Human Centered Autonomous and Assistant Systems Testbed for Exploration Operations

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The Engineering and Mission Operations Directorates at NASA Johnson Space Center are combining laboratories and expertise to establish the Human Centered Autonomous and Assistant Systems Testbed for Exploration Operations. This is a testbed for human centered design, development and evaluation of intelligent autonomous and assistant systems that will be needed for human exploration and development of space. This project will improve human-centered analysis, design and evaluation methods for developing intelligent software. This software will support human-machine cognitive and collaborative activities in future interplanetary work environments where distributed computer and human agents cooperate. We are developing and evaluating prototype intelligent systems for distributed multi-agent mixed-initiative operations. The primary target domain is control of life support systems in a planetary base. Technical approaches will be evaluated for use during extended manned tests in the target domain, the Bioregenerative Advanced Life Support Systems Test Complex (BIO-Plex). A spin-off target domain is the International Space Station (ISS) Mission Control Center (MCC). Products of this project include human-centered intelligent software technology, innovative human interface designs, and human-centered software development processes, methods and products. The testbed uses adjustable autonomy software and life support systems simulation models from the Adjustable Autonomy Testbed, to represent operations on the remote planet. Ground operations prototypes and concepts will be evaluated in the Exploration Planning and Operations Center (ExPOC) and Jupiter Facility.

HCAAST
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DRAFT

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Overview

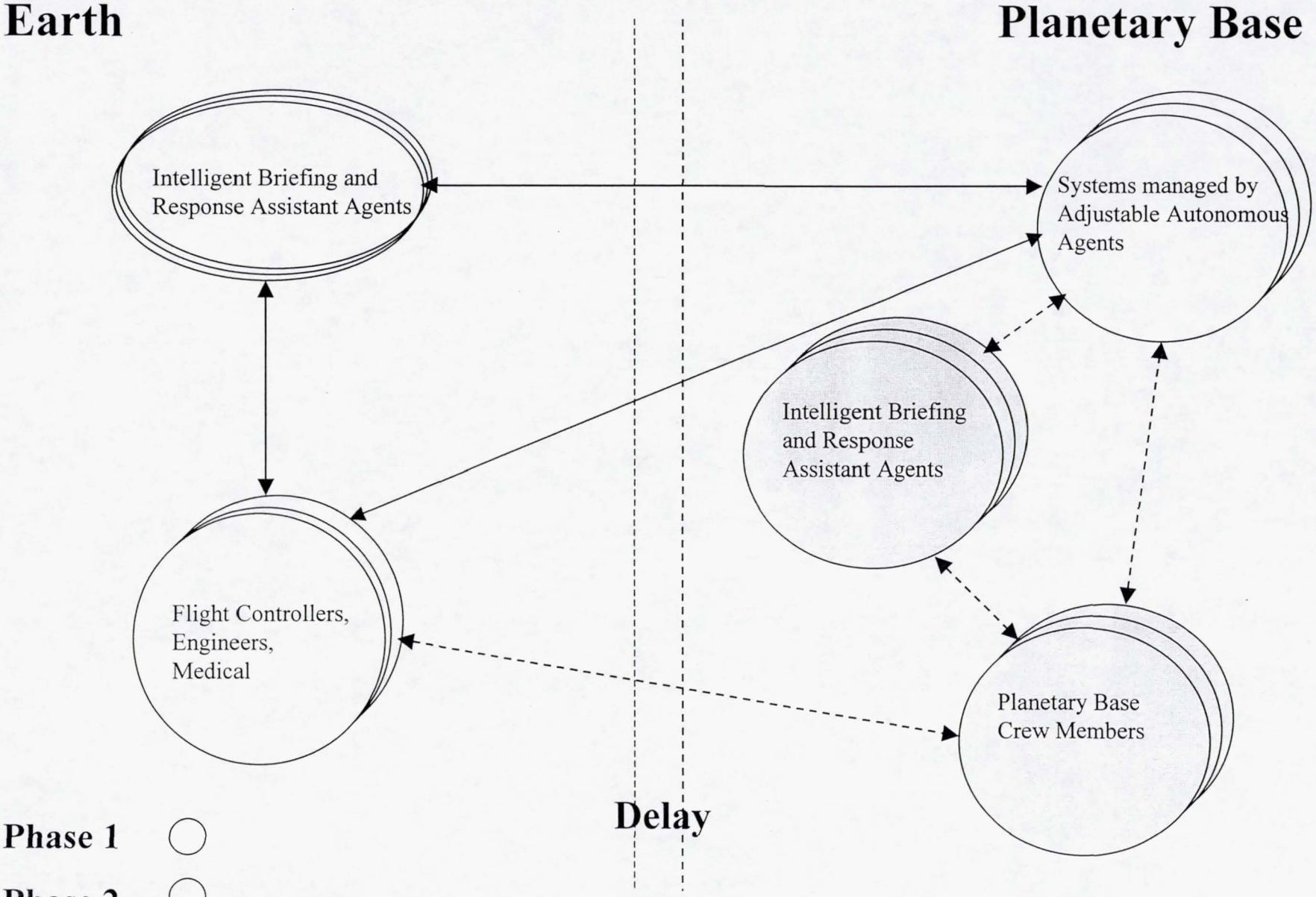
- HCAAST goals and challenges
- Human Centered analysis and design work
- Intelligent systems research challenges
  - Mixed initiative interaction with distributed intelligent agents
  - Data understanding
  - User interfaces
- HCAAST phasing and FY01 plan

