Subsystem Requirements

Introduction
Subsystems
•Actuation
•Formation Control
•Control
•**Metrology**
•**Requirements**
•Trades
•Design
•Issues
•Budget Estimates
•Electronics
•Structure/Power
Operations
Implementation
Conclusion

- Determine separation distance
  - Goal: sense to one-tenth the control tolerance
- Determine relative attitude (direction) of vehicle to an angular tolerance dependent on angular controllability
  - Goal: sense to one-tenth the control tolerance
- Full field of view : 360 degrees in two dimensions
- Sensing presence of other vehicles to a distance compatible with test facilities

Trades

Introduction
Subsystems
•Actuation
•Formation Control
•Control
•Metrology
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Electronics
•Structure/Power
Operations
Implementation
Conclusion

Sonic and IR based system

- Similar to SPHERES metrology
- Expected improvement in performance due to 2D operation
- New technology should eliminate some accuracy of the errors encountered by SPHERES
- Low refresh rate will require the use of gyros and accelerometers

Design

Introduction

Subsystems

•Actuation

•Formation Control

    •Control

    •Metrology

        •Requirements

        •Trades

        •<u>Design</u>

        •Issues

        •Budget Estimates

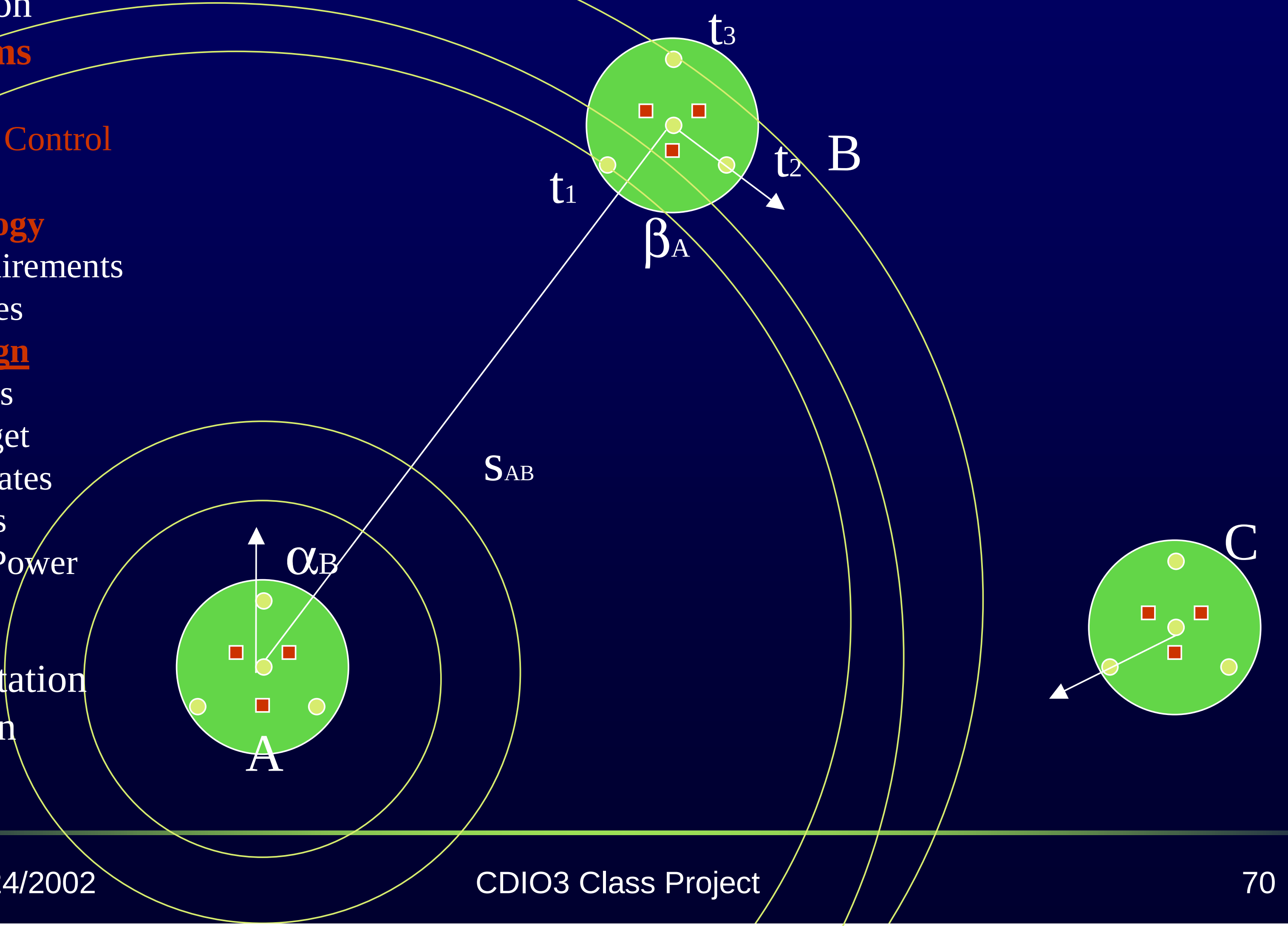
•Electronics

•Structure/Power

Operations

Implementation

Conclusion



Design

Introduction
Subsystems
- Actuation
- Formation Control
  - Control
  - **Metrology**
    - Requirements
    - Trades
    - **Design**
    - Issues
    - Budget Estimates
- Electronics
- Structure/Power

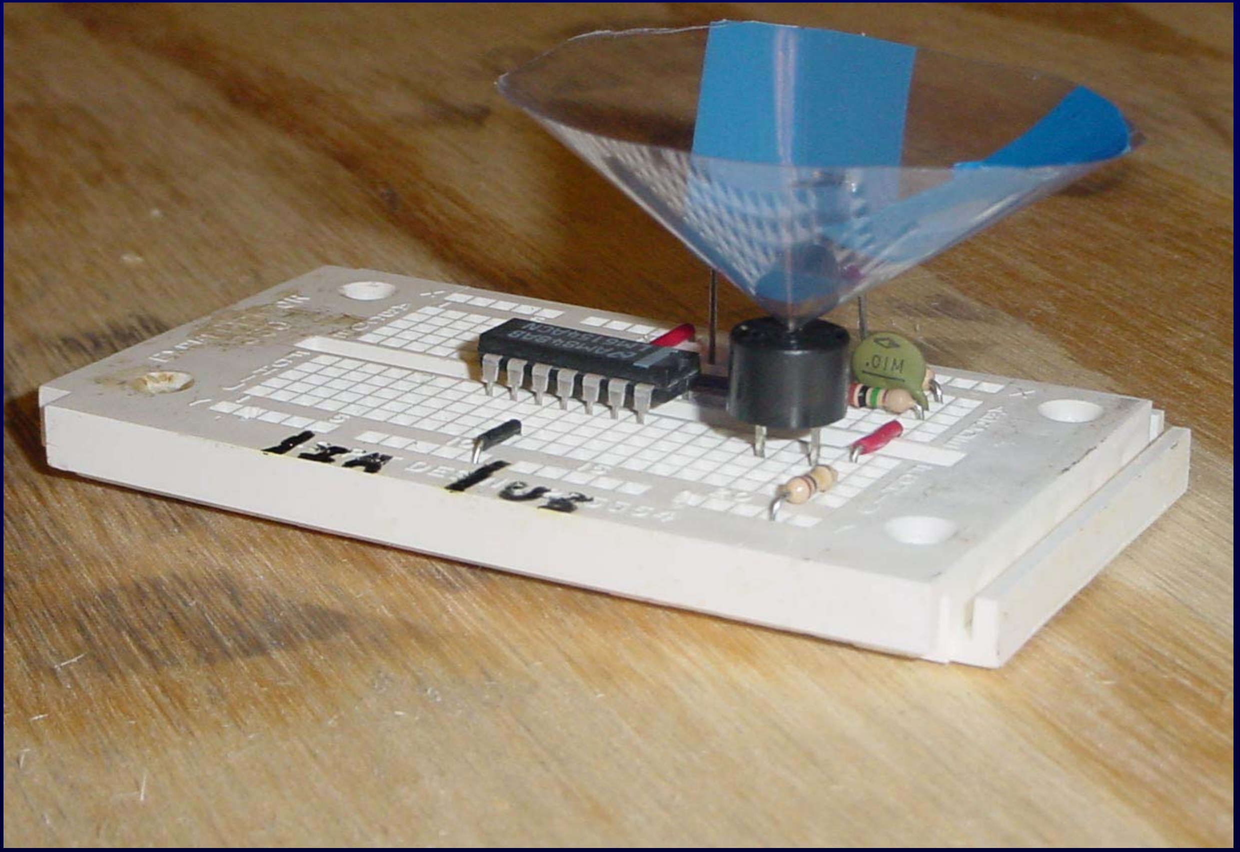
Operations
Implementation
Conclusion

- 1 ultrasonic omni-directional transmitter (Mimio)
- 3 ultrasonic omni-directional receivers (cones)
- 3 IR receivers & 2 transmitters
- 1 rate gyro
- 1 2-axis accelerometer

