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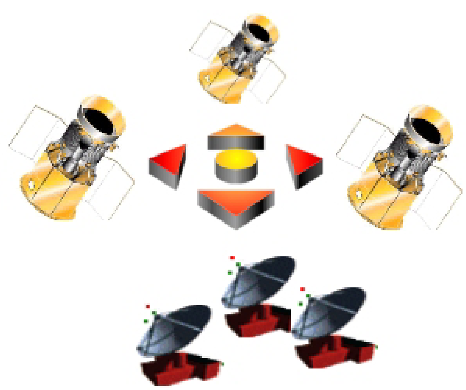
CONCEPT OF OPERATIONS

for the

Onboard Automation for Autonomous Constellation Operation



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1 SCOPE

This section provides an overview of the scope and content of this Concept of Operations (CONOPs).

1.1 Identification

This CONOPs applies to an effort by Aeroflex Altair Cybernetics Corporation (Altair) to demonstrate functionality of onboard automation and operation of an autonomous homogenous constellation.

1.2 Document Overview

Although tailored for the GSFC Demonstration, this document complies in format and content with Version 2.5 of IEEE P1362, IEEE Guide for Concept of Operations Document, dated 26 February 1996. IEEE P1362 serves as a standard for CONOPs supporting software developments. A discussion on metrics to be gathered during development and test, and a description of Altair's plans for test and integration have been added in Section 4 (Concepts for the Proposed System) of this CONOPs to comply with Altair's Statement of Work (SOW) for this project.

1.3 System Overview

This CONOPs applies to an autonomous homogeneous constellation and ground control system. Three virtual spacecraft will be created using ***Altairis Mission Control System (MCS)* ™**. The spacecraft subsystems will be modeled and simulated with Finite State Modeling. The spacecraft and the ground station will be linked as nodes, where spacecraft to spacecraft and spacecraft to Mission Operations Center (MOC) communication is required. The ***Altairis Mission Control System (MCS)* ™** will also be used to simulate the functionality of a MOC. The communication bandwidth and nodal connections will be monitored as the spacecraft and the constellation configuration changes.

2 REFERENCED DOCUMENTS

This section provides a list of reference documents for this CONOPs.

1. Statement Of Work (SOW) for NASA Goddard Space Flight Center. S-49965-G
2. IEEE P1362, IEEE Guide for Concept of Operations Document, Draft 2.5, 26 February 1996
3. http://ipinspace.gsfc.nasa.gov, OMNI – Operating Mission as Nodes on the Internet. Jim Rash and Keith Hogie, June 2001.
4. Stephen J. Talabac, *Spacecraft Constellations: The Technological Challenges in the New Millennium,* September 27, 1999. AETD Information Systems Center Code 588.

3 THE CURRENT SITUATION

This section provides a description of the situation, as it currently exists.

3.1 Background, Objectives and Scope

Since the launch of Sputnik in 1957, many organizations of the world have collectively launched thousands of spacecraft into a variety of orbits. The capabilities, complexity, and sophistication of these spacecraft have increased dramatically in the past years. This rapid evolution of spacecraft is a direct consequence of the accelerating pace of significant advances in the technologies that have enabled these spacecraft to be designed.

In recent years, the need to launch a constellation of spacecraft has increased dramatically, to support complex science missions and the rapidly expanding telecommunication market. To date, however, constellation launches and operations have mostly been in the planning stage, or are experiencing difficulties operating a constellation of spacecraft.

The main difficulty and concern in the aerospace community is the lack of a strategy to effectively monitor and react to conditions reported through telemetry data from multiple spacecraft. If a traditional approach is taken, the cost will simply increase proportional to the number of spacecraft. In addition, with a traditional approach, the complexity of the operation would also increases dramatically if the constellation consisted of heterogeneous spacecraft.

This CONOPs shows a strategy to effectively manage a spacecraft constellation through the usage of ***Altairis MCS™*** and it's finite state control technology. This CONOPs will demonstrate an autonomous homogeneous constellation and ground control system, which is capable to perform fault detection, isolation and recovery. It is important to note that adding the ground station and considering the station as a part of the constellation, the system can be considered a non-homogeneous system.

4 CONCEPTS FOR THE PROPOSED SYSTEM

This section describes the proposed system in a high level manner, indicating the operational features that are to be provided without specifying design details. The design details will be specified and discussed in the "Architecture Description for the Onboard Automation for Autonomous Constellation Operation" document.

