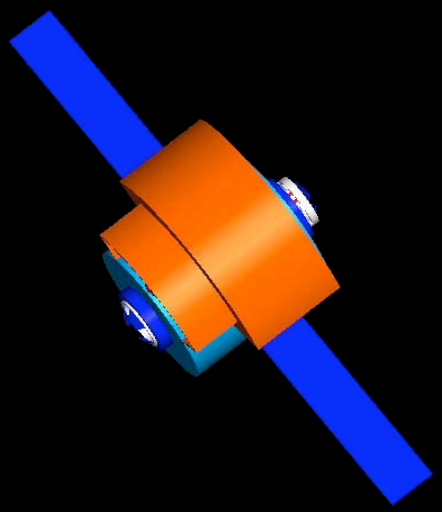
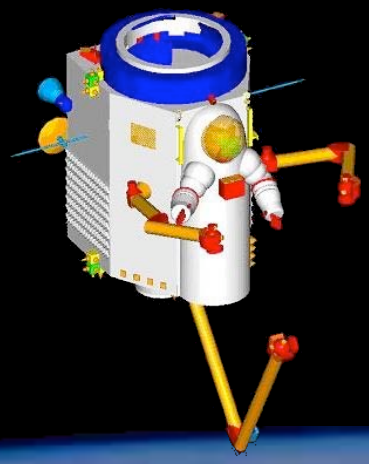
SCOUT

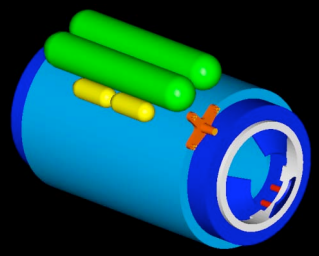
Project SCOUT

Critical Design Review

May 3, 2003





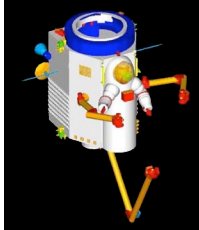


University of Maryland

SCOUT

Overview

- What is SCOUT?
- Systems Integration
- Mission Planning and Analysis
- Life Support and Human Factors
- Loads, Structures, and Mechanisms
- Avionics
- Propulsion, Power, and Thermal
- Costing
- Conclusions



SCOUT

Systems Integration

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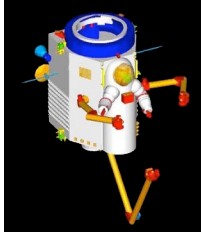
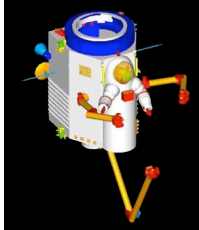


SCOUT

What is Project SCOUT?

- SCOUT: Space Construction & Orbital Utility Transport
  - An assessment of a closed-cabin atmospheric system for extravehicular operations
  - Proposed element of the Orbital Aggregation & Space Infrastructure Systems (OASIS) program
  - Designed to operate with the proposed Gateway Station at the Earth-Moon L1 Point
  - Includes two SCOUT pods, a docking fixture for attachment to the Gateway station with accommodations for replenishment of consumables between missions, and an XMP (extended mission pallet)
  - Provides extensive dexterous operations in the vicinity of the Gateway station



OASIS

SCOUT

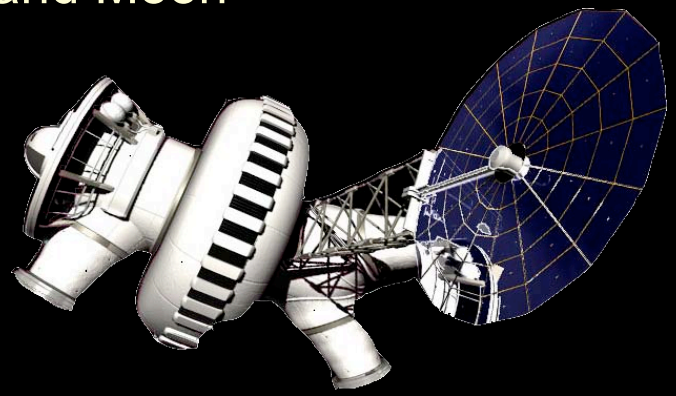
- Objectives:
  - To develop robust and cost effective concepts in support of future space commercialization and exploration missions
  - To accomplish reusable in-space transportation architecture composed of modular fuel depots, chemical/solar electric stages and crew transportation elements
  - To maximize modularity, reusability and commonality of elements across many missions, enterprises and organizations
- Infrastructure Elements:
  - Lunar Gateway
  - International Space Station
  - Crew Transfer Vehicle
  - Solar Electric Propulsion
  - Chemical Transfer Module

OASIS Executive Summary Report

Gateway Station

SCOUT

- Next major goal in space exploration
- Located at L1 point between Earth and Moon
- Focal point for future:
  - Large telescope assembly
  - Moon missions
  - Science missions
- Resupply strategy
  - Once every six months
    - Food, clothing, medical supplies
  - Once every two years
    - Station keeping propellant, ECLSS consumables, tools, experiments
- Proposed Extravehicular Activity (EVA) to be performed by:
  - Astronauts in space suits
  - Robonaut
- SCOUT is designed to incorporate best of EVA and robotics, and provide new capabilities from the synthesis of the two

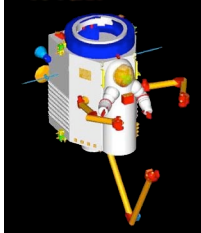


NASA-OASIS

Systems Integration Requirements

SCOUT

- Level One Requirements
  - I1: The SCOUT system shall be designed to operate from the L1 Gateway system
  - I2: The system shall be designed to be readily modifiable for operations on International Space Station
  - I3: Systems design shall consist of the SCOUT vehicle, and a docking and recharge facility to be attached to the hosting station
  - I4: Systems design shall be conducted in accordance with NASA Standard JSC-28354, Human-Rating Requirements
  - I5: All system technologies shall be at a minimum NASA technology readiness level (TRL) of 3 on Jan. 1, 2005, and shall be capable of reaching a TRL of 6 by the technology cut-off date of Jan.1, 2008
  - I6: All components for SCOUT system installation and operation shall be designed for launch on US launch vehicles currently planned to be operational in 2005



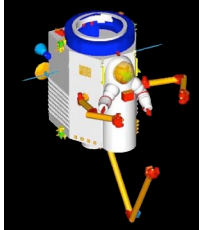
SCOUT

Systems Integration Requirements

- I7: The SCOUT system shall be designed to accommodate servicing access to all components at the host station. Items planned for nominal replacement cycles shall be reachable in shirt-sleeve conditions
- I8: All SCOUT systems shall be capable of contingency operations without internal pressurization
- I9: System shall provide for a single-interface replenishment at the docking port
- I10: System shall provide for a single-person checkout and refurbishment between each use. Total time for this activity is not to exceed one hour
- I11:All safety-critical systems shall be two-fault tolerant. Sufficient sensors shall be incorporated to allow positive diagnosis of all credible failures

• Level Two Requirements
  - I1.1Needs to have appropriate docking capabilities
  - I1.2Needs to be able to get to Earth-Moon L1
  - I2.1Needs to be designed to withstand environment of L1 and LEO

SCOUT



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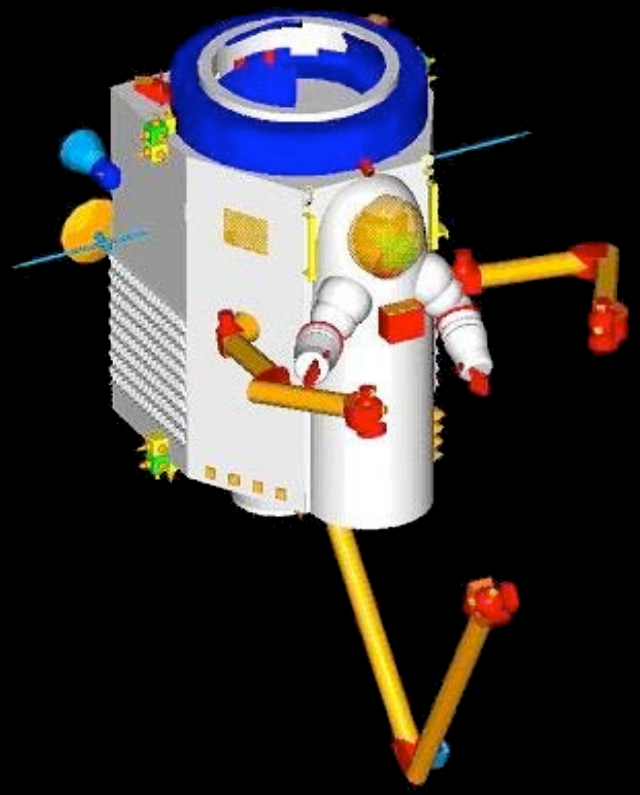
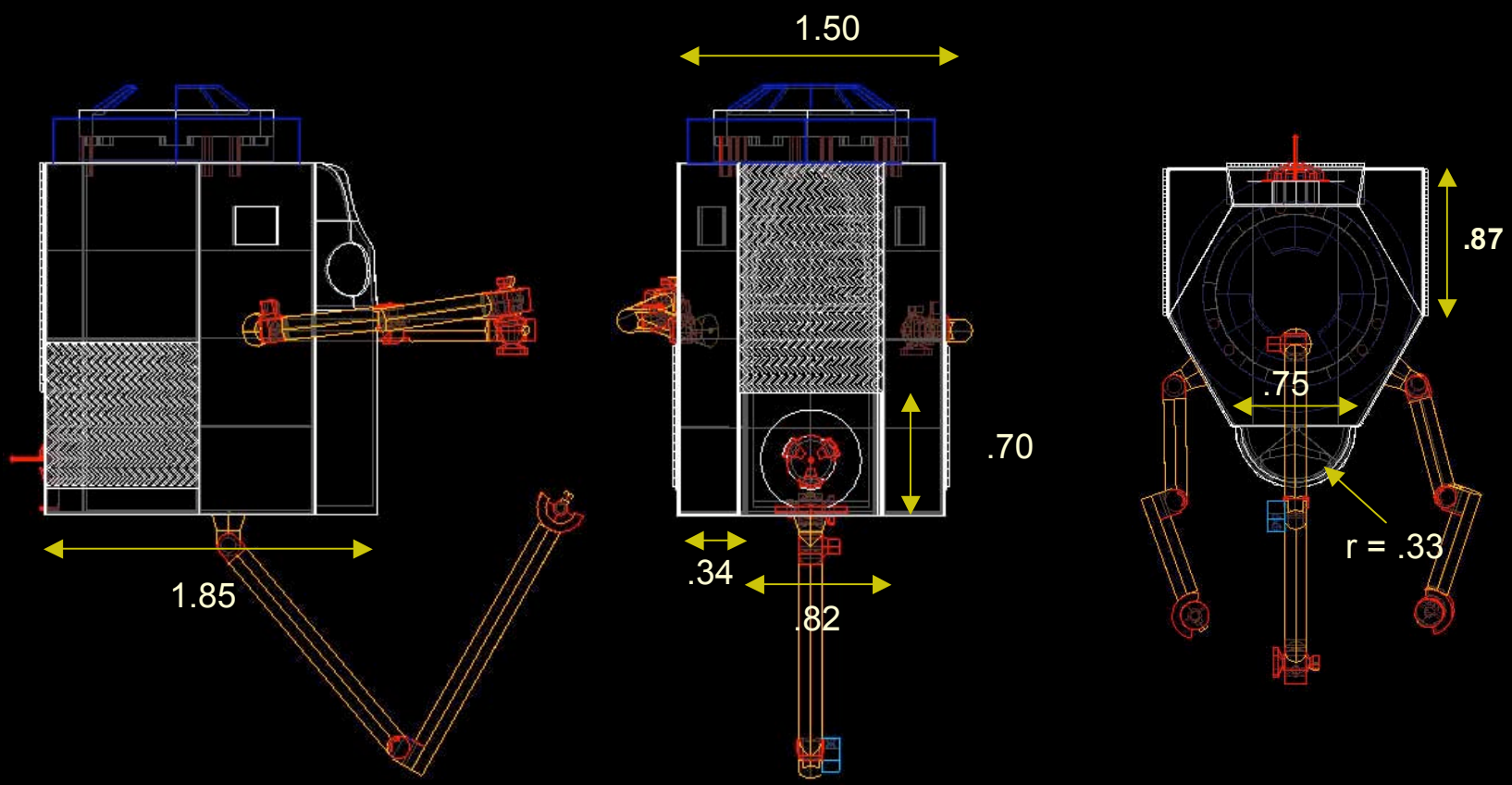


- Major Design Constraints
  - Robot arms interacting with human arms
  - Large propellant tanks
  - Use of RMS attach fitting
  - Hinged back panel for access to batteries
  - Placement of escape system/grapple arm
  - IBDM internal hatch opening
  - Minimum interior work and rotation volume
  - Operate at 8.3 psi

Basic SCOUT Dimensions

SCOUT



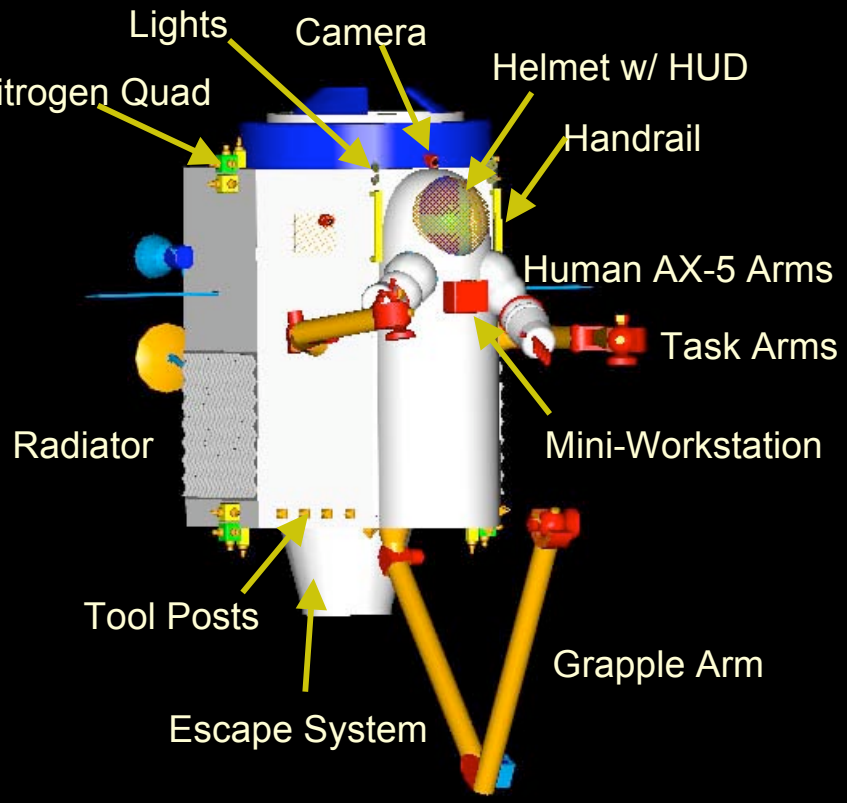
Side View

Rear View

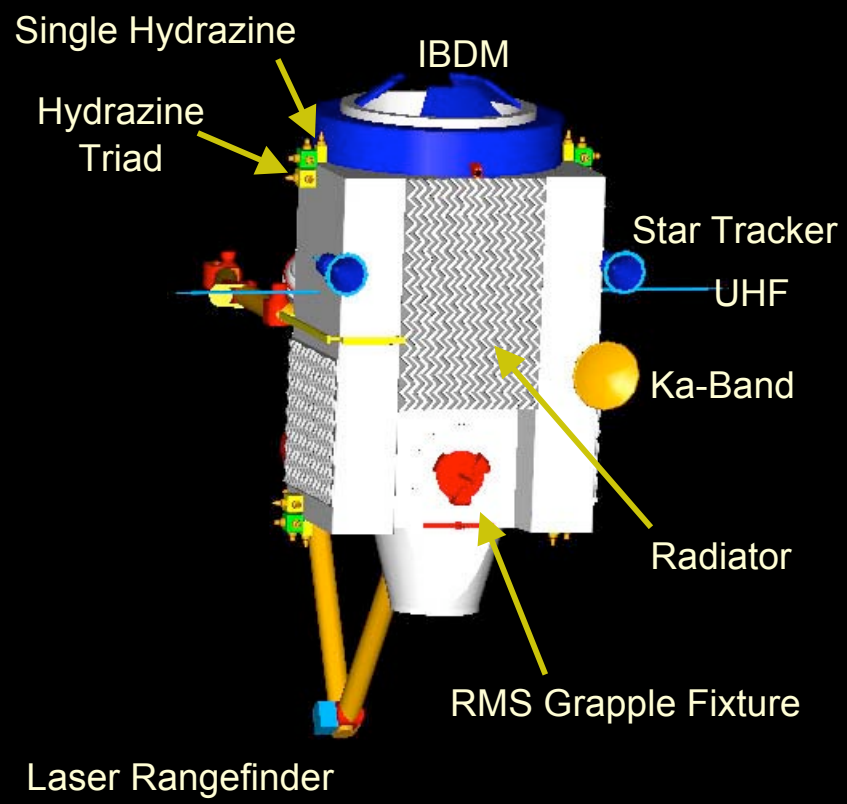
Bottom View

Exterior Features

SCOUT



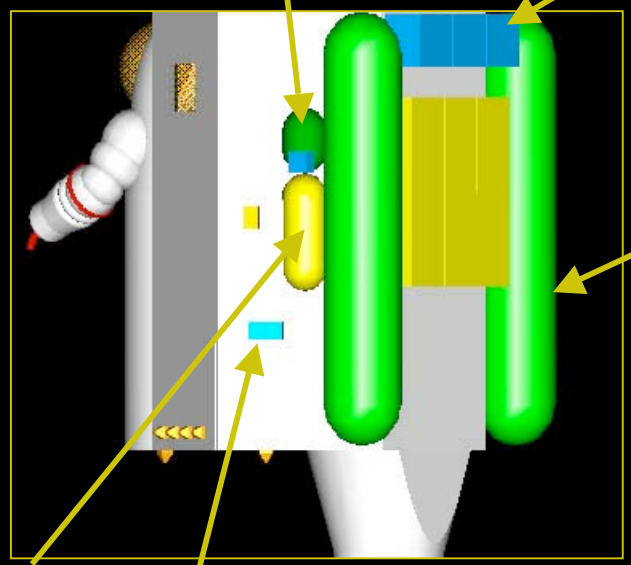
Front View

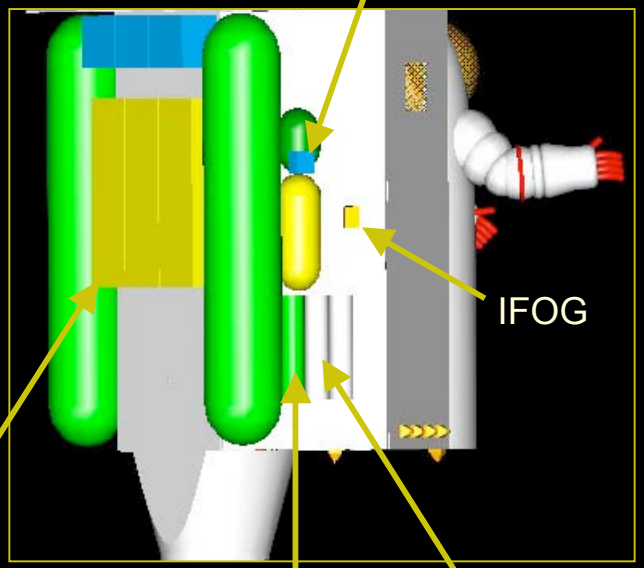


Rear View

External Panels Removed

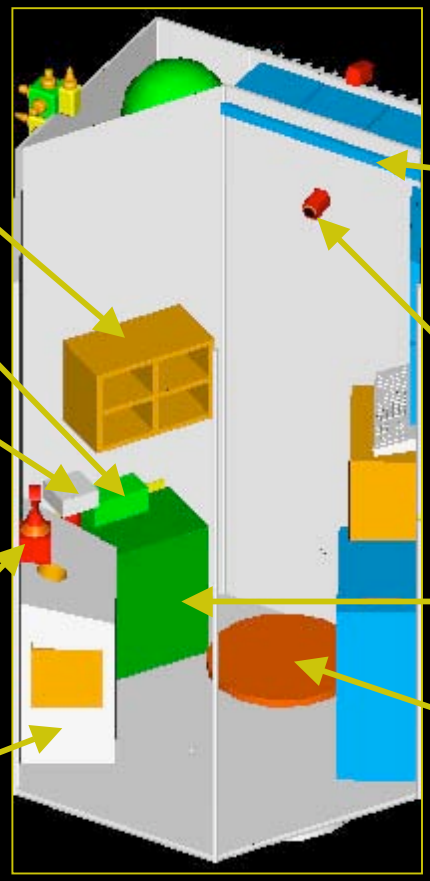
SCOUT



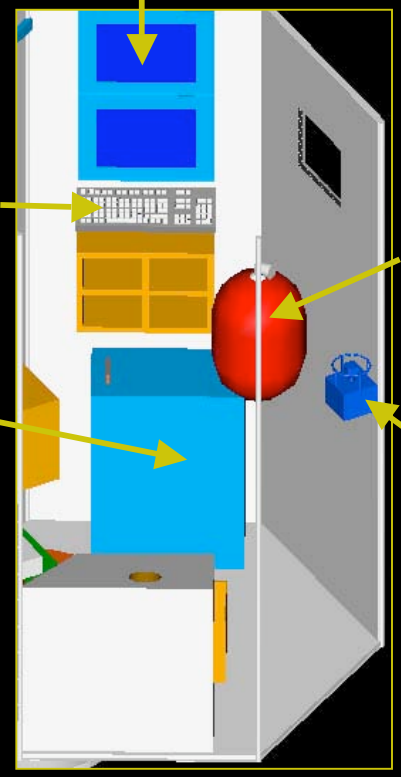


Interior Features

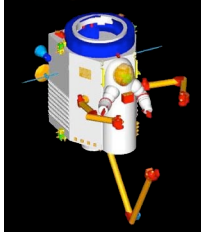
SCOUT



Right Side



Left Side



SCOUT

Vehicle Mass/Power Breakdown

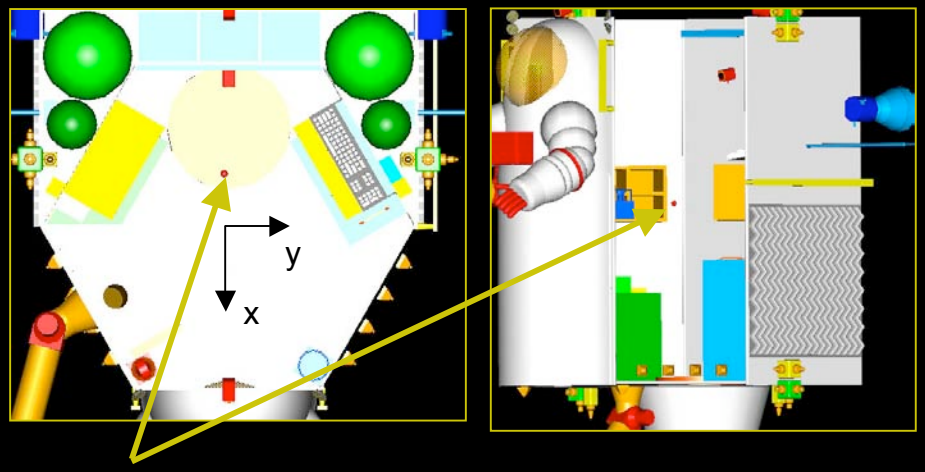
System	Allotted Mass (kg)	Actual Mass (kg)	Power (W)
Loads, Structures, and Mechanisms	375	691 - 845	216 - 264
Life Support and Human Factors	150	212 – 259	266 – 326
Avionics	200	172 – 210	266 – 325
Power, Propulsion, and Thermal	775	570 - 696	77 – 94
Total	**1500**	**1670 - 2040**	**824 - 1010**

[Note: Actual Mass and Power incorporate a ±10% margin.
Nominal Power is shown. Peak power near 2900W]

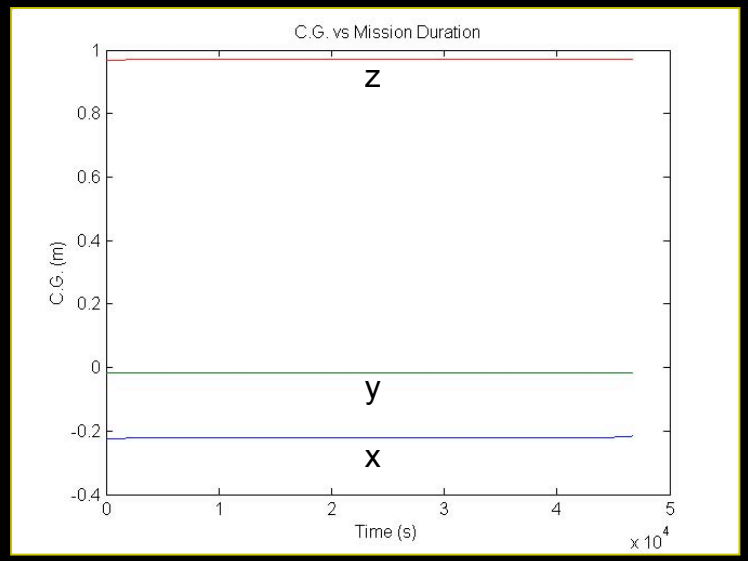
Center of Gravity

SCOUT

- Reference Coordinate System – center of bottom hexagonal plate
  - X points to the front of SCOUT, Y to the left, Z is up
- Calculated using MATLAB, and c.g. of each component on IDEAS
- Center of gravity with fully fueled propellant tanks, task and grapple arms in their stowed conditions
  - X = -0.23m, Y = -0.016m, Z = 0.97m
- Center of gravity at mission end, task and grapple arms in their stowed conditions
  - X = -0.21m, Y = -0.017m, Z = 0.97m
  - Minimal change, led to placement of thrusters at X = -0.22m



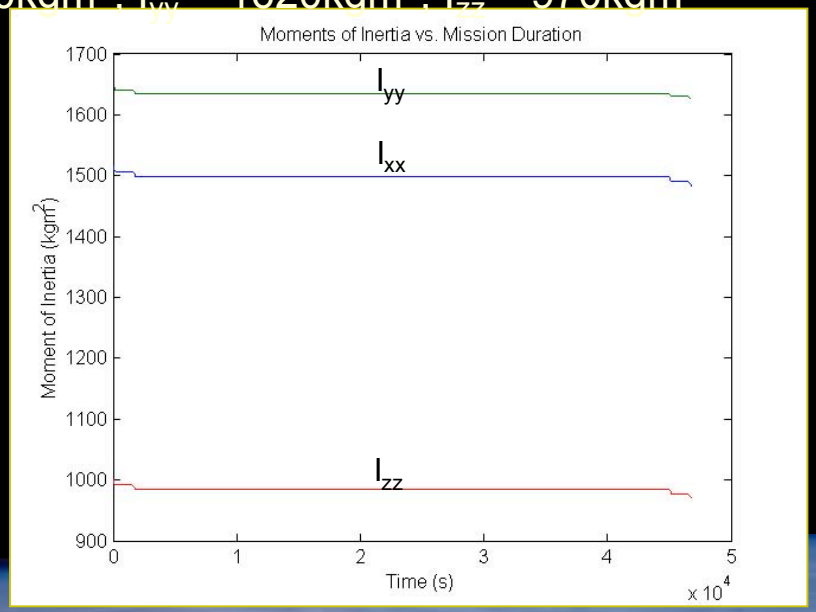
Red sphere (r = 0.15) indicates range of c.g. locations with arms stowed.



[Note: Only reflects changes in c.g. due to propellant loss]

Moments of Inertia

- Calculated using MATLAB, and M.O.I.'s of each component using IDEAS
  - Moments incorporate a fractional increase of 10% due to the fact that the IDEAS model had only 90% of the masses listed in the Component Table (propellant lines, wiring, etc. were not modeled)
- Moments of Inertia with fully fueled propellant tanks, task and grapple arms in their stowed conditions (kgm^2)
  - I_{xx} = 1520kgm^2, I_{yy} = 1650kgm^2 , I_{zz} = 1000kgm^2
- Moments of Inertia at mission end, task and grapple arms in their stowed conditions (kgm^2)
  - I_{xx} = 1480kgm^2, I_{yy} = 1620kgm^2, I_{zz} = 970kgm^2



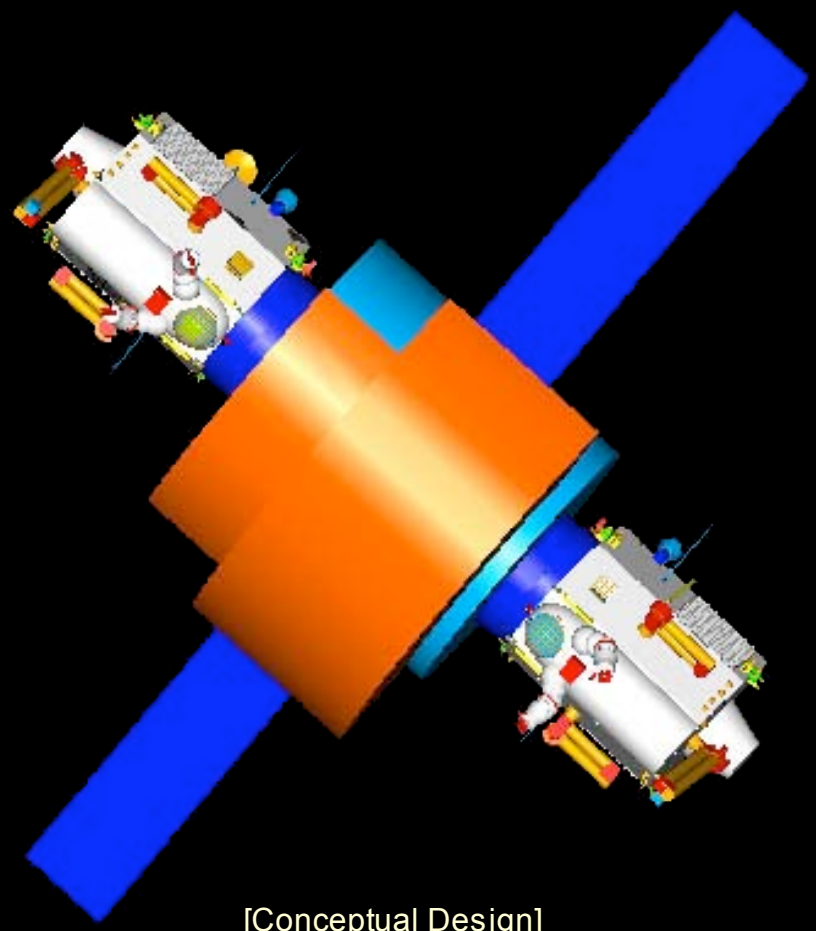
[Note: Only reflects changes in M.O.I.'s due to propellant loss]

SCOUT

Docking Module

SCOUT

- Three IBDM docking ports
  - Two ports will accommodate SCOUT vehicles
  - One port will accommodate the Gateway Station inflatable docking ring
- Ingress/Egress in shirt-sleeve conditions

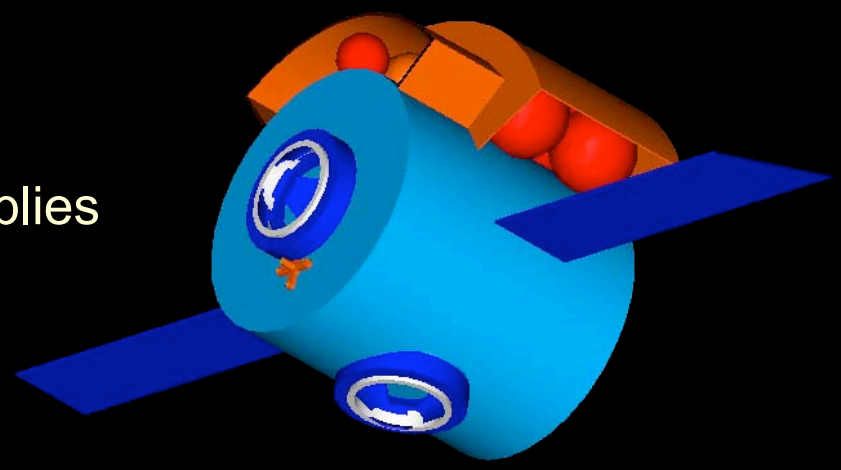


[Conceptual Design]

Docking Module

SCOUT

- Protective shields over tanks for micrometeoroid and thermal protection
- Storage needs for 6 months
  - N_2 propellant and tanks
  - N_2H_4 propellant and tanks
  - Glove/Arm replacement supplies
  - Spare batteries
  - Solar arrays
  - Metox needs
  - VGS V-shaped passive target
  - Power harness
  - Other miscellaneous supplies

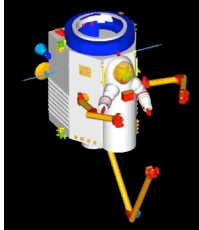


[Conceptual Design]

SCOUT

Docking Module Components

Item	Mass[kg]	Power [W]
Structure	360	N/A
Solar Arrays	20	-3270
Spare Battery	155	N/A
METOX Regenerator	50	1000
N_2 Storage	2420	N/A
Hydrazine Storage	620	N/A
Glove and Arms replacements	150	N/A
IBDM (3)	645	TBD
Total	**4420**	**Self Sufficient**



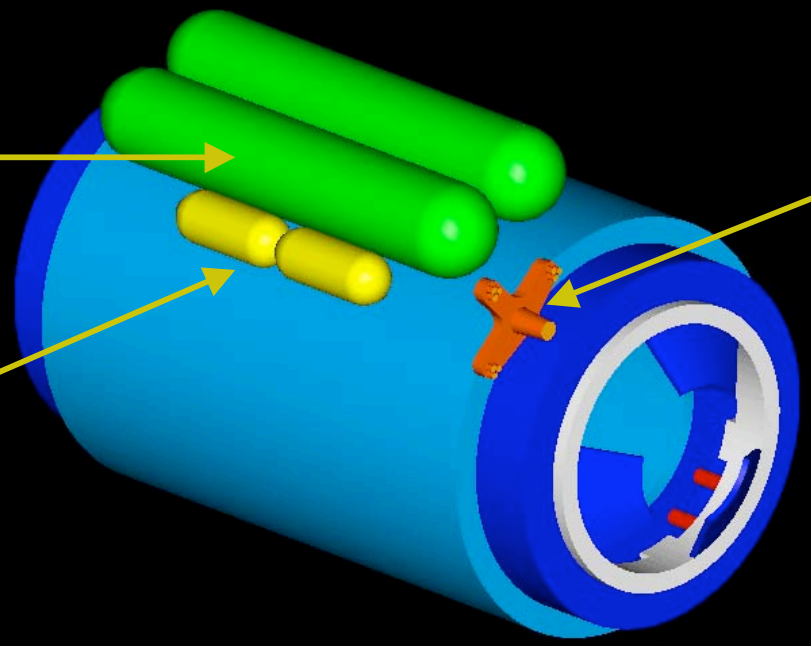
XMP

SCOUT

- eXtended Mission Pallet (XMP):
  - Supports off-site extended sorties:
    - Attaches between SCOUT and tow-vehicle
    - Remains attached to tow-vehicle while SCOUT performs worksite operation
    - Provides off-site refueling/ recharging
    - Shirt-sleeve atmosphere allows passage from SCOUT to tow-vehicle
  - Mission Flexibility:
    - May be tailored to particular extended mission
    - IBDM permits docking with any OASIS vehicle
  - Possible Extended Missions:
    - Lunar orbit operations
    - Geostationary satellite servicing
    - ISS servicing

XMP

- Configuration for Lunar Operations Support:

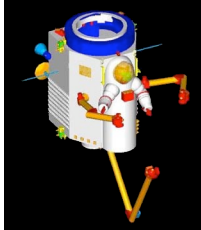


[Conceptual Design]

Batteries and PDUs stored inside module

Module kept at shirt-sleeve atmosphere to permit passenger transfer

SCOUT

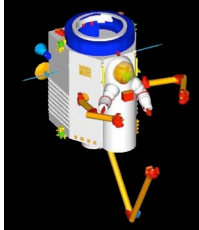


XMP

SCOUT

Lunar Operations Pallet:

Item	Quantity	Mass (kg)
Structure	1	100
IBDM	2	430
N_2	N/A	91
N_2 Tanks	2	196
N_2H_4	N/A	30
N_2H_4 Tanks	2	3.5
Batteries	2	116
PDU	2	20
VGS	1	8
Total	**-**	**995**



SCOUT

Mission Planning & Analysis

Chris Bowen

Jackie Reilly

Sadie Michael

Kirstin Hollingsworth

Wendy Frank

SCOUT

MPA Requirements

- M1: All nominal ingress/egress shall be accomplished in shirt-sleeved conditions
- M2: The design reference mission shall consist of a series of phases
  - M2.1: Test Mission
  - M2.2: Nominal Mission
  - M2.3: Aggressive Mission
  - M2.4: Extended Mission
- M3: The SCOUT system shall provide the capability for the operator to interact with the work site using her/his own hands
- M4: The SCOUT system shall provide the capability for the operator to interact with the worksite via dexterous manipulators
  - M4.1: The dexterous manipulators, also know as the task arms, must have the capability to handle several different types of hardware
  - M4.2: The task arms must be positioned in order to allow for the greatest range of motion around and access to large manipulated hardware
  - M4.3: The task arms will be designed for a defined series of common tasks
- M5: The SCOUT system shall provide the capability for attaching to the worksite via robotic manipulators or other adjustable restraint mechanism
  - M5.1: A grapple arm will be used to grasp the worksite

SCOUT

MPA Requirements

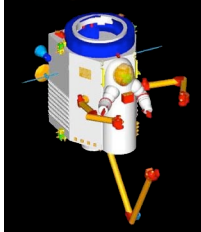
- M6: The SCOUT system shall de designed for a single operator under nominal conditions
- M7: Standard operational capabilities for the SCOUT system shall meet or exceed EVA capabilities demonstrated in Hubble Space Telescope and International Space Station operations
- M8: SCOUT shall be designed not to preclude successive operations on a daily basis for indefinite periods of time
  - M8.1: Servicing Schedule
- M9: SCOUT shall provide attitude control for itself at all times, and for the grappled spacecraft being serviced. For design purposes, the reference size for a grappled target spacecraft will be assumed to be equivalent to Hubble Space Telescope

- I1: The SCOUT system shall be designed to operation from the L1 Gateway system
- I2: The system shall be designed to be readily modifiable for operations on International Space Station
- I3: Systems design shall consist of the SCOUT vehicle, and a docking and recharge facility to be attached to the hosting station
  - !3.1: SCOUT vehicle
  - I3.2: Docking module

MPA Requirements

- I4: Systems design shall be conducted in accordance with NASA Standard JSC-28354 Human-Rating Requirements
  - I4.1: The cumulative probability of safe crew return over the life of the program exceeds 0.99
- I5: All components for SCOUT system installation and operation shall be designed for launch on US launch vehicles currently planned to be operational in 2005
  - I5.1: Launch or SCOUT system to Low Earth Orbit shall be achieved on space shuttle.
  - I5.2: LEO to L1 transit shall be on OASIS SEP

SCOUT



SCOUT

Launch Overview

- The SCOUT system will be launched to Low Earth Orbit by the space shuttle
- In LEO, the system will be attached to a Solar Electric Propulsion (SEP) stage for transfer to the L1 Gateway station
  - SEP ion engines provide a low-impulse, spiral trajectory to L1
  - OASIS plans for 7 reusable SEPs
- This shuttle-SEP plan allows the SCOUT system to be launched fully fueled and loaded with replacement parts for its first 6-month mission
- Estimated cost: $500M for additional shuttle launch

SCOUT

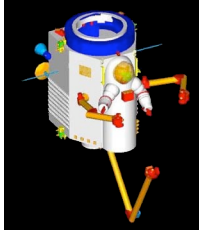
Arrival at L1 Gateway

- SCOUT system (aboard SEP) arrives at Gateway at about the same time as the first scheduled crew rotation
- SEP and/or CTM will be used to bring SCOUT system close to Gateway station
- Gateway crew uses Gateway's Remote Manipulator System to grab SCOUT and attach the SCOUT Docking Module (DM) to Gateway's EVA airlock
- Nominal SCOUT operations can begin immediately

SCOUT

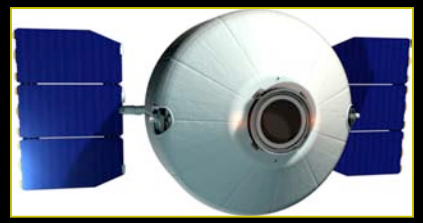
SCOUT Resupply at Gateway

- SCOUT vehicles are designed to automatically resupply fuel, atmosphere, and power after each sortie by docking at the DM
- DM also provides storage for other consumables, including, but not limited to: suit arms and gloves, batteries, charcoal filters, and micrometeoroid protection panels (MMPPs)
- For nominal missions (15 sorties per SCOUT over a 6-month mission), DM requires resupply every 6 months
- For aggressive missions (30 sorties per SCOUT), DM requires resupply every 3 months

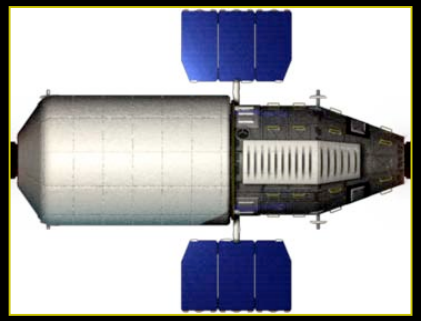


SCOUT

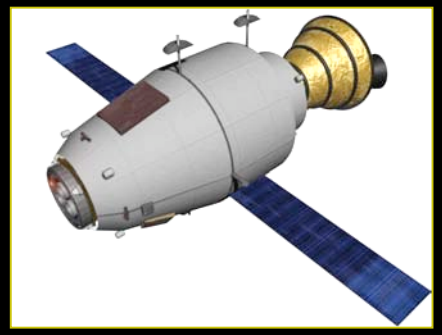
OASIS Supply Vehicles



- Crew Transfer Vehicle (CTV)
  - Transfer crew from LEO to L1 and back
  - Rotate crew every 6 months
  - Human consumables resupplied with crew rotation
  - Life support resupply every two years

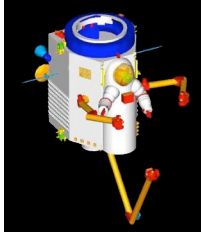


- Hybrid Propellant Module (HPM)
  - Resupply liquid Oxygen, liquid Hydrogen, Xenon propellants
  - Every 6 months



- Chemical Transfer Module (CTM)
  - Ferry payloads short distances
  - Provides high-impulse transfer from LEO to L1
  - Use for extended duration missions

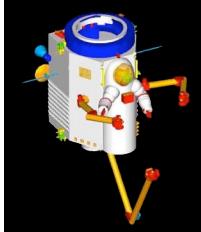
Lin, Frank. Lunar L1 Gateway & SEP Design Briefing. 02 Nov 2001.



SCOUT

Resupply Between Missions

- OASIS supply vehicles will be used to supply the SCOUT system at Gateway
  - HPM and CTM carry propellant and atmospheric consumables
  - CTV (or other manned vehicle) carries replacement parts
  - Six-month resupply for nominal use of fuel, atmospheric consumables, and short-term replacement parts
- Long-term parts such as batteries, charcoal filters, MMPPs, and replacement parts will be delivered to the docking module every two years as needed
- Resupply vehicles will be stacked with other OASIS elements for transfer from LEO to L1

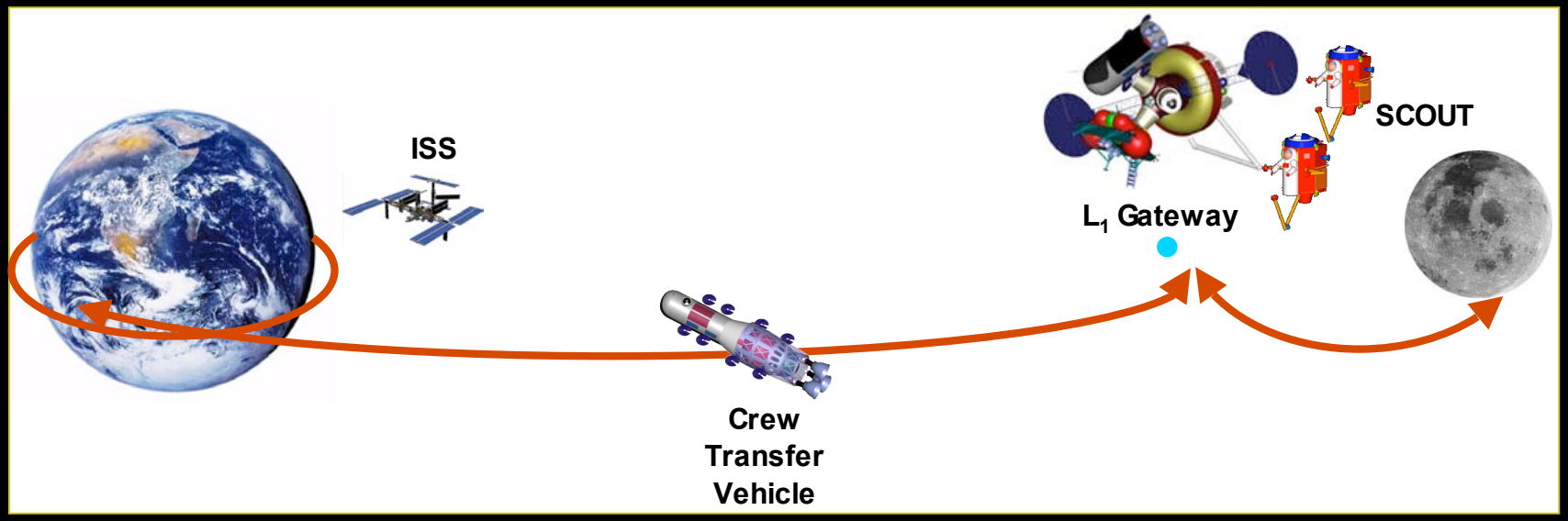


SCOUT

SCOUT Servicing

- Servicing of the SCOUT vehicles at Gateway will nominally include:
  - Replacement of worn-out or damaged suit arms and gloves every few sorties
  - Replacement of charcoal filters every 30 sorties
  - Replacement of on-board batteries every year
- Suit arm/glove and battery replacement services will require an EVA in another SCOUT
- Other servicing scenarios are possible as needed, such as
  - Replacement of MMPPs
  - Repair/replacement of robot arms
- If service cannot be completed at Gateway, SCOUT must be returned to LEO and ISS for further repairs or component replacement

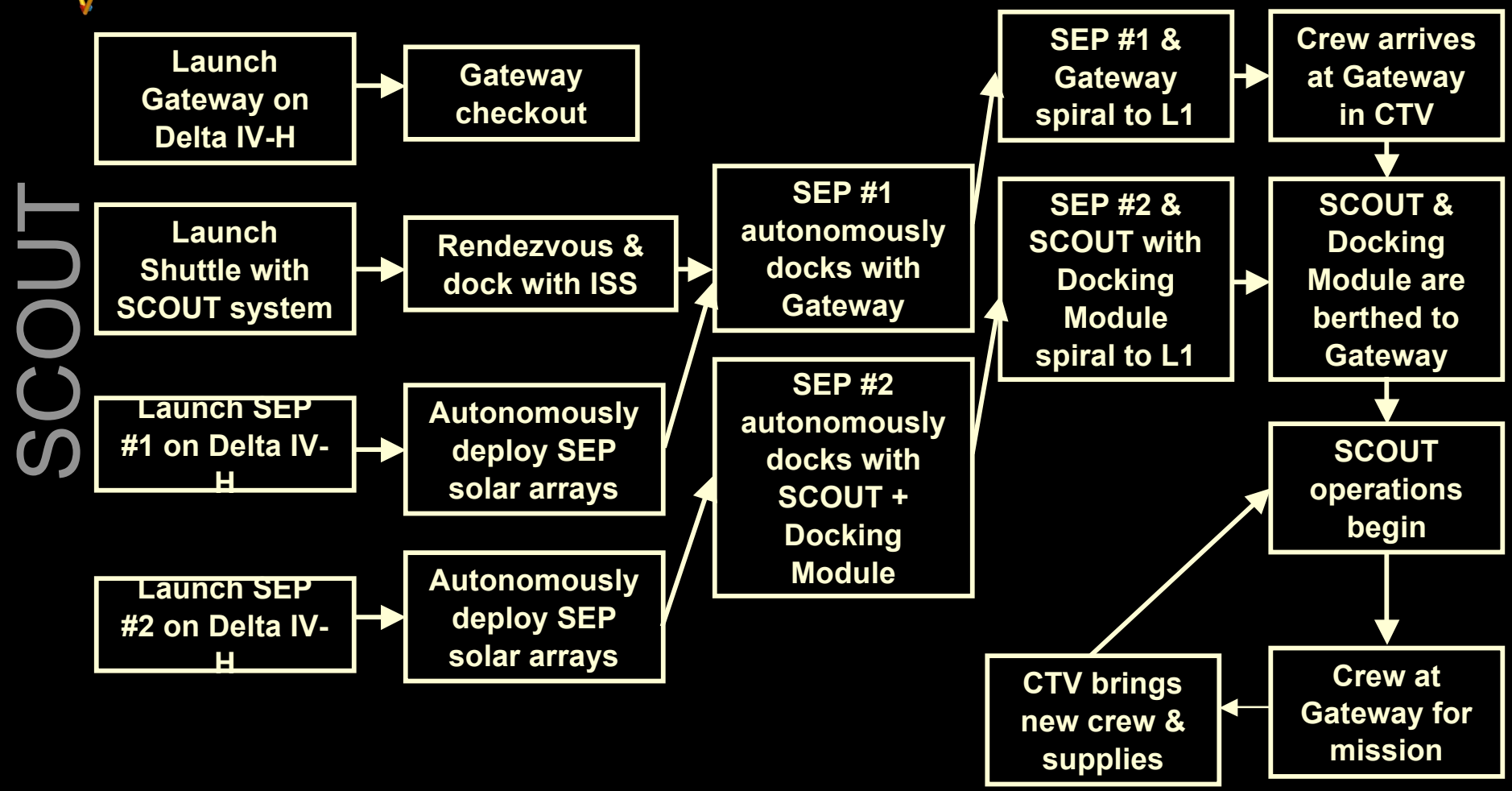
Trajectory to L1

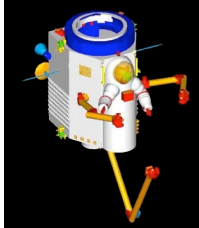


Lin, Frank. Lunar L1 Gateway & SEP Design Briefing. 02 Nov 2001.

After 6 month test mission at ISS, SCOUT system will travel along the same trajectory to L1 as the Gateway Station and OASIS Infrastructure

SCOUT Mission Profile



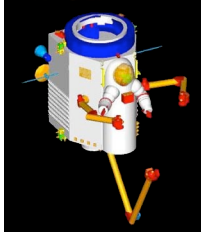


SCOUT

Testing Facilities

Test	Neutral Buoyancy	Docking Simulator	Computer Simulator	ISS
Robotic Dexterous Manipulators (RDM)	X		X	X
Human Arms + RDM	X		X	X
Docking and Rendezvous		X	X	X
Astronaut Training	X	X	X	X
Arm Change-out			X	X
Self Maintenance and Refueling	X		X	X

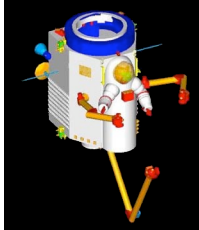
- The Neutral Buoyancy Facility simulates a 0g environment and gives first hand evidence of problems that may arise in 0g
- The Rendezvous Docking Simulator gives astronauts practice and experience in rendezvous and docking in a near space environment



SCOUT

Test Mission

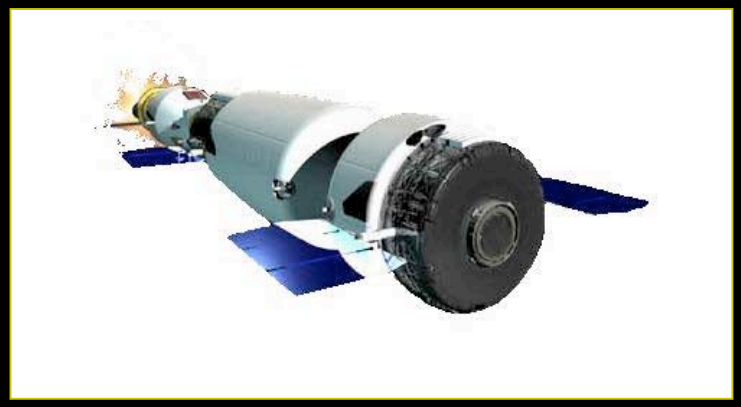
- Specific tests that must be completed in the neutral buoyancy facility are:
  - Change-out of tools and end effectors with robotic dexterous manipulators
  - Installation of a UHF Antenna, an intricate task involving small components, with robotic dexterous manipulators and human arms
  - Installation of a truss segment, a large task using mainly robotic dexterous manipulators
  - Change out of orbital replacement units with robotic dexterous manipulators and human gloved arms simultaneously
  - Refueling operation
- After earth-based testing, SCOUT will be sent to ISS for a six month test mission



SCOUT

Crew Transport

- Crew transport accomplished through use of OASIS infrastructure
- CTV/HPM/CTM stack will ferry crew to L1 Gateway in a 4-6 day travel period
- The CTV will remain at L1 and serve as an emergency return vehicle to ISS
- CTV is capable of traveling from LEO to L1 and back as well as to ISS and any other crewed infrastructure
- Crew will carry out a 6 month mission prior to their replacement with a new CTV stack carrying crew and supplies
- The extended mission will use the CTV stack to travel to the lunar orbit



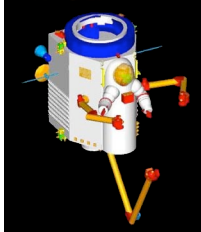
Lin, Frank.

