National Aeronautics and Space Administration

Autonomous Crew Operations Technical Interchange Meeting

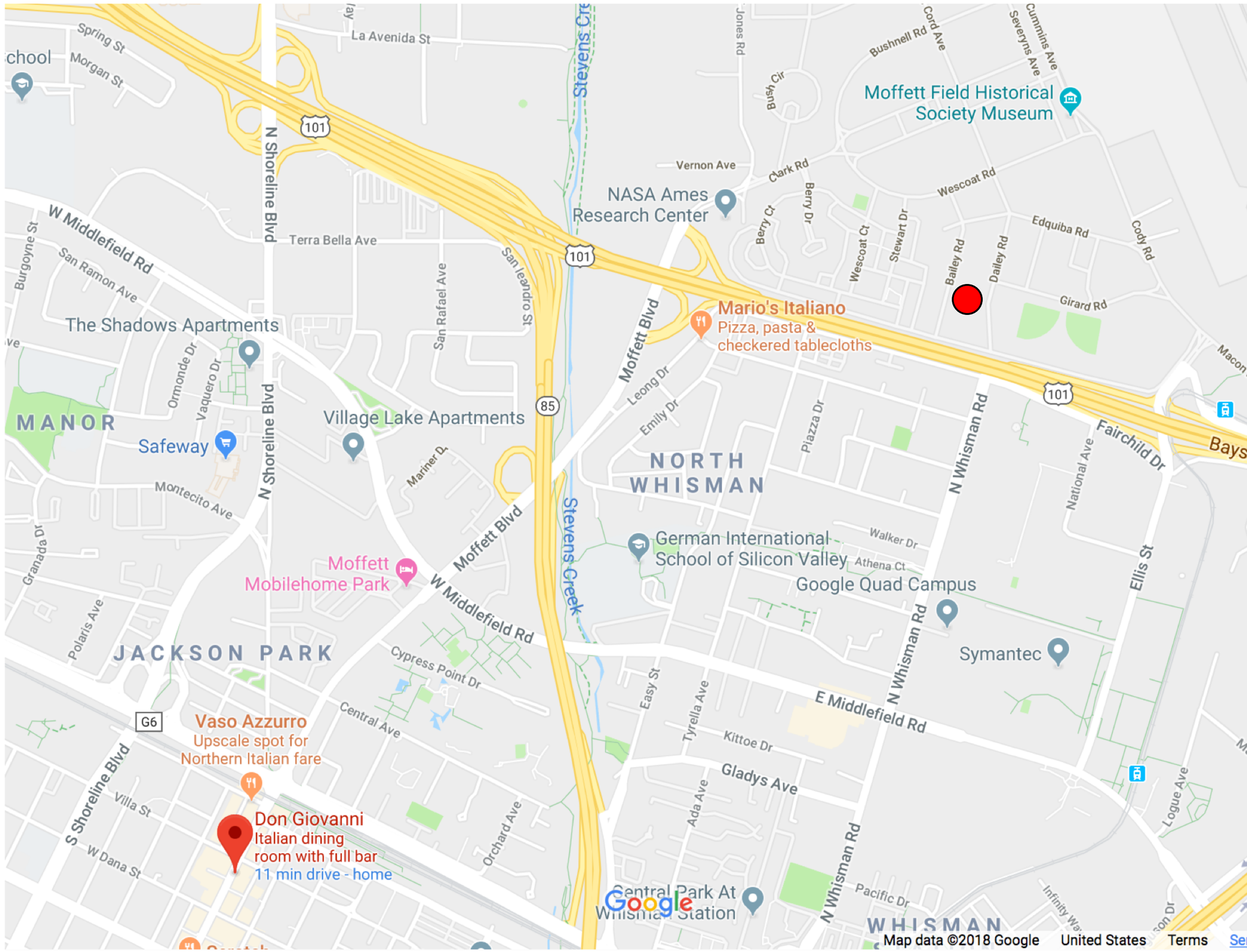
NASA Human Research Program

NASA Ames Research Center - 6 August 2018

Meals

- Lunches in

- Dinner at Don Giovanni
  235 Castro, Mountain View



National Aeronautics and Space Administration

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Agenda Overview

Autonomous Crew Operations Technical Interchange Meeting

NASA Ames Conference Center (Bldg 152, Room 116/117)