4.1 Background, Objectives and Scope

The present Autonomous Constellation CONOPs calls for the deployment of three fully autonomous spacecraft and a ground station to support a constellation mission.

Each spacecraft and the ground station are linked as nodes on an existing network. The objective of this CONOPs is to demonstrate that current technology can reliably mimic human intervention that is often necessary to control and adapt to complex spacecraft operations.

4.2 Operational Policies and Constraints

The present Autonomous Constellation CONOPs calls for the deployment of three fully autonomous spacecraft and a ground station to support a constellation mission.

These spacecraft and ground station will be simulated using existing computers. All systems, spacecraft and ground station will be modeled by Altair's Finite State Modeling technology and ***Altairis MCS™*** will be scaled to operate within this environment. For the Autonomous Constellation CONOPs, four core systems are identified and analyzed. The core systems are:

- Autonomous spacecraft
- Autonomous ground station
- Autonomous constellation, which consists of above two systems
- Constellation Network Communication

Operational policies and constraints imposed on the core systems are described below.

4.2.1 Autonomous Spacecraft

Each of the autonomous spacecraft is imposed with the following constraints.

1. The system is required to autonomously execute scheduled tasks.
2. The system is required to perform fault detection, isolation and recovery.
3. The system is required to reschedule activities without intervention from the ground station.
4. The system is required to receive data from two separate locations and is required to transmit data to two separate locations. One of the receivers and one of the transmitters are dedicated for ground contact.

4.2.2 Autonomous Ground Station

The autonomous ground station is imposed with the following constraints.

1. The system is required to recognize and verify the state of the spacecraft.
2. The system is required to perform fault detection, isolation and recovery

3. The system is able to function autonomously, however, is required to be able to accept external commands (human intervention).

4.2.3 Autonomous Constellation

The autonomous constellation is imposed with the following constraints.

1. The constellation is required to detect resource failures and diagnose the cause of the failure.
2. The constellation is required to autonomously reschedule a task when a failure is detected in order to achieve its original schedule (dynamic scheduling).

4.2.4 Constellation Network Communication

The constellation network communication is imposed with the following constraints:

1. All nodes of the network (spacecraft and ground station) will use the DUP/IP or TCP/IP to communicate the spacecraft or ground system states.
2. The communication bandwidth and connections will be monitored as the configuration of both the individual spacecraft and the constellation changes.

4.2.5 Metrics During Development and Test

The following is a summary of metrics that Altair plans to collect, evaluate and report during the GSFC demonstration project.

1. Spacecraft system automation. This includes failure detection and reaction to the failure on spacecraft level.
2. Ground station automation. This includes the autonomous reconfiguration of the ground station resources to support the constellation functionality.
3. Constellation system automation. This system ties the spacecraft system and the ground station system as one unified system as nodes on an existing network. The auto reconfiguration of the operation modes will be tested and verified. The modes of operation will be described in Section 4.4.
4. Constellation network communication. Spacecraft to spacecraft communication along with spacecraft to ground station communication will be simulated.

4.3 Description of the Proposed System

This paragraph provides a description of the proposed system:

4.3.1 Operational Environment and its Characteristics

The present Autonomous Constellation CONOPs calls for the deployment of three fully autonomous spacecraft and a ground station to support a constellation mission.

These spacecraft and ground station will be simulated using existing computers. The virtual spacecraft will be using a telemetry structure used for Wide-Field Infrared Explorer (WIRE). Sample constraints and hardware limits will be obtained from this spacecraft as well, in order to model a realistic spacecraft. Additional capabilities, however, are added to the spacecraft model, such as spacecraft to spacecraft communication capability to operate as a constellation. WIRE is a spacecraft from the Small Explorer (SMEX) Program, originally deployed to survey primarily galaxies with unusually high rates of star formation or "starburst" galaxies, which emit most of their energy in the far-infrared. A pictorial overview of the constellation system is shown in Figure 1.

