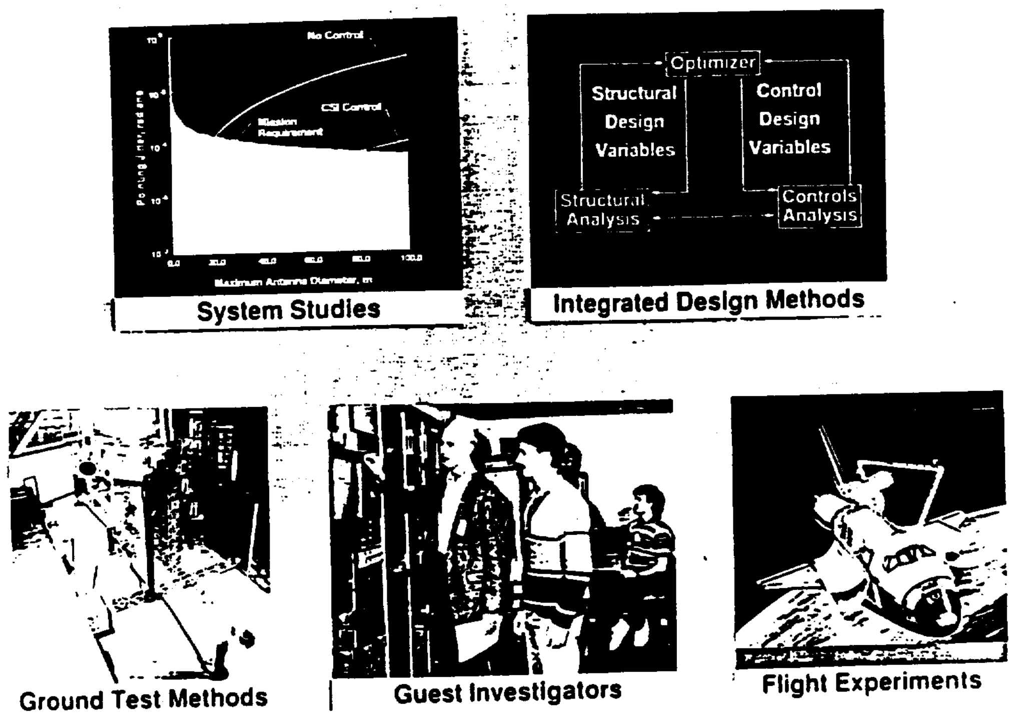
CSI PROGRAM FOCUS MISSIONS

EARTH OBSERVATION PLATFORM

OPTICAL INTERFEROMETER

ASTROPHYSICS

CONTROLS STRUCTURES INTERACTION PROGRAM

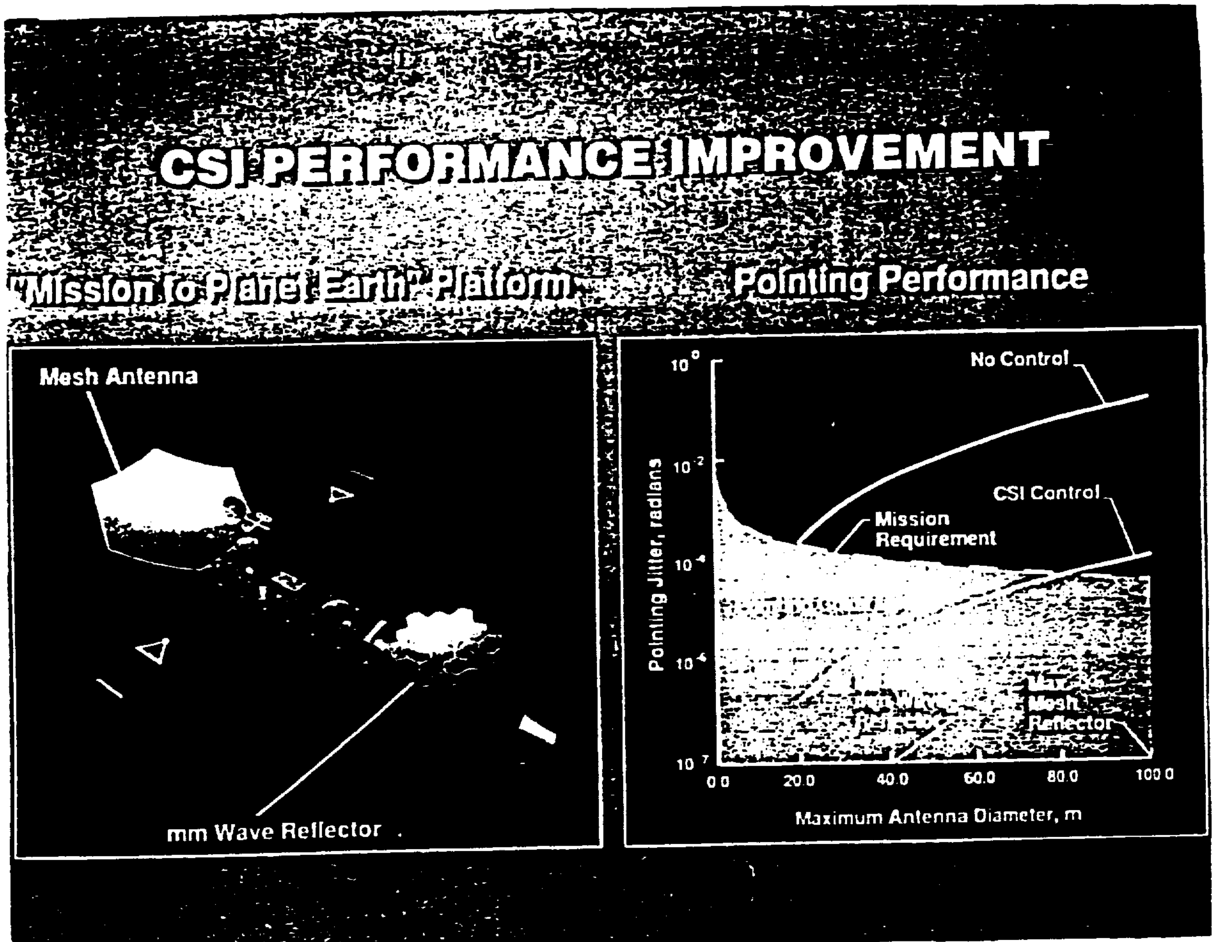


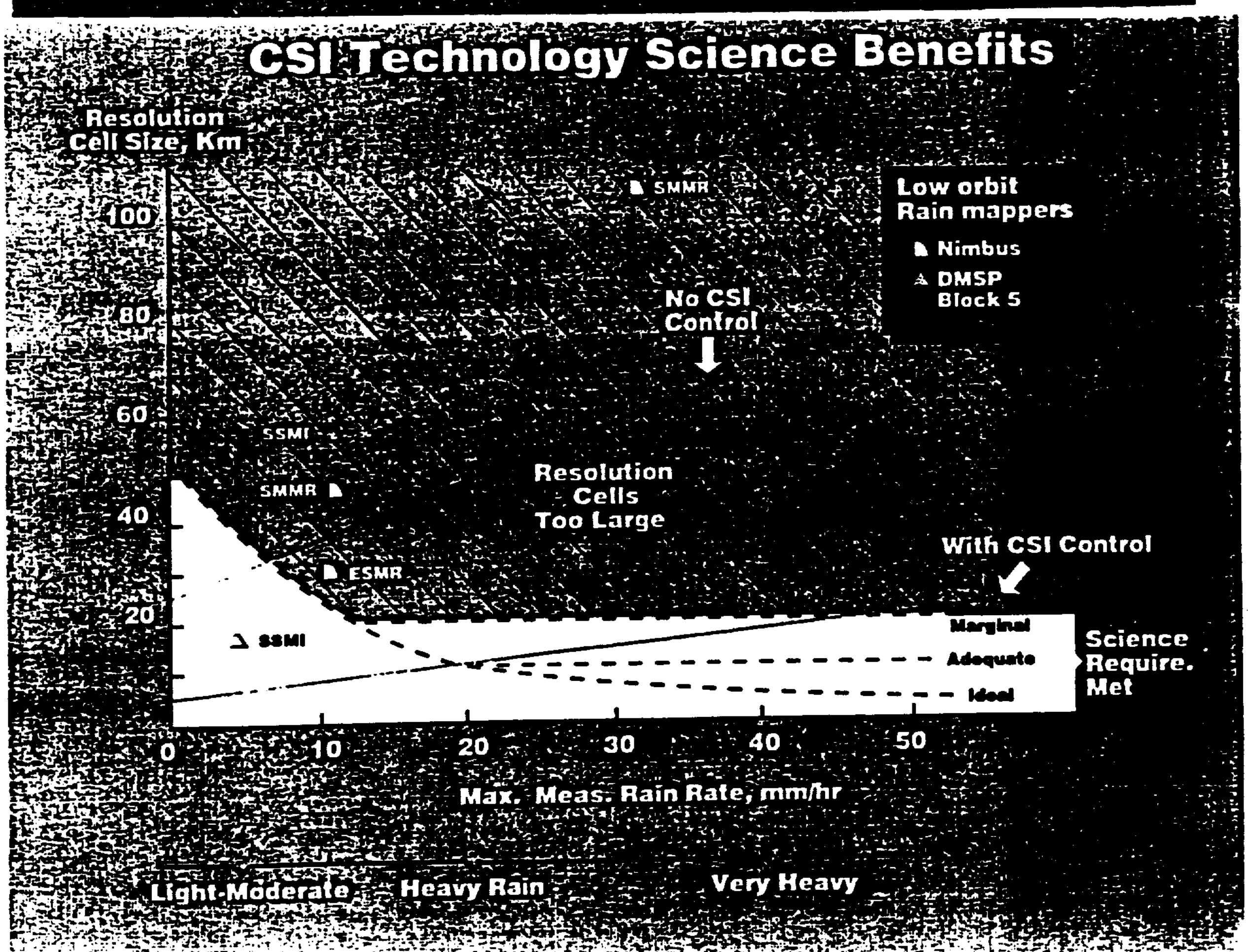
BENEFITS STUDY

- PURPOSE: To Quantify the Specific Advantages of CSI Technology for Future Missions Requiring Large Space Structures.

- APPROACH: Select a Future NASA Mission and Define Differences in the Spacecraft Design and Performance Capability Using Both the Conventional and CSI Approach.