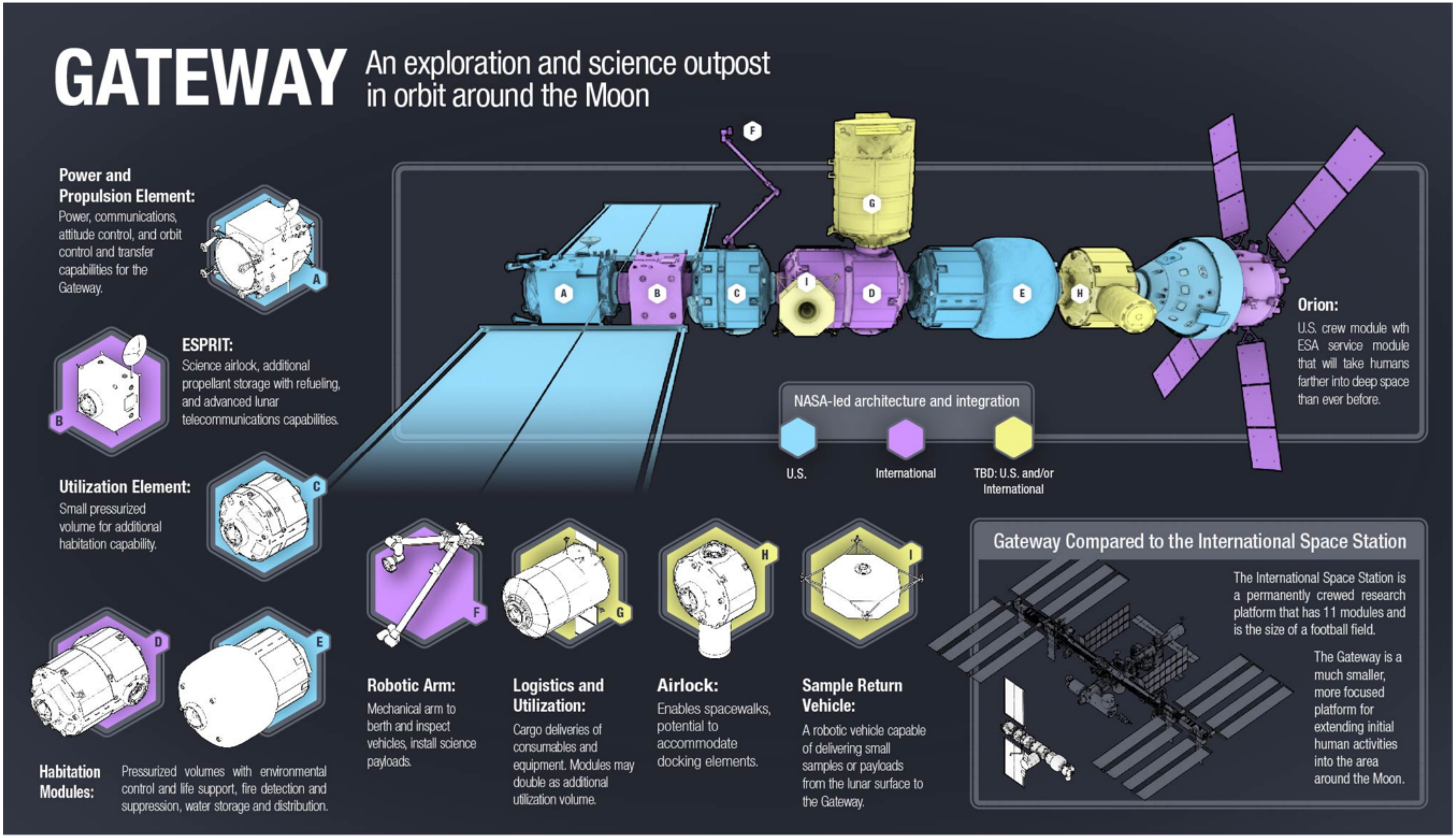
Monday August 6, 2018 Agenda

8:30	**Welcome and Coffee**
Big Picture	
9:00	**Autonomous Crew Operations: Vision, Ideas, Actions** Tom Williams, NASA Johnson Space Center
9:30	**Autonomy and the Gateway** Terry Fong, NASA Ames Research Center
10:00	**Moving from Mission Control to Mission Support** Rick Davis, NASA Headquarters
10:30	**Enabling Autonomous On-Board Trouble-Shooting** Alonso Vera, NASA Ames Research Center
11:00	**Break**
Standards and Guidelines	
11:15	**Gateway Human Systems Integration & Beyond** Kara Latorella, NASA Langley Research Center
11:40	**Human Capabilities Assessment for Autonomous Missions (HCAAM)** Tina Holden, NASA Johnson Space Center
12:05	**Group Discussion 1: The Autonomous Wallpaper Project**
12:30	**Lunch Break**
Analog Environments	
13:30	**Twenty-first Century Warships and the Lessons They Can Teach Us: A Case Study of LCS** Nita Shattuck, US Navy Naval Postgraduate School
14:00	**Crew Autonomy for Military Ground Vehicles** Kaleb McDowell, Army Research Laboratory
14:30	**ConOps for Self-Sufficient Operations Panel**
15:00	**Group Discussion 2: DoD/NASA Common Operation Themes**
15:30	**Break**
15:45	**Adaptive Problem Solving and Mitigation** Steve Hillenius, NASA Ames Research Center Marc Reagan, NASA Johnson Space Center
16:10	**Integration and Test of Gateway Technology** William Othon, NASA Johnson Space Center
16:35	**On-Board Integrated Information Systems** Thomas Van Keeping, NASA Johnson Space Center Matt Guibert, NASA Ames Research Center
17:00	**Group Discussion 3: Analog Lessons Learned**
17:30	**Wrap Up and Adjourn**
18:30	**No-host Group Dinner**

Tuesday August 7, 2018 Agenda

8:30	**Welcome Back and Coffee**
Keynote Address	
9:00	**Challenges of Autonomous Human Spaceflight – a Scientist/Astronaut's Perspective** Steve Robinson, University of California, Davis
9:45	**Break**
Technology	
10:00	**Artificial Intelligence: Powering Missions to Mars** Kerry McGuire, NASA Johnson Space Center Angie Haddock and Brooke Allen, NASA Marshall Space Flight Center
10:25	**Augmenting Space Exploration** Victor Luo, Jet Propulsion Lab
10:50	**Trustworthiness and Autonomy** Patrick Lincoln, SRI International
11:15	**Group Discussion 4: Automation and Augmentation**
11:45	**Lunch Break**
12:45	**From Sensed Buildings to Autonomous Buildings: A Kind of Uncanny Valley** Mario Berges, Carnegie Mellon University
13:10	**AI-enhanced Energy Diagnostics and Autonomous Energy Management** Mark Chung, Verdigris
13:35	**ACE: Assurance, Composed and Explained** Chengtao Wen, Siemens **Applic-ACE-ions: How can this help us?** Reed Williams, Siemens
14:00	**Technologies for Autonomous Logistics** James Broyan, NASA Johnson Space Center
14:15	**Group Discussion 5: Smart Structure Technologies**
14:45	**Break**
15:00	**Embodied AI Vision** Jeff Kephart, IBM Research
15:15	**Conversational and Discovery Approaches to Informing Experts** Bill Murdock, IBM Research
15:45	**NASA Use Case: Pilot Expert Advisory System** Graham Katz, IBM Jon Holbrook, NASA Langley Research Center
16:05	**Embodied AI Prototypes and Research Directions** Jeff Kephart, IBM Research
16:30	**Group Discussion 6: AI Cognitive Assistant**
Big Picture	
17:00	**Out-brief and Next Steps** Alonso Vera, NASA Ames Research Center
17:30	**Adjourn**

Gateway – Notional Architecture



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Enabling Autonomous On-Board Trouble-Shooting

Alonso Vera

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Autonomous Crew Operations Technical Interchange Meeting

NASA Ames Research Center - 6 August 2018

Crew and Vehicle Health

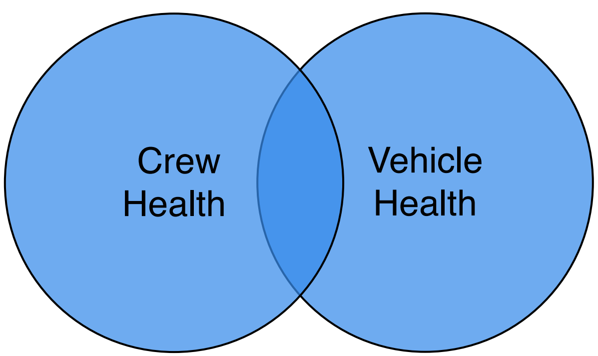
- Toward more autonomous and self-sufficient crewed space missions:

Crew Health: Loss of Crew / Loss of Mission threats identified and working to mitigate risks

Vehicle Health: focus of much of our engineering efforts with many predictive analytical approaches (Hazards Analyses, Probabilistic Risk Assessment, Failure Modes Effects Analysis, etc.) – mitigations should be built in by the engineering process

Risk Anticipation

Crew Training



Autonomous Systems

On-Board Support Systems

On-Board Anomaly Diagnosis & Response

CDRA Repair

2016

Urine Processor
Assembly Repair

Items For Investigation (IFI) Priority Level Definition: High

- The anomaly has the potential to cause disabling or fatal injury to an ISS crewmember
- The anomaly has the potential to lead to the evacuation of and/or loss of the ISS
- The anomaly and/or its resolution potentially impacts the assembly, resupply, or crew-rotation launch schedule, or the on-orbit assembly sequence
- The anomaly has the potential to cause the loss of an ISS element, the inability to use an ISS element, the loss of an on-orbit life sustaining / critical crew health maintenance function, or the loss of an emergency system
- The affected hardware has a failure effect criticality of 1
- The affected hardware is a critical item (CI) or a critical spare

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ISS: High Priority IFIs, Significant Incidents

Cooling Loop A Flow Control Valve Anomaly
IFI 8744 12/2013

12/2013 Loop A Flow Control Valve Anomaly

On 11DEC2013, fault detection on Active Thermal Control System (ATCS) was tripped by a low temperature measurement of ammonia circulating in Loop A.

Fault detection is used to assure that ammonia temperature is not so cold as to freeze the water used in heat exchangers regulating internal ISS environment.

The anomaly required that internal thermal loads be shed to Loop B (redundant system), thus reducing internal thermal management redundancy.

Because pump modules of ATCS are external to ISS, trouble shooting is done without direct observation of hardware, using indirect sensing and measurements.

Fault was eventually isolated to the Flow Control Valve (Loop A pump module) that mixes cool and warm ammonia to achieve set temperature. Valve position found to be biased 30 deg off from telemetered position.

Work arounds were attempted but unsuccessful, so decision was made to replace pump module.

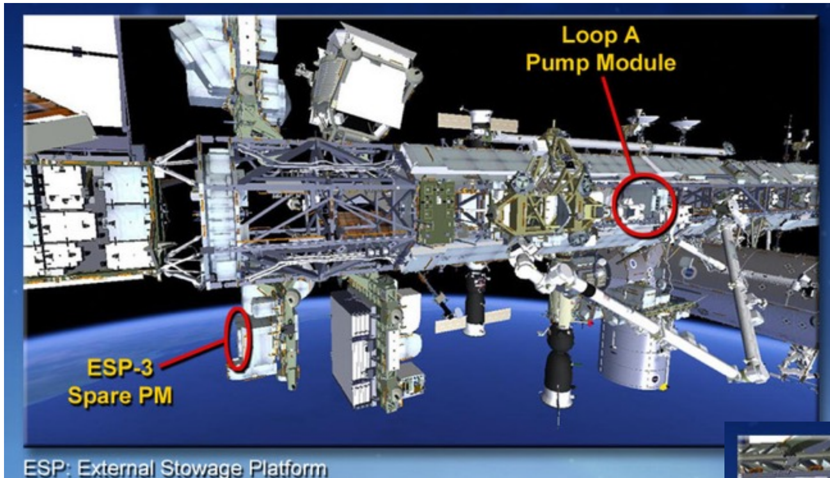
No root cause for bias in valve position was found

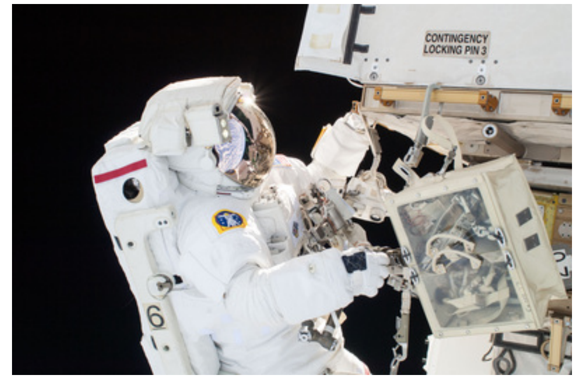
Anomaly ultimately required 14 days of 24/7 MER attention; diversion/additional activity by the crew; ground teams engineering work-arounds; and 2 EVAs lasting more than 12 hours in total.