Design

Introduction
Subsystems
•Actuation
•Formation Control
    •Control
    •Metrology
        •Requirements
        •Trades
        •Design
        •Issues
        •Budget Estimates
•Electronics
•Structure/Power

Operations
Implementation
Conclusion



Design

Introduction
Subsystems
•Actuation
•Formation Control
•Control
•Metrology
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Electronics
•Structure/Power

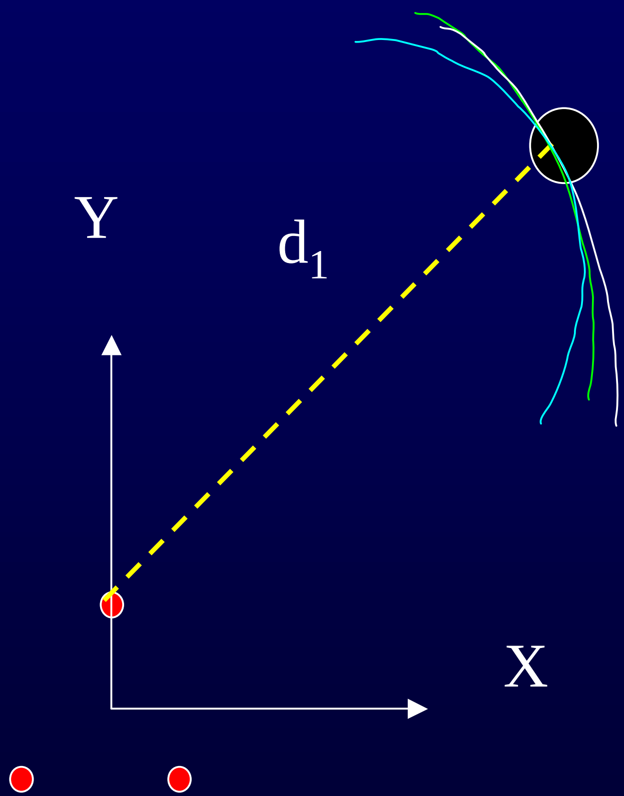
Operations
Implementation
Conclusion

- System relies only on distance readings
- Uses data from all three sensors
- Calculates relative attitude and distance directly to center of vehicle

Design

Introduction
Subsystems
•Actuation
•Formation Control
  •Control
  •**Metrology**
    •Requirements
    •Trades
    •**Design**
    •Issues
    •Budget Estimates
•Electronics
•Structure/Power

Operations
Implementation
Conclusion



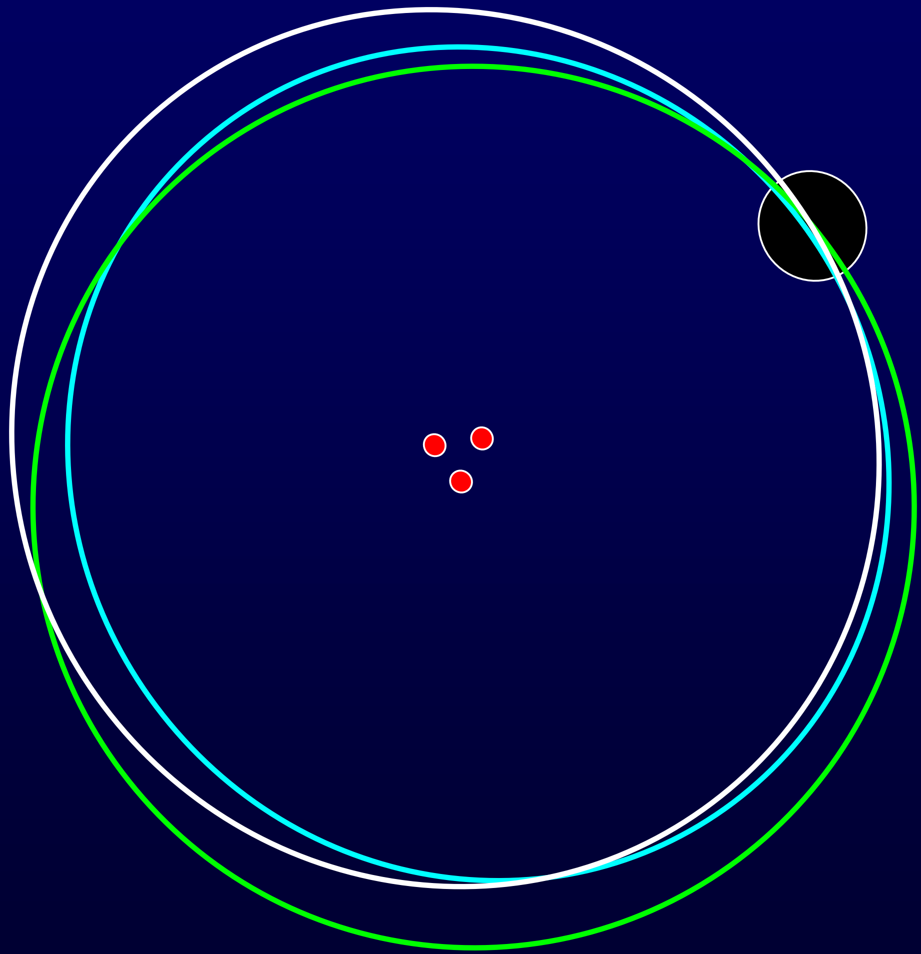
•Origin at center of vehicle
• x_i and y_i are position of the sensors

$$(x+x_1)^2+(y+y_1)^2=d_1^2$$
$$(x+x_2)^2+(y+y_2)^2=d_2^2$$
$$(x+x_3)^2+(y+y_3)^2=d_3^2$$

Design

Introduction
Subsystems
•Actuation
•Formation Control
•Control
•Metrology
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Electronics
•Structure/Power

Operations
Implementation
Conclusion



Issues

Introduction
Subsystems
- Actuation
- Formation Control
  - Control
  - **Metrology**
    - Requirements
    - Trades
    - Design
    - **Issues**
    - Budget Estimates
- Electronics
- Structure/Power

Operations
Implementation
Conclusion

- Omni-directional sonic sensors
  - Hand made cones added to current sensors
- Effect of magnetic forces
- Range and accuracy
- Refresh rate
  - Sound signal leaving the testing area
  - Rate gyros and accelerometers

Budget Estimates

Introduction
Subsystems
- Actuation
- Formation Control
  - Control
  - Metrology
    - Requirements
    - Trades
    - Design
    - Issues
    - Budget Estimates
- Electronics
- Structure/Power

Operations
Implementation
Conclusion

Part	Cost ($)	Mass (kg)	Power (W)
Sonic (1+3)	70	0.05	0.3
IR (2+3)	30	0.04	0.25
Gyros	1200	0.06	0.36
Accelerometers	1200	0.05	0.18
Total (per vehicle)	2500	0.20	1.09
Total (system)	7500	0.60	3.27

Introduction

Subsystems

- Actuation
- Formation Control
- **Electronics**
    - **Comm**
        - **Requirements**
        - **Trades**
        - **Design**
        - **Issues**
        - **Budget Estimates**
    - **Avionics**
- Structure/Power

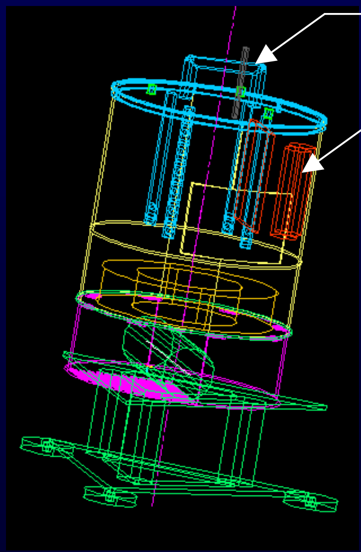
Operations

Implementation

Conclusion

Communications

Jennifer Underwood



Comm. Antenna

Comm. Board

Communications

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Comm
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Avionics
•Structure/Power
Operations
Implementation
Conclusion

- "The technology employed in transmitting messages"
  - Architecture
  - Hardware
  - Software
  - Interfacing

Subsystem Requirements

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Comm
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Avionics
•Structure/Power

Operations
Implementation
Conclusion

- Send information and instructions automatically from vehicle to vehicle
  - Control and metrology purposes
- Send information and instructions on command from ground to vehicle
  - Begin preprogrammed tests
  - Emergency intervention procedures
- Send flight health data to “ground” operator
- Have no protruding antennae that might interfere with dynamics

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Comm
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Avionics
•Structure/Power

Operations
Implementation
Conclusion

Trades

- Hardware
  - Processor board (chosen by avionics → TT8)
  - Transceiver
- Architecture

Transceiver Metrics

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
  •Comm
    •Requirements
    •Trades
    •Design
    •Issues
    •Budget Estimates
  •Avionics
•Structure/Power