- EXAMPLES: (1) Geostationary Platform
  (2) Shuttle RMS
  (3) Multipayload Platform





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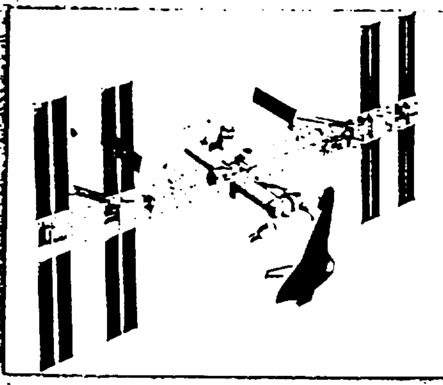
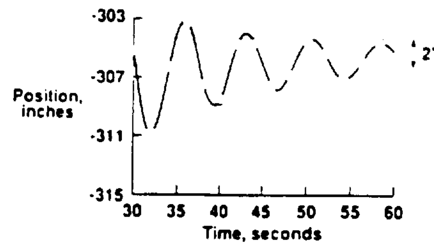
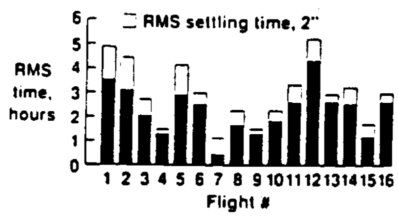
POTENTIAL SPACE STATION ASSEMBLY BENEFITS DUE TO CSI (Timeline)



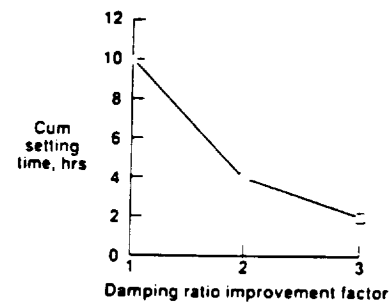
Draper RMS Simulator response
Payload 3500 lbs