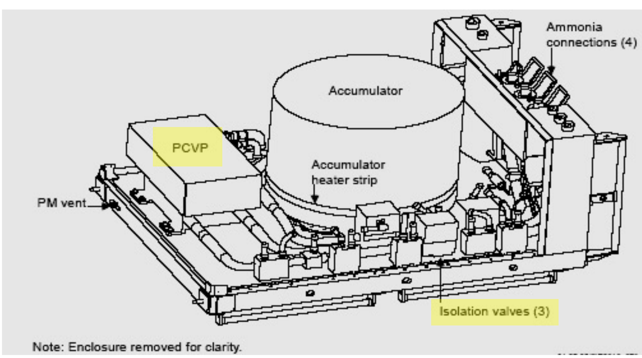
12/2013 Loop A FCV Anomaly—Timeline

Crew	Day/Time	Ground
• Notified. Assist ground in shedding thermal loads.	GMT 345/14:20	• Under-temp shuts down Cooling Loop A. Pump recovery started; internal thermal loads moved to Loop B.
• Halt/move experiments requiring cooling of bio samples.	GMT 345/15:00	• Loop A pump successfully restarted. Valve response and flow rates characterized. Temp remains low.
• Assist in trouble shooting.	GMT 346/8:00	• Troubleshooting begins. Full valve response tested. 30 deg error from commanded position identified.
• Assist EVA planning.	GMT 346/21:00	• Pump power cycled. Tests re-done with same results. EVA planning for pump module repair/replace starts.
	GMT 347/16:00	• Line heaters started to raise temps but insufficient (i.e., work-around failed).
	GMT 347/22:00	• Attempt to use downstream isolation valve to control temp (i.e., ammonia flow). Testing continues for 2 days. Software patch developed for control.
	GMT 351/07:00	• Isolation valve testing halted/pump shutdown to up load patch. Tests continue.
	GMT 352/12:00	• Re-integration of internal loads, outlet temps still unstable. Insufficient control authority using isolation valve (i.e., work-around failed).
• EVA prep	GMT 352	• Orb-1 Cygnus launch delayed. Pump to be replaced by EVA. Troubleshooting stopped.
• Install contingency jumper	GMT 353/15:00	• Loop A shutdown for contingency jumper installation. Restarted.
• EVA prep	GMT 354	• EVA prep –pump module SN04 to be replaced with SN06
• EVA #1 (5 hr, 28 min)	GMT 355	• EVA #1
• EVA #2 (7 hrs, 30 min)	GMT 357	• EVA #2.
• Return to normal config/ops.	GMT 359	• Loop A re-pressurized and returned to normal ops. (MER 14 days 24/7)

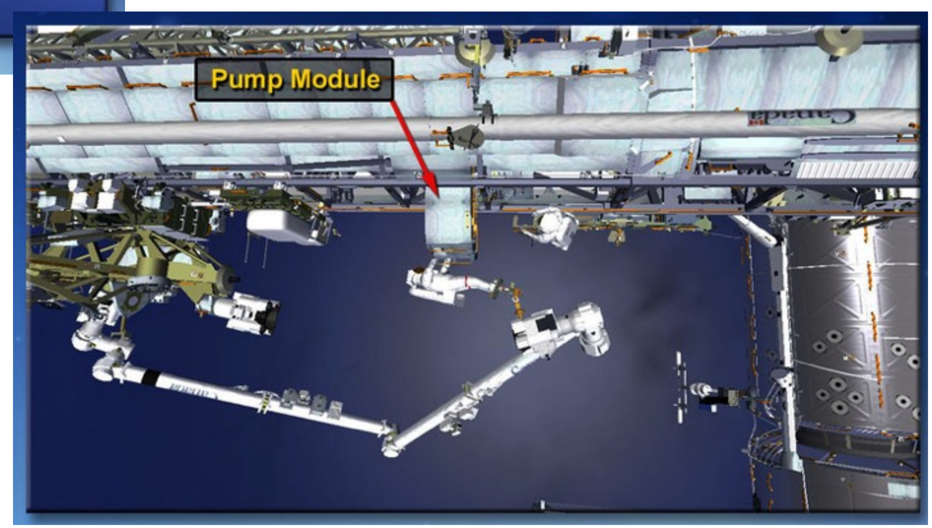
12/2013 Loop A FCV Anomaly—PM Replacement EVAs







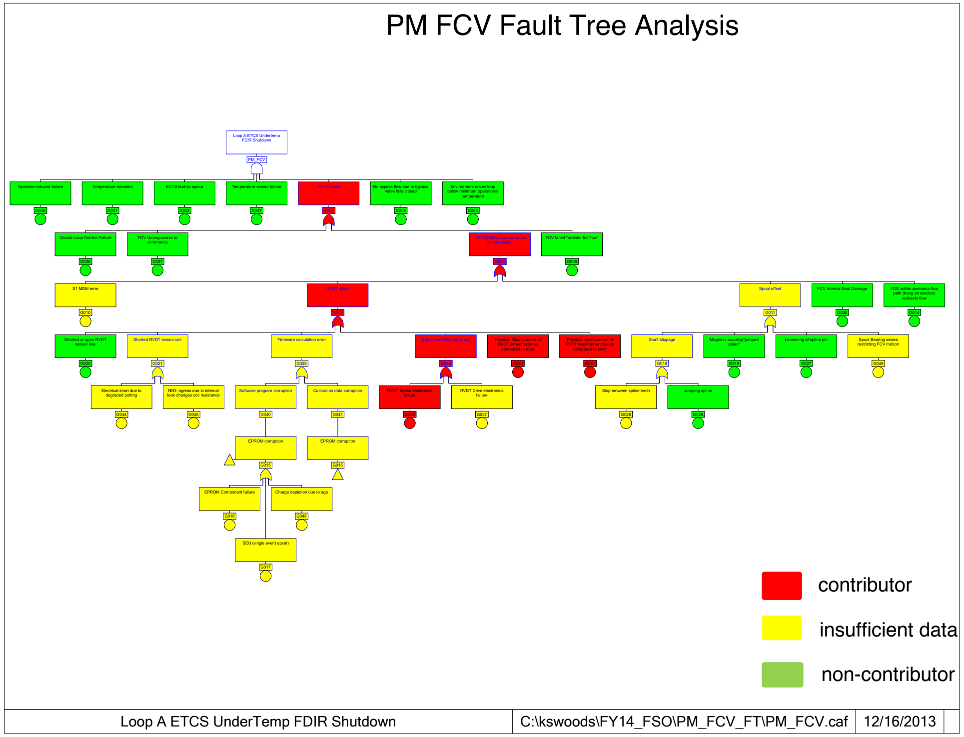
Pump Module



12/2013 Loop A FCV Anomaly—Engineering Products

- Chits (Mission Action Requests):
  - VIPER Short-Term Plasma Forecast for PM R&R EVAs 24, 25 & 26
  - S1P1 DBCL for ETCS Loop-A Return Isolation Valve
  - Command from Scratch Request for ETCS Loop A Radiator Return Valve Positioning
  - US EVA 24, 25, & 26 S1 Pump Module R&R Vent Coordination
  - Operating Loop A PCVP at High Outlet Temperatures
  - US EVA 24, 25, 26 Depress/Repress of EATCS Loop A
  - Request for Analysis of ATA Jumper Line Hydrostatic Lock Constraints

- EFNs (Electronic Flight Notes):
  - ISS MER ART Summaries, 1-6
  - Loop A Configuration and System Impacts
  - Loop A FCV Mapping
  - Loop A FCV Anomaly impacts to crew
  - Loop A PCVP Power Cycle for FCV Troubleshooting
  - Contingency Increase Temperature-Closed Radiator Return Valve
  - Contingency Increase Temperature using Line Heaters
  - Thermal Mitigation via Partial Radiator Isolation Valve Closure
  - Loop A NWF Big Picture Words
  - LOOP A “Warmjump” Tests
  - Valve Characterization Tests
  - Shutdown and Restart Procedures for FCV-degraded Config
  - S1-1 MDM Patch Load
  - Spare Pump Module Checkout
  - PM Removal Procedure



12/2013 Loop A FCV Anomaly—Background

The Active Thermal Control System (ATCS) is the main permanent active heat rejection system on the station. It acquires, transports, and rejects excess heat from all U.S. and international partner modules except the Russian modules. Two external loops (Loops A and B) circulate ammonia to transport heat and cool equipment.