Operations
Implementation
Conclusion

- EM rejection (frequency)
- Bandwidth/data rate
- Weight
- Ease of interface
- Size
- Cost
- Power consumption
- Range

Transceiver Trades

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Comm
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Avionics
•Structure/Power

Operations
Implementation
Conclusion

- Radio Frequency (RF) vs.. Wireless LAN
  - Avg cost of LAN > avg cost of RF
  - LAN requires a base station ($$)
  - Size and weight of LAN > RF
  - LAN bandwidth, range > RF
  - Power drain of LAN < RF
  - Both have capacity to reject EM (high frequencies) and are easily interfaced
- Choice: RF

RF Trades

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Comm
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Avionics
•Structure/Power

Operations
Implementation
Conclusion

	AC5124C-10	RF Monolithics (DR3000-1)
Size	2.65˝x1.65˝x0.20˝	1”x1.5”
Power	0.35 W	0.04 W
Frequency	2.402 –2.478GHz	916.5 MHz
Weight	0.02 kg	Hardly any, < AC5124C-10
Data rate	115.2-882 kbps	115.2 kbps
Range	91m indoors	Short-range wireless
Ease of Interface	Relatively Easy	Relatively Easy
Cost	~$245	$35
Availability	Company in Europe	DR1012 avail from SPHERES for prototyping
Complexity	OEM kit, not familiar	Development kit ready, familiar to staff, students

Transceiver Selection

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
  •Comm
    •Requirements
    •Trades
    •Design
    •Issues
    •Budget Estimates
  •Avionics
•Structure/Power

Operations
Implementation
Conclusion

- Preliminary final product:
  - DR 3000-1
    - Sufficient EM rejection
    - Familiarity
    - Power drain
- Prototyping product:
  - DR1012
    - Availability
    - Familiarity

Architecture Trades

Introduction
Subsystems
•Actuation
•Formation Control
•**Electronics**
  •**Comm**
    •**Requirements**
    •**Trades**
    •**Design**
    •**Issues**
    •**Budget Estimates**
  •**Avionics**
•Structure/Power

Operations
Implementation
Conclusion

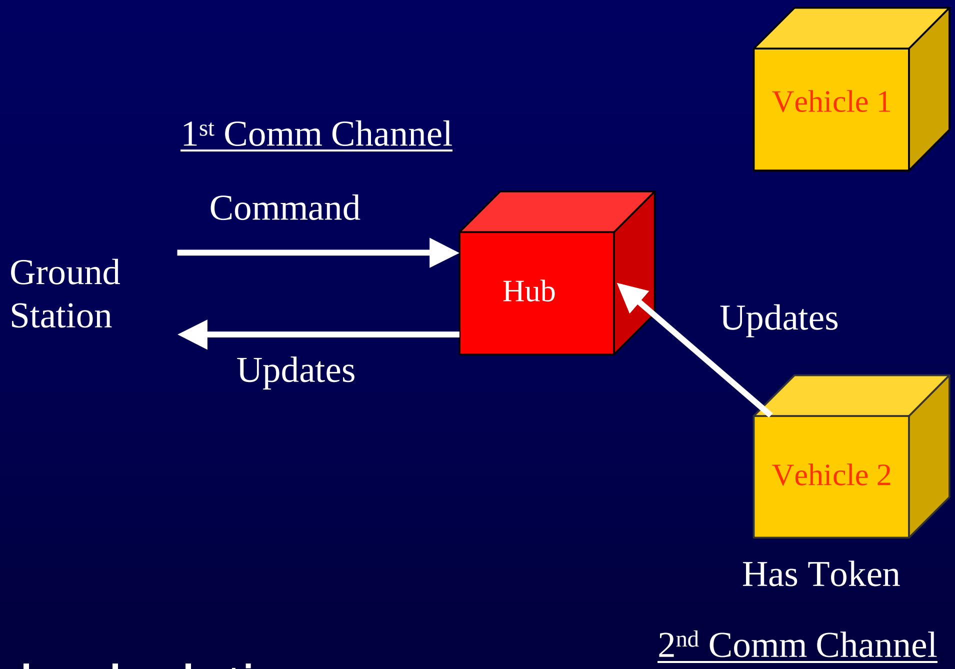
- Sequential
  - Pass token to determine who talks and to whom
  - Hub makes calculation
- Simultaneous
  - Pass token to determine who talks to everyone
  - All vehicles make calculations
- Hybrid
  - Combination of Sequential and Simultaneous
- Reliability deciding factor

Architecture Trades

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Comm
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Avionics
•Structure/Power

Operations
Implementation
Conclusion

- Sequential
  - Vehicle 2 talks to Hub
  - Token passed to Vehicle 1
  - Vehicle 1 talks to Hub
  - Hub makes control calculations and sends commands to Vehicle 1 and Vehicle 2



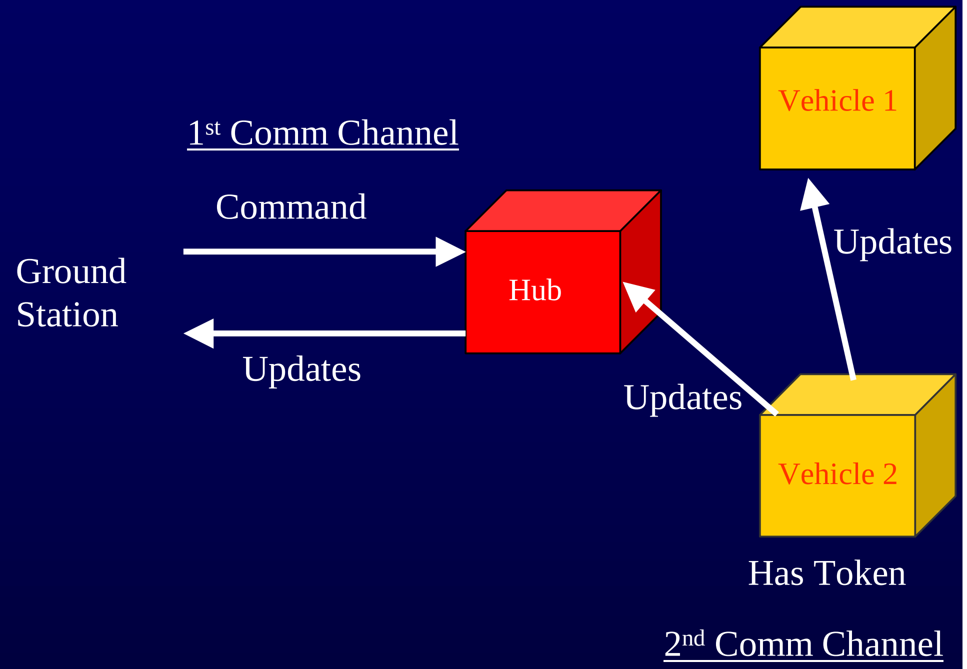
Architecture Trades

Introduction
Subsystems
- Actuation
- Formation Control
- **Electronics**
  - **Comm**
    - **Requirements**
    - **Trades**
    - **Design**
    - **Issues**
    - **Budget Estimates**
  - **Avionics**
- Structure/Power

Operations
Implementation
Conclusion

Simultaneous

- Vehicle 2 talks to Hub and Vehicle 1
- Token passed to Vehicle 1
- Vehicle 1 talks to Hub and Vehicle 2
- Token passed to Hub
- Hub talks to Vehicle 1 and Vehicle 2
- Each vehicle makes control calculations

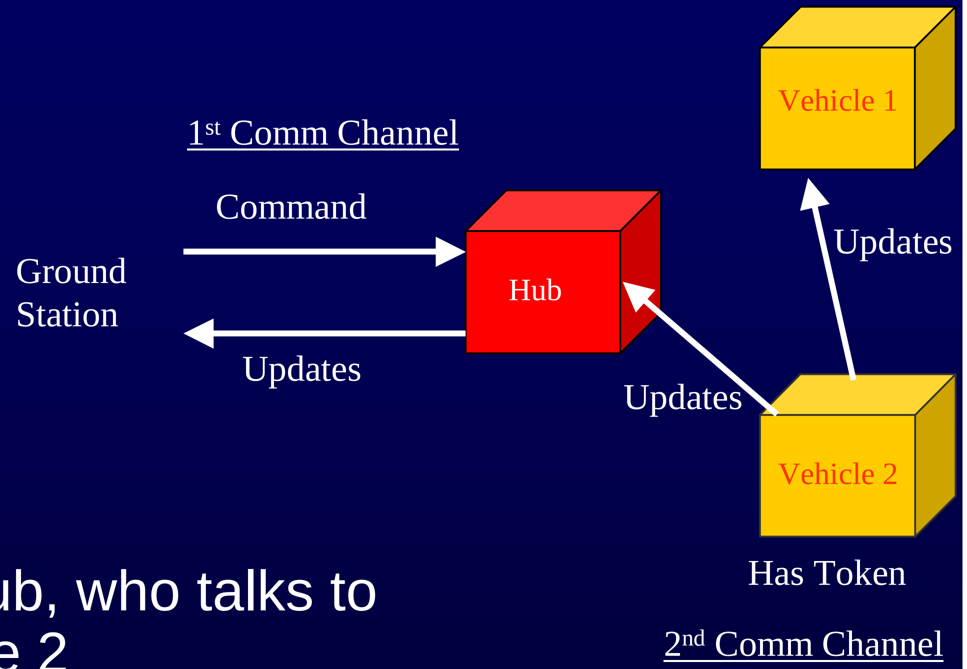


Architecture Trades

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Comm
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Avionics
•Structure/Power