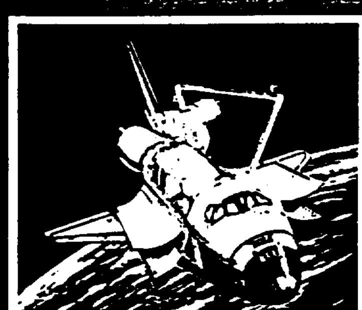
RMS settling time



Potential CSI benefits

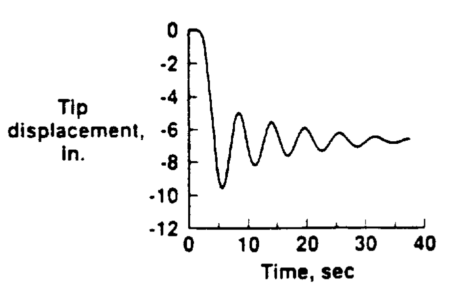


ACTIVE VIBRATION CONTROL OF THE SHUTTLE RMS

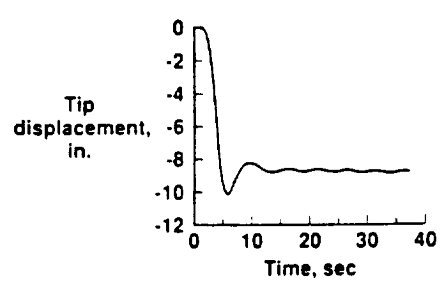


Typical RMS flexible mode
f = 0.26 Hz

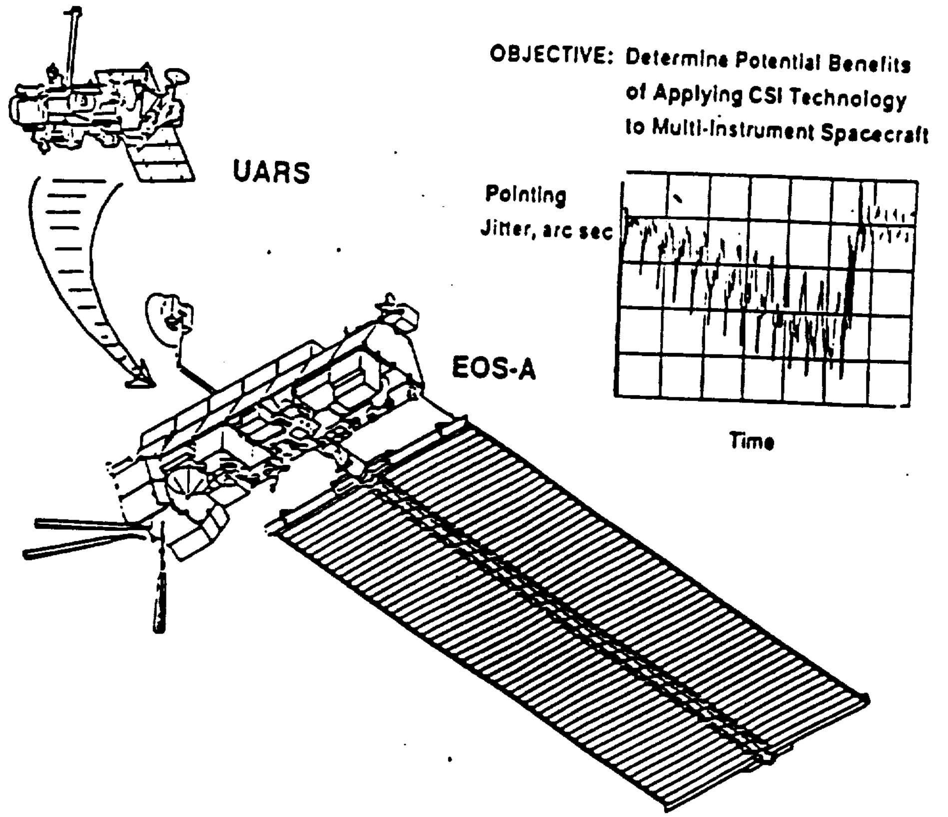
TIP response
without active vibration control



TIP response
with active vibration control



MULTI-PAYLOAD PLATFORM CSI STUDY



GROUND TESTS AND TEST METHODS

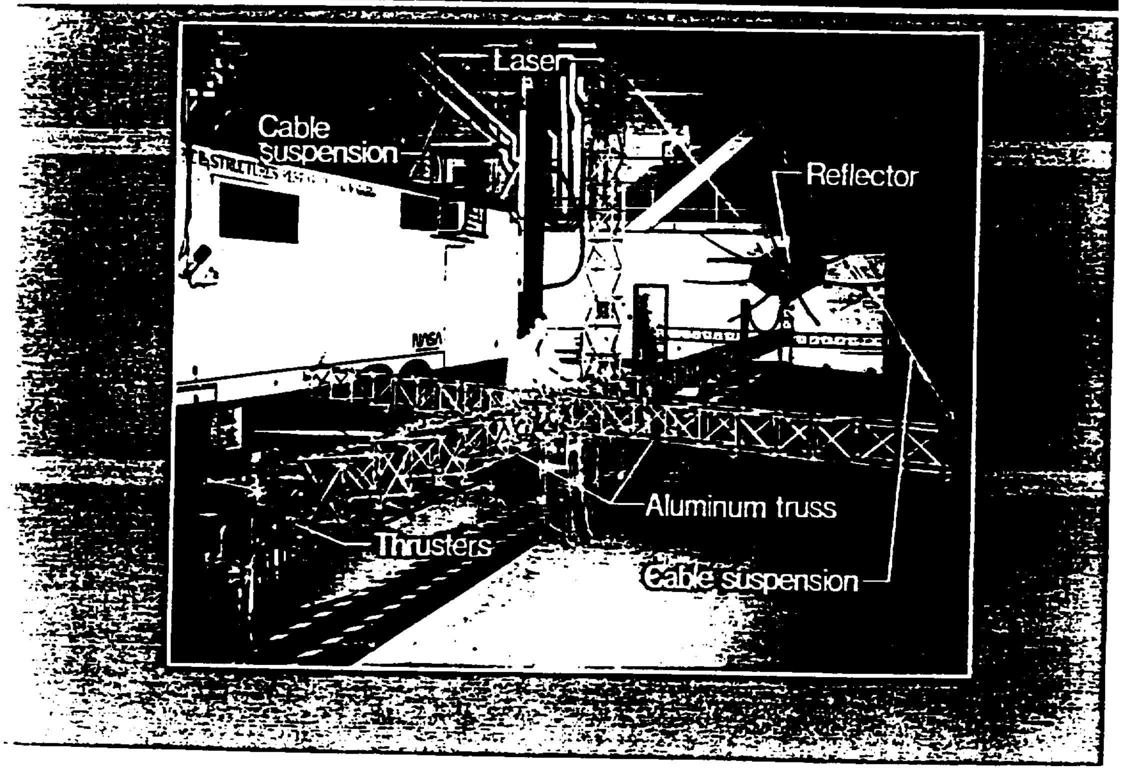
Objectives

- To ascertain the applicability of theoretical CSI developments to complex hardware systems
- To develop ground test methods suitable for verifying that CSI spacecraft systems are adequate for flight

Approach

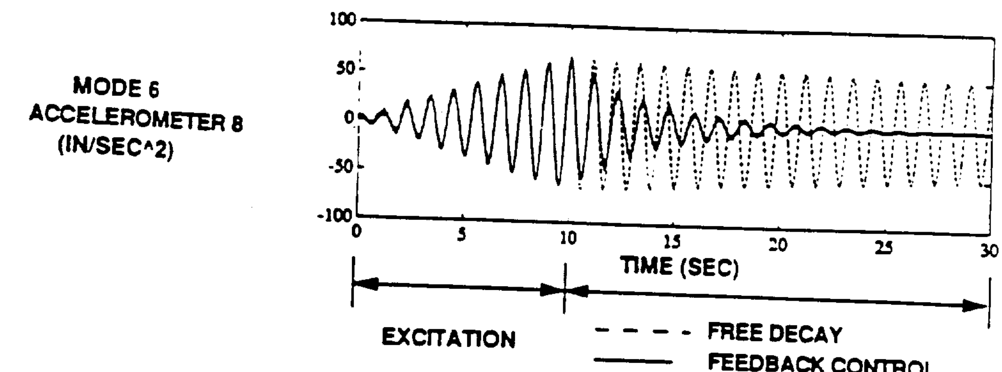
- Develop hardware testbeds
- Perform in-house analysis and tests
- Conduct guest-investigator studies