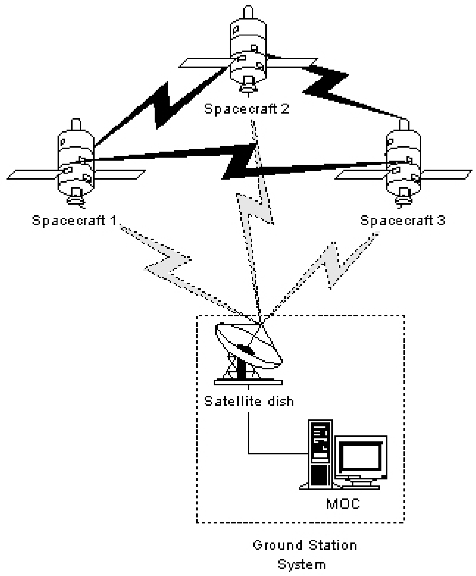

Figure 1. Constellation System Operational Environment Overview

4.3.2 Major System Components and Interconnections

The constellation is divided into smaller systems in order to demonstrate the capabilities and verify the interconnections between the systems. The high level system is the constellation as a whole, and the lower level systems include three autonomous spacecraft, ground station, the inter-nodal connectivity system. The inter-nodal connectivity system will provide the connection between the network nodes (spacecraft to spacecraft and spacecraft to ground station).

4.3.3 Capabilities / Functions of the Proposed System

The constellation system is the system responsible for fault detection, isolation and recovery. The reaction ranges from the reconfiguration of a single spacecraft, ground station, or reconfiguration of the constellation as a whole. The constellation system will consist of all the nodes on the network (three spacecraft and ground station) and the connectivity between the nodes. The modes of operation of the constellation system are described in Section 4.4.

The spacecraft system is a spacecraft modeled using finite state modeling. The system will recognize only the spacecraft wide events and states. In order to automate the constellation, the spacecraft system also requires an even higher level of automation to react to the commands issued by the constellation system.

The ground station system is similar to the spacecraft system. The system will recognize only the ground station wide events and states. The spacecraft and the ground station will work as an identical node on the network, however, the resources on the ground station and the spacecraft are clearly different. This difference of resources adds heterogeneity to this project.

The inter-nodal connectivity system is responsible for the monitoring of the connection between the nodes. The system will detect any failure to the communication links between the nodes.

4.3.4 Performance Characteristics

The control system for the constellation will be hosted on a homogeneous architecture using PCs with Windows operating system (2000 or NT). The control system will be able to support real time monitor and control operations.

4.4 Modes of Operation

The autonomous constellation can be operated in the following modes.

4.4.1 Configuration Manager Mode

In this mode of operation, each system (spacecraft and ground station) will only recognize it's own states. Each system will not have any configuration knowledge of other systems. One node on the network is given the role of configuration manager. This is the only system that recognizes the state of the constellation as a whole. The node that takes the role of the configuration manger will issue all commands to the spacecraft to achieve the specified tasks. This Mode is described in Figure 2. Where the spheres are the nodes on the network, either spacecraft or ground station. The individual state knowledge is shown in yellow and the overall system state (constellation state) is shown in red.

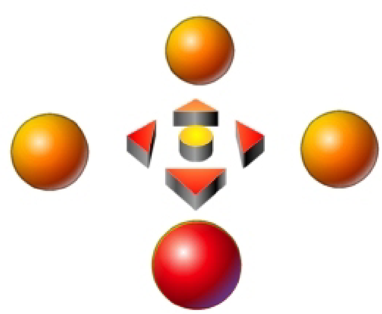

Figure 2. Configuration Manager Mode. Only one node acknowledges the configuration of the constellation.

4.4.2 Conflict Mediator Mode

In this mode of operation, each system (spacecraft and ground station) recognizes both it's own states and knowledge of other systems. Each node on the system is able request commands to autonomously configure the constellation. However, in order to keep the integrity of the constellation, one node on the network will be given the role of conflict mediator role. This node on the network receives all the commands requested by other nodes and selects the most appropriate command. This node is the only node which issues commands to the spacecraft to achieve the specified tasks. This Mode is described in Figure 3. Where the spheres are the nodes on the network, either spacecraft or ground stations. The individual state knowledge is shown in yellow and the overall system state (constellation state) is shown in red.

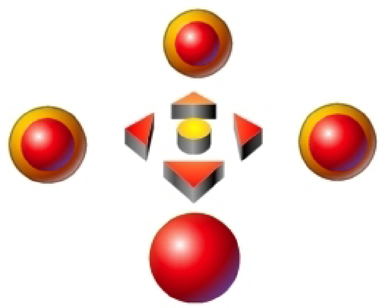

Figure 3. Conflict Mediator Mode. All systems acknowledge the constellation configuration. However, only one node determines the "desired" states.