SCOUT

Nominal Mission Timeline

- All calculations will be based on the nominal mission timeline
- All missions will occur at a distance less than 1000m
- Crew of four will complete 15 eight-hour sorties per 6 month period per SCOUT
- Total SCOUT mission (for two pods) = 240 working hours and 330 hours inside pods (including breaks and travel)
- Mission tasks will NOT require work from both pods; two pods will perform work at nearby (within 100m) sites
- Tasks include the service, checkout and assembly of a 25m telescope and others listed later in the presentation
- Consumables, propellants and shelf life sensitive items will be resupplied every 6 months with OASIS
- End of mission at 600 sorties per pod (10 years)

Example Workday

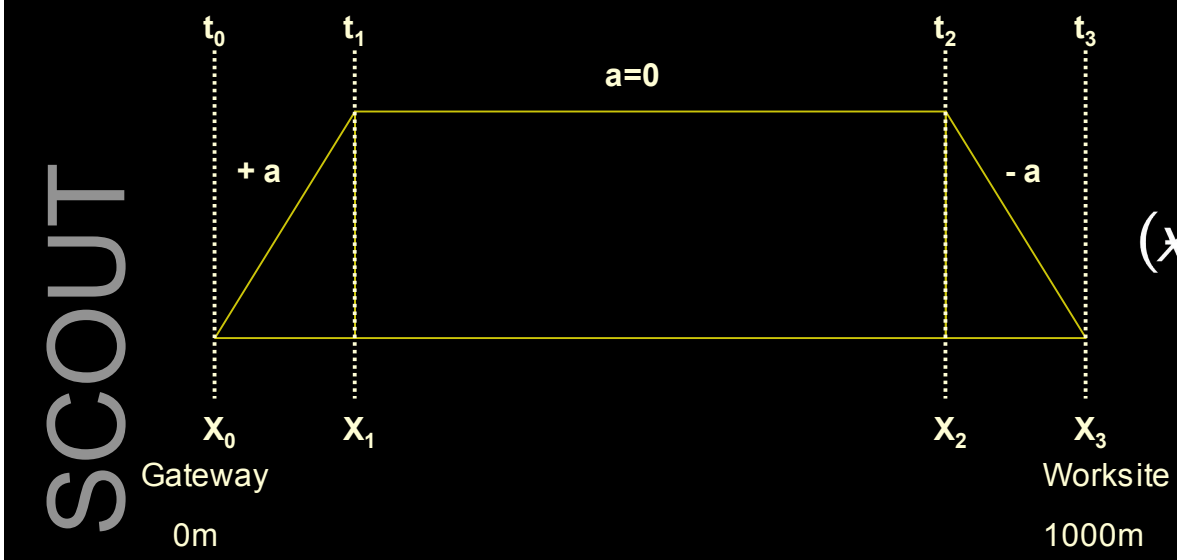


SCOUT

Time Duration	SCOUT and Crew Activity
0:30:00	Travel to worksite
0:30:00	Translation at site
2:00:00	Work period 1
0:15:00	Break 1
2:00:00	Work period 2
0:30:00	Lunch- Break 2
2:00:00	Work period 3
0:15:00	Break 3
2:00:00	Work period 4
0:30:00	Travel from site
0:30:00	Translation and docking at Gateway

Total Work time	**8:00:00**
Total Sortie	**11:00:00**

ΔV – L1 to worksite



$t_0 = 0\text{sec}$

$t_3 = 1800\text{sec}$

$(x_0) = 0\text{m}$ $(x_3) = 1000\text{m}$

$F = ma$

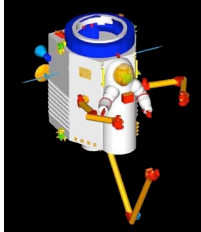
$\Delta v_x = \Delta x / \Delta t$

$\Delta v_{rms} = 1000/t_1$

$\Delta v_{rms} = 1000/1800$

$\Delta v_{total} = 2*(1000/1800)$

$\Delta v_{total} = 1.110/91.1\ m/s$



SCOUT

ΔV – Worksite Translation

- The ΔV for translation assumes a 17.5 second travel time between the two farthest points of an ORU (2.2m)
- It is estimated that during a two hour work period SCOUT will translate at most 20 times
- The amount of translation per day is at most 80 times
- A total ΔV for translation each day per pod is 20m/s

$$t_0 = 0\text{sec}$$

$$t_3 \le 17.5\text{sec}$$

$$(x_1 - x_0)\ \text{m} = \quad - \quad =$$

$$F = m \cdot a$$

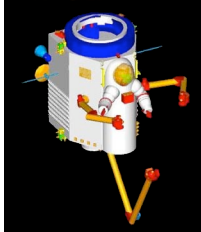
$$\Delta v_x = \Delta \quad / \Delta$$

$$\Delta v_{rms} = 2.2/17.5$$

$$\Delta v_{rms} = 2.2/17.5$$

$$\Delta v_{rms_{total\ tasks}} = 2*(2.2/17.5)$$

$$\Delta v_{rms_{total\ tasks}} = 0.25/$$



SCOUT

Aggressive Mission Timeline

- The aggressive mission is based on the assumption of frequent and inexpensive resupply of propellants and consumables
- All missions will occur at a distance less than 1000m
- Crew of four will complete 30-eight hour mission walks per 6 month period per SCOUT
- Total SCOUT mission (for two pods)=480 working hours and 660 hours inside pods (including breaks and travel)
- Mission tasks will NOT require work from both pods; two pods will perform work at nearby sites
- Tasks include nominal tasks, but astronauts are able to complete more tasks per mission
- The aggressive mission gives a 100% increase in SCOUT usage
- End of mission at 600 sorties per pod (10 years)

SCOUT

Extended Duration Mission

- The planned extended mission is to Lunar Orbit from L1
- SCOUT will be transported to Lunar Orbit by the CTV stack that will carry crew and a XMP carrying extra propellant and consumables
- The ΔV required to get the CTV stack with SCOUT into lunar orbit is 707m/s
- One pod will complete tasks in a 16 hour workday
- After the fourth two hour work period, SCOUT will be refueled and refurbished through the XMP
- CTV will act as a safety return vehicle
- SCOUT is NOT designed to land on the lunar surface, all work will take place in lunar orbit

Extended Mission Workday

SCOUT

Time Duration	SCOUT and Crew Activity
23:00:00	Travel to Lunar Orbit via CTV
00:30:00	Translation at site
02:00:00	Work period 1
00:15:00	Break 1
02:00:00	Work period 2
00:30:00	Lunch- Break 2
02:00:00	Work period 3
00:15:00	Break 3
02:00:00	Work period 4
06:00:00	SCOUT refuel and battery recharge
02:00:00	Work Period 5
00:15:00	Break 5
02:00:00	Work Period 6
00:30:00	Break 6
02:00:00	Work Period 7
00:15:00	Break 7
02:00:00	Work Period 8
23:00:00	Travel to L1 and docking at Gateway

Total Work Time	**16:00:00**
Total Sortie	**70:30:00**

ΔV – L1 to Lunar Orbit

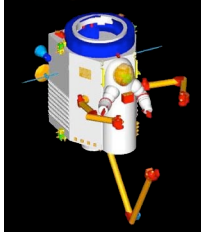
SCOUT

- The ΔV calculated requires a 23 hour travel time from L1 to the Lunar Orbit
- Because of the large ΔV, the XMP is required for the mission to provide fuel and consumables
- SCOUT will travel docked to the CTV, with the crew inside, until the start of the work period
- During breaks SCOUT operator can go through XMP into CTV
- Crew will travel back to L1 within the CTV

ΔV – L1 to GEO

SCOUT

- Travel to Geosynchronous Orbit via CTV may be possible
- The total ΔV from L1 to GEO is 1020m/s
- Total time of travel to GEO is 58 hours each way
- The XMP is also needed for this mission



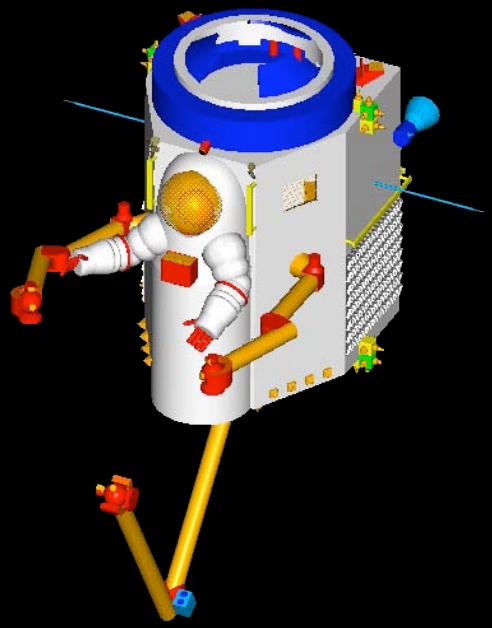
SCOUT System Requirements

SCOUT

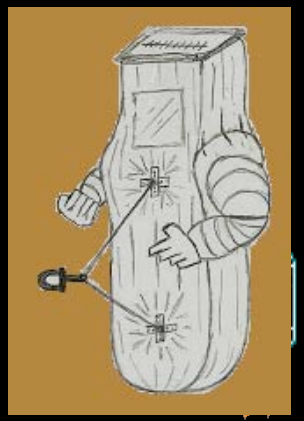
- Crew Survival Criteria
  - Cumulative probability of safe crew return over the life of the program must exceed 0.99 (JSC-28354 Human-Rating Requirements)
  - Probability of safe crew return per sortie is approximately 0.99999 based on 600 sorties per pod lifetime
  - System shall provide for emergency alternative access and EVA "bailout" options (Requirement L7)
- Pod Vehicle Failure
  - Any system failure that affects the health/safety/survival of the crew (NASA-STD-3000 Man-Systems Integration Standards)
  - Sufficient sensors shall be incorporated to allow positive diagnosis of all credible failures (Requirement I11)
  - Failure types: abort of sortie and bailout
- Pod Vehicle Reliability: $R_{pod} = 0.99$
  - Probability that pod will <u>NOT</u> fail in such a way to require bailout during a sortie
  - Based on allowance for 10, 99.9% reliable systems

SCOUT System Components

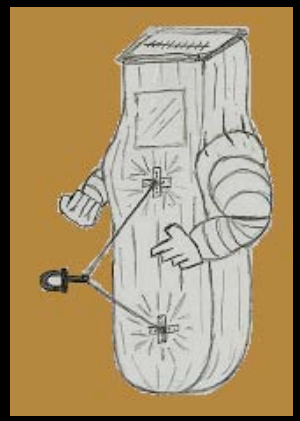
SCOUT



Pod



Propulsion-Equipped Bailout System (PEBS)

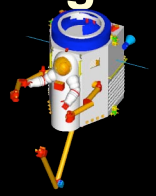


Bailout System (BS)

SCOUT

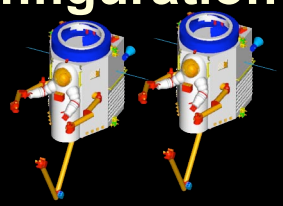
System Configurations Considered

Configuration 1:



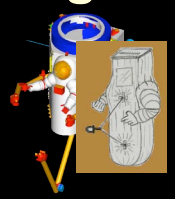
- One Pod
- No Escape

Configuration 2:



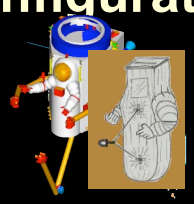
- Two Pods
- No Escape

Configuration 3:



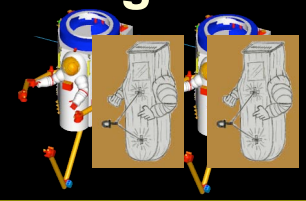
- One Pod
- Bailout System

Configuration 4:



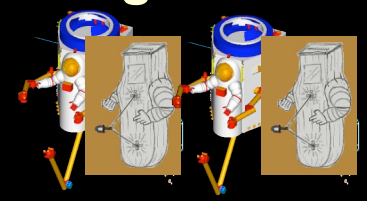
- One Pod
- Propulsion Bailout System

Configuration 5:



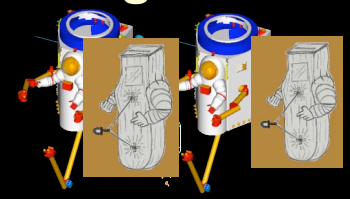
- Two Pods
- Bailout Systems

Configuration 6:



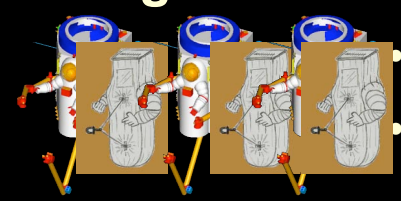
- Two Pods
- Propulsion Bailout Systems

Configuration 7:

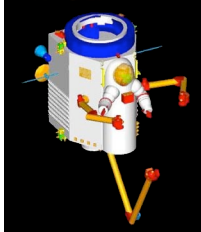


- Two Pods
- Propulsion / Bailout Systems

Configuration 8:



- Three Pods
- Bailout Systems



SCOUT

Reliability Estimations

- Reliability Assumptions:
  - Pod failure will force bailout of pod crewmember
  - Pod crewmember must rely on independent propulsion system for safe return to Gateway
  - Escape components consist of life support (BS) and propulsion systems (PEBS)
  - Each escape component will have equal reliabilities within the same system
- Pod reliability based on # of crew critical systems

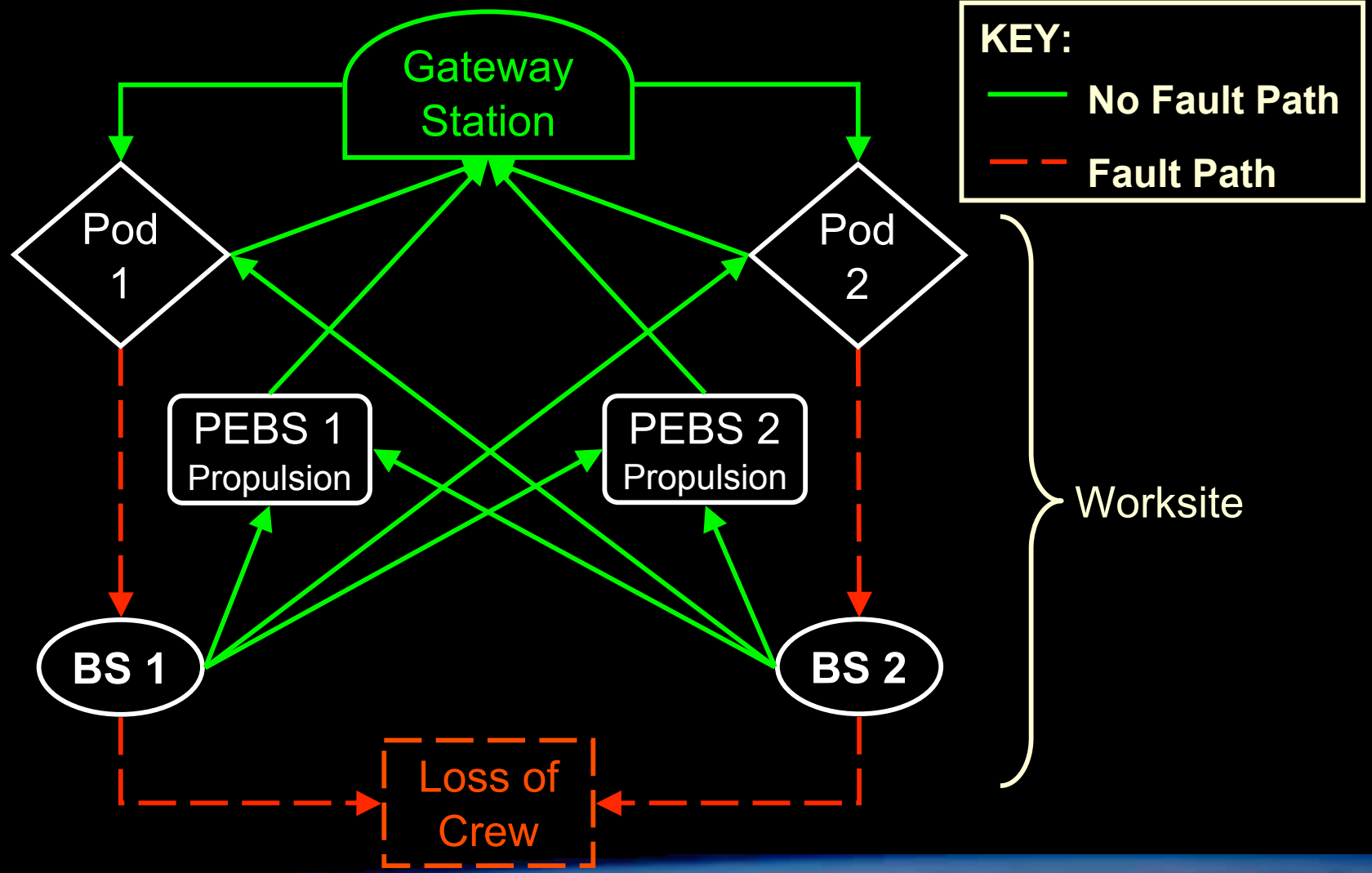
SCOUT

Reliability Requirement Summary

System Configuration		Pod Reliability	Escape System Reliability
1	One Pod	0.99999	--
2	Two Pods	0.99591	--
3	One Pod + BS	0.99	0.99832
4	One Pod + PEBS	0.99	0.99916
5	Two Pods + 2 BS	0.99	NOT VIABLE
6	**Two Pods + 2 PEBS**	**0.99**	**0.97943**
7	Two Pods + 1 PEBS + 1 BS	0.99764	0.99764
8	Three Pods + 3 BS	0.99	0.99954

Configuration 6 Rescue Scenarios

Two Pods + Propulsion-Equipped Bailout Systems (PEBS)



SCOUT

SCOUT Operation Modes

SCOUT

- Double Pod Mode ("Buddy System")
  - Pod vehicles perform sorties in pairs
  - Both involved in tasks at the worksite
  - Crew survival per sortie: 0.99999
  - Preferred mode of operation
- Single Pod Mode
  - One pod vehicle at worksite per sortie
  - Other pod vehicle ready at Gateway station
  - Gateway crewmember on ready-alert for worksite pod distress call
  - Crew survival per sortie: 0.98999
  - More risky mode of operation

SCOUT Contingency Responses

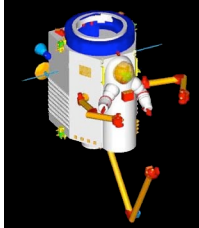
SCOUT

Primary Failure	Primary Response	Secondary Response
Avionics	Abort	Pod 2 Rescue
Collision	Abort/ Pod 2 Rescue	Bailout w/ Prop.
Docking	Bailout w/ Prop.	Self Rescue/Pod 2
Explosion/Fire	Abort/ Pod 2 Rescue	Bailout w/ Prop.
Injured/Sick Crew	Abort	Pod 2 Rescue
Life Support	Bailout w/ Prop.	Pod 2/Self Rescue
Micrometeoroid Impact	Bailout w/ Prop.	Pod 2/Self Rescue
Power	Abort/ Pod 2 Rescue	Bailout w/ Prop.
Propulsion	Pod 2 Rescue	Bailout w/ Prop.
Robot Arm(s)	Abort	Pod 2 Rescue
Solar Particle Event	Abort	Pod 2 Rescue

SCOUT

Task Requirements

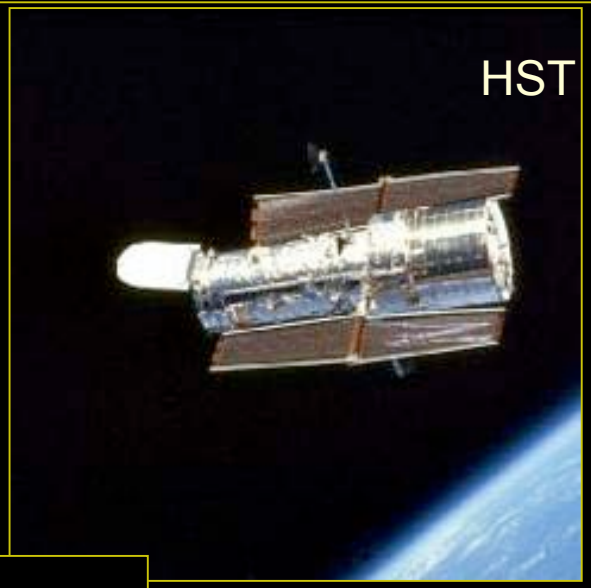
- Meet or exceed EVA capabilities demonstrated in International Space Station (ISS) operations
- Meet or exceed EVA capabilities demonstrated in Hubble Space Telescope (HST) operations
- Assembly of a 25m infrared (IR) space telescope
- Lunar Lander, CTV, CTM, HPM, SEP maintenance
- Gateway station maintenance once every six months
- Service other SCOUT pods



SCOUT

Task Categories

- Orbital Replacement Units (ORUs)
- Truss Segments
- Modules
- Flexible Materials
  - Outer blankets
  - Multi-layer insulation
- Fragile Materials
  - Antennas
  - Solar Arrays
  - Mirrors



HST

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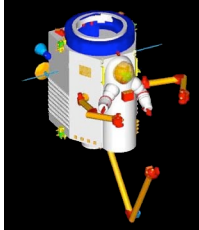
ISS

SCOUT

Orbital Replacement Units

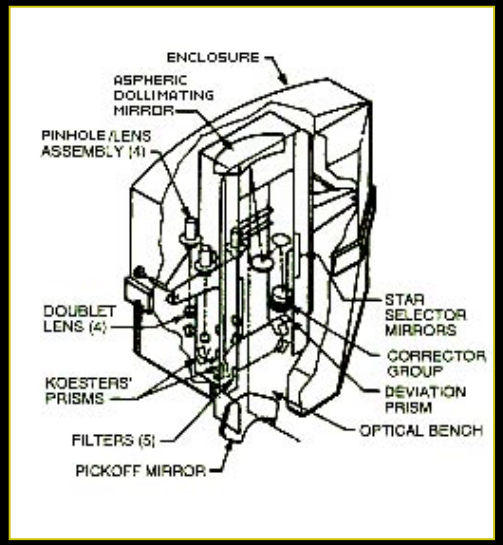
- ISS ORU/Manipulated Hardware
  - Referenced from Space Station Program Robotic Systems Integration Standards (SSP 30550)
  - Maximum dimensions: 1.6m x 1.6m x 1.6m
  - Maximum mass: 600kg
- HST ORU
  - Referenced from NSTS 07700
  - Maximum dimensions: 0.91m x 0.91m x 2.2m
  - Maximum mass: 341kg
- Worse Case Scenario
  - Maximum dimensions: 1.6m x 1.6m x 2.2m
  - Maximum mass: 600kg

ORU Tasks



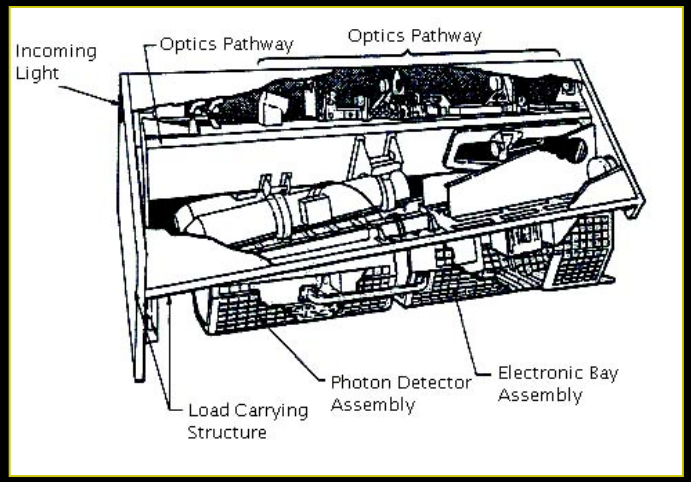
SCOUT

- Manipulate, install, remove ORUs
  - Remove/replace ORU from/in receptacle
  - Release/fasten keyway slot bolts
  - Release/fasten electrical connector drive
  - Install guide studs
  - Mate/demate connectors
  - Remove connector caps
  - Install/demate groundstrap
  - Install/remove handhold
  - Remove/install fuse plugs
  - Retract/stow thermal covers
  - Open/close bay doors



Fine Guidance Sensor

HST Servicing Mission Press Kits 3A and 3B



Fine Object Camera

Truss Segments

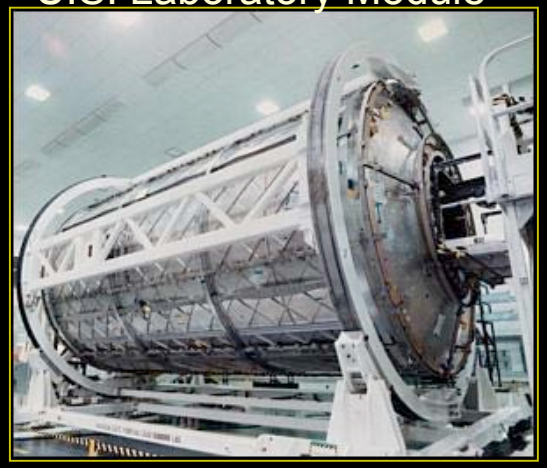
SCOUT

- Large structures
  - Maximum dimensions: 13.7m x 4.6m x 1.8m
  - Maximum mass: 14,000kg
- Tasks
  - Release/tighten clamshell fasteners
  - Remove and stow drag links
  - Release launch restraint bolts
  - Install circuit breakers
  - Remove thermal cover

Modules

- ISS Modules
  - Russian Progress
  - U.S Laboratory Module
  - Multi-Purpose Logistics Modules
  - Quest Joint Airlock
- Cylindrical shape
  - Dimensions: 8.5m long, 4.3m diameter
  - Mass: 6000kg
- Tasks
  - Connect/disconnect electrical, data and cooling lines
  - Latch module to permanent location
  - Install thermal covers

U.S. Laboratory Module



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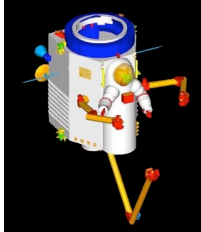
SCOUT

Fragile Materials

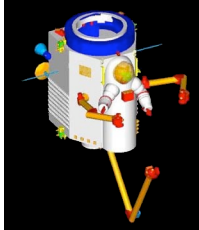
- Antennas
  - Remove antenna from launch restraints
  - Bolt antenna in location
  - Connect cables
  - Deploy antenna booms
- Solar Arrays
  - Engage/disengage tang bolts
  - Deploy solar array panel
  - Release/engage latch
  - Release solar array brake



SCOUT

Flexible Materials

- Install/remove insulating blankets
  - Unpack blanket
  - Attach straps
  - Unroll blanket
  - Secure starting edge with Velcro straps
- Install/remove Outer Blanket Layer
  - Install vent hole plugs
  - Connect ground caps to J-Bolts
- Remove/store Multi-Layer Insulation
- Install/remove thermal covers



SCOUT

Human Tools

- Pistol Grip
  - Interface with many types of mechanisms and fasteners
  - Separate manual ratchet and motorized torque modes
- Torq-Set
  - Secure fasteners
  - Removal and capture of fasteners
- Connector Tools
  - High torque
  - SMA coax
- Multi-Layer Insulation (MLI) Blanket Tool
  - Push back blankets
  - Apply a strip of tape to a ripped or torn blanket

Pistol Grip Tool

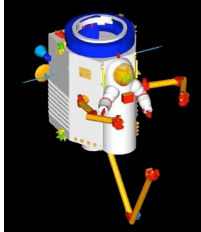
Torq-Set

Connector Tool

MLI Blanket Tool

Swales Aerospace

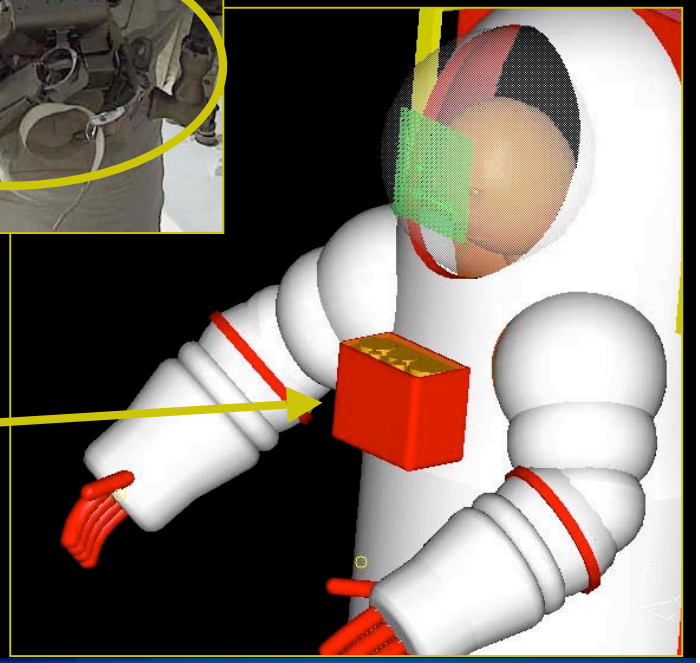
Mini-Workstation



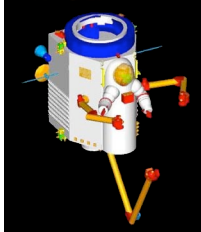
SCOUT

- Similar to the mini-workstation currently used on EVA spacesuits
- Tether human tools in place on chest of SCOUT
- Additional tools stored in docking module or sent up with specific part
- Tool change out completed by EVA or another SCOUT

NASA



Mini-Work station



SCOUT

Number of Task Arms

- One arm
  - Instability when maneuvering large items
  - Cannot grasp ORU while removing bolts and latches
- Two arms
  - Can grasp item during entire procedure
  - Additional grapple point on worksite, if needed
  - Similar to the two arms of human which may ease control of task arms
- Three arms
  - Additional grasping point on large items as compared with two arms
  - Concern of interference of arms with each other
- Decided two task arms is the best choice

SCOUT

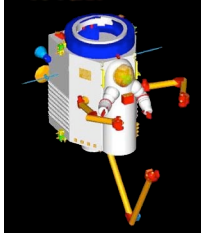
Vertical Position of Task Arms

- Used maximum size ORU for analysis
- Determination of gross vertical location SCOUT
  - Top: limited access to bottom of ORU without maneuvering
  - Middle: reach top and bottom with no maneuvering
  - Bottom: limited access to top of ORU without maneuvering
- Relative location with respect to human arms
  - Above: limits peripheral vision of astronaut; easier to grasp items from above
  - Level: greater chance of collision between the pairs of arms due to being on the same plane of operation
  - Below: does not affect peripheral vision; easier to grasp things from below

SCOUT

Horizontal Position of Task Arms

- Determination of gross horizontal location SCOUT
  - On the chest: limits the ability to reach around large hardware; cannot get close to the worksite
  - On sides near front: sides of large hardware accessible; getting close to worksite is capable
  - On sides near back: loss of operative length due to arms positioned away from the front half of the pod
- Summary of chosen position
  - In the middle of SCOUT just below the human arms
  - On the sides of SCOUT on the front half
  - Provides the ability to interact with the human arms



SCOUT

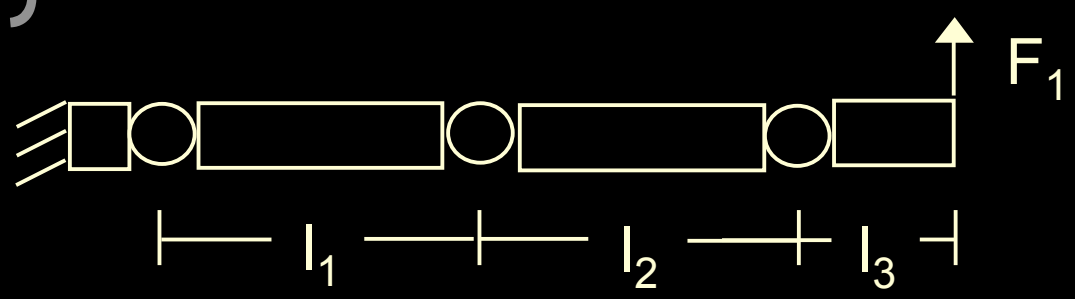
Task Arm Force

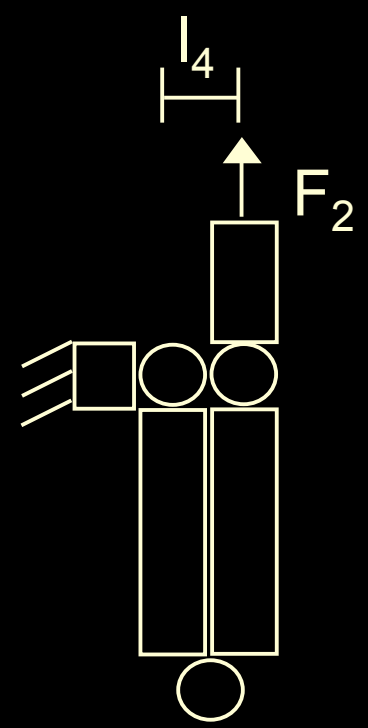
- Maximum ORU actuation force
  - Referenced from NSTS 07700
  - Suited subject in foot restraints was able to create a straight-ahead push with a maximum magnitude of 200N
- Worst Case
  - Outstretched arm with a perpendicular force of 200N
  - Torques for the three joints – shoulder, elbow, wrist – determined
- Best Case
  - Folded arm with a parallel force F_2
  - Maximum force of task arm determined

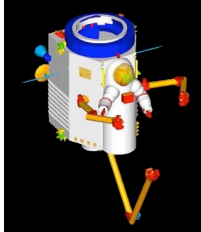
Worst and Best Case Scenarios

SCOUT

- Given F_1 = 200N, l_1 = l_2 = 0.68m, l_3 = 0.34m
  - $\tau_3 = F_1 l_3$ = 68N-m
  - $\tau_2 = F_1(l_2 + l_3)$ = 204N-m
  - $\tau_1 = F_1(l_1 + l_2 + l_3)$ = 340N-m
- Given τ_1, τ_2, τ_3, l_4 = 0.13m
  - $F_2 = \tau_1 / l_4$ = 2616N
- Maximum force of the task arms on the worksite is 2616N



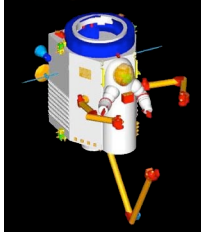




Task Arm Tool Torque

SCOUT

- Current EVA Tools
  - Torque limiter, multisetting
    - Referenced from EVA Tools and Equipment Reference Book (JSC-20466)
    - Torque limit ranges up to 51.5N-m
  - Pistol Grip Tool (PGT)
    - Referenced from Swales Aerospace Crew Aids and Tools (CATs)
    - Multiple setting torque limiter torque setting up to 52.2N-m
- Torque capability of at least 52.2N-m
- Ability to choose torque settings and number of turns

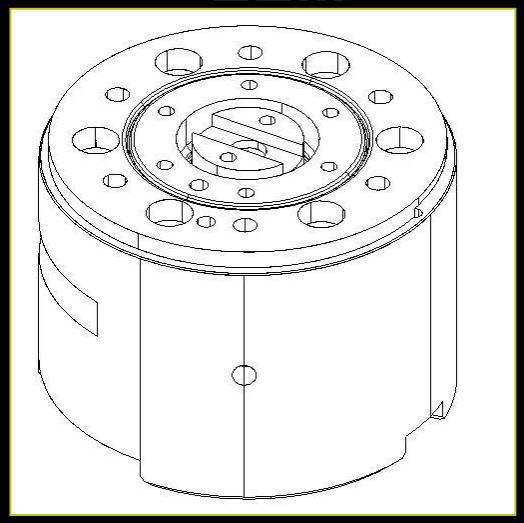


Task Arm Base Design

SCOUT

- Task arms are modeled after the end effector design that the Ranger Telerobotic Shuttle Experiment uses
- An interchangeable end effector mechanism (IEEM) is common to all end effectors which allows for one interface to remove and replace tools

IEEM



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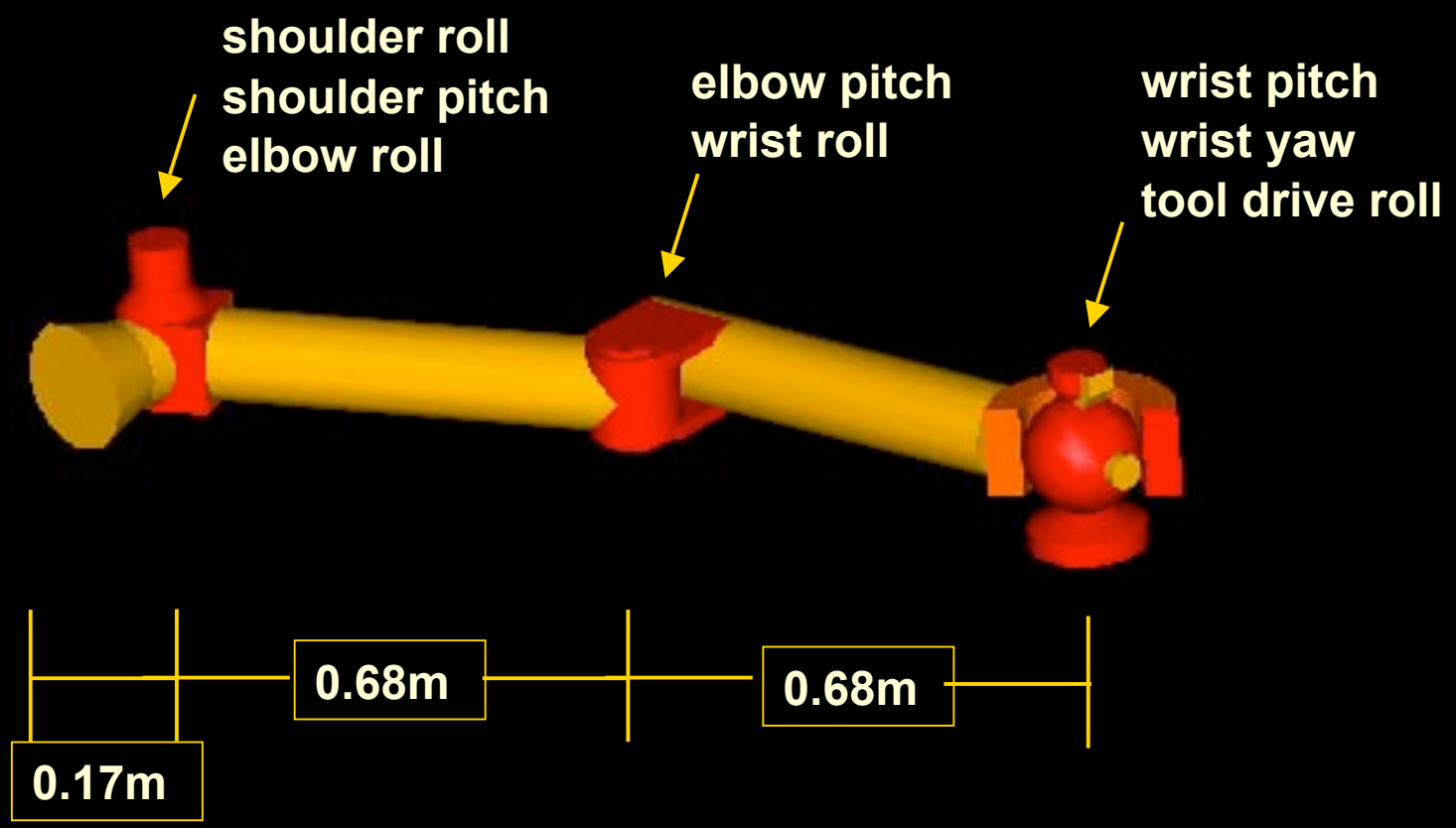
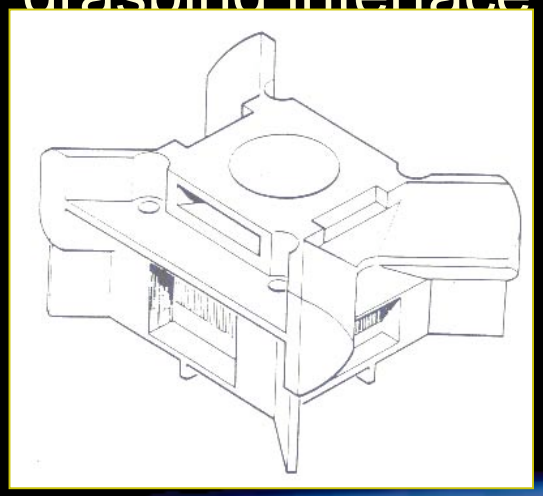
Task Arm Base Design

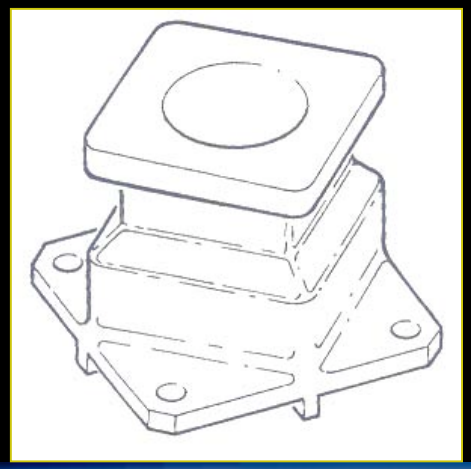
SCOUT



ORU Grasping Interfaces

- Referenced from ISS Robotic Systems Integration Standards: Volume 2 (JSC-37996)
- Includes interfaces such as an h-fixture (left picture), micro fixtures (right picture), parallel jaw interface, and a micro-conical fitting
- EVA handrails, while not included in the interface reference table, are considered an additional grasping interface





JSC-37667

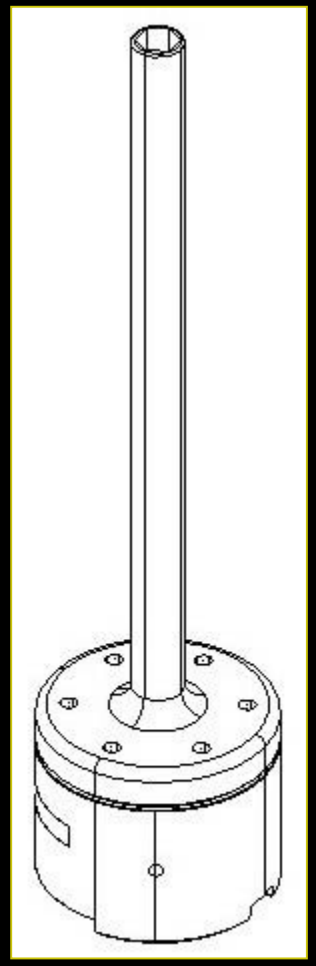
SCOUT

Task Arm End Effectors

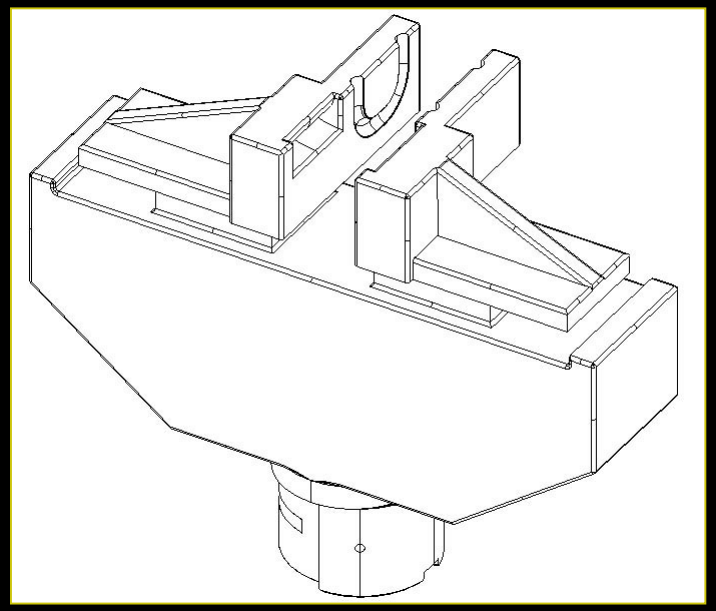
- Hand-over-hand (HOH) end effector
  - Conceptual design that has the ability to grip several different items within set dimensions
  - Used for non-thrusting maneuvering
- Bare bolt drive (BBD) end effector
  - Head-on approach to bolt with a long drive shaft
  - Used to drive bolts for insertion and extraction of ORUs
- Parallel Jaw Mechanism (PJM) end effector
  - Different “fingers” depending upon the grasping surface
  - Used to grip items such as h-fixtures and flat grasping surfaces
- Microconical End Effector (MEE)
  - Used to grip microconical grasping interface

End Effectors

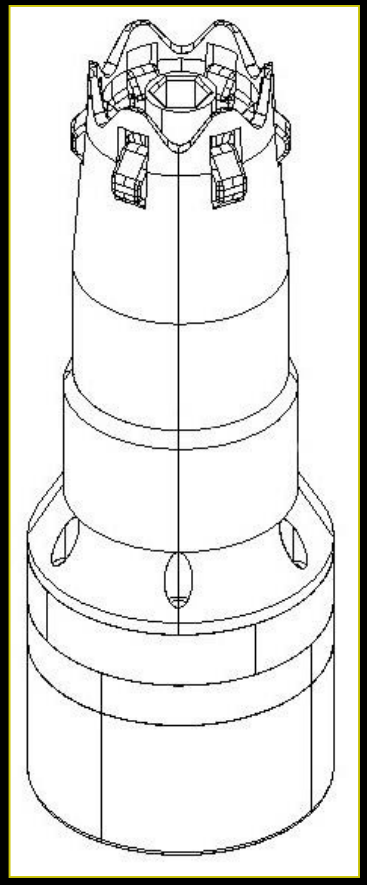
SCOUT



Bare Bolt Drive



Parallel Jaw Mechanism



Microconical

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SCOUT

Location of End Effectors

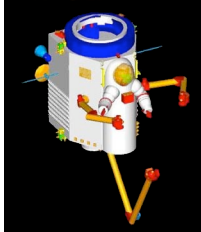
- 10 tool posts total
  - Four tool posts located directly below each task arm
  - Two tool posts located on the front, bottom of SCOUT
- Eight specific-arm tool posts
  - Four specific tool posts for each arm
  - Contains one of each end effector: HOH, BBD, PMJ, MEE
- Two common tool posts
  - Allows for moving end effectors from one task arm to the other
  - Broken end effector can be stowed and the remaining working end effector of that type transferred, as needed, between the two arms

Task and Human Arm Interaction

SCOUT

- Task arm operations
  - Non-thrusting maneuvering (HOH)
  - Gripping & maneuvering (PJM)
  - ORU maneuvering (MEE)
  - Removal and insertion of bolts (BBD)
- Human arm operations
  - Fragile materials
  - Electrical and cooling connectors, lines, etc.
  - Soft materials

- Task arms complete 57% of tasks and human arms 43%
- Does not include bolt and latch interaction by the astronaut – other tasks that the astronaut will complete
- Estimated that during a single task, at least 50% of the task will involve intimate task and human arm interaction



HST Electronics Control Unit

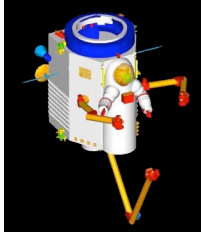
SCOUT

- Task operations
  - Release keyway slot bolts – robotic arm
  - Grasp tether loop – robotic arm
  - Release electrical connector drive – human arm
  - Remove ORU from receptacle – either
    - Release tether loop prior to removal if human arm is used
    - Release tether loop after removal if robotic arm is used
  - Replace ORU in receptacle – either
    - Grasp tether loop prior to replacement if robotic arm is used
    - Grasp tether loop after replacement is human arm is used
  - Fasten electrical connector drive – human arm
  - Release tether loop – robotic arm
  - Fasten keyway slot bolts – robotic arm
- 100% of task involves intimate interaction due to constant alternation of use between the robotic and human arms

SCOUT

Non-Thrusting Maneuvers

- Task arms provide maneuvering using specific end effectors
  - HOH end effectors required on both arms
  - “Climbing a rope” movement if long axis of SCOUT is aligned with the direction of motion
  - “Sliding” movement if short axis of SCOUT is aligned with the direction of motion
  - Grapple arm is not required for movement
- Grapple arm located on the bottom of SCOUT
  - Provides movement for relocation of SCOUT during task operations
  - No large translational movements without releasing the grapple arm and engaging in a different location



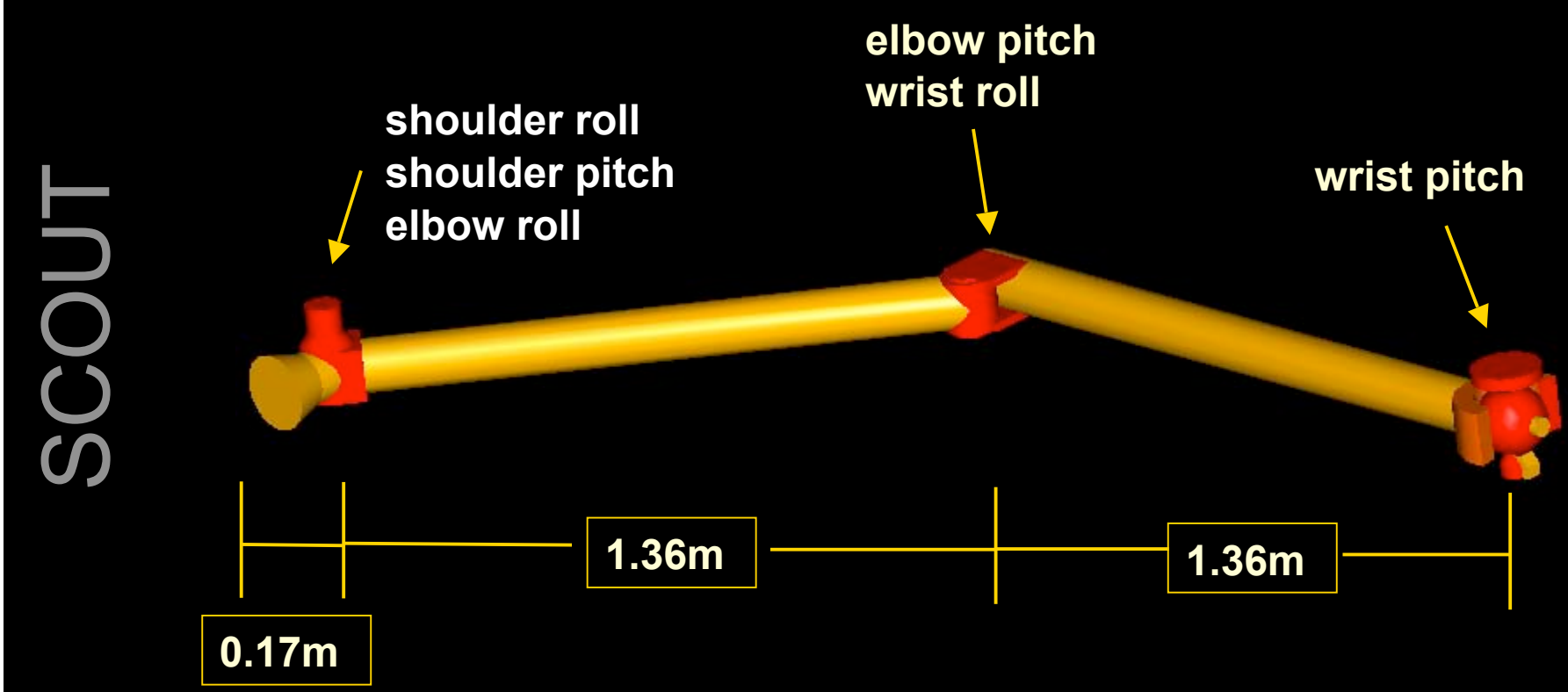
SCOUT

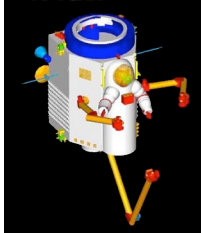
Grapple Arm

- Chosen over tethers for stiffness and maneuvering capabilities
- End effector with means to grip several different items within set dimensions
- Laser rangefinder incorporated into the elbow of the grapple arm
- Must be designed to withstand the forces, moments, and torsion created by the task arms during operation

Grapple Arm

SCOUT

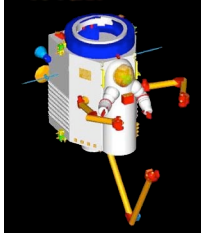




Plume Impingement on Grapple Arm

- Four thrusters located 0.85m away from the center point of the grapple arm
- Hydrazine can produce 6N of force and nitrogen 1N
- Displacement due to thruster force is small
  - $P = 6N$
  - $L = 0.85m$
  - $A = \pi*[(0.065m)^2 - (0.06425m)^2]$
  - $E_{Al} = 7.1x10^{10} N/m^2$
  - $\delta = PL/AE = 2.36x10^{-7} m$
- Corrosive nature of hydrazine must be taken into account for grapple arm material

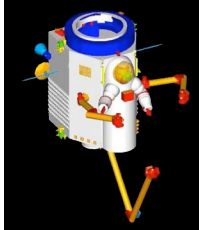
SCOUT



SCOUT

Control of Dexterous Manipulators

- Hand controllers
  - Used during operations that only use the task arms
  - Provide both gross and fine control
  - Two 3-DOF controllers: translational and rotational
- Glove sensors
  - Used when operations require task arms and human arms to be used within a short period of time
  - Master/slave system to switch between human movement and task arm movement
- Voice activation
  - Used during operations for task arms only and for combined task and human arms
  - Gross commands only; no fine control
    - Stop
    - Left arm, change end effector, tool post one



SCOUT

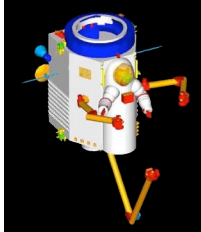
Life Support and Human Factors

Avi Edery
Kathryn Catlin
John Hintz
Alexandra Langley
Andrew Long

LSHF Requirements

SCOUT

- L1: All crew interfaces shall accommodate 95th percentile American males to 5th percentile Japanese females.
- L2: All crew interfaces shall adhere to NASA-STD-3000, Man-Systems Integration Standards.
  - L2.1: System shall be two fault tolerant and redundant.
  - L2.2: Air maintenance system shall be in place.
  - L2.3: SCOUT shall adhere to all requirements for crew safety.
  - L2.4: SCOUT must incorporate a comfortable cabin layout and suit interface for all sizes of people.
  - L2.5: External lighting shall provide sufficient illuminance levels within the astronauts reach envelope for EVA satellite servicing with the use of complex tools and for providing visual tasks with small, low constraint objects.
  - L2.6: Internal lighting shall be of variable intensity to provide illuminance levels appropriate for each task performed by the crew.
- L3: The SCOUT vehicle shall provide nominal capabilities for eating, drinking, and waste elimination.
  - L3.1: SCOUT shall provide 8 ounces of drinking water per hour.
  - L3.2: Must be sufficient sustenance on SCOUT for a standard sortie length.
  - L3.3: Waste elimination system shall be designed so that its used does not require deviation from the normal diet provided on Gateway.

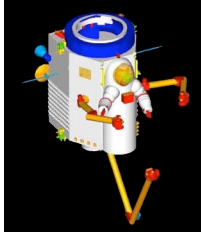


LSHF Requirements

SCOUT

- L4: System shall provide necessary support for extravehicular operations on a daily basis.
  - L4.1: SCOUT must be periodically resupplied with consumables.
  - L4.2: SCOUT must provide waste removal capabilities.
  - L4.3: SCOUT must undergo routine system maintenance.
- L5: Life support systems shall provide sufficient consumables to support the user for the maximum reference mission duration plus two hours reserve.
  - L5.1: Sufficient O2 consumables for 13 hours of operation.
  - L5.2: Must have sufficient CO2 scrubbing capabilities with backup.
  - L5.3: SCOUT will provide TCC consumables through use of activated charcoal bed and particulate filter.
- L6: Radiation dosages shall, under all conditions, conform in all respects to the current NASA standards for astronaut radiation limits.
  - L6.1: Astronaut radiation dosage must not exceed 3% increase in lifetime excess fatal cancer.
  - L6.2: Radiation shield must be designed to keep radiation levels As Low As Reasonable Achievable (ALARA).
- L7: System shall provide for emergency alternative access and EVA "bailout" options.
  - L7.1: Second hatch must be attached to SCOUT for alternate egress.
  - L7.2: Bailout system must be capable of transferring astronaut away from SCOUT quickly in case of emergency.

LSHF Requirements



SCOUT

- L8: System shall be capable of safely initiating operations with zero pre-breathe time.
  - L8.1: System shall accommodate variable pressure levels between station and worksite.
- L9: If the system accommodates variable pressure levels, it must support in-situ denitrogenation during nominal operations

- M1.1: Astronaut must be able to go from station to SCOUT with zero pre-breathe time.
- M3.1: Space suit arms and glove must be used for human interaction with worksite.
- M3.2: Range of motion of arms/gloves assembly must be adequate for task completion.

- X1.1: System is designed to last 20.5 hours with an absolute max of 41 hours (utilizing all of backup O2 tanks).
- X1.2: SCOUT shall provide 8 ounces of water for each hour of extended mission.
- X1.3: Depending on mission length SCOUT may require additional waste storage.

Crew Life Support Requirements

All Values are for a single EVA with SCOUT,

13 Hrs (Nominal Mission + 2Hrs).

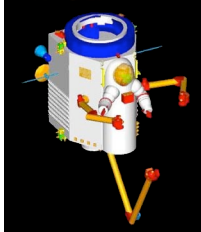
SCOUT

2.8kg H_2O → 0.5kg CO_2

0.45kg O_2 → 0.85kg urine

0.3kg Food → 0.11kg solid waste

Total: 4kg 1.46kg



SCOUT

Power Requirements

System		Require Power (kW)
Air System	SCOUT	0.14
	Module	1
Water System		0.12
Fire Suppression		N/A
Suit Arms/Gloves		N/A
N_2 % O_2 Tanks		0
Valves, Piping,etc.		0.03
Monitoring		TBD
Waste Collection		0.001
Internal Lighting		0.005
Total		**>0.3kW (0.7-Goal)**

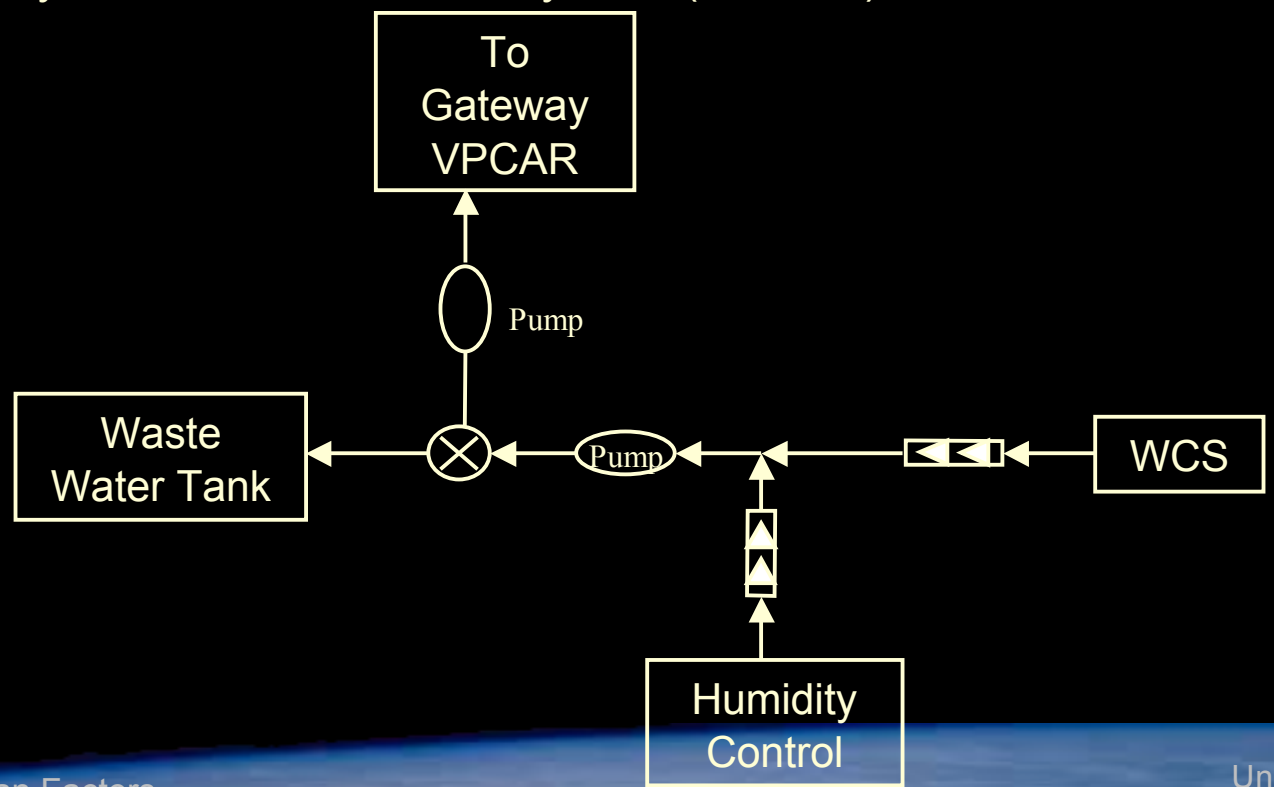
SCOUT

Mass/Volume Requirements

System		Mass (kg)	Volume (m^3)
Air System	SCOUT	81.25	0.0934
	Module	65	0.1755
Waste Collection		10-15	0.042
Bailout		100	< 0.25
Gloves/Arms		< 20	TBD
Food/Water		3.1kg	0.003
Interior Cabin		0	2.8
Total		**220 (150-Goal)**	**Internal: 2.8**

Water System

- 105oz of water carried on board in a standard re-hydratable drink container (3.1kg)
- Waste water from waste collection unit and humidity control is channeled into tank
- Waste water tank is emptied into Gateway station's vapor phased catalytic ammonia removal system (VPCAR) after each sortie



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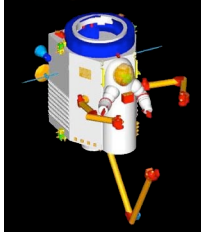


SCOUT

Food

- Nominal one meal per day on SCOUT
- Meals are catered to astronauts palatability for individual foods on Earth
- Nutrition requirements
  - Protein: 150g/day
  - Carbohydrate: 350g/day
  - Lipids: 85g/day
- Sample Meals
  - Sample 1
    - Shrimp cocktail (re-hydratable)
    - Granola w/blueberries (re-hydratable)
    - Dried Fruit
  - Sample 2
    - Chunky chicken stew (thermostabilized)
    - Beef goulash (thermostabilized)
    - Pudding (thermostabilized)
    - Peanuts

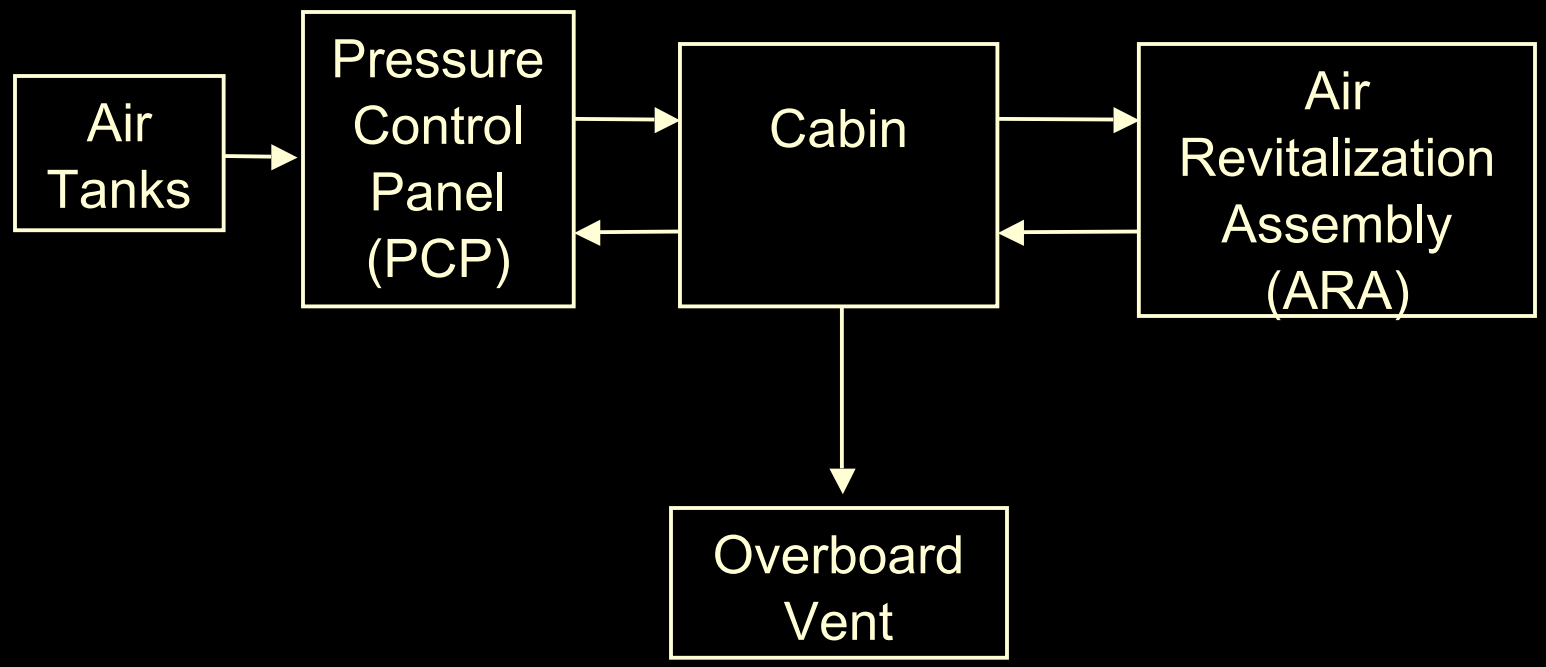
SCOUT

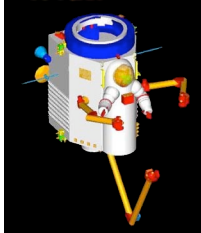
Air Replenishment and Revitalization System

- Provides constant atmospheric pressure and composition
- Allows pressure transition between hosting station and worksite
- Scrubs away carbon dioxide
- Clears trace contaminants
- Dehumidifies and cools
- Shirt-sleeve environment
- Zero pre-breathe

ARRS Block Diagram

SCOUT

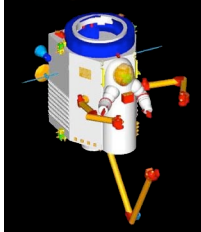




Air Pressure, Composition, and Supply

SCOUT

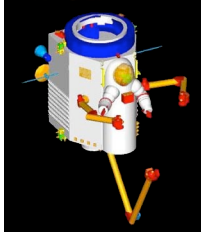
- 8.3psi, 43% O_2 / 57% N_2
  - Accommodate NASA AMES AX-5 style arms
- Aluminum tanks at 3000psi
- Total mass: 13.25kg
  - 0.727kg O_2 in each of 2 tanks
  - 0.636kg N_2
  - 3.72kg per tank
- Approximate volume: 0.0138m^3
- Provides nominal 20.5 hours; 41 hours as absolute maximum
  - One oxygen tank is emergency backup



SCOUT

Pressure Control Panel

- Firmware controller
  - Controls the nominal pressure
  - Reprogrammable
- Pressure sensor
- Tank regulator valves
- Tank refill interface
- Mass spectrometer
  - Determines partial pressure of gases and trace contaminants
- Keeps ppO_2 between 3.3 and 3.9psi and total pressure above 8.1psi at all times
- 15kg; 100W