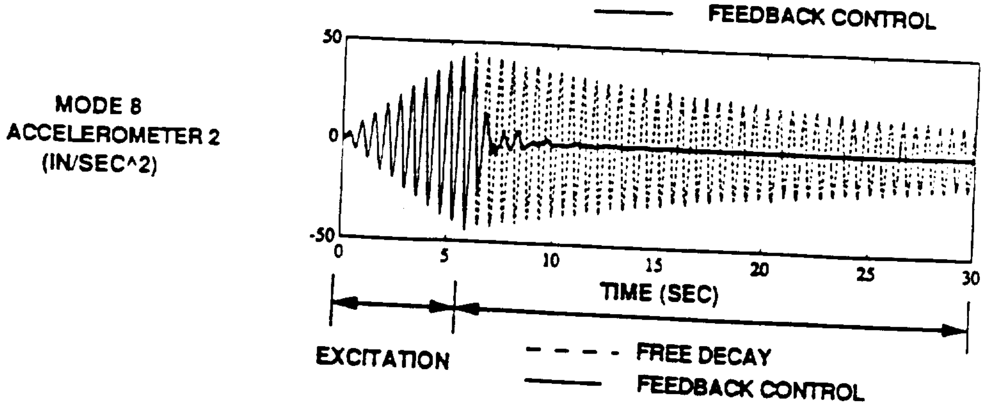
THE PHASE-ZERO EVOLUTIONARY MODEL: A CONTROLS-STRUCTURES INTERACTION TESTBED



EXPERIMENTAL RESULTS

OPEN AND CLOSED-LOOP RESPONSES





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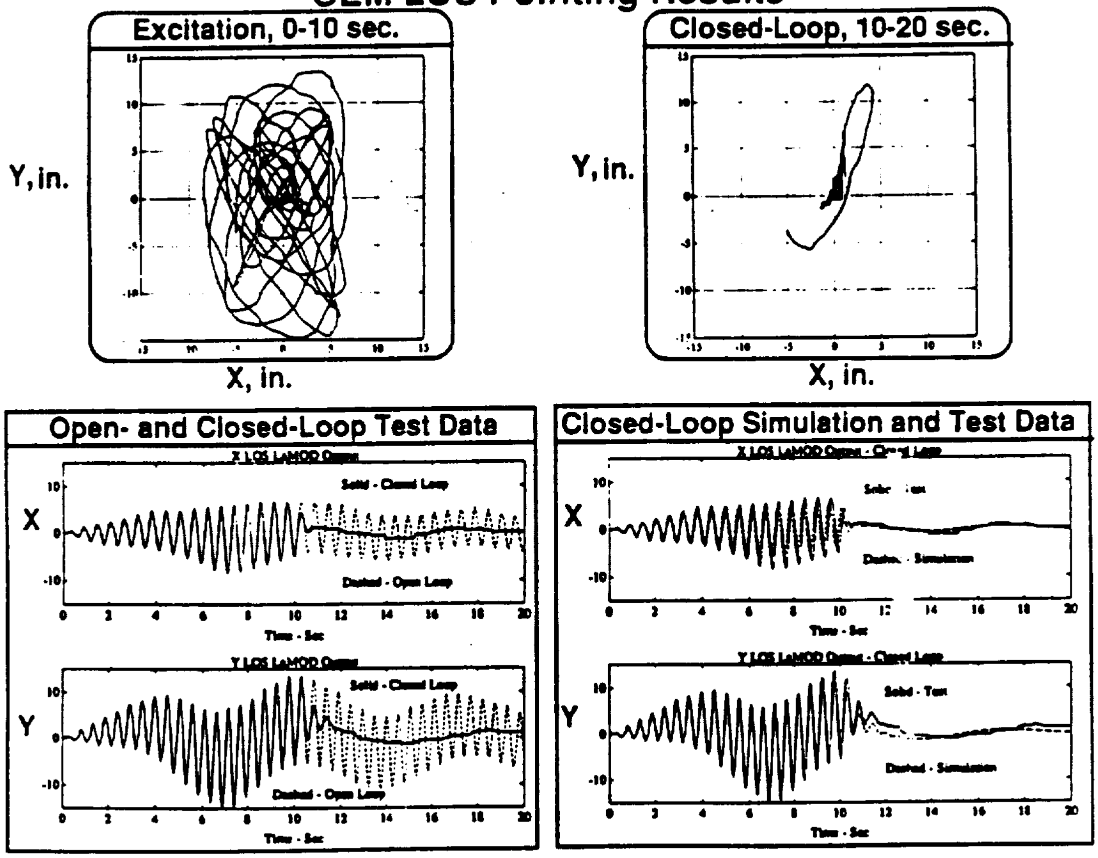
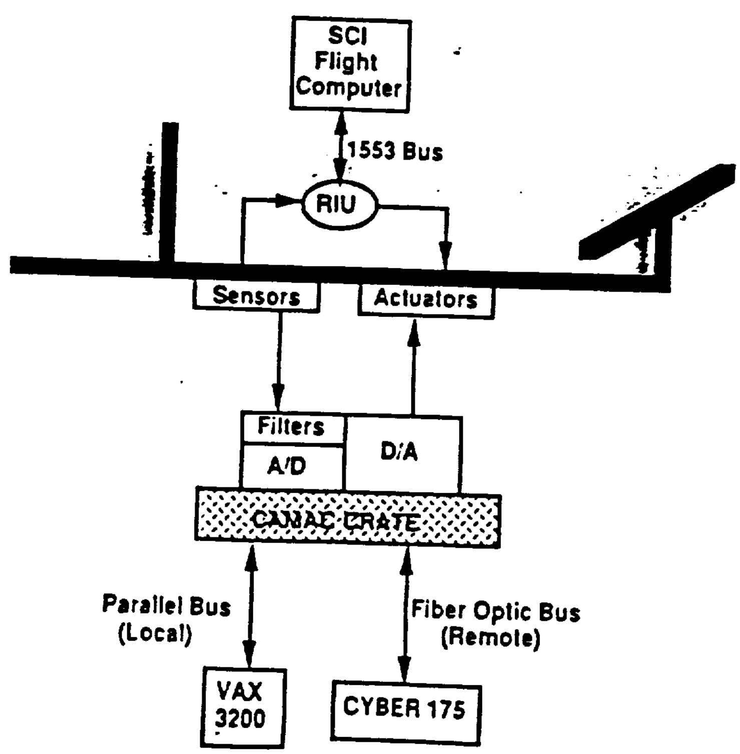
CEM LOS Pointing Results



Real-Time Computer Hardware



SOFTWARE DEVELOPMENT OVERVIEW

- Entire software system developed at Langley (ACD/FSGB)
  - Real-Time Executive, Interfaces, Applications
  - RIU and 1553B interface software developed jointly with SED
- Software for all 1750A's and PC/AT will be written in Ada
- This is Langley's first production Ada project
- Similar Ada based 1750A systems are proposed for EOS missions
- Software system designed using object-orientated design methods
  - Allows software to evolve in step with hardware system
  - Testbed modules can be reused on future missions (CSI, EOS)
- Believed to be one of the first real-time distributed Ada based 1750A production systems anywhere.

