NASA GSFC

Formation Flying Experiments on the Orion-Emerald Mission

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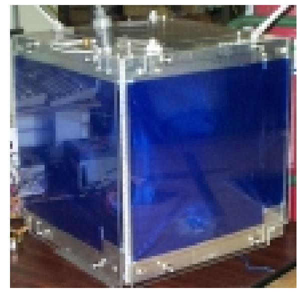
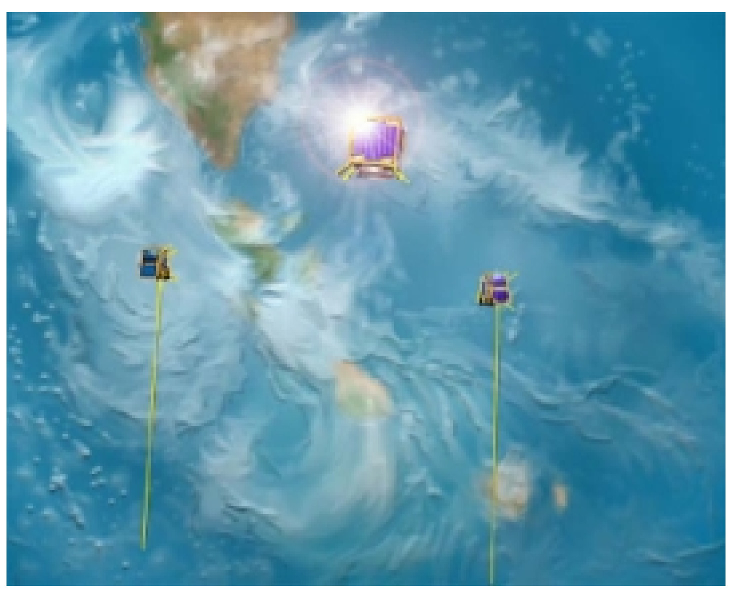


Introduction

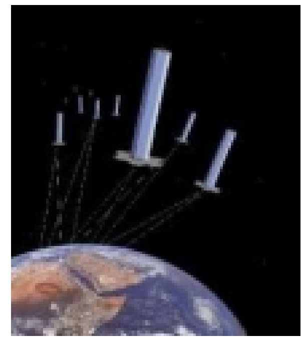
- **Present updated Orion mission operations**
  - Goals & timelines
  - Mission profile
- **Describe key Orion hardware**
- **Current research topics**



Artist's impression of Orion/Emerald (Nanosat-1) spacecraft on-orbit

Orion-Emerald Mission Goals

- **First on-orbit demonstration of precise relative navigation using Carrier Phase Differential GPS**
  – Use this sensor to perform tight formation control
- **Operate in a semi-autonomous fashion, reducing the need for frequent ground communications**
- **Onboard control calculations:**
  – Implement optimal station keeping
  – Formation change maneuvers optimized by linear programming



- **Technologies directly applicable to future formation flying missions such as TechSat21**