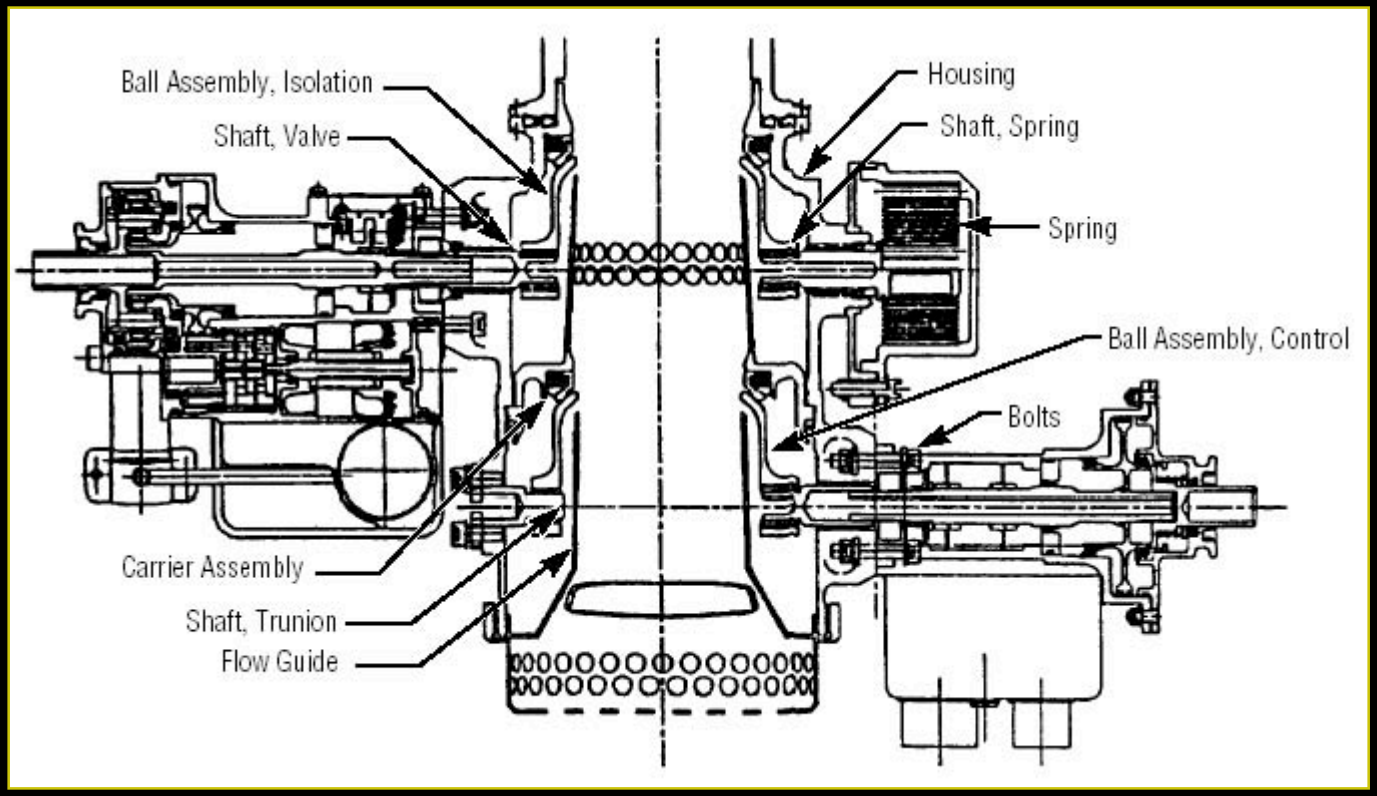


SCOUT

Pressure Transition

- At Gateway:
  - PCP set to “docked”
  - 9psi
- Away from Gateway:
  - PCP set to “working”
  - Vent/Relief Valve (VRV) opens and releases air until pressure is less than 8.4psi
- Docking:
  - PCP set to “docked”
  - VRV remains closed
  - PCP increases pressure to 9psi
  - Vent in hatch equalizes pressures
- VRV passes air through overboard vent to vacuum

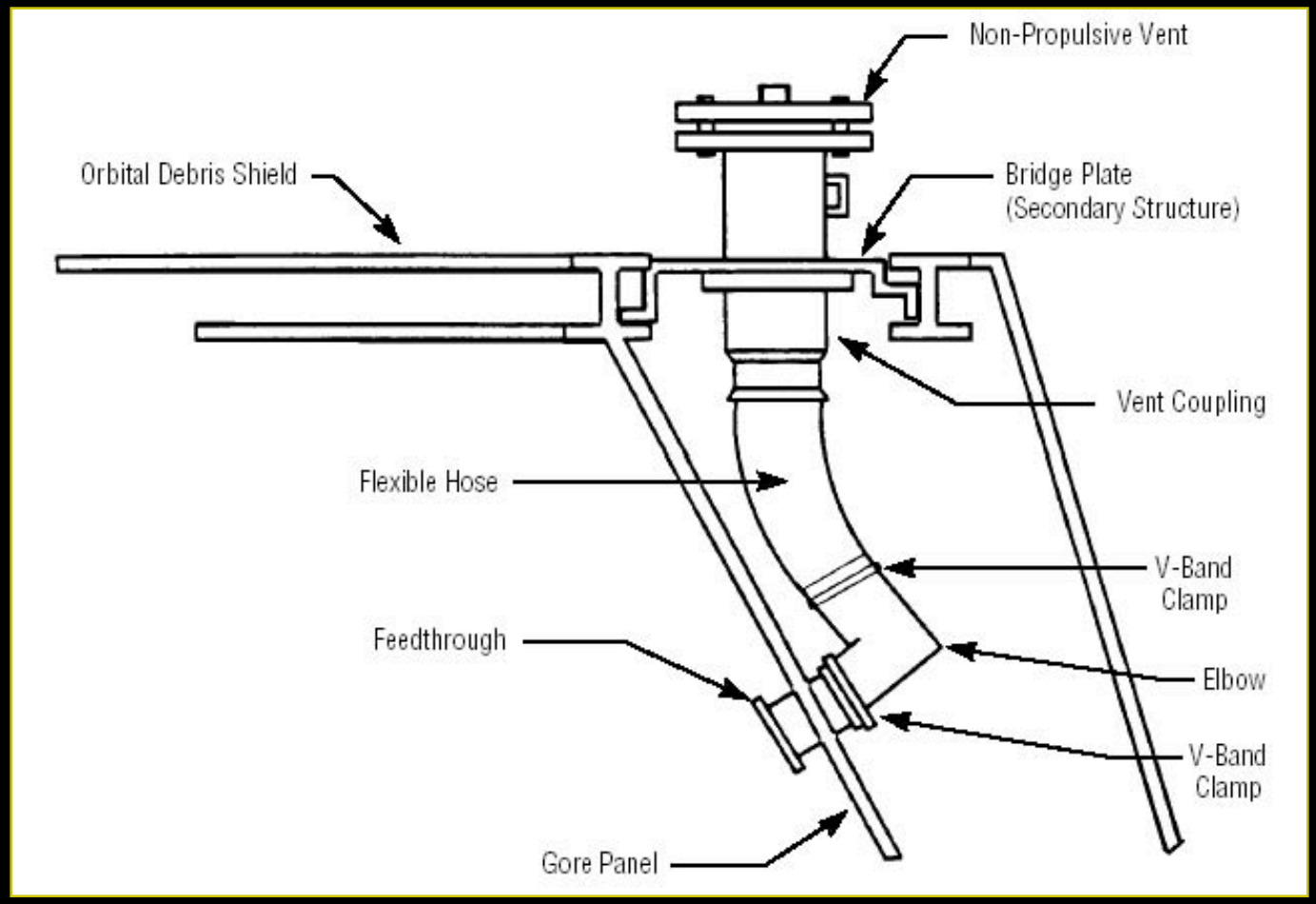
Vent/Relief Valve



Weiland, 1998

SCOUT

Overboard Vent



Weiland, 1998

SCOUT

SCOUT

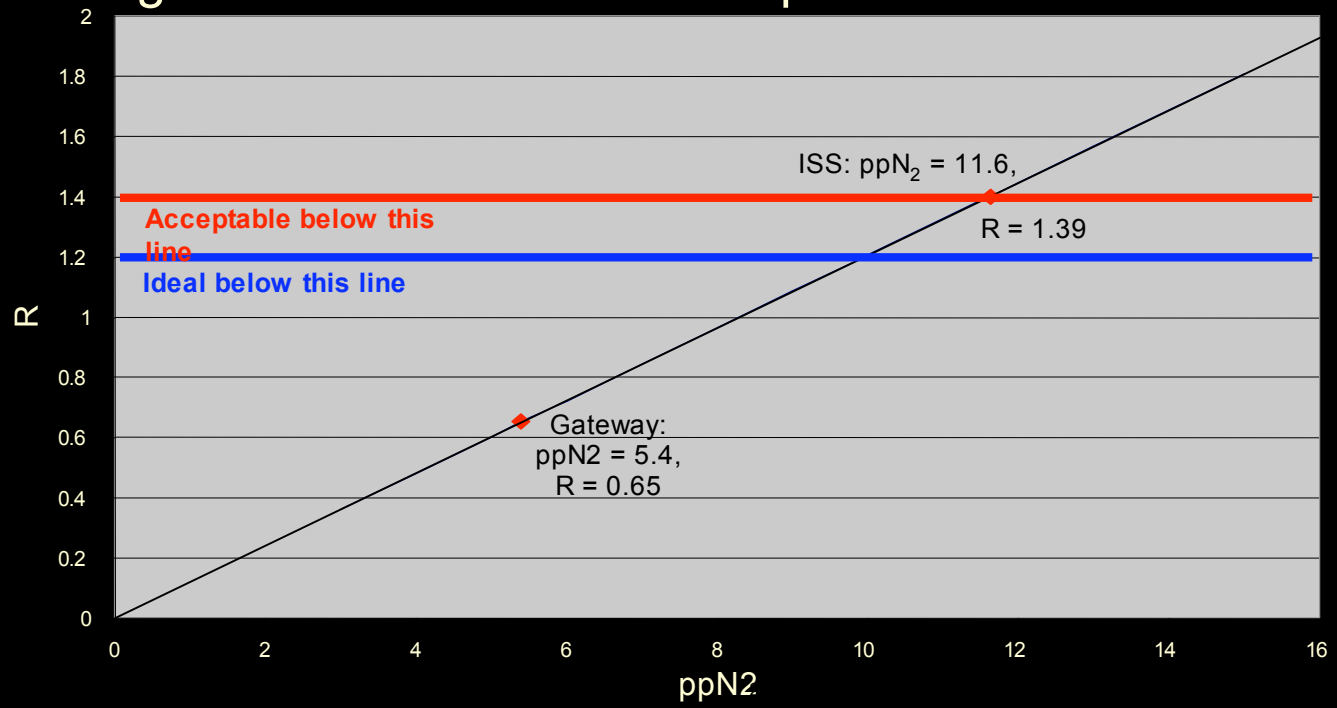
Launch Venting

- Must prevent underpressurization
  - SCOUT must always be at a greater pressure than the surrounding medium to prevent hull breach
- Ambient pressure (14.7psi)
- Pneumatic valves
  - In VRV hole
    - VRV replaced on orbit
- Keeps internal pressure around 14.7psi
  - Will immediately dock with ISS, which is at 14.7psi
- Keeps internal pressure greater than external pressure

Zero Pre-Breathe

- R = ppN_2 in prebreathed air (Gateway) / total pressure of EVA air (SCOUT)
- For no pre-breathe:
  - R = 1.2 is good; R = 1.4 is acceptable
  - Higher values: Risk of decompression sickness

SCOUT

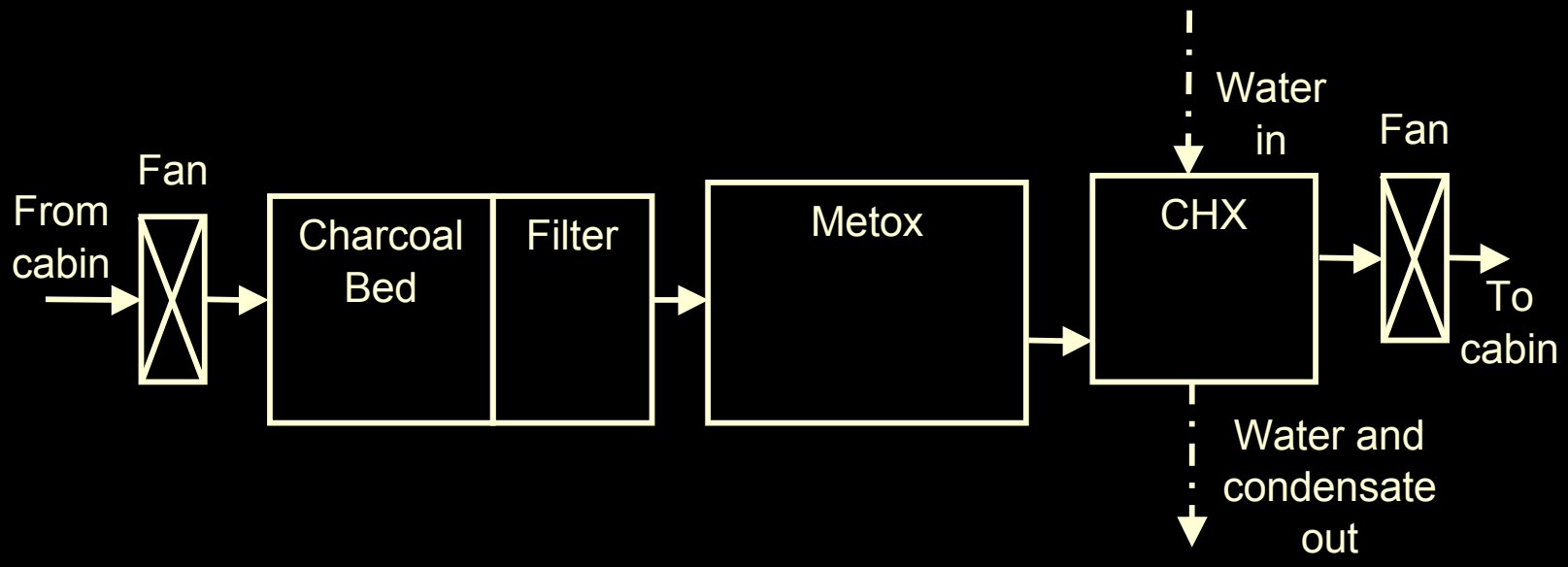


R Value for Various Nitrogen Partial Pressures of Stations Docking SCOUT

SCOUT

Air Revitalization Assembly

- Trace contaminant and particulate removal
- Carbon dioxide scrubbing
- Temperature and humidity control
- 24kg; 70W



Contaminant Control

SCOUT

- Activated charcoal bed
  - Nonregenerable
    - Replaced every three months or when PCP reports high incidence of contaminants
  - Phosphoric acid impregnated
  - Removes trace contaminants such as ammonia and methane
- Particulate filter

Carbon Dioxide Removal

- Metal oxide (metox) canisters
- Each canister 15kg, lasts one sortie
- Extra canister on board
- Regenerable

SCOUT

Hamilton Sundstrand International

Metox Regeneration

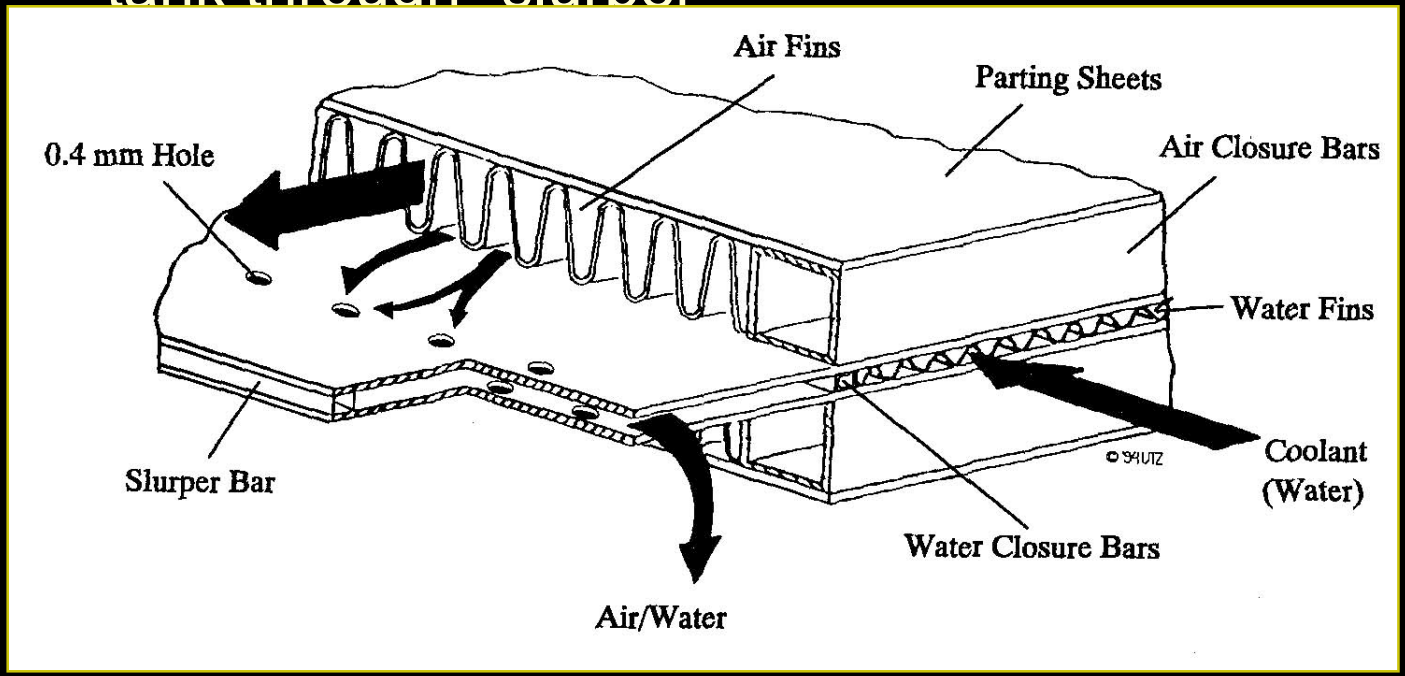
- Regenerator in docking module
- 2 canisters at once
- Heats canisters while exposing to vacuum
- 10 hours plus cool-down period
- 50kg; 1kW

Hamilton Sundstrand International

SCOUT

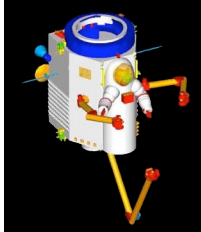
Temperature and Humidity Control

- Condensing Heat Exchanger (CHX)
- Uses cool water from waste water tank to bring air below dew point
- Gathers and removes condensation to waste water tank through "slurper"



Eckart, 1996

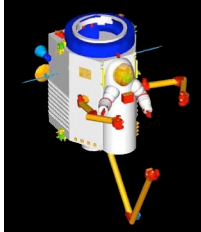
SCOUT



SCOUT

ARRS Maintenance

- Air Supply
  - Oxygen and nitrogen tanks refilled after each sortie from Gateway cryogenic supplies
- Charcoal bed
  - Replaced every 3 months or as necessary
- Particulate filter
  - Cleaned when replacing charcoal bed
  - Replaced every 5 years or as necessary
- Metox
  - Regenerated after each sortie
  - System lifetime: 60 cycles, or 2 years of nominal mission operations



SCOUT

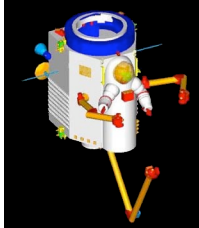
Backup Systems

- Supplemental oxygen tank
  - Adds 20.5 hours to operating time
  - Automatic use if primary tank malfunctions or empties
  - Can also be manually switched
- Emergency oxygen tank
  - 3 hour supply
  - Portable tank and mask
  - Used during bail-out, fire, or other emergency or malfunction
- Air revitalization
  - Extra metox canister
  - Astronaut replaces canister if CO_2 level becomes dangerous

ISS Operation

- Docked pressure of 14.7psi
  - Requires alteration of PCP's firmware for "docked" mode
- Possibility of decompression sickness in some astronauts
  - Astronauts must be aware of this, and immediately don oxygen mask and return to station if any symptoms noted
- Air replenishment
  - ISS uses compressed gas, not cryogenics – tank refilling will be easier

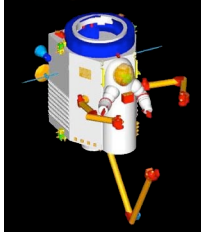
SCOUT



SCOUT

Air System Summary

	Mass (kg)	Volume (m^3)	Dimensions (m)	Power (W)
Each SCOUT				
Tanks	13.25	0.0138	Each of 3 tanks: 0.111 Diameter, 0.471 height	-
PCP	15	0.002	0.1x0.1x0.2	100
ARA	24	0.04	0.5x0.4x0.2	40
Metox	15	0.01	0.25x0.4x0.1	0
CHX	5	0.02	0.1x0.5x0.4	0
Filters	2	0.0003	0.1x0.1x0.03	0
Fans, etc.	2	0.01	0.25x0.4x0.1	40
Spare Metox	15	0.01	0.25x0.4x0.1	0
Valves, Piping, and Other Incidentals	14	-	-	30
Total	**81.25**	**0.0934**	**-**	**170**
Docking Module				
Metox Regenerator	50	0.1655	0.45x0.4826x0.762	1000
4 Spare Metox	15	0.01	0.15x0.4x0.1	0
Total	**65**	**0.1755**	**-**	**1000**

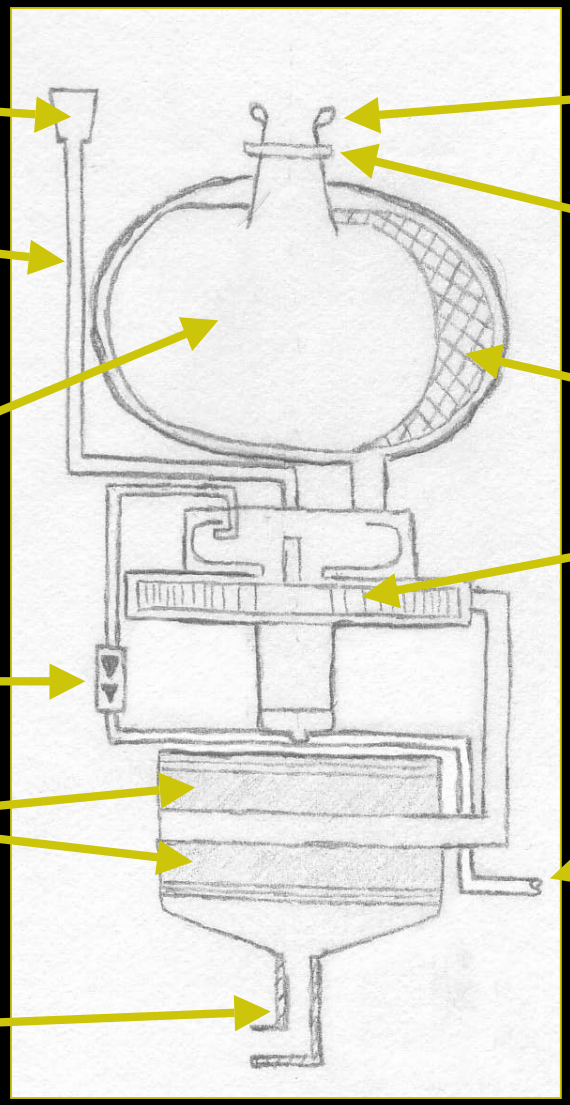


SCOUT

Waste Collection System

- Smaller version of Shuttle WCS
  - Convenient
  - Use does not require deviation from nominal diet
- Estimated 10kg, 1W
- Fan draws air through collection unit at approximately 850L/min (30CFM)
- Solid waste collected in removable liner and dried by airflow
- Personal urinal attached to flexible hose, can be mounted to seat and repositioned to fit crew member
- Liquid waste removed from airflow by centrifugal fan separator
- Liquid waste transferred to SCOUT waste water tank
- Air passes through odor and bacteria filter and is returned to cabin atmosphere
- Unit includes storage for liners and sanitary wipes and bin for wet trash collection

Waste Collection System Diagram



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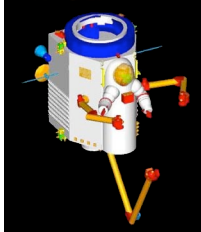
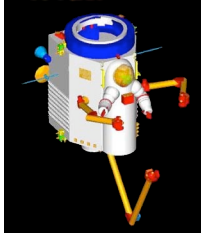


SCOUT

Internal Lighting

- Minimum required illuminance by task:
  - Hatches/Handles/Ladders: 108LUX
  - Waste Management: 164LUX
  - Workstation Controls: 215LUX
  - First Aid: 269LUX
  - Dining: 269LUX
  - Food Preparation: 323LUX
  - Reading/Recreation: 323LUX
- Cabin lit by variable-intensity LED lamp
  - ~ 2W
- Small LED flexible light also available for additional task lighting



SCOUT

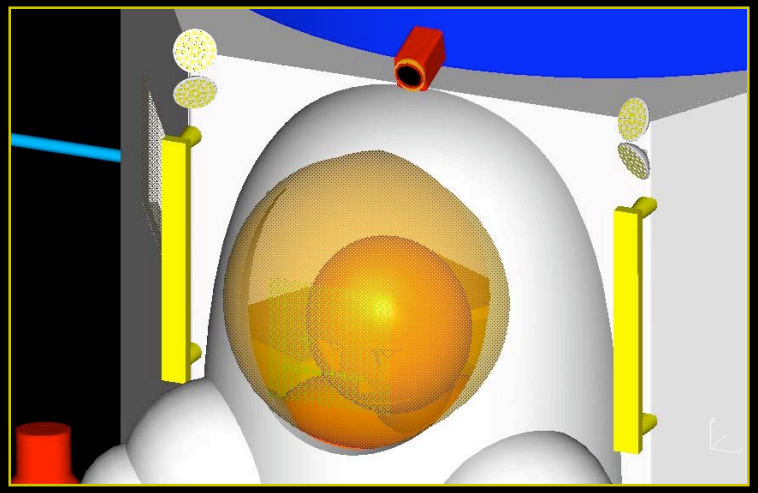
External Lighting Requirements

- Required illuminance by task:
  - Movement to worksite: 55-110LUX
  - Visual tasks with large or high-contrast objects: 215-325LUX
  - Visual tasks with small or medium-contrast objects: 325-750LUX
  - Visual tasks with very small or low-contrast objects: 540-1080LUX
  - Satellite servicing with simple hand tools: 325+ LUX
  - Satellite servicing with complex tools: 540+ LUX
- Light sources not placed within 60º of center of crew member's field-of-view
- Lights must be controllable from inside SCOUT

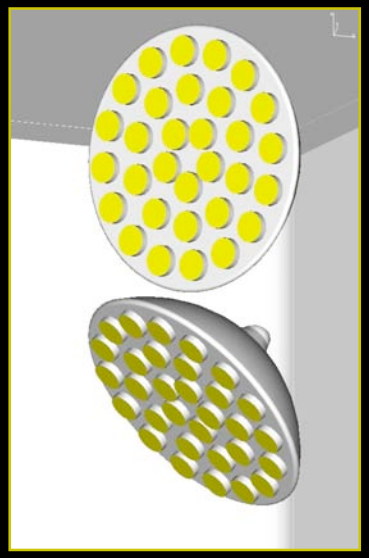
External Lighting Type and Placement

SCOUT

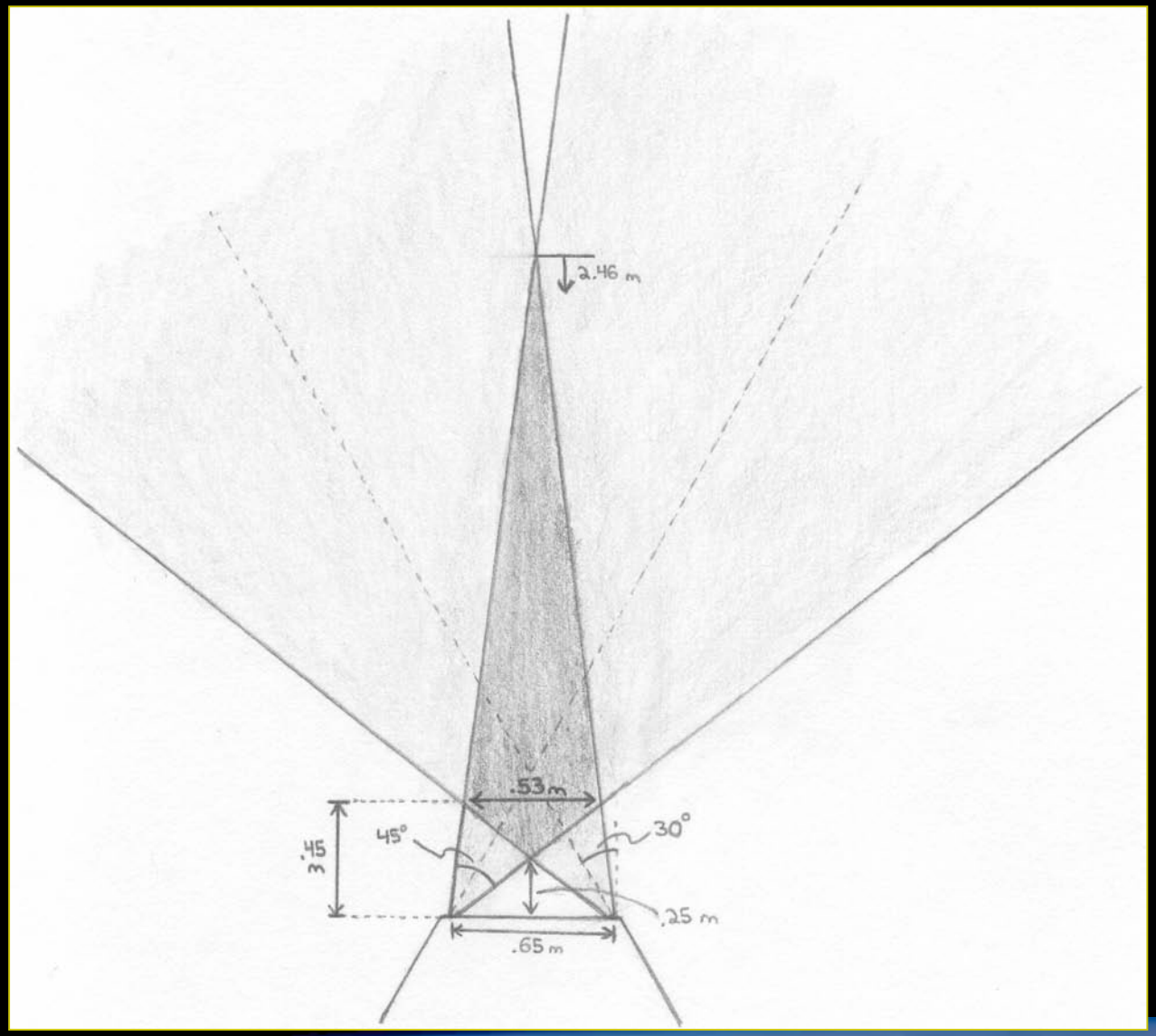
- Lighting type:
  - 4 LED array lamps
  - 45º viewing angle
  - Approximately 2.5W each



- Placement:
  - 2 lamps on each side of helmet
  - Groups spaced 0.65m apart
  - 2 lamps angled up at 22.5º, 2 angled down at 22.5º
  - All lamps angled in towards work envelope at 30º



Worksite Illumination



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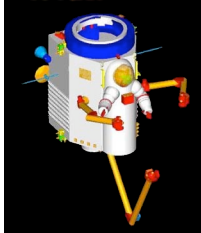


Extended Mission Requirements

SCOUT

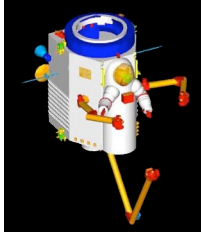
For Lunar Orbit Mission

- 46 hours travel time
- 20 hours using SCOUT resources while working
- Air system:
  - Does not need extra oxygen tank (2 current O_2 tanks supply 40 hours)
  - 2 supplementary Metox canisters
    - Change during 6 hour break
    - 2nd is for backup
- Water system:
  - 8oz drinking water per hour on SCOUT
  - For 20 hours, requires 160oz
  - This is 55oz more than a nominal mission

Secondary Egress / Bailout (SHEEP)

SCOUT

- Final design of a secondary egress point not completed
- Current designs lean towards an externally expandable hybrid spacesuit, to be known as the SCOUT Hybrid Expandable Escape Pod (SHEEP)
  - Hybrid design of the current NASA bailout ball, and the past Rockwell conceptual design of the Rib Stiffened Expandable Escape System (RSEES) escape system
  - escape pod would be contained within a canister that is located on the outside of SCOUT
  - In the event of an emergency, the crewmember would deploy the spacesuit, climb in, close the suit, and detach from SCOUT
  - Allow the crewmember minimal use of their hands in order to control SHEEP's propulsion device and translate along EVA handrails

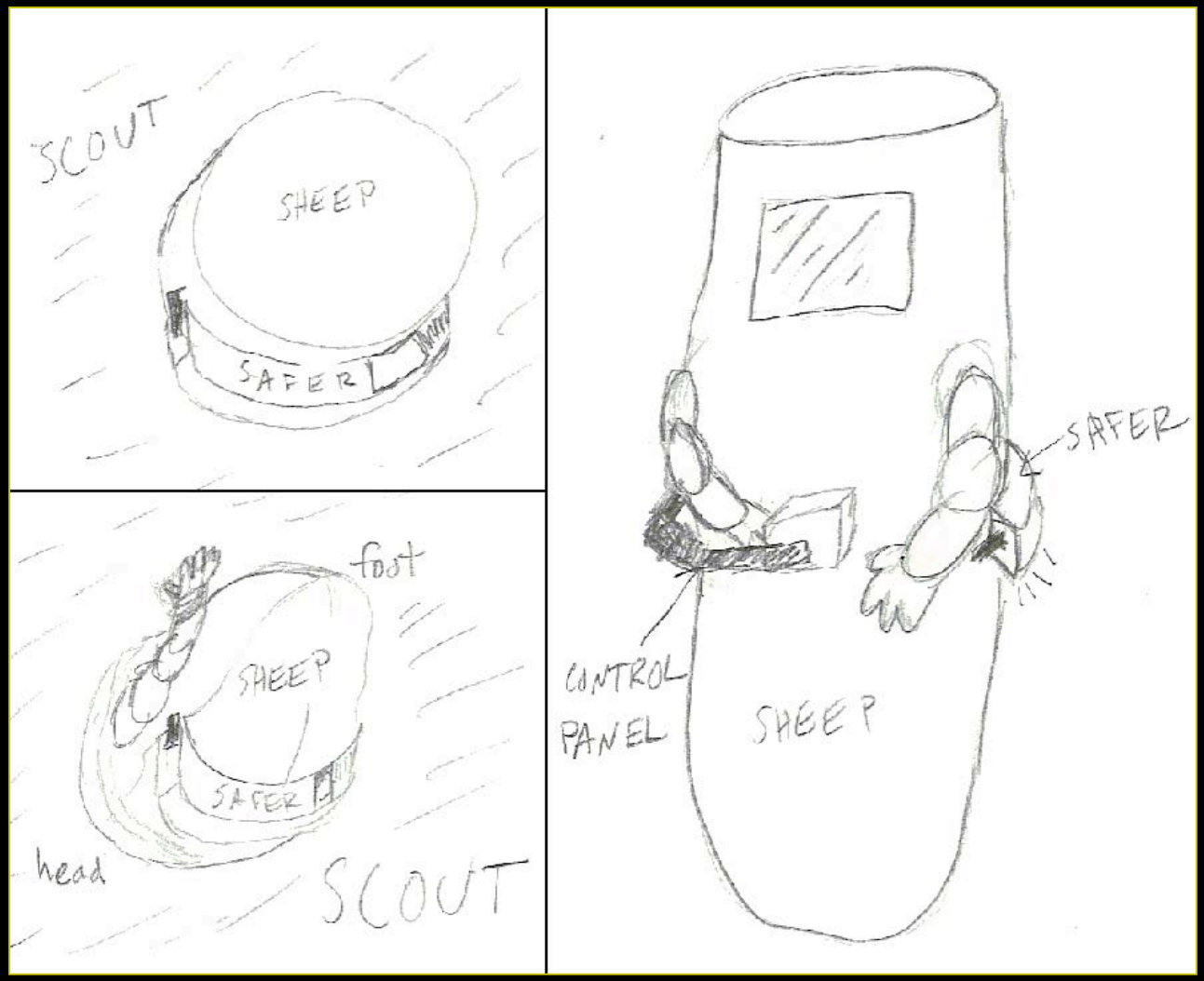


SCOUT

SHEEP Systems

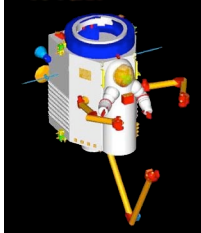
- Propulsion
  - Slightly modified version of NASA's SAFER (Simplified Aid For EVA Rescue)
  - Latches to waist
    - Replace backpack latches from EMU version
    - Removable if necessary
  - Deploys with SHEEP
  - Control unit moves to front
  - 13 minutes of N_2 with 6DOF motion; initial ΔV of 3m/s
  - 39kg
- Air
  - 4 hour emergency O2 tank with mask is brought on SHEEP when deployed
- Communications
  - Battery-powered emergency beacon begins broadcasting immediately when SHEEP deploys

SHEEP Deployment



Sketch of SHEEP with propulsion system from SAFER in undeployed, deploying, and maneuvering modes

SCOUT



Bailout Procedure and Orientation

SCOUT

- In the case of an emergency, the crew member will:
  - Make a controlled tumble from their current orientation so that their head is oriented towards the escape hatch
  - Deploy the SHEEP system
  - Equalize pressure and open emergency hatch
  - Make another controlled tumble and egress from SCOUT feet first
  - Close emergency hatch
  - Seal the SHEEP system
  - Detach from SCOUT
  - Activate propulsion system (if applicable)

Radiation Types

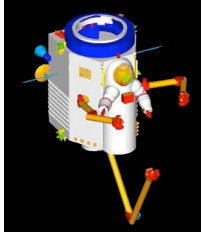
- Radiation levels are higher at L1 than in LEO
- Types of radiation found at L1
  - Galactic Cosmic Radiation (GCR)
    - Background radiation produced by the universe
    - Consists of about 85% protons, 14% alpha particles, and ~1% nuclides
    - Energies of these particles range anywhere from 0 to over 10GeV (giga-electron volts)
    - Because of their high energies, GCR is difficult to shield against, however, GCR has relatively low flux levels

SCOUT

SCOUT

Radiation Types Continued

- Solar Particle Events (SPEs)
  - 90% protons
  - Energies ranging from about 10MeV to 1GeV
  - Lower energy levels than GCRs, but can have up to 4 times the flux levels
  - Magnitude of SPEs reaches a maximum ~every 11 years
  - Because SPEs emit radiation in concentrated period of time, they can be fatal to astronaut working on SCOUT
  - Recommend that the astronaut return to the Gateway station as soon as warning of a SPE is given (assume that Gateway will have a “storm shelter” with shielding of ~20g/cm^2 or more of water equivalent material)
  - Scientists have been able to predict SPEs up to 6 hours in advance of their arrival at earth using satellites such as SOHO, ACE and advanced modeling techniques. Future satellites such as STEREO (2004) will further refine the predictions



SCOUT

Exposure Limits*

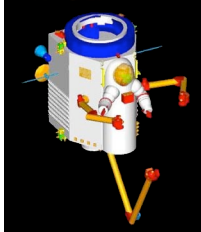
For Organs

Exposure Interval	Depth (BFOs) (5cm)	Eye (0.3 cm)	Skin (0.01 cm)
30 days	25 REM	100 REM	150 REM
Annual	50 REM	200 REM	300 REM
Career	100 to 400 REM	400 REM	600 REM

For Career

	Age			
Gender	25	35	45	55
Male	150 REM	250 REM	325 REM	400 REM
Female	100 REM	175 REM	250 REM	300 REM

*Numbers based on 3% lifetime excess risk of cancer mortality *NASA*



SCOUT

Exposure Limits Cont.

- To determine type and amount of shielding to use, need to break down exposure limits
- Assuming radiation exposure to BFOs
  - 50 allowable rems / 365 days = 0.14rems/day
  - (.14rems/day) / (24hrs/day)

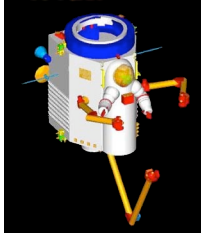
    = 0.007 allowable rems/hr
- Assuming radiation exposure to skin
  - 300rems / 365 days = .82rems/day
  - (.82rems/day) / (24hrs/day)

    = 0.34 allowable rems/hr
- Estimated total time in pod per astronaut
  - (6mo)(15days/6mo)(13hrs/day) =195hrs
- Total radiation exposure
  - (0.007rem/hr)(195hrs) = 1.4 allowable rems

SCOUT

Preliminary Radiation Shielding

- Aluminum shielding
  - Density = 2700kg/m^3
- With 4g/cm^2 aluminum shielding data from STS-89
- 62 days exposure = 0.6% increase in excess fatal cancer
  15 days exposure ~ 0.2% increase in excess fatal cancer
  << 3% lifetime limit
- Assuming Gateway radiation levels =< SCOUT
  180 days exposure ~1.74% increase in excess fatal cancer
  < 3% lifetime limit
- Nominal shield thickness ~0.015m
- Additional protection from radiation absorbing electronics and micrometeoroid shielding



SCOUT

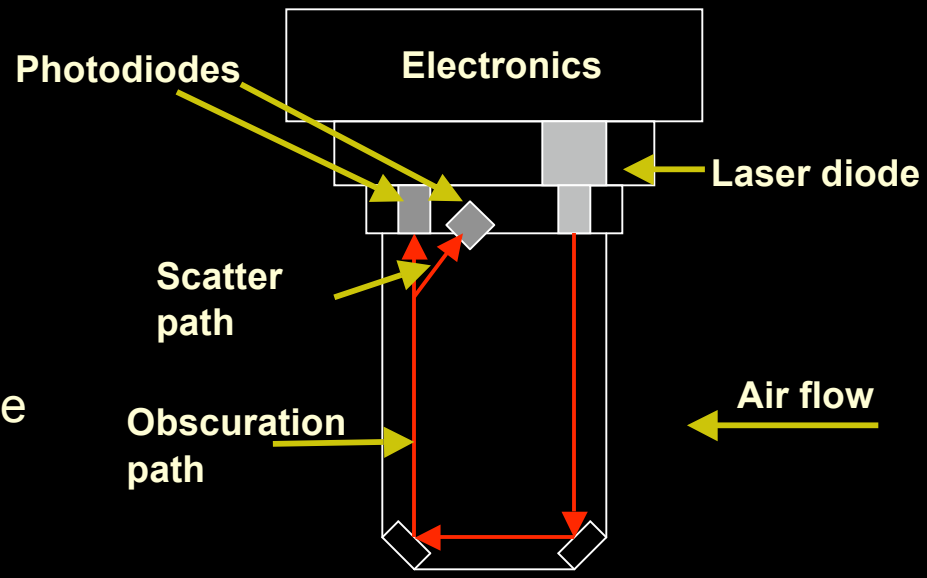
Additional Measures to Minimize Radiation

- NASA requirements
  - Detailed flight crew exposure records
  - Planned exposures must be kept As Low As Reasonably Achievable (ALARA)
  - Operational procedures and flight rules to minimize excessive exposure
- SCOUT requirement recommendations
  - Astronauts in SCOUT must keep passive dosimeter on them at all times and update records after each sortie
  - Radiation exposure levels on Gateway must be monitored
  - Astronauts cannot work on SCOUT every day of a 6 month mission
  - Astronauts MUST return to Gateway ASAP when major SPE is detected

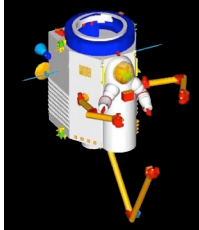
Fire Sensing

SCOUT

- Photoelectric Smoke Detector
  - Based on scattering of laser beam by smoke particles
  - Two photodiodes, one measures laser beam, one measures scattered laser beam
  - After certain difference in photodiode voltages, alarm sounds
  - Capable of detecting particles of 0.3μm or higher
- Astronaut visual and nasal cues→ astronaut has ability to detect fire quickly using senses



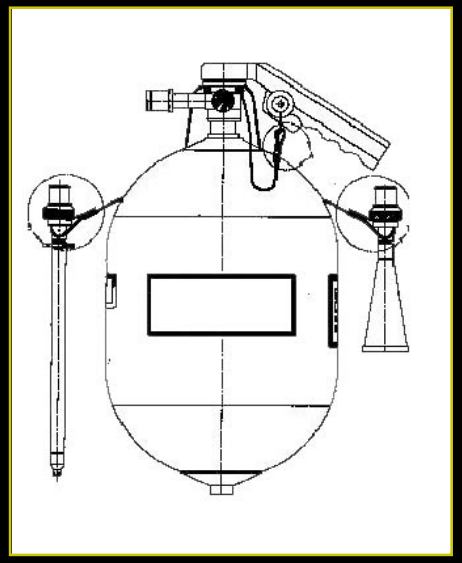
NASA



SCOUT

Fire Suppression

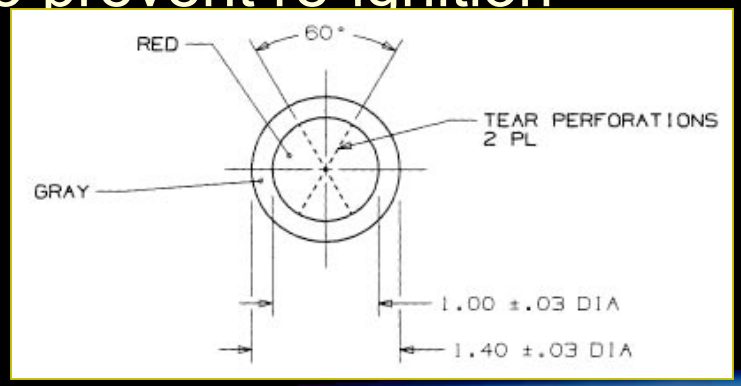
- Nitrogen (N_2) Portable Fire Extinguisher
  - Inert gas
  - Safe non-toxic gas for small habitable volumes
  - Rated safe for use on BC type fires (flammable liquid/electrical)
  - Will not harm electronics
- Works by oxygen dilution
  - Requires > 50% N_2 concentrations in local volumes
- SCOUT Portable Fire Extinguisher
  - 2.7lbs N_2 gas at 5.8MPa
  - Range up to 2.5m
  - Fully discharges ~45 seconds
  - Overall mass 3.7kg



NASA

Fire Suppression Procedures

- Shut off air flow system to prevent further spread of fire
- Wear portable breathing apparatus (PBA)
- Use portable fire extinguisher
  - Open air nozzle → if fire occurs in crew cabin
  - Closed volume nozzle → if fire occurs behind panels nozzle is inserted into fire suppression ports
- Continue dispensing agent after fire appears to be out to prevent re-ignition



NASA

SCOUT

Portable Breathing Apparatus

- Recommend astronaut put on PBA as soon as possible during fire event
- Consists of mask, oxygen bottle, and hose
- Oxygen bottle same as from escape system
- Capable of providing up to 3 hours of oxygen

NASA

SCOUT

SCOUT

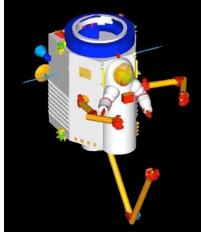
Post Fire Recovery

- SCOUT must return to Gateway station immediately
  - If not possible due to fire damage, emergency bailout or rescue must be performed
  - Post fire recovery systems will be stored on Gateway
- Gaseous contaminants removed
  - SM - Micropurification Unit → Removes 19 different gaseous contaminants
  - FGB - Harmful Impurities Filter → Removes gaseous trace impurities (particles of 0.5 to 300mm)
  - Lab - Trace Contaminant Control Subsystem (TCCS) → Removes gaseous contaminants
- Repairs and/or replacement of parts or vehicle in case of excessive vehicle damage

SCOUT

Depressurization

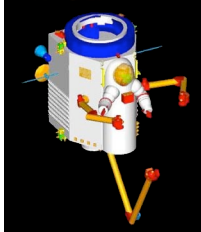
- Depressurization in a small cabin can reach dangerous limits within a short period of time and lead to quick onset of hypoxia and decompression sickness
- If Class 1 alarm sounds to alert to decompression, astronaut must bail out of SCOUT



SCOUT

Health Monitoring

- Astronaut must be constantly monitored during SCOUT missions per EVA requirements
  - O_2 consumption (air system)
  - Suit pressure (air system)
  - CO_2 pressure (air system)
  - Radiation exposure (portable dosimeter)
  - Heart rate and EKG signal
    - Operational bioinstrumentation system
    - 3 chest electrodes, signal conditioner, and connecting cables; provides an EKG signal
    - Real-time data transmission



SCOUT

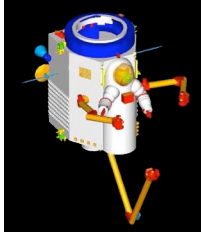
First Aid

- SCOUT shall be equipped with a first aid kit
  - The full list of items required is found in the NASA STD 3000 document. They include:
    - Bandages
    - Alcohol wipes
    - Burn kit
    - Motion sickness pills
    - Tylenol®
    - Scissors
    - Tweezers
    - Pain medications
    - Decongestants
    - Adhesive tape
    - Pen light
  - The kit will be stored in a storage locker
  - In situation where crew member is unable to treat themselves and is in urgent need of care, SCOUT must return to Gateway station

SCOUT

Caution and Warning Systems

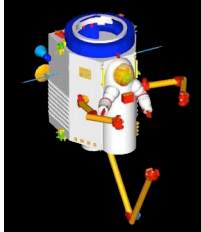
- Caution and warning system (C/W) is necessary to warn the astronaut of conditions that may adversely affect SCOUT operations
- 3 types of alarms (From NASA STD 3000)
  - Emergency (class 1)
    - The presence of fire and/or smoke
    - A rapid change in pressure within a pressurized element
    - The presence of toxic atmospheric conditions
  - C/W (class 2)
    - Loss of a total system
    - Loss of a Function category hardware or function
    - Loss of insight into and/or control of a Function category or hardware function
    - Accumulation of failures that jeopardize a category hardware function.
    - A criticality category failure
    - Exceeding a predefined redline/safety limit
  - Alert (class 3)
    - Conditions of a less time critical nature, but with the potential for further degradation if crew attention is not given
    - Messages that flag loss of redundant equipment such that a subsequent failure could result in a warning condition



SCOUT

Aural and Visual Alerts

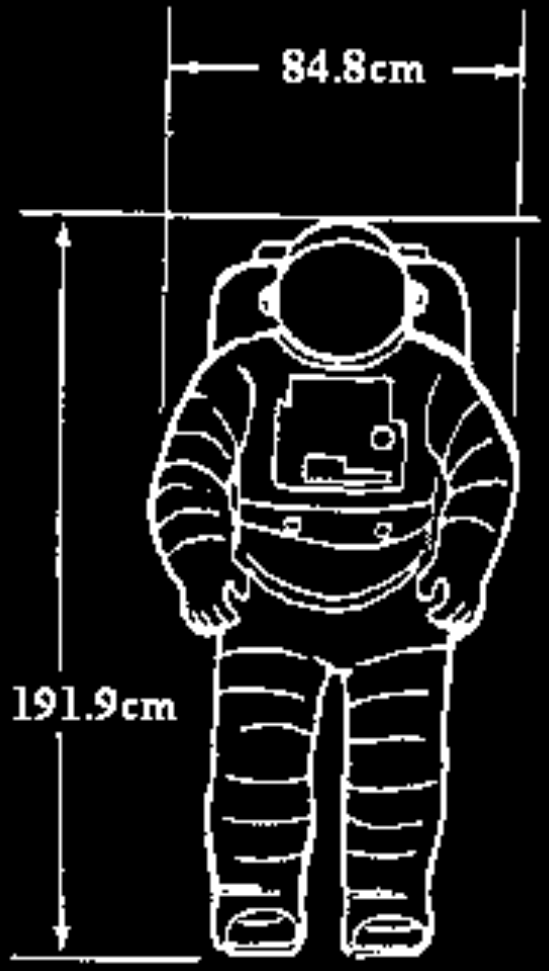
- The Caution and Warning system will interface with all systems on SCOUT such as life support, propulsion, and power systems
- Aural Alerts
  - Class 1 - Siren
  - Class 2 - Alarm
  - Class 3 - Systems management alert tone
- Visual Alerts
  - Class 1 - Master alarm → red
  - Class 2 - C/W indicators on panels → yellow
  - Class 3 - SM alert lights → blue
  - In addition
    - Parameter status lights
    - Fault messages and status messages on screens



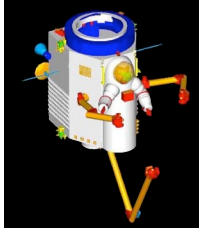
SCOUT

Affected Spacecraft Dimensions

- In order to keep existing worksite layouts unchanged, the surface in which the "hands on" interface of SCOUT exists was designed such that it will not be larger than the maximum designed shuttle spacesuit dimensions
- More precisely, one side of SCOUT, the part in which the AX-5 suit arms exist, will not be larger than a 95% STS EMU spacesuit
- SCOUT is required to accommodate all range of body types; 5% Japanese Female to 95% American Male. Therefore, "hands on" interaction must also follow those guidelines.
  - Poses a problem concerning gloves sizing for the range of possible users
  - Design team has concluded that some form of glove change out is required



NASA-STD-3000



SCOUT

Spacesuit gloves and arm Design

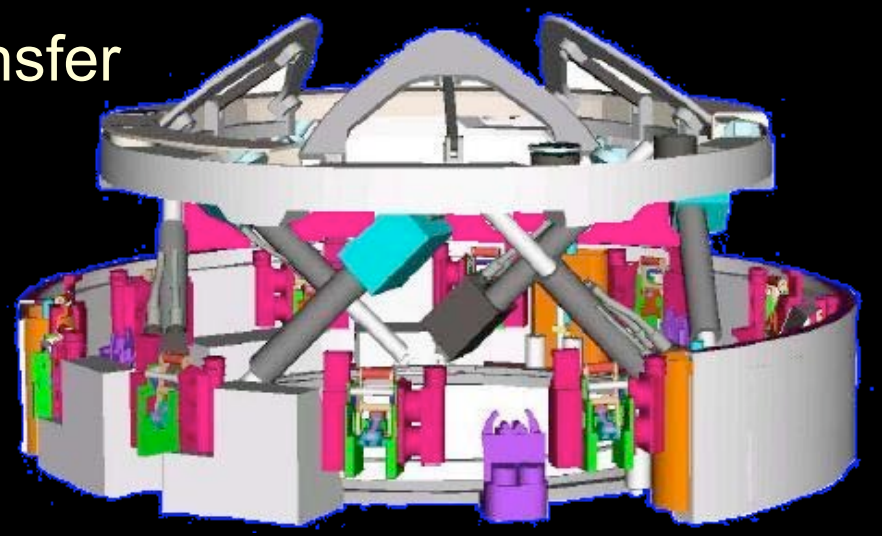
- Current design for spacesuit arms and gloves are modeled after the NASA AMES AX-5 suit
- Development of the AX-5 space suit is based on the capability of providing the crewmember with a zero pre-breath mission
- Notes:
  - Mass of arms: < 20kg
  - Shoulder and elbow joints are lubricated approximately every 3 months.
  - Operating pressure: 8.3psi
  - Pictured gloves are standard STS EMU gloves, not AX-5 gloves

NASA AMES

Main Ingress/Egress

SCOUT

- International Berthing and Docking Mechanism (IBDM)
- IBDM chosen because it enables commonality among all the OASIS elements, the ISS (expected), and Lunar Gateway
- Enables consumable transfer
  - (Based on available data)
- Max Dimensions:
  - 1.4m Dia x 0.25m thick
  - 0.8m Pass through
- Mass : 215kg
- Expected design completion 2005
- Allows for additional rescue scenarios



NASA-GATEWAY

Mock-up

SCOUT

IBDM

Minimal volume required

Torso cast

Mock-up cont.

SCOUT

Possible Contoured Hull Design

Internal Cabin

(Pressure Hull)

Mock-up cont.

SCOUT

Internal Cabin

Mock-up cont.