GTM Testbed Description/Goals

Phase 0
Global LOS Pointing objective.
Uniform structure.
500 micro radians accuracy.
Active only, 8 accels, 8 thrusters.

Implement LAC/HAC controller on structure with realistic dynamics of space platforms.

Phase 1
Global LOS Pointing objective.
Integrated controller & structure.
500 micro radians accuracy.
Active only, 8 accels, 8 thrusters.

Quantify benefits of integrated controller & structure design and assess predictive accuracy.

Phase 2
Multi-Payload Pointing objective.
Phase 1 structure.
5 micro radians accuracy.
24 piezo struts, 3 gimbals.

Implement distributed/centralized controllers for multi-payload platforms.

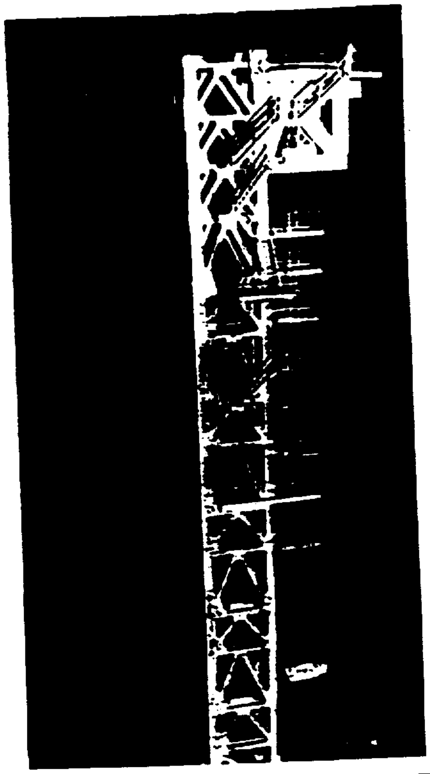
Phase 3
Multi-Payload Pointing objective.
Redesigned structure.
5 micro radians accuracy.
24 piezo struts, 3 gimbals.
100 passive struts,optimal sensor actuator placement.

Verify integration of passive, active smart systems with multi-objective controller.

Phase 4
Integrated controller & structure multi-payload free-flyer design.
5 micro radians accuracy. Integrated passive and active sensors/actuators and on-board power and computers.

Ground test experiment for CSI Class 1 & 2 flight demonstration.

CASES GTF (Ground Test Facility)



- **Status: Partially Operational**

Test Articles: Boom, MPESS, Tip Plate completed
Boom/MPESS suspended

Disturbance System: Integration nearing completion

Computer System: Delivered, Tested
CASES Software being developed

Sensors & Actuators:
AMED system: Final testing prior to integration
BLTs tested
BMT/TDS design in progress
Auxilliary sensors obtained (Accels, Force, etc...)

Electronics: Several subsystems complete
(Mux/Demux, Reaction Wheel, Gyro, etc....)

- **Baseline Operational: Aug/Sept 1991**

AMEDs	Angular Momentum Exchange Devices
BLTs	Bidirectional Linear Thrusters
BMT/TDS	Boom Motion Tracker/Tip Displacement Sensor
CASES	Controls, Astrophysics, and Structures Experiment in Space
MPESS	Mission Peculiar Experiment Support Structure

GUEST INVESTIGATOR PROGRAM

- GOAL: OBTAIN BEST AVAILABLE CSI TECHNOLOGY EFFORT FROM RESEARCHERS IN ACADEMIA & INDUSTRY.

- APPROACH: GENERAL SOLICITATION OF PROPOSALS THROUGH NRA WITH INTERCENTER SELECTION TEAM.

- STATUS:

<u>Phase I</u> - Completed
Eight Investigators
Two Test Beds
LaRC - Mini-MAST
MSFC - Advanced Control Evaluation for Structures (ACES)

<u>Phase II</u> - Joint Program with the Air Force, Edwards AFB
101 Proposals Received
Five Winners Announced December 1990
Three Test Beds
LaRC - CSI Evolutionary Model (CEM)
MSFC - Control, Astrophysics, and Structures Experiment in Space (CASES)
AF - Advanced Space Structure Technology Research Experiments (ASTREX)

PHASE 1 GUEST INVESTIGATOR PROGRAM

UNIVERSITY INDUSTRY	PRINCIPAL INVESTIGATOR	PRIMARY THRUST
CAL TECH	Dr. John Doyle	Noncollocated Controller Design
MIT	Dr. W. Vander Velde	Off-Line and On-Line Sys. ID Algorithms
PURDUE	Dr. Robert Skelton	Noncollocated Controller Design
U. CINCINNATI	Dr. Randall Allemang/ Dr. Slater	Off-Line System ID Algorithms
U. TEXAS	Dr. Bong Wie	Collocated/Noncollocated Controller Design
HARRIS	Dr. David Hyland	Noncollocated Controller Design
BOEING	Dr. Michael Chapman	Nonlinear Math Modeling
Dynamic Engin. /VPI	Wilmer Reed	Design of Passive and Active Suspension Systems