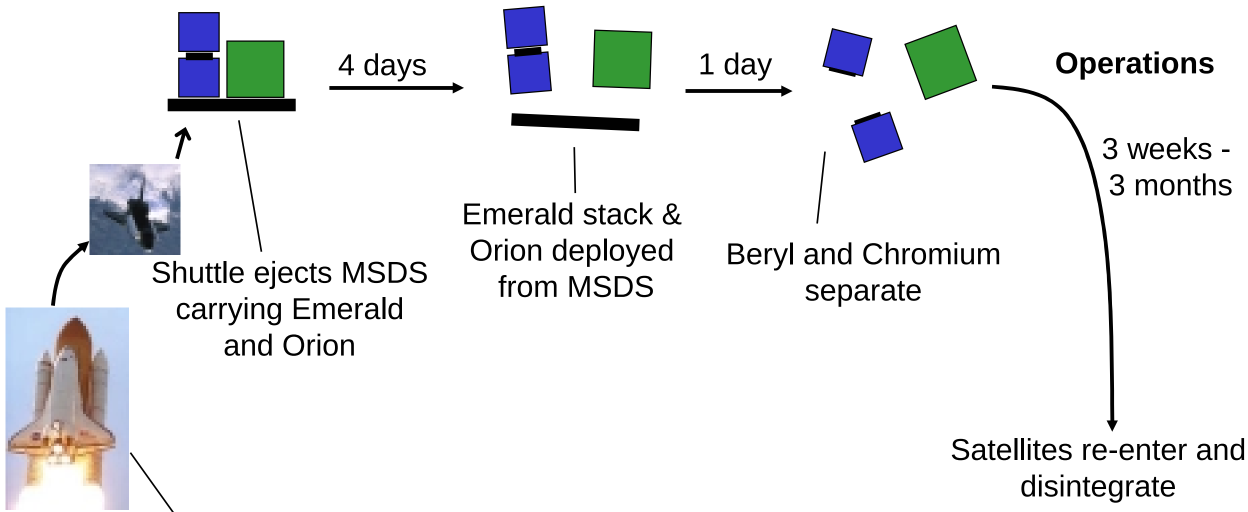
Formation Flying Testbed

Orion spacecraft
- 45 cm cube
- 35 kg
- Al honeycomb

Emerald (2 vehicles)
- ~ 40 cm, 15 kg
- Drag panels for control
- Single GPS receiver
- Several additional experiments

Orion systems:
- Relative navigation (carrier phase differential GPS).
- GN_2 propulsion
- ACS
- Formation-keeping control
- Torquer coils for detumbling

Mission Profile



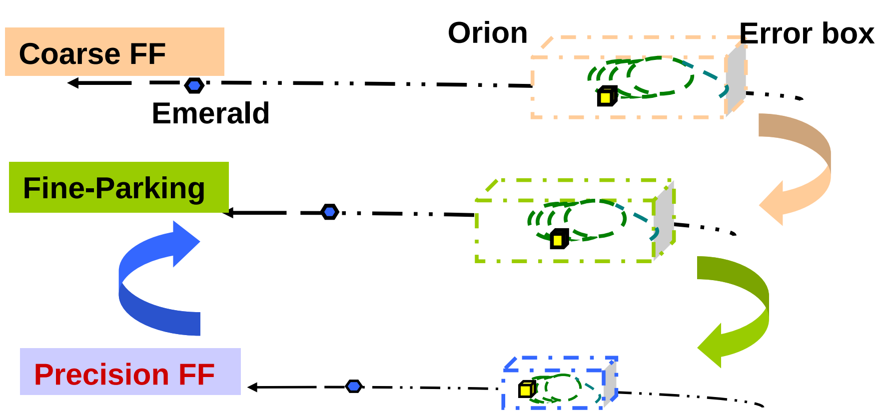
Space Shuttle Launch
- Spring 2003
- SHELS platform

Three primary **activities** during **operations stage**:
1. Formation stabilization (~1 day)
2. In-Track experiment (~30 days)
3. Cross-track experiments (~ 60 days, optional)

Formation Flying Experiments

- **Activity 2: In-Track Experiments**

Experiments	In-track Separation (m)	Relative Radial Tolerance [m]
Coarse FF	300	10-20
Fine Parking	100	10
Precision FF	100	2



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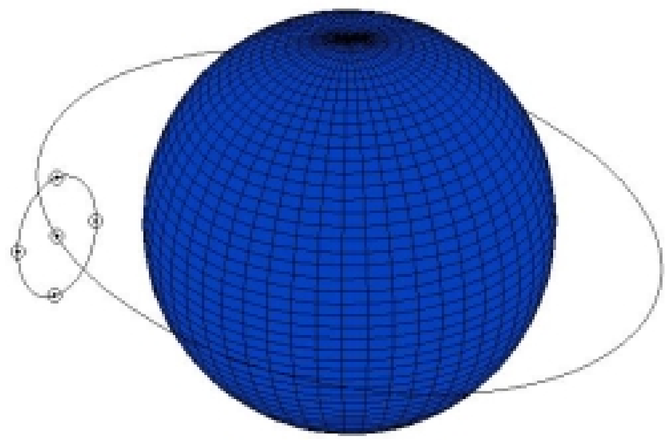
Formation Flying Experiments