SCOUT

Human/Robot Interaction

SCOUT

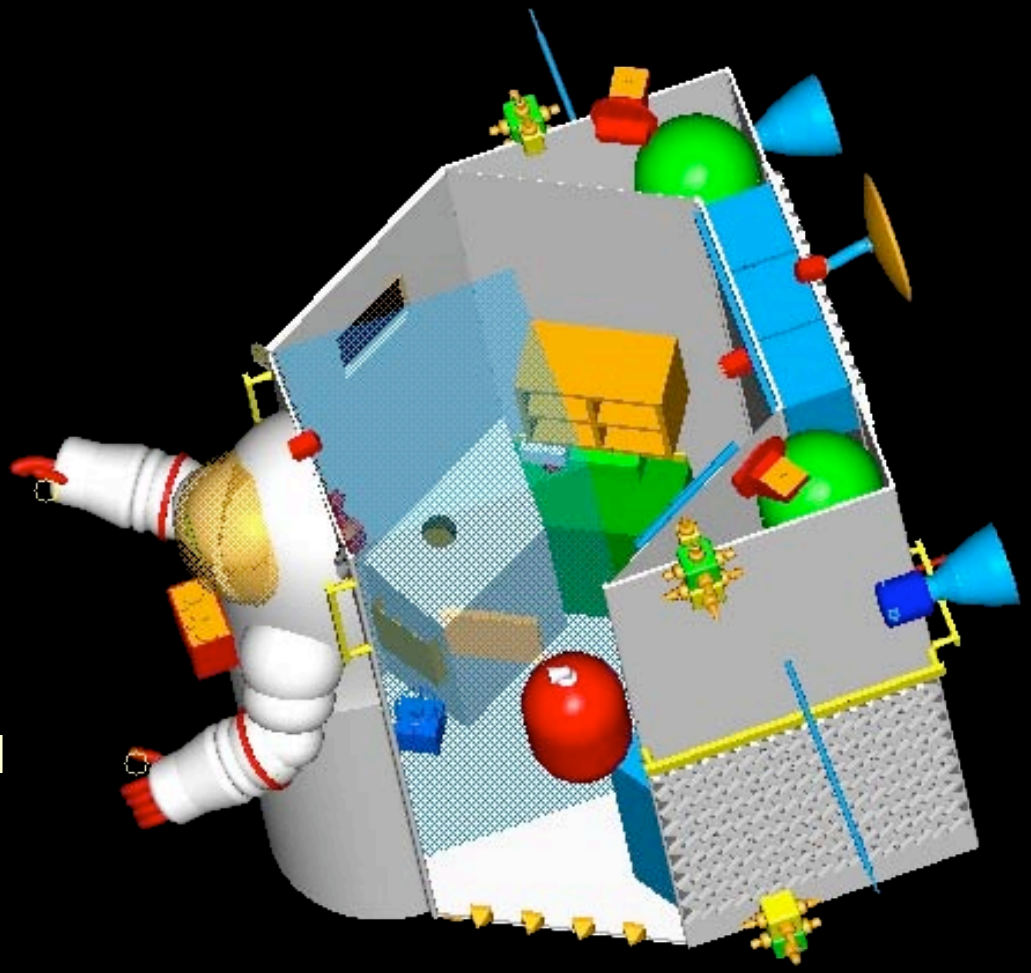
Mock-up Lessons Learned

- Both the IBDM hatch and Escape hatch must open towards the back of the cabin
- Therefore, any and all critical systems may not be located on the back wall
- Foot Restraints for use with the hand controllers could be placed on floor or back wall of cabin
- Crewmember must have their head within the helmet of the torso if they wish to view either the worksite or robotic arms with their own eyes
- Windows are therefore not required for eyes-on sight requirements. However, windows are the only way to view behind the field of view of the helmet
- Robotic arms are capable of contact with human arms.
- Contoured hull is the preferred deign to provide the crew with interaction to the worksite

Internal Volume Constraints

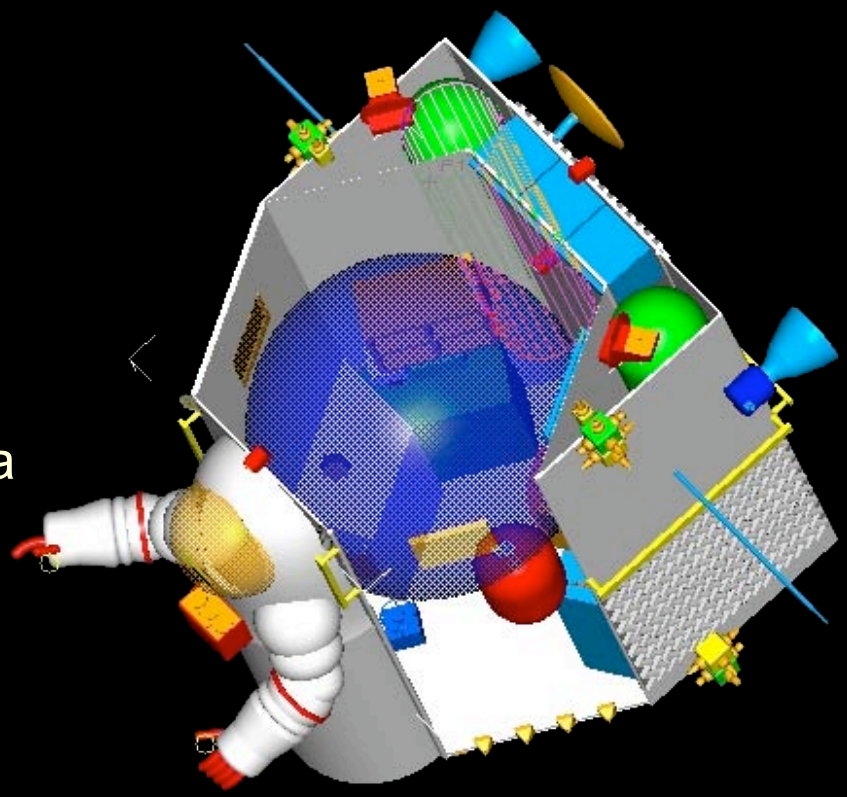
SCOUT

- Two major volume requirements being designed into the cabin layout are the minimal volume required to accommodate a 95% American male and the volume required for a controlled tumble
- Minimum habitual volume was placed within that cabin and all components were placed in accordance
- Measurement of the minimum habitable volume is
  0.72m x 0.71m x 0.172m

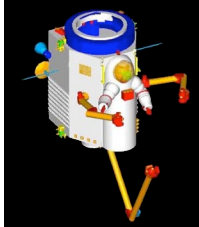


Internal Volume Constraints

- Required volume for a controlled tumble was also place within the cabin
  - All cabin components also placed in accordance with this volume requirement
- Restraint placed based on the fact that in the event of an emergency the crew member will have to make a controlled tumble in order the re-orient themselves
- Minimum tumble volume (spherical) is very approximate
  - Diameter of 1.22m



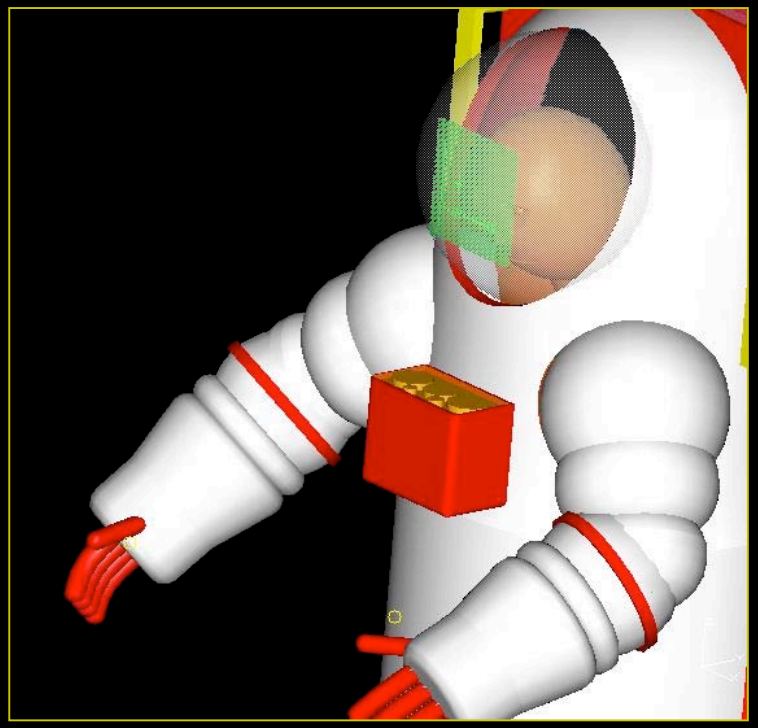
SCOUT



Contoured Hull

- The contoured torso hull will be place on the relative front of SCOUT and be aligned with the relative top of the vehicle
- The design of the torso hull was based off the torso of other hard suits, more precisely the Mark III and AMES AX-5

SCOUT

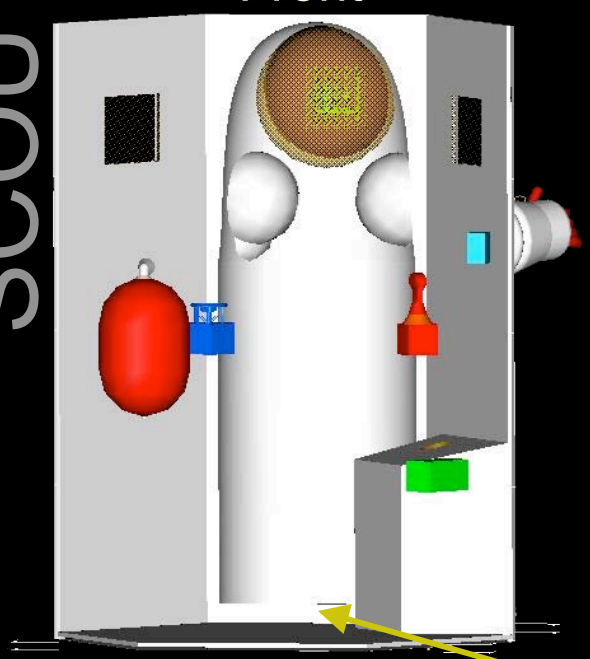


Internal Layout

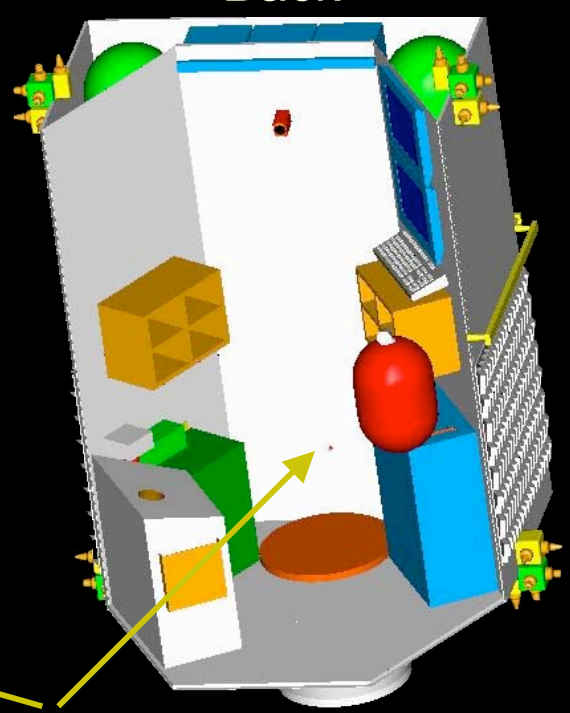
- Solid Models of SCOUT's internal cabin are displayed below
- Foot restraints are not pictured, but will be placed on the lower back wall of the cabin and on the floor towards the front

SCOUT

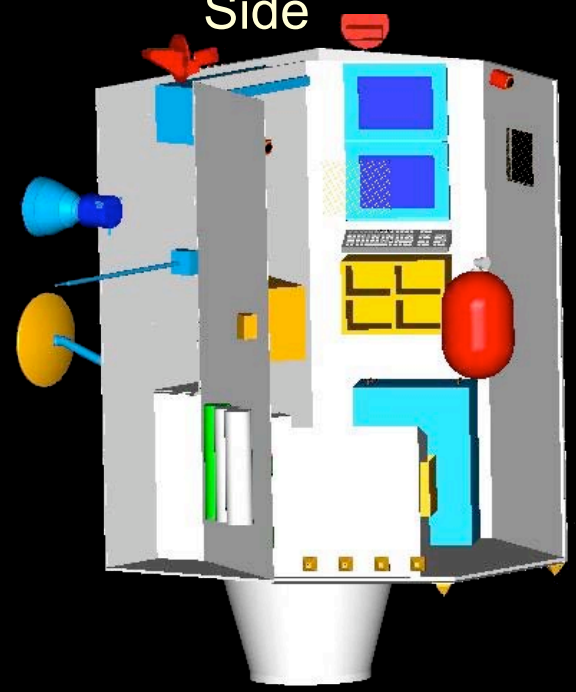
Front



Back



Side



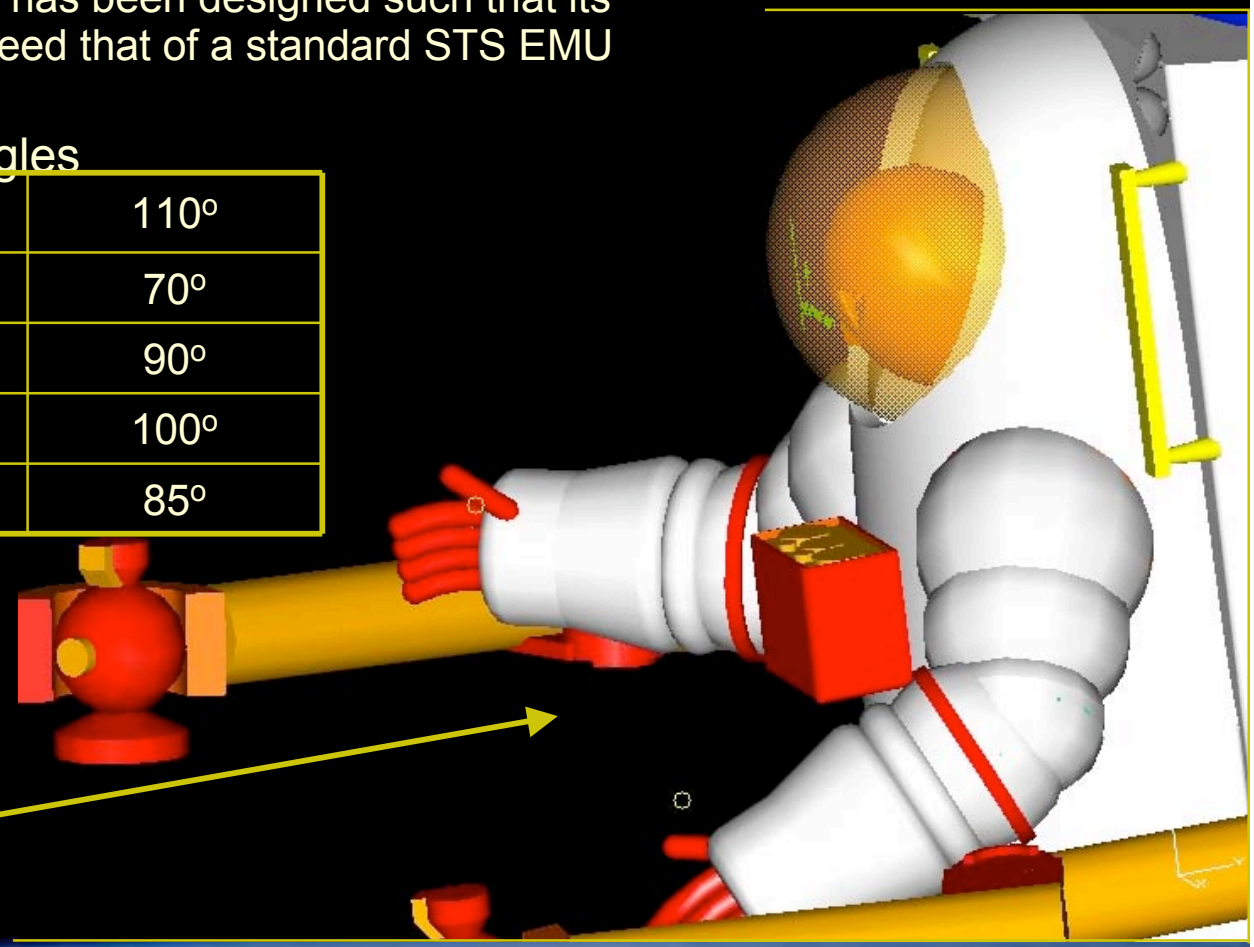
Foot restraint locations

Lines of Sight

SCOUT

- Main operation lines of sight for SCOUT will be provided by the spherical helmet contained in the contoured body
  - Spherical helmet has been designed such that its lines of sight exceed that of a standard STS EMU space suit
- Estimated sight angles

Superior	110º
Inferior	70º
Temporal	90º
Superior Temporal	100º
Inferior Temporal	85º

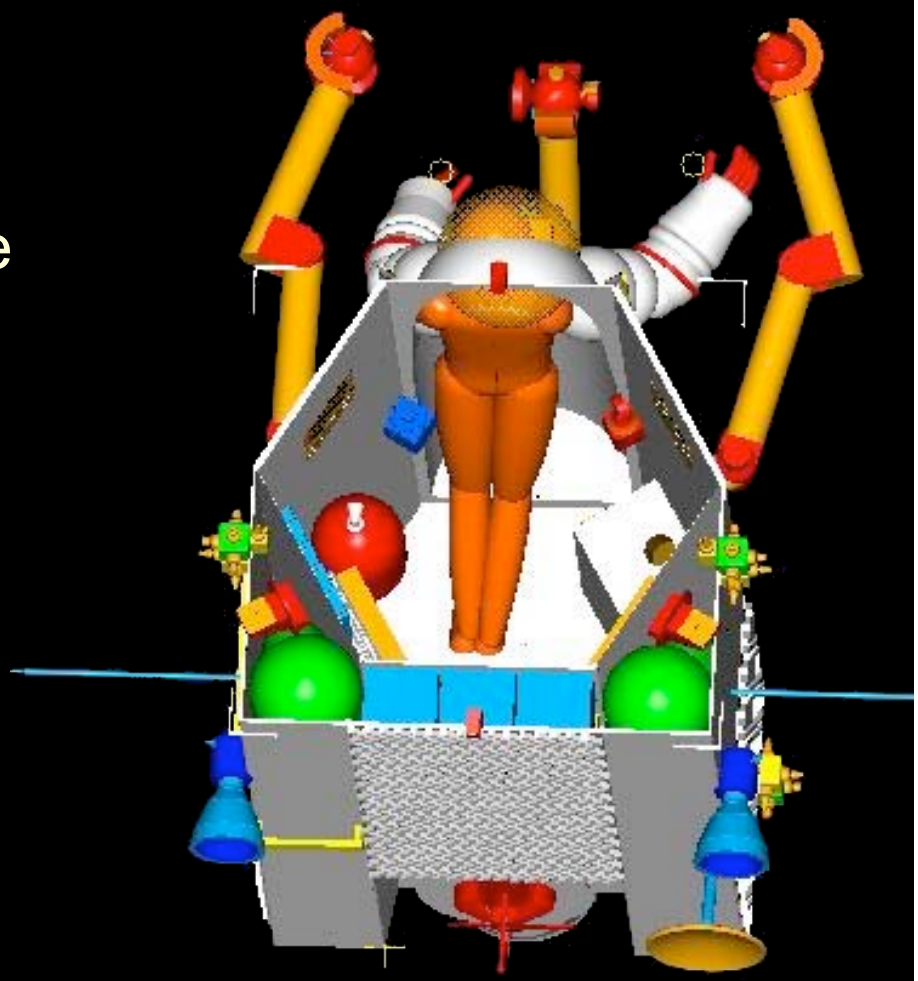


Solid model pictures display the crewmember with their head in the spherical helmet

Hands-on Orientation

SCOUT

- Orientation of the crewmember within the cabin when scout is being used in a “hands on” mode
- Crewmember is using the floor restraint located on the floor, their head is in the helmet, and their torso is located within the contoured hull
- Crewmember can control the robotic arms either by voice command or master/slave mode

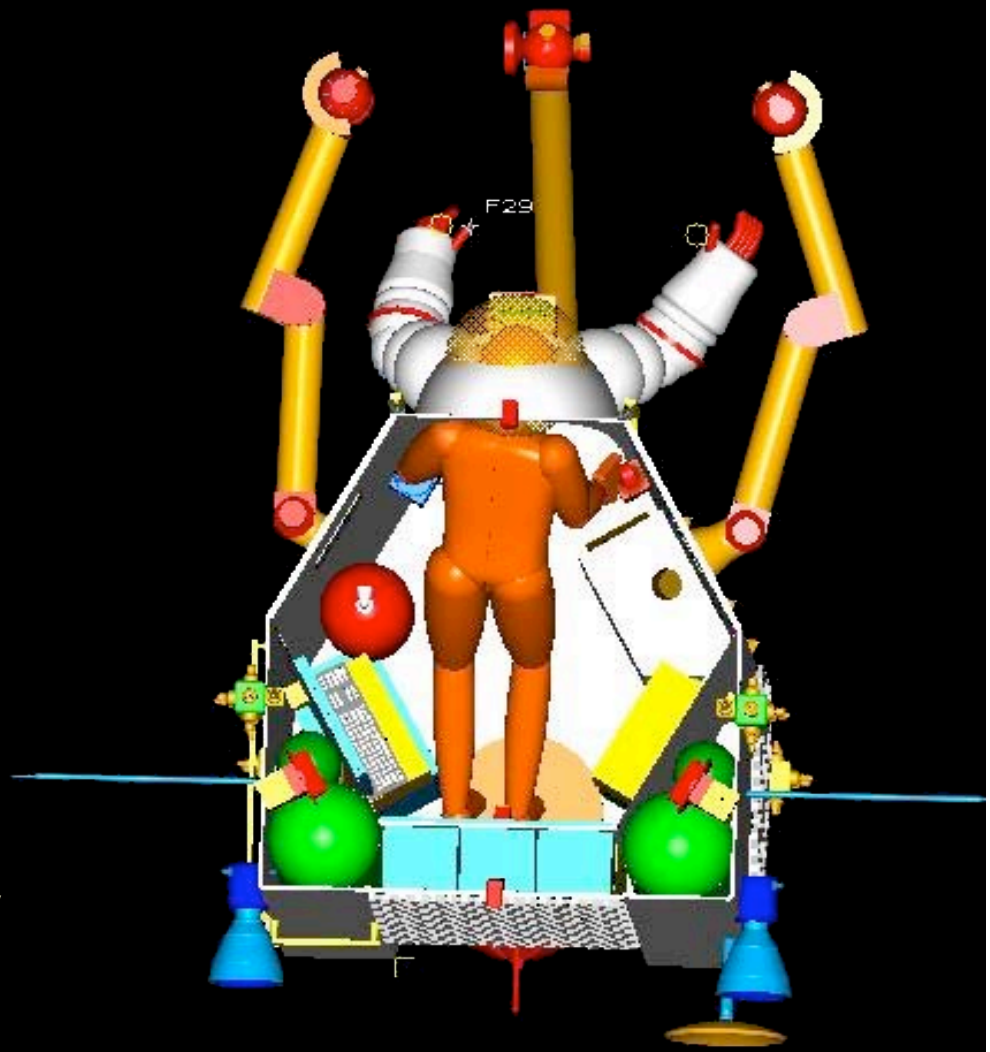


Robotic Arms/Flight Control Orientation

SCOUT

The orientation for use of the hand controllers is a follows:

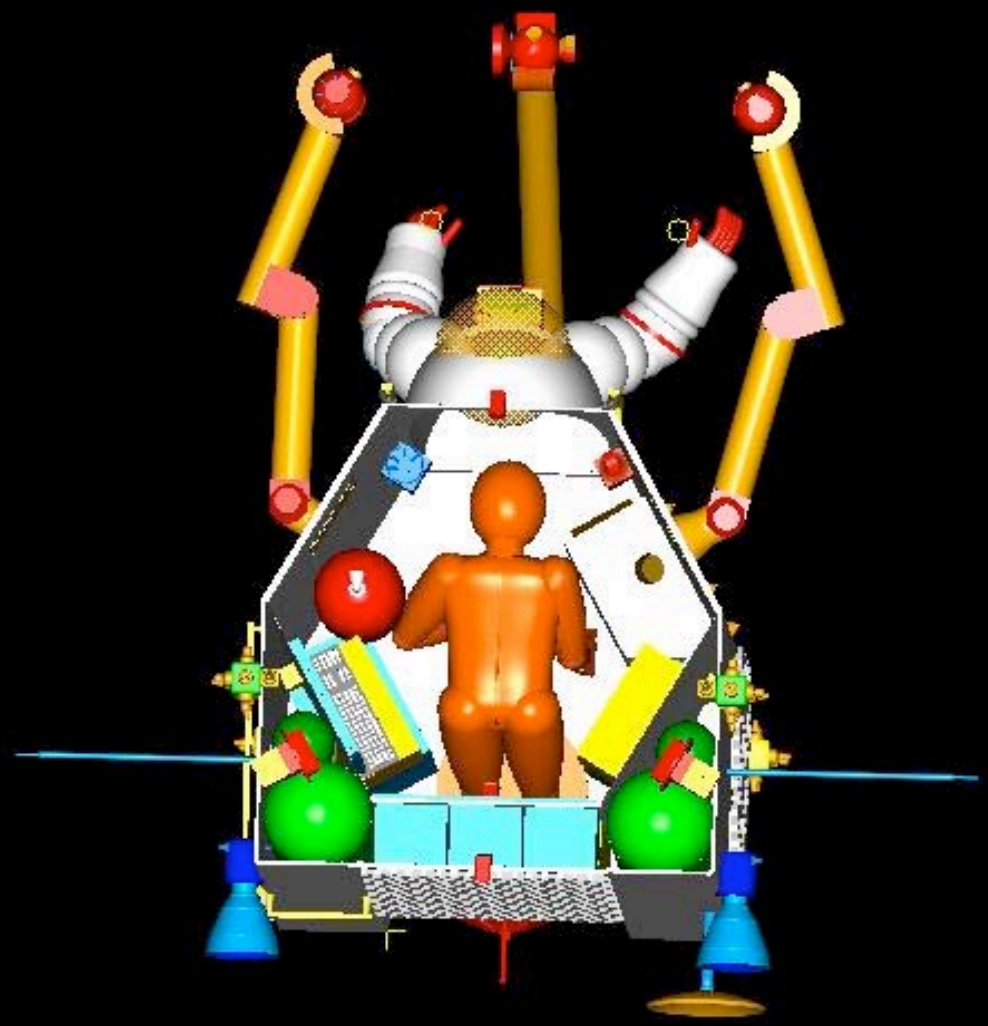
- The crewmember will use the foot restraints on the back wall of the cabin
- Their head will be in the spherical helmet, similar to that of the “hands-on” mode
- The 2- 3DOF hand controller are located either just outside or within the contoured body
- In this position the crewmember has the ability to control the robot arms either by voice command or through the use of the hand controllers



Escape Orientation

SCOUT

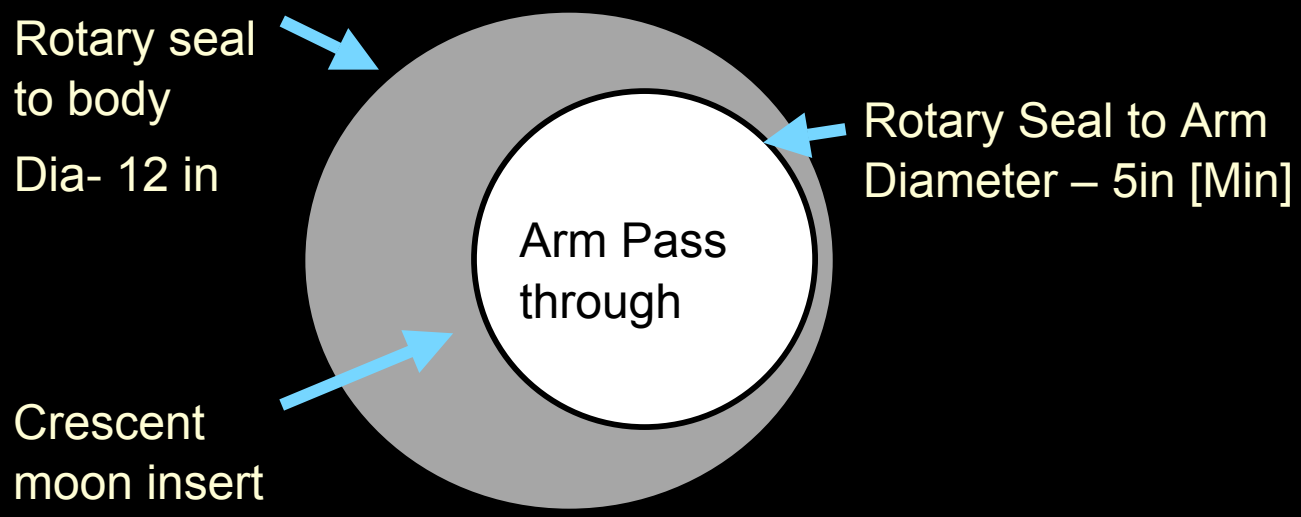
- The final orientation depicts the crewmember escaping SCOUT through the escape/bailout system, SHEEP
- Due to the design of the Bailout system, the crewmember must first make a controlled tumble resulting in their head being located at the escape hatch
- From there the crewmember will activate the escape system, make another controlled tumble, and egress the vehicle feet first



SCOUT

Shoulder Sizing

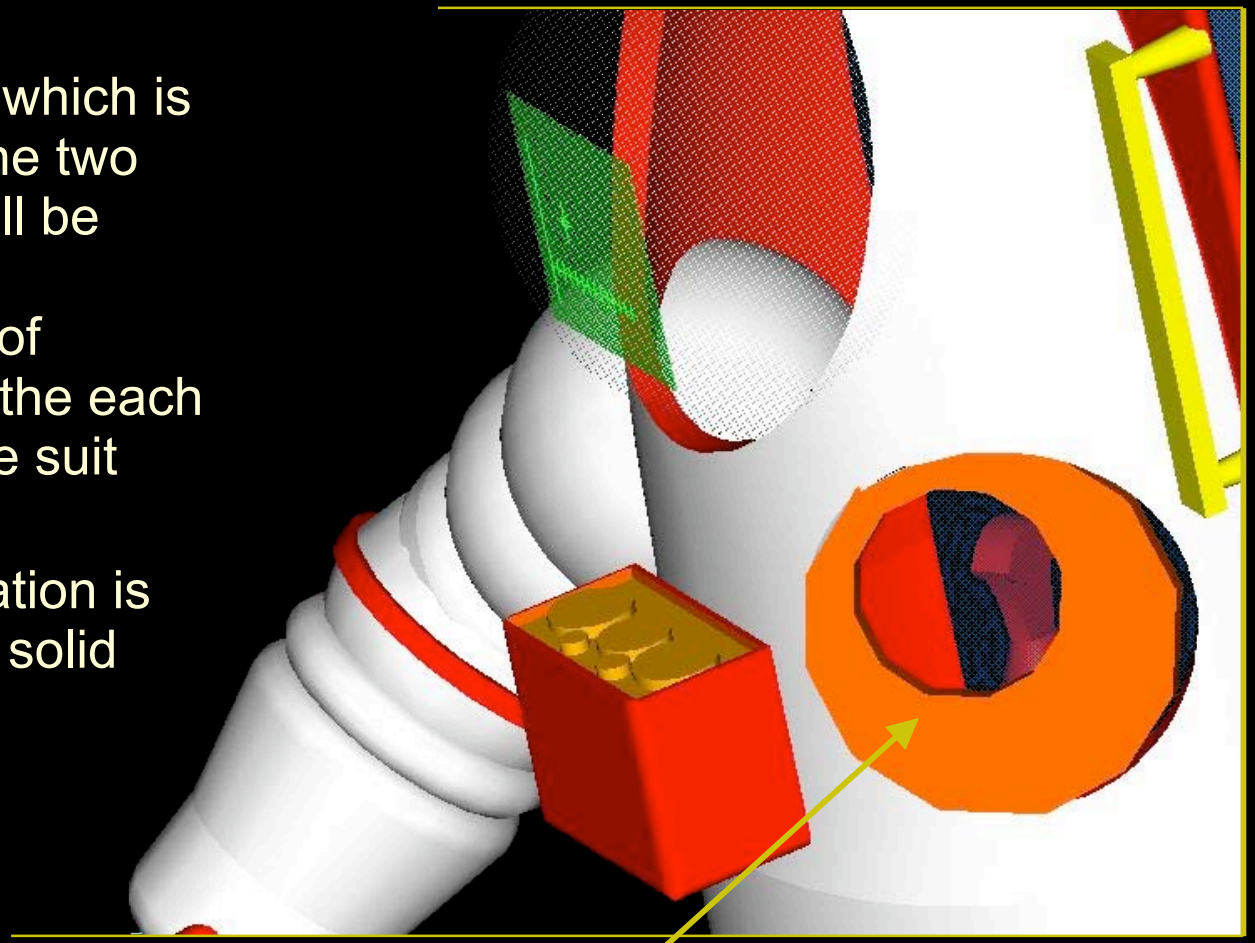
- Major concern of SCOUT is it's ability to accommodate the varying sizes of crewmembers when it comes to operating the suit arms
  - Combination of two rotary seals will be used to accommodate the varying shoulder berths and sizes of the wide range of users
  - Pass through for the crewmembers' arm will be able to rotate within the outer rotary seal
    - Seal will be set ~20 degrees of the center axis of the body
    - Compensates for the varying width of the crew's shoulders



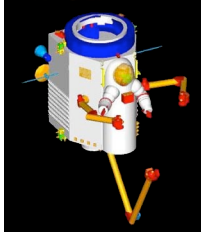
Universal Shoulder Joint

SCOUT

- The Universal Shoulder joint, which is composed of the two rotary seals, will be located on the contoured hull of SCOUT within the each arm hole for the suit arms
- The exact location is depicted in the solid model



Rotary seal shoulder joint



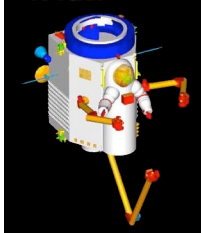
SCOUT

Change-Out

- Actual operational life for the AX-5 arms and gloves are unknown
- Operational life was based off of the current life of Shuttle Gloves
  - Shuttle gloves are changed out and stripped down after every 3 EVAs (~24 Hrs of operation)
- Current plan is to change out gloves after 24 hrs of operation

Hours of Gloves Interaction per SCOUT EVA	Time between glove change-out (EVAs)
1.0	**24**
1.5	**16**
2.0	**12**
3.0	**8**
4.0	**6**
5.0	**4**

Current design calls for glove change-out every 5th SCOUT EVA (Mission Planning)

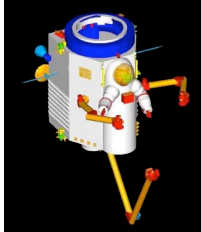


SCOUT

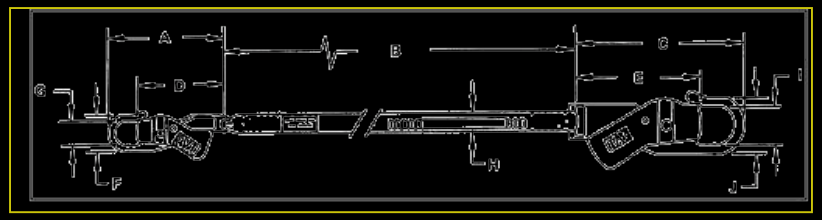
Glove and Arm Change-Out Procedure

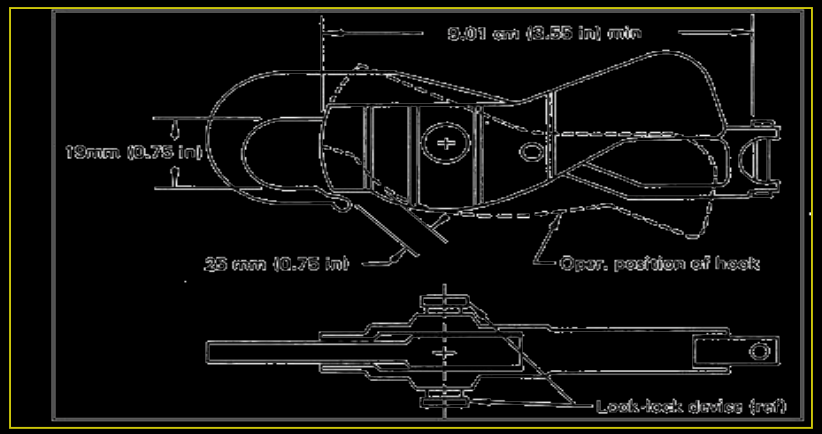
- Current procedure are:
  - Glove change out will require a crewmember to go EVA
    - done when general external maintenance to SCOUT is performed [~after every 5th SCOUT mission]
  - During previous SCOUT mission, crew member will seal the rotary seals that attach the arms to the body using a plate or other simplified form of hatch
  - Crew member will then depressurize the arms, before departing SCOUT
  - Before the next mission, after external maintenance has been performed, crewmember will re-pressurize the arms and remove the seal
  - Arm change out will be exactly identical to gloves change out, except that it is projected that this will only have to be done every three (3) months
- Future change-out options are:
  - Develop a way for the robot arms to change out the gloves
  - Currently, the ability and interface requirements for the robotic arms to be capable of glove and arm removal have not been investigated

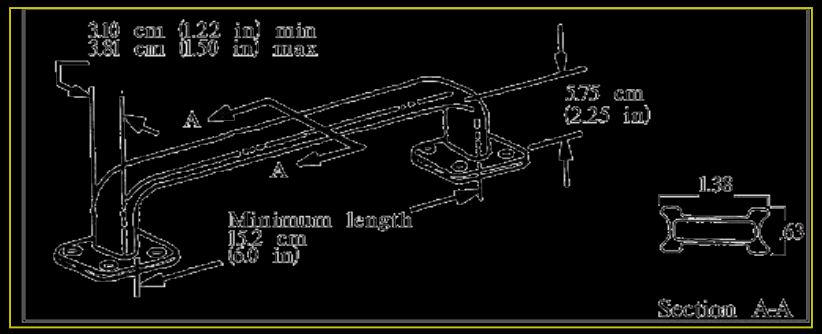
External Restraints



- Crewmember carries two tethers for redundancy
- External handrails provide support and allow translation







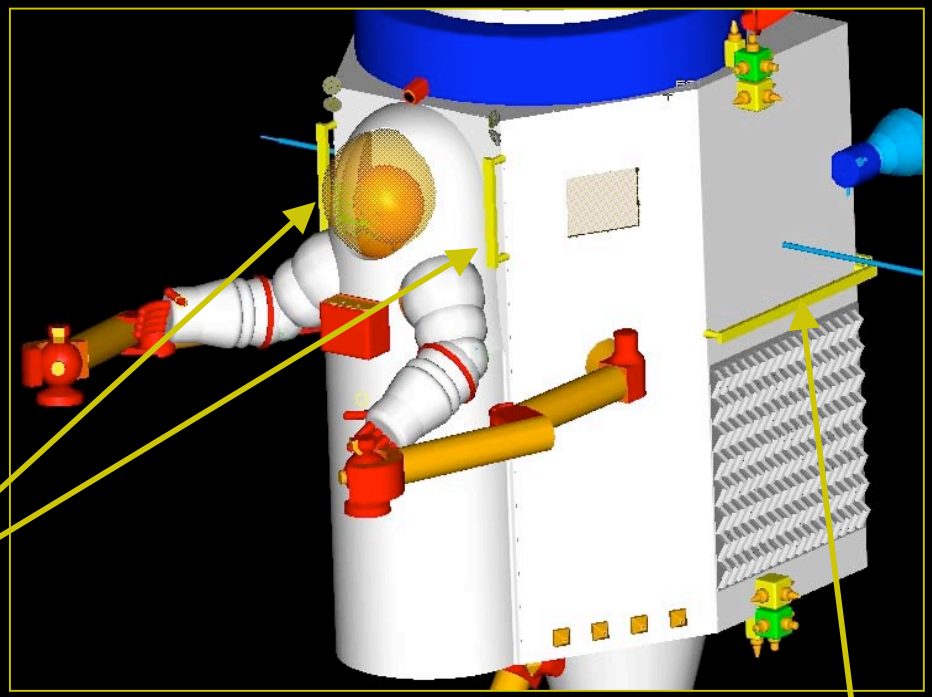
NASA STD-3000

SCOUT

External Handrail Locations

SCOUT

- Handrails are required for when a crewmember performs scheduled external maintenance on SCOUT
- Handrails have been placed in order to accommodate the following tasks:
  - Battery replacement
  - Glove change out
  - Arm change out
  - Robotic arm maintenance
  - Emergency egress

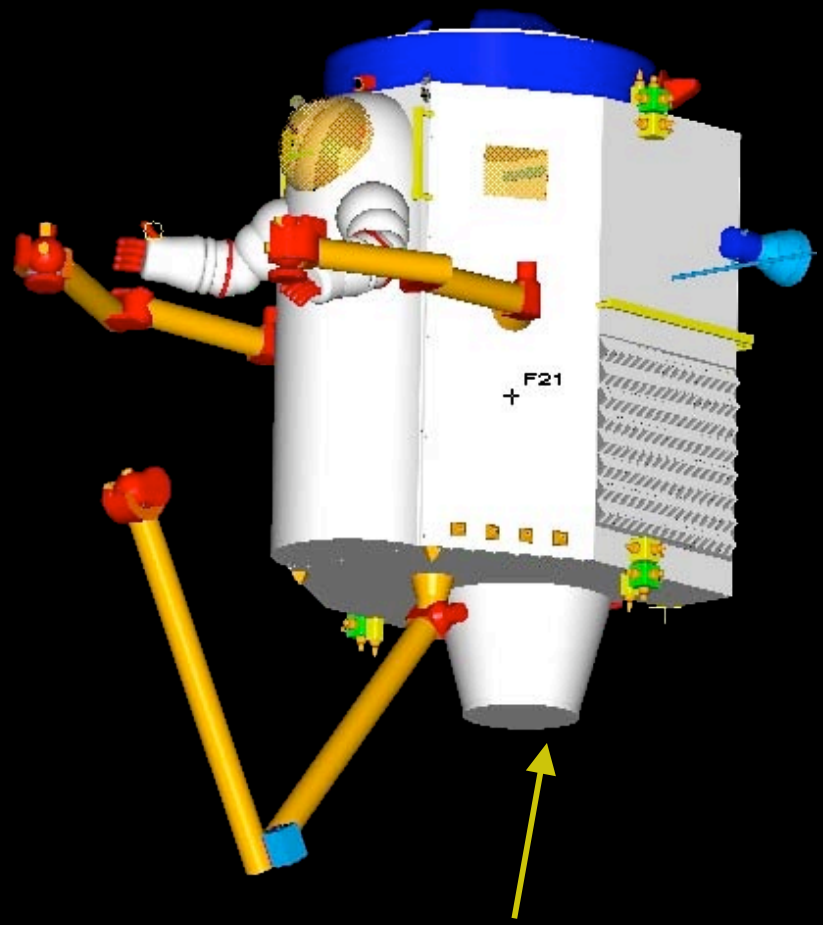


Handrails for change-out

Handrail for access to back of SCOUT

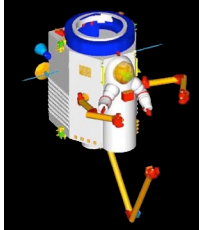
SHEEP Location

SCOUT



SHEEP escape systems (Collapsed)

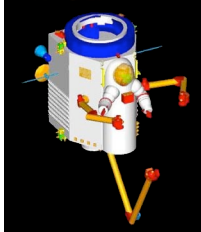
- The SHEEP system will be located on the relative bottom of SCOUT
- The approximate location will be towards the middle of the craft behind the grapple arm
- This location was chosen based on the available surface space on SCOUT's exterior, along with the required internal cabin accommodations for emergency bailout



SCOUT

Loads, Structures, and Mechanisms

Justin Richeson
Eric Rodriguez
Ernest Silva
Yudai Yoshimura



SCOUT

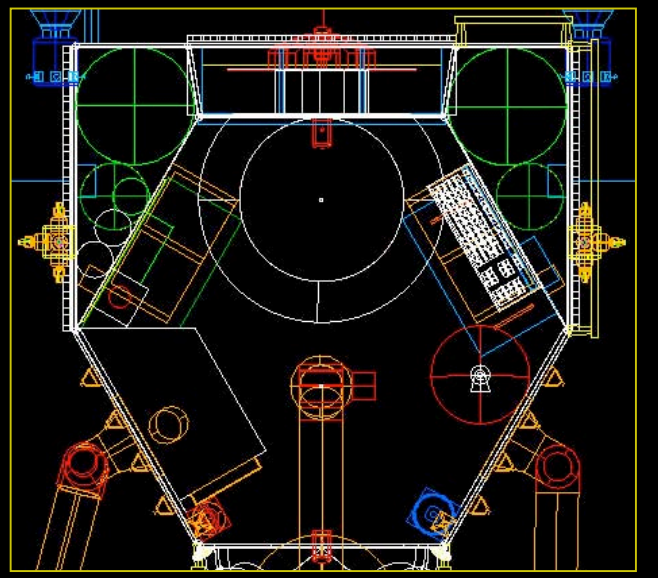
LSM Requirements

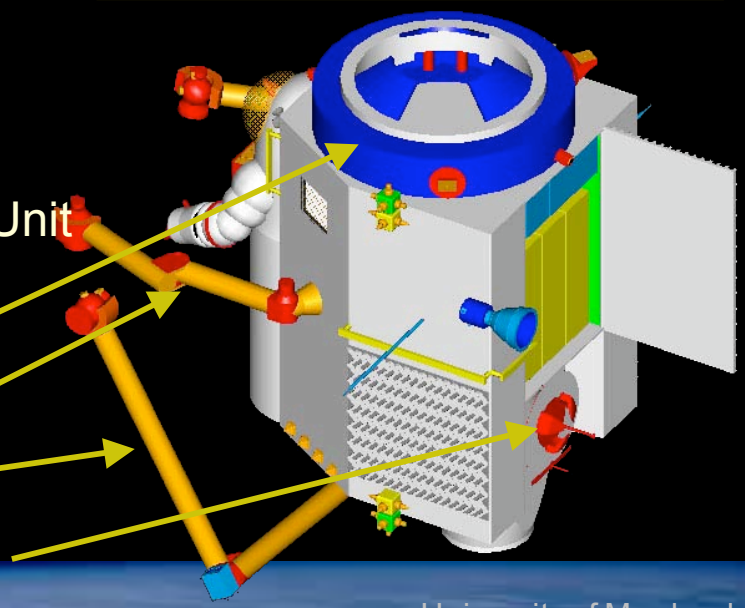
- SI: All systems shall be designed to provide a non-negative margin of safety for worst-case loading conditions incorporating the following factors of safety:
  - Secondary structure: 1.5
  - Primary structure: 2.0
  - Pressurized tanks: 3.0
  - Pressure lines: 4.0
- S2: All structural systems shall provide non-negative margins of safety for all loading conditions due to launch vehicles
  - S2.1: Load-bearing elements have a minimal thickness of 1.5 mm (0.060 in) for handling purposes and manufacturing ease
  - S2.2: Micrometeoroid protection design shall adhere to NASA-SSP-52005B 5.1.5, Payload Flight Equipment Requirements
- I11: All safety-critical systems shall be two-fault tolerant. Sufficient sensors shall be incorporated to allow positive diagnosis of all credible failures.

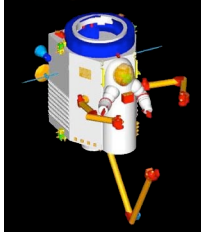
SCOUT

Overall Structural Design

- Hexagonal Pressure Hull
  - Load-bearing Aluminum panels incorporating Micrometeoroid and Orbital Debris Protection
  - Stringers to transfer panel loads and serve as hard attachment points for Shuttle launching
- Outer Frame
  - Load-bearing Aluminum panels with MM and OD Protection
  - House external tanks and electronics
  - Back Panel hinged for Li-Ion Battery replacement and Power Distribution Unit servicing
- Main mechanisms
  - International Berthing and Docking Mechanism (IBDM)
  - Dexterous Manipulators
  - Remote Manipulator System (RMS)







SCOUT

Structural Component Table

Structure	Mass (kg)	Power Required (W)
Structural Panels	201	N/A
Micrometeoroid Protection	23.7	N/A
Extra Radiation Shielding	118	N/A
Structural Frame	15	N/A
IBDM	215	N/A
Grapple Arm	75	80
Robotic Arms (2)	100	160
Tool Posts (10)	10	N/A
End Effectors (8)	18.3	N/A
RMS Grapple Fixture	20	N/A
TOTAL	**796**	**240**

SCOUT

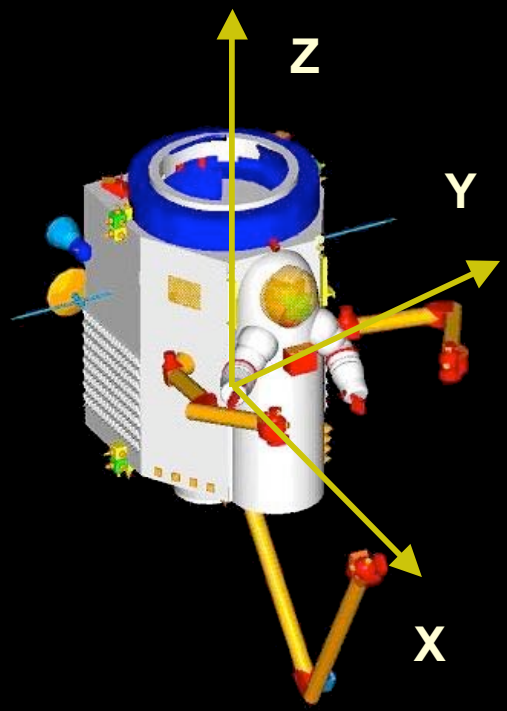
Loading Configurations

- 4 loading configuration models considered
  - Launching in cargo bay of Shuttle Orbiter
  - Transferring from Gateway Station to worksite
  - Operating at worksite
  - Docking to module
- Used model to determine
  - Primary and secondary structures of SCOUT
  - Loads on structures and which scenario will be the critical scenario for a given structure

Loading Configuration - Launch

SCOUT

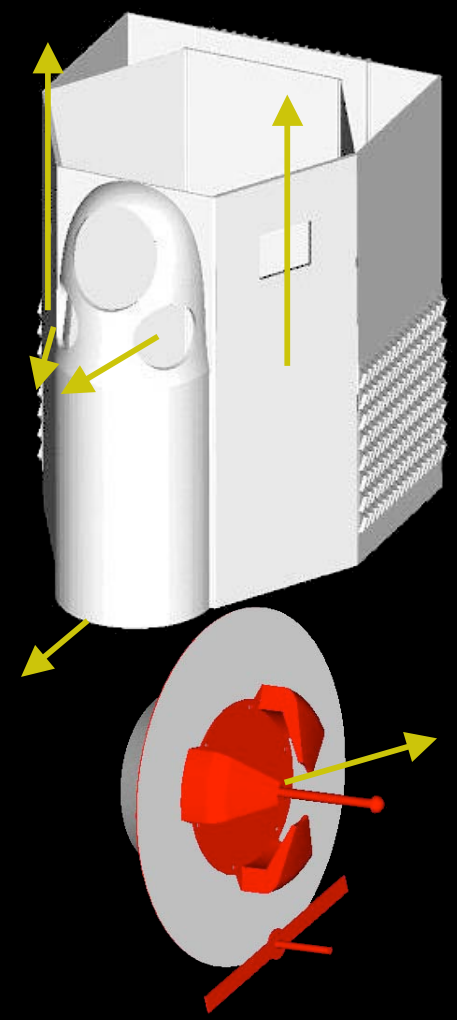
- Considered
  - Major inertia loads
    - All components over 2kg considered
    - Components masses multiplied by shuttle launch loads
      - X = 5.8g, Y = 4.85g, Z=8.5g
    - Forces in 350N – 20,000N range
  - Pressure load
    - Constant, pressurized at 1atm
- Not considered
  - Assumed negligible compared to launch induced loads
    - Launch acoustics
    - Random launch vibration
    - Thermal variation



Loading Configuration - Operation

SCOUT

- Pressure
  - Design Load: 1atm, 101.3kPa (departing from ISS)
  - Other loads: 62kPa (departing from Gateway), 57kPa (operating at worksite)
- Task Arms
  - 2616N Force, 374N-m Bending Moment, 52.2N-m Torque
  - At shoulder mount, in best case position
- Grapple Arm
  - 400N Tensile Force, 400N Shear Force, 1170N-m Bending Moment, 1168N-m Torque
  - At shoulder mount, from various worst case configurations induced by task arm forces
- Human Arms
  - 1138N Force, max force exerted by 95% male upper arm in Space Suit (NASA-STD-3000)
  - At shoulder mount of AX-5 Arms
- Remote Manipulator System (RMS)
  - 890N, 20º off perpendicular to grapple shaft



(on back)

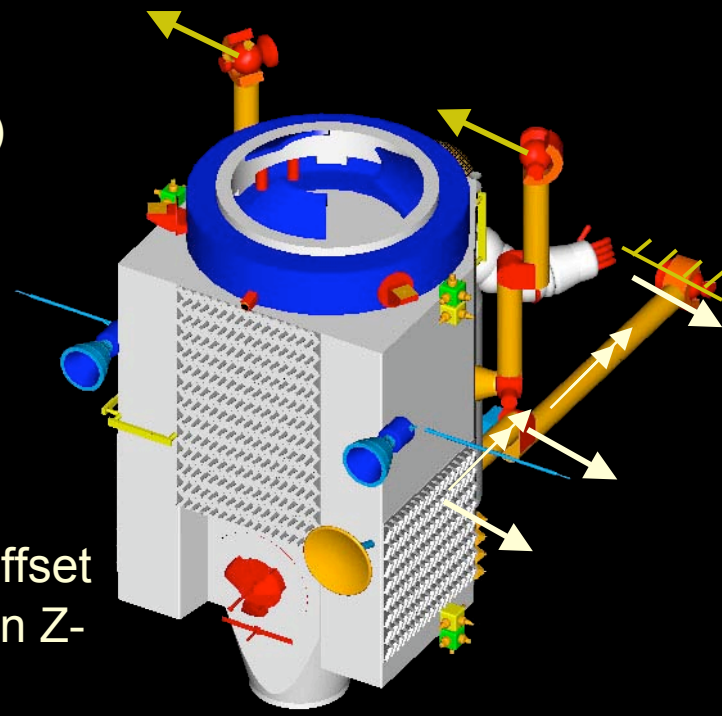
Grapple Arm Load Configurations

- Maximum Shear Stress
  - Configuration
    - Grapple fully extended forward (X)
    - Task Arms Extended Up: Each exerting 200N in Y-direction
  - Force

    400N Shear
  - Moment
    - F x (Task arm length + Shoulder offset between Task and Grapple Arms in Z-direction)
    - 400N x (1.87m + 1.05m) =

      1168N-m Torque

      through all grapple arm joints



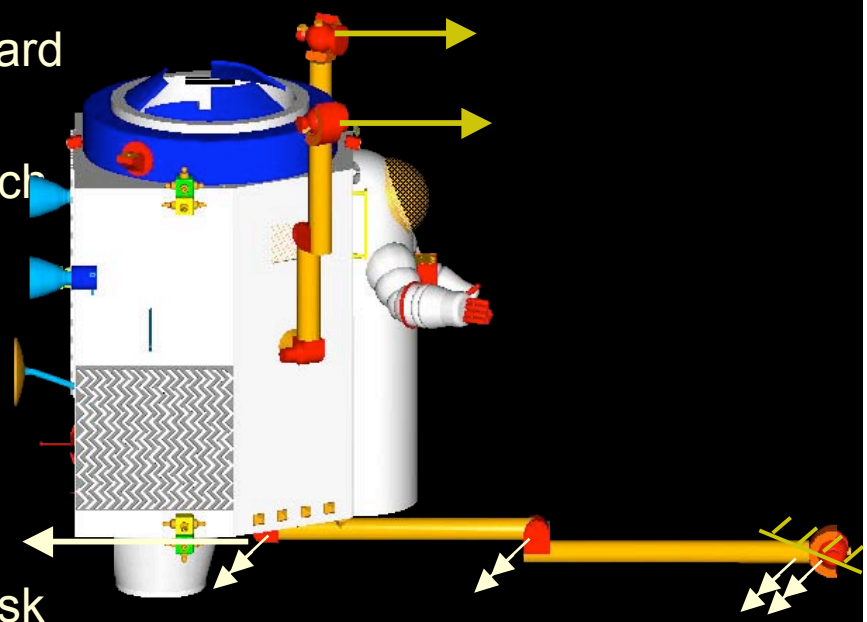
Force →

Reaction →

SCOUT

Grapple Arm Load Configurations

- Maximum Normal Stress I
  - Configuration
    - Grapple fully extended forward (X)
    - Task arms extended up: Each exerting 200N in X-direction
  - Force
    - 400N Tension
  - Moment
    - F x (Task arm length + Shoulder offset between Task and Grapple Arms in Z-direction)
    - 400N x (1.87m + 1.05m) = 1168N-m Bending Moment through all joints

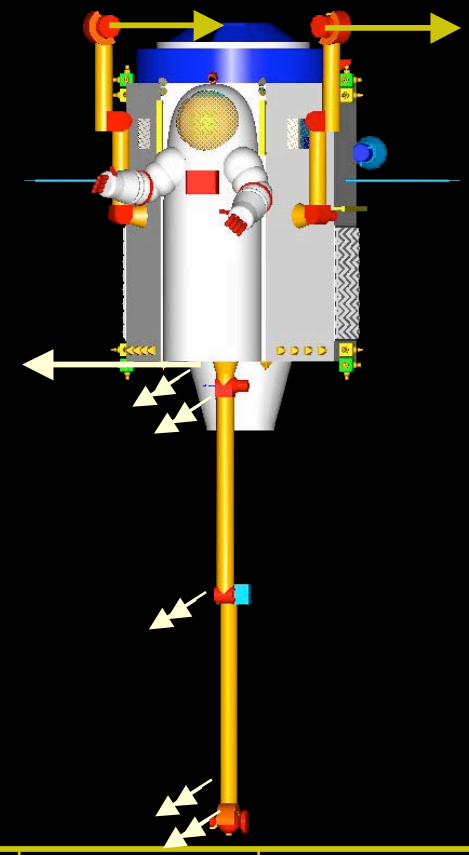


SCOUT

Grapple Arm Load Configurations

SCOUT

- Maximum Normal Stress II
  - Configuration
    - Grapple fully extended down (-Z)
    - Task arms extended up: Each exerting 200N in Y-direction
  - Force
    - 400N Shear
  - Moment
    - F x (Task arm length + Shoulder offset between Task and Grapple Arms in Z-direction + Length From Shoulder Mount) = 400N x (1.87m + 1.05m + L)

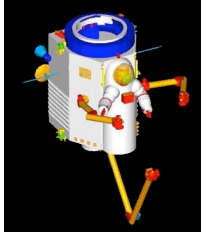


	Shoulder Mount	Shoulder Joint	Elbow Joint	Wrist Joint	Grapple
Length from Shoulder Mount	0.0m	0.17m	1.53m	2.89m	3.23m
Bending Moment	1168N-m	1236N-m	1780N-m	2324N-m	2460N-m

SCOUT

Loading Configuration - Other

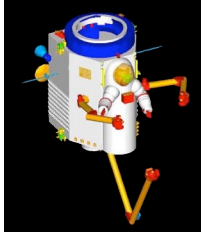
- Worksite transfer
  - Thrusters forces on the order of 1N
- Docking
  - IBDM docking loads ~2N
    - Maximum docking velocity = 0.06m/s
    - Assumed 1 minute to dock
  - Berthing, if using RMS
    - Already accounted for in operational loading configuration
- Quantification of loads resulted in analysis of only 2 configurations
  - Shuttle launch
  - Worksite operation



SCOUT

Finite Element Analysis

- FEA was conducted using SDRC IDEAS rev 9 software
- Based on the general SCOUT shape, models were developed and run through linear dynamic testing
- The results yielded no stress because of warnings encountered during the solving process
- The conclusion made from this was that hand calculations would need to be done for the structural analysis of SCOUT



SCOUT

Hand Calculations Overview

- Hand calculations were done to determine the thickness of the SCOUT panels
- 3 different situation were analyzed
  - Pressurization loading
  - Operational loading
  - Launch loading
    - Axial direction
    - Shear direction
- Each system was optimized to the minimum thickness based on the lowest non negative margin of safety that was acceptable for all requirements
- Both micrometeoroid and radiation protection were taken into account for these calculations

Example – Pressure Load

Hoop Stress Equation

SCOUT

- $P = 101{,}325 N/m^2$
- Max Allowable Yield Stress = 275MPa

MOS=(Allowable/Design)-1

- Example: Plate 1 (top panel)
- $V = 2.92 m^3$ h=2m r=0.68m

Thickness	0.0015m	0.00025m	0.0025m
σ	46.1MPa	275MPa	27.6MPa
MOS	4.97	0	8.95

Minimum usable thickness

Minimum thickness for a non-negative MOS

Thickness choice, this is based off of another loading condition that had a larger stress level than pressure loading

Example - Axial Loading

(Equation 8, Table 26, Roark's pg 464)

- Rectangular plate, all edges fixed
- Uniform load over a small concentric circle w/ radius r_o'

$$r_o' = \mathrm{sqrt}(1.6 * r_o^2 + t^2) - 0.675 * t$$

- Factor of Safety included in the load, W
- B_1 is a constant based on a/b chart

- Example: Plate 8 (Bottom Panel, Operational Load)
  - a=1.5 b=1.5 a/b=1 B_1=-0.238 r_o=.25m W=200N
  - Max Allowable Yield Stress: 275MPa

Thickness	0.0024m	0.0006m	0.053m
σ	20.6MPa	275MPa	2.1MPa
ro'	0.314m	0.310m	0.313m
MOS	12.4	0	61.9

Thickness choice, based on different loading condition

SCOUT

Example - Shear Loading

- T=1.5xV/A
  - A=cross sectional area
  - Max Shear Stress=132MPa

SCOUT

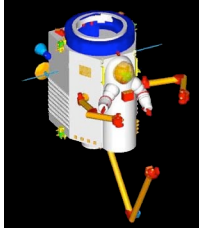
- Example: Plate 4 (Left Back Pressure, Shear Launch Load)
  - Shear Loading = 45294.6N

Thickness	0.0024m	0.00069m	0.0054m
τ	37.7MPa	132MPa	16.8MPa
MOS	2.50	0	6.87

Minimum micrometeoroid protection

Minimum thickness for a non-negative MOS

Thickness choice, based on different loading condition



SCOUT

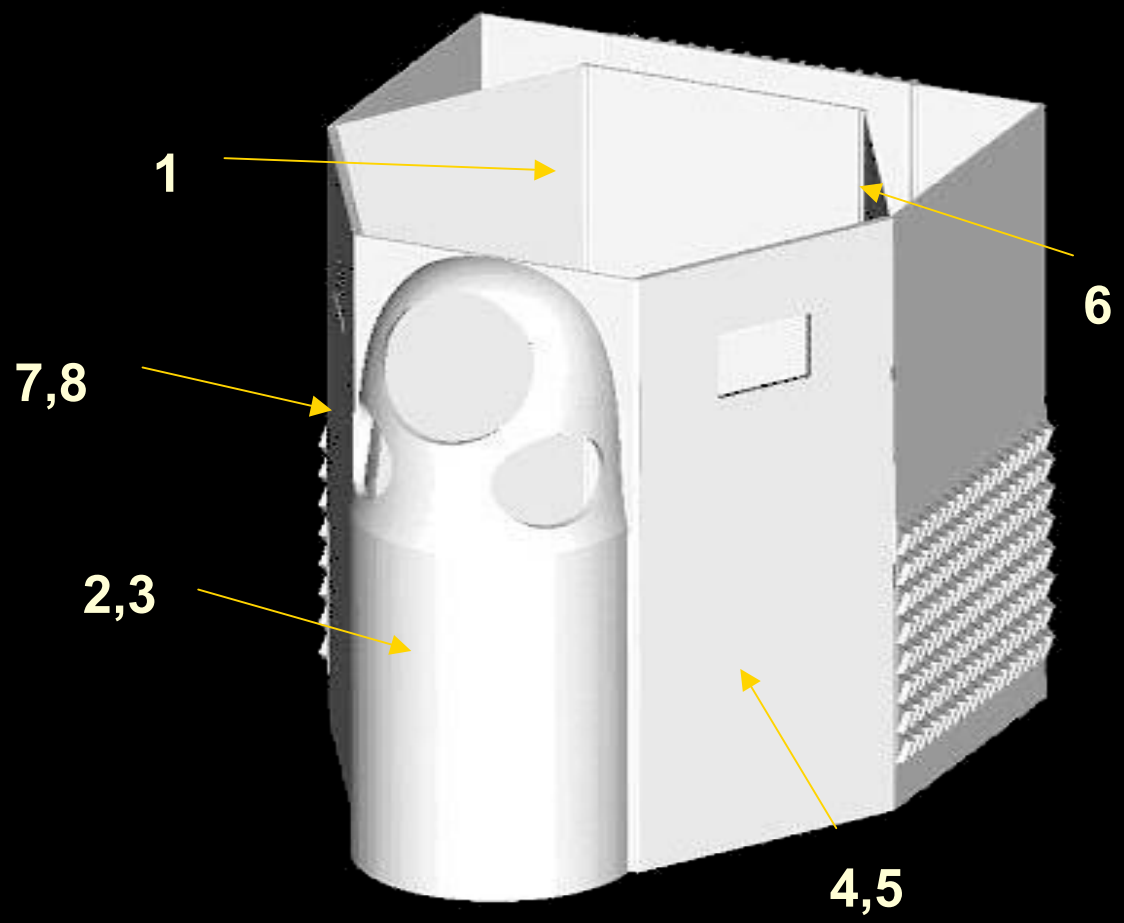
Panel Structure

Factor of Safety – 2.0 : Primary

#	Name	Mass (kg)	Material	Design Load (MPa)	Yield Stress (MPa)	MOS	Based On
1	Top	13.7	Alum 6061-T6	136	275	0.057	Axial Launch Loading
2	Front	11.3	Alum 6061-T6	124	275	0.042	Operational Loading
3	Front Extra	48.6	Alum 6061-T6	124	275	27.1	Radiation Protection
4	Left Front	23.5	Alum 6061-T6	131	275	0.048	Axial Launch Loading
5	Left Front Extra	36.5	Alum 6061-T6	131	275	5.44	Radiation Protection
6	Left Back Pressure	21.9	Alum 6061-T6	135	275	0.019	Axial Launch Loading
7	Right Front	26.3	Alum 6061-T6	132	275	0.047	Axial Launch Loading
8	Right Front Extra	33.6	Alum 6061-T6	136	275	4.14	Radiation Protection