Operations
Implementation
Conclusion

- Hybrid
  - Vehicle 2 talks to Hub and Vehicle 1
  - Token passed to Vehicle 1
  - Vehicle 1 talks to Hub and Vehicle 2
  - Token passed to Hub, who talks to Vehicle 1 and Vehicle 2
  - All vehicles make control calculations but only Hub determines commanded control vector → sends commands to Vehicle 1 and Vehicle 2, ground listens in



Architecture Trades

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Comm
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Avionics
•Structure/Power
Operations
Implementation
Conclusion

- Sequential
  - Requires excess code, bandwidth (BW)
  - Reliable from control point of view
- Simultaneous
  - Easy to implement
  - Not reliable from control point of view
- Hybrid
  - Reliable and versatile from control and comm point of view
  - Increased bit rate required, excess code, BW
- Design Choice: Hybrid

Design

Introduction

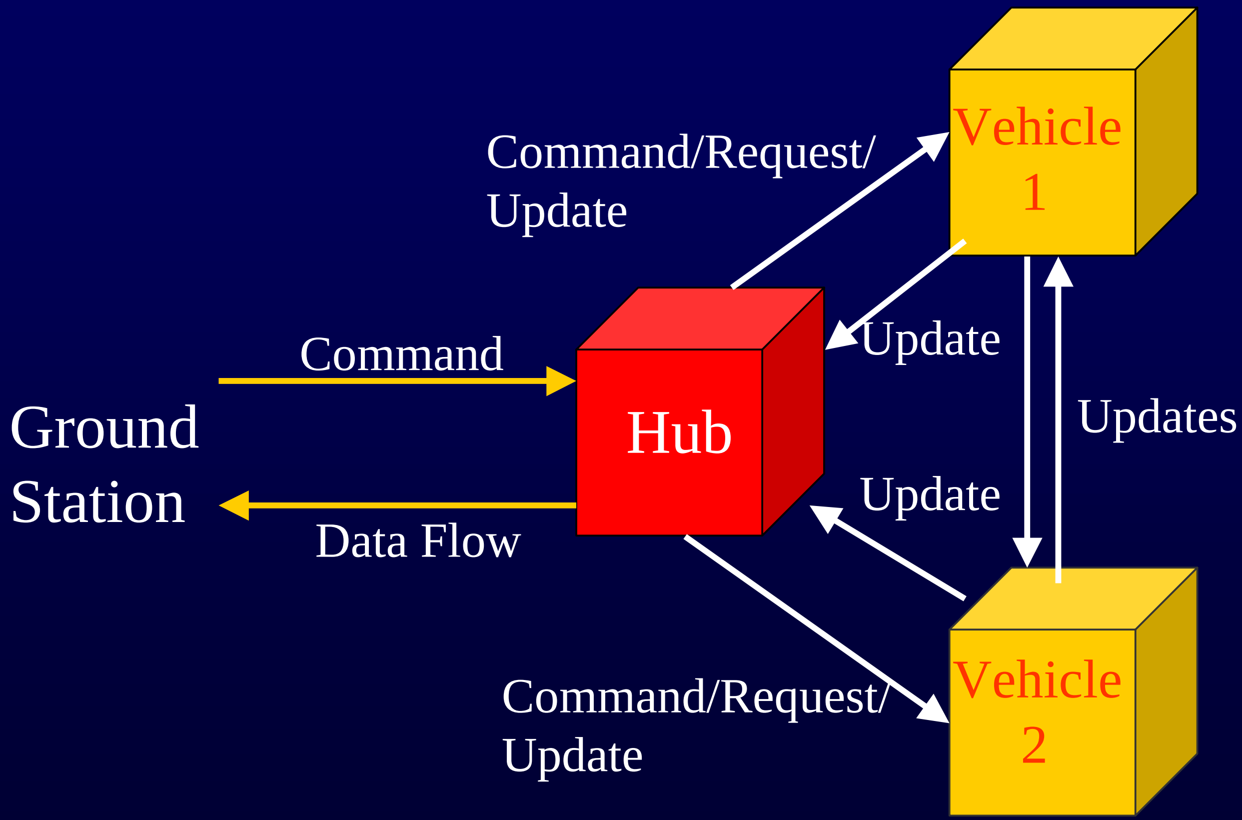
Subsystems

- Actuation
- Formation Control
- **Electronics**
  - **Comm**
    - **Requirements**
    - **Trades**
    - **Design**
    - **Issues**
    - **Budget Estimates**
  - **Avionics**
- Structure/Power

Operations

Implementation

Conclusion



Design

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Comm
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Avionics
•Structure/Power
Operations
Implementation
Conclusion

- Design Considerations
  - Comm channel usage
  - Transmission rates
  - Data framing
  - Error detection/correction
  - Channel coding
  - Automatic Repeat Request (ARQ) protocols

Data Framing

Introduction

Subsystems

- Actuation
- Formation Control
- **Electronics**
  - **Comm**
    - **Requirements**
    - **Trades**
    - **Design**
    - **Issues**
    - **Budget Estimates**
  - **Avionics**
- Structure/Power

Operations

Implementation

Conclusion

Header				Data	Check
Start	From/To	Type	Size	Data 1…Data n	Check
8bit	8bit	8bit	8bit	?	?

- Data framing is essential
  - Who to send info to
  - Who sent info (Hub, Vehicle 1, Vehicle 2)
  - Type of data
  - Size of data packet
  - Error checking
- Ease of transmitting chunks (1 byte)

Channel Usage

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Comm
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Avionics
•Structure/Power

Operations
Implementation
Conclusion

- Cluster Comm Channel
  - 6 variables in state vector (Control)
  - 4 variables to actuators (EM, RWA)
  - About 800 bits/cycle for control
  - About 500 bits/cycle for health updates
- Ground Link Comm Channel
  - Undefined requirements
  - On the order of 400 bits per complete cycle

Transmission Rates

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Comm
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Avionics
•Structure/Power
Operations
Implementation
Conclusion

- How frequently to measure systems/states?
  - Control runs at 50 Hz
  - Health max set at 10 Hz
- Therefore, we can estimate the transmission rate required:
  - 800 bits/cycle * 50 cycles/sec + 500 bits/cycle * 10 cycles/sec = 45kbps

Current Capabilities

Introduction
Subsystems
•Actuation
•Formation Control
•**Electronics**
  •**Comm**
    •**Requirements**
    •**Trades**
    •**Design**
    •**Issues**
    •**Budget Estimates**
  •**Avionics**
•Structure/Power

Operations
Implementation
Conclusion

- TT8 to TT8 communication
  - Currently connected through UART channel
- Two byte transmission
  - Send and receive between two TT8's, one direction only
  - High-Byte, Low-Byte
    - [1 1 1 1 1 1 1 1] [1 1 1 1 1 1 1 1] = 1111111111111111
      High Byte | Low Byte

Issues

Introduction

Subsystems

- Actuation
- Formation Control
- **Electronics**
  - **Comm**
    - **Requirements**
    - **Trades**
    - **Design**
    - **Issues**
    - **Budget Estimates**
  - **Avionics**
- Structure/Power

Operations

Implementation

Conclusion

- Processor/transceiver shielding
- Reliability
  - EM resistance
  - Error probability
- Communication channel load

Budgets Estimates

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
  •Comm
    •Requirements
    •Trades
    •Design
    •Issues
    •Budget Estimates
  •Avionics
•Structure/Power

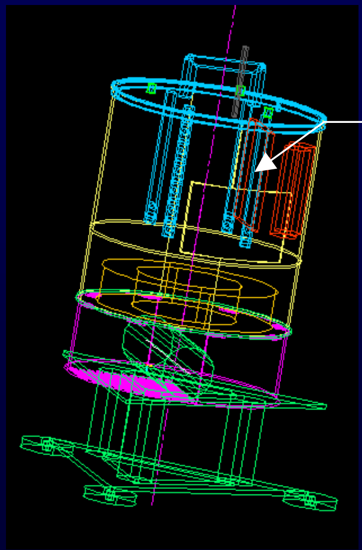
Operations
Implementation
Conclusion

Part	Cost ($)	Mass (kg)	Power (W)
Transceiver	$35 each	0.02	0.04
Miscellaneous parts	$100	0.1	-
Replacements/repairs	$70	-	-
Total (per vehicle)	$275	0.24	0.08
Total (ground station)	$275	0.24	0.08
Total (system)	$1100	0.96	0.32

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
    •Comm
    •Avionics
        •Requirements
        •Trades
        •Design
        •Issues
        •Budget Estimates
•Structure/Power

Operations
Implementation
Conclusion

Avionics



Avionics Board

Subsystem Requirements

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Comm
•Avionics
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Structure/Power
Operations
Implementation
Conclusion

- Manage timing and resources for all subsystems
- Run control loop in real-time
  - Inputs, calculations, outputs
- Administer preprogrammed tests
- Be easily programmable
- Stay within system budgets

Trades - Metrics

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Comm
•Avionics
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Structure/Power
Operations
Implementation
Conclusion

- Processing speed
- Interfaces (I/O)
- Data storage (RAM/ROM)
- Constraint considerations
  - Cost
  - Size and mass
  - Ease of use

Trades - Metrics Details

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Comm
•Avionics
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Structure/Power
Operations
Implementation
Conclusion

- Processor speed
- I/O capabilities
  - Digital vs.. analog
  - Subsystem input and output needs not necessarily the same
- RAM and ROM capacity
  - Flash memory
- Power consumption
- Cost

Trades - Interfaces

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Comm
•Avionics
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Structure/Power

Operations
Implementation
Conclusion

The avionics team must interface with all subsystems.