4.4.3 Synchronous Operation Mode

In this mode of operation, each system (spacecraft and ground station) will only recognize it's own states. Each system is able to detect failure and reconfigure only within the system. In addition, each node is given the schedule and task to achieve the goal of the constellation. This schedule and task is a high level schedule issued from the ground station. Cross-nodal state information is only shared in order to synchronize the activities. Each individual system will "synchronize" its own schedule and activity to achieve the overall schedule. This Mode is described in Figure 4. Where the spheres are the nodes on the network, either spacecraft or ground station.

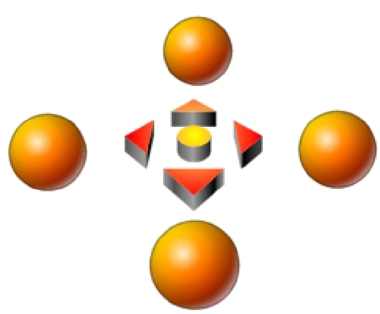

Figure 4. Synchronous Operation Mode. Each nodes only recognize it's own states. Cross nodal state information is only shared in order to synchronize the activities.

4.4.4 Plans for Test and Integration

Altair plans on setting test milestones during the development of the Demonstration. These milestones can be monitored through the success or failure of the development scenarios associated with tests. The "x" next to the scenario number denotes that there are multiple variations of the same scenario.

Scenarios D1x	-	Single spacecraft automation test phase
Scenario D2	-	Single ground station automation test phase
Scenarios D3x	-	Nodal communication test phase
Scenarios D3x1	-	Spacecraft to spacecraft communication
Scenarios D3x2	-	Spacecraft to ground station communication
Scenario D4x	-	Constellation automation test phase

Each of these phases will incorporate one or more scenarios as detailed below. Each of the scenarios follows the template below:

Scenario <#>	**<Test NAME>**
Description	<A textual description of the scenario>
Procedure	<The steps for performing this test. > 1. Step 1 2. Step 2
Result	<The expected results of performing the procedure. (Note that the results may reference particular numbered steps in the procedure)>
Evaluation	<Criteria to judge whether the test was successful or not>

Following this is a scenario diagram that shows the major interactions being tested.

4.4.4.1 Scenario D1x – Single Spacecraft Automation Test Phase

The single spacecraft automation test phase is detailed in Table 1.

Table 1. Single Spacecraft Automation Test Phase – Scenario D1x

Scenario D1x	**Single Spacecraft Automation Test Phase**
Description	This scenario for the single spacecraft automation test phase evaluates the ability of the spacecraft to perform fault detection, isolation and recovery.
Procedure	1. Deploy a single spacecraft model. 2. Pass a pre-obtained WIRE telemetry data 3. Schedule an undesirable/unexpected state through a state simulation engine.
Result	The system should detect the unexpected state. The system should report what the unexpected state was and the reason of the failure The system should reschedule its state in order to recover from the failure and hence driven to the expected state.
Evaluation	Check if the diagnosis is correct by comparing to the Step 3. of the procedure. Evaluate if the spacecraft rescheduled itself to the desired/expected

	states. Evaluate if the spacecraft reached the desired/expected states.

Note that this test phase has to be repeated for each spacecraft.

4.4.4.2 Scenario D2 – Single Ground Station Automation Test Phase

The single ground station automation test phase is detailed in Table 2.

Table 2. Single Ground Station Automation Test Phase – Scenario D2

Scenario D2	**Single Ground Station Automation Test Phase**
Description	This scenario for the single ground station automation test phase evaluates the ability of the ground station to perform fault detection, isolation and recovery.
Procedure	1. Deploy a ground station model. 2. Pass a pre-obtained WIRE states. These states are obtained from Scenario D1x described in Section 4.4.4.1. 3. Schedule an undesirable/unexpected state through a state simulation engine.
Result	The system should detect the unexpected state. The system should report what the unexpected state was and the reason of the failure The system should reschedule its state in order to recover from the failure and hence driven to the expected state.
Evaluation	Check if the diagnosis is correct by comparing to the Step 3 of the procedure. Evaluate if the ground station rescheduled itself to the desired/expected states. Evaluate if the ground station reached the desired/expected states.

4.4.4.3 Scenario D3x – Nodal Communication Test Phase

The nodal communication test phases are detailed in Table 3 and Table 4. Table 3 tests the spacecraft to spacecraft communication and Table 4 tests the spacecraft to ground station communication.