Panel Structure

SCOUT



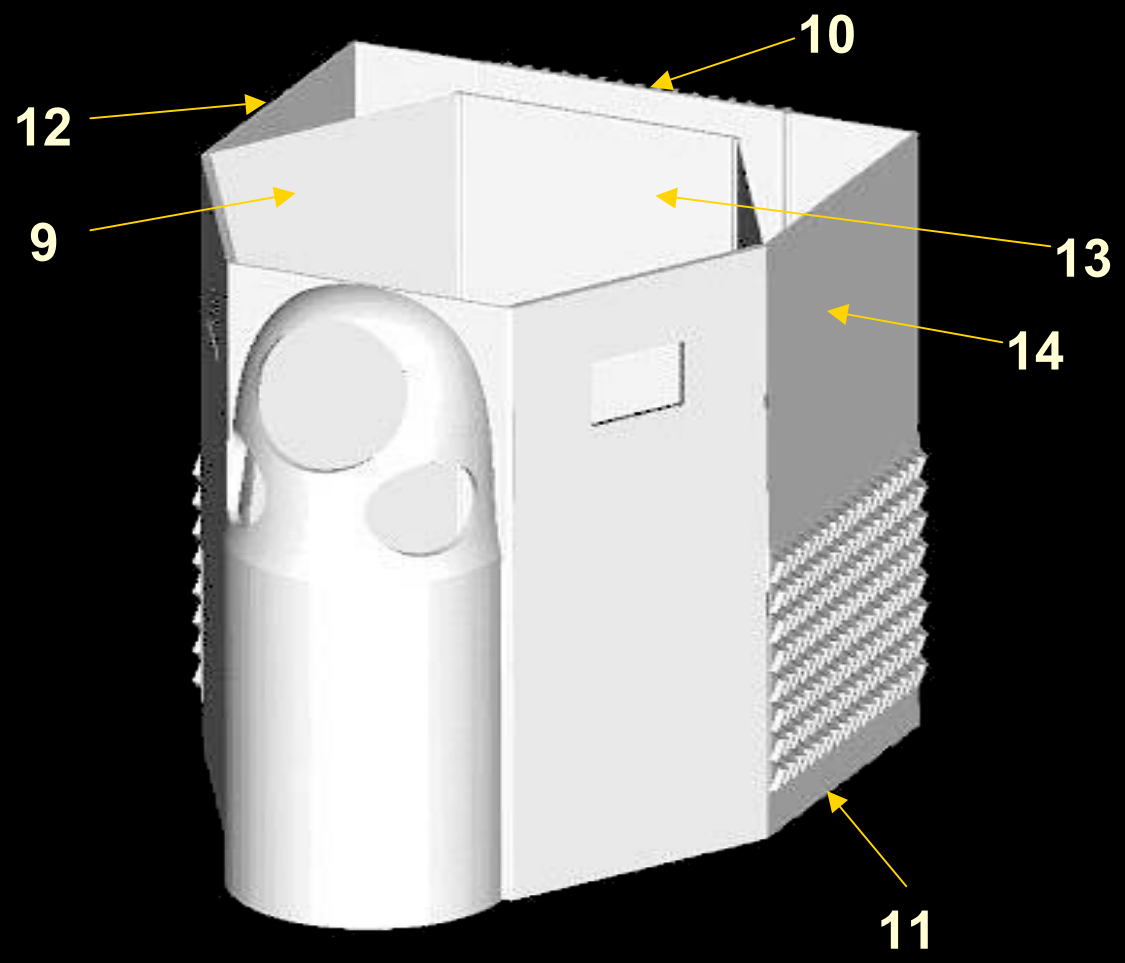
Panel Structure

SCOUT

Factor of Safety – 2.0 : Primary

#	Name	Mass (kg)	Material	Design Load (MPa)	Yield Stress (MPa)	MOS	Based On
9	Right Back Pressure	21.9	Alum 6061-T6	124	275	0.019	Axial Launch Loading
10	Back Panel	19.4	Alum 6061-T6	124	275	N/A	Not Load Bearing
11	Bottom	26.5	Alum 6061-T6	131	275	0.034	Axial Launch Loading
12	Right Back	11.3	Alum 6061-T6	131	275	0.443	Axial Launch Loading
13	Back Pressure	13.8	Alum 6061-T6	135	275	0.019	Axial Launch Loading
14	Left Back	11.3	Alum 6061-T6	132	275	0.052	Axial Launch Loading

Panel Structure



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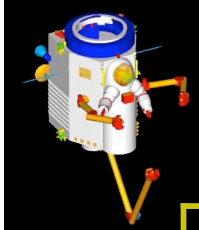


Dexterous Manipulator Structure

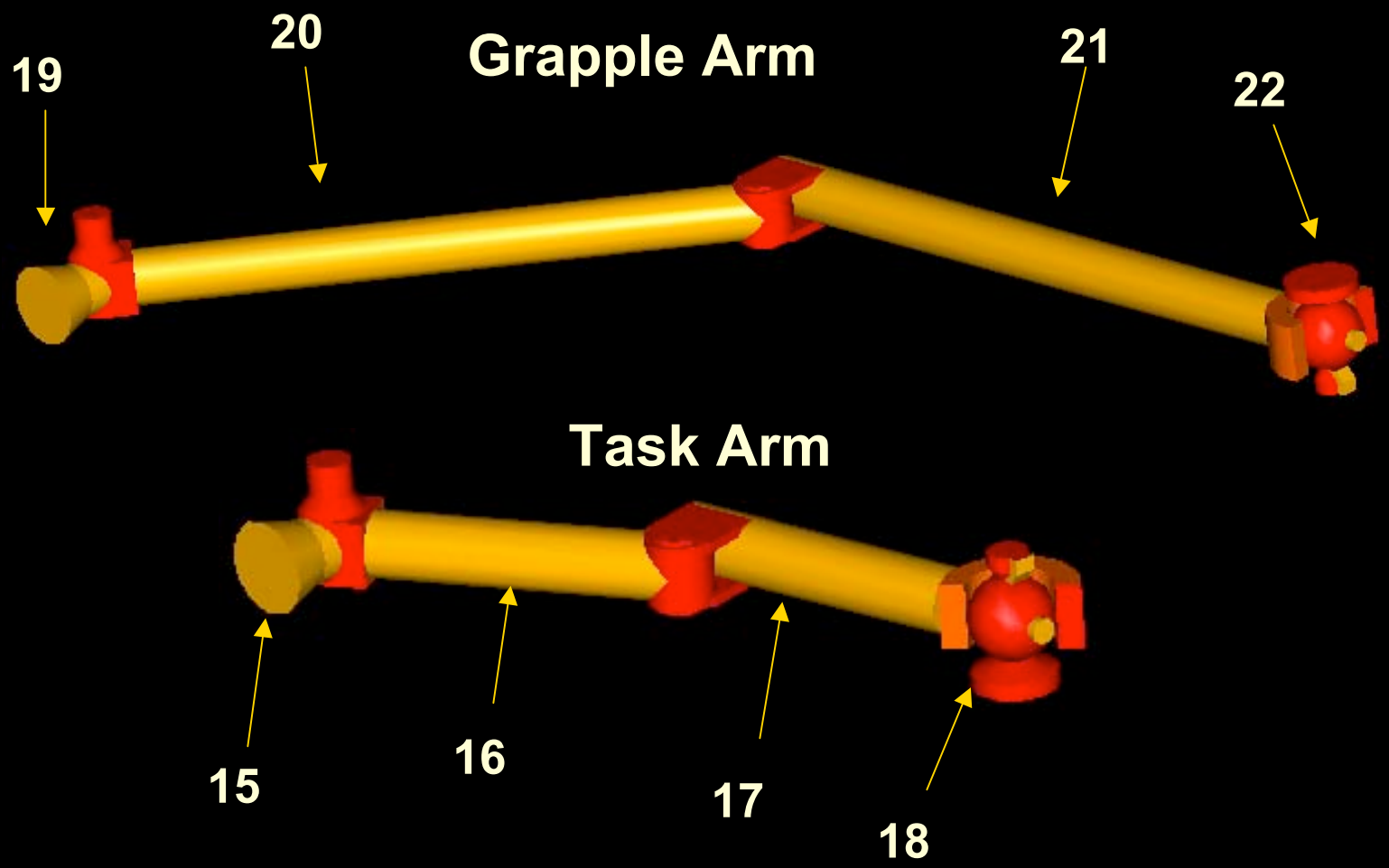
SCOUT

Factor of Safety – 2.0 : Primary

#	Name	Mass (kg)	Material	Design Load (MPa)	Yield Stress (MPa)	MOS	Based On
15	Task Arm, Segment 1	0.0023	Alum 6061-T6	38.9	275	2.54	Axial Arm Load
16	Task Arm, Segment 2	0.0092	Alum 6061-T6	37.1	275	2.70	Axial Arm Load
17	Task Arm, Segment 3	0.0092	Alum 6061-T6	30.1	275	3.57	Axial Arm Load
18	Task Arm, Segment 4	0.0046	Alum 6061-T6	23.0	275	4.98	Axial Arm Load
19	Grapple Arm, Segment 1	0.0023	Alum 6061-T6	64.3	275	1.14	Axial Arm Load
20	Grapple Arm, Segment 2	0.0018	Alum 6061-T6	92.6	275	0.486	Axial Arm Load
21	Grapple Arm, Segment 3	0.0018	Alum 6061-T6	121	275	0.138	Axial Arm Load
22	Grapple Arm, Segment 4	0.0046	Alum 6061-T6	128	275	0.075	Axial Arm Load

Dexterous Manipulator Structure

SCOUT



Propellant Tanks and Lines

Factor of Safety – 3.0 : Propellant Tanks

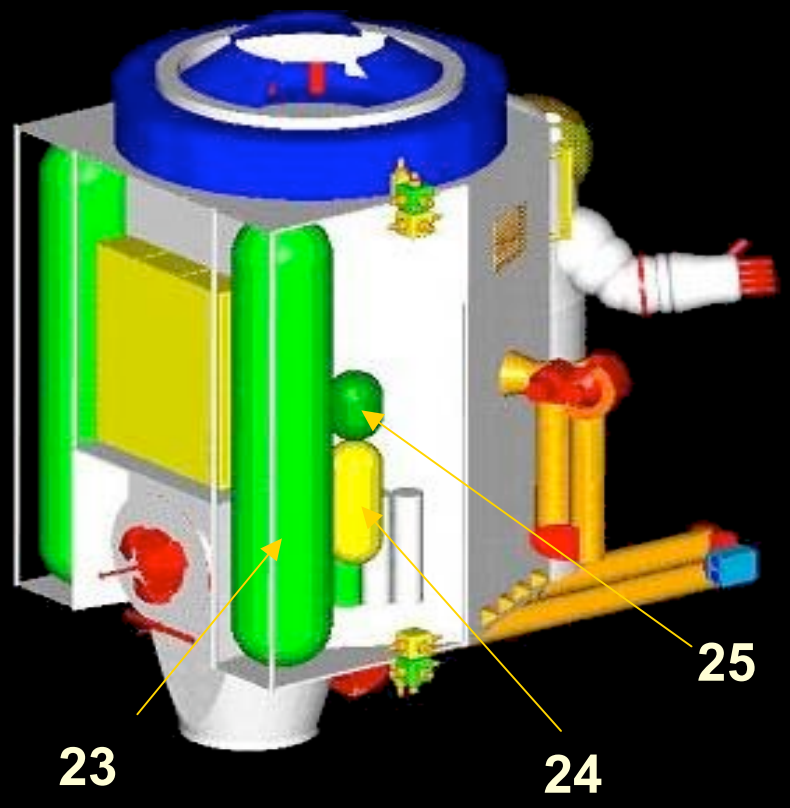
Factor of Safety – 4.0 : Propellant Lines

#	Name	Mass (kg)	Material	Design Load (MPa)	Yield Stress (MPa)	MOS	Based On
23	N_2 Tank	97.9	Titanium 6AL-4V	367	1103	0.0018	Propellant Pressure
24	Hydrazine Tank	1.76	Titanium 6AL-4V	367	1103	0.0018	Propellant Pressure
25	N_2 Pressurant Tank	1.74	Titanium 6AL-4V	367	1103	0.0018	Propellant Pressure
26	N2 Lines	5.22	Titanium 6AL-4V	275	1103	0.0027	Propellant Pressure
27	Hydrazine Lines	5.91	Titanium 6AL-4V	275	1103	0.0027	Propellant Pressure
28	N_2 Pressurant Lines	1.74	Titanium 6AL-4V	275	1103	0.0027	Propellant Pressure

SCOUT

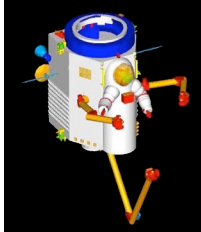
Propellant Tanks and Lines

SCOUT



26, 27, 28

Not Shown



SCOUT

Radiation Protection

- Panels that need extra radiation protection
  - Front, extra 3.23gm/cm^2
  - Left Front, extra 2.42gm/cm^2
  - Right Front, extra 2.23gm/cm^2
- These numbers are to meet the LSHF requirement of having radiation protection of 4gm/cm^2
- The current plan for SCOUT for the Gateway missions is to have these panels as extra aluminum panels
- This increases the MOS for those panels of the spacecraft
- All other areas of the spacecraft have enough mass and surface area of other components that no extra radiation protection is required
- With future innovation in radiation protection, SCOUT's front 3 panels can be outfitted with any material that will meet the above criteria
- Also for missions that may require more stringent radiation requirements, SCOUT can have panels added in locations requiring more protection

Stringer Analysis

- Materials considered

Material	Density (kg/m^3)	Yield Strength (MPa)
Aluminum (2014-T6)	2796	414
Steel (A36)	7861	250
Titanium	4429	924

- Stringer cross sectional area
  - Total Vehicle Mass = 1850kg
  - Factor of Safety = 2.0 (Level I Requirement)
  - Launch loads = maximum 13g's

  - Aluminum: 1.0 e^{-5}m^2 (0.10cm^2)
  - Steel: 1.6 e^{-5}m^2 (0.16cm^2)
  - Titanium: 4.0 e^{-6}m^2 (0.04cm^2)

SCOUT

Stringer Analysis

- Loading Conditions
  - Axial Loading:

    Area fixed for given material and maximum load

  - Bending Loads:

    minimize to minimize

  - Shear Loading:

    minimize to minimize

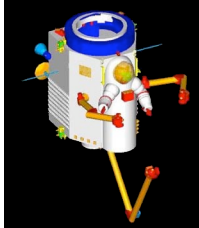
SCOUT

Stringers & Ribs

- Maximizing I_y reduces axial stress due to bending and shear stress
  - Concentrating cross sectional area away from the neutral axis maximizes I_y
- Minimizing to minimize shear stress
  - Arrange cross sectional area to satisfy:
- Based on the analysis, a symmetric parabolic “X” shaped cross section is recommended
- Ribs are used mainly to join structure since buckling of the stringers is not an issue

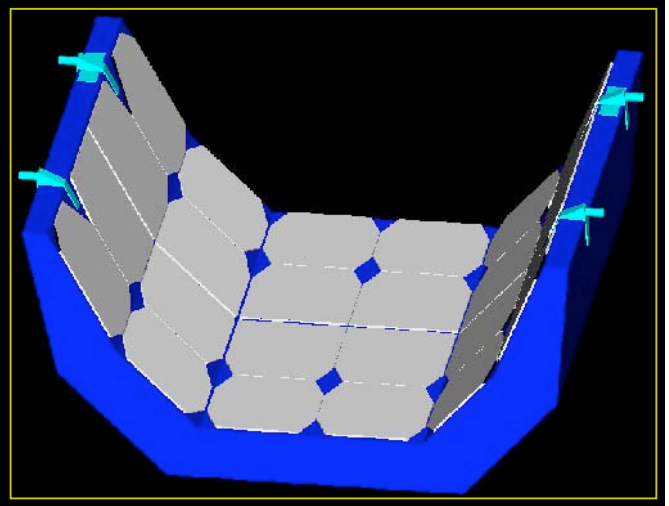
SCOUT

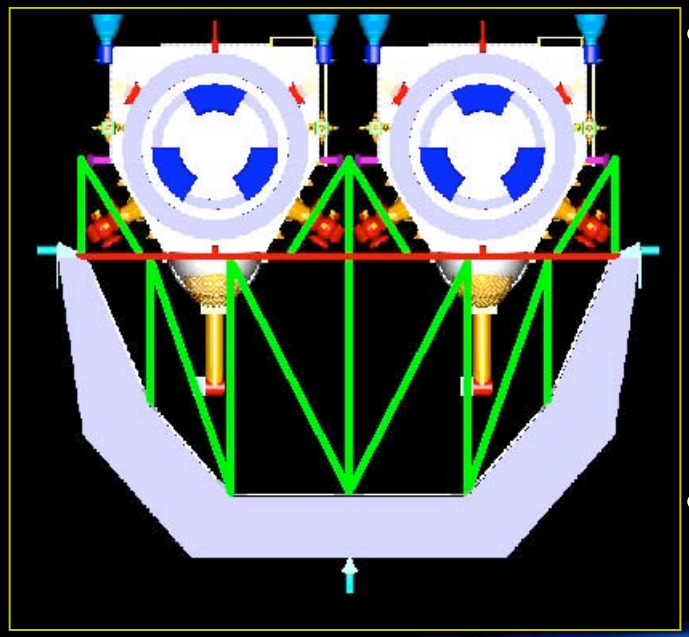
Launch Vehicle Integration



SCOUT

- Using Spacelab Logistics Pallet with 5 point attachment:
  - 2 sill fittings ±X & ±Z loads
  - 2 sill fittings ±Z loads
  - 1 keel fitting ±Y loads





- Attaching two SCOUTs side by side with 5 point attachment:
  - 2 sill fittings ±X & ±Z at front sides
  - 2 sill fittings ±Z at back sides
  - 1 keel fitting ±Y at bottom side
- Docking module and XMP also attached to pallet similarly

Dexterous Manipulators Analysis

SCOUT

- Determine required thickness of each section:

Aluminum 6061-T6:

E =70GPa

G = 26GPa

Yield Stress = 275MPa

Density = 2700kg/m^3

FOS = 2 r = 0.065m

Or,

SCOUT

Dexterous Manipulators

- Calculate Margin of Safety:
- Determine deflection of each section:

or,

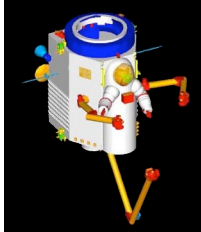
- Use deflections from bending to get effective stiffness:
- Calculate mass and natural frequency of section:

Dexterous Manipulators

SCOUT

Arm Section:	Task Arms 2	Task Arms 3	Grapple Arms 2	Grapple Arms 3
Maximum Normal Stress	37.1MPa	30.1MPa	92.6MPa	120.8MPa
Thickness required	0.39mm	0.32mm	1.0mm	1.3mm
Thickness used	1.5mm	1.5mm	1.5mm	1.5mm
Margin of Safety	2.7	3.6	0.49	0.14
Effective Stiffness	1.64MPa	0.82MPa	0.21MPa	0.10MPa
Natural Frequency	13.4kHz	9.45kHz	0.11kHz	0.08kHz

Maximum Shear Stress	1.36MPa	1.36MPa	30.7MPa	30.7MPa
Thickness required	0.03mm	0.03mm	0.645mm	0.645mm
Thickness used	1.5mm	1.5mm	1.5mm	1.5mm
Margin of Safety	50.6	50.6	1.3	1.3
Effective Stiffness	.48MPa	.80MPa	6.0MPa	1.1MPa
Natural Frequency	7.2kHz	9.3kHz	18.1kHz	24.3kHz



Dexterous Manipulators

SCOUT

- Assumptions:
  - Analysis on robot arms done without taking into consideration the effects of wiring and other attached components
  - Worst case loads on the arms were assumed to be point loads
- Results:
  - Minimum thickness required to withstand yielding due to the worst case bending and axial combined loads are smaller than the minimum usable thickness
  - Minimum thickness required to withstand a worst case torsional loads are smaller than the minimum usable thickness
  - All sections of dexterous manipulators will have 1.5mm thick walls

Micrometeoroid and Orbital Debris Protection

SCOUT

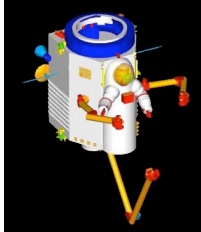
- Definitions of Terms
  - Meteoroid
    - Natural origin
    - Micrometeoroid = 10^{-18} – 1.0gm in mass [NASA PD-EC-1107]
  - Orbital/Space Debris
    - Artificial objects
    - Exist below 2,000 km altitude (LEO)

- Requirement
  - The design shall provide a minimum Probability of No Penetration (PNP) defined by:

A = exposed surface area (m^2)

Y = exposure time (year)

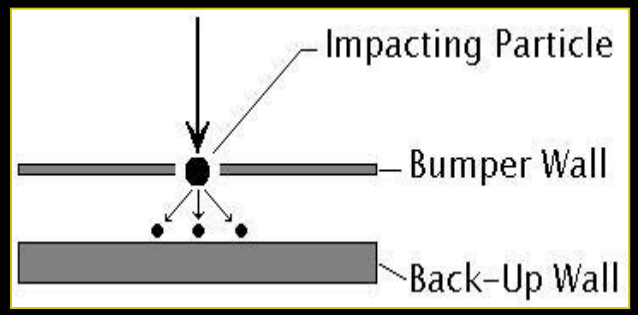
Requirement for Space Shuttle Payload
[NASA SSP-52005B]



SCOUT

Design Options

- Passive Protection
  - Effective to small particles (up to ~1cm)
  - Single Wall
  - Multiple Wall
    - More efficient than single wall
    - Dual-Wall System

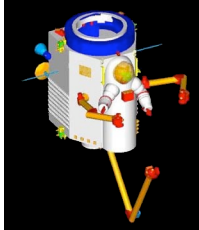


Dual-Wall System

(Suggested by Fred Whipple in the 1960s)

- Active Protection [Future Study]
  - Collision Warning and Avoidance System
  - Laser jet method
    - Effective Particles size range: 1 – 10cm
    - Possible to put on a spacecraft [Tikhonov, 1998]

Protection Design Process



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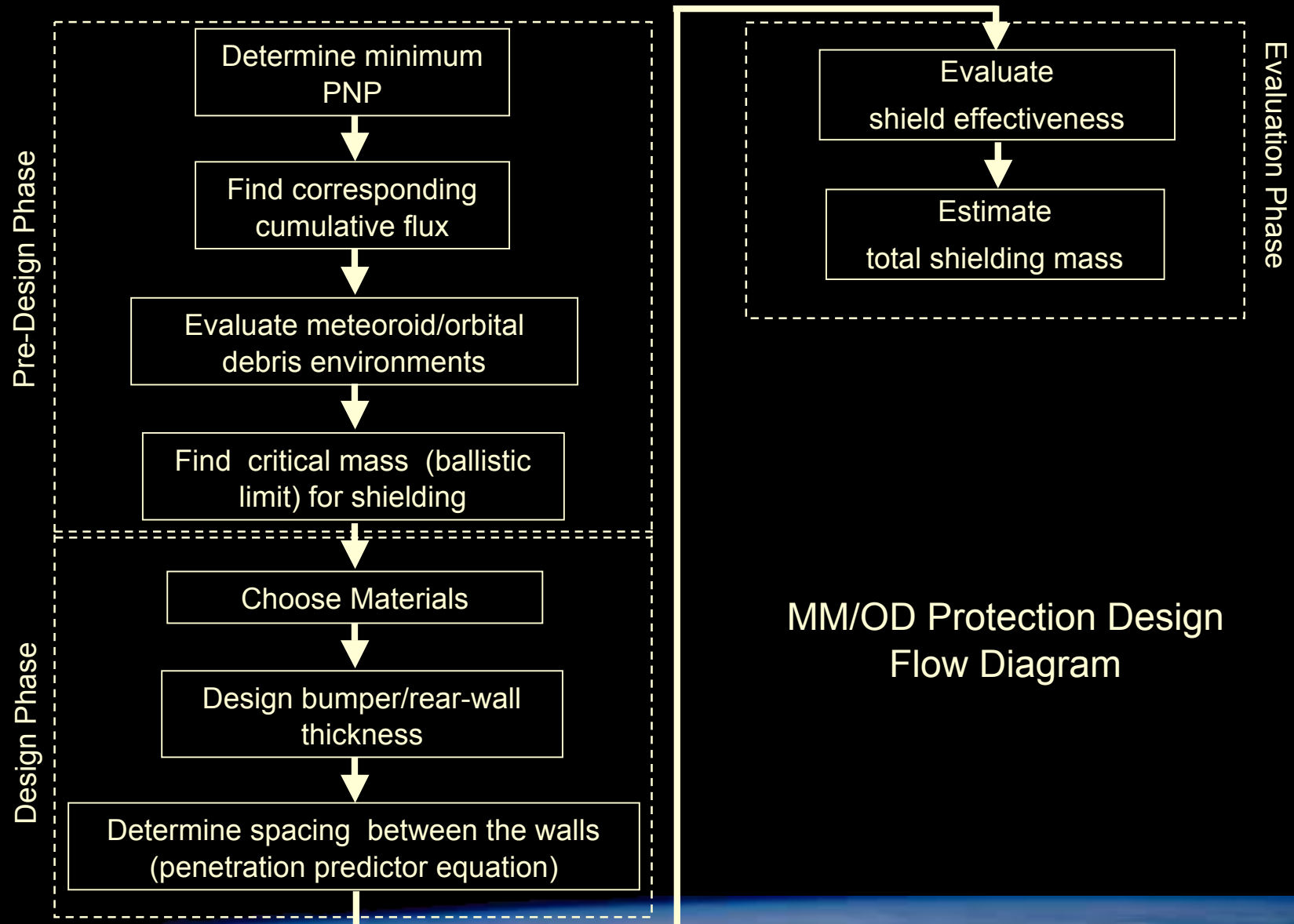


MM/OD Protection Design Flow Diagram

Micrometeoroid Environment

SCOUT

- Meteoroid Flux-Mass Model
  - Model Used: Grün Model (1985)
  - Provides the total average meteoroid flux (F) as a function of meteoroid mass (M): F = f(M)

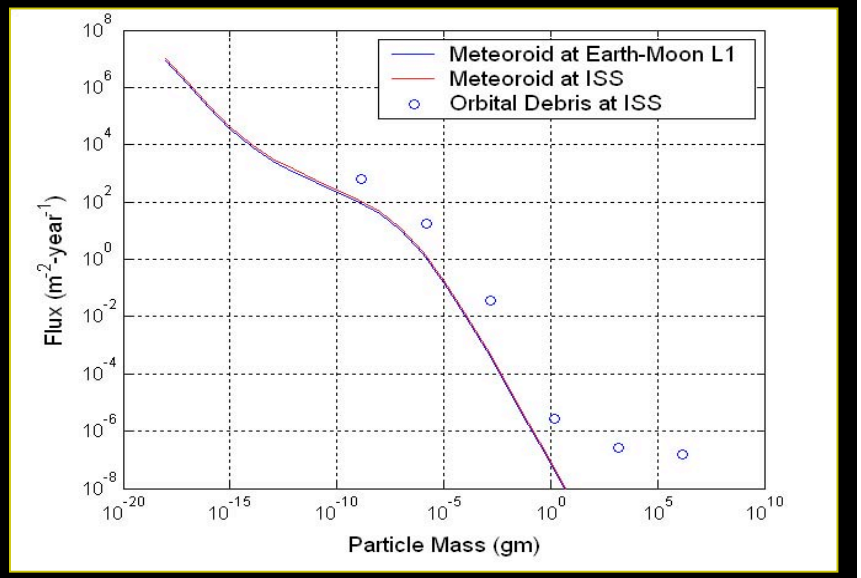
Flux corrected for body shielding and gravitational focusing effects due to Earth and Moon

- Average Impact Velocity
  - ~15 km/sec (at E-M L1)
  - ~19 km/sec (at ISS orbit)

- Meteoroid Mass Density

Density (gm/cm^3)	Mass (gm)
2.0	$M < 10^{-6}$
1.0	$10^{-6} < M < 0.01$
0.5	$0.01 < M$

[NASA SSP-30425]



MM/OD Environments: Flux-Mass Models

Orbital Debris Environment

SCOUT

- Orbital Debris
  - More hazardous than micrometeoroid environment below 2,000km altitude
  - Must be taken into account for the use at ISS
- Model Used:
  - NASA Orbital Debris Engineering Model (ORDEM2000)
  - Software available on online
- Average Impact Velocity
  ~7km/sec (at ISS orbit)
- Space Debris Mass Density
  2.8gm/cm^3

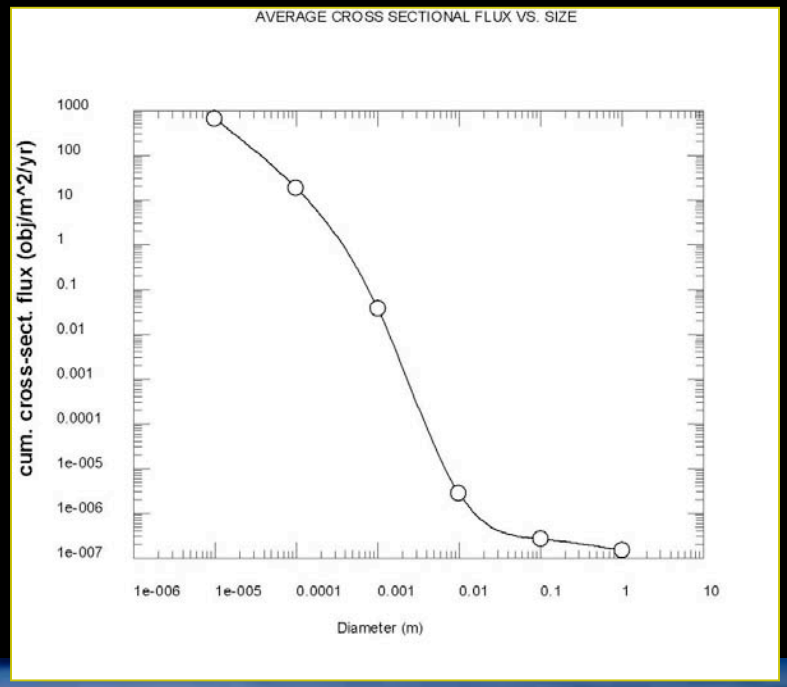
Orbital Debris Environment:

Flux vs. Particle Size at ISS orbit

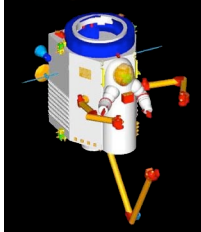
Result Plot from NASA ORDEM2000:

Altitude = 400km, Inclination = 51.6deg,

Year of Observation = 2008



[NASA ORDEM2000]



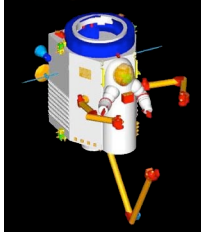
Design Shielding for SCOUT

SCOUT

- Minimum PNP per mission
  - Exposed surface area = 12.8m^2
  - Exposed time = 10 years
  - Minimum PNP = 0.987
  - F = 1.0 x 10^{-5} particles/m^2-year
- Critical Mass/Ballistic Limit

Mission	M_{cr} (gm)	D_{cr} (cm)
Earth-Moon L1	0.0043	0.19
ISS	0.082	0.38

- Particle/Wall Interaction Model
  - Model Used: New Cour-Palais Model (1990)
    - $D_{cr} = f(t_b, t_w, \rho_p, \rho_b, \theta, V, S, \sigma_{yield})$ [Hayashida, 2000]
  - Use this model to determine Spacing between the two walls



SCOUT

Shielding Design Details

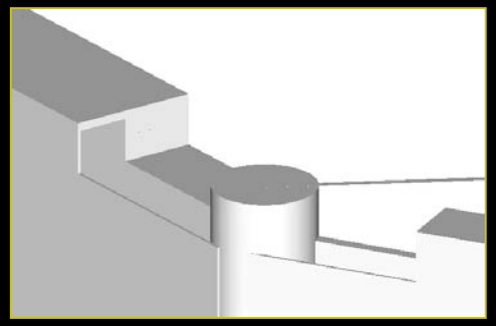
- Bumper Wall (Outer Wall)
  - Aluminum 6061-T6 (small density)
  - Thickness: 0.06cm
- Back-Up Wall (Inner Wall)
  - Aluminum 6061-T6
  - Spacing = 1.0cm
  - Thickness: minimum of 0.24cm required

Panel No.	Face	Surface Area (m^2)	Back-Up Wall Thickness (cm)
2,3	Front	1.5	1.48
4,5	Left Front	1.5	1.48
7,8	Right Front	1.5	1.48
10	Back	3.0	0.24
11	Bottom	2.0	0.53
12	Right Back	1.6	0.24
14	Left Back	1.6	0.24

Evaluation of Shield Effectiveness

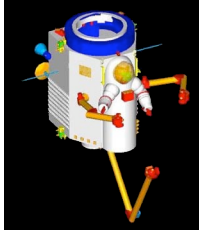
- PNP per mission Estimate
  - M_{cr}/D_{cr} is different for each panel
  - Find flux value corresponding to M_{cr}/D_{cr} for each

Minimum PNP requirement satisfied



- Total MM/OD Protection Shielding Mass
  246kg
  - This number includes a part of radiation protection and structural components mass

SCOUT



SCOUT

Avionics

William Miller
Gregory Stamp
Oliver Sadorra
Aaron Hoskins

Avionics Requirements

SCOUT

Communication

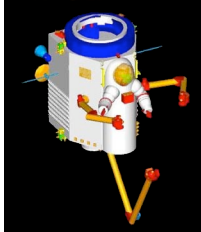
- A1: The system shall be capable of supporting continual bi-directional transmission of high-definition television (9Mbps) plus 1Mbps of continuous digital data to the hosting station.
  - A1.1: Communication system shall be compatible with all OASIS components.
  - A1.2: Communication system shall be compatible with existing ISS systems.
  - A1.3: Emergency communication shall be provided to Earth.
  - A1.4: System shall be capable of communication with another SCOUT pod.
    - A1.4.1: System shall be capable of simultaneous communication with another pod and hosting station.

Avionics Requirements

SCOUT

Computers

- A2: Onboard computers shall control attitude determination, flight control, command and data handling, fault detection and correction and robotic manipulator control.
  - A2.1: Onboard processing shall be powerful enough to accommodate all system loads as a real-time process.
  - A2.2: Avionics computer system reliability shall be at least 99.9%.
  - A2.3: Each flight computer shall be able to independently maintain critical SCOUT systems if other flight computers become disabled. This flight computer shall maintain as much nominal functionality as possible.



Avionics Requirements

SCOUT

Control

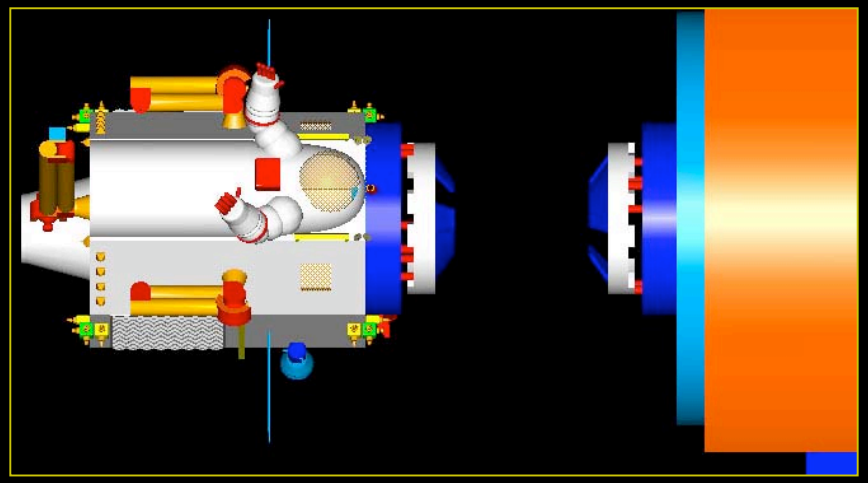
- A3: The system shall be capable of operating in any of the following control modes for any or all of the nominal mission segments:
    - Teleoperation
    - On-board direct human control
    - Supervisory control
    - On-board autonomous control
  - A3.1: The system shall provide full six degree-of-freedom control, since SCOUT will need to align itself relative to any workspace.
    - A3.1.1: No torque mechanism shall be permitted to reach saturation.
    - A3.1.2: The system shall prevent SCOUT from spinning at a rate faster than 45deg/sec on any axis for more than one revolution, for the pilot's safety.

Avionics Requirements

SCOUT

Control

- A3.2: System shall be capable of docking with the hosting station, and assure no damage to SCOUT or station components.
  - A3.2.1: System shall be capable of docking through direct pilot control, teleoperation from the hosting station, and autonomous control.
- A3.3: System shall be able to dock with another SCOUT pod.



Avionics Requirements

SCOUT

Sensors

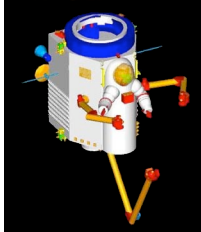
- A4: Sufficient sensors shall be incorporated to allow positive diagnosis of all credible failures in safety-critical systems.
  - A4.1: Position sensors shall be able to locate the Gateway station and SCOUT work site from within a radius of 2000m.
    - A4.1.1: Position sensors shall have a minimum detection range of 1m or closer.
    - A4.1.2: For any range from a target, position sensors shall have an accuracy of 5% of that distance or better.
  - A4.2: Spacecraft attitude shall be accurate to 0.05 degrees (3 arcmin).
  - A4.3: Spacecraft rate knowledge should be accurate to 0.1deg/sec (6arcmin/sec).

Avionics Requirements

SCOUT

Power Distribution

- A5: Power distribution system shall provide continuous power to all SCOUT components.
  - A5.1: System shall have two-fault tolerant power connections.
  - A5.2: System shall be capable of distributing the base power load of 900W with a peak power of approximately 3kW.
    - A5.2.1: System shall have an efficiency of at least 95%.
  - A5.2.2: System shall be at least 99.9% reliable per sortie.
  - A5.3: System shall support nominal mission operations of up to 13 hours.



Avionics Requirements

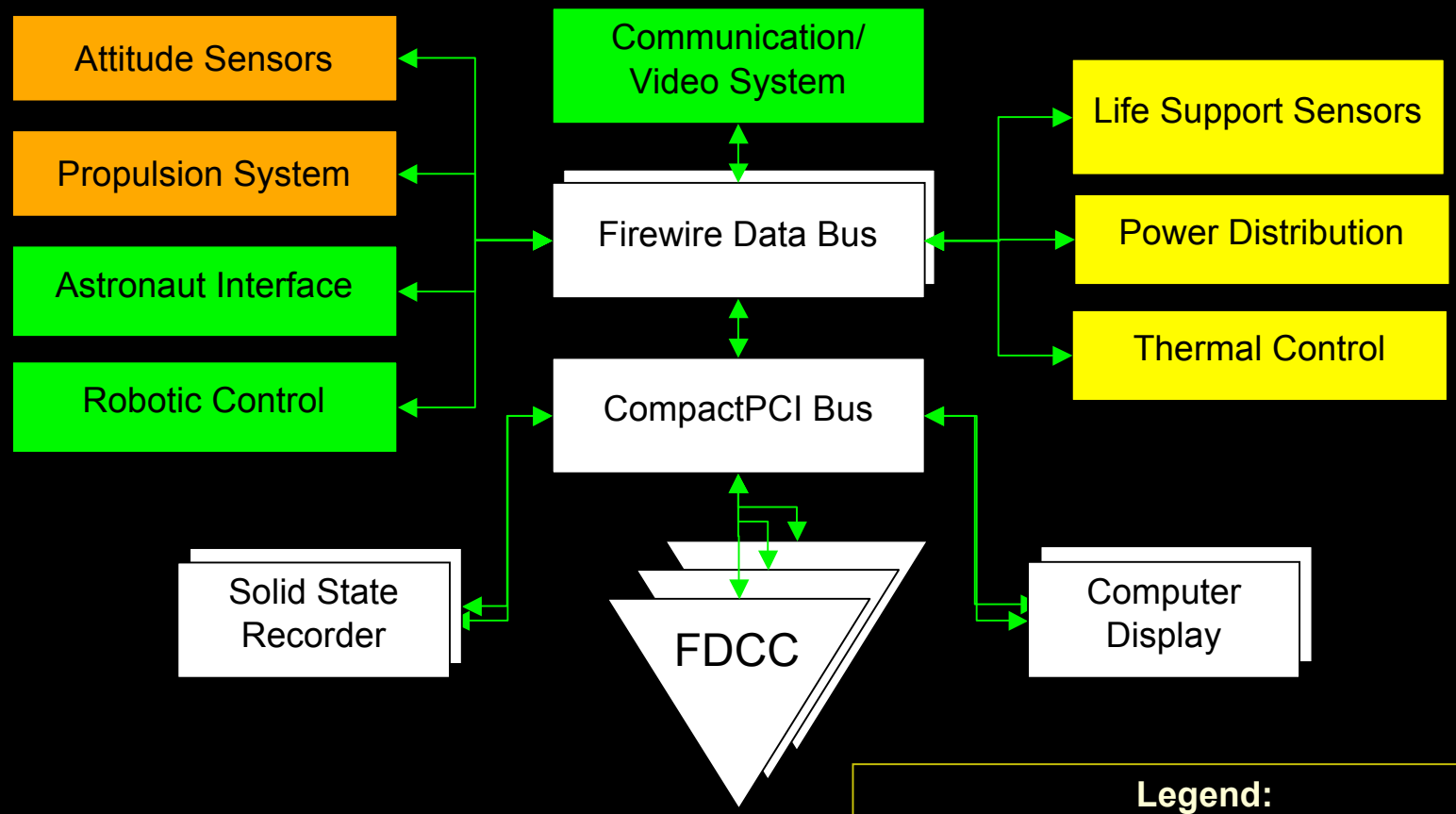
SCOUT

Extended Mission

- X1: System shall be designed to accommodate supplemental payload kits to enable extended missions, including:
    - Extended ΔV missions
    - Extended duration missions
    - Cargo transport missions
- AX.1: For an extended mission, Earth radar shall be used for position measurement.
- AX.2: System shall maintain continuous communication with the hosting station, with the exception of the far side of orbit.
  - AX.2.1: System shall be capable of contacting Earth.
- AX.3: Docking system shall be compatible with extended mission host vehicle (e.g. CTV).
- AX.4: Power distribution shall support the vehicle for the duration of any extended mission (e.g. 66 hours for a lunar orbit mission).

Avionics Top-Level Block Diagram

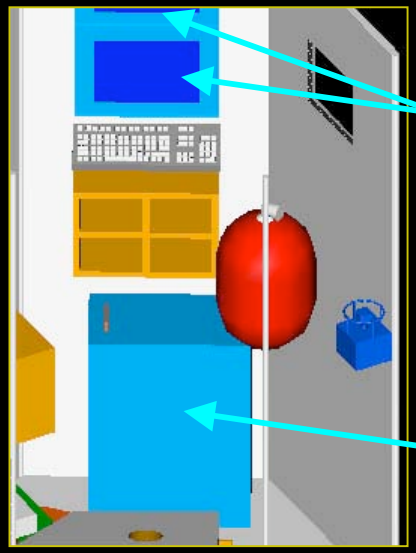
SCOUT



Legend:
FDCC - Flight & Data Control Computer
- Primary Avionics Components
- Critical Crew Survival Systems
- Flight Control Systems
- Mission Systems

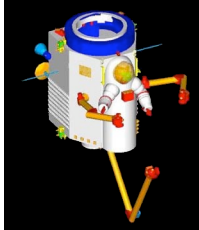
Primary Avionics Components

- Components on CompactPCI bus interface:
  - Computer subsystem
    - Three identical Flight & Data Control Computers
    - Each will be a single-board RAD750 computer
  - Data bus interface (I/O)
    - Two redundant Firewire (IEEE 1394) interface cards
  - Mass memory storage
    - Two identical solid state recorder cards of at least 1GB each
  - Video interface cards
    - One card for each touch-screen monitor



Single Board Computer

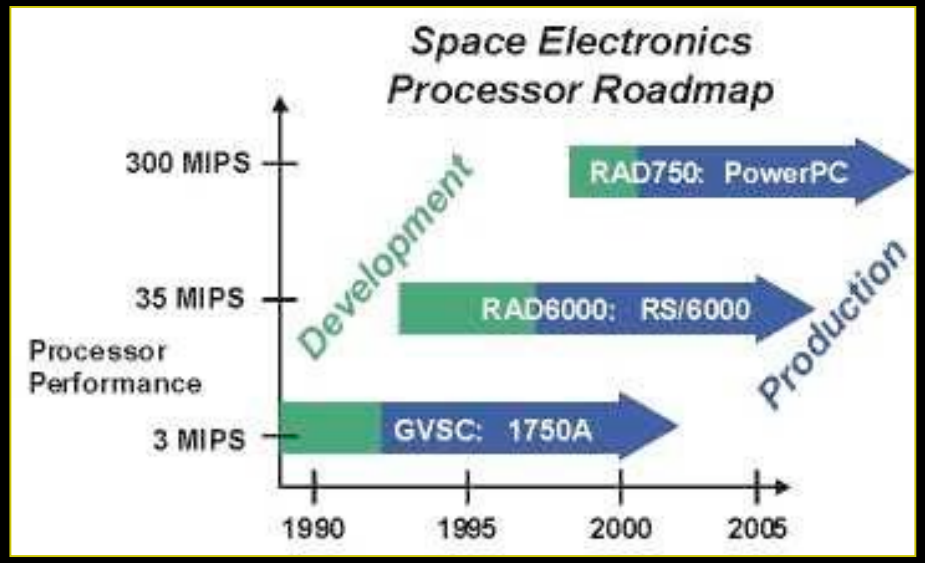
BAE Systems



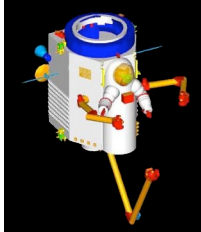
SCOUT

Processor Selection

- Several industry standard processors were compared on the basis of power consumption, performance, and radiation hardening
- RAD750 is the most capable radiation hardened processor anticipated to be in use during the SCOUT mission timeline
  - MTBF >390K hours = Reliability of >99.9% over 6 month mission
- SCOUT nominal operation distributes load between two FDCCs
  - Third FDCC for backup
  - Each FDCC is capable of individually supporting SCOUT tasks



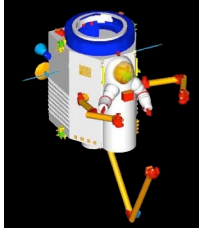
BAE Systems



SCOUT

Data Bus Selection

- Advanced technologies in data transfer medium are focused mainly on the following:
  - Firewire (IEEE 1394)
  - Ethernet
  - Optical (Fiber optic)
  - RF (Wireless)
    - Not feasible for SCOUT due to radio interference and reliability constraints
- The following table illustrates the capabilities of several data transfer mediums that were considered in this trade study
  - Particular focus was on proven military standard and projected future technology data transfer interface



SCOUT

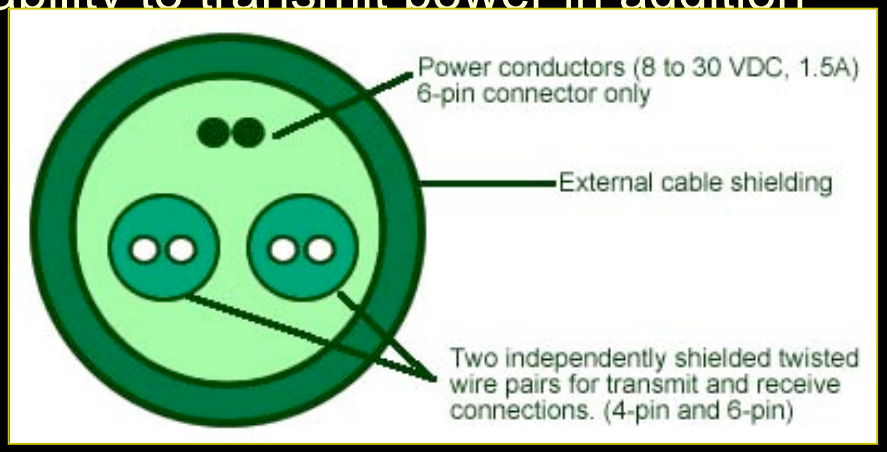
Data Bus Comparison

Data Bus Type	Data Format	No. Drivers/ Receivers	Max Data Rate	Transfer Medium	Data Trans. Mode
RS 232	7-8 bits	1 Driver 1 Receiver	Up to 20kbps	Multi-core Copper	Synchronous Asynchronous
RS 485	7-8 bits	32 Drivers 32 Receivers	100kbps to 10Mbps	Twisted pair Copper	Synchronous Asynchronous
1 Gbps Ethernet	60-1500 bytes	100+ Receivers	Up to 54Mbps	Fiber optic /Copper	Station to Station
Mil-STD-1553	256 bytes	32 Receivers	Up to 1Mbps	Copper	Full-Duplex
Mil-STD-1773	256 bytes	32 Receivers	Up to 1Mbps	Copper	Half-Duplex
Firewire (IEEE 1394)	20k bytes at 400Mbps	63 Receivers	Up to 500Mbps	2 Signal 2 Power	Asynchronous /Isochronous
Fibre Channel	2100bytes	126+ Receivers	Up to 400Mbps	Fiber optics /Coaxial	Asynchronous

Data Bus: IEEE 1394

SCOUT

- SCOUT Baseline Design: IEEE 1394 (Firewire)
  - Firewire exceeds the A1 requirement of 10Mbps data transfer (Max transfer of 500Mbps)
  - Lower power requirements than Ethernet
  - Predicted to be the standard bus to transfer large amounts of rapidly between peripherals and computers
  - Lowers cost of ground support equipment
  - Hot-swappable
  - Firewire has the added ability to transmit power in addition to data



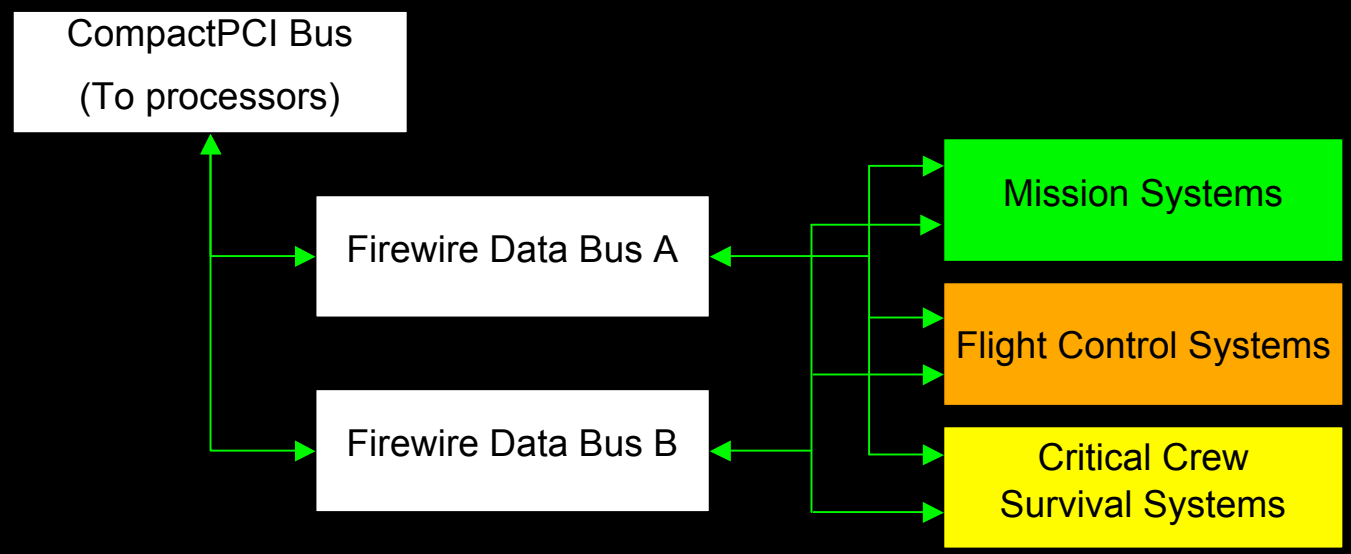
Quatech

Network Systems

- Bus Topology: All stations are attached to the same cable; Messages transmitted directly from sender and receiver
- Daisy Chain: Components connected together in sequential form
- Ring Topology: All connections on a ring; Data is transmitted from one station to the next
- Star Topology: All messages go through a central node, which relays data according to station address

	Bus Topology	Daisy Chain	Ring Topology	Star Topology
Advantages	•No single point failure •Components added/remove while network is operating •Simple to implement •Modular based •Easy expansion	•Easy to assemble •Reduces amount cables needed •Easy to expand anywhere in the chain	•Few connections required •Local protocol structure •Easy expansion	•Few connections required •Whole network not affected by non-central node failure •Fixed number of stations
Disadvantages	•Difficulty in troubleshooting •Minimum security	•Single point failure •Network halts during components replacement	•Single point failure •Time transfer proportional to the amount of stations	•Single point failure at central node •Requires centralized protocol

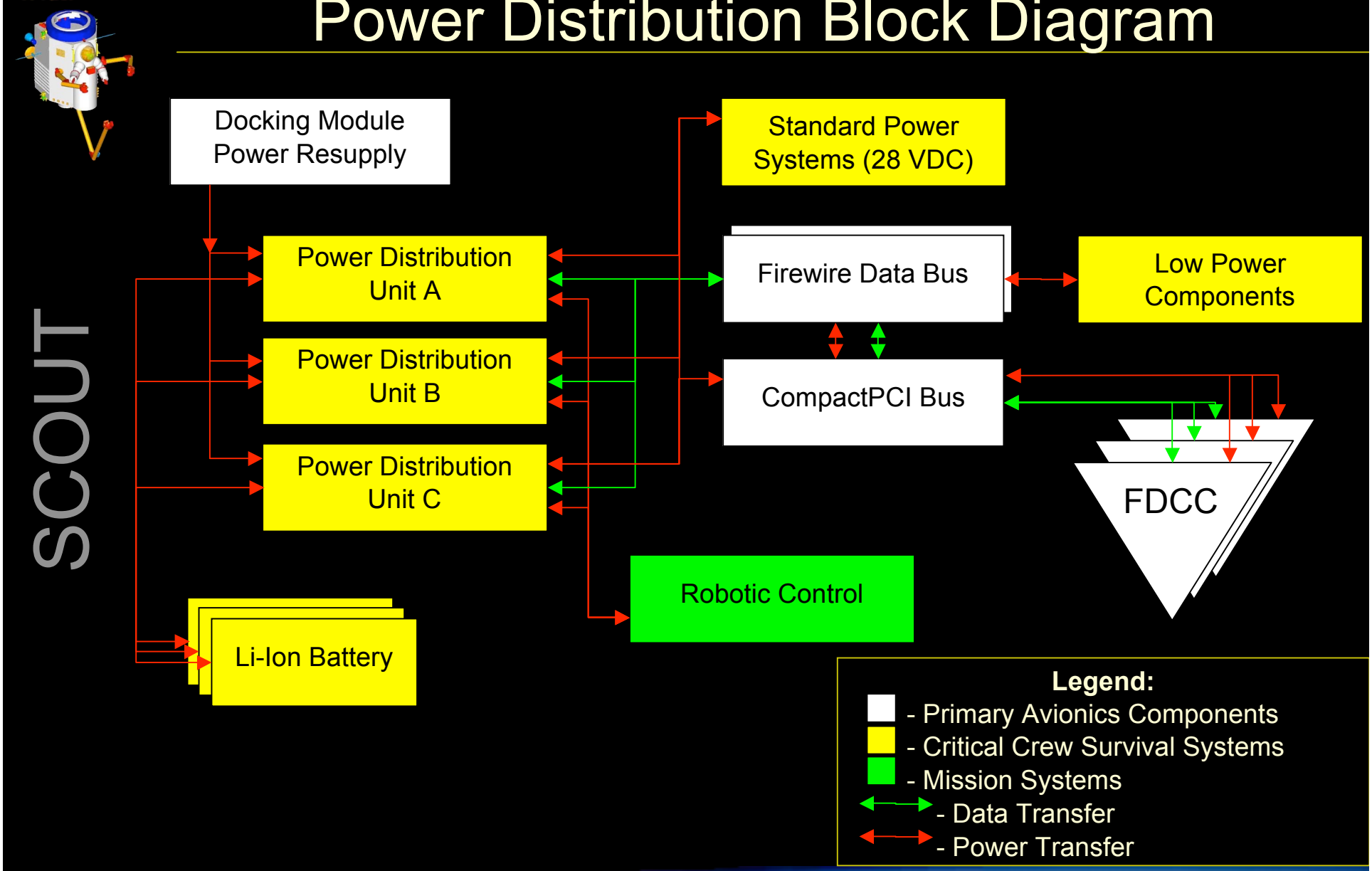
Network Systems



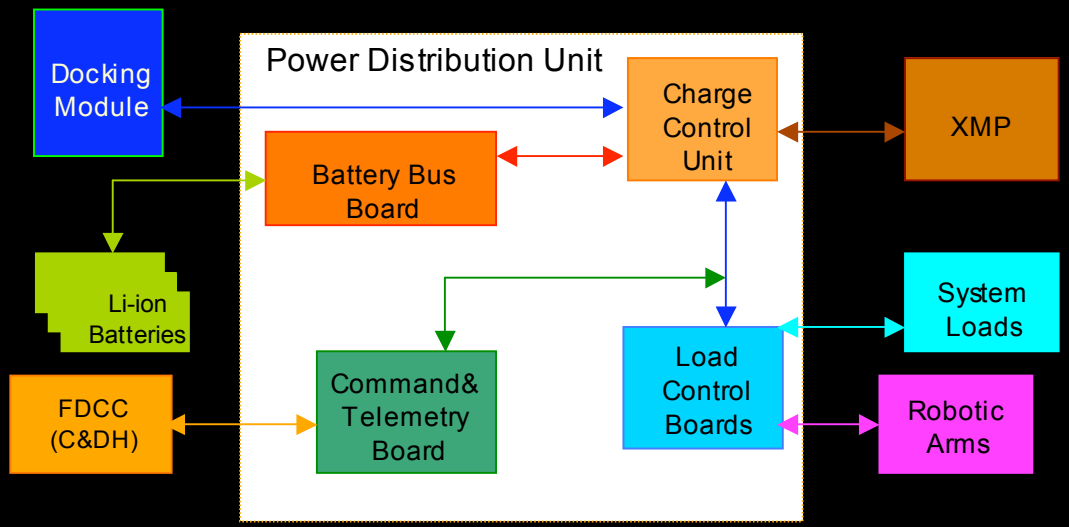
SCOUT

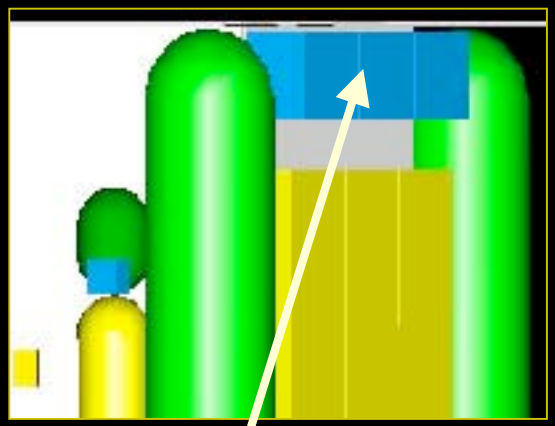
- SCOUT Baseline: Redundant Linear Bus Topology
- With the added data bus:
  - The possibility of the whole network failing is reduced
  - A reliability of above 99% can be achieve given that each data bus has a reliability of above 97%

Power Distribution Block Diagram



PMAD Basic Operations

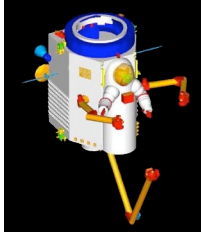




Power Distribution Units

PMAD basic operations:

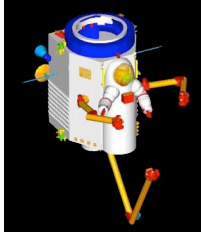
- 3 redundantly connected PDUs will regulate the 100VDC from the Li-ion batteries to two 28VDC power buses through the charge control unit and load control boards
- Only 2 PDUs will operate nominally, the other will be a backup if a failure occurs
- Approximately 900W is supplied during nominal mission and 3kW during peak load demand
- PDUs will be able to accommodate power from the solar arrays and power storage on docking module



SCOUT

Power Management

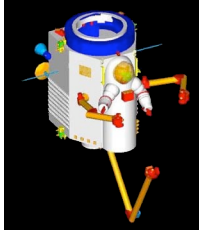
- A standard spacecraft power management system includes power regulators and power converters
- Several primary functions of the power management system
  - Communicates with FDCCs using IEEE 1394
  - Displays operational status for each PDU and all major components linked to the system
  - Regulates 100VDC from power source to robotic arms and produces a constant 28VDC for distribution to all other electronic components
  - Conditions power by using digitally controlled DC-DC converters
  - Dissipates excess power through following:
    - Shunt regulators
    - Series regulator