INPUTS

- **Metrology:**
  - 3 Ultrasonic sensors (digital)
  - 1 IR timing (digital)
  - 1 rate-gyro (analog)
  - Possibly 2 accelerometers (analog)
- **Communication**
  - Inter-vehicle data and instructions (digital)
- **Health Indicators (digital)**

Trades - Interfaces

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Comm
•Avionics
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Structure/Power
Operations
Implementation
Conclusion

The avionics team must interface with all subsystems.

OUTPUTS

- Communication
  - Requests and commands (digital)
- Actuators
  - 3 for Y-pole magnet (analog)
  - 1 for RW (analog)
- Metrology
  - 1 for ultrasonic transmitter (digital)
  - 1 for IR timing transmitter (digital, split)

Trades: Computer Comparison

Introduction
Subsystems
- Actuation
- Formation Control
- **Electronics**
  - **Comm**
  - **Avionics**
    - **Requirements**
    - **Trades**
    - **Design**
    - **Issues**
    - **Budget Estimates**
- Structure/Power

Operations
Implementation
Conclusion

Feature	Needs	TT8	C40	6701
Speed	50 Hz	16 MHz 4 MIPS	50 MFLOPS	167 MHz 1 GFLOPS
I/O	4D, 1A in 1D, 4A out	25D I/O 8A, 14 time	D parallel 64 I/O	N/A
RAM	~16 kB	256kB	16 MB	16 MB
ROM	~8kB	256kB	640 kB	512 kB
Power	Low	1.8 Watts	N/A	N/A
Cost	Low	(~$500)	Custom	High

Trades: other considerations

Introduction
Subsystems
- Actuation
- Formation Control
- **Electronics**
  - **Comm**
  - **Avionics**
    - **Requirements**
    - **Trades**
    - **Design**
    - **Issues**
    - **Budget Estimates**
- Structure/Power

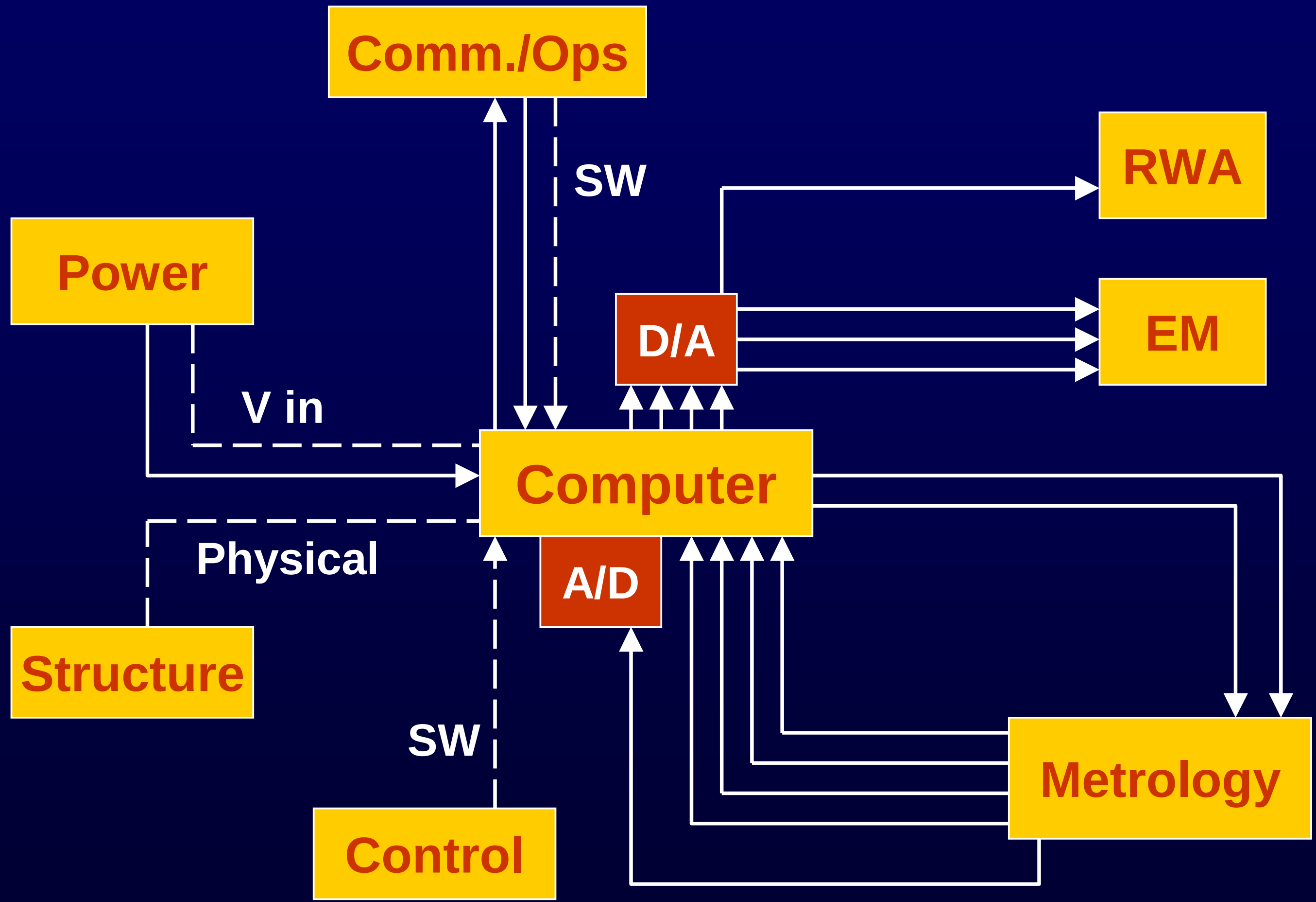
Operations
Implementation
Conclusion

- Other Computer Considerations
- Size/weight satisfactory for structure?
- Available/Replaceable?
- Easy to use?
- Expandable?

Design: Hardware

Introduction
Subsystems
- Actuation
- Formation Control
- **Electronics**
  - **Comm**
  - **Avionics**
    - **Requirements**
    - **Trades**
    - **Design**
    - **Issues**
    - **Budget Estimates**
- Structure/Power

Operations
Implementation
Conclusion



Design: Software

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Comm
•Avionics
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Structure/Power
Operations
Implementation
Conclusion

- Language: C
- Coding environment
  - Creating: Metroworks CodeWarrior
  - Loading to vehicle: Motocross
- Procedures
  - Control loop
    - Metrology updates
    - Matrix calculations
    - Actuation commands
  - Test programs
  - Health, test data reports

Issues

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Comm
•Avionics
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Structure/Power
Operations
Implementation
Conclusion

- Software is the high-risk item for the avionics subsystem.
- Preliminary Test Prototyping Design to find complications early.
  - Develop a clock-interrupt
  - Blink an LED
  - Signal Reproduction via PWM
- Preliminary Prototype to be completed by end of semester.

Budget Estimates

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
  •Comm
  •Avionics
    •Requirements
    •Trades
    •Design
    •Issues
    •Budget Estimates
•Structure/Power

Operations
Implementation
Conclusion

- Mass
  - 0.028 kg per tattletale
    - May need two
  - 0.028 per subsystem circuit board
- Power
  - Highest power draw: two main computers
  - Power required: 3.6 Watts
- Cost
  - Per-vehicle needs, system-wide extras
  - $500 total allocated for TT8 repairs
  - $6500 for circuit boards (power, comm., controls, metrology)

Budget Estimates (cont.)

Introduction
Subsystems
- Actuation
- Formation Control
- **Electronics**
  - **Comm**
  - **Avionics**
    - **Requirements**
    - **Trades**
    - **Design**
    - **Issues**
    - **Budget Estimates**
- Structure/Power

Operations
Implementation
Conclusion

Part	Cost ($US)	Mass (kg)	Power (W)
TT8 (x2)	500	0.057	3.6
Boards	6500	0.113	?
Total (vehicle)	1060	0.113	?
Total (system)	7000	0.339	?