Table 3. Nodal Communication Test Phase – Scenario D3x-1

Scenario D3x-1	**Nodal Communication Test Phase**
Description	This scenario for the nodal communication test phase evaluates the spacecraft to spacecraft communication. The test phase will test for connectivity and the bandwidth measurement verification.
Procedure	1. Deploy two spacecraft models. (Spacecraft 1 and Spacecraft 2) 2. Manually send a bit stream 3. Command one spacecraft to schedule a state on the other spacecraft.
Result	For the second step of the procedure, the receiving spacecraft should receive a bit stream from the transmitting spacecraft After the third step is executed, the scheduled spacecraft should transition the spacecraft subsystem.
Evaluation	Verify the received bit stream. Compare the data to ensure the integrity.

	For the third step, verify that the second spacecraft transitions its state. The state should match the state commanded.

Repeat this test with spacecraft 2 and spacecraft 3, then with spacecraft 1 and spacecraft 3 communications.

Table 4. Nodal Communication Test Phase – Scenario D3x-2

Scenario D3x-2	**Nodal Communication Test Phase**
Description	This scenario for the nodal communication test phase evaluates the ground station to spacecraft communication ability. The test phase will test for connectivity and the bandwidth measurement verification.
Procedure	1. Deploy a spacecraft model (start with spacecraft 1) and the ground system model. 2. Manually send a bit stream from the ground system to the spacecraft in test. 3. Manually send a bit stream from the spacecraft to the ground system. 4. Command the ground station to schedule a state on the spacecraft under test.
Result	For the second and third step of the procedure, the receiving system should receive a bit stream from the transmitting system. After the fourth step is executed, the scheduled spacecraft should transition the spacecraft subsystem.
Evaluation	Verify the received bit stream. Compare the data to ensure the integrity. For the third step, verify that the spacecraft transitions its state. The state should match the state commanded by the ground station.

Repeat this test with spacecraft 2 and ground system, then with spacecraft 3 and ground system communications.

4.4.4.4 Scenario D4x – Constellation Automation Test Phase

The constellation automation test phase is detailed in Table 5. These scenarios will test all nominal modes of operation. The modes of operation are described in Section 4.4.

Table 5. Constellation Automation Test Phase – Scenario D4-1

Scenario D4-1	**Constellation Automation Test Phase (Configuration Manager Mode)**
Description	This scenario for the constellation automation test phase evaluates the configuration manager mode.
Procedure	1. Deploy three spacecraft models and the ground station model. 2. Set the constellation to configuration manager mode. Set one of the spacecraft as the configuration manager node. 3. Disconnect one of the nodes other than the configuration manager node.
Result	The constellation transitions to the configuration manager mode. All nodes will send state information to the configuration manager node.
Evaluation	Verify that only the configuration manager node has the state

	information for the remaining system. Verify that the configuration manager node retains the state information after one of the nodes is disconnected.

Table 6. Constellation Automation Test Phase – Scenario D4-2

Scenario D4-2	**Constellation Automation Test Phase (Conflict Mediator Mode)**
Description	This scenario for the constellation automation test phase evaluates the conflict mediator mode.
Procedure	1. Deploy three spacecraft models and the ground station model. 2. Set the constellation to conflict mediator mode. Set one of the spacecraft as the conflict mediator node. 3. Set three of the nodes to request a command to change the constellation schedule. The commands will be two identical one conflicting command.
Result	The constellation transitions to the conflict mediator mode. All spacecraft will receive the constellation state. All commands will go through the conflict mediator node.
Evaluation	Verify that all nodes receive the constellation state information. Verify that the conflict mediator node receives command request from other nodes and sends the appropriate command.

Table 7. Constellation Automation Test Phase – Scenario D4-3

Scenario D4-3	**Constellation Automation Test Phase (Synchronous Operation Mode)**
Description	This scenario for the constellation automation test phase evaluates the synchronous operation mode.
Procedure	1. Deploy three spacecraft models and the ground station model. 2. Set the constellation to synchronous operation mode. 3. Send the synchronization command.
Result	The constellation transitions to the synchronous operation mode. All nodes should work synchronously without cross-link. Nodal schedules will update after the synchronization command.
Evaluation	Verify that the constellation system transition to the synchronous mode by evaluating the nodal communication. Verify that the schedule updates after the synchronization command.