SCOUT

Power Distribution

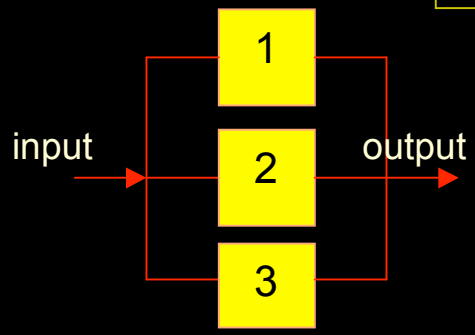
- Standard spacecraft distribution system includes the protective switchgears, wiring harnesses, and connectors
- Distribution voltage selection
  - Investigated SCOUT load profile in order to implement one the following power distribution methods:
    - Low-to high DC (5-270VDC)
    - High voltage single phase AC (115RMS, 60Hz)
    - High voltage three phase AC (120/440VRMS, 400Hz)
    - 28VDC power bus
- Conducted trade study for the use of DC or AC power on SCOUT
  - Direct Current System:
    - Fewer electronics needed for conversion (less mass)
    - Optimum for systems requiring low to medium voltage (5-120VDC)
  - Alternating Current System:
    - Extensive power conversion from any DC power source (Li-ion batteries and solar arrays)
    - Used only on large spacecraft with high power requirements (e.g. ISS)
- SCOUT baseline voltage selection:
  - 100VDC to robotic arms
  - 28VDC to A & B power buses for distribution to all other components



SCOUT

Reliability Analysis

- Redundancy and reliability of PDUs and power bus:
  - General Parallel Network equation for (n) identical components:



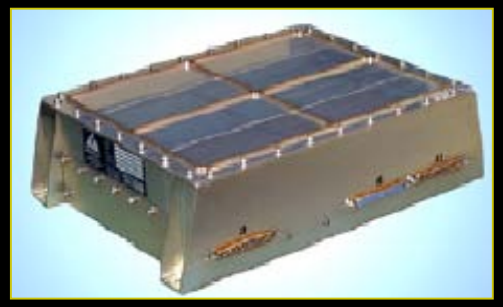
R_s=system reliability
R=component reliability

- Given each PDU and power bus is 97% reliable
  - With dual redundant power distribution (Bus A, Bus B), power bus system reliability will be:
  - Reliability for the 3 identical PDUs:

SCOUT

Power Distribution Units

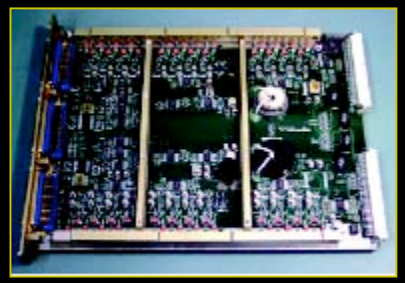
- The projected future technology of power distribution systems:
  - Modulated control devices
  - Miniaturized high efficiency power electronics devices
  - Automated control by system processor with manual backup for manned spacecraft
- Typical example of a Power Distribution Unit:
  - PDU can be customized to the power requirements of the spacecraft
- PDU Highlights:
  - Modulated for easy reconfiguration to meet specific requirements
  - Capable of providing 97% efficiency at 1500W
  - Low electromagnetic interference (EMI) from switching converter/regulator units
  - Space qualified on several spacecraft
    - Mars Odyssey, Gravity Probe B, Lunar Prospector
  - Scheduled to be implemented in future missions from 2003 to 2006

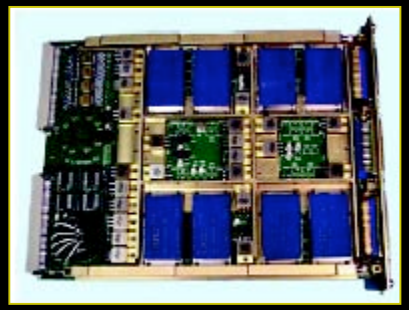


SpectrumAstro

Power Distribution Units

- Functions provided by each control board within the PDU:
- Charge Control Boards (CCB) Provide:
  - Control and management of solar power outputs and charging/discharging of batteries
  - Monitoring of battery terminal voltages and temperatures
  - Conditioning of overall power with DC-DC converters and voltage regulators
- Command and Telemetry Boards (CTB)
  - Provides interface between electronic power system and data management system
- Load Control Board (LCB)
  - Distributes power via switched or unswitched modes with the use of solid state logic reset switches (analogous to traditional circuit breakers)
  - Provides fault detection and correction

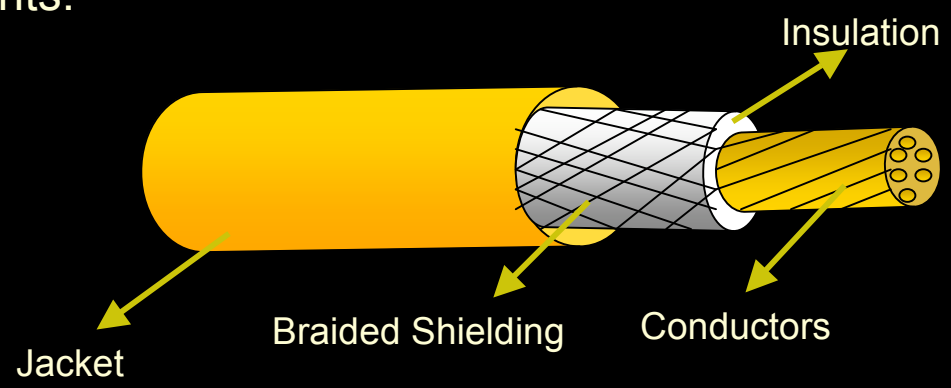




SpectrumAstro

Wiring Harnesses

- Wiring harness design must consider selection of the following components:



- Type of harness is selected to be
  - Lightweight
  - Capable of supporting a 3kW maximum power load
  - Efficient during power transmission
  - Flexible
  - Strong enough to support loads
- Stranded conductors:
  - Widely used in aerospace over solid conductors
  - More flexible and fracture resistant

Wiring Harnesses Conductors

- Copper/Copper Alloys and Aluminum are the leading choices for conductor in power distribution systems
- A comparison conductor wires:

	Copper/Copper Alloys	Aluminum
Advantages	•High electrical conductivity •High ductility and malleability •High thermal conductivity (up to 600°F) •High tensile strength (up to 97ksi, depending on size) •Relatively low cost	•High ductility •High malleability •High tensile strength (up to 40ksi) •Very inexpensive (available in abundance)
Disadvantages	•Approximately 35% heavier than Al	•Relative low conductivity (60% of Cu) •Difficult to bond with (lead–tin solder) •Possibility of galvanic corrosion

Harness Voltage and Power Losses

- Voltage Drop and Power Dissipation:
  - Wire sizes are set in accordance to American Wire Gauge (AWG) standard
  - Typical wire sizes range from 40 AWG (3.1 mils diameter) to quadruple zeros (#4/0 AWG) at approximately 0.5in
  - Voltage drop and power dissipation can be calculated by the following:

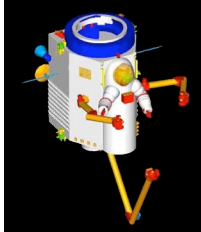
E = voltage drop (V)
I = current (A)
R = resistance/1000ft
L = length of wire (ft)
P = power dissipated (W)

SCOUT

Harness Voltage and Power Losses

- Using the max expected length the wires may travel:
  - 2.36m (~7.75ft) (half the circumference of SCOUT)
- Each section of the harness should be the smallest wire that will support the maximum amperage of that component

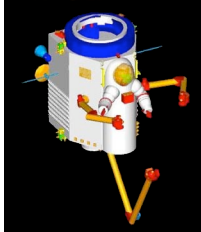
Wire Size (AWG)	Diameter (in)	Max Current (A)	Resistance (Ωm/1000ft)	Voltage Drop (V)	Power Loss (W)
20	0.032	7.5	10.25	0.60	4.47
18	0.04	10	6.44	0.50	4.99
16	0.051	13	4.76	0.48	6.23
14	0.064	17	2.99	0.39	6.70
12	0.081	23	1.88	0.34	7.71
10	0.102	33	1.1	0.28	9.28
8	0.128	46	0.7	0.25	11.48
6	0.162	60	0.436	0.20	12.16
4	0.204	80	0.274	0.17	13.59
2	0.258	100	0.179	0.14	13.87
1	0.289	125	0.146	0.14	17.68
1(0)	0.325	150	0.114	0.13	19.88
2(0)	0.37	175	0.09	0.12	21.36
3(0)	0.365	200	0.072	0.11	22.32



Harness Mass Estimates

SCOUT

- Wiring harness mass sizing:
  - A small to large spacecraft typically has a wiring harness mass of 1% to 4% of vehicle dry mass
  - For SCOUT at 1800kg dry mass the mass range would be 18-72kg
- With the expected advancements in wiring harness technology, one can assume that mass of wiring harness will decrease
- SCOUT harness mass estimate:
  - 2.5% of the vehicle dry mass
  - Wiring harness mass of approximately 45kg



SCOUT

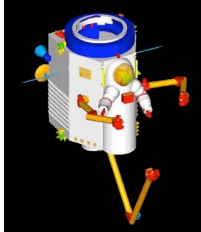
SCOUT Wiring Harnesses

SCOUT Baseline:

- Polymide insulation used on SCOUT
  - Lightweight and fire resistant foam insulation
- Braided shielding used for SCOUT
  - More effective for EMI protection than spiral shielding
- Copper conductors
  - Consider aluminum for components with much lower current requirements if mass of wiring becomes an issue
- Connectors will meet military specifications
- IEEE 1394 can also provide power along with data signals to components with max operate voltages of 30VDC

Technological advances will produce:

- Higher efficiency solar cells
- Higher energy density batteries (lower mass)
- More efficient electronics (lower wire harness size)



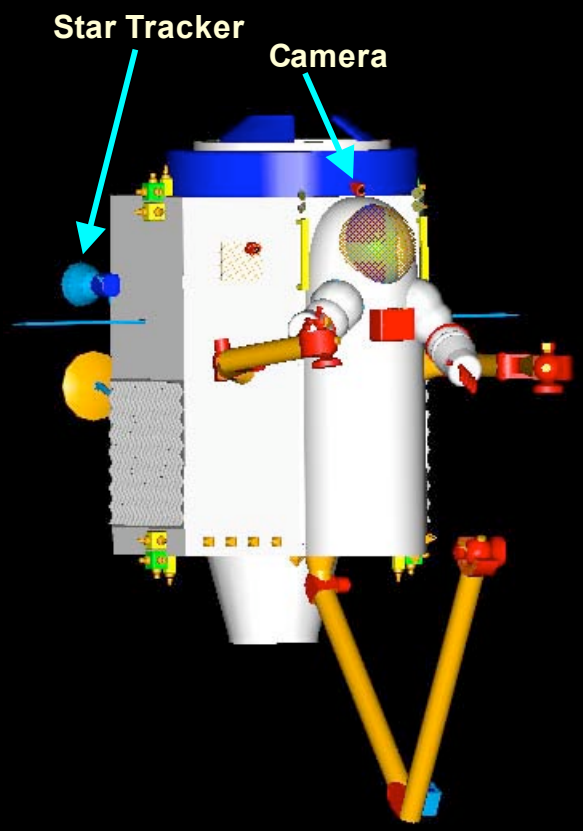
SCOUT

Sensor Selection

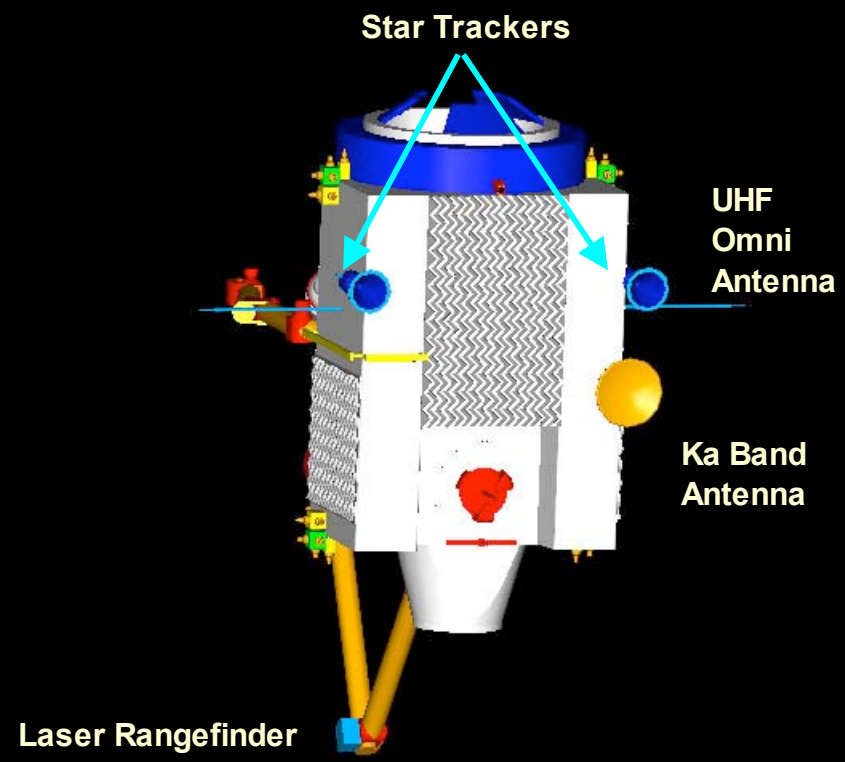
- Attitude sensors
  - Needed for directional navigation
  - Flight control system will use to set heading towards destination, allow fine measurement for close maneuvering
- Ranging sensors
  - Gives flight control system relative measurements of surroundings, most importantly the host station and SCOUT worksite
- Internal and external HDTV cameras
- Crew Interface sensors
  - Allows manual flight control and robotic manipulator control
- System sensors: redundantly placed in all critical systems
  - Life support: partial pressures, cabin atmospheric temperature
  - Propulsion: propellant tank pressures, temperatures
  - Power: voltage, current, temperature

SCOUT Sensor Placement

SCOUT



Front View



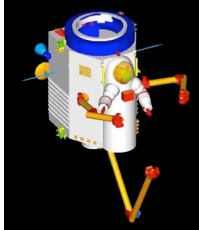
Rear View

SCOUT

Attitude Sensors

Sensor	Accuracy	Pros	Cons
Star Tracker	<10arcsec	2.4kg, 9W	Relatively expensive
Coarse Sun Sensor	5deg	Large field of view Reliable, simple design	No information during eclipse Low accuracy
Fine Sun Sensor	1arcmin (0.01deg)	1.3kg, 0.2W Reliable Inexpensive	No information during eclipse Small field of view
Three-Axis Magnetometer	<5deg	Reliable	Negligible magnetic field at L1 – useless
Ring Laser Gyroscopes	0.02deg/sec	No moving parts	Potential for mirror fogging
Interferometric Fiber Optic Gyroscopes	0.02deg/sec	No moving parts Less expensive Lower wattage	

SCOUT Baseline Design: Redundant star trackers, redundant IFOGs



SCOUT

SCOUT Attitude Sensors

- State-of-the-art instruments were selected for our baseline design to demonstrate feasibility
- Star Tracker (x2) – Ball CT-633:
  - Mass: 2.4kg
  - Dimensions: L=14.3cm d=13.5cm
  - Accuracy of 6arcsec
  - Star trackers will be used to remove IFOG drift when rates are low enough
- Interferometric Fiber Optic Gyro (IFOG)
  - Mass: 0.47kg
  - Dimensions: 9.6 x 6.9 x 5.5cm
  - Resolution of 0.03deg/sec
  - Maximum rate of 500deg/sec
  - Gyro rates can be used by the spacecraft to control spacecraft spin

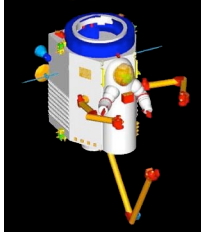
Ball Aerospace

Fizoptika

Ranging Sensors

SCOUT

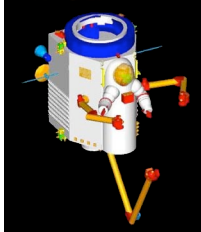
- Ranging sensors provide relative position measurements primarily during the rendezvous process
- Rendezvous Targets
  - Hosting Station (e.g. Gateway)
    - After each sortie, SCOUT returns to and docks with the Docking Module
    - Docking maneuvers are to be performed autonomously and can be teleoperated in the event of an emergency
    - Proposed sensors: Laser Rangefinder (long-range sensor) and Video Guidance Sensor (short-range docking sensor)
  - Work Site
    - For each sortie, SCOUT approaches and berths with the work site using its grappling arm
    - Approach and berthing is to be performed manually by the astronaut
    - Proposed sensor: Laser Rangefinder
  - XMP (eXtended Mission Pallet)
    - Proposed sensors: Laser Rangefinder (long-range) and Video Guidance Sensor (short-range docking)



Laser Rangefinder

SCOUT

- Laser rangefinder provides both long-range and short-range relative position measurements as well as relative velocity measurements to the target
  - Long-Range (>10m)
    - Time-of-Flight (TOF) measurements used to calculate range
    - Desired Maximum Range: 2km
    - Expected Maximum Range: >10km
    - Accuracy remains fairly constant as distance increases
  - Short-Range (<10m)
    - Triangulation method used to calculate range
    - Desired Minimum Range: 1m
    - Accuracy decreases at a nonlinear rate as distance increases
  - Relative Velocity
    - Determined after several measurements have been taken
    - Pulse Repetition Frequency: 1kHz (1000 measurements per second)
- In addition to measurements, laser rangefinder has capability of scanning target and producing a 3-Dimensional image of the scene
  - Laser performs a raster scan to capture a complete range and intensity image of the target
  - 3-D image serves as an aid to astronaut in addition to 2-D camera images, especially useful for extended missions

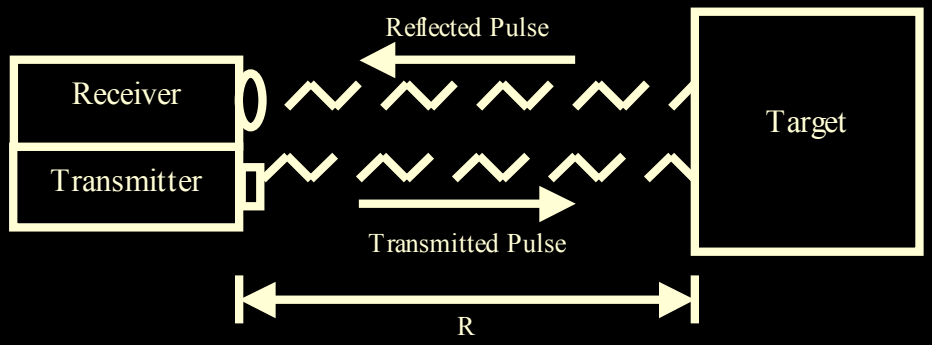


SCOUT

Laser Rangefinder

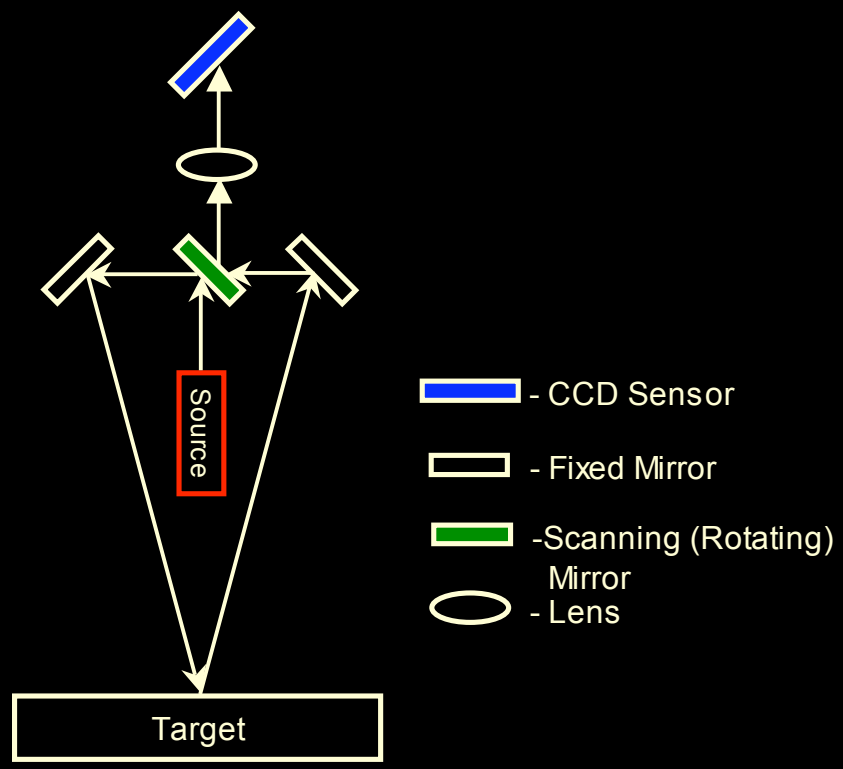
- For relative distances greater than 10m, a TOF calculation is used to calculate the range
  - $R = c*t/2$
    - R = range
    - c = speed of light
    - t = time of flight
- Accuracy Requirement
  - ±10cm (<2.5% difference at all times)

Operation:
- High intensity laser pulse fires
- Pulse reflects off the target
- Reflected pulse is absorbed by the receiver optics
- Relative range measurements are calculated



Laser Rangefinder

- Less than 10m, a triangulation technique is to be implemented
- Accuracy Requirement
  - ±10cm at 10m
  - ±0.5cm at 1m



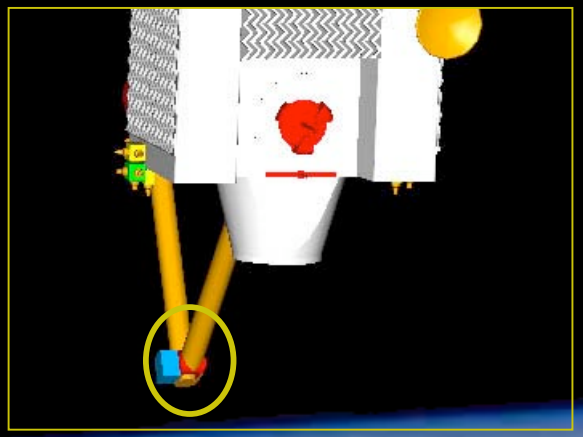
Operation:

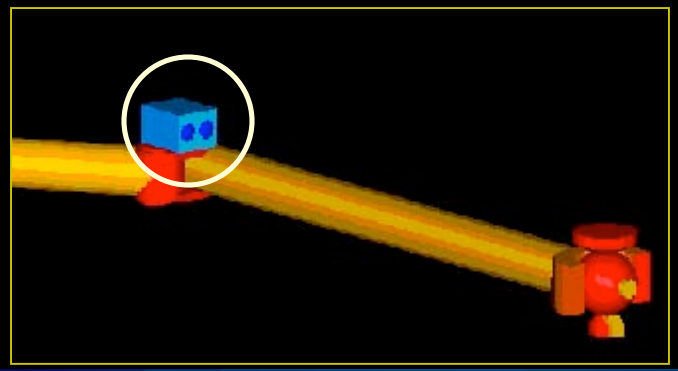
- High intensity laser fires and is reflected onto target by means of the scanning mirror followed by a fixed mirror
- Beam is reflected back to second fixed mirror then onto the opposite side of the double-sided scanning mirror
- Beam passes through lens onto CCD sensor
- As range changes, triangulation angle changes, thus position on CCD changes
- Range determined from known angular position of the scanning mirror and position of image on CCD

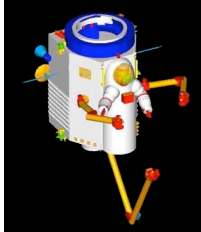
Laser Rangefinder Placement

SCOUT

- Estimated Rangefinder Specifications
  - Laser: Neodymium Yag (Nd:Yag) eye-safe, scanning laser with 1064nm wavelength
  - Dimensions: 150mm x 125mm x 100mm
  - Receiver Aperture: 50mm diameter
  - Pulse Repetition Frequency: 1kHz
  - Maximum Unambiguous Range: 150km (far greater than 2km requirement)
  - Mass: 2kg
  - Peak Power: 15W
- Laser Rangefinder to be mounted on the SCOUT grapple arm to allow movement to aim toward target



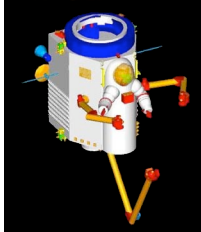




SCOUT

Video Guidance Sensor

- Autonomous Docking
  - Ease of operating SCOUT is greatly enhanced
  - Computer controlled maneuvers allow for better accuracies, more efficient maneuvering and a “softer” dock
  - Emergency scenario is created in the event that the astronaut is unable to continue with the sortie
- Video Guidance Sensor (VGS)
  - Originally developed as part of NASA’s Automated Rendezvous and Capture (AR&C) system at Marshall Space Flight Center
  - Currently, one of the most developed systems for automated docking
    - On-orbit tests include: STS-87, STS-95
    - Future tests are to be performed aboard the Demonstration of Autonomous Rendezvous Technology (DART) vehicle under development by Orbital Sciences Corporation
    - Current development schedule shows that it will be available to implement on SCOUT
- VGS provides all relative position and attitude measurements (6-DOF) to the Guidance, Navigation, and Control (GN&C) system



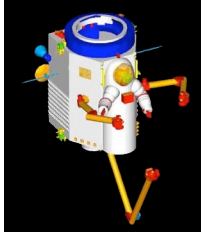
Video Guidance Sensor

SCOUT

- Estimated VGS Specifications
  - Dimensions: 15.0 x 12.5 x 10.0cm
  - Mass: 5kg
  - Power: 20W
- Range Limits: 0.5m (minimum) to 500m (maximum)
- Field of View: square of 14° to 16°

Measurement Accuracies (at range limits of 1m to 110m)

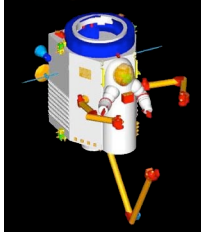
Operating Range (m)	X-Offset (mm)	Y/Z-Offset (mm)	Roll/Pitch/Yaw (Deg)
1-3	±3	±2	±0.3
>3-5	±10	±5	±0.75
>5-10.5	±100	±50	±1
>10.5-30	±300	±100	±2
>30-50	±1000	±200	±3
>50-110	±3000	±2000	±5



Video Guidance Sensor

SCOUT

- Active Sensor
  - Sensor head includes
    - Two sets of four laser diodes: each set operates at a distinct wavelength (808nm and 940nm)
    - Thermo-Electric Coolers (TECs)
    - High frame rate CMOS black and white digital camera
      - Frame rate: 250 frames per second
      - Resolution: 1024x1024
    - Digital Signal Processor (DSP): image processing and relative measurement calculations
    - Single Board Computer (SBC): housekeeping and communication
  - Redundant sensors are to be mounted symmetrically around the IBDM on SCOUT with 120° of separation, each 60° from the centerline
    - Only one sensor is to operate at a time
    - In the event of failure in one sensor, SCOUT will roll 120° at which the second sensor will take over



Video Guidance Sensor

SCOUT

- Passive Target
  - Retro-reflectors are mounted on the target (i.e. the Gateway Docking Module); filters on retro-reflectors allow a wavelength of 940nm to pass while absorbing a wavelength of 808nm
  - Target designed to resemble an upside-down T shape
    - Three clusters of retro-reflectors arranged along the bottom of the target with the central cluster raised above the outer ones
    - A fourth cluster of retro-reflectors is found at the top of the shape, aligned with the central cluster
    - Pattern of clusters is recognized by VGS allowing relative position and attitude to be calculated
  - Similar, smaller T assemblies are mounted along bottom of larger T assembly, between outer clusters and central cluster; these are to be used for very short-range (<5m) maneuvers

Video Guidance Sensor

- Four Modes of Operation

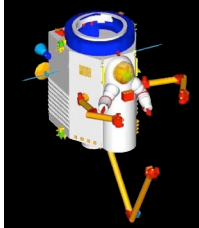
Power-Up/Reset: Restores hardware and software to initial state; performs self-testing; automatically moves into standby

Standby: Awaits further command

Acquisition: Receives estimated position information; searches for and acquires target

Tracking: Scan target and output relative position and attitude measurements at a 20 Hz rate

SCOUT

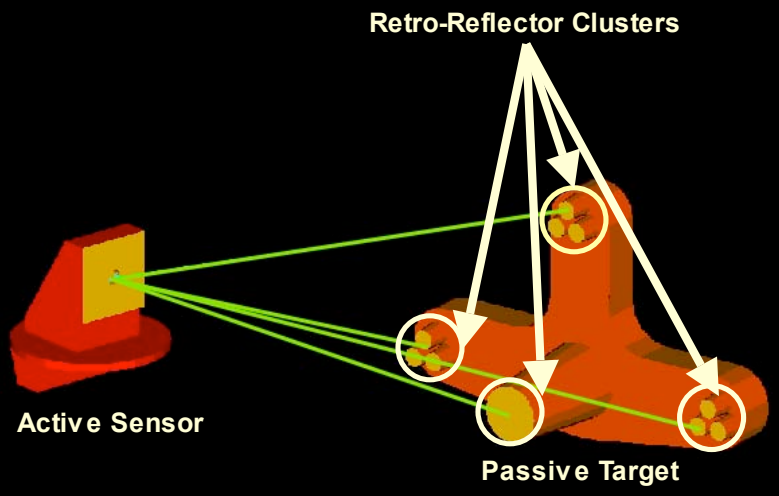


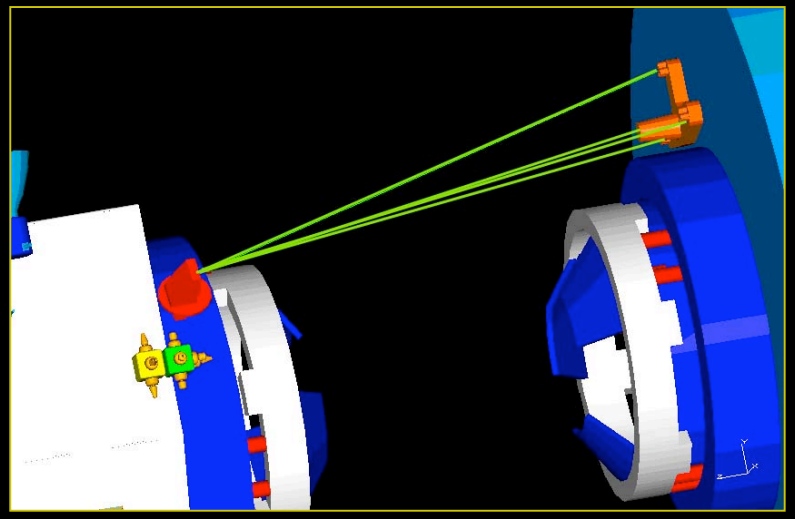
SCOUT

Video Guidance Sensor

Operation:

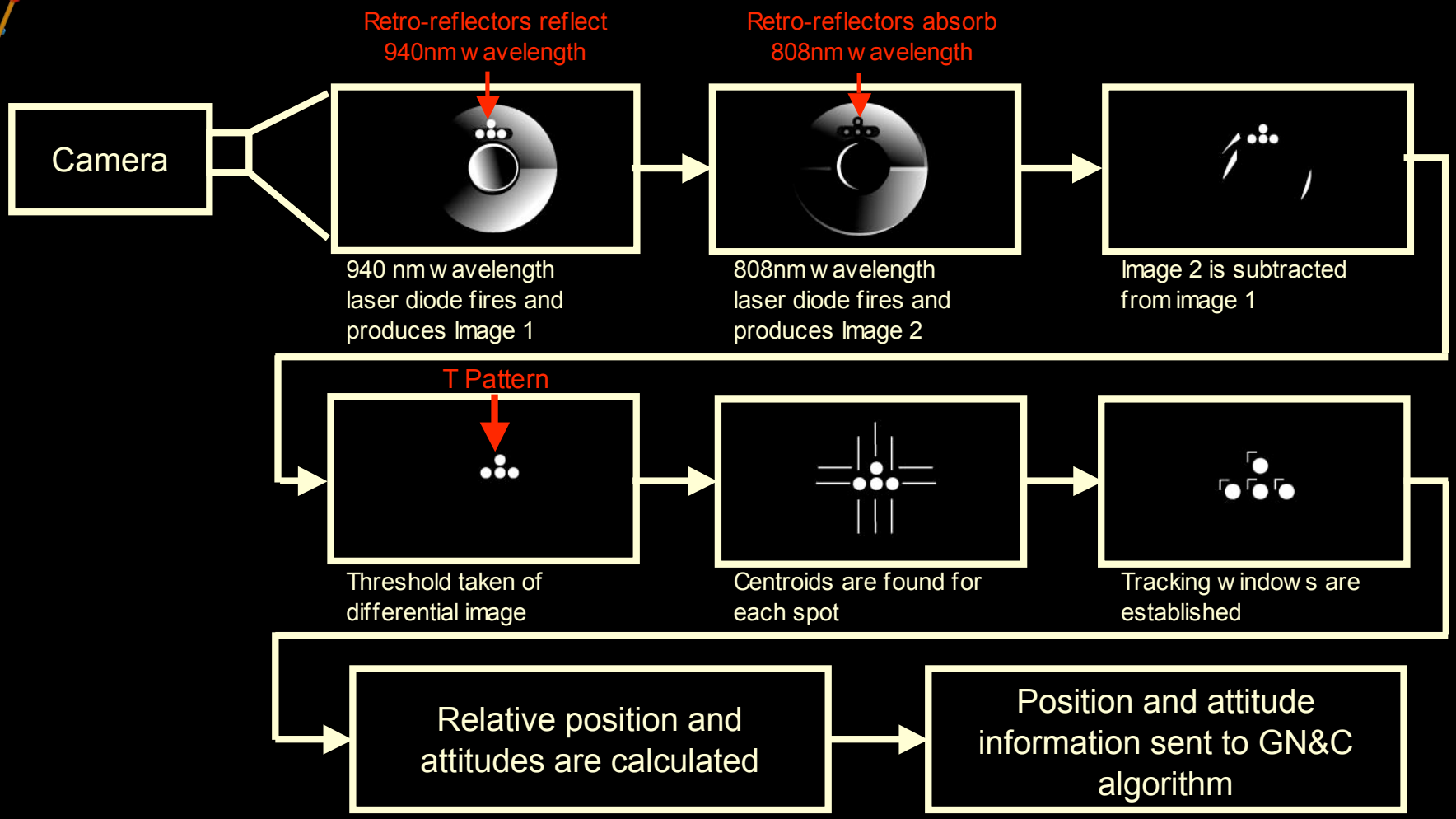
- Laser diodes illuminate retro-reflectors mounted on the target
- CMOS camera detects reflected beams from target
- DSP translates video information and converts it into relative position and attitude measurements
- SBC sends information to Guidance, Navigation, and Control (GN&C) system





Video Guidance Sensor

- Logic Flow Diagram of Image Processing Sequence



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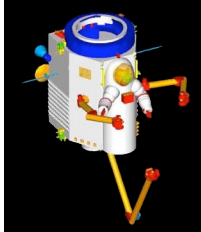
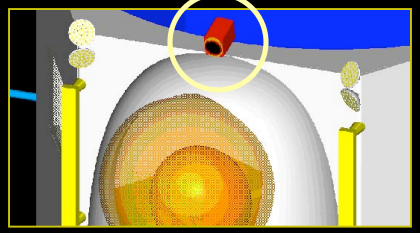


SCOUT

Video Cameras

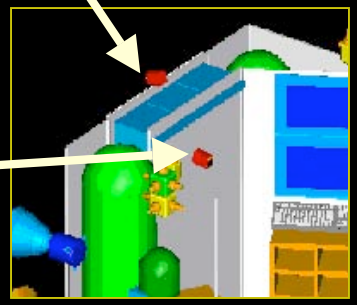
- Digital video cameras are to be placed on SCOUT to serve as an aid to the astronaut
- Estimated Camera Specifications
  - Sensor: Complementary Metal Oxide Semiconductor (CMOS) Active Pixel Sensors (APS)
    - Higher Frame Rates than CCD (Charge Couple Devices)
    - Smaller Dimensions
    - Lower Mass
    - Lower Power Consumption
    - More tolerant to radiation
  - Dimensions: 90 x 55 x 80mm
  - Lens Aperture: 40 mm diameter
  - Total Mass (including Gimbals): 5.5kg
  - Total Peak Power (including Gimbals): 15W
- 3 Cameras to be used on SCOUT
  - 2 External
    - Front
    - Rear
  - 1 Internal

Front Camera



Rear Camera

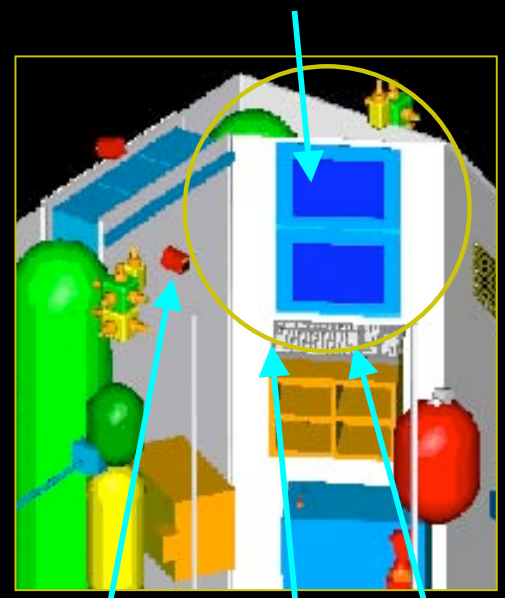
Internal Camera

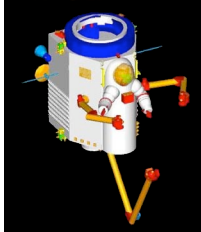


Crew Interface - Comm Station

SCOUT

- Touch Screen Monitors (x2)
  - 15in display
  - Mass: 7.3kg
  - Dimensions: 49 x 36 x 7cm
  - Peak Power: 26W
  - Accepts both HDTV and computer input
  - Primarily used as a reconfigurable computer display during system monitoring and video communication
- Keyboard
  - Mass: 0.85kg
- Internal Camera
  - Used for real-time video conferencing

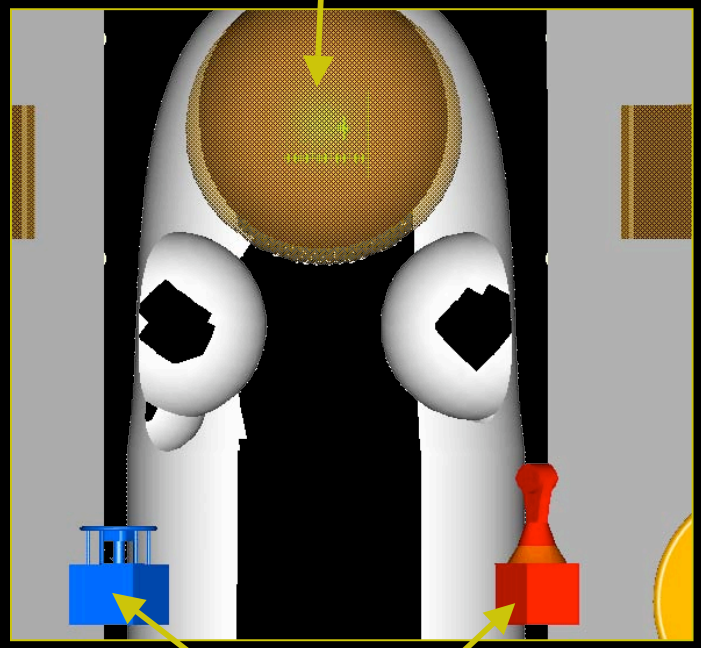




SCOUT

Crew Interface – Contoured Hull

- Heads-Up Display (HUD)
  - Mass: 2kg
  - Peak Power: 5W
  - Used for display while operating hand controllers (flight or robotic control) or human AX-5 arms
- Hand Controllers
  - 2 3-DOF controllers used for manual flight control and operation of the manipulator arms
- AX-5 Arm and Glove Sensors
  - Sensors can be used to control manipulator arms
  - Activated/deactivated by voice command
  - Can move robotic arms without taking hands out of gloves
- Voice Recognition
  - System utilizes pre-allocated communications hardware with the FDCCs to process voice commands
  - Can be used from anywhere within SCOUT



SCOUT

Communication System Requirements

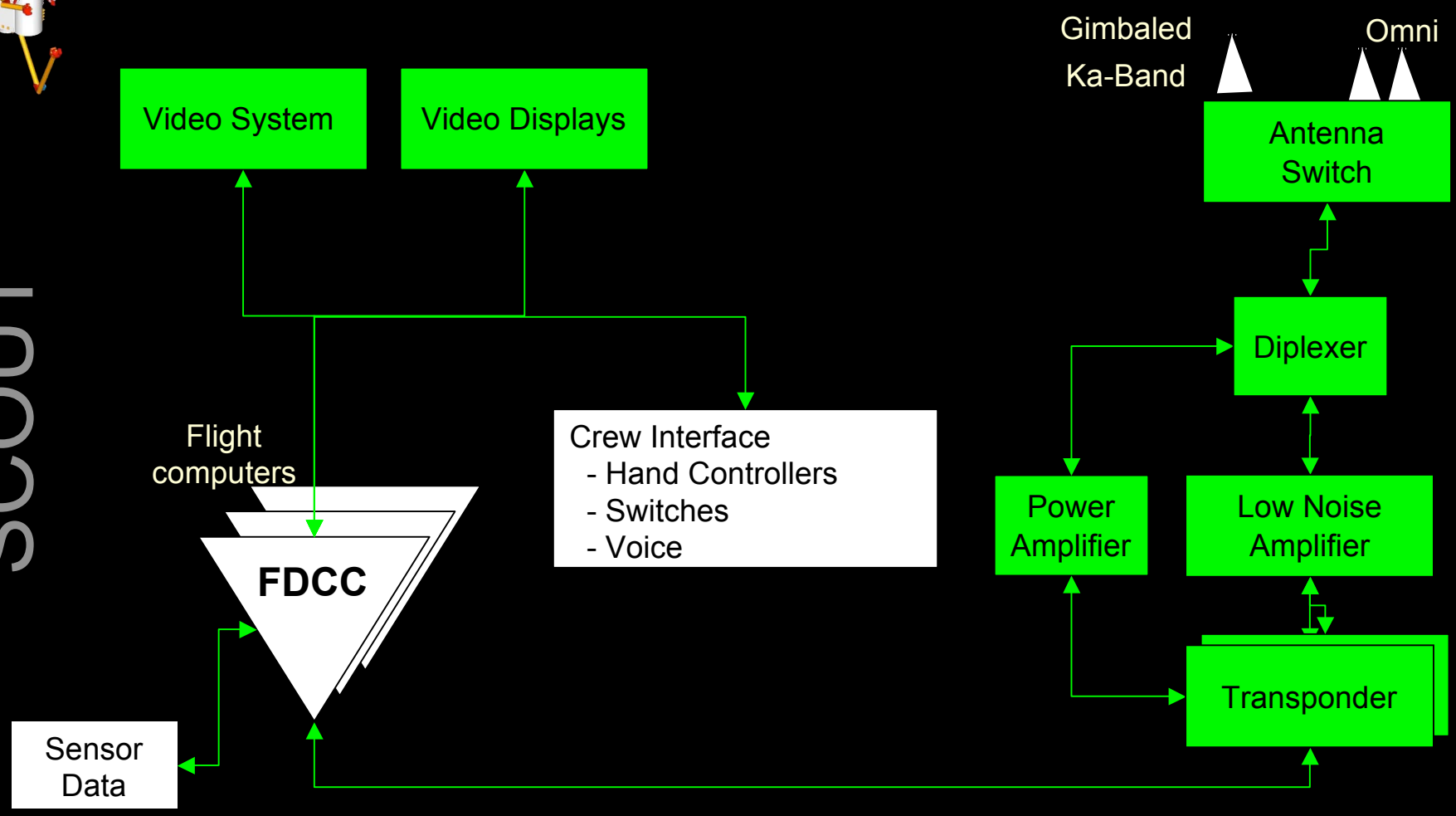
- Transmission rate = 9Mbps (HDTV) + 1Mbps (data) =10Mbps
- To fulfill requirement A1, a transmission rate of 10Mbps must be provided and must be capable of traveling 1000 meters from the worksite to the hosting station
- All link budgets used in the upcoming analysis had a minimum link margin of 3dB

SCOUT

Communication Equipment

- Signal processing will be accomplished with the use of a transponder, diplexer, power amplifier, and low noise amplifier
- Transmitted data and video will be generated by inputs coming from sensors, cameras, microphones, etc.
- Received data and video will be sent to onboard systems, monitors, speakers, etc.

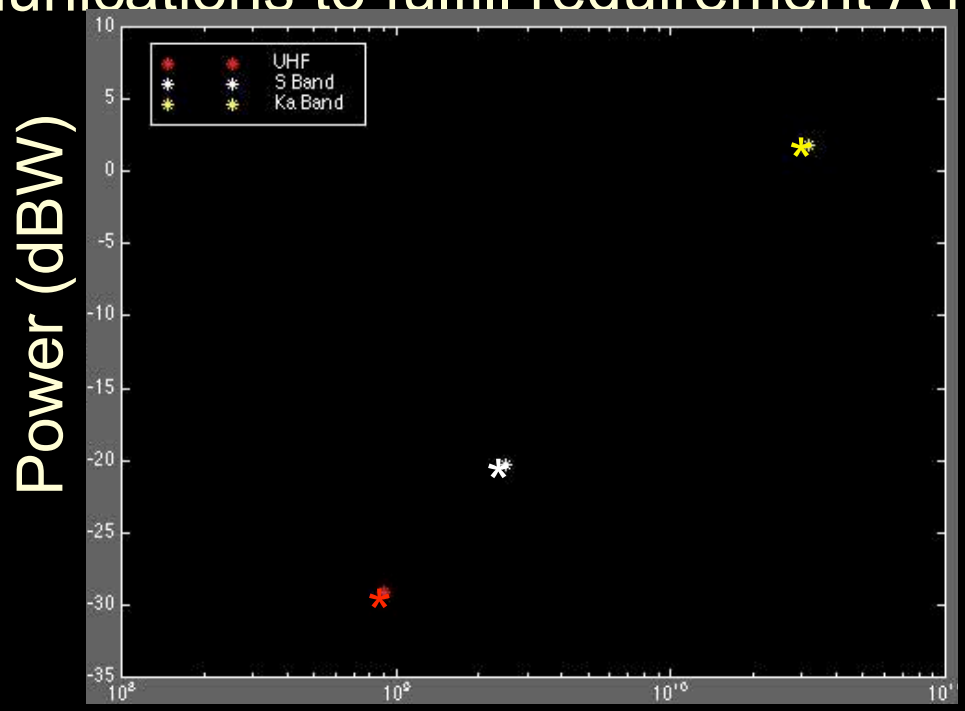
Communication Block Diagram



SCOUT

Primary Antenna Selection

- Omni-directional antennas are ideal for communications across 1000 meters
- Ultrahigh frequency (UHF) requires significantly less power. Therefore it is chosen for primary communications to fulfill requirement A1



SCOUT

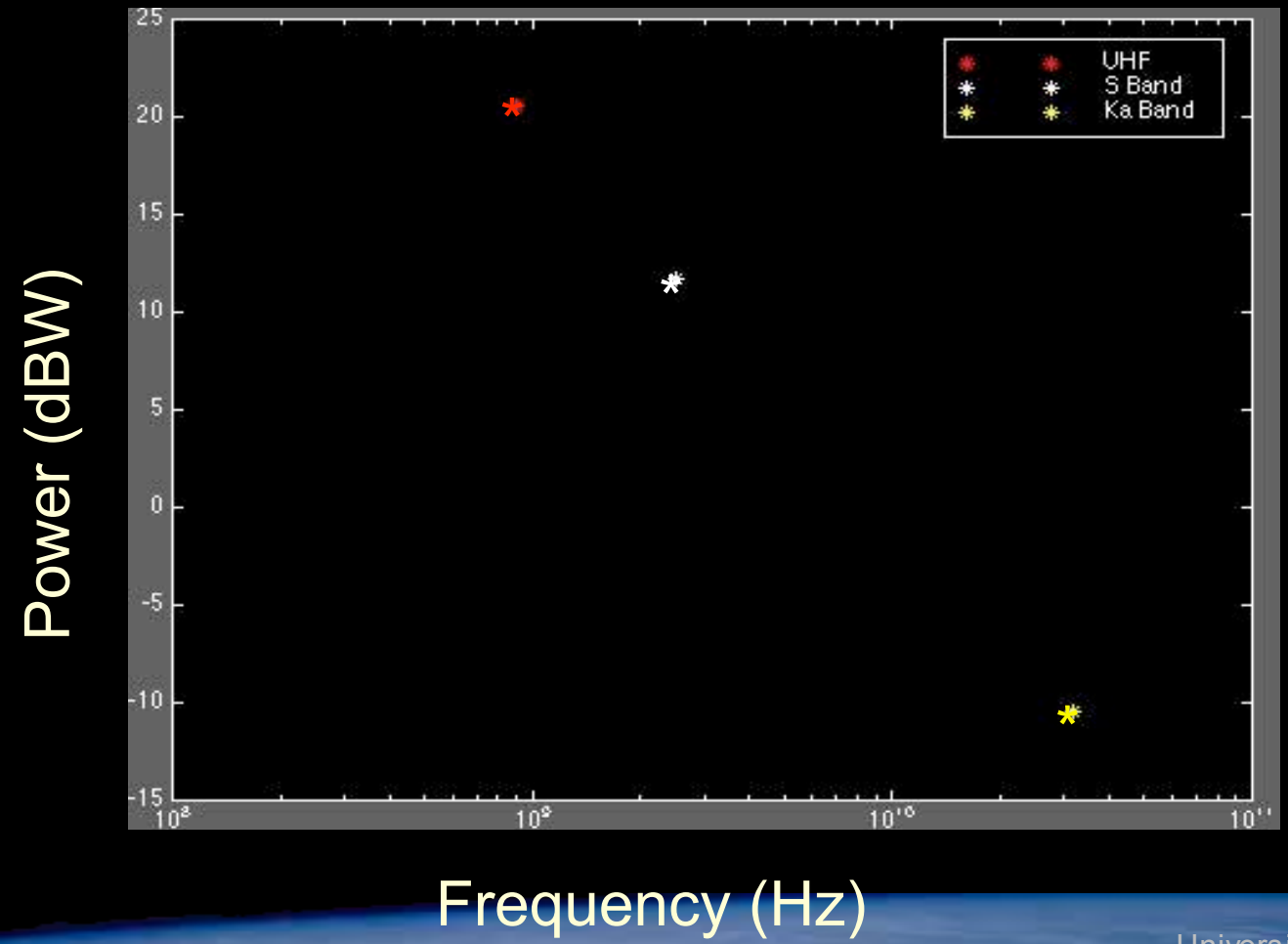
SCOUT

Communication with Other Vehicles

- To communicate with other vehicles and the hosting station at the same time, four frequencies will be used
  - Requirement A1.4.1 is fulfilled
- Any OASIS vehicle in communication with SCOUT will be within 1000 meters
  - SCOUT will be able to communicate from 1000 meters away; requirement A1.1 is fulfilled
- Second SCOUT will be at most 100 meters away
  - SCOUT will be able to communicate from 1000 meters away; requirement A1.4 is fulfilled

Emergency Communications

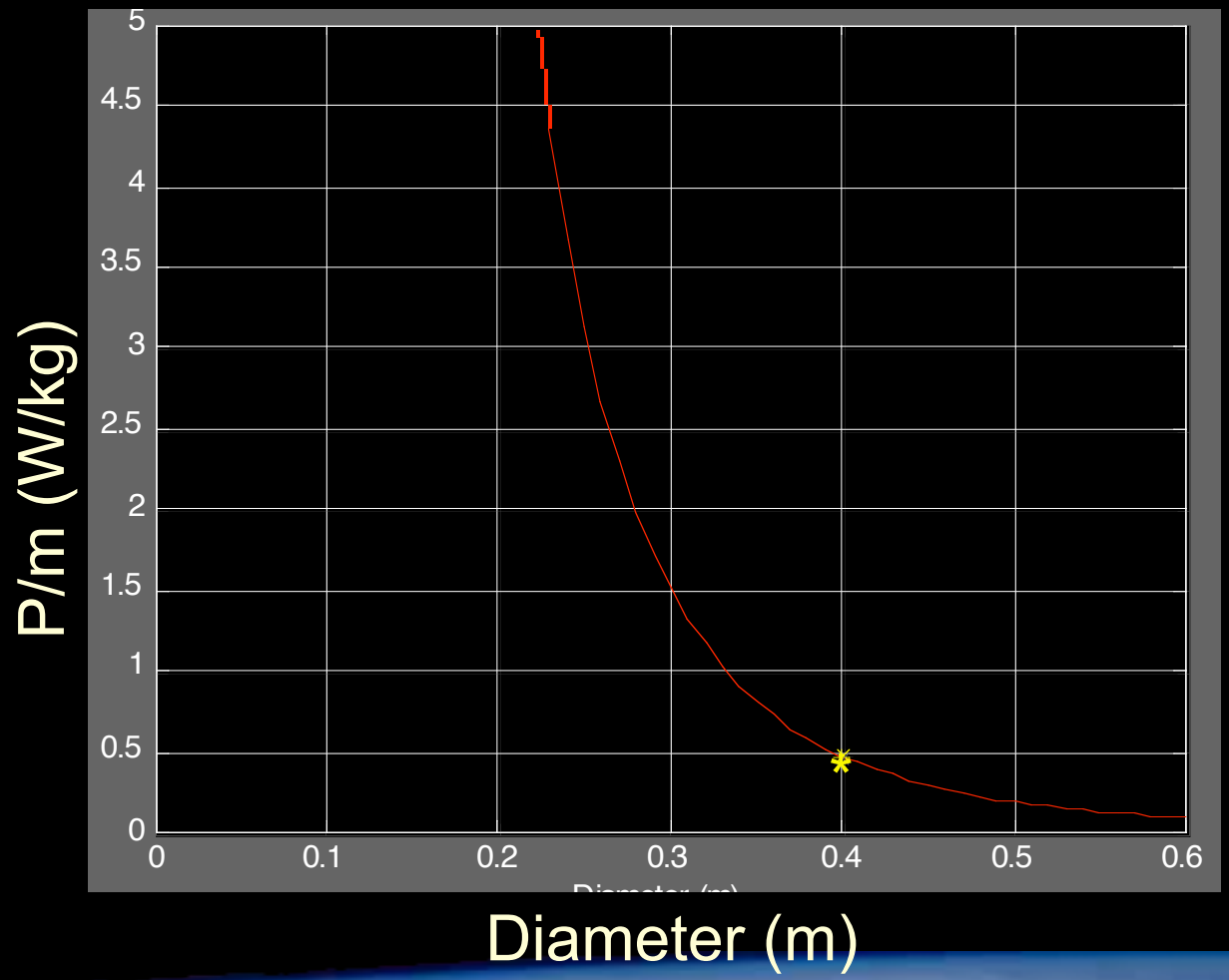
- To fulfill requirement A1.3 a Ka band antenna is selected because it requires less power



SCOUT

Ka Band Sizing

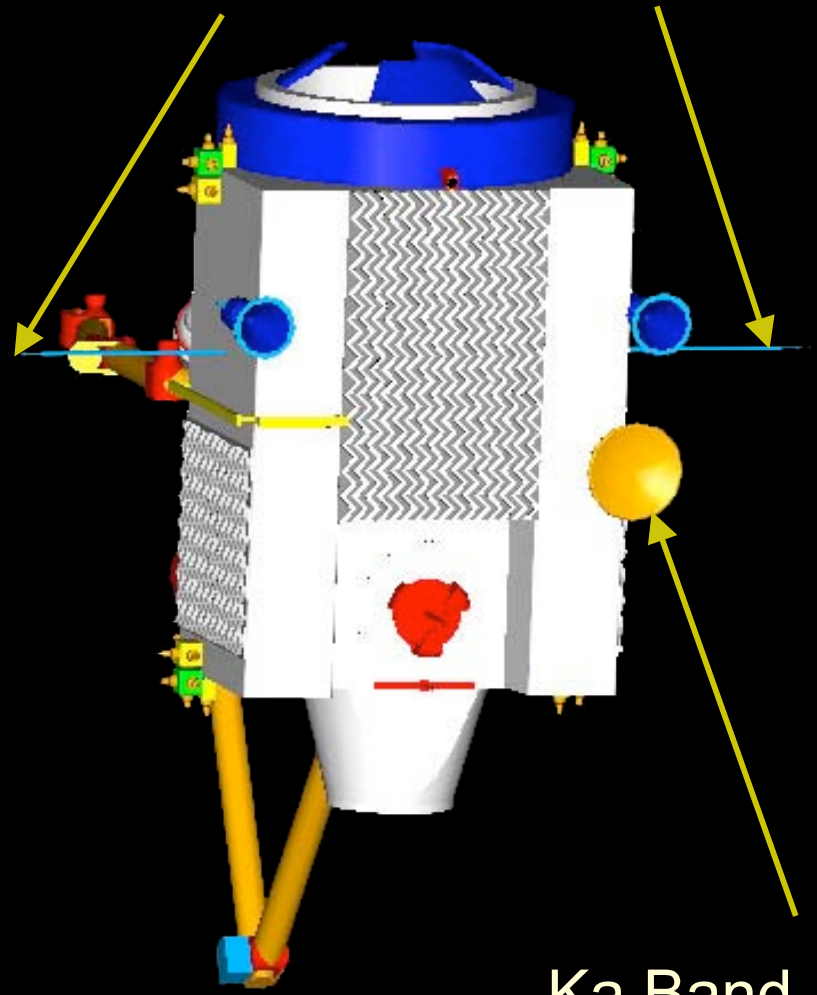
- The Ka Band Antenna will have a 0.4 meter diameter



SCOUT

Placement of Antennas

UHF Omni-Directional Antennas



Ka Band Antenna

SCOUT

SCOUT

Antenna Feasibility from Moon

Frequency	Contact	Diameter (m)	Power (W)	Feasible
UHF	Gateway	Omni	4,050,000	No
UHF	Gateway	1	51,800	No
UHF	Gateway	2	13,000	No
Ka Band	Gateway	1	3.28	Yes
Ka Band	Gateway	2	0.82	Yes
Ka Band	Earth	34	0.12	Yes

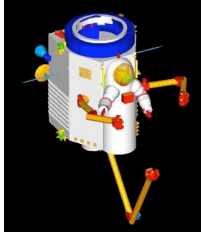
- The current Ka band antenna will be used on a mission to Lunar orbit
  - A gimbaled system is now needed to point the antenna
- Requirements AX.2 and AX.2.1 are fulfilled

SCOUT

Antenna Feasibility from GEO

Frequency	Contact	Diameter (m)	Power (W)	Feasible
Ka	Gateway	1	82.3	No
Ka	Gateway	2	20.6	Yes
UHF	Earth	34	17.1	Yes
Ka Band	Earth	34	0.001	Yes

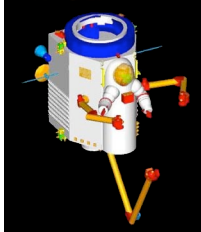
- The current Ka band antenna will be used on a mission to GEO
  - UHF will be used in an emergency situation
- Requirements AX.2 and AX.2.1 are fulfilled



SCOUT

Avionics Mass/Power Budget

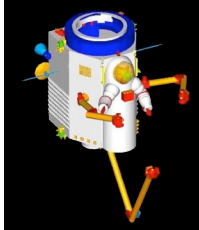
Component	Mass (kg)	Power (W)	Maturity
Star Tracker (2)	4.8	9	Measured
IFOG (2)	0.94	3	Measured
Laser Rangefinder (1)	2	15	Measured
Rendezvous Sensor (VGS-2)	10	20	Measured
Life Support Sensor I/F	0.08	3	Estimated
Propulsion Sensor I/F	0.52	4	Estimated
Power Sensor I/F	0.12	1	Estimated
Thermal Sensor I/F	0.08	2	Estimated
Structural Sensor I/F	0.12	1	Estimated
Transponding Modem (STM-2)	8	12	Measured
Power Amplifier	0.65	5	Measured
Diplexer	0.6	10	Measured
UHF Antenna (2)	2	0.00242	Calculated
Ka-Band Antenna & Gimbal Mech.	5.9	15	Calculated
Microphones	3.8	0.5	Estimated
Speakers	3.8	0.5	Estimated



SCOUT

Avionics Mass/Power Budget

Component	Mass (kg)	Power (W)	Maturity
CompactPCI Box - 6U Chassis	15	N/A	Estimated
FDCC Single-Board Computers (3)	1.65	20.4	Measured
Solid State Recorder Card (2)	1.84	12	Measured
IEEE 1394 Data Bus Card (2)	1.84	10	Measured
Video Display Graphics Card (2)	2	10	Measured
Open CompactPCI Card Slot (5)	5	30	Estimated
Crew Interface Display - 15" (2)	14.6	52	Measured
Keyboard and Hand Controllers (2)	5.35	1	Estimated
Heads-Up-Display Electronics	2	5	Estimated
Crew Interface Switches	6.3	1	Estimated
Internal and External Cameras	1.5	9	Measured
Camera Gimbals	10	30	Measured
Power Distribution Unit (3)	30	15	Estimated
Wiring Harness	50	N/A	Calculated
Total	**191**	**295**	