Introduction

Subsystems

•Actuation

•Formation Control

•**Electronics**

•**Structure/Power**

- •**Power**
  - •**Requirements**
  - •**Trades**
  - •**Design**
  - •**Issues**
  - •**Budget Estimates**
- •**Structure**

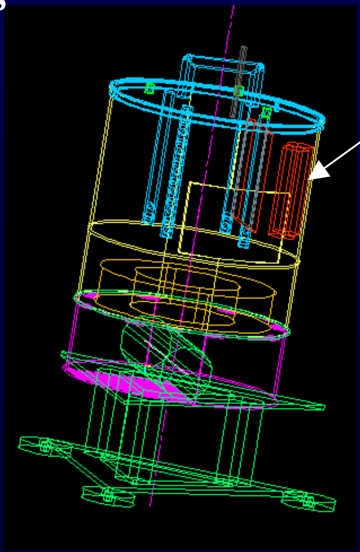
Operations

Implementation

Conclusion

Power

Amy Schonsheck



Power

Requirements

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Structure/Power
•Power
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Structure

Operations
Implementation
Conclusion

- No external umbilicals
  - On-board power supply
- Provide sustainable power for 30 minutes
- Use a renewable or rechargeable energy source

Power Trades

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Structure/Power
•Power
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Structure

Operations
Implementation
Conclusion

- Solar power vs.. batteries
  - Power requirements too demanding for solar power
  - Rechargeable batteries the best option
- Choice of battery chemistry

Battery Selection

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Structure/Power
•Power
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Structure

Operations
Implementation
Conclusion

- For expected voltage and current requirements, viable options include:
  - Lithium Ion (Li-ion)
  - Nickel Cadmium (NiCd)
  - Nickel Metal Hydride (NiMH)

Battery Selection

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Structure/Power
•Power
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Structure

Operations
Implementation
Conclusion

- Li-ion:
  - High energy density
  - Low discharge rate (2 Amps max.)
- NiCd:
  - Adequate discharge rate
  - Low efficiency at high current draws
- NiMH: → Final choice
  - High energy density
  - Fast discharge rate
  - Efficient even at high current draw

Power Design

Introduction
Subsystems
•Actuation
•Formation Control
•**Electronics**
•**Structure/Power**
  •**Power**
    •**Requirements**
    •**Trades**
    •**Design**
    •**Issues**
    •**Budget Estimates**
  •**Structure**

Operations
Implementation
Conclusion

Subsystem power estimates:

Subsystem	Voltage (V)	Power (W)
Avionics: Tattletale (x 2?)	9-12 (each)	2 (each)
Metrology: Accelerometers	8-30	0.18
Metrology: Gyros	12-18	0.36
Metrology: Transmitters/Receivers	3	0.066
Comm/Ops: (shares Tattletale)	9-12	0.1
RWA: Reaction Wheel	28?	13
EM: Electromagnet	12 (min.)	60-70
	TOTAL:	~ 90 W (max)

Power Design

Introduction
Subsystems
•Actuation
•Formation Control
•**Electronics**
•**Structure/Power**
  •**Power**
    •**Requirements**
    •**Trades**
    •**Design**
    •**Issues**
    •**Budget Estimates**
  •**Structure**

Operations
Implementation
Conclusion

- Total current draw: 7 Amps (current design)
- Operation time: 30 minutes (min.)
- Total energy: 3.5 Ah
- Candidate battery: Panasonic HHR200SCP
  - Voltage - 1.2 V
  - Capacity - 1.9 Ah
  - Weight – 42 g
  - Dimensions: 23 mm diameter, 34 mm height

Power Design

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Structure/Power
•Power
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Structure

Operations
Implementation
Conclusion

- Candidate battery architecture:
  - 1 “Pack” = 15 batteries x 1.2 V (wired in series)
    - 18 V
    - 1.9 Ah
  - 2 Packs wired in parallel
    - 18 V
    - 3.8 Ah
    - Sufficient voltage, current for the system

Power Design

Introduction
Subsystems
•Actuation
•Formation Control
•**Electronics**
•**Structure/Power**
•**Power**
•**Requirements**
•**Trades**
•**Design**
•**Issues**
•**Budget Estimates**
•**Structure**

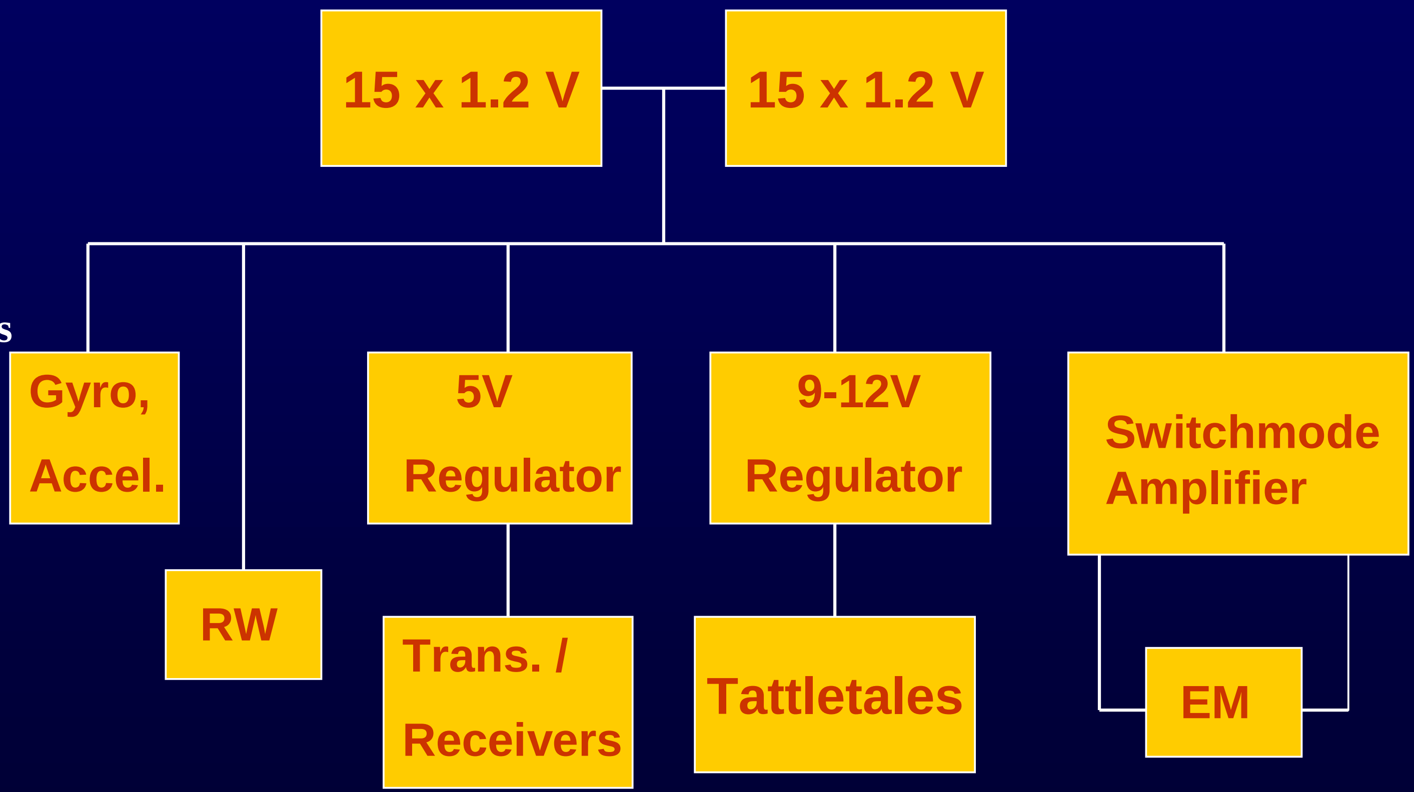
Operations
Implementation
Conclusion

- Voltage Regulators used to step down voltages
  - 9-12 V : Tattletale processors
  - 5 V : Transmitters/Receivers
  - Gyros, accelerometers may have built-in voltage regulators
- Switchmode amplifier used to control current through electromagnet
  - Commercially available

Power Flowchart

Introduction
Subsystems
- Actuation
- Formation Control
- **Electronics**
- **Structure/Power**
  - **Power**
    - **Requirements**
    - **Trades**
    - **Design**
    - **Issues**
    - **Budget Estimates**
  - **Structure**

Operations
Implementation
Conclusion



Issues

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Structure/Power
•Power
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Structure

Operations
Implementation
Conclusion

- NiMH batteries have strict charge/discharge limits
  - Overcharging decreases performance
  - Rapid discharge → produces heat
- Safety precautions
  - Avoid excessive heat
  - Avoid contact with water

Issues

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Structure/Power
•Power
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Structure
Operations
Implementation
Conclusion