- **Activity 3: Combination of in-track and cross-track**
  - Similar sequence to in-track experiments
  - Orion follows elliptical path around Emerald(s)
    - Orion applies control to stay within an error box that moves around ellipse following natural orbital dynamics
  - Fuel intensive, so:
    - Optional to mission success
    - Performed at end of mission



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Resource Analysis Modes

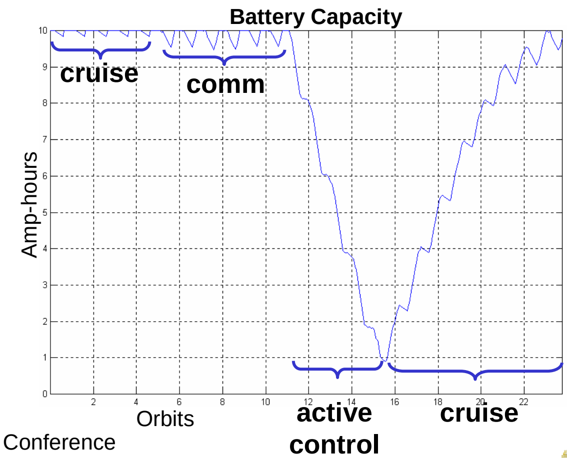
- **Power usage depends on spacecraft *modes* within *activities***
- **5 different spacecraft *modes* for resource planning purposes**
  - **Active control mode**
    - All formation flying experiments occur in this mode
    - Propulsion system is active
    - Require full (3) GPS suite and science computer
    - Extensive real-time inter-satellite communication
  - **Cruise mode**
    - Low power state for battery recharging with solar cells
    - Minimal communication
  - **Communicate mode**
    - Briefly communicate with ground
    - 1 GPS receiver active to retain GPS lock
    - Receive commands and download telemetry
  - **Computing mode**
    - Science computer carries out large computational tasks not required in real-time
  - **Stabilization mode**
    - De-tumble spacecraft using magnetometer and torquer coils & obtain GPS lock
    - Propulsion system not activated until in active control mode

Power Budgets

- **Power drives stage durations and frequencies**
  - Solar cells provide time averaged power of 18W to the bus
  - Used to recharge batteries
- **Use simulations to investigate power state during mission**
  - Plots battery capacity for typical formation experiment
- **Simulations indicate that maximum experiment time ~ 4 orbits**
  - Experiment cycle consists of prep, active control, & then recovery

Mode	Power (W)
Cruise	**4.1**
Compute	6.7
Stabilize	7.6
Comm	8.6
Active	**32.8**

Data acquired from actual hardware measurements



Fuel Budgets

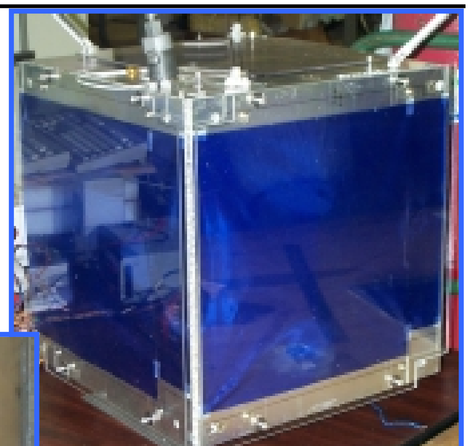
- **Fuel non-renewable, so it drives ultimate mission length**
  - Total predicted ΔV ~ 25m/s
- **Each experiment cycle ~ 350 mm/s**
  - Each cycle includes cruise, communicate, compute, active control, cruise
- **Prediction for the formation-keeping control required to compensate for differential drag ~10 mm/s/orbit**
  - Result of differing ballistic coefficients on dissimilar spacecraft
- **Attitude Control ~ 4 mm/s/orbit**
  - ± 20º per axis
  - Switching-line control algorithm
- **Corresponds to approximately 55 experiment cycles over 48 days.**