SCOUT

Propulsion, Power, and Thermal

Cagatay Aymergen

Matthew Beres

Nathan Moulton

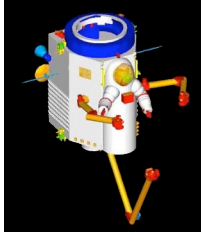
Chris Work

SCOUT

PPT Requirements

- P1: System shall provide a low-contamination (inert gas) propulsion system for operations in contamination-critical regions
- P2: Power and thermal control systems shall be non-venting.
- Secondary requirements:
  - The system shall be capable of slew rates no more than 30 deg/sec
  - Total mass for the entire propulsion system shall not exceed 500 kg

- M9: SCOUT shall provide attitude control for itself at all times, and for the grappled spacecraft being serviced. For design purposes, the reference size for a grappled target spacecraft will be assumed to be equivalent to Hubble Space Telescope
- S1: All systems shall be designed to provide a non-negative margin of safety for worst-case loading conditions incorporating the following factors of safety:
  - Secondary structure: 1.5
  - Primary structure: 2.0
  - Pressurized tanks: 3.0
  - Pressure lines: 4.0

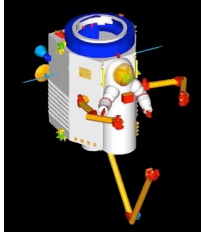


SCOUT

System Characteristics

- ΔV distribution
  - ΔV necessary for 1000m translation is 1.10m/sec
  - ΔV necessary for the rest of the mission is 70m/sec
- Propulsion Systems:
  - Hydrazine System
    - To and from the worksite
    - Translations around the worksite
    - Attitude control when mission is non-critical
    - 50% of the total ΔV
      - Pressurization system
        - » Nitrogen pressurant
        - » Elastomeric diaphragm
  - Nitrogen System
    - Docking and undocking
    - Attitude control around critical components
    - 50% of the total ΔV

Mass Estimation Relations (MER)



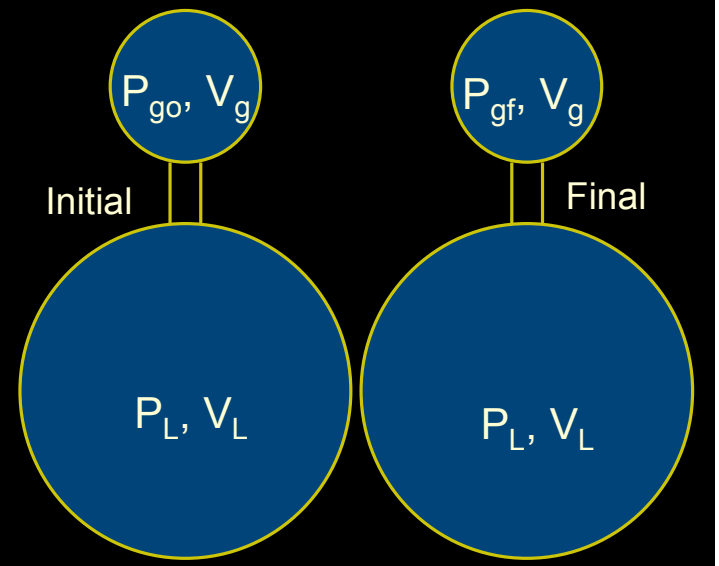
SCOUT

- Basic MER
  - Where $g_o = 9.81$
- Hydrazine Propellant:
  - ΔV = 36m/sec - Isp = 237sec
  - Mass of Hydrazine = 23kg
- Nitrogen Propellant:
  - ΔV = 36m/sec - Isp = 76sec
  - Mass of Nitrogen = 69kg
- Propellant Compensation

Propellant Inventory	Percentage	Hydrazine	Nitrogen
Total Propellant Needed (kg)	-	23	69
Off-Nominal Allowance	1.5%	0.35	1.4
Trapped Propellant	3%	0.69	2.07
Loading Uncertainty	0.5%	0.12	0.35
Reserves	25%	5.75	17.25
Total (kg)	**30%**	**30**	**91**

Pressurant MER

- Nitrogen Pressurant



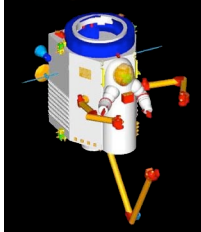
Where

- Pgo = Initial gas pressure = 27.5Mpa
- Pgf = Final gas pressure = 2.7Mpa
- PL = Operating pressure of propellant tank = 2.2Mpa
- VL = Volume of propellant tank = $0.03m^3$
- γ = Specific heat constant of Nitrogen = 1.4

– Volume of Pressurant = $0.012m^3$
  - Using density of Nitrogen at 20 ^oC and Pgo ($280kg/m^3$)

– Mass of Pressurant = 3.41kg

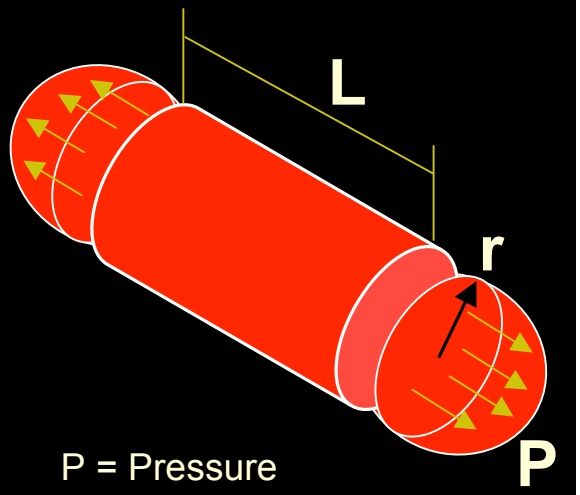
SCOUT



SCOUT

Tankage MER

- Material
  - Titanium 6Al-4V MIL-T-9046 Comp. AB1
  - Solution Treated and Aged
  - Ultimate Strength σ_y= 1.1Gpa
  - Density = 4430kg/m^3
- MER
  - Allowable stress for the tanks is
  - With a safety factor of 3, σ_a= 367Mpa
  - For a given radius r, and a volume V
  - Thickness of the tank is
  - Mass of the tanks is



P = Pressure
t = Thickness
L = Length of the barrel
r = Inner radius of the tank

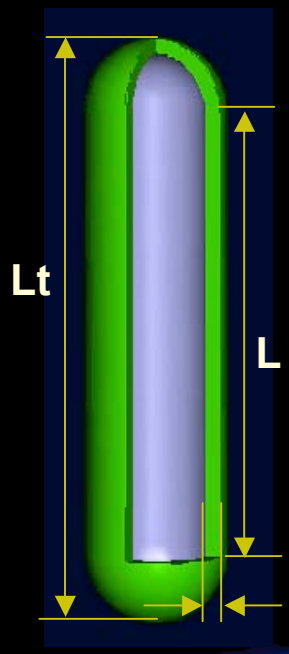
Tankage MER

- Requirements for tanks

	Nitrogen Propellant	Hydrazine Propellant	Nitrogen Pressurant
Max. Operating Pressure (Mpa)	27	2.2	27
Inner Radius (m)	0.17	0.10	0.09
Volume of the Tank (m^3)	0.32	0.03	0.012

SCOUT

Nitrogen Propellant



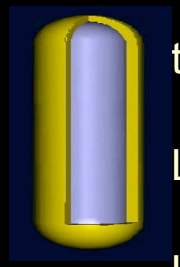
t = 0.013m

L = 1.6m

Lt = 2m

Mass = 98kg

Hydrazine Propellant



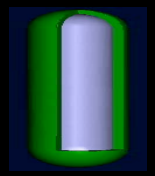
t = 0.002m

L = 0.33m

Lt = 0.5m

Mass = 1.8kg

Nitrogen Pressurant



t = 0.0071m

L = 0.09m

Lt = 0.3m

Mass = 1.7kg

* 2 tanks of each per SCOUT

Pressure Lines Diaphragms and Tank Attachments

SCOUT

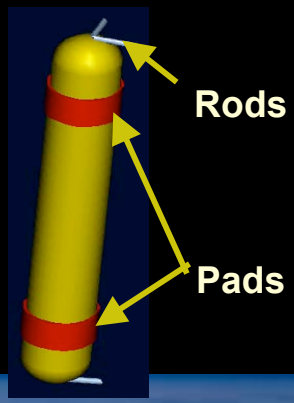
- Pressure lines
  - A similar analyses as the tankage MER analysis has been conducted with a factor of safety of 4

	Nitrogen Low Pressure Lines	Hydrazine Low Pressure Lines	Nitrogen High Pressure Lines
Max. Operating Pressure (Mpa)	2.7	2.2	27
Inner Radius (m)	0.005	0.005	0.005
Length of the Lines (estimated) (m)	15	20	5
Mass of the Lines (kg)	5	7	2

- Diaphragms with thickness t = 0.002m

= 0.234kg

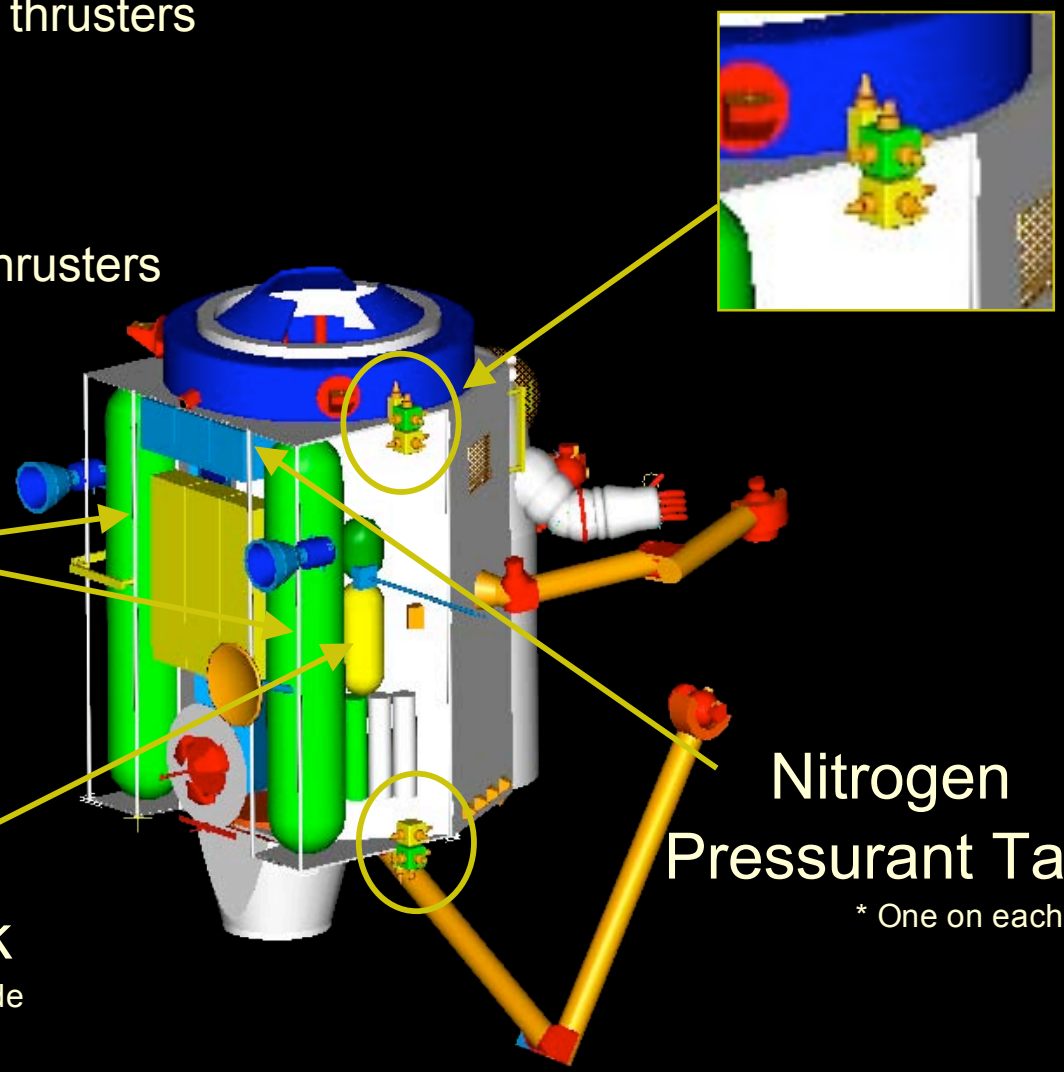
- Tank Structural Attachments
  - Pads and Rods/Hooks
  - Estimated 2% of the supported weight
    - Support for Nitrogen Propellant = 3.78kg
    - Support for Hydrazine Propellant = 0.10kg
    - Support for Nitrogen Pressurant = 0.63kg



Tank Placement

- Sixteen, 6N Hydrazine thrusters
  - –4 triads
  - –4 singles
- Sixteen, 1N Nitrogen thrusters
  - –4 quads

SCOUT

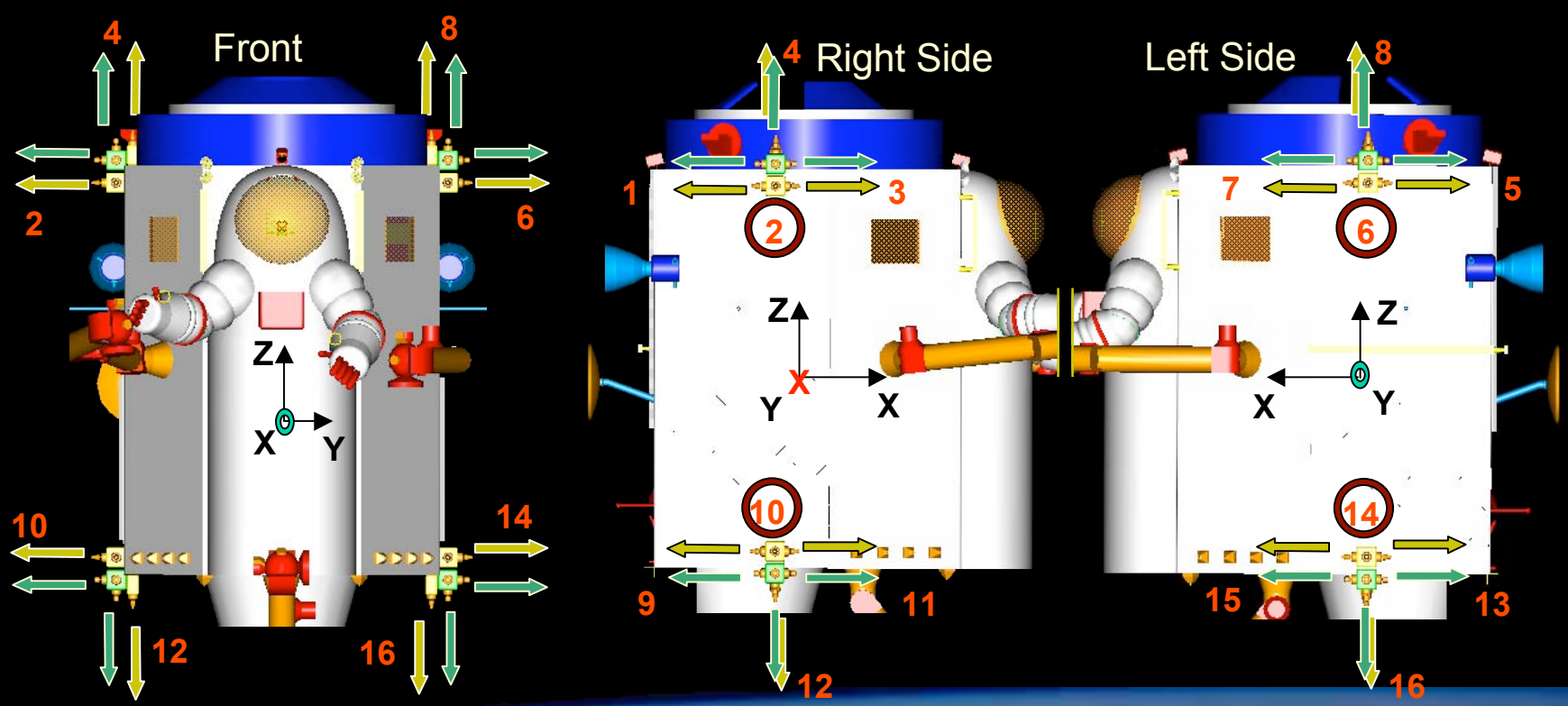


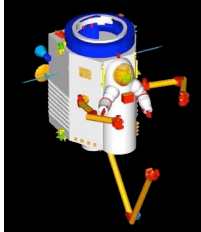
Thruster Placement and Maneuvers

- Pitch = (1+5) + (11+15)
+ Pitch = (3+7) + (9+13)
- Roll = (6+10) +/or (4+16)
+ Roll = (2+14) +/or (8+12)
- Yaw = (5+13) + (3+11)
+ Yaw = (1+9) + (7+15)

+X Trans = (1+5) + (9+13)
-X Trans = (3+7) + (11+15)
+Y Trans =(2 +10)
-Y Trans = (6+14)
+Z Trans = (12+16)
-Z Trans = (4+8)

SCOUT





SCOUT

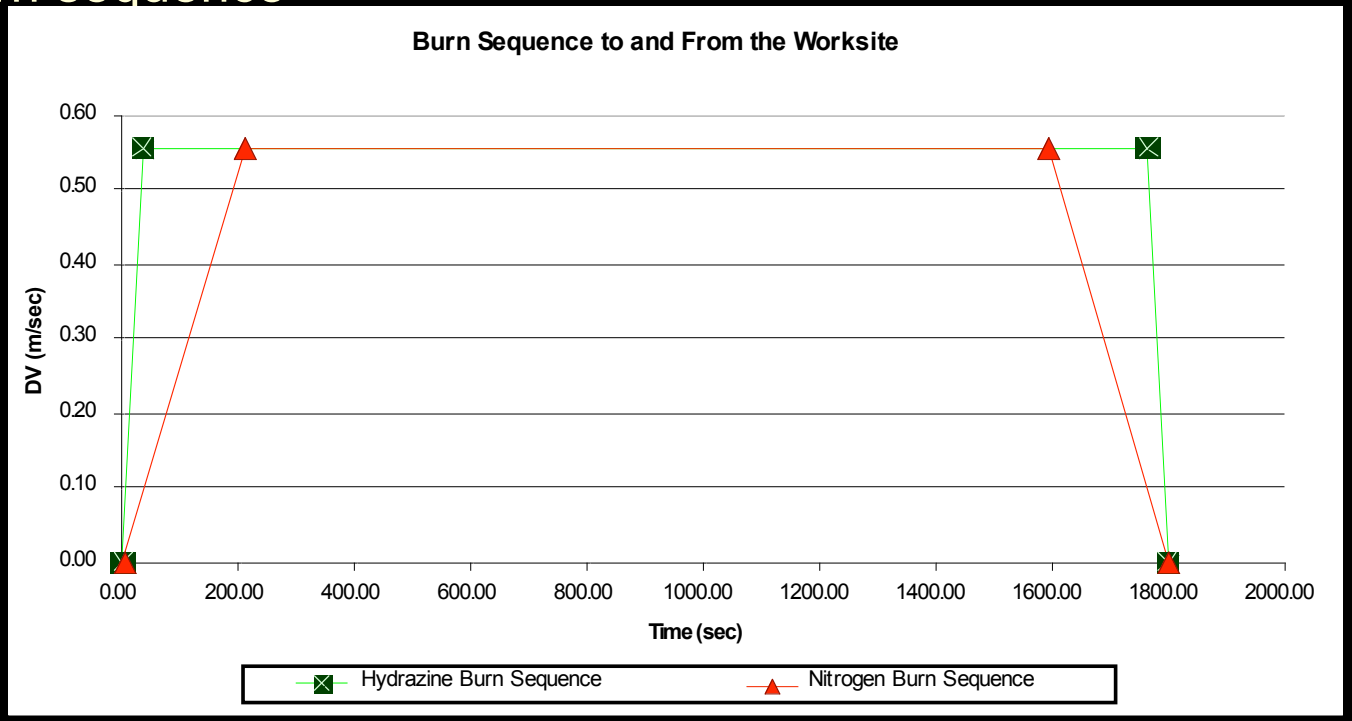
Other Components

- Four Pressure regulators
  - Max inlet pressure: 35Mpa
  - Regulated pressure: 0.1 – 3.5Mpa
  - Mass: 2.35kg each
- Sixteen isolation valves
  - Mass: 2.35kg each
- Twenty Flow control valves
  - Mass: 0.420kg each
- Relief valves
- Heaters
  - Line heaters
  - Thrust chamber heaters
  - Catalyst be heaters
- Filters

* All components are readily available and can be improved upon in the upcoming years

Trip To the Worksite

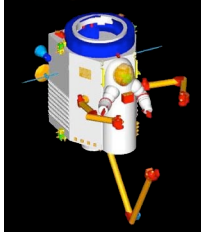
- Burn sequence



	Hydrazine: Time (sec)	V	Nitrogen: Time (sec)	V
Initial Burn	0.00	0.00	0.00	0.00
Cut-Off	35	0.56	208	0.56
Final Burn	1765	0.56	1592	0.56
Cut-Off	1800	0.00	1800	0.00

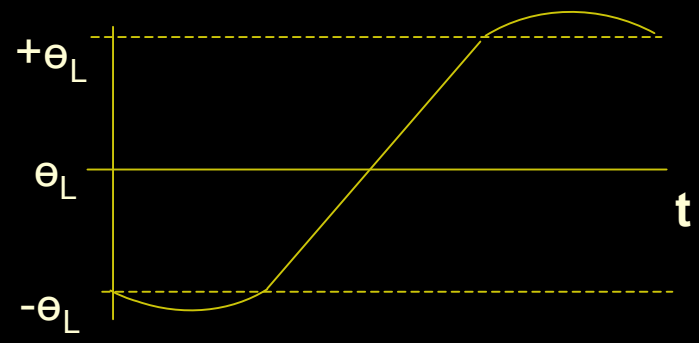
SCOUT

Limit Cycles and External Torques



SCOUT

- Limit Cycles
  - Length of each cycle (t_c)
  - Propellant consumption per cycle
  - Propellant consumption per second

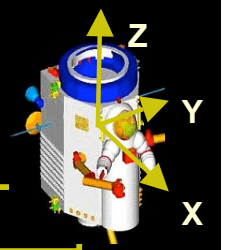


Where
- θ_L = Angular limit
- I_V = Moment of inertia of the vehicle
- n = Number thrusters firing
- F = Force of the thrusters
- P_w = Minimum impulse width
- I_{min} = Minimum impulse bit
- L = Moment arm

- External Torques
  - With an applied external torque, T_e, and a Torque, T, created by the thrusters (assuming T_e is an impulse load)
    - Burn time necessary to counteract T_e is a function of velocity achieved with T over the acceleration achieved with T_e

Control of SCOUT

	X	Y	Z
Moment of inertia of the vehicle (kg-m^2)	1520	1650	1000



- Limit Cycles - Dead Band width is 3% of 360° (θ_L = 0.19 rad)

	Hydrazine			Nitrogen		
	X	Y	Z	X	Y	Z
Moment arm (m)	0.7	0.85	0.8	0.95	0.95	0.8
Number of thrusters	2	4	4	2	4	4
Minimum impulse bit (Imin) (Nsec)	0.3	0.3	0.3	0.1	0.1	0.1
Minimum impulse width (Pw) (sec)	0.05	0.05	0.05	0.1	0.1	0.1
Total limit cycle time (min)	**46**	**20**	**13**	**100**	**54**	**39**
Propellant consumption per second (kg/cycle)	**0.051**	**0.010**	**0.010**	**0.051**	**0.011**	**0.011**

- Slew Rates – Minimum time to rotate 180°

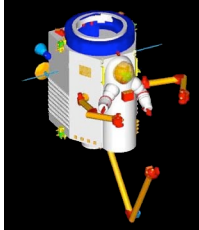
Number of thrusters	4	4	4	4	4	4
Total limit cycle time (sec)	**34**	**32**	**26**	**71**	**74**	**63**
Slew rate (deg/sec)	**11**	**11**	**14**	**5**	**5**	**6**

- External Torques – maximum of 380 Nm for 0.05 sec

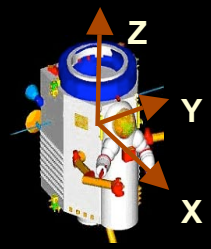
Acceleration due to thruster torque (m/sec^2)	0.011	0.013	0.02	0.0025	0.0023	0.0038
Velocity induced by external torque	0.25	0.23	0.38	0.125	0.115	0.19
Burn time to recover (sec)	**11.3**	**9.31**	**9.31**	**50**	**50**	**50**

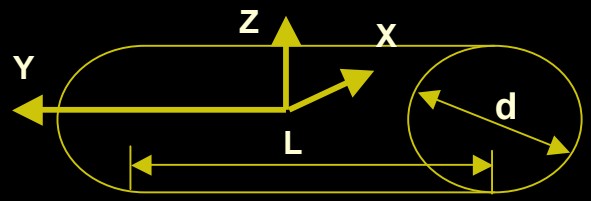
SCOUT

Control of Worksite



- Hubble
  - Mass = 11110kg
  - Length L = 15.9m
  - Diameter d = 4.2m





	X	Y	Z
Moment of inertia of the vehicle and Hubble (kg-m^2)	260000	37000	260000

- Limit Cycles - Dead Band width is 3% of 360º (e_L = 0.19rad)

	Hydrazine			Nitrogen		
	X	Y	Z	X	Y	Z
Moment arm (m)	0.85	23	2.3	0.95	2.3	2.3
Number of thrusters	2	4	4	2	4	4
Minimum impulse bit (Imin) (Nsec)	0.3	0.3	0.3	0.1	0.1	0.1
Minimum impulse width (Pw) (sec)	0.05	0.05	0.05	0.1	0.1	0.1
Total limit cycle time (min)	**6406**	**168**	**1183**	**8598**	**505**	**3551**
Propellant consumption per second (kg/cycle)	**0.005**	**0.010**	**0.010**	**0.011**	**0.011**	**0.011**

- Slew Rates – Minimum time to rotate 180º

Number of thrusters	4	4	4	4	4	4
Total limit cycle time (min)	**7**	**2**	**4**	**16**	**4**	**10**
Slew rate (deg/sec)	**0.8**	**4**	**1.5**	**0.4**	**1.7**	**0.6**

SCOUT

Hydrazine System Schematic

SCOUT

- Fill and Drain Valve
- Flow Control Valve Normally Closed
- Flow Control Valve Normally Open
- Filter
- Thrust Chamber Valve (TCV)
- Valve Branch A
- Valve Branch B
- Heater
- (P) Pressure
- (T) Temperature
- Thruster
- Isolation Valve

Top Left Panel: (T8), (T6), (T7), (T5)

Bottom Left Panel: (T16), (T14), (T15), (T13)

GN_2 (P) (T)

N_2H_4 (P) (T)

GN_2 (P) (T)

N_2H_4 (P) (T)

1A 4A 1B 4B 2 5 3A 6A 3B 6B

Top Right Panel: (T4), (T2), (T3), (T1)

Bottom Right Panel: (T12), (T10), (T11), (T9)

Valve Heaters

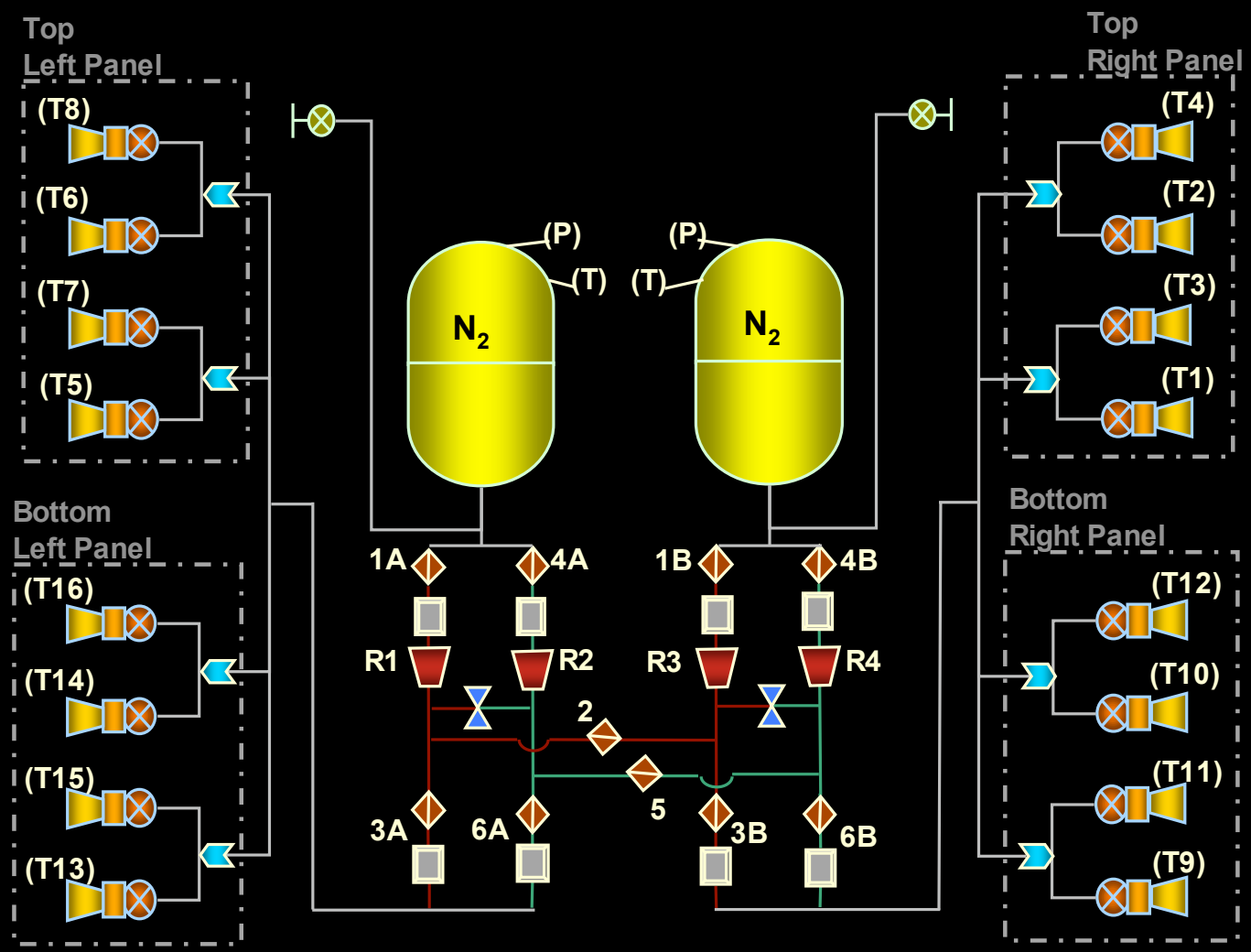
Line Heaters

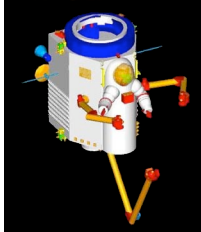
Catalyst Bed Heaters

Nitrogen System Schematic

SCOUT

- Fill and Drain Valve
- Flow Control Valve Normally Closed
- Flow Control Valve Normally Open
- Filter
- Thrust Chamber Valve (TCV)
- Valve Branch A
- Valve Branch B
- Heater
- (P) Pressure
- (T) Temperature
- Thruster
- Isolation Valve
- Pressure Regulator
- Relief Valve





SCOUT

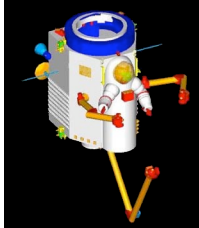
System Failure Tolerance

- Hydrazine and Nitrogen

Failure	Corrective Action	Mission Effects
Leakage below valve 3A	Close valve 3A	NONE
Leakage above valve 3A	Close valve 1A and valve 2	NONE
Leakage below valve 3B	Close valve 3B	NONE
Leakage above valve 3B	Close valve 1B and valve 2	NONE
Valve 2 failure – on or off	Close 1A and 1B	NONE
Leakage below valve 6A	Close valve 6A	NONE
Leakage above valve 6A	Close valve 4A and valve 5	NONE
Leakage below valve 6B	Close valve 6B	NONE
Leakage above valve 6B	Close valve 4B and valve 5	NONE
Valve 5 failure – on or off	Close 4A and 4B	NONE
Thrust chamber failure	Close corresponding isolation valve	NONE
Thruster failure	Close corresponding isolation valve	NONE

- Nitrogen only

Failure	Corrective Action	Mission Effects
Regulator 1 (R1) failure	Close valve 1A	NONE



SCOUT

Mass Budget

Components	Unit Mass (kg)	No.	Total Mass (kg)
Hydrazine	30	-	30
Nitrogen	91	-	91
Nitrogen	3.4	-	3.4
Tank: Hydrazine	1.8	2	3.6
Tank: Nitrogen	98	2	196
Tank: Nitrogen (Pressurant)	1.7	2	3.4
Hydrazine Lines	7	-	7
Nitrogen Low Pressure Lines	5	-	5
Nitrogen High Pressure Lines	2	-	2
Hydrazine Thrusters (6N)	1.50	16	24
Nitrogen Thrusters (1N)	1.50	16	24
Diaphragms	0.23	2	0.46
Structural Attachments	4.5	-	4.5
Pressure Regulators	2.4	4	9.6
Isolation Valves	2.4	16	38
Flow Control Valves	0.42	20	8.4
Misc. (Filters, Relief Valves, Heaters… etc.)	20.0	-	20.0
Total			**469**

Docking Module Propellant Storage

SCOUT

- Nominal Schedule (min ΔV):
  - 30 Sorties/ 2 SCOUTs/ 6 months

Total ΔV / Sortie (m/sec)	Propulsion Description	%
0	RMS Controlled	10
35	Limited Req'd Maneuvers	40
70	Max Design Maneuvers	50

- Nominal Schedule (max ΔV):
  - 30 Sorties/ 2 SCOUTs/ 6 months
  - SCOUT exhausts all N_2 / N_2H_4 propellants each sortie
  - (ΔV ~ 70m/sec)

- Aggressive Schedule (max ΔV):
  - 60 Sorties/ 2 SCOUTs/ 6 months
  - SCOUT exhausts all N_2 / N_2H_4 propellants each sortie
  - (ΔV ~ 70m/sec)

Docking Module Propellant Storage

SCOUT

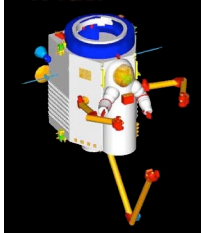
For 6 months:

	Nom Schedule (Min ΔV)	Nom Schedule (Max ΔV)	Aggr Schedule (Max ΔV)
Mass N_2	1908kg	2726kg	5452kg
Mass LN_2 Tanks	70kg	99kg	196kg
# LN_2 Tanks/ diameter	8/1.2m	8/1.3m	12/1.5m
Mass N_2H_4	622kg	888kg	1776kg
Mass N_2H_4 Tanks	55kg	78kg	153kg
# N_2H_4 Tanks/ diameter	3/0.74m	3/0.82m	3/1.04m

SCOUT

Design Requirements

- Storage tanks must be able to hold fuel required for six months
- Tanks must be lightweight
- Provide for volume considerations
- Provide for temperature/pressure constraints
- Pressurized tanks have FOS of 3
- Provide for less than 5 hr. refueling time (extended sortie mission)



SCOUT

Generalized Tank Calculations

- Find volume
- The radius of the tank can be determined from:

$$r=(V*(3/4)*\pi)^{1/3}$$

- Determine thickness:

$$t=((P*r)/\sigma_h)*FOS$$

- Volume of tank material is calculated:

$$V_{tank}=4*\pi*r^2*t$$

- Find mass of tank:

$$M_{tank}=V_{tank}*\rho_{material}$$

SCOUT

Material Properties

- Aluminum
  - Density of 2.80g/cm^3
  - Tensile Strength of 455MPa
- Carbon Composites
  - Density of 1.8g/cm^3
  - Tensile Strength of 6895MPa
- Titanium
  - Density of 4.60g/cm^3
  - Tensile Strength of 1241MPa

N_2 Tanks

- Spherical Composite Cryogenic Tanks
- Aluminum inner liner
- 8 tanks, each with a volume of 0.850m^3
- Each tank is 9.37kg
- Consistent with Hybrid Propellant Module (HPM) values
- Pressurant tank is 26.08kg, radius is 0.35m to hold 0.185m^3

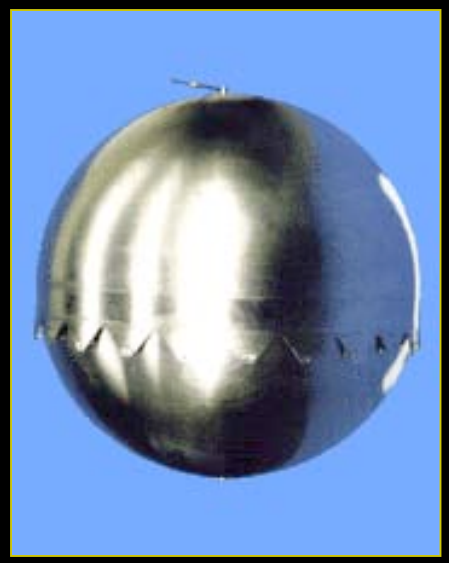
Courtesy of Microcosm

Courtesy of Microcosm

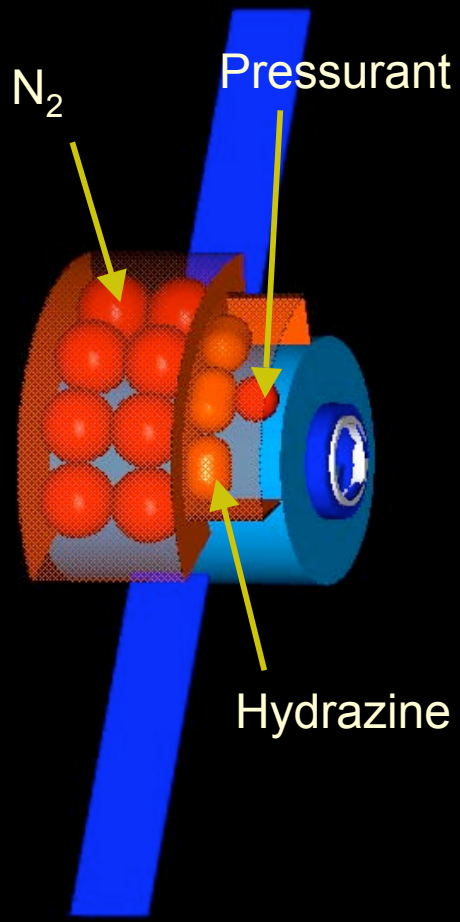
Hydrazine Tanks

SCOUT

- Three spherical titanium pressure vessels
- Volume is 0.639m^3
- Radius is 0.534m
- Thickness is 0.33cm
- Mass is 58.1kg



Astria Space Infrastructure



Thermal Insulation

SCOUT

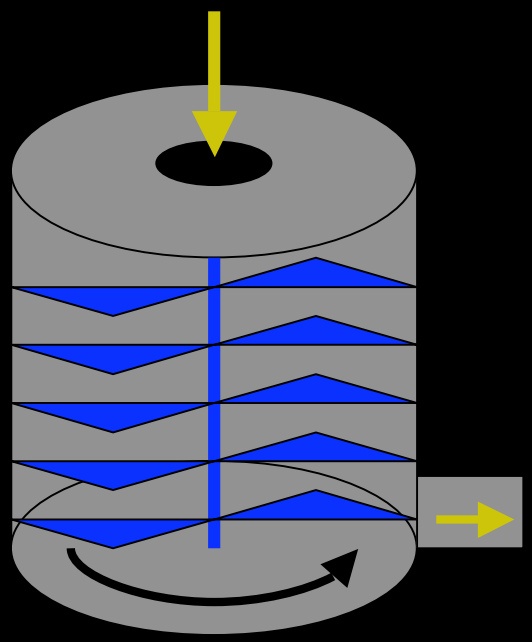
- Perforated double aluminized Mylar separated with polyester net spacers
- 30 ply is 7mm thick (MLI)
- Provides 0.029mW/m-k thermal conductivity
- Reflective outer surface coating to minimize heat from sunlight

Niels Bohr Institute for Astronomy, Physics and Geophysics

Turbomolecular Gas Pump

- Used to pump N_2 and pressurant from storage to SCOUT tanks
- Vibration issues

SCOUT



Kurt J. Lesker Company

SCOUT

In-Flight Refueling of Hydrazine

- When docked, SCOUT vents pressurant (N_2 gas) to space
- Valve between SCOUT pressurant tank and SCOUT hydrazine tank and the valves between hydrazine storage and SCOUT hydrazine tank open, creating vacuum
- Vacuum sucks bladder up into its start position, sucking hydrazine from storage tank into hydrazine fuel tank
- Valves between SCOUT hydrazine and pressurant tank closes when hydrazine tank is full, and valves between SCOUT hydrazine tank and storage are closed and purged
- SCOUT pressurant tank valve closes
- Valve between pressurant storage and SCOUT pressurant opens, and pressurant is refilled from storage on docking module
- Pressurant valves for storage and SCOUT pressurant tanks close

In-Flight Refueling of Hydrazine

SCOUT

- N_2H_4 refuel rate of 0.01m^3/min less than what was demonstrated could be achieved during the Vented Tank Resupply Experiment (VTRE) flown aboard STS 77 (2.73gal/min)
- Hydrazine Refueling Summary:
  - 2 Step Refueling: N_2H_2 refuel → N_2 pressurant refuel
  - N_2 pressurant refueling rate ~ 0.01m^3/min
  - N_2 pressurant total refueling time ~ 20min
  - N_2H_4 refueling rate ~ 0.01m^3/min
  - N_2H_4 total refueling time ~ 70min

Total Refueling Time = 1 hour

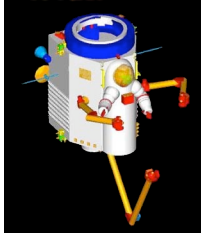
NASA

- N_2H_4/N_2 Pressurant Refueling Time < 11hrs (nominal sortie)
  < 5hrs (extended sortie)

SCOUT

In Flight Refueling of Nitrogen

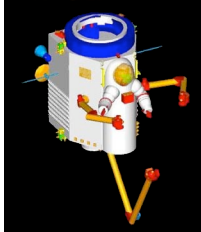
- When docked, N_2 pressure inside SCOUT N_2 fuel tank is sensed and relayed to the Gateway docking module
- Valves between N_2 fuel tank and N_2 storage open
- Pressure from pump connected to storage tank pushes N_2 into SCOUT N_2 fuel tank until full
- Valves between N_2 fuel tank and storage tank close



In Flight Refueling of Nitrogen

- N_2 gas flow will be $0.1 m^3/min$ and will be controlled by a gas mass flow controller
- N_2 gas Refueling Summary:
  - N_2 gas refueling rate ~ $0.1 m^3/min$
  - N_2 gas total refueling time ~ 70min
- N_2H_4 /N_2 Pressurant Refueling Time
  - <11hrs (nominal sortie)
  - <5hrs (extended sortie)

SCOUT



SCOUT Power System Requirements

SCOUT

- Base-Load Power Requirements:
  - Loads assumed constant throughout mission duration
  - Loads assumed safety-critical

System	Power Required (W)
Loads, Structures, and Mechanisms	240
Life Support and Human Factors	295
Avionics	295
Power, Propulsion, and Thermal	85
Total	**915**

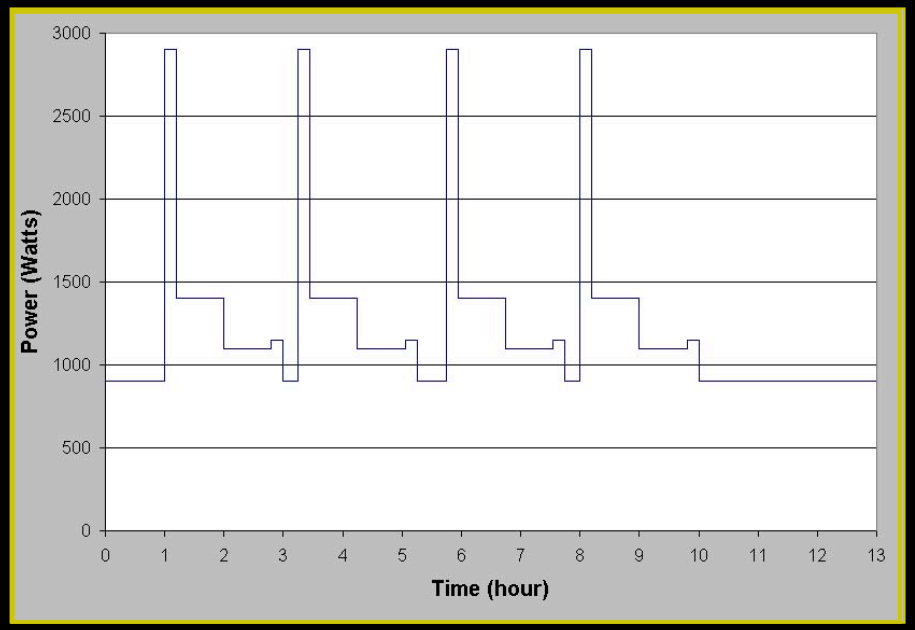
- Peak-Load Power Requirements (for 2hr work period):
  - Loads vary throughout work period
  - Loads not safety-critical

Arm/ Type Operation	Time (hr)	Power Required (W)
Task/ Max Draw (2)	0.2	2000
Task/ Maneuvering (2)	0.8	400
Task/ Position Hold (2)	0.8	200
Grapple/ Maneuvering	0.2	250

SCOUT Power System Requirements

SCOUT

- Design Cycling Description: 30 sorties/ 6 months
- Power system lifetime > 1 year
- Recharge/ resupply via the docking ring interface
- Maximum of 11 hours for recharge/refill between each sortie
- Nominal Sortie Length with 2-hr reserve = 13 hour
- Nominal Sortie Power Required vs. Time Curve (below):



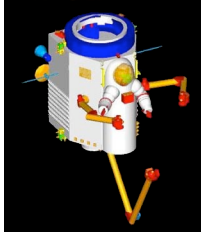
Total Energy ~ 15,420W*h

Nominal Power ~ 900W

Peak Power ~ 2900W

Nom Discharge Rate (@ 100V) ~ 9A

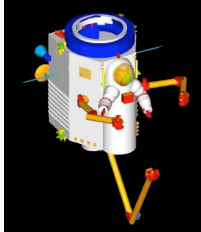
Max Discharge Rate (@ 100V) ~ 29A



SCOUT Power Systems Considered

SCOUT

- Secondary Battery Systems
- Fuel Cell Systems
- Solar Arrays/ Secondary Battery Systems (NOT VIABLE):
  - Inflexible to mission tasks
  - Overly cumbersome (A_{req} = 3.7m^2, Square → 1.92m x 1.92m)
    - Assuming Ga-As Solar Panels: η_{eff} = 23 %
    - Assuming sunlight available entire 13 hours: I_s = 1394W/m^2
    - Assuming total energy evenly distributed over 13 hrs: P_{avg} = 1186W
- Flywheel Energy Storage (NOT VIABLE):
  - A flywheel unit of the large storage capacity required (~23.3kW*hr) will not be at a TRL of 3 by 2005
- RTG (NOT VIABLE):
  - RTG's yield too high a radiation risk to crew in an already high radiation environment



Secondary Battery Systems

SCOUT

- Battery Chemistries Considered:
  - Ni-MH
  - Ni-H_2
  - Li-Ion (state of the art)
  - Li-Polymer (near-future state of the art)
- Nominal Sortie System Requirements/ Performance:
  - Total Energy Required = 15,420W*hr
- Battery Analysis Method:
  - Determine total energy for each battery necessary to provide 2-fault tolerance
  - Determine Energy Density, taking into account loss mechanisms
  - Use redefined Energy Density to determine system mass and volume
- Battery Capacity Loss Mechanisms Evaluated:
  - Maximum Depth of Discharge (DOD%)
  - Non-optimal operating temperature (TL%)
  - Self-discharge (SD%)
  - Non-optimal rate of charge/ discharge (D%)
  - Cycling (CL%)
  - Memory effects (ME%)

SCOUT

Secondary Battery Systems

- Total Energy Required/ Battery to Provide 2-Fault Tolerance:
  - Worst-Case condition = 2 failures at end of nominal 11-hour sortie
  - Assume each battery depleted equally (parallel operation)
  - Energy remaining in each battery at end of 11-hour reference sortie:

    Energy Remaining/ Battery = (900W*2 hr)/3 = 600W*hr

  - Safety-critical baseload of 900W required for 2 hours
  - Additional Energy needed per battery:

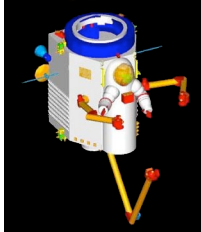
    ΔE Needed/ Battery = (900W*2 hr) – 600W*hr = 1200W*hr

  - Pad with extra 150W*hr to permit robot arm operations and off-nominal conditions:

    Total ΔE required = 1200W*hr + 150W*hr = 1350W*hr

  - Total Energy Needed/ Battery:

    Total Energy Required/ Battery = 6490W*hr



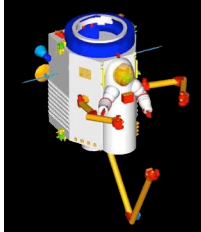
SCOUT

Secondary Battery Systems

- Battery Analysis Assumptions:
  - Superposition applies for each of the loss mechanisms above relative to nominal capacity condition
  - Self-discharge occurs linearly over time
  - Capacity losses obtained through correlation of data provided by vendors (data from Saft, Ultralife, and Chung Pack analyzed)
  - 15% increase in predicted values of mass and volume due to packaging

Battery Chemistry	EOL/Worst-Case Conditions Energy Density (W*hr/kg)	EOL/Worst-Case Conditions Energy Density (W*hr/L)
Ni-MH (Chung Pack)	29	74
Ni-H2 (Saft)	32	41
Li-Ion (Ultralife)	98	247
Li-Polymer (Ultralife)	80	164

Fuel Cell Systems



SCOUT

- Fuel Cell Reactor Types Considered:
  - Alkaline (Shuttle UTC Fuel Cell):
    - 6160W power output

      Mass = 115.7kg LOX Rate = 1.81kg/hr

      Volume = 0.14m^3 LH2 Rate = 0.27kg/hr
  - PEM (based on Gemini and current terrestrial models)
    - 3500W power output

      Mass < 60kg LOX Rate = 1.17kg/kW*hr

      Volume < 0.15m^3 LH2 Rate = 0.18kg/kW*hr
  - Regenerative Fuel Cell (HELIOS Flying Wing):
    - Electrolyzer:

      Mass = 10.5kg Volume < 0.004m^3
    - Reactor:

      Mass = 10.8kg Volume < 0.005m^3
    - Reactant Rates:

      LOX Rate = 1.81kg/hr LH2 Rate = 0.23kg/hr

Fuel Cell Systems

SCOUT

- Fuel Tank Properties:
  - Small LOX Tank (based on Gemini and Shuttle tanks):

    Mass = 14.5kg Volume = $0.07m^3$ Holds 57kg of LOX

  - Small LH2 Tank (based on Gemini and Shuttle tanks):

    Mass = 22.5kg Volume = $0.19m^3$ Holds 9kg of LH2

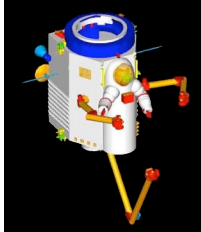
- H_20 Tank Properties:
  - Fuel Cell Reaction Chemistry:

    $$H_2 + (1/2)O_2 \text{ ---> } H_2O$$

  - Based on reactant flow rates given for Shuttle Fuel Cell:

    $0.001m^3$ H_2O produced/ 1kg LOX consumed

  - V_{H2O} ~ 0.006m3 for Shuttle Fuel Cells
  - m_{H2O} ~ 0.5kg (arbitrarily chosen---> V_{H2O} very small)



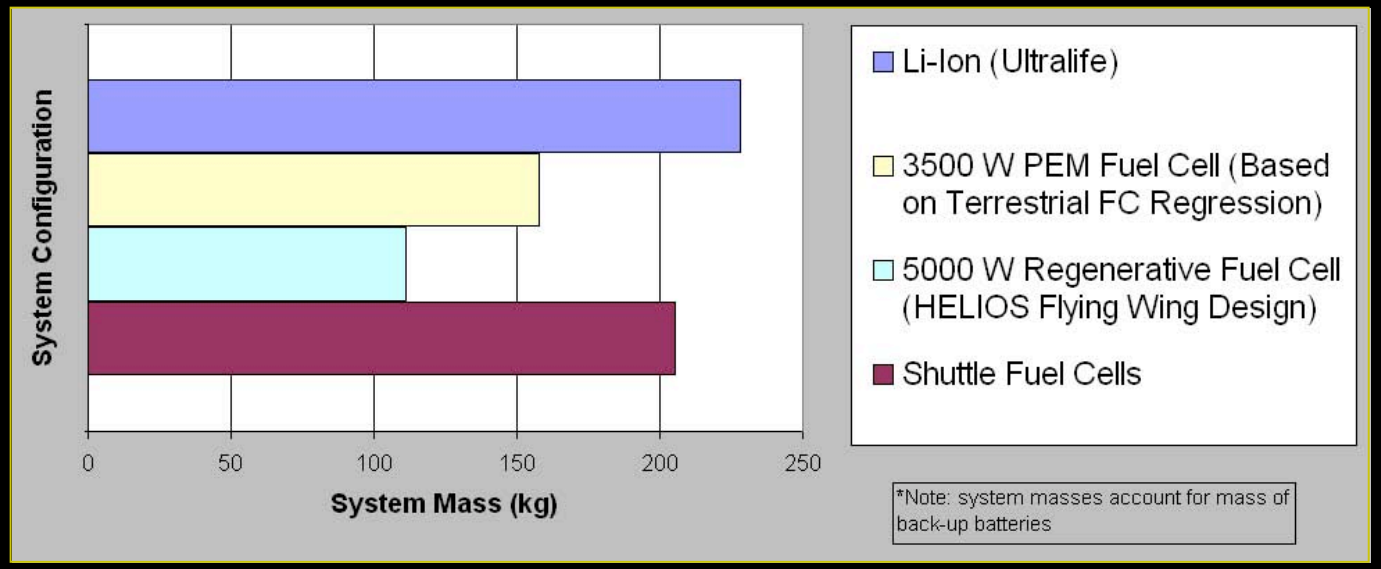
SCOUT

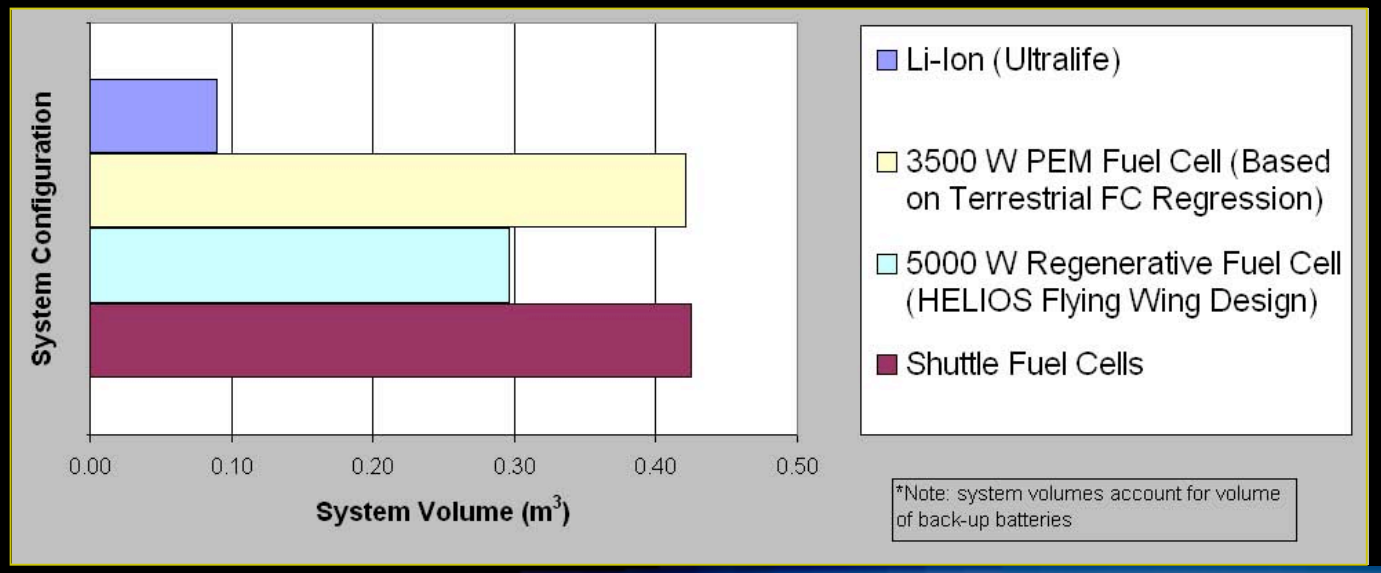
Fuel Cell Systems

- Back-Up Batteries (for 2-Fault Tolerance):
  - Li-Ion batteries baselined for back-up batteries because:
    - Do not require venting
    - Sufficient storage life (1 year)
    - May be trickled-charged to counter self-discharge
    - May be reconditioned periodically
    - Relatively high energy density (98W*hr/kg)
  - Each back-up must provide 900W for 2 hr (+150W*hr padding to permit robot arm operations and off-nominal conditions)
  - Assuming a 15% increase in mass and volume due to packaging:

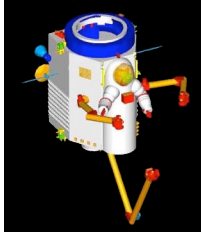
Mass/ Battery = 23kg	Total Mass = 46kg
Volume/ Battery = $0.01m^3$	Total Volume = $0.02m^3$

Performance Comp of SCOUT Power Systems





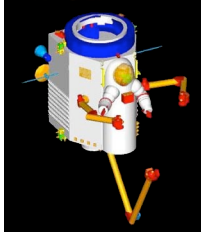
SCOUT



SCOUT Power System Conclusions

SCOUT

- Li-Ion are the best performing cells under worst-case EOL conditions:
  - Ni-MH, Ni-H_2 presumed cost benefits do not justify the increase in system mass of ~207-239% (relative to Li-Ion)
  - Li-Polymer cells might be re-examined in future to see if anticipated performance characteristics achieved
  - For now Li-Ion cells should be considered as baseline for secondary battery type
- Mass savings of 10-30% for standard fuel cells do not justify their use:
  - Volume increases by nearly 367% (relative to Li-Ion)
  - Purging/venting required every 12 hours
  - Inter-flight servicing is required
  - OASIS infrastructure, while supporting LOX/LH_2 resupply, may not be capable of refueling the very small cryo tanks on SCOUT
  - 25 minute warm-up time needed before mission start
  - Water storage tanks need to be emptied after each mission



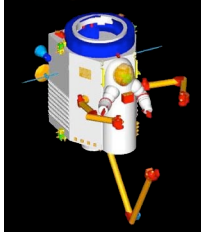
SCOUT Power System Conclusions

SCOUT

- Viability of Regenerative Fuel Cells undetermined:
  - Mass savings of nearly 50% (relative to Li-Ion)
  - Volume increases by nearly 170% (relative to Li-Ion)
  - Purging/venting requirements unknown
  - Inter-flight servicing requirements unknown
  - Warm-up time unknown
  - Electrolyzer draws large amount of power, the duration of this process unknown
  - Closed-loop system eliminates cryogenic refueling issues

*Li-Ion batteries should be used for the nominal mission power storage

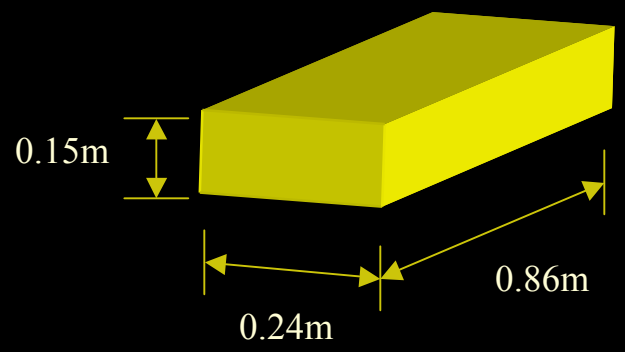
*Li-Polymer batteries and Regenerative Fuel Cells should be reevaluated against baseline Li-Ion system as new information and research emerges



SCOUT Power System

SCOUT

- Rechargeable Li-Ion Battery System:
  - 3 Independent Li-Ion Batteries:
    - Total EOL Energy/ Battery ~ 6490W*hr
    - Total Mass / Battery ~ 76kg
    - Total Volume / Battery ~ $0.03m^3$



    - Scaling Issues:
      - Current design based on ~1A*hr capacity cells
      - Larger cells ~45A*hr developed for EMU (Yardney)
        - » Cells can be made to nearly any dimension
        - » Nominally performance appears similar to the Ultralife Li-Ion cells, but data on loss mechanisms limited

SCOUT Power System

SCOUT

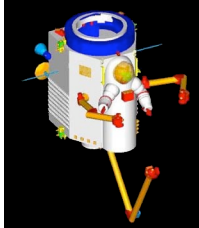
– Power System Requirements Summary:

	Nominal Sortie
Peak Power Required	2900W
Nominal Discharge Rate Required	9A @ 100V DC
Maximum Discharge Rate Required	29A @ 100V DC
Max Charge Time Allowed	11 hours