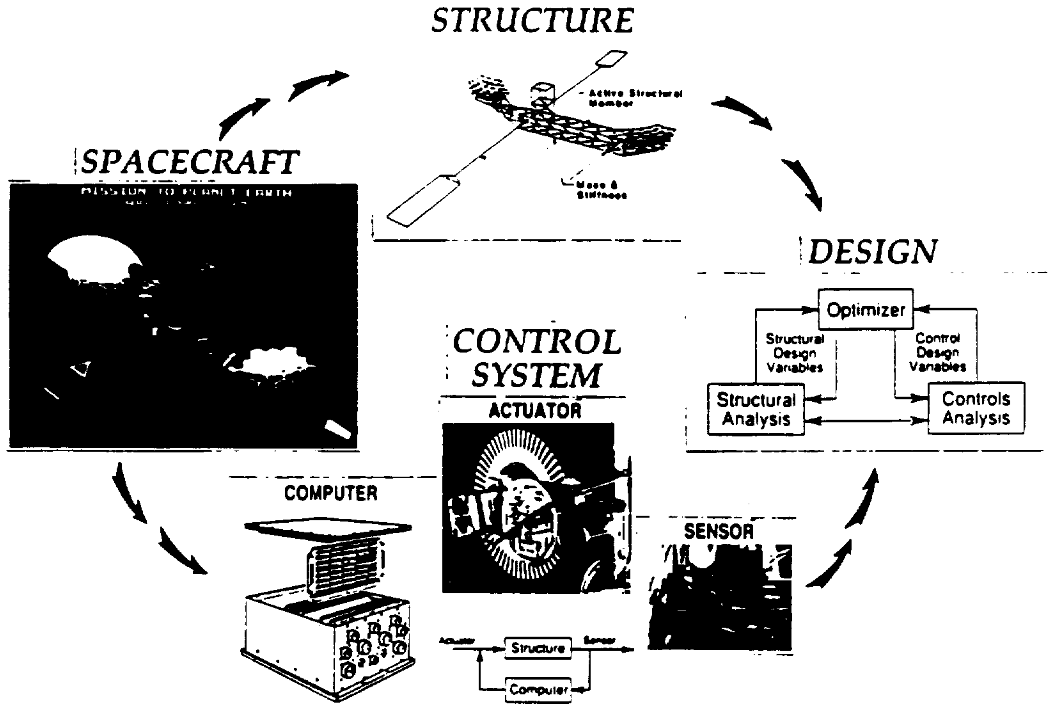
MAJOR LESSONS LEARNED

- Modeling sensors, actuators, and electronics as important as modeling structure
- Single-input single-output control design approach for flexible structure control can be effective
- System identification is an essential element for successful flexible structure control

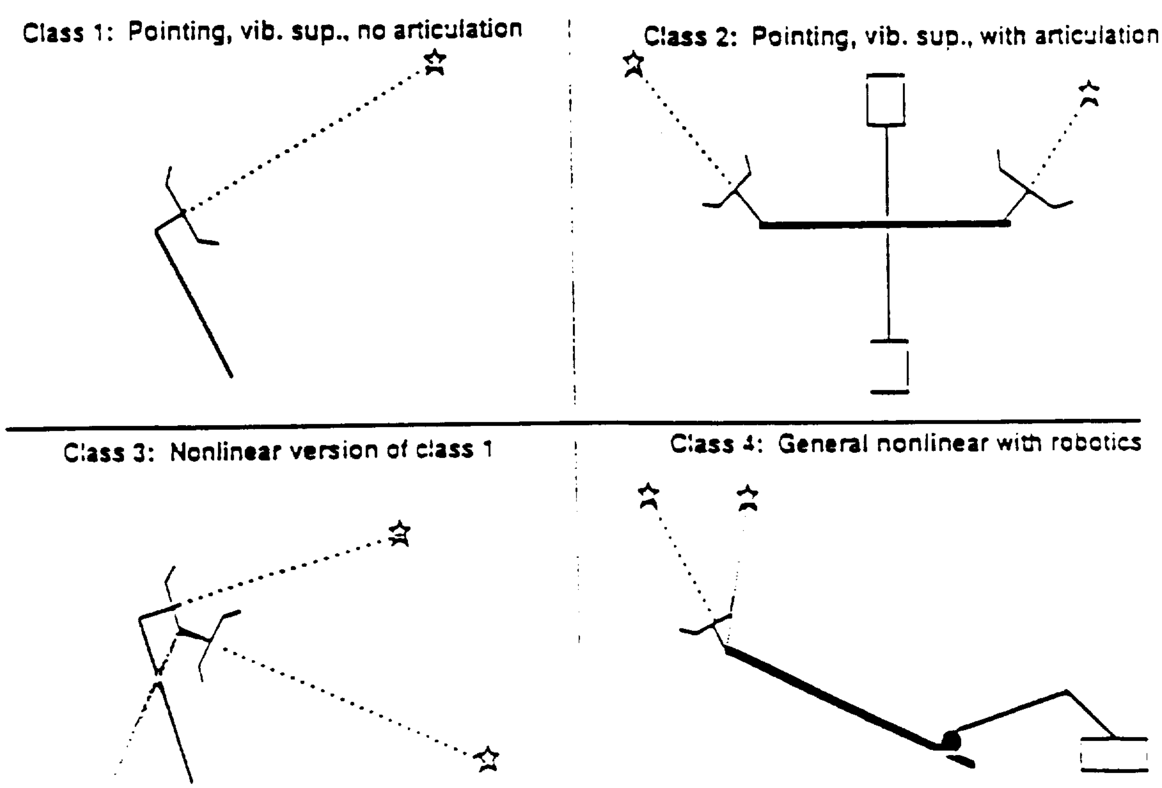
PHASE II GUEST INVESTIGATORS

UNIVERSITY/ INDUSTRY	PRINCIPAL INVESTIGATOR	PRIMARY THRUST (Facility)
Martin Marietta	Eric Schmitz	Smart Struts & Controller Design LaRC CSI Evolutionary Model
Harris Corporation	David Hyland	Noncollocated Controller Design MSFC Ground CASES
Boeing Aerospace	David Warren	CMG/RCS Pointing & Slewing Air Force ASTREX
MIT	Andy von Flotow	Passive Damping/Controller Design Air Force ASTREX
Texas A&M	Srinivas Vadali	Controller Design Air Force ASTREX

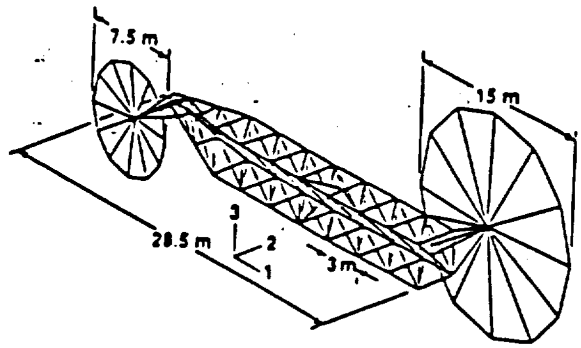
INTEGRATED STRUCTURE/CONTROL DESIGN



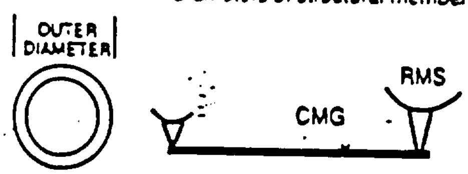
PROBLEM CLASSIFICATION



DESIGN PROBLEM I



- Design Variables – Dissipative controller gains
  Diameters of structural members