Communication Constraints

- **Data for ground post-processing must be small enough for download**
  - Approximately 25 min of contact time per day (ground station at Stanford)
  - Each overhead pass lasts ~ 6 minutes
- **Available baud rate: 9600 bps**
  - Overhead, signal acquisition time and error correcting all contribute to a total effective download data rate of **375 kBytes/day**.
- **Each sample is 911 bytes**
  - Only 411 samples can be downloaded per day
  - **Large mission constraint since this only corresponds to 1/3 orbit of data per day (0.2 Hz data collection rate)**
- **Possible solutions**
  - Have other Universities world-wide help acquire data
  - Store non-critical data for download later in mission

Orion Hardware

- **Primarily COTS Parts**
  - Low cost
  - Easy to work with
- **Subsystems:**
  - Propulsion
  - Position & Attitude Determination
  - ACS
  - CPU/Data Bus
  - Communications
  - Power
  - Science Computer

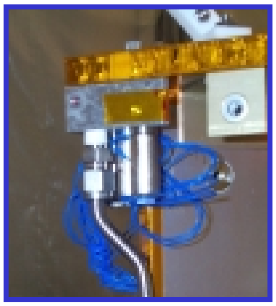


Orion Prototype as of March 2001

Orion Flight Model as of August 2001

Propulsion

- **12 cold gas (GN2) thrusters**
  - 4 groups of 3
  - 3-axis translation and attitude
  - Thruster max ~ 60 mN
  - Most parts are COTS
- **Predicted ΔV ~ 25 m/s**



Orion flight propulsion system in clean room at Stanford

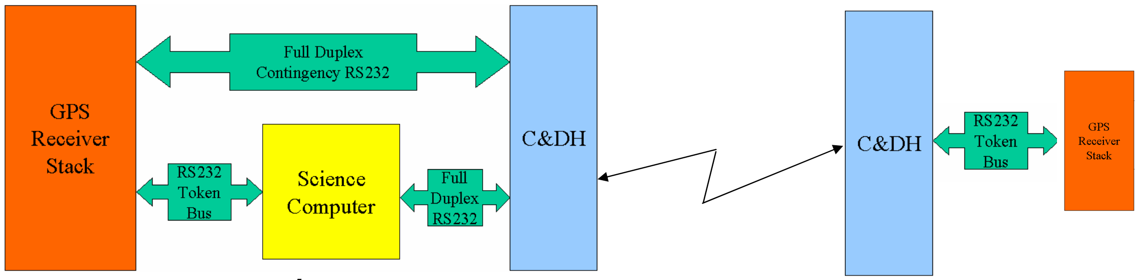
CPU/Data Bus/Communications

- **SpaceQuest CPU**
  - 10MHz Processor
  - 1MB EDAC Ram
  - Space Craft operating system by BekTek (flight heritage)
- **SpaceQuest Modem**
  - 9600 baud
  - Half-duplex crosslink, full-duplex downlink
  - Omni-directional antennae
  - **Space heritage**
- **Data Bus**
  - COTS standard by Dallas
  - I^2C rate of 100kbps
  - PIC board as bus controller

Orion CPU "SpaceQuest"

GPS Payload

- **Payload consists of:**
  - GPS receiver suite for position and attitude determination system
  - Science computer