5 DEMONSTRATION SCENARIOS

This section provides an overview of the operational scenarios for the proposed system. For the purpose of the demonstration, there are two main classes of scenarios that must be demonstrated. The first class of scenario is the operational scenarios. These scenarios will demonstrate the different modes of operation of the constellation. The second class of scenarios is the failure scenarios. In these scenarios, different failures will be introduced and the constellation reaction will be monitored.

Operational Scenarios

Scenario O1	-	Configuration manager mode
Scenario O2	-	Conflict mediator mode
Scenario O3	-	Synchronous operation mode
Scenario O4x	-	Unexpected discovery of target of opportunity.

Failure Scenarios

Scenarios F1x	-	Unexpected loss of signal of a non-critical node.
Scenarios F2x	-	Unexpected loss of signal of a critical node. (i.e., Configuration Manager or Conflict Mediator node)
Scenarios F3	-	Emergency SSR dump during the Configuration Manager mode.

The scenario descriptions will follow the same guidelines as expressed in section 4.4.4. the “x” at the end of scenario number indicate multiple variation of the scenario.

5.1 Operational Scenarios

The three operational scenarios (O1-O3) described in this section is a demonstration of the constellation automation test phase described in section 4.4. The modes will transition sequentially from the ground station system. The fourth scenario (Scenario O4) demonstrates flexibility and advantage of onboard automation of autonomous constellation.

Table 8. Operational Scenarios – Scenario O1 through O3

Scenario O1 **Scenario O2** **Scenario O3**	**Constellation Operational Scenarios**
Description	This demonstration scenario will go through all the mode of operation.
Procedure	1. Deploy three spacecraft models and the ground station model. 2. Set the constellation to configuration manager mode. 3. Transition the constellation to conflict mediator mode 4. Transition the constellation to synchronous operation mode.
Result	1. All system will be deployed and set to configuration manager

	mode. Only the configuration manager node will have the state information of the remaining nodes. 2. During the transition to conflict mediator mode, all the states will be shared to the existing nodes. After the states are shared out, the conflict mediator node will be established. All other nodes will request the commands affecting the constellation through the conflict mediator node. 3. After the conflict mediator is terminated and transitioned to the synchronous operation mode, all the nodes are responsible and only aware of the individual nodes.
Evaluation	Mode changes, inter-nodal communication and state knowledge will be able to be monitored and evaluated with the GUI.

Table 9. Operational Scenarios – Scenario O4x

Scenario O4x	**Unexpected discovery of target of opportunity**
Description	This demonstration scenario will demonstrate the autonomous rescheduling of constellation configuration.
Procedure	1. Deploy three spacecraft models and the ground station model. 2. Set the constellation to configuration manager mode. 3. Simulate an appearance of a target of opportunity.
Result	1. All system will be deployed and set to configuration manager mode. Only the configuration manager node will have the state information of the remaining nodes. 2. After a target of opportunity is discovered, the configuration manager reschedules that constellation to reconfigure the states for the target of opportunity.
Evaluation	Verify the configuration changes of the constellation.

This demonstration is also supported for conflict mediator mode.

5.2 Failure Scenarios

Following scenarios demonstrates the autonomous reconfiguration of the constellation as failure is detected.

Table 10. Unexpected loss of signal of a non-critical node. – Scenario F1-1

ScenarioF1-1	**Unexpected loss of signal of a non-critical node.**
Description	This demonstration scenario shows the effect of unexpectedly loosing a connection with a non-critical node
Procedure	1. Deploy three spacecraft models and the ground station model. 2. Set the constellation to configuration manager mode. 3. Disconnect one of a non-critical node. 4. Reconnect the previously disconnected node.
Result	1. All system will be deployed and set to configuration manager mode. Only the configuration manager node will have the state information of the remaining nodes. 2. After the non-critical node is disconnected, the configuration manager node will retain the state knowledge of the rest of the nodes. 3. The configuration manager node will acknowledges when the node is reconnected.

Evaluation	Verify that the configuration manager node acknowledges the states of the remaining nodes. Mode changes, inter-nodal communication and state knowledge will be able to be monitored and evaluated with the GUI.