- Objective Function – For parameter $0 \leq \beta \leq 1$,

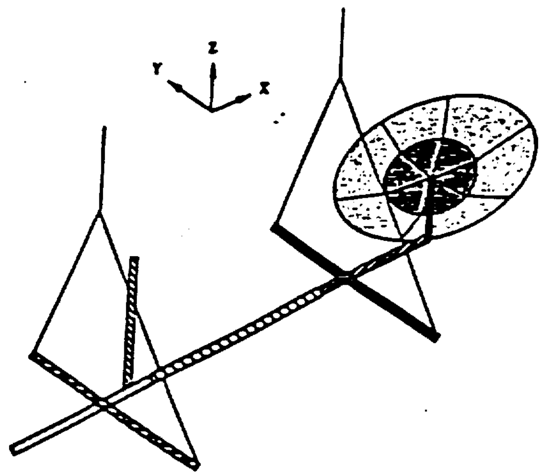
  $$\text{Minimize}\left[\beta \cdot \text{Total Mass} + \frac{(1-\beta)}{\text{Controlled Performance}}\right]$$

- Constraints
  – Structural member sizes and RMS pointing error at large antenna

CONVENTIONAL VS. INTEGRATED
(Dynamic Dissipative Controller)
RMS < 10 μrad

	Controlled Performance	Structural Mass	Actuator Mass	Total Mass
Initial Design	1.0	1.0	1.0	1.0
Control-optimized Design β=0.15	1.30	1.0	1.45	1.18
Integrated Design β=0.15	4.03	0.66	1.44	0.97

INTEGRATED DESIGN VALIDATION
PHASE-1 CEM



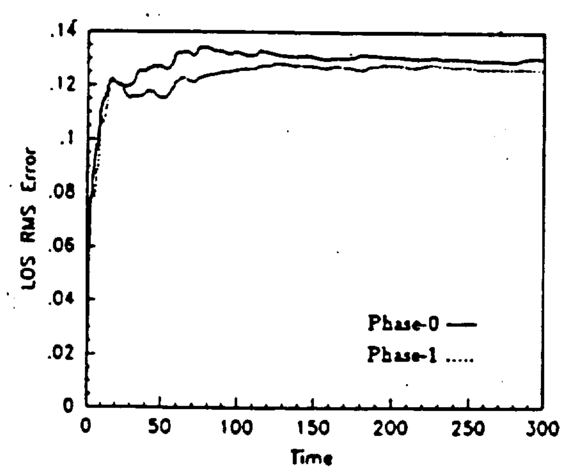
- OBJECTIVE: MINIMIZE THE AVERAGE CONTROL POWER WHILE MAINTAINING THE RMS LINE OF SIGHT (LOS) TO A SPECIFIED VALUE WITHOUT ANY INCREASE IN STRUCTURAL MASS (OVER PHASE-0 DESIGN).

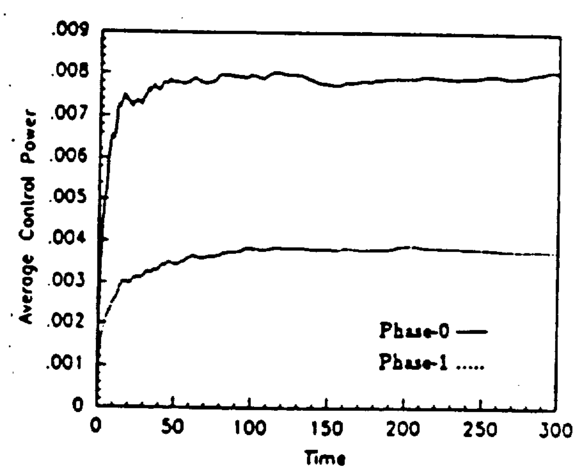
- DESIGN VARIABLES

  STRUCTURE - EFFECTIVE CROSS-SECTIONAL AREAS OF 21 LONGERONS, BATTENS, AND DIAGONALS

  CONTROL - ELEMENTS OF THE COMENSATOR AND GAIN MATRICES OF A DYNAMIC DISSIPATIVE CONTROLLER

SIMULATION RESULTS





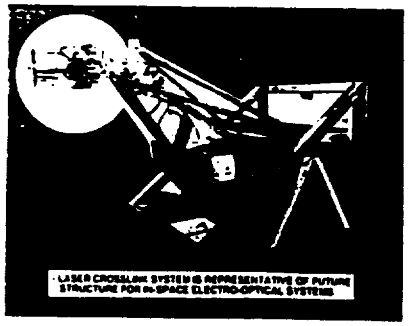
JUSTIFICATION FOR ON-ORBIT CSI EXPERIMENTS

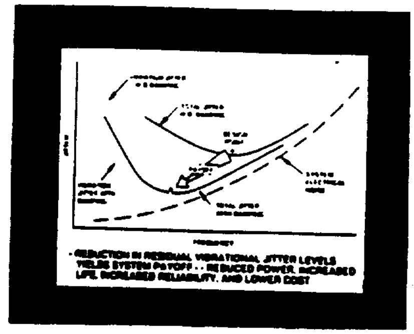
- DEVELOP UNDERSTANDING OF GRAVITY EFFECTS ON GROUND TESTING
  - Direct Gravity Effects: stiffness, modal coupling, damping
  - Indirect Gravity Effects via Suspension system dynamics: pendulous modes, local attachment loads, large angle articulation limitations, etc.
- QUANTIFY ACCURACY OF PREDICTIONS OF ON-ORBIT PERFORMANCE
- DEMONSTRATE NEW FLIGHT QUALIFICATION PROCEDURE
  - Dependent on on-orbit dynamic testing
  - Subsequent adjustment of controller parameters

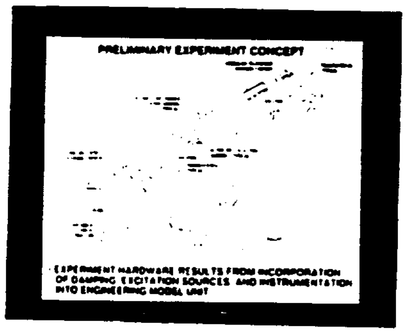
CSIO FLIGHT EXPERIMENTS

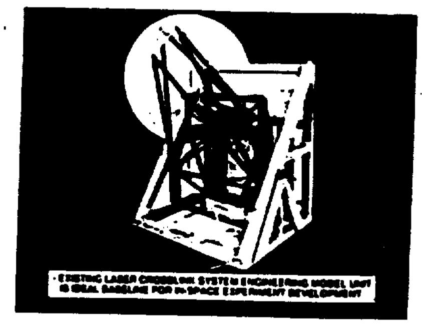
- JITTER SUPPRESSION EXPERIMENT (JSX)
  - McDonnell Douglas Prime Contractor
  - Funded by OAET's In-Space Technology Experiments Program (In-STEP)
- MIDDECK ACTIVE CONTROL EXPERIMENT (MACE)
  - MIT Prime Contractor
  - Funded by In-STEP
- ADVANCED FREE-FLYER EXPERIMENT
  - LaRC/MSFC/JPL Conceptual Definition in Progress