HCAAST Goals

- Develop, integrate and validate human centered intelligent systems technology
  - Mission operations support systems with embedded intelligent systems technology
  - Human centered analysis and design for intelligent systems
  - Intelligent systems technology components

A Joint Engineering and Operations Testbed

- Management team and networked labs from Engineering and Mission Operations Directorates
  - Exploration-class mission control communications, data storage and workstations
  - Intelligent Systems Laboratory (Engineering)
    - Intelligent autonomous control of simulated production plant on Mars
  - Quest Lab, RaPID Lab and ExPOC (Mission Operations)
    - Intelligent assistant systems on earth
  - BioPLEX target (Engineering)
    - Initial focus on air processing, transfer and storage for life support


Earth
Planetary Base
Intelligent Briefing and Response Assistant Agents
Systems managed by Adjustable Autonomous Agents
Intelligent Briefing and Response Assistant Agents
Flight Controllers, Engineers, Medical
Planetary Base Crew Members
Delay
Phase 1
Phase 2

Cooperating Intelligent Agents

- Adjustable Autonomous Agents
  - Plan/schedule, execute, monitor, safe and recover
  - Detect, diagnose, assess
  - Recommend, predict, evaluate plans and actions
  - Adjust level of autonomy and support mixed initiative
- Intelligent Briefing and Response Assistant Agents
  - Monitor, make console log entries and alert
  - Analyze data patterns
  - Search
  - Build and organize briefings

Challenges for Autonomous Agents

- Autonomous remote processing plants with limited communication
  - Delays of up to one hour and low bandwidth
- Shifting between autonomy and teamwork to handle inevitable unexpected problems
- Loose coordination for flexible teams
  - Mixed initiative interaction and coordination
  - Updates and orientation rather than monitoring
  - Loose commanding rather than synchronized traded control