– Li-Ion Nominal Operation Mode (3 Battery Systems):

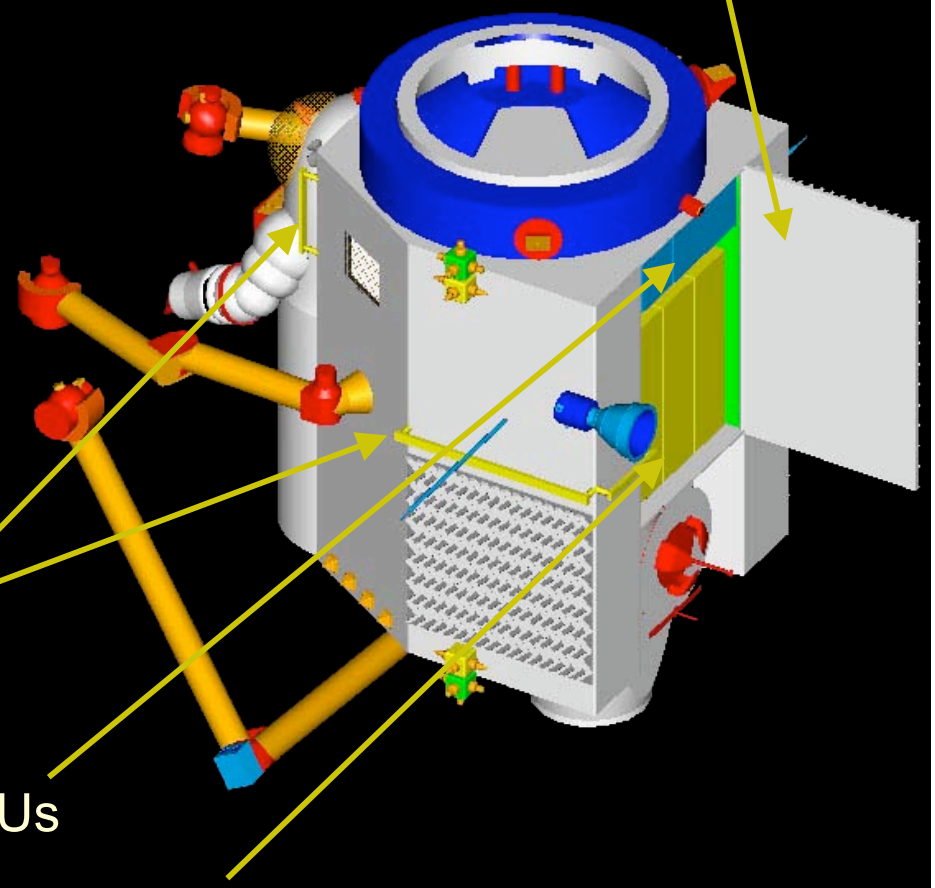
	No Fail	1 Fail	2 Fail
Li-Ion Peak Power Available	18.7kW	12.4kW	6.2kW
Li-Ion Nom Discharge Rate (@100 V DC)	14A	10A	5A
Li-Ion Max Pulse Discharge Rate (@ 100 V DC)	187A	124A	62A
Li-Ion Nom Charge Time	8.3 hrs	-	-
Li-Ion Nom Operating Temperature (+/- 10 K)	293K	-	-
System Endurance (9 A @ 100 V DC)	13 hrs	4.4 hrs	2.2 hrs

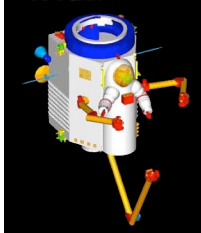
SCOUT Power System



SCOUT

- Located by PDUs
- Accessible via EVA to fix/ replace:
  - 1 spare stored in docking module
  - 3 batteries replaced once a year





Docking Module Power System Requirements

SCOUT

- Gateway Power:
  - 12kW continuous, 14kW peak
  - Energy buffer system supports 13hr max eclipse/ 6 months
- SCOUT Refurbishment Requirements:

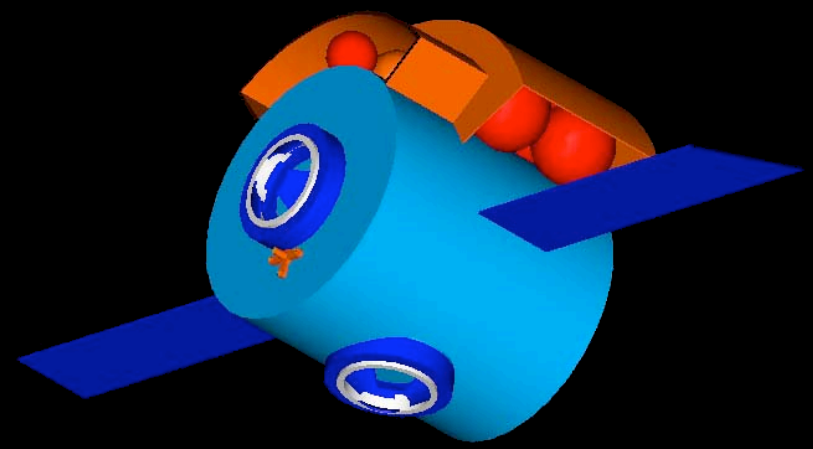
	Power (W)	# Hours
Nominal Sortie Battery Recharge (2x)	2724	10
Metox Regeneration	1000	10
Liquid Nitrogen Cryogenic Storage	TBD	continuous

- Docking module will generate power via solar arrays
  - Refurbishment during night cycle: batteries recharged via Gateway
  - Refurbishment during day cycle: batteries recharged via solar arrays
  - Solar arrays will store surplus energy in Gateway flywheels and battery energy storage system

Docking Module Power System

SCOUT

- Triple Junction Crystalline Solar Arrays:
  - Advanced radiation protection
  - Consistent with OASIS design
  - I_s = 1394W/m^2
  - ρ_{power} = 250W/kg
  - η_{eff} = 40%



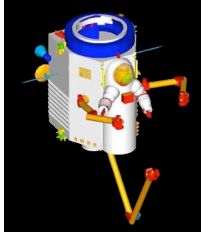
Total Power Output	5000W
Surface Area/ Panel	4.5m^2 (1 x 4.5m)
Mass/ Panel	20kg

XMP Power System Requirements

SCOUT

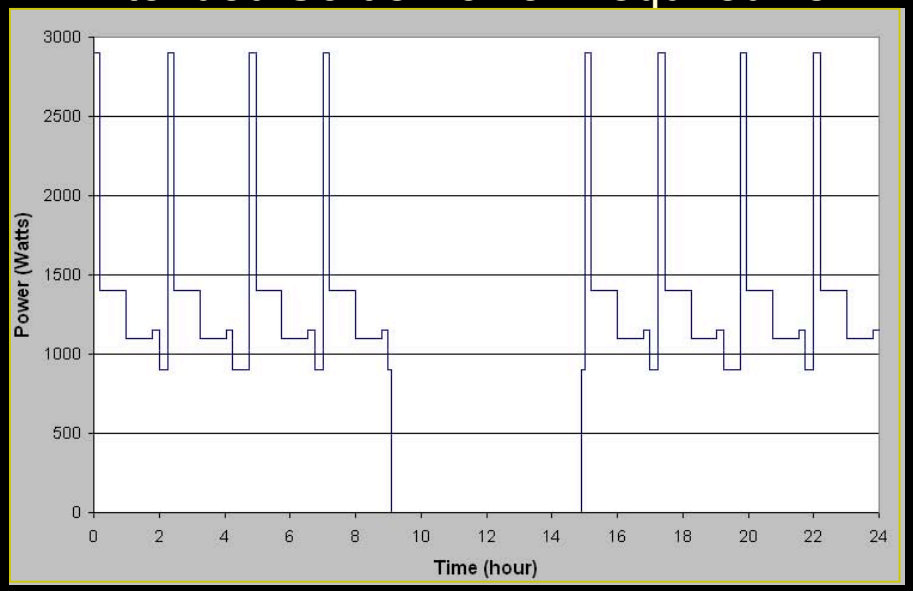
- XMP flexible to range of missions
  - Pallet can be adjusted according to mission requirements
- Possible XMP Power Systems include:
  - Secondary Batteries
  - Solar Arrays
  - Fuel Cells
- Reference Mission (Lunar Operations Pallet):
  - L1 to Lunar Orbit
  - 23 hour travel by tow vehicle to worksite
    - SCOUT crew member travels in tow vehicle to worksite
    - Power requirements minimal during transit to worksite
    - SCOUT required power drawn from tow vehicle during transit via XMP
  - Extended sortie consists of:
    - Two 8-hr work periods w/ short breaks
    - Extended 6 hour resupply/ break period separating work periods
  - Work period power requirements assumed similar to nominal reference sortie

XMP Power System Requirements



SCOUT

- Single cycle life required
- Provide minimum of 7500 W*hr to SCOUT (2 hr reserve margin met)
- Max of 5 hours to recharge SCOUT batteries
- Recharge/ resupply via the docking ring interface
- Facilitate power transfer from CTV to SCOUT
- XMP power system not safety-critical: 2 fault tolerance not required
- Extended Sortie Power Required vs. Time Curve (below):



Total Energy ~ 22,140W*h

Nominal Power ~ 900W

Peak Power ~ 2900W

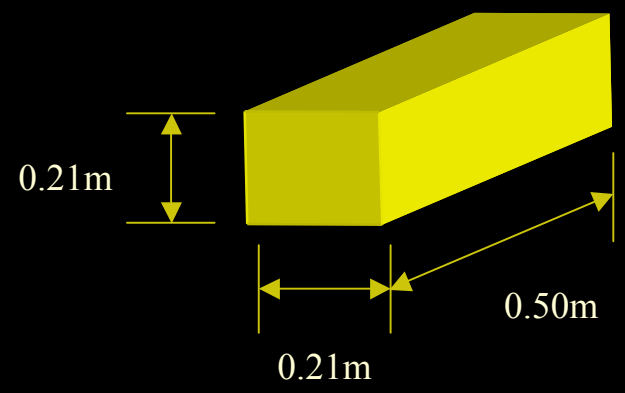
Nom Discharge Rate (@ 100V) ~ 9A

Max Discharge Rate (@ 100V) ~ 29A

XMP Power System

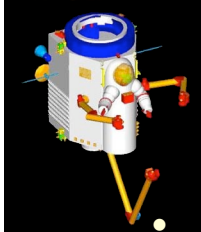
SCOUT

- Rechargeable Li-Ion Battery System:
  - 2 Li-Ion Batteries:
    - Total EOL Energy/ Battery ~ 4900W*hr
    - Total Mass / Battery ~ 58kg
    - Total Volume / Battery ~ $0.02m^3$



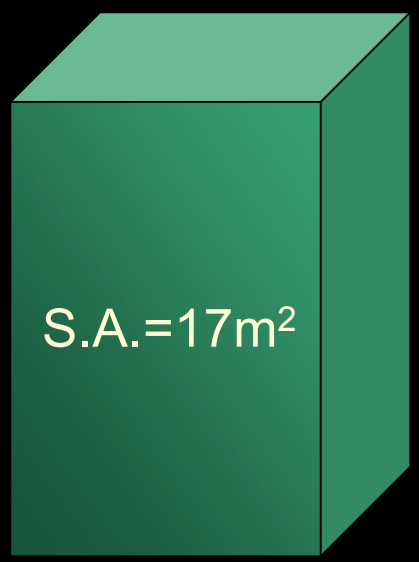
- System Non-Redundant
  - If XMP power system fails, SCOUT aborts second work period
- XMP power system oversized to accommodate rapid recharge of SCOUT power system

Thermal Control Systems



SCOUT

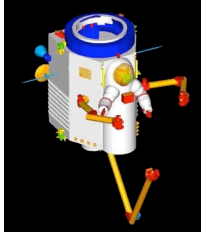
- Thermal Model
  - Assumed a rectangular box for basic model analysis (Surface Area = 17 m²)



Non-Ideal Radiative Heat Transfer

$$I_s \alpha A_s + P_{int} = \varepsilon \sigma A_{rad}(T_{rad}^4 - T_{env}^4)$$

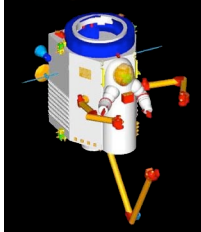
I_s = Intercepted radiation
a = Absorptance
A_s = Area exposed to flux
P_{int} = Internal electrical power and heat generated by astronaut
e = Emittance
s = 5.67×10^{-8} W/m²K⁴
A_{rad} = Area of radiating surface
T_{rad} = Equilibrium temperature
T_{env} = Free space temperature (4 K)



SCOUT

Thermal Requirements

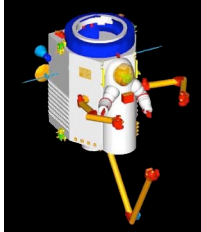
- Maintain thermal equilibrium of pod
  - All nominal ingress/egress shall be accomplished in shirt-sleeve environment
  - Provide for shirt-sleeve environment inside SCOUT
    - Internal ambient temperature of pressure hull shall be maintained nominally at 294 ± 3K
  - Subsystems shall operate at required temperature levels
    - Crew Systems shall also be maintained at nominal pressure hull temperature
    - Electronic Systems shall be maintained within operating limits (218 to 398K)
    - Power Supplies shall be maintained at 293 ± 10K
    - Fuel shall be stored at 293 ± 5K
- Capable of withstanding worst-case mission scenarios
  - 13 hrs of direct sunlight exposure
  - 13 hrs of darkness
- Provide protection from harmful radiation due to solar flux
- Ability to radiate heat effectively
- Shall be non-venting



Systems Overview

SCOUT

- Passive Thermal Control
  - Thermal Control Coatings
    - Have excellent radiation properties
    - Surfaces are usually covered with black or white paints, or gold, silver, and aluminum foils
    - Different coatings can be combined
    - Coatings are very efficient and lightweight (minimal use of space)
  - MultiLayer Insulation (MLI)
    - External thermal blanket acts as both a thermal insulator and a solar radiation shield
    - Consists of closely spaced layers of aluminized mylar and kapton alternated with layers of dacron to keep heat from conducting between layers
    - Thickness is usually in the millimeter range
  - Phase Change Materials (not viable)
    - Disadvantage is that once the phase change has taken place, the device is unable to absorb large amounts of heat allowing temperature to climb
    - Higher masses than other forms of thermal control (typical PCM of Phosphonium chloride, PH_4Cl, would require about 50kg needed for SCOUT)



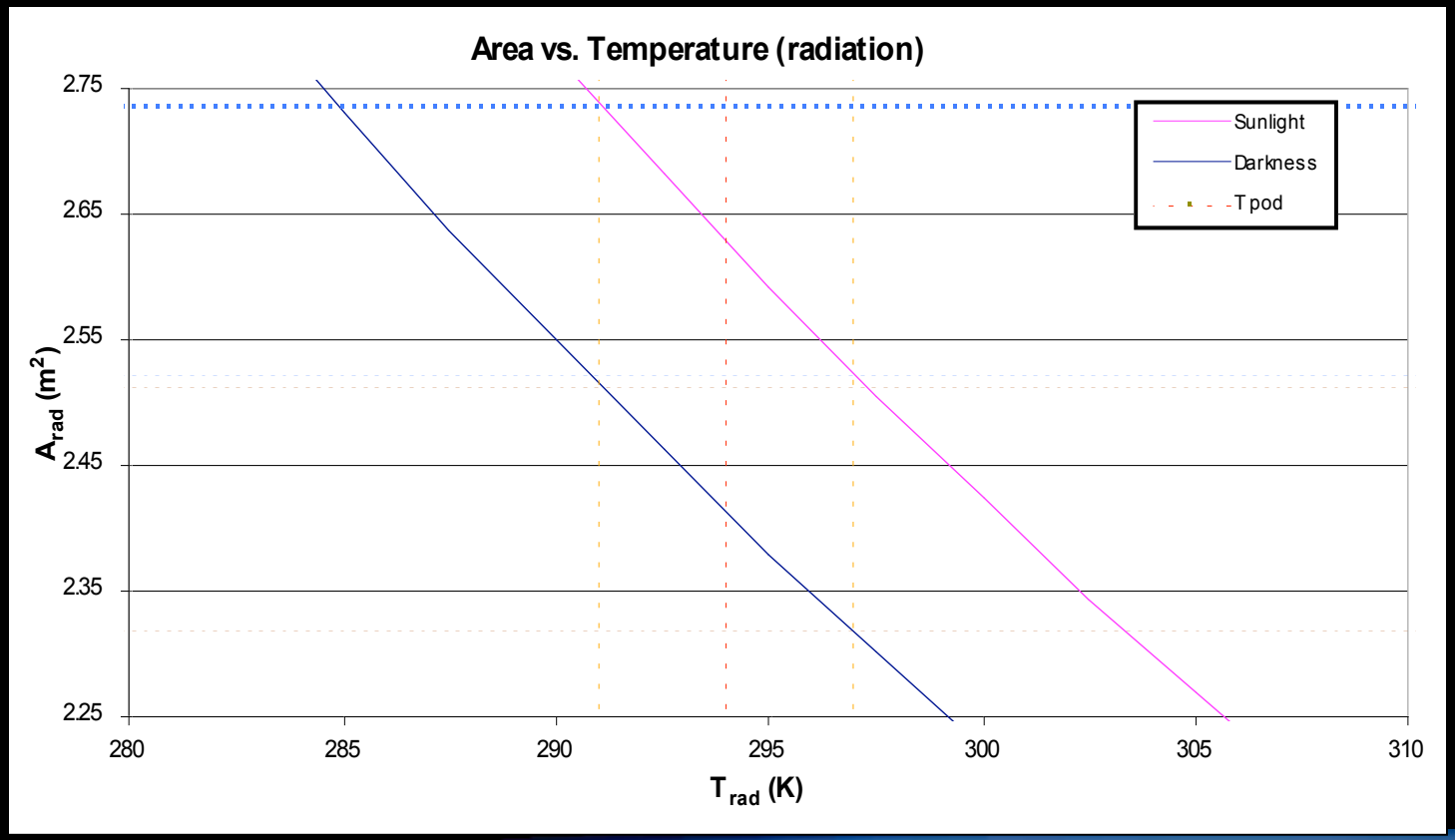
SCOUT

Systems Overview

- Active Thermal Control
  - Heat Pipes
    - Thermal energy is absorbed by a working fluid inside of the pipe and carried to a radiator
    - Exhibits high conductance and extremely high heat transfer rates
    - Low mass and volume characteristics
    - Capillary action minimizes number of parts needed and lowers amount of complexity as opposed to a pump system
  - Radiators
    - Primary system of heat rejection for manned spacecraft
    - Located on outer surface of spacecraft
    - Large surface areas are capable of radiating massive amounts of heat
  - Heat Exchangers
    - Transfers heat between two or more fluids operating at different temperatures
  - Louvers (NOT VIABLE)
    - Coated with thermal coatings but high temperatures can be achieved if directly pointed towards the sun
    - Temperature range not achievable for worst case scenarios
  - Heaters
    - Primary method of adding heat to spacecraft
    - Generate heat by running an electrical current through a resistor

Equilibrium Analysis

- Area versus temperature contours for thermal radiation
  - Plotted over minimum and maximum radiator surface areas for worst case thermal scenarios
  - Upper and lower temperature constraints bound the range of surface area available for the radiator

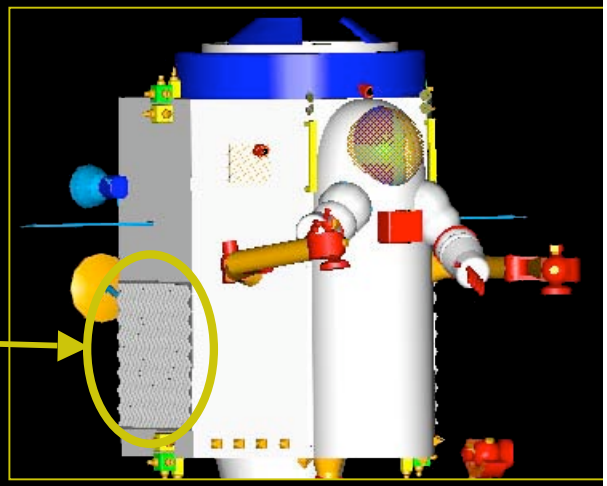


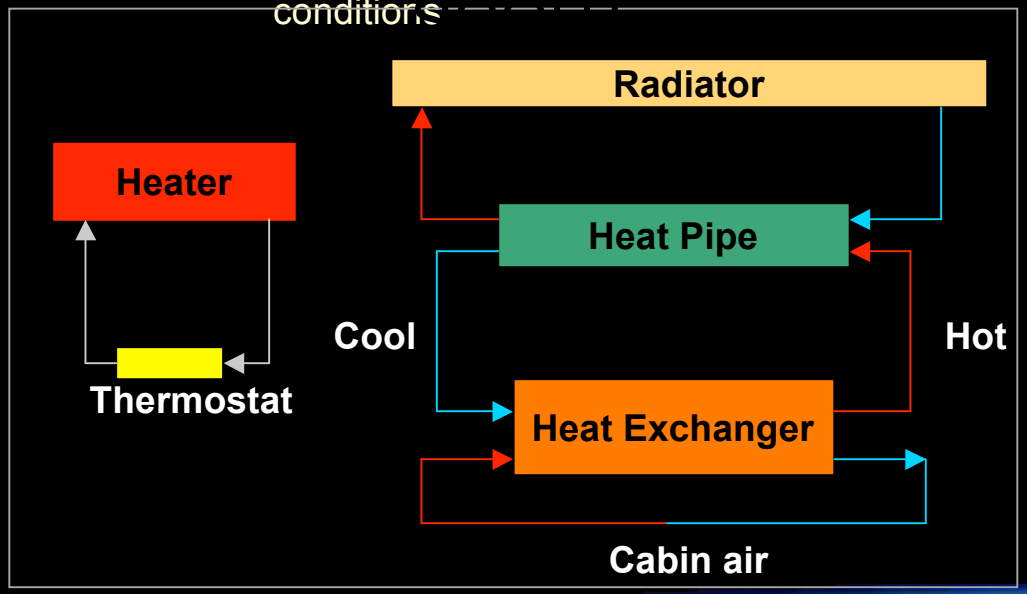
SCOUT

Internal Environment

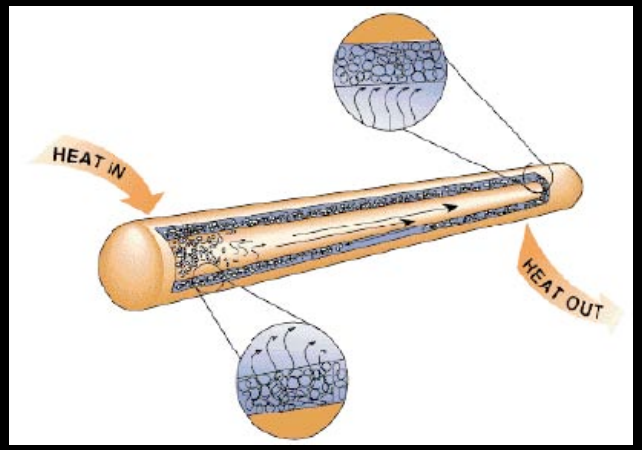
SCOUT

- Thermal Control
  - The interior of the pod, specifically the pressure hull, will be maintained thermally by utilizing a series of different systems.
    - Heat Exchanger: transfer heat from circulating 'cabin' air to working fluid in heat pipe
    - Heat Pipe: transport heat to radiator using ammonia via capillary action
    - Radiator: radiate heat to space
    - Heater: trim temperature during colder conditions

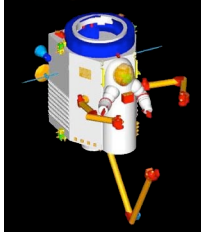




Heat Pipe schematic



ChE Plus



SCOUT

Calculations

- The amount of heat needed to radiate from the pressure hull for thermal equilibrium during direct solar exposure is:

$$Q_{rad} = I_s \alpha A_s + P_{int} = 560W$$

where: I_s is incoming radiation of solar flux (S_f), Earth and Moon albedo (E_{al}, M_{al})and IR (E_{IR}, M_{IR})

$S_f = 1394W/m^2$ $E_{al} = 190mW/m^2$ $E_{IR} = 91mW/m^2$

$M_{al} = 89mW/m^2$ $M_{IR} = 110mW/m^2$ $\alpha = 0.12$

$A_s = 0.5m^2$ $P_{int} = 480W$ (Electronics, Crew Systems, and astronaut's body heat)

- The radiating area can then be determined, from the Stefan-Boltzman equation, as follows:

$$A_{rad} = Q_{rad}/[\varepsilon\sigma(T_{rad}^4 - T_{env}^4)] = 1.44m^2$$

where: $\varepsilon = 0.92$ $\sigma = 5.67*10^{-8}\ W/(m^2K^4)$

$T_{rad}4 = 294K$ $T_{env}4 = 4K$

- For colder conditions the pod's temperature will be trimmed with a heater so that it remains within the design limits. The amount of heat necessary can be calculated from:

$$Q_{htr} = \varepsilon\sigma(T_{rad}^4 - T_{env}^4)(A_{rad,s} - A_{rad,d}) = 85W$$

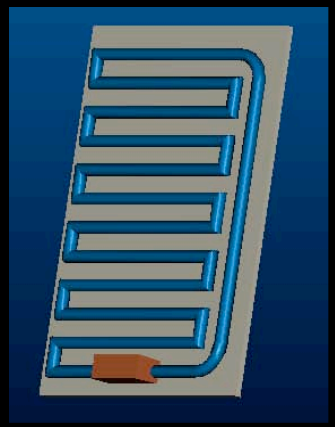
where: $A_{rad,s} = 1.44m^2$ (radiator area needed for direct sunlight conditions)

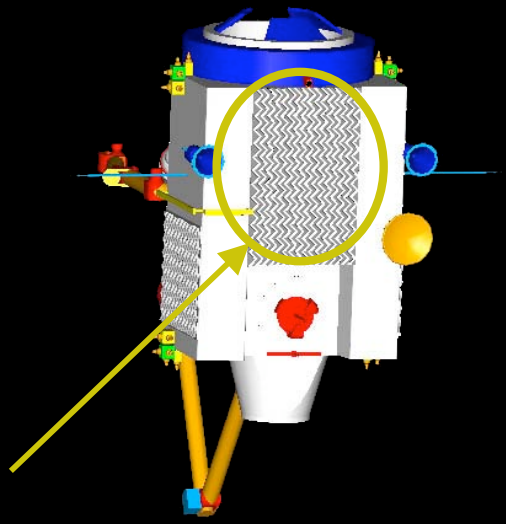
$A_{rad,d} = 1.22m^2$ (radiator area needed for dark conditions)

Battery Subsystem

SCOUT

- Thermal Control
  - The batteries will be controlled thermally by an active radiator system
    - Radiator: radiate heat generated from battery packs using a system of cooling loops and a working fluid consisting of freon
    - Pump: circulate freon through radiator





- Calculations
  - The radiating area for the battery system can be calculated using the Stefan-Boltzman equation for non-ideal situations:

$$A_{rad} = Q_{rad}/[\varepsilon\sigma(T_{rad}^4 - T_{env}^4)] = 1.15m^2$$

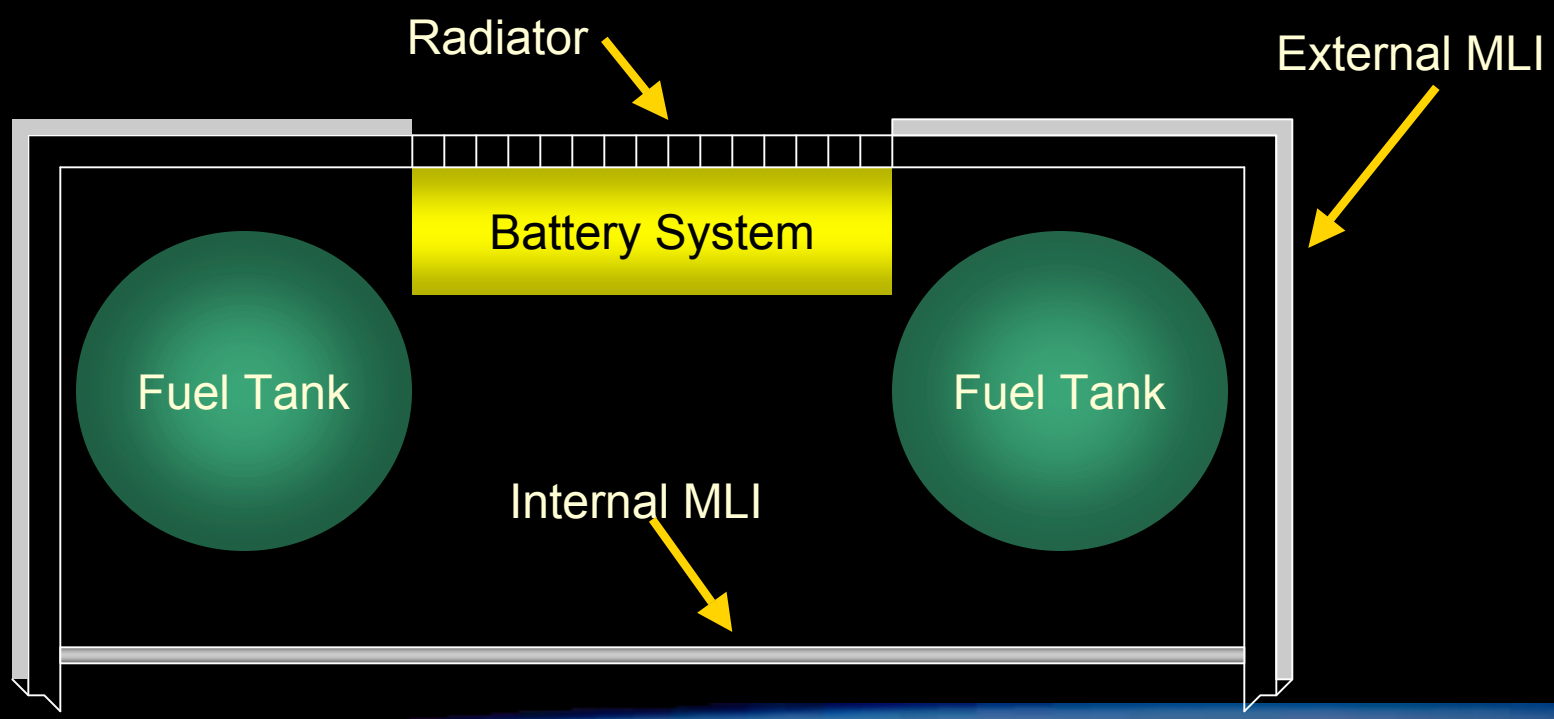
where: Qrad = 450W (amount of heat generated from battery, assuming uniform heat distribution throughout SCOUT)

T_{rad} = 293K (nominal operating temperature)

Propulsion Subsystem

- The propulsion system requires that the fuel be stored nominally at 293 K
- The fuel will be maintained thermally by insulating it next to the battery system
  - Fuel storage tanks are located next to the batteries
  - Have similar operating temperature limits
  - The storage tanks produce no amount of heat (Q)
  - Will be insulated along with the batteries using MLI

SCOUT



Exterior Surface

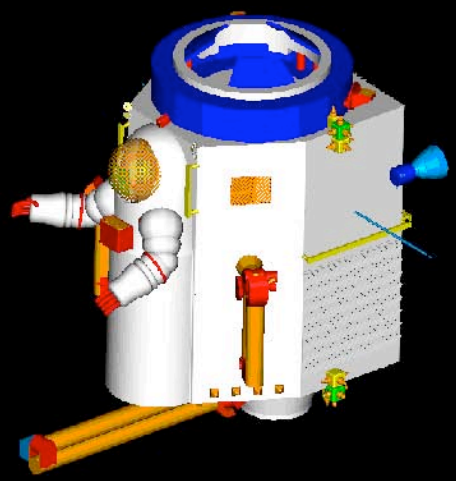
SCOUT

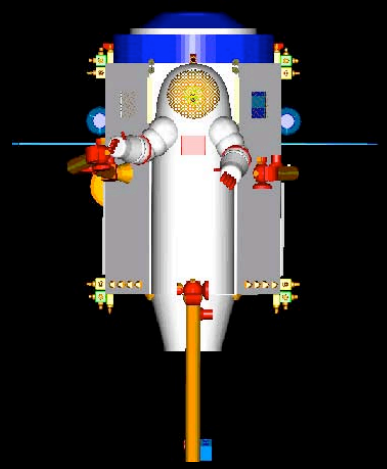
- Exterior of SCOUT will be covered in MultiLayer Insulation (MLI) and YB-71 surface coating to reduce amount of absorption due to radiation flux
  - MLI properties

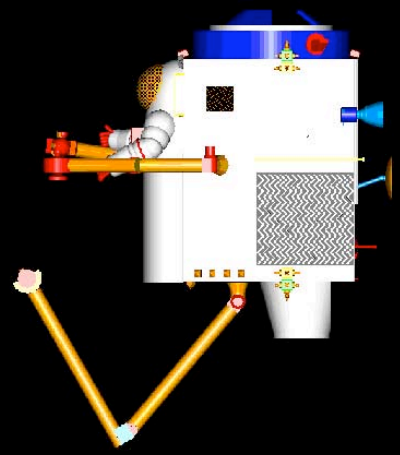
    $\varepsilon = 0.03$ area $=15m^2$ $\rho = 0.3kg/m^2$

  - YB-71 properties

    $\varepsilon = 0.92$ $\alpha = 0.12$ $\rho = 0.24kg/m^2$



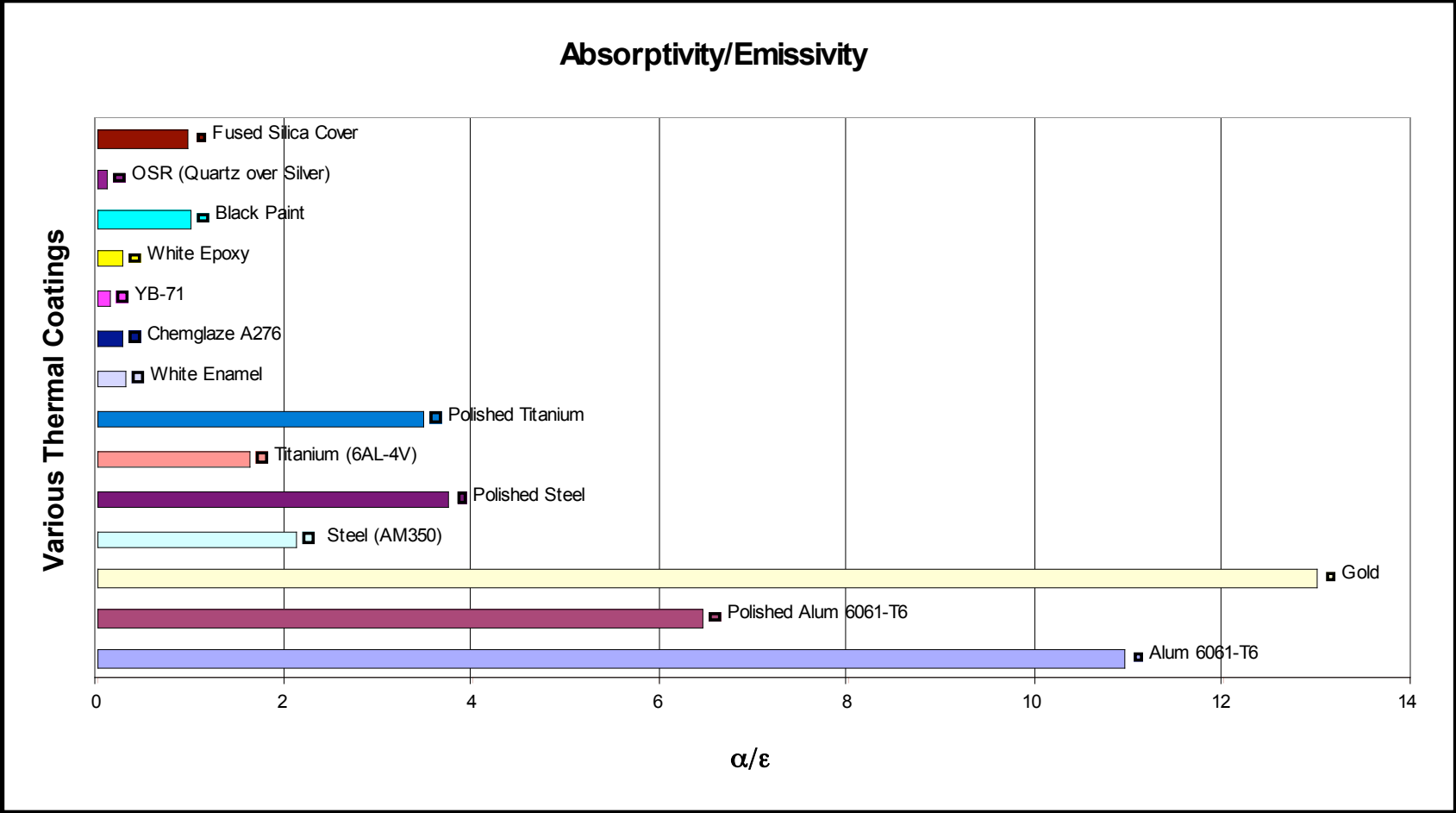




- Interior of SCOUT will be painted with high-emissivity (0.98) black paint to maximize radiation coupling and minimize thermal gradients

Exterior Analysis

- YB-71 proves to be the best application for thermal coating based on a/e ratio and mass constraints (lower ratio indicates lower equilibrium temperature)

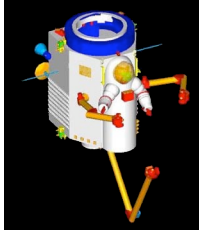


SCOUT

SCOUT

Masses

Components	Unit Mass (kg)	No.	Total Mass (kg)
Internal Pressure Hull:			
Heat Exchanger	1	2	2
Heat Pipe	0.33	2	0.66
Radiator			Accounted be LSM
Heater	0.05	2	0.10
Thermostat	0.0085	2	0.0170
Propulsion Subsystem:			
Multi-Layer Insulation (MLI)	1.2	N/A	1.2
Battery Subsystem:			
Radiator			
Cooling Pipes	5	1	5
Pump	2	1	2
Exterior Surfaces			
MultiLayer Insulation (MLI)	4.5	N/A	4.5
YB-71 Thermal Coating	0.12	N/A	0.12
Total			**~16**



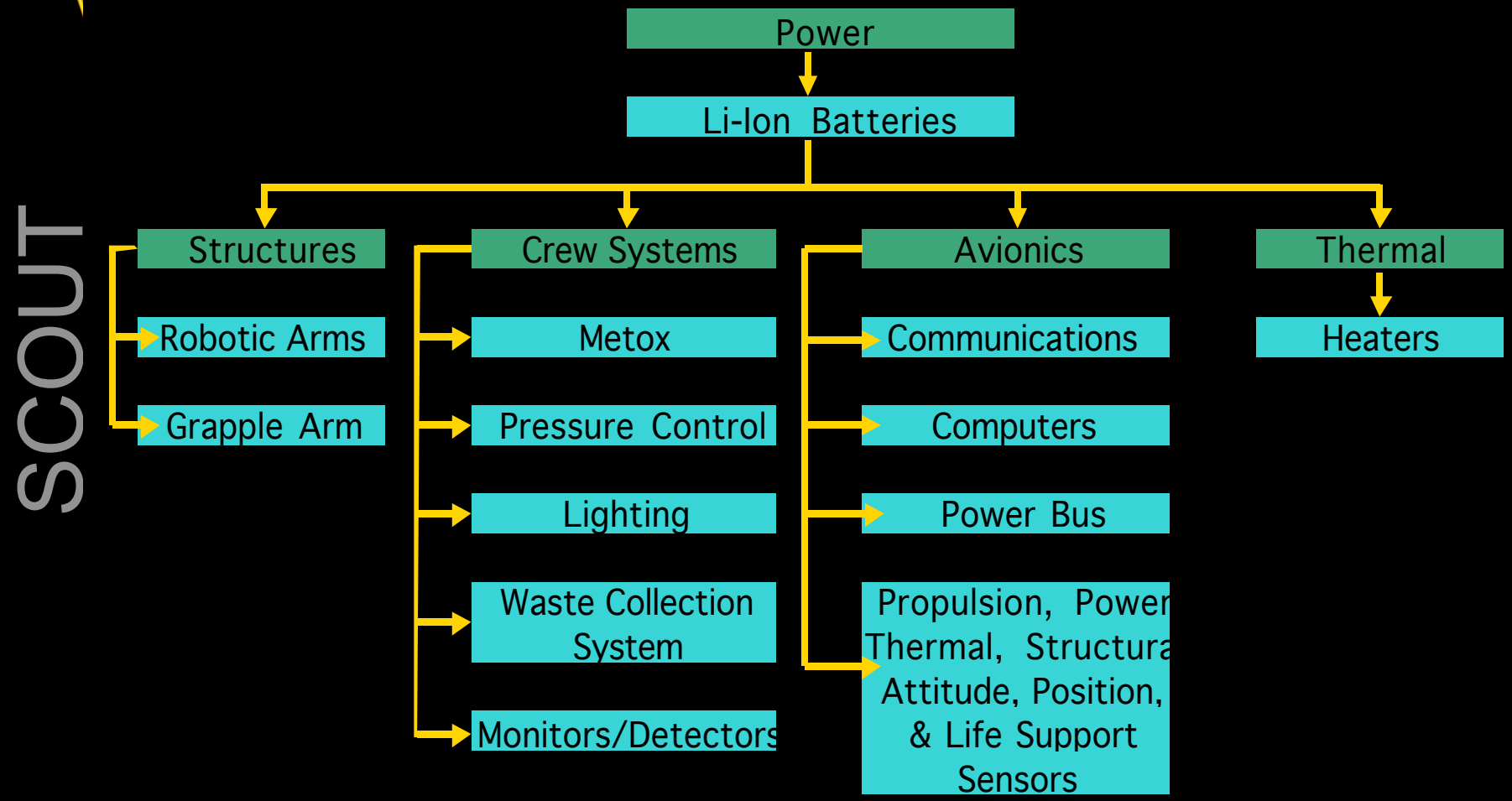
SCOUT

Systems Integration Continued

J. Thomas Christy

Meghan Baker

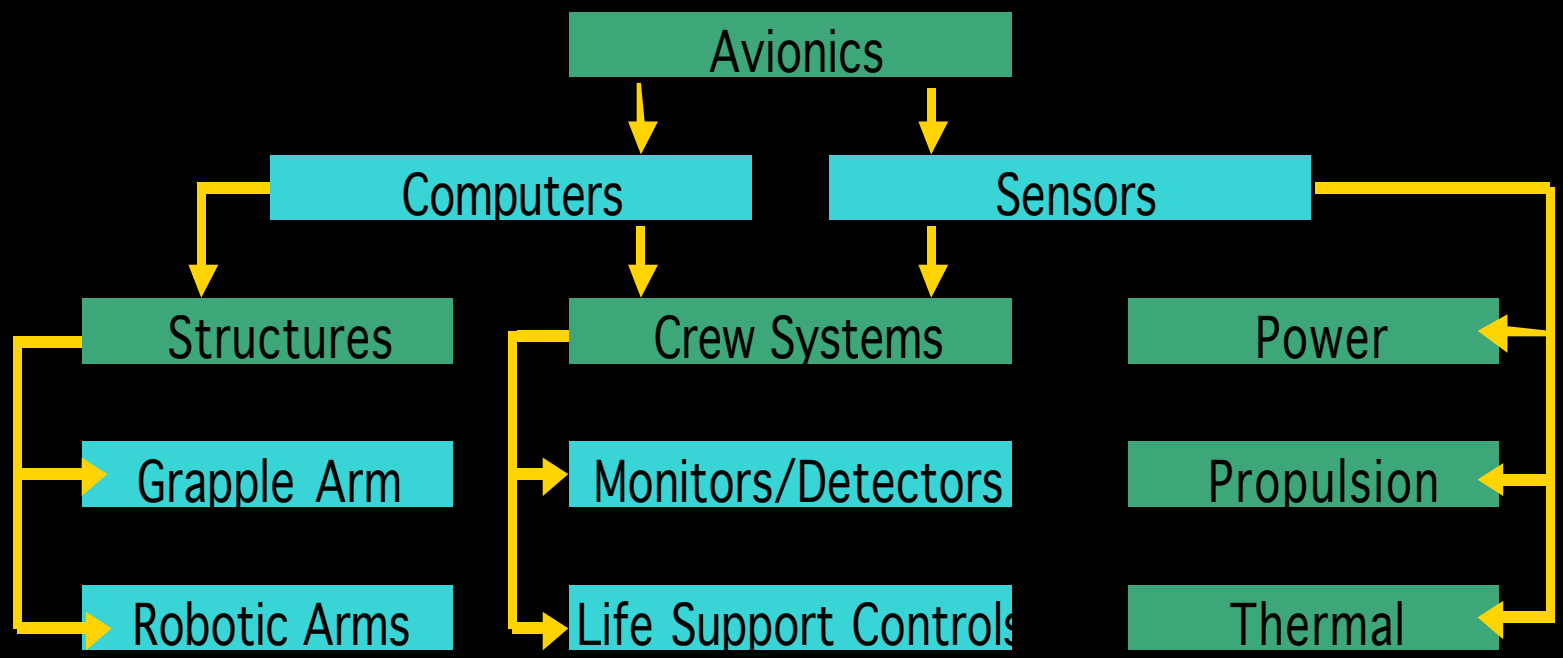
System Failure Block Diagram



SCOUT

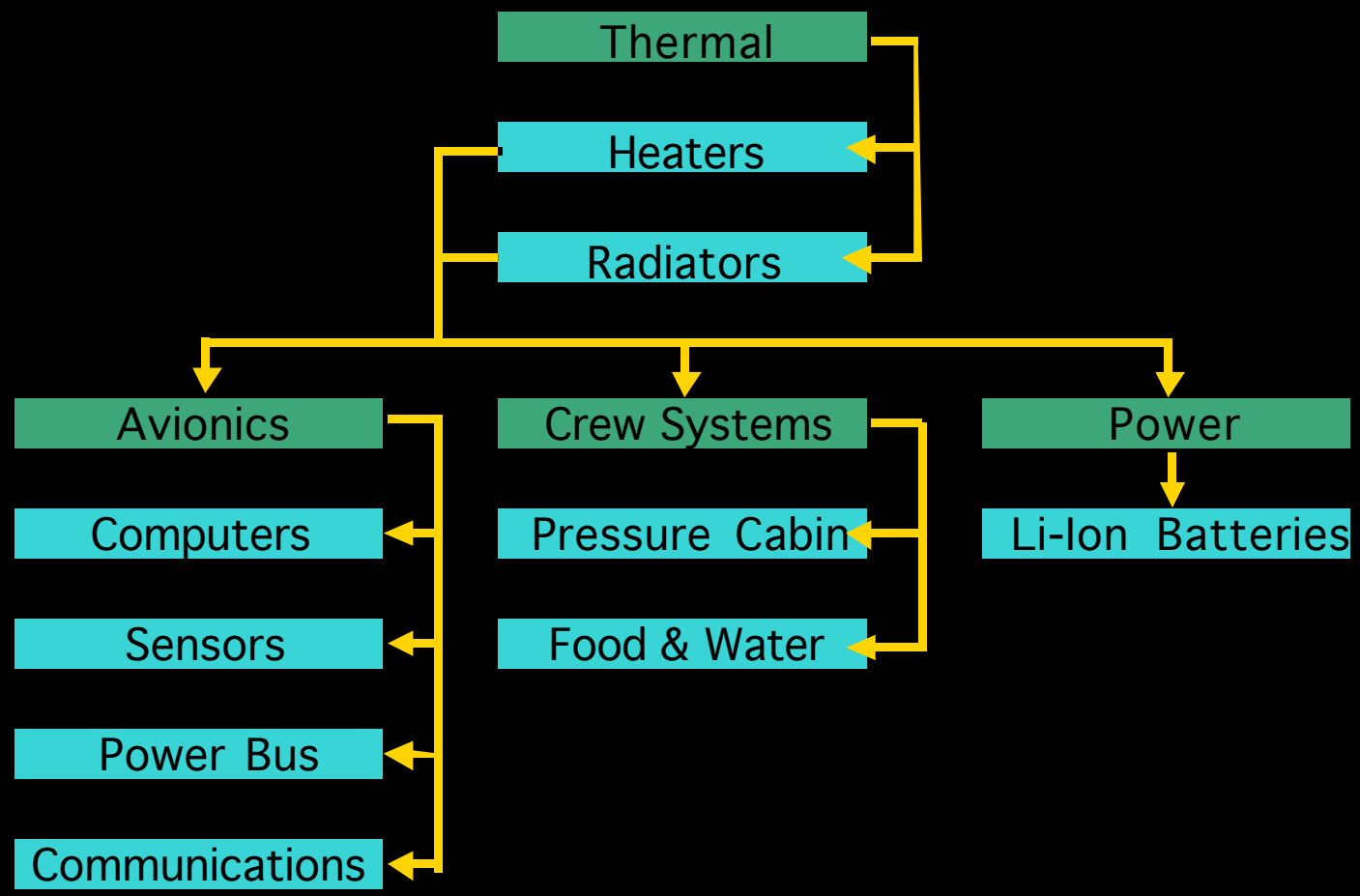
System Failure Block Diagram

SCOUT



System Failure Block Diagram

SCOUT



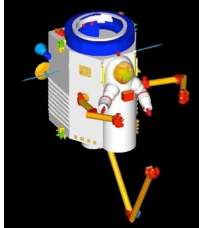
Program Development Schedule

SCOUT

Task	Year 1	2	3	4	5	6	7	8
Advanced Studies	■							
Mission Concept Review	ψ							
Preliminary Analysis	■ ■							
Mission Definition Review	ψ							
Definition (SCOUT)	■ ■							
Definition (MODULE)	■							
Definition (XMP)	■							
Preliminary Design Review	ψ							
Design (SCOUT)	■ ■ ■ ■	■						
Design (Module)	■ ■ ■							
Design (XMP)	■ ■							
Critical Design Review	ψ							
Development (SCOUT #1)	■ ■ ■	■ ■ ■	■ ■ ■	■ ■ ■	■ ■ ■	■ ■ ■	■ ■ ■	■
Development (Module)	■ ■ ■	■ ■ ■	■ ■ ■					
Development (XMP)	■ ■ ■	■ ■ ■	■ ■ ■					
Development (SCOUT #2)				■ ■ ■	■ ■ ■	■ ■ ■	■ ■ ■	■
Ready for Launch								ψ
Evaluation at ISS								■ ■
Evaluation Review								ψ
Deployment to Gateway								■

ψ Indicates that this action will take place at the end of the indicated time period

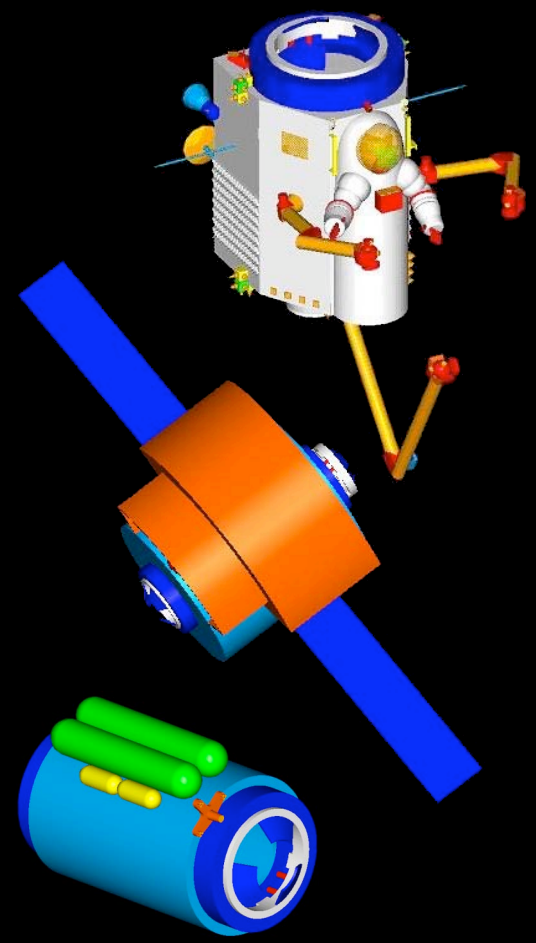
Costing



SCOUT

- Cost based on heuristic formulas at the vehicle level for both SCOUTs, the docking module, and the XMP
- SCOUTs
  - Non-recurring Cost ($M) = 18.06 $[M_{kg}]^{0.55}$
    - $1090 Million
  - 1st Unit Production =0 .5686 $[M_{kg}]^{0.662}$
    - $79 Million
  - 2nd Unit Production = 0.8*(1st Unit)
    - $63 Million
- Docking Module
  - Non-recurring Cost ($M) = 3.44 $[M_{kg}]^{0.55}$
    - $260 Million
  - 1st Unit Production = 0.3908 $[M_{kg}]^{0.662}$
    - $71 Million
- XMP
  - Non-recurring Cost ($M) = 3.44 $[M_{kg}]^{0.55}$
    - $142 Million
  - 1st Unit Production = 0.3908 $[M_{kg}]^{0.662}$
    - $35 Million

Total = $1740 Million



Cost Spreading

- Used Beta Function provided at http://www.jsc.nasa.gov/bu2/beta.html
  - Assume Cost fraction of 0.5 and peakedness of 1

SCOUT

Year	Time Fraction	Cost Fraction	Cost ($M2003)	NPV(2003) (r=0.10)	NFV(2010) (r=0.10)
2003	0.13	0.02	28	28	54
2004	0.25	0.10	150	140	270
2005	0.38	0.28	300	250	480
2006	0.50	0.50	390	290	570
2007	0.63	0.73	390	270	520
2008	0.75	0.90	300	190	360
2009	0.37	0.98	150	86	170
2010	1	1	28	14	28
Total			**1740**	**1260**	**2460**

Discussion of External Work Stations

SCOUT

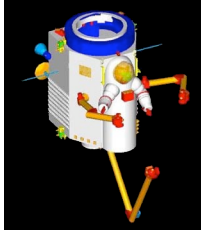
ILC Dover

NASA Johnson Space Center

EVA Suit with Man Maneuvering Unit

Robonaut

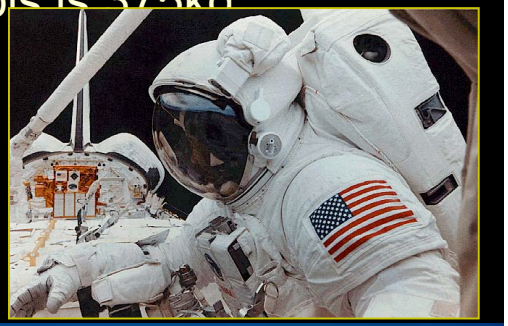
SCOUT



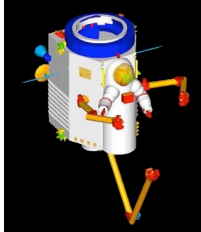
SCOUT

Pressure Suits

- Must pre-breathe for:
  - 4 hours in 14.7psi environment
  - 40 minutes after 24 hours in 10.2psi environment
- Significant radiation exposure: shield = 3gm/cm^2
- Fatigue
- Limited micrometeoroid protection
- Lack of mobility within space suit
- Self-contained supplies for a nominal mission of 5-7 hours, limiting duration of activity
- Small and easily stored (volume of .905m^3)
- Mass of one suit is 159kg (from Lunar L1 Gateway & SEP Design Briefing)
  - Mass of vehicle support, EVA translation and tools is 375kg
  - Lunar L1 Gateway airlock will be 433kg
  - Total EVA mass is 967kg



NASA



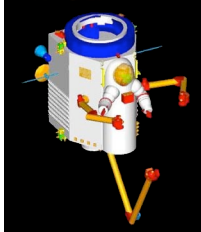
SCOUT

Pressure Suits

- Advantages
  - Task flexibility at the work site
  - Dexterous manipulation and one handed or two handed manipulation at the task site
  - High resolution visual interpretation of the task site
  - Human cognitive and interpretive capability at the task site
  - Decision maker and effector are at the task site
  - Crewmember at the task site is capable of implementing real-time alternative and unique approaches to a problem

- Limitations
  - Hazards to the EVA crewmember
  - Sensory degradation – from fatigue, etc.
  - Limited duration
  - Limited crewmember mobility and dexterity, force application, and endurance
  - Operations time and resource overhead requirements
  - Working volume and access limitations

NASA STD-3000

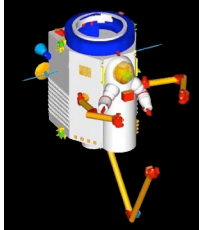


SCOUT

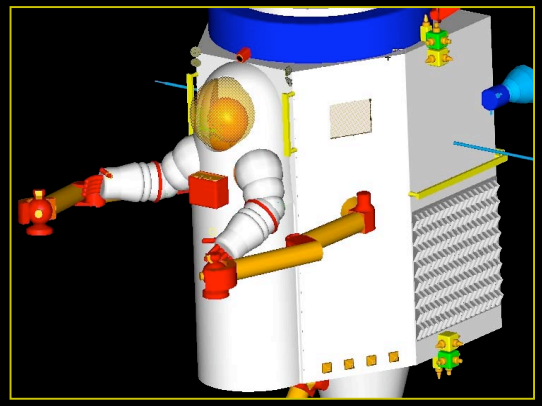
Robonaut

- Needs to be attached to something at all times (to robotic arm, station, or worksite)
- Can perform tasks similar to those done by a human
- Designed to use the same tools used by astronauts
- Two arms designed to be equivalent to human strength, scale, reach, and dexterity
  - Can lift a 21lb object on earth
- Each hand has 14 degrees of freedom
  - Dexterous work set used for manipulation
  - Grasping set used for manipulating or actuating objects
- Five pound fingertip strength
- Has cameras in place of eyes
- Can be controlled through teleoperation, shared control, and full autonomy
- Height = 1.9m; Mass = 182kg
- Flight readiness date still in question

NASA Johnson Space Center



SCOUT



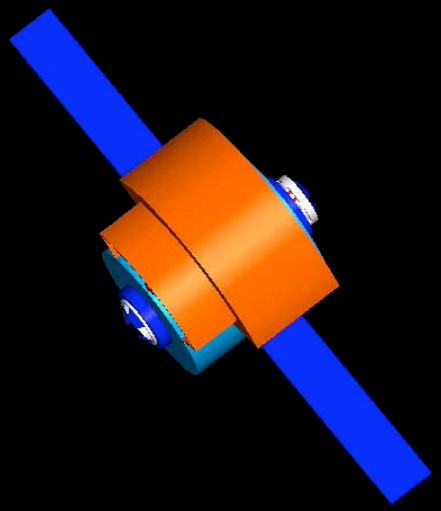
- Mass
  - Pod: 1860kg
  - Module: 4420kg
  - XMP: 1000kg
- SCOUT has a major advantage over both pressure suits and Robonaut because:
  - No extra exertion for the astronaut
  - No need for pre-breathing
  - Room for astronaut to move in vehicle
  - Potential for long term excursions
  - Can travel up to 1km to and from the worksite
  - Provides extra protection from deep space environment
    - Radiation
    - Micrometeoroids
    - Thermal conditions
  - Allows for use of robotic arms and human arms together in a complimentary manner
  - Ability to maintain and repair Gateway Station and itself

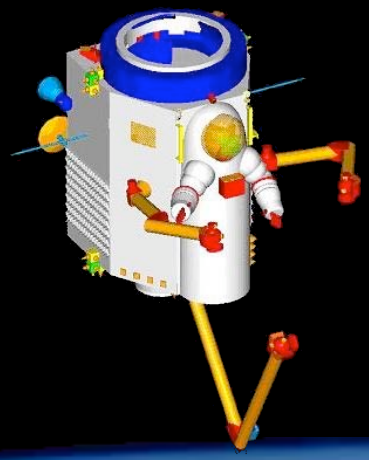
SCOUT

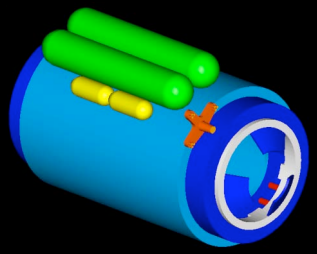
Project SCOUT

Critical Design Review

May 3, 2003







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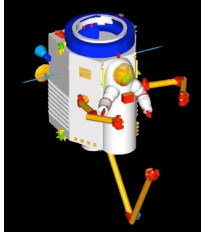

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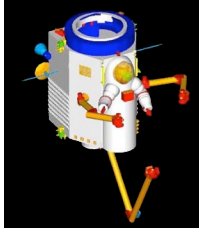

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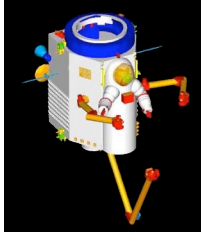

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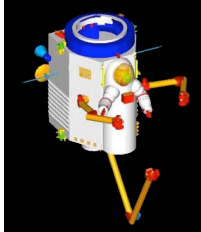

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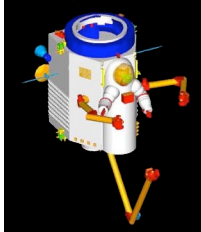

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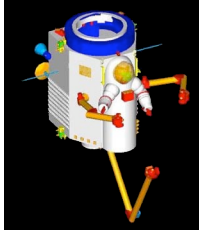

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