Pump modules (PM) for the two loops are situated outside the pressurized part of the station on the station's main truss. They provide circulation, loop pressurization, and temperature control of the ammonia. The Pump & Control Valve Package (PCVP) provides flow control. The Flow Control Valve (FCV) located within the PCVP regulates the temperature of the ammonia. The FCV mixes "cool" ammonia exiting the radiators with "warm" ammonia that has bypassed the radiators.

Each Loop is CRIT1R. A failure doesn't place the crew in any immediate danger but it does remove redundancy, which could make a second failure a far more serious concern.

When major abnormalities develop, some equipment is moved to the other loop for cooling and other equipment powered down.

Historically, Loop A pump modules have been problematic: e.g., in July 2010, the pump module completely failed and needed 3 EVAs to be replaced.

- the first indication of an anomaly in 2010 was an over-current alarm that tripped and awoke the crew
- retrospectively, anomalous trends were seen in pump pressure data as early as 2008. Current spikes were also seen.
- there is no record of the 2010 Loop A pump failure in the summary of "high priority" IFIs

- **There were initially 4 pump module spares on-orbit; 2 have now been used and one additional spare delivered in 2018**
- **PRA results show the contribution to overall EVAC risk (1 in 32) is 1 in 320 from ATCS**

CDRA CO_2 Removal Rate Anomalies

IFI 2211 JUL-AUG/2006

JUL-AUG/2006 CDRA CO_2 Removal Rate Anomalies

Concern over Carbon Dioxide Removal Assembly (CDRA) performance was raised when a cursory comparison of JUL2006 flight data showed different ppCO_2 profiles for time periods when CDRA was running without support from Shuttle LiOH canisters. A subsequent CDRA performance test in AUG2006 also indicated CO_2 removal performance degradation. (See yellow highlighted regimes in following plot.)

The target partial pressure of CO_2 on ISS is ~3.5 mm Hg (compared to < 1 mm Hg on earth). During periods of performance degradation noted above, the ppCO_2 increased to 5-6mm Hg. (Mild symptoms related to ppCO_2 (e.g., headache) don't begin until >15 mmHg.)

There are 2 CDRA's on board the USOS—they are redundant systems but they can't be run concurrently to reduce CO_2 because too much power is drawn and heat generated. Additional capacity is maintained through LiOH canisters. In the Russian segment, the Vozdukh system scrubs CO_2.

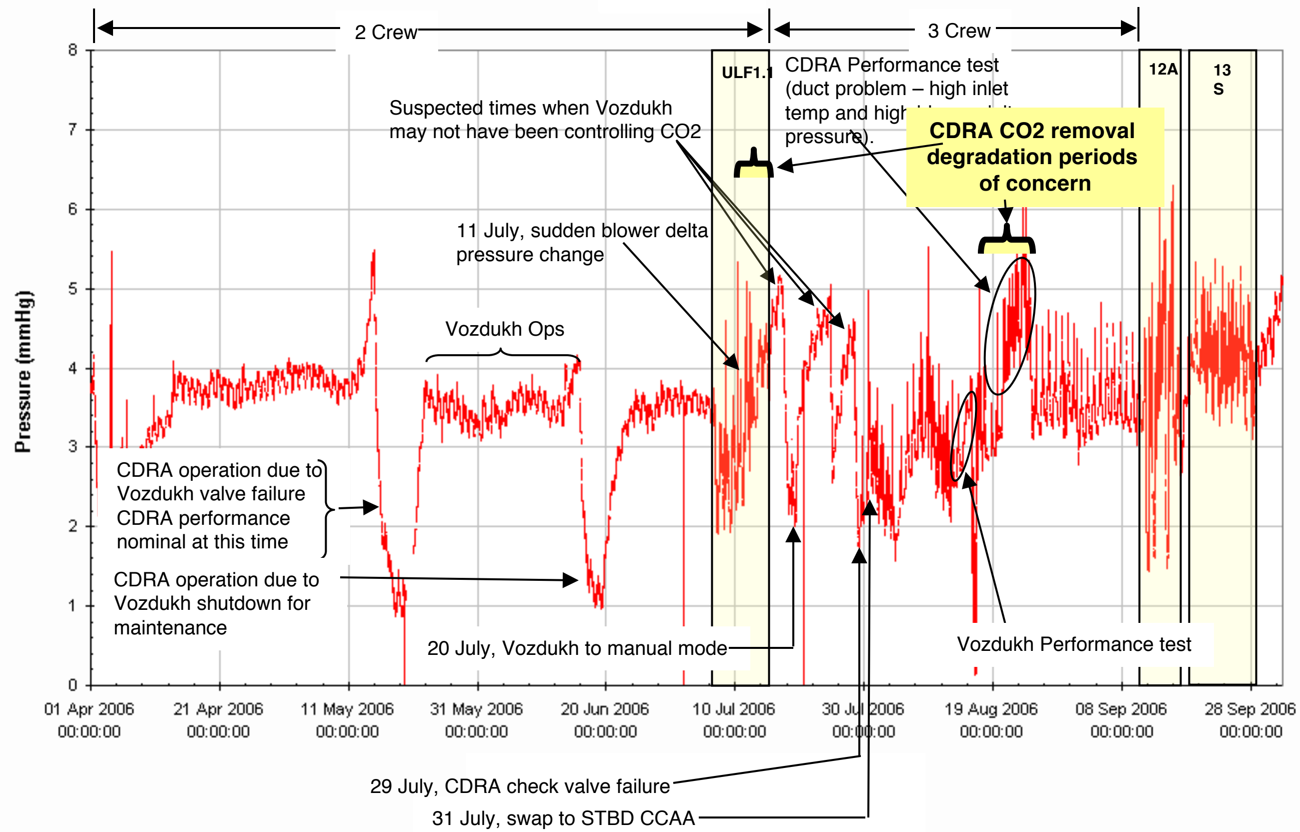
Verifying CDRA performance by analysis and review of on-orbit data requires the comparison of all variables affecting ppCO_2. Changes in configuration (e.g., fan ops) and loads (e.g., no. of crew) complicates the understanding of performance. There were ~9 configuration changes between APR and SEP 2006, including a check valve failure.

Investigation did not conclusively determine whether or not CDRA was performing normally due to the numerous variables influencing CO2 removal performance evaluation.

The reduced CO_2 removal noted in JUL2006 was probably due to a combination of clogged sock filter, Vozdukh underperformance, lack of shuttle booster fan, and LiOH usage. For that seen in AUG2006, the CDRA air inlet flow was found to be low due to an inadvertently disconnected duct that allowed humid/warm air to enter the CDRA. This, coupled with the clogged sock filter, appears to have resulted in the observed behavior.

Anomaly resolution required significant data analysis by ground and troubleshooting/inspection by crew over 2 mo.

JUL-AUG/2006 CDRA CO_2 Removal Rate Anomalies—ppCO_2 data



Attachment 2; Carbon Dioxide Partial Pressure Performance Summary

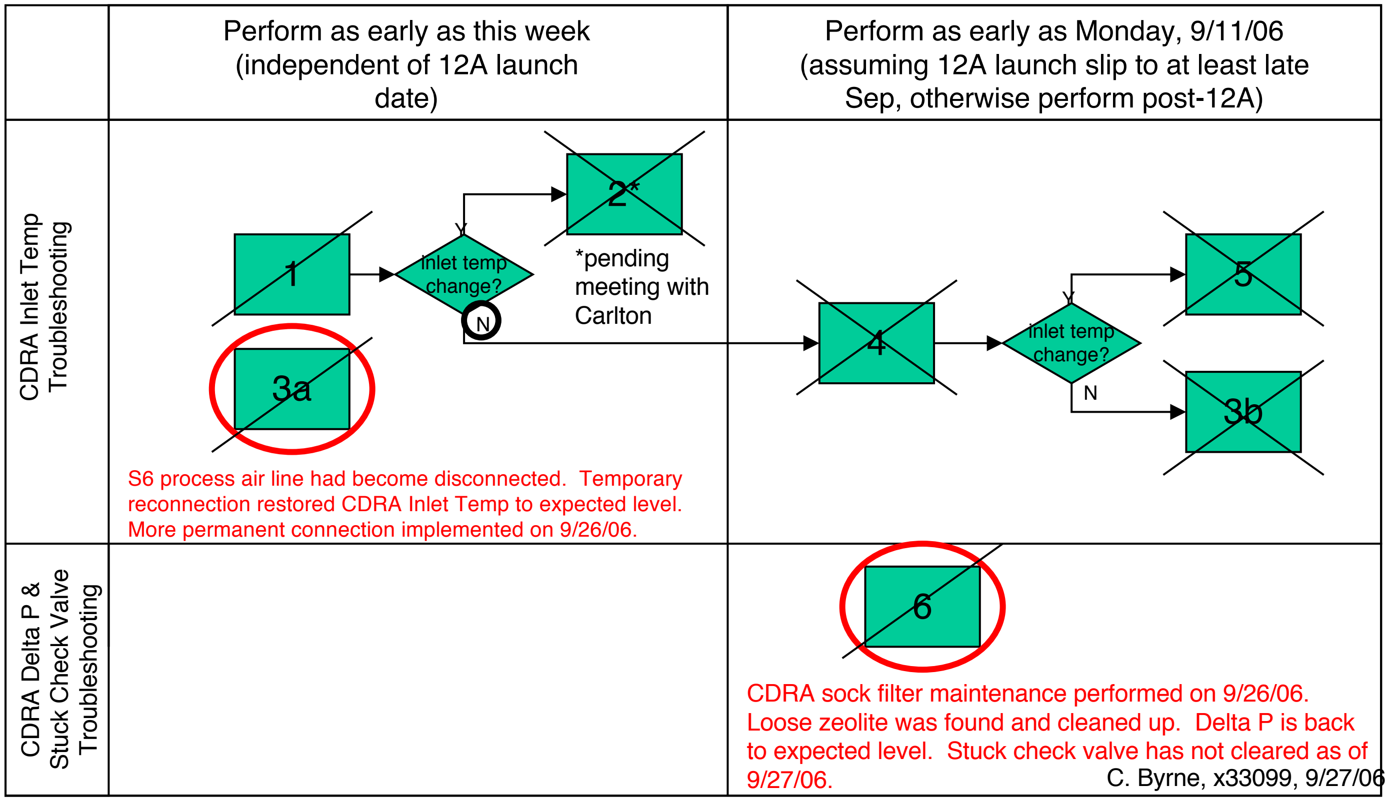
JUL-AUG/2006 CDRA CO_2 Removal Rate Anomalies