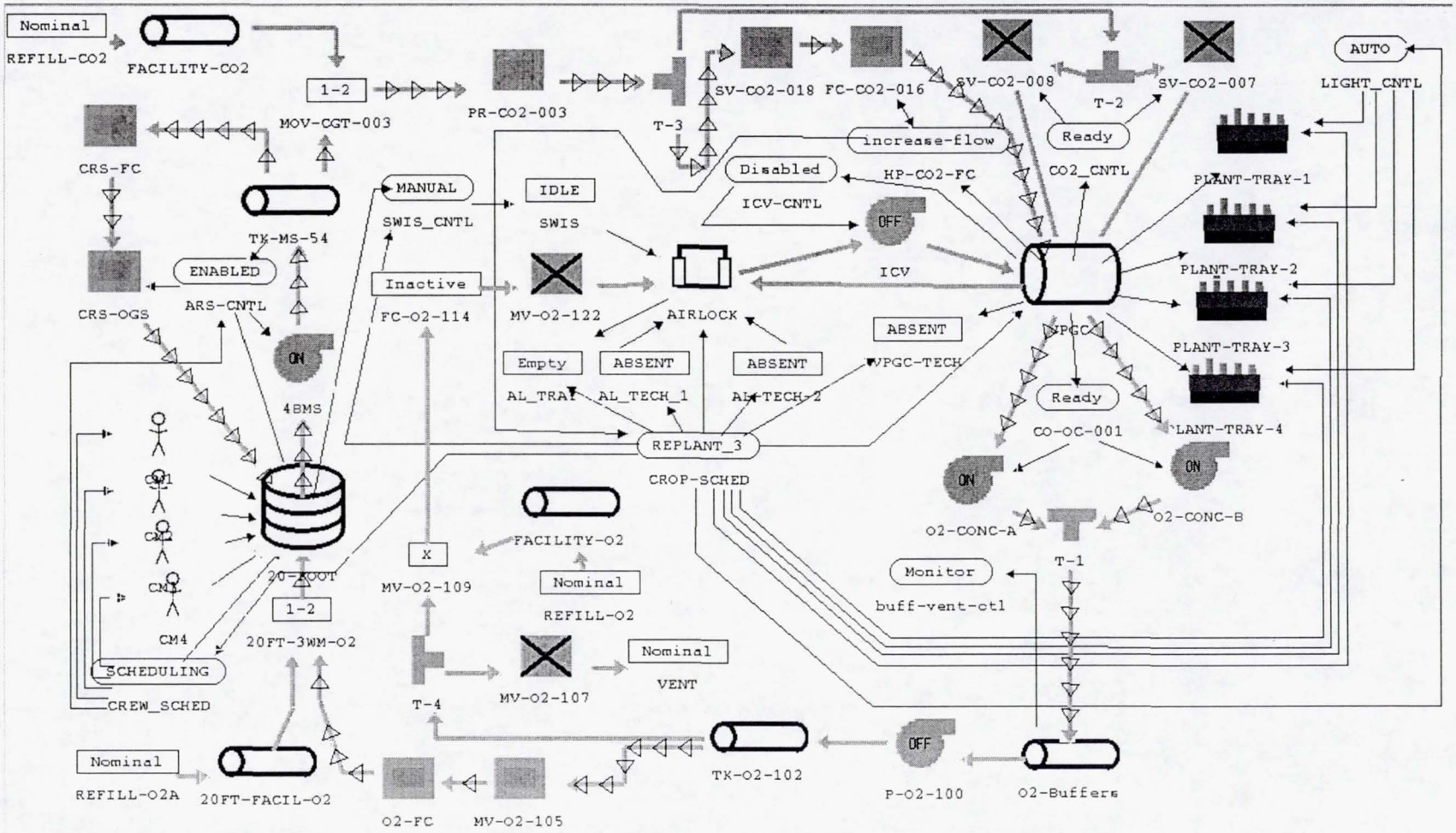
Leveraging Projects for Component Technology

- Adjustable Autonomy Testbed/Cooperative Fault Management (CETDP projects)
  - 3T/Livingstone agent architecture and user interfaces
  - CONFIG hybrid models and simulation of operation of planetary systems hardware
- Operations Assistants Technology (MOD)
  - Electronic Console Logging prototype
- Anomaly Response Analysis Archiving (previous Code U NRA and MOD)
  - ARTIS anomaly response team archive prototype
- NRAs and other coordinated in-house projects

Cooperative Adjustable Autonomous Fault Management Projects

- HCAAST leverages CETDP projects with simulated autonomous operations on the planet
  - Scenario-based hybrid simulation of life support hardware and operations – initially gas processing
  - Adjustable autonomous control and fault management by 3T and Livingstone agents
    - Planner with goals and plans
    - Reactive activity layer with tasks and intentions
    - Model-based agent with state assessments, diagnoses and recommended recovery actions
  - Focus of these projects in FY01 is on cooperative fault management – situation assessment and conflict resolution

Model of Planetary Life Support System Testbed used to Evaluate Intelligent Control Software



Human Centered Technology for Analysis and Design

- Make intelligent systems team players
  - Study exploration mission operations team analogs, to design cooperating intelligent systems
  - Design intelligent agents for mixed initiative interaction
  - Evaluate intelligent agents in mixed initiative interaction scenarios
- Make analysis products more useful and usable for developers of intelligent systems technology
  - Models and other products from field studies and evaluations
  - Investigate just-in-time analysis for levels of design