Table 11. Unexpected loss of signal of a non-critical node. – Scenario F1-2

ScenarioF1-2	**Unexpected loss of signal of a non-critical node.**
Description	This demonstration scenario shows the effect of unexpectedly loosing a connection with a non-critical node
Procedure	1. Deploy three spacecraft models and the ground station model. 2. Set the constellation to conflict mediator mode. 3. Disconnect one of a non-critical node. 4. Reconnect the previously disconnected node
Result	1. All system will be deployed and set to conflict mediator mode. All nodes will share the state information with the remaining nodes. 2. After the non-critical node is disconnected, the configuration manager node will retain the state knowledge of the rest of the nodes. 3. The conflict mediator node will acknowledge when the node is reconnected.
Evaluation	Verify that the conflict mediator node acknowledges the states of the remaining nodes. Mode changes, inter-nodal communication and state knowledge will be able to be monitored and evaluated with the GUI.

Table 12. Unexpected loss of signal of a critical node. – Scenario F2-1

ScenarioF2-1	**Unexpected loss of signal of a critical node.**
Description	This demonstration scenario shows the effect of unexpectedly loosing a connection with the configuration manager node
Procedure	1. Deploy three spacecraft models and the ground station model. 2. Set the constellation to configuration manager mode. 3. Disconnect a critical node.
Result	1. All system will be deployed and set to configuration manager mode. 2. After the configuration manager node is disconnected, the constellation transitions to synchronous mode.
Evaluation	Verify that the constellation transitioned to synchronous mode. Mode changes, inter-nodal communication and state knowledge will be able to be monitored and evaluated with the GUI.

Table 13. Unexpected loss of signal of a critical node. – Scenario F2-2

ScenarioF2-2	**Unexpected loss of signal of a critical node.**
Description	This demonstration scenario shows the effect of unexpectedly loosing a connection with the conflict mediator node
Procedure	1. Deploy three spacecraft models and the ground station

	model. 2. Set the constellation to conflict mediator mode. 3. Disconnect a critical node.
Result	1. All system will be deployed and set to conflict mediator mode. 2. After conflict mediator node is disconnected, another node with the most resource will take over the role of the conflict mediator node.
Evaluation	Verify the transition of the conflict mediator node. Mode changes, inter-nodal communication and state knowledge will be able to be monitored and evaluated with the GUI.

Table 14. Emergency SSR dump during the configuration manager mode – Scenario F3

ScenarioF3	**Emergency SSR dump during the configuration manager mode.**
Description	This demonstration scenario will demonstrate the autonomous rescheduling of a node based on state information of another node.
Procedure	1. Deploy three spacecraft models and the ground station model. 2. Set the constellation to configuration manager mode. 3. Simulate a condition so that one of the spacecraft will require a dump of SSR data.
Result	1. All system will be deployed and set to configuration manager mode. 2. When the configuration manager node detects the need of the SSR data dump. 3. The reschedule command is sent from the configuration manager node to the ground system when the contact is made. 4. The ground station will be reconfigured to receive the SSR data.
Evaluation	Verify the transition of the ground station state. Mode changes, inter-nodal communication and state knowledge will be able to be monitored and evaluated with the GUI.

6 ANALYSIS OF THE PROPOSED SYSTEM

6.1 Summary of Improvements

Previously deployed constellations have relied on ground system control to manage operations. Each individual spacecraft may have some level of autonomous control to monitor individual health, but the information is relayed only to the ground. When not in contact with the ground stations, the constellation cannot adapt to failures of individual spacecraft. There is not a controlling mechanism for the system without the ground station.

By first recognizing that a practical method exists for providing onboard automation for a single spacecraft, the intelligence of the ground station can begin to move onboard. The space-to-space communications link provides a method for distributed information sharing among the spacecraft in the constellation. Through the use of standard Internet protocols for communication, methods used for distribution of control task on ground networks can also be applied on orbit. The constellation can now share information and computing resources.

This final step allows for the arbitrary migration of system control from the ground stations for the spacecraft. Each spacecraft can receive information about the state of the other spacecraft and can send its own state information over the space-based network. In addition to monitoring individual health, each spacecraft now has the ability to monitor the state of the other spacecraft and react to that information. Now, instead of multiple individual spacecraft operating independently with a common data collection, the spacecraft can be configured to operate as a coherent system to optimize data collection.

This prototype demonstrates that a group of spacecraft can be considered as a single system when the appropriate control and communications are applied onboard. The “intelligence” is moved from the ground station to the orbital resources allowing for continuous control of the constellation independent of the ground station.

While this prototype will only be able to demonstrate a selected subset of the domains and services available, a significant advantage can be shown over current constellation control system technologies.