GMT	DATE	EVENT
2006/134-140	5/14/2006 - 5/20/2006	CDRA operation in May 2006 due to failed Vozdukh valve
2006/187	7/6/2006	ULF1.1 docking
2006/192	7/11/2006	CDRA check valve failure (valve cleared in 2 half cycles and dual bed ops resumed)
2006/193	7/12/2006	Sudden change in CDRA blower delta pressure
2006/196	7/15/2006	ULF1.1 undocking
2006/210	7/29/2006	CDRA check valve failure (valve did not clear)
2006/212	7/31/2006	Swap to Starboard CCAA and sudden CDRA inlet temperature increase
2006/226	8/14/2006	Vozdukh performance test begins
2006/227	8/15/2006	Vozdukh performance test ends
2006/233	8/21/2006	CDRA performance test begins
2006/235	8/23/2006	CDRA performance test ends
2006/248	9/5/2006	CDRA Starboard process air inlet hose discovered to be detached
2006/254	9/11/2006	12A docking
2006/260	9/17/2006	12A undocking
2006/269	9/26/2006	CDRA Starboard process air inlet hose repaired
2006/269	9/26/2006	CDRA sock filter cleaned - near normal delta pressure recovered

JUL-AUG/2006 CDRA CO_2 Removal Rate Anomalies—Troubleshooting

1. Operate P6 CCAA fan, look for changes in CDRA inlet temp (Ground command)
2. Cycle Process Air Valve with P6 CCAA fan on (Ground command)
3a. Inspect process air conn. at S6 rack interface (5-10 min crew time)
3b. Inspect process air conn. at AR rack interface (40 min crew time)

4. Swap from S6 CCAA to P6 CCAA (45 min crew time)
5. Inspect AR process air conn. at S6 CCAA HX (1.5 hour crew time)
6. Inspect & clean CDRA sock filter (30 min crew time)



ATTACHMENT #5; CDRA Troubleshooting Steps

JUL-AUG/2006 CDRA CO_2 Removal Rate Anomalies—Background

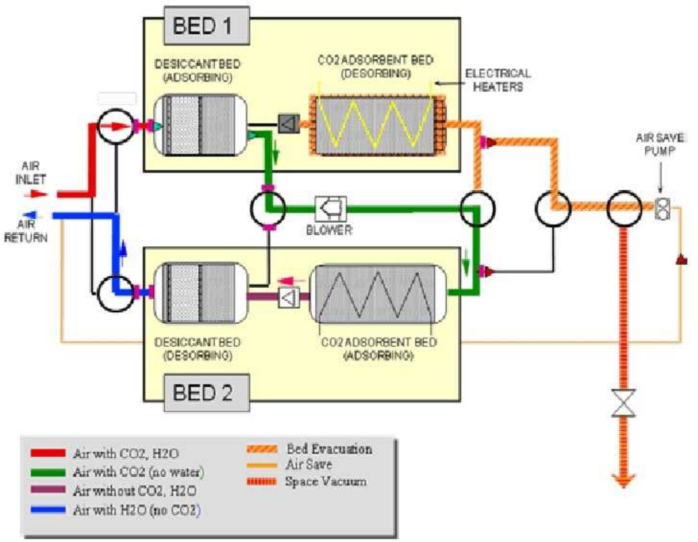


Figure 1. CDRA schematic. Architecture of the CDRA, showing desiccant-adsorbent Bed 2 adsorbing CO_2 from the cabin and desiccant-adsorbent Bed 1 desorbing to the space vacuum.[2]

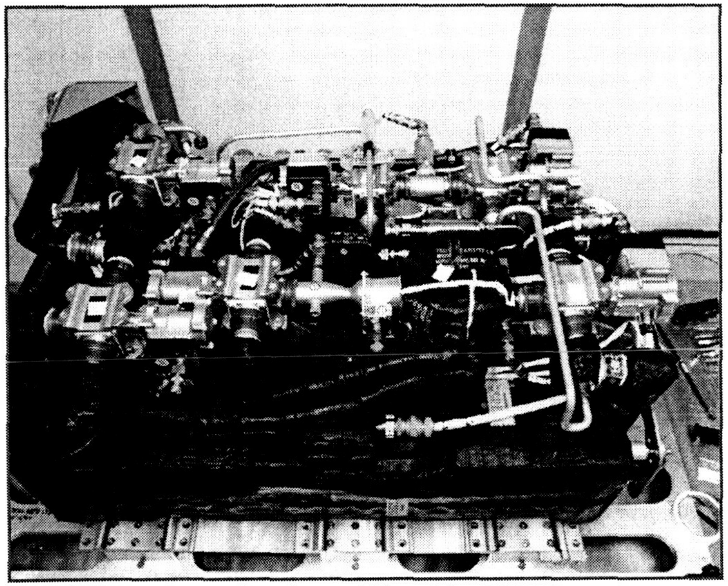
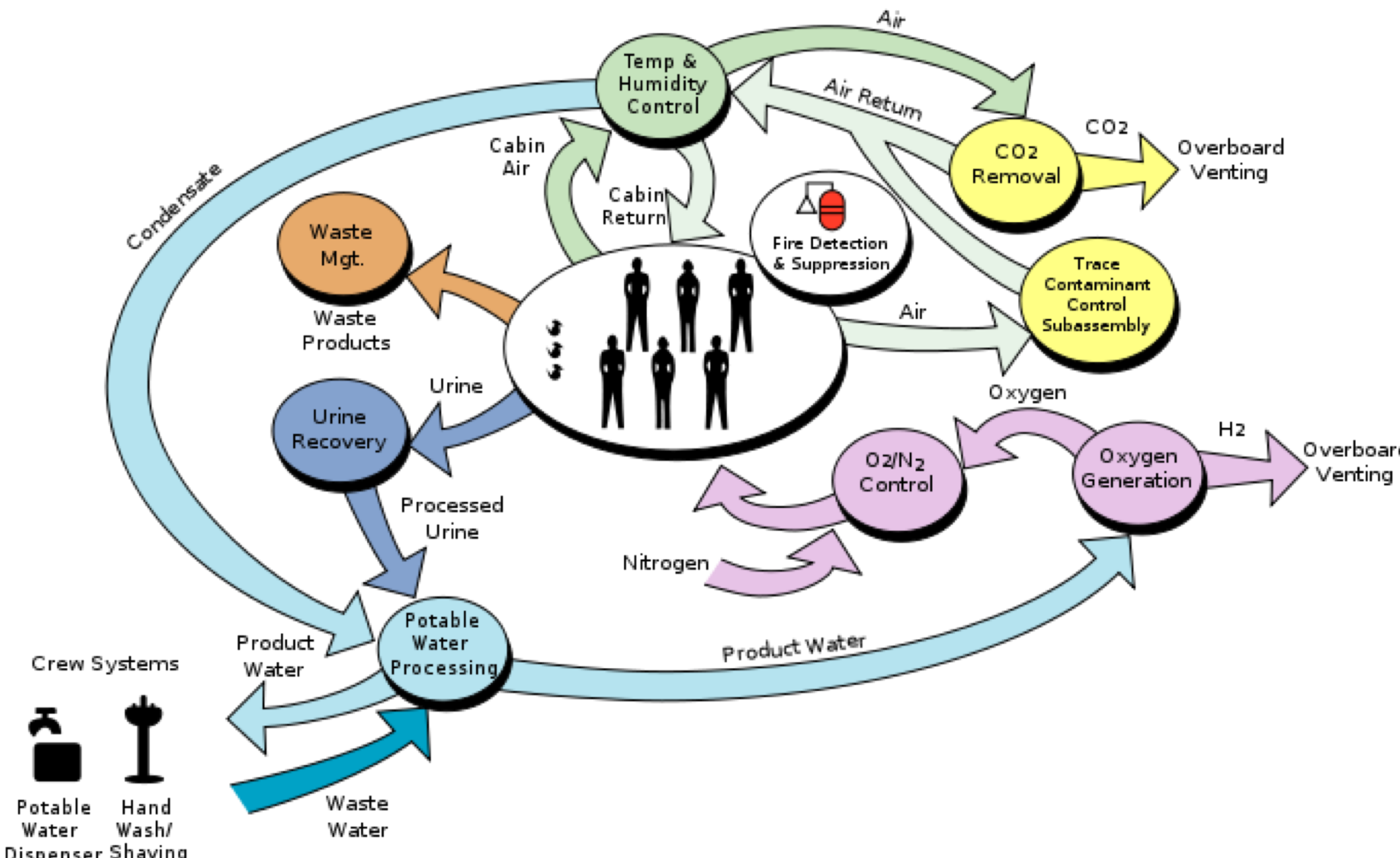