- Possible greater power requirements
  - Current design allows 7 amps
  - EM may require up to 10 amps
    - May require more batteries
    - Possibly switch to next higher battery model (much higher mass)
- Charging takes ~ 1.2 hours
  - Two or three complete battery sets needed (per vehicle) → higher cost

Budget Estimates

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Structure/Power
•Power
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Structure

Operations
Implementation
Conclusion

- Mass:
  - 30 batteries
  - 42 g each
  - Total battery weight: 1.26 kg
  - Additional components: ~ 50 g (regulators, amplifier)

Budget Estimates

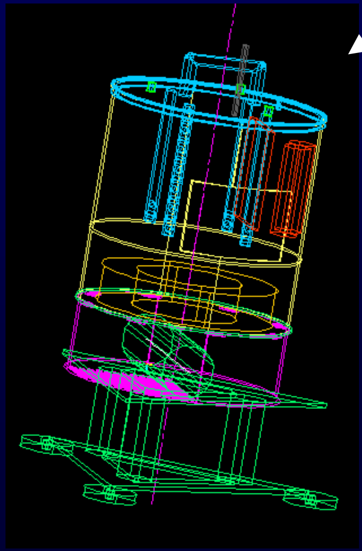
Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Structure/Power
•Power
•Requirements
•Trades
•Design
•Issues
•Budget Estimates
•Structure

Operations
Implementation
Conclusion

- Cost:
  - Switchmode amp: ~$65
  - Voltage regulators: ~ $60
  - Batteries: $400 - $500
- Power:
  - Supply 100% of EMFFORCE power needs

Introduction
Subsystems
•Actuation
•Formation Control
•**Electronics**
•**Structure/Power**
•**Power**
•**Structure**
•**Requirements**
•**Geometrical Overview**
•**Trades**
•**Design**
•**Budget Estimates**
Operations
Implementation
Conclusion

Structure



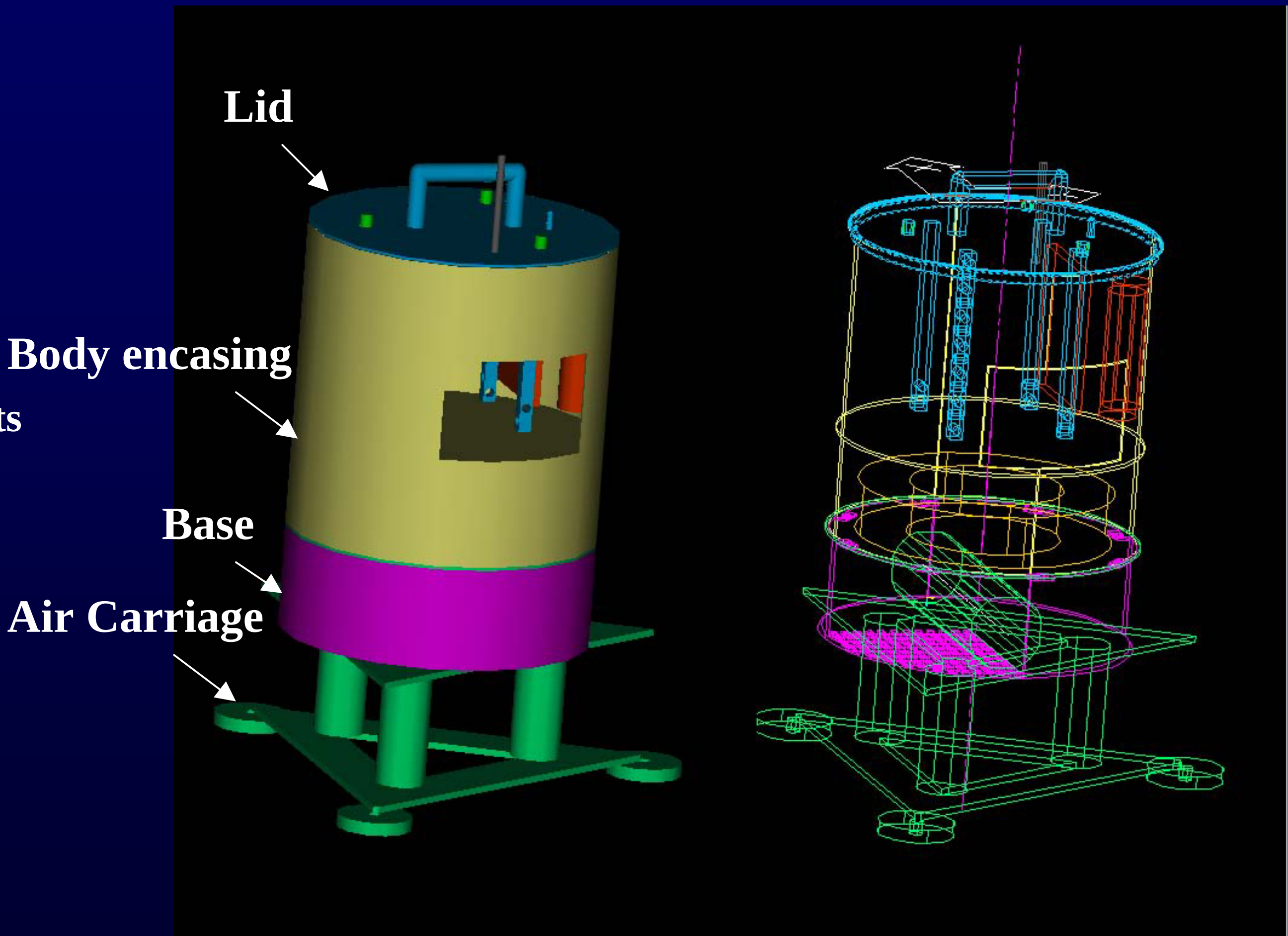
Structure Requirements

Introduction
Subsystems
•Actuation
•Formation Control
•**Electronics**
•**Structure/Power**
•**Power**
•**Structure**
•**Requirements**
•**Geometrical Overview**
•**Trades**
•**Design**
•**Budget Estimates**
Operations
Implementation
Conclusion

- Vehicle Casing:
  - Provide physical interfacing capability
  - Prevent damage in case of collision
  - Thermal considerations due to magnet heating
- Magnetic Shielding:
  - Protect electronics hardware from magnetic interference
- Air Carriage:
  - Provide adequate cushion height for vehicle mass

Geometric Overview

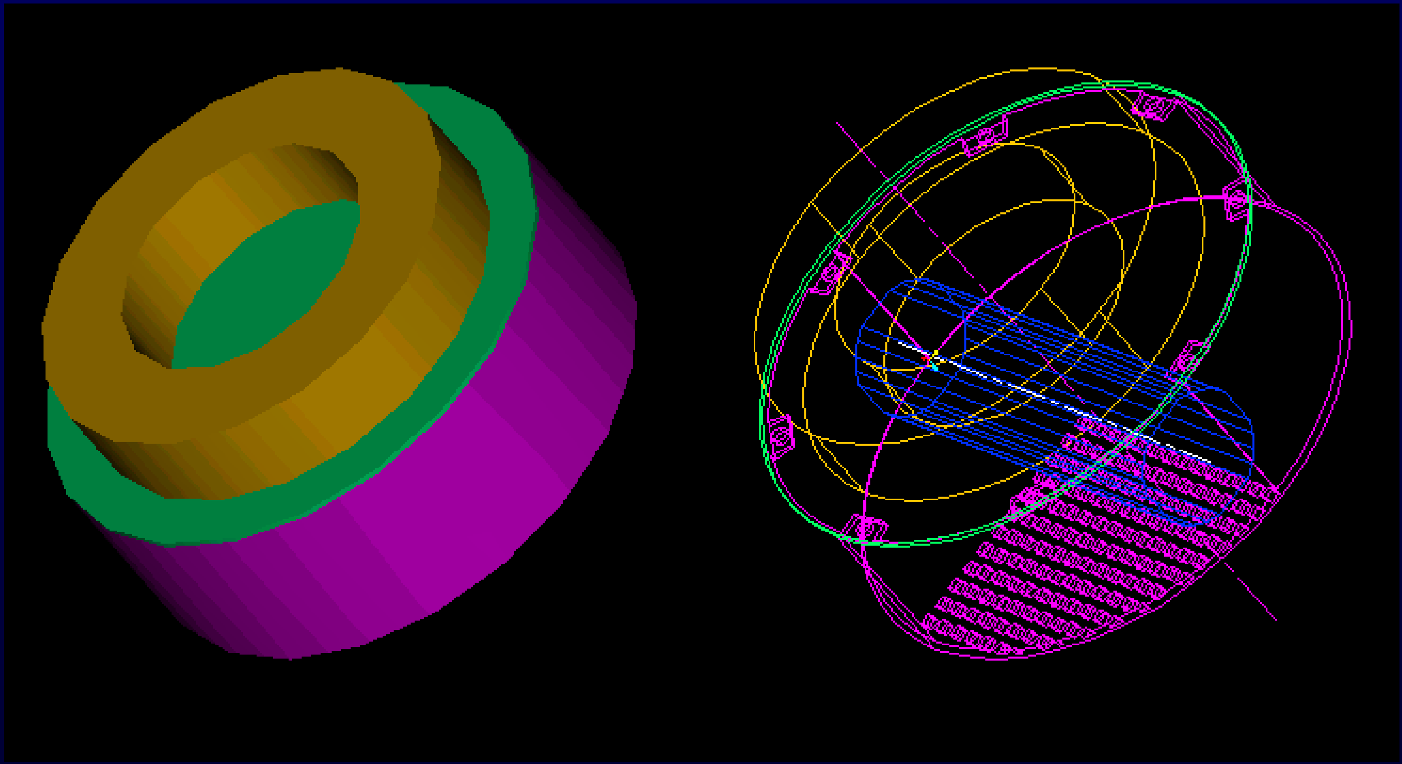
Introduction
Subsystems
•Actuation
•Formation Control
•**Electronics**
•**Structure/Power**
  •**Power**
  •**Structure**
    •**Requirements**
    •**Geometrical Overview**
    •**Trades**
    •**Design**
    •**Budget Estimates**
Operations
Implementation
Conclusion