JITTER SUPPRESSION
FOR
PRECISION SPACE STRUCTURES

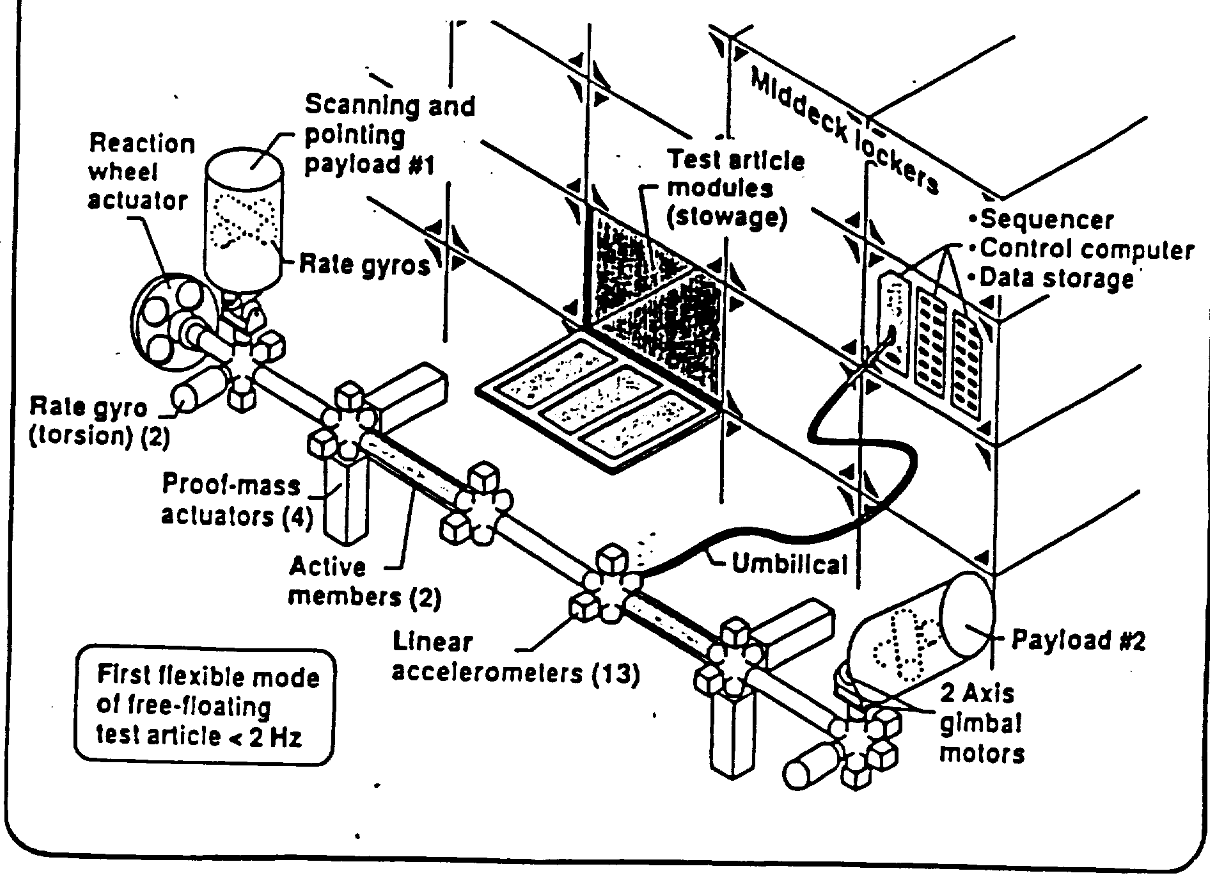




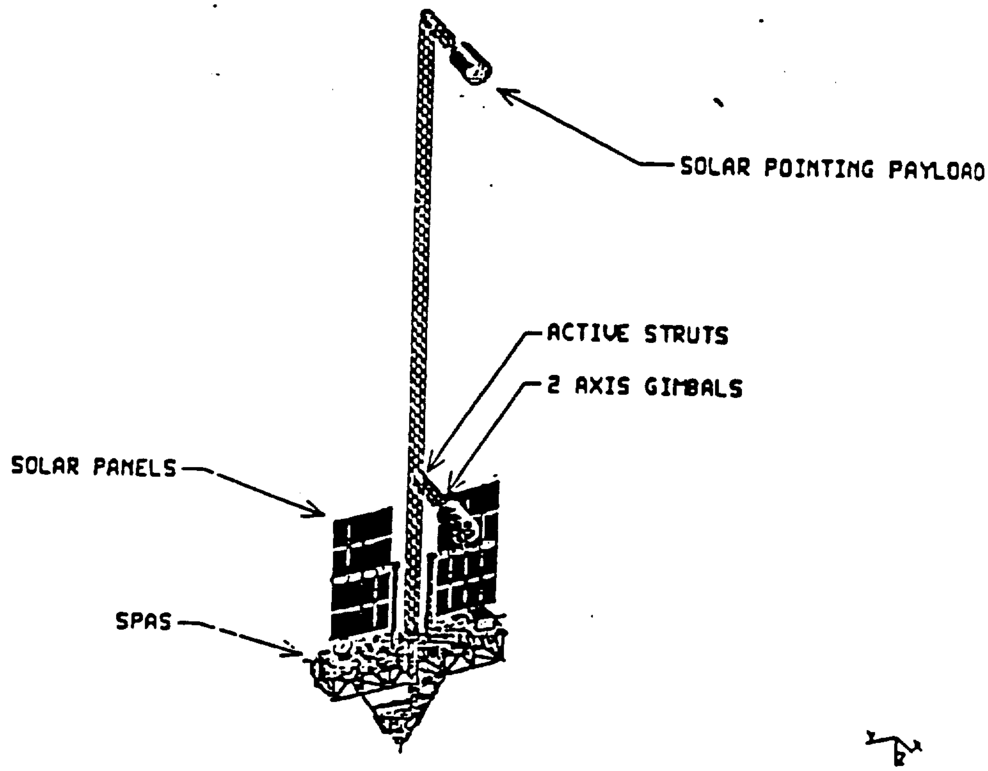




MIDDECK ACTIVE CONTROL EXPERIMENT (MACE)



CSI FREE FLYING EXPERIMENT



SUMMARY

- CONTROLS-STRUCTURES INTERACTION (CSI) IS A KEY ENABLING TECHNOLOGY FOR FUTURE NASA SPACECRAFT
- PROPER IMPLEMENTATION OF CSI TECHNOLOGY OFFERS THE POTENTIAL FOR SIGNIFICANT IMPROVEMENTS IN CAPABILITY
- CSI IS EFFECTIVELY A NEW DISCIPLINE WHICH ENCOMPASSES AND INTEGRALLY MERGES STRUCTURES AND CONTROLS
- NASA HAS EMBARKED ON A MAJOR MULTI-CENTER EFFORT TO DEVELOP THIS TECHNOLOGY FOR PRACTICAL APPLICATION TO SPACECRAFT