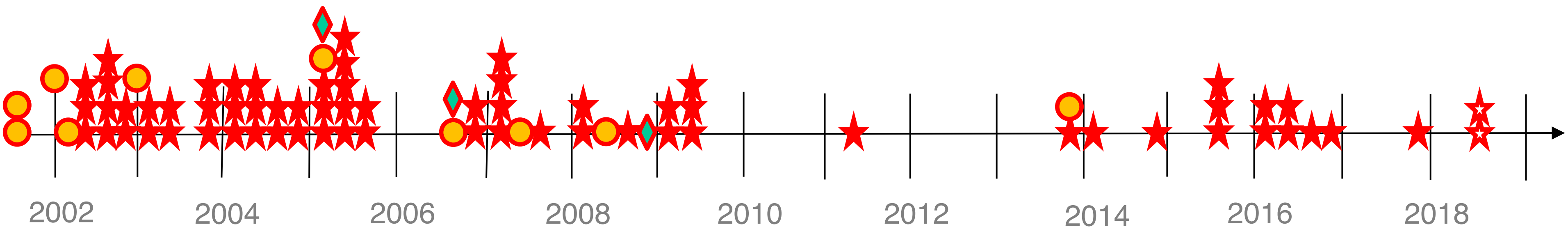
Figure 1. Carbon Dioxide Removal Assembly (CDRA)

JUL-AUG/2006 CDRA CO_2 Removal Rate Anomalies—Background



The interactions between the components of the ISS Environmental Control and Life Support System (ECLSS)

ISS: High Priority IFIs, Significant Incidences



C&DH ✓
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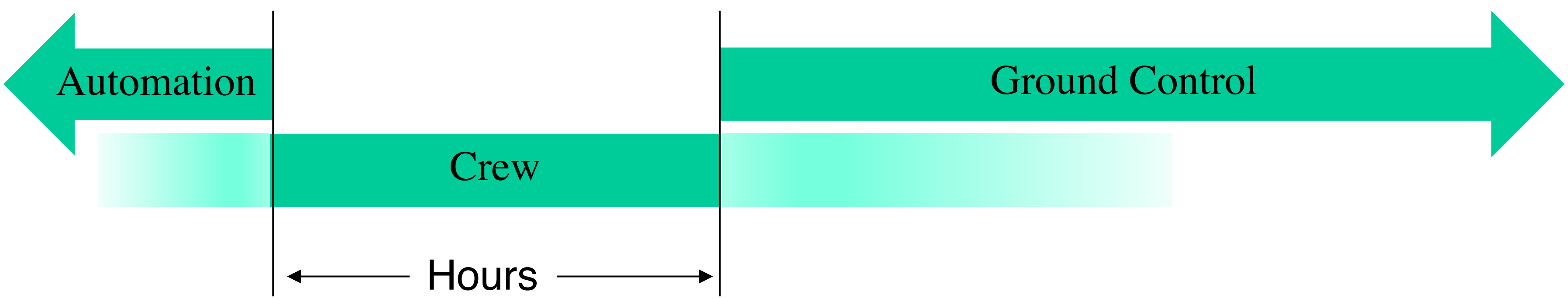
Safety ✓

Z-Card Incidents 2015
IFI (by closed date)
IFI (open)
Fire/Overheat (Z-Card 2015)

Enabling Crew Problem-Solving

On-Board Problem Solving for Potential Loss-of-Crew / Loss-of-Vehicle Anomalies



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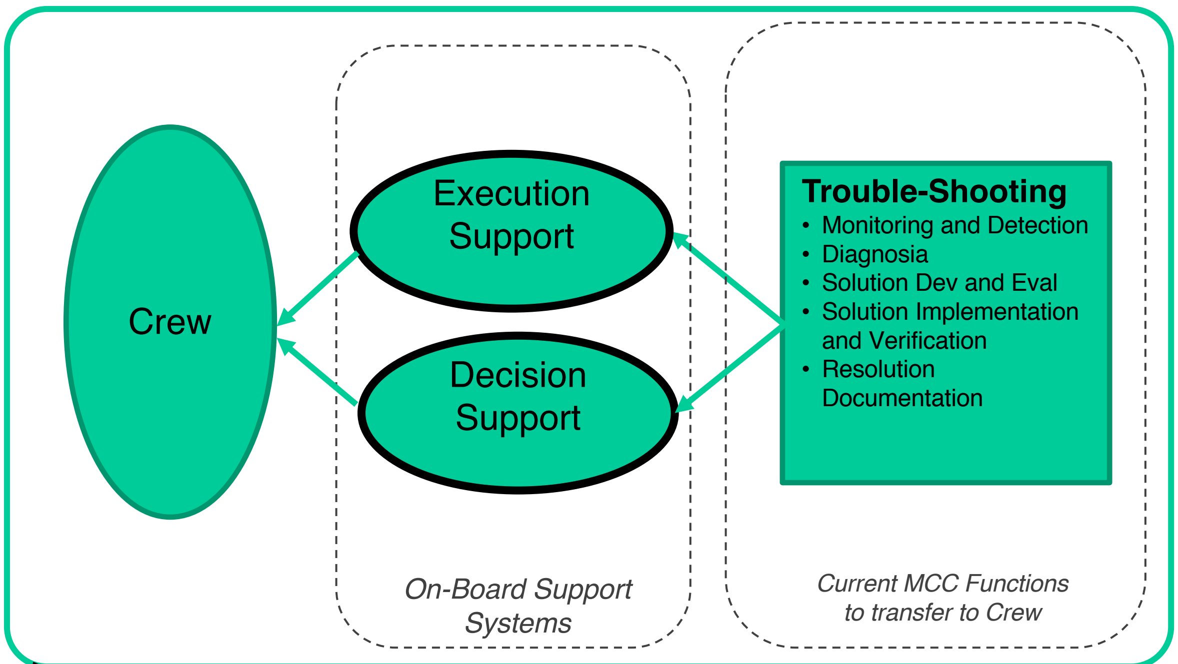
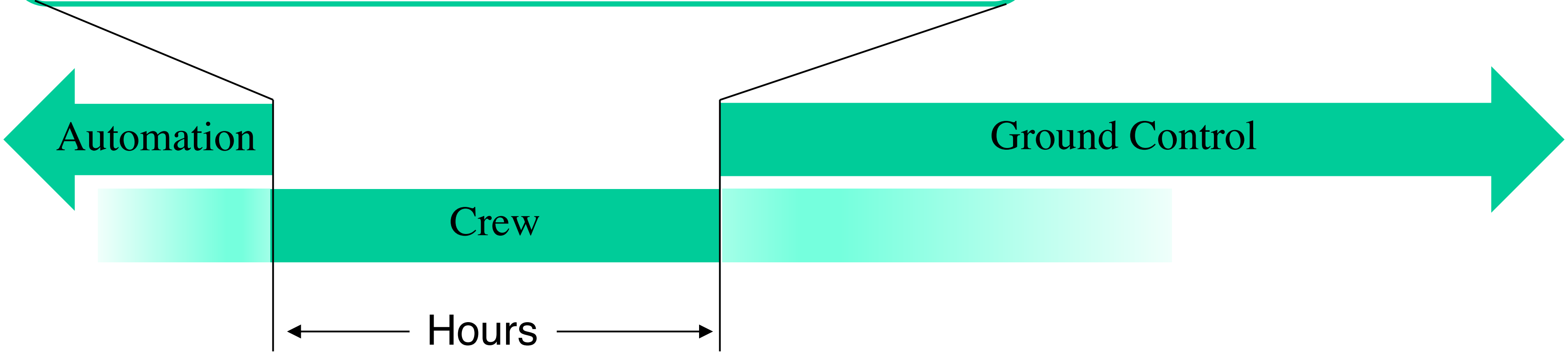
Enabling Crew Autonomy