Geometric Overview

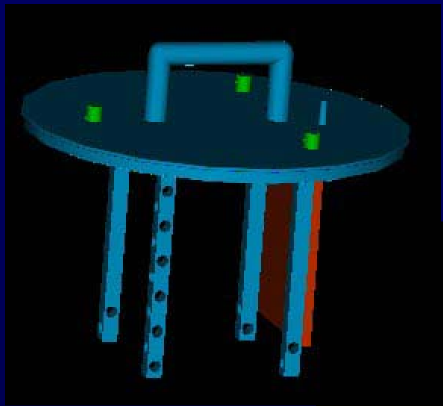
Introduction
Subsystems
- Actuation
- Formation Control
- **Electronics**
- **Structure/Power**
  - **Power**
  - **Structure**
    - **Requirements**
    - **Geometrical Overview**
    - **Trades**
    - **Design**
    - **Budget Estimates**

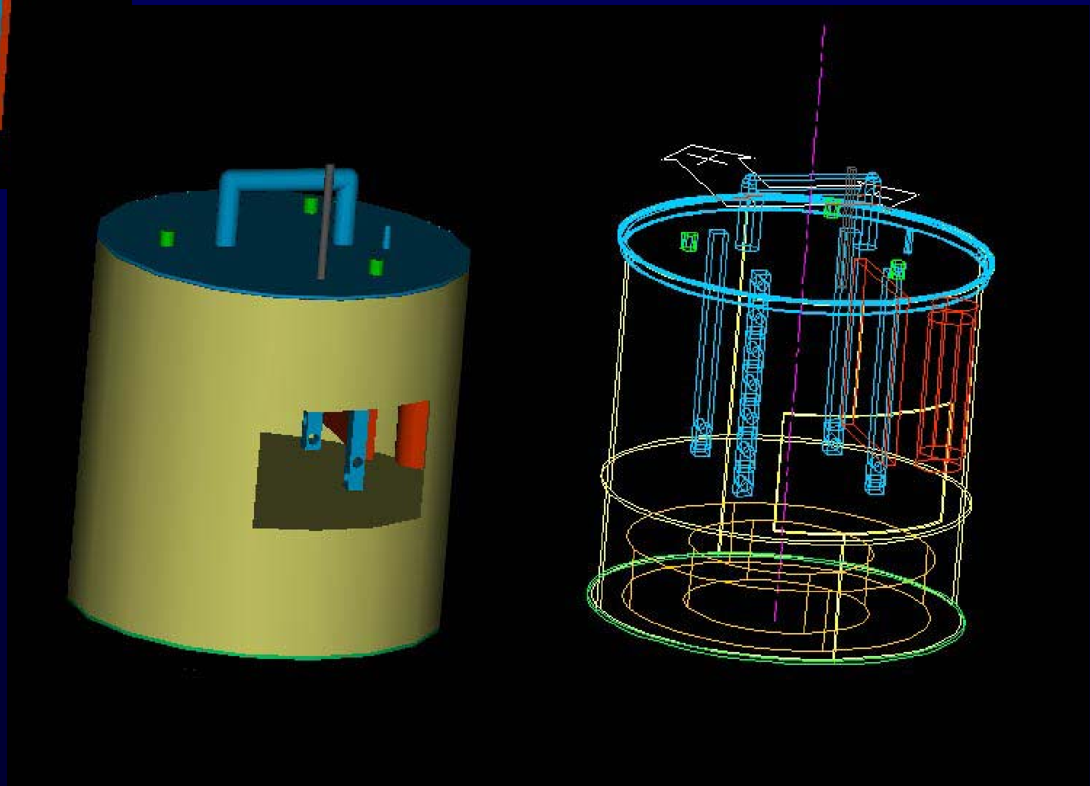
Operations
Implementation
Conclusion



Geometric Overview

Introduction
Subsystems
•Actuation
•Formation Control
•**Electronics**
•**Structure/Power**
  •**Power**
  •**Structure**
    •**Requirements**
    •**Geometrical Overview**
    •**Trades**
    •**Design**
    •**Budget Estimates**
Operations
Implementation
Conclusion





Shielding

Introduction
Subsystems
- Actuation
- Formation Control
- **Electronics**
- **Structure/Power**
  - **Power**
  - **Structure**
    - **Requirements**
    - **Geometrical Overview**
    - **Trades**
    - **Design**
    - **Budget Estimates**

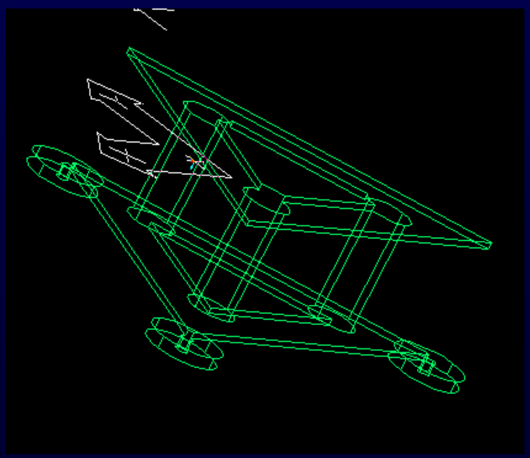
Operations
Implementation
Conclusion

- Sample kit includes various materials of different properties.
- Determine functional material at least mass.
- Conduct tests using electronics/ electromagnets, and test shielding material.

Air Carriage: Trades

Introduction
Subsystems
•Actuation
•Formation Control
•**Electronics**
•**Structure/Power**
•**Power**
•**Structure**
•**Requirements**
•**Geometrical Overview**
•**Trades**
•**Design**
•**Budget Estimates**
Operations
Implementation
Conclusion

- Fabricate vs.. Off-the-Shelf
  - Cost, Efficiency
- Tanks vs.. Compressors
  - Cost, Power, Mass
  - Infinite(?) air supply



Air Carriage: Design

Introduction
Subsystems
•Actuation
•Formation Control
•**Electronics**
•**Structure/Power**
•**Power**
•**Structure**
•**Requirements**
•**Geometrical Overview**
•**Trades**
•**Design**
•**Budget Estimates**
Operations
Implementation
Conclusion

- Objective: For a given weight accurately predict and obtain a maximum air cushion thickness
- Design variables
  - Supply pressure
  - Puck radius
  - Supply orifice

Air Carriage: Model Assumptions

Introduction
Subsystems
•Actuation
•Formation Control
•Electronics
•Structure/Power
•Power
•Structure
•Requirements
•Geometrical Overview
•Trades
•Design
•Budget Estimates
Operations
Implementation
Conclusion

- Linear radial pressure distribution for single, central orifice

$$P(r_p) = P_s - (P_s - P_a)\frac{r_p}{R_p}$$

- Possible compressible effects near aperture

Air Carriage: Lubrication Theory

Introduction
Subsystems
•Actuation
•Formation Control
•**Electronics**
•**Structure/Power**
•**Power**
•**Structure**
•**Requirements**
•**Geometrical Overview**
•**Trades**
•**Design**
•**Budget Estimates**
Operations
Implementation
Conclusion

- Thin film:
  - $h \ll R_p$
  - very low Reynolds Number

$$\mathrm{Re} = \frac{\rho_a U c}{\mu_a} \propto \frac{\rho_a R_p U_p}{\mu_a}\left(\frac{h^2}{R_p^{\ 2}}\right)$$

- Similarities to Couette and Poiseuielle flows: parabolic velocity distribution

Air Carriage: Next Steps…

Introduction
Subsystems
•Actuation
•Formation Control
•**Electronics**
•**Structure/Power**
  •**Power**
  •**Structure**
    •**Requirements**
    •**Geometrical Overview**
    •**Trades**
    •**Design**
    •**Budget Estimates**
Operations
Implementation
Conclusion

- Lubrication flow solver
  - Pressure gradient
  - Flow Velocity
  - Load
  - Cushion thickness
- Assess compressible behavior
- Assess puck designs