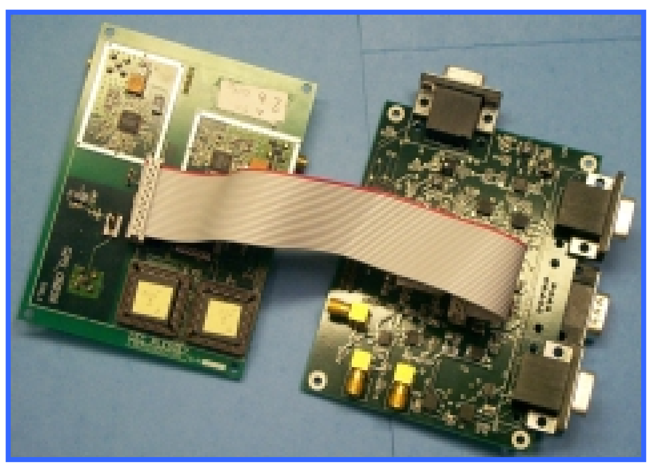
Orion

Emerald

- **Connectivity**
  - RS232 token bus
  - Contingency link to C&DH used as primary link for Emerald spacecraft

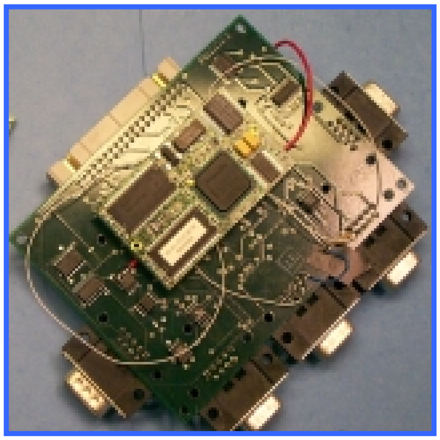
Position and Attitude Determination

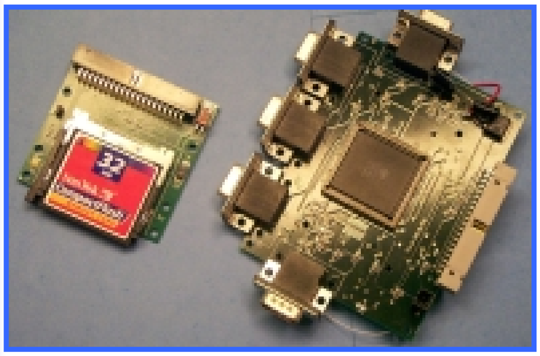
- **The Orion receiver is a state-of-the-art design**
- **3 receiver cards, each with 2 RF front ends (total of 6 antennas)**
- **Each RF has a GP2021 correlator capable of tracking 12 channels of L1 carrier**
  - 36 channels total
- **Each board has an ARM60 processor**
  - Basic estimation algorithms
  - Signal conditioning
  - Error checking



The "GPS Orion" Receiver and Interface Board

Science Computer





- **200MHz StrongARM embedded Processor**
- **ARM-Linux embedded operating system**
- **Low power consumption (~3.5W at max utilization)**
  - 1700 MIPS/Watt is unrivaled in the embedded processor Industry
- **Natural radiation tolerance**
- **"CompactFlash" mass storage**

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Future Work

- **Orion mission preparation has raised several key questions:**
  - How to distribute the computational load for the estimation and control?
  - How to design future microsats to handle very limited ground communications?
  - Current formation flying control and autonomous fleet operations require extensive real-time data transfer between the spacecraft
  - Scalability with a larger number of vehicles?
- **Researching use of software agents to address these issues**
  - Researching ways to permit agents to monitor their workload and "farm out" tasks to less taxed agents
  - Agents can tolerate minimal ground contact due to their robustness: "hot swappability", modularity, fault detection
  - Developing communication schemes that scale well with number of spacecraft

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AIAA Space 2001 Conference
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Conclusions

- **Orion-Emerald mission is currently scheduled for Space Shuttle launch in May 2003.**
- **Construction of Orion flight model nearing completion and integration testing will continue through September.**
- **Power, fuel, and communications are significant constraints for Nanosat-1**
  - Predictions based on measurements from flight hardware indicate that all mission goals should still be achievable
- **The Orion-Emerald Mission should help "pave the way" for many future formation flying missions.**

www.mit.edu/people/jhow/orion/