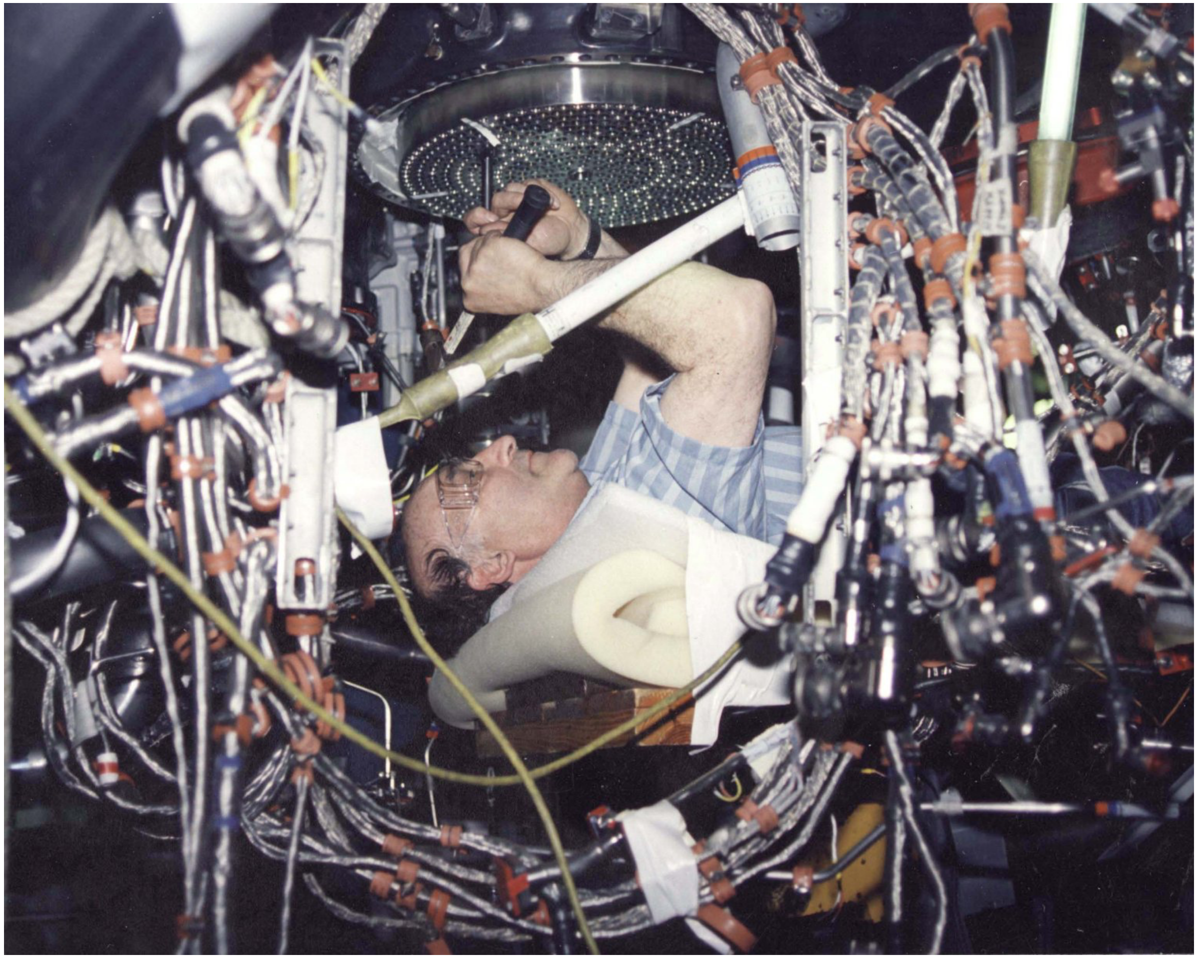




Current Command & Control approach wit ~150 ground based experts conducting most aspects of mission operations.

On-board self-scheduling during 2017 ISS Crew Autonomous Scheduling Test (CAST).

How Not to End up Making Things Harder?



Shuttle Main Engine Maintenance on the Ground, 1995

Avoiding the Autonomy Paradox

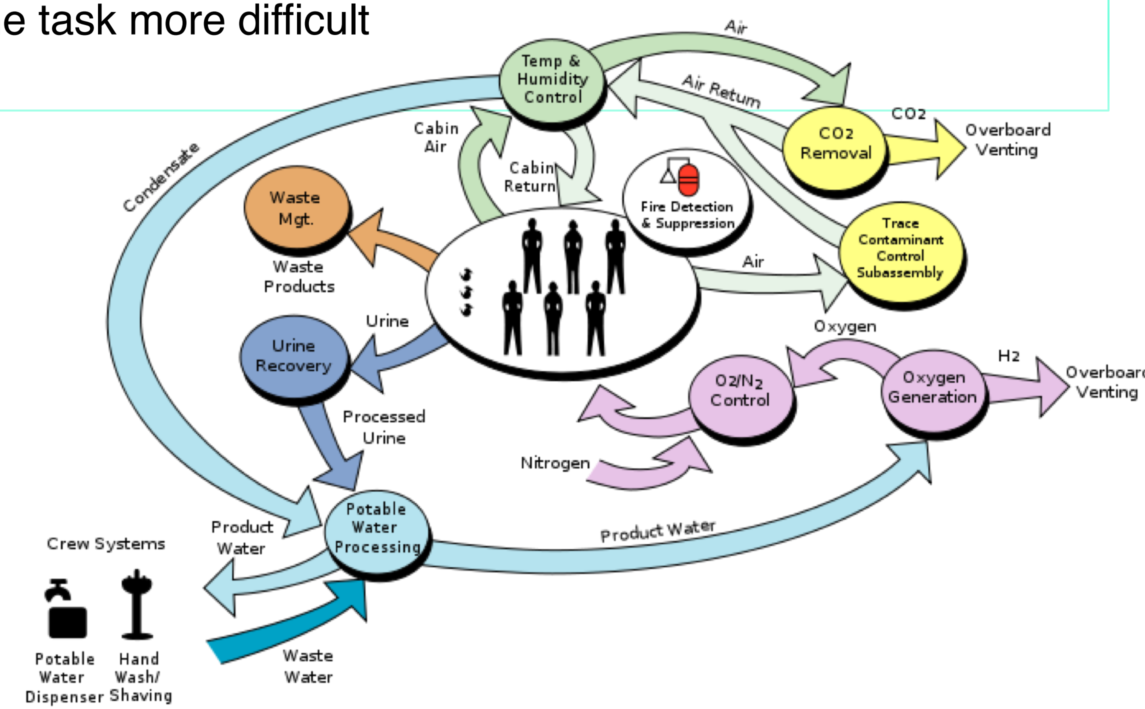
The Autonomy Paradox

(Blackhurst, Gresham & Stone, 2011)

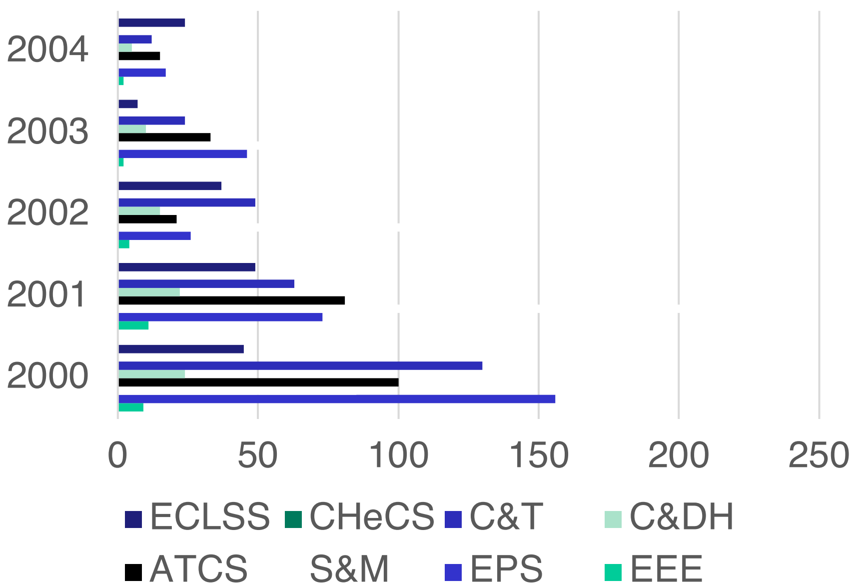
- In the summed experience of DoD, Autonomy investments lead to increased costs
- Autonomy doesn't get rid of humans, it changes their roles
- Unless attention is paid to how the new intelligent systems will work with humans, they will end up making the task more difficult