The most significant advantage is minimization of ground contact, which translates into a significant cost savings. Spacecraft in the constellation have autonomous control and can react to events when not in contact with a ground station. The ground station is utilized only for data collection, spacecraft calibration operations, and anomaly investigation and reconfiguration in those few instances when the onboard systems require human intervention for unknown conditions.

The ability to dynamically reconfigure based on conditions allows for optimization of data collection and dramatically reduces risk to the mission. A spacecraft failure will be known to the constellation and an appropriate reconfiguration will occur to attempt to recover from the failure. If possible, the remaining resources will reconfigure to continue collecting science data.

6.2 Disadvantages and Limitations

This demonstration will only be able to demonstrate a selected subset of the domains and services available. This will be a functional demonstration based on COTS hardware for ground-based use. No space-qualified hardware will be used at this time. Follow-up projects will migrate this prototype to space qualified hardware and eventually to on-orbit test and verification.

Due to hardware availability, the constellation to be demonstrated consists of three satellites and a ground station. This should be sufficient to demonstrate the concepts of constellation operations, but future work should expand the number of nodes to determine any additional issues that arise from large constellation.

In the absence of any real standard of spacecraft-to-spacecraft communication, the demonstration will use standard Ethernet with software limiting bandwidth to rates emulating what will be available to on orbit constellations.

6.3 Alternatives and Trade-Offs Considered

The focus of this effort is to demonstrate the functional capabilities of using the ***Altairis MCS™*** as an on-board constellation control system and to demonstrate an operations concept for autonomous constellation control.

This prototype will use the Windows2000/NT operating system as opposed to a real-time operating system. This allows for rapid development of the prototype functionality without the need for a port to a new OS. Once the prototype is functional, the system will be ported to a real-time OS in a future development phase.

An estimate of where on-board computing capabilities will be in 5 years has provided a goal for this prototype and future development. This project assumes a Pentium class processor running at 150Mhz with 64MB or more of available system memory will be standard on NASA spacecraft in this time frame. In this phase of development, the prototype will be tested against various hardware configurations to determine current needs. The delta between the prototype hardware requirements and the goal will provide the basis a for development plan to scale the automation technology for operation within the constraints of on-board capabilities.

Physical Ethernet connections will be used instead of RF connections to simulate space-to-space connections and space-to-ground connections. The space-to-space and space-to-ground visibility will also be simulated. Future development will incorporate the use of RF modems or equivalent. The Ethernet connections will be metered with software to emulated any desired rate of information flow allowing a simulation of data rates expected on-orbit.

7 NOTES AND ACRONYMS

This section contains any additional information that will aid in understanding this CONOPS. This section should include an alphabetical list of acronyms.

List of Acronyms

Term	Definition
Altair	Aeroflex Altair Cybernetics Corporation
CONOPs	Concept of Operations
GSFC	Goddard Space Flight Center
GUI	Graphical User Interface
MCS	Mission Control System
MOC	Mission Operations Center
NASA	National Aeronautics and Space Administration
SOW	Statement of Work
WIRE	Wide-Field Infrared Explorer

Appendix A

Appendices are added to the document to provided easy reference to charts, classified data, etc. The location of data in appendices should be referenced in the body of the document.

Glossary

This section provides a clear and concise definition of terms used in this CONOPS.

Term	Definition
Finite State Model	**–** A structured approach to systems engineering which utilizes a tree-structured breakdown that includes the operational characteristics and functional relationships of the system
State	**– A**n operational state for each element in the tree-structure and is defined by functional relationships
Transitions	**–** defined steps for moving between states for each element of the structure
Configuration Manager Mode	**–** Each system only recognizes it's own states. Only one node in the network is able to recognize the state of the entire constellation and issues commands to the other spacecraft.
Conflict Mediator Mode	**–** Each system recognizes both it's own state, has knowledge of the other systems, and is able to request commands to autonomously configure the constellation. One node is responsible for receiving all the commands, selecting the most appropriate command, and issuing commands to the other spacecraft.
Synchronous Operation Mode	**–** Each system recognizes it's own states and failures. Each node is given the schedule and of the constellation and cross-nodal communication is only used to synchronize activities such tat each system is can synchronize it's own schedule.
WIRE	- A spacecraft from the Small Explorer (SMEX) Program, originally deployed to survey primarily galaxies with unusually high rates of star formation or "starburst" galaxies, which emit most of their energy in the far-infrared.