Three Levels of Analysis for System Design

- Work system objectives, strategies, operations concepts
  - Work flow models, artifact models
- Functions, tasks, activities, work and system structures
  - Structured models of supported tasks, activities
- Information, displays and controls
  - Decisions to support, information, communication

Support for Intelligent Systems Technology Development

- TRL 4 Laboratory validation of in-house and externally developed technology
  - Prepare for TRL-5/6 exploration testbeds
    - BIO-Plex life support testbed
    - Mission Control testbeds in Quest Lab and ExPOC
- TRL 3 Proof-of-concept studies
  - Support with system-level simulation of operations scenarios
- TRL 1-2 Challenges for exploration operations
  - Automated Reasoning: Mixed initiative interaction with distributed intelligent agents
  - Intelligent Data Understanding
  - Design for Future User interfaces

Roles of Autonomous Systems

- When situation is routine, autonomous system is like flight controller, loosely coordinating with rest of team – periodic update reports
- When recognizing a problem, autonomous system is like Station Duty Officer
  - Notify, analyze, report with assessments, near-term actions, predictions
- When solving a problem, autonomous system is like member of anomaly response team
  - Continue to function as remote "flight controller"
  - Compare and resolve conflicts, evaluate, update and rehearse chosen course of action

Mixed Initiative Interaction Research Challenges

- Agents on planet and on earth, with variable communication delays
- Provide information to establish shared frame of reference in periodic updating of on-call operators
  - Communicate high level assessments, plans, operations
- Communicate among heterogeneous agents managing multiple complex systems
- Give and get help with anomaly response
- Handle loose commanding and delegation
- Negotiate and evaluate alternatives

Results of Human-centered Research

- Mission Control Center: a place where teams manage unexpected situations
  - Loose coordination via voice loops, console logs or diaries, shift change updates
  - Anomaly response teams with diverse viewpoints
- HC Research: Analyses, models, designs for group communication and information processing support
  - Common ground and common representations supporting awareness for coordination
  - Conflict resolution that leads to better team assessments, goals and plans

Common Ground

- Updates replace real-time monitoring
  - Briefings and logs rather than conversation
  - High level, with access to lower-level information and data
  - Information above data level, organized for review and revision
    - Plans, situations, issues and recommendations
- Goal is to relieve some escalation pressures by establishing common ground of awareness and providing appropriate level of information

Conflict Resolution Challenges

- Long-distance "negotiation" and delegation for anomaly response
- Expose alternatives and potential conflicting assessments, interests/goals, operations
- Support generation of options and analysis and evaluation of assessments and plans
  - "Current" and predicted status and capabilities communicated to ground
- Design for loose commanding (delegation) in face of uncertain state on planet after time delay
  - Goals and conditions communicated to planet with acknowledgements and commands

Challenges of Changing Plans and Procedures

- Communicating novel procedures and plans
  - Use activity trees to change operations without programming?
- Assessing feasibility, safety and mission impacts of new procedures and plans
  - On earth and on the planet
- How are procedure and plan updates handled between ground and space now?

Research Challenges for Data Understanding & Human Interfaces

- Operate remote complex systems autonomously with limited communication
  - Interpret, filter, correlate, summarize and manage
    - Planetary systems data
    - High level autonomy information
  - Adapt and learn
- Design for integration of novel interfaces for exploration operations
  - Adaptive interfaces
  - Multimodal interfaces (e.g., interactions with EVA robotic assistant, virtual presence)

HCAAST Phasing Approach

- FY01-03 Cooperative autonomous planetary operations and fault management of life support systems, with mission controllers on earth
  - Distributed intelligent briefing and response assistants for orientation and intervention
- FY03-05 Cooperative autonomous planetary operations and fault management of life support systems, with earth and planet (crew) mission controllers
- FY04-05 Given appropriate funding, multi-modal user interfaces for distributed mobile agents

HCAAST FY01 Plan

- Establish testbed of networked labs, with equipment to support analysis and evaluation
- Select, use and evaluate usefulness of HC analysis, design and evaluation methods and products, for HCAAST system developers
- Design, prototype and evaluate initial HCAAST BIO-Plex oriented systems
- Support spin-offs to JSC Mission Operations Directorate Advanced Development groups