As machine intelligence advances, the need for functional integration with human capabilities increases

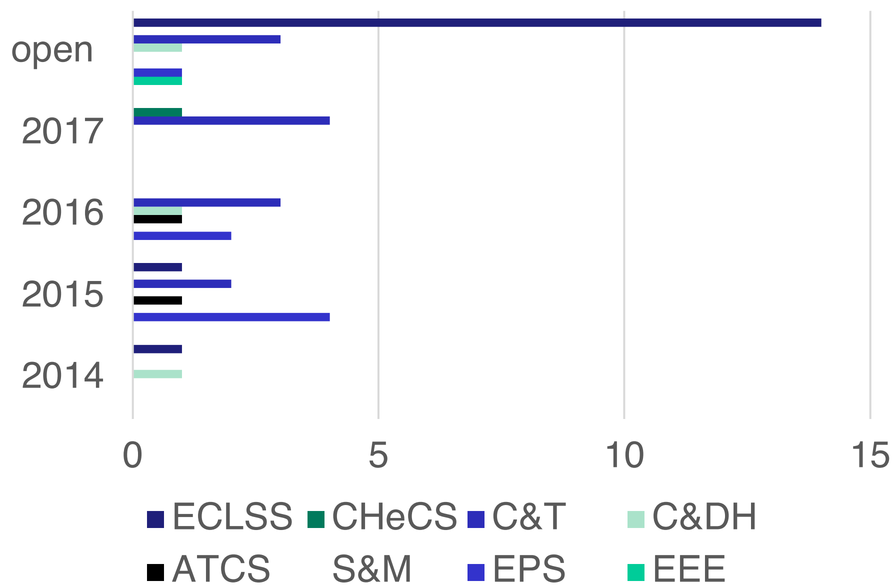
This won't happen by itself -- needs to be driven by research that informs engineering requirements



PRACAs: First Five Years*



PRACAs: Last Five Years



** Excludes EVR, Environ, M&P, FCS, GN&C, Payload, and RCS for comparison purposes*

The Significant Incidents and Close Calls, Z-Chart

- **Charts present visual overview of major losses and close calls spanning the history of the International Space Station to heighten awareness of the risks that must be managed as human space flight continues to advance.**
- **Events on the chart are organized by flight phase and ordered chronologically within each phase.**
- **Three types of important events are highlighted: loss of crew, crew injury, and related or recurring events.**
  - Events with one or more crew fatalities are considered a loss of crew and highlighted in red.
  - Crew injury or illness and/or loss of vehicle or mission is designated by orange shading.
  - Related or recurring events are grouped together and set apart by yellow shaded boxes. These events have occurred repeatedly, are similar in nature, and may continue to occur today.

MCC

Flight Controller	Call Signs	Responsibilities on ISS
Flight Director	Flight	Oversees team of Flight Controllers
Communication and Tracking	CATO	Manages on-orbit communications & telemetry
Onboard Data and Information Network	ODIN	Manages computer hardware & software
Environmental Control and Life Support Systems	ECLSS	Manages cabin air supply, humidity, and temperature, along with other systems that influence the station's environment
Power, Heating, Articulation, Lighting, and Control	PHALON	Manages the electricity to operate the station and its payloads
Attitude Determination and Control	ADCO	Integrates guidance and navigation for the station using the Motion Control System and manages docking of spacecraft on ISS
Thermal Operations and Resources	**THOR**	**Manages the thermal control system, which regulates the dissipation of waste heat generated by equipment and payloads onboard the ISS**
Robotics Operations System	ROBO	Plans and executes robotic operations
Extravehicular Activity	EVA	Responsible for all spacesuits and space walk activities
Operation Support Officer	OSO	Manages all station maintenance activities that includes maintaining the mechanic systems for attachment of modules to the ISS
Operation Planner	Ops Plan	Plans the station's short-term crew schedules
Assembly, Activation & Checkout Officer	ACO	Responsible for all new assembly for development of station and all checkout procedures
Cargo Integration Officer	CIO	Assists in managing inventory of cargo that includes materials and equipment
Trajectory Operations and	TOPO	Manages station's trajectory planning all orbital positions
Visiting Vehicle Officer	VVO	Monitors visiting vehicles' activities, while docking and undocking at the station
Flight Surgeon (SURGEON)/ Biomedical Engineer	BME	Monitors and manages the health of the crew
Ground Control	GC	Maintains Mission Control Center's computers and coordinates the telemetry between MCC and the station
Spacecraft Communicator	CAPCOM	The spokesperson for Mission Control Center to the crew on station
Public Affairs Officer	PAO	Responsible to communicate to news media and the public the activities on station
Payload Operations director at POIC	POD	POD oversees the team of Flight Controllers at MSFC, however he is directly responsible to MCC for the payloads onboard station

Exhibit 4. MCC consoles and their MER counter parts

MCC Console	MER Counter Part
Flight	MER Manager
CATO	C&T
ODIN	C&DH
ECLSS	MERLIN
PHALON	PHOENIX
ADCO	GN&C, PROP
THOR	PTCS, **ASTRO**
ROBO	EVR
EVA	EVA, EV&CS
OSO	S&M, L&M, FCS
Ops Plan	No MER counter part
ACO	VIPER, L&M, FCS
CIO	VIPER, L&M, FCS, OPSLAN
TOPO	GN&C
VVO	GN&C, PROP, RPOC
SURGEON (BME)	CHeCS
GC	No MER counter part
CAPCOM	No MER counter part
PAO	No MER counter part

MER

Flight Controller	Call Signs	Responsibilities on ISS
MER Manager	MER Manager	Oversees team of Flight Controllers in MER
Command & Data Handling	C&DH	Manages computer hardware & software
Communication and Tracking	C&T	Manages on-orbit communications & telemetry
Configuration Management	CM	
Crew Health Care System	CHeCS	Monitors and manages the health of the crew
Mission Evaluation Room Life Support Integration	MERLIN	Manages cabin air supply, humidity, and temperature, along with other systems that influence the station's environment
Power Hardware, Operations, Electrical Networks, and Illuminating eXperts	PHOENIX	Manages the electricity to operate the station and its payloads
Extravehicular and Crew Systems	EV&CS	Responsible for spacesuits and all space walk activities
Extravehicular Activity	EVA	Responsible for all spacesuits and space walks activities
Vehicle Integrated Performance and Resources	VIPER	Responsible for assembly and checkout procedures for station and assists in managing inventory of cargo that includes materials and equipment
Extravehicular Robotics	EVR	Plans and executes robotic operations
Flight Crew Systems	FCS	Manages all station maintenance activities that includes maintaining the mechanic systems for attachment of modules to the ISS, assists in managing cargo inventory, and responsible for assembly and checkout procedures for station
Guidance, Navigation & Control	GN&C	Integrates guidance and navigation for the station using the Motion Control System and manages docking of spacecraft
Logistics & Maintenance	L&M	Manages all station maintenance activities that includes maintaining the mechanic systems for attachment of modules to the ISS, assists in managing cargo inventory, and responsible for assembly and checkout procedures for station
MPLM NASA Element Management Officer	MNEMO	
Operations Local Area Network	Ops LAN	
Propulsion	Prop	Monitors visiting vehicles' activities, while docking and undocking at the station
Rendezvous, Proximity Ops, and Capture	RPOC	Monitors visiting vehicles' activities, while docking and undocking at the station
Structures & Maintenance	S&M	Manages all station maintenance activities that includes maintaining the mechanic systems for attachment of modules to the ISS
Safety & Mission Assurance	S&MA	
Passive Thermal Control System	PTCS	Manages the passive thermal control system, which helps to regulate the dissipation of waste heat generated by equipment and payloads
Active Station Thermal Resources & Operations	**ASTRO**	**Manages the active thermal control system, which regulates the dissipation of waste heat generated by equipment and payloads**