

# IV&V of the Canadian-provided International Space Station Mobile Servicing System (MSS) Displays

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# The Heritage of the Space Shuttle Remote Manipulator System

In the 1970's, NASA contracted with SPAR, in Brampton, Ontario, for the development of a payload deployment system for the Shuttle.

The highly successful Remote Manipulator System resulted.

SPAR was bought by McDonald-Detweiler Robotics, which later became MD Robotics.

# Shuttle Remote Manipulator System



Payload on  
End Effector

Wrist (3 DOF)  
Elbow (1 DOF)

Shoulder (2 DOF)



The RMS is 50 feet long  
Weighs 1,000 pounds  
and can move 150,000 pound payloads.

RMS control modes include  
hard wired and computer-  
augmented.

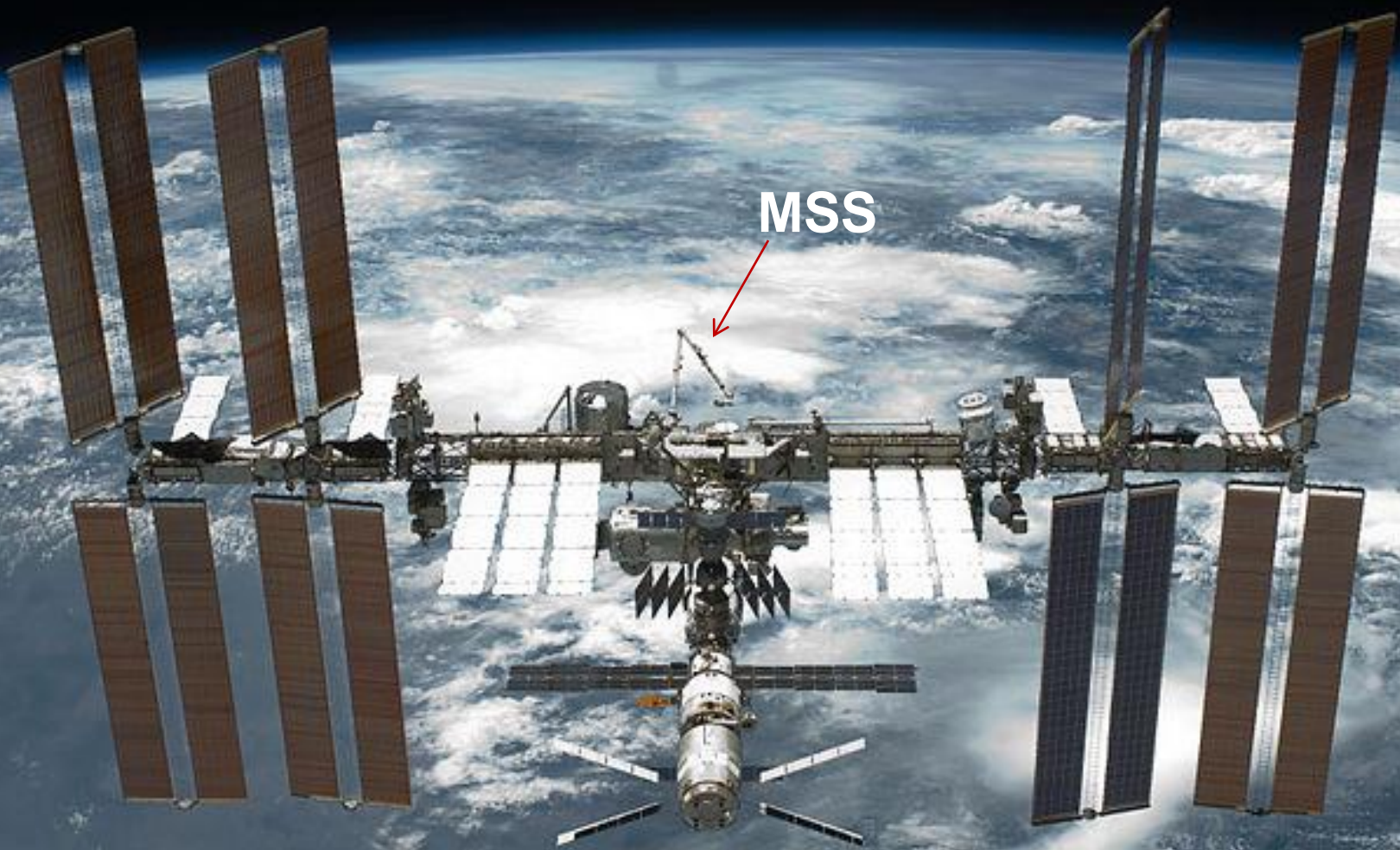
Astronaut operating the RMS  
from the aft Flight Deck

Partner nations of the International Space Station contribute services in return for access or other services onboard the ISS.

Canada provided the Mobile Servicing System to the ISS as its contribution.

As a second generation robot with capabilities exceeding that of the Shuttle RMS, the MSS set the standard for robotics for human spaceflight.

# The International Space Station



MSS

The MSS provides transportation, power, and data connectivity of ISS components, equipment, and EVA astronauts for assembly and maintenance.

(2001) SSRMS -Space Station Remote Manipulator System

(2002) MBS - Mobile Base System

(2002) MT -- Mobile Transporter (US provided)

→ these contributed pivotally to assembly of the ISS:

100 EVAs 43 shuttle payloads 20 assembly operations

10 logistics ops & captured two free-flying spacecraft H-II

(2010) SPDM -- Special Purpose Dexterous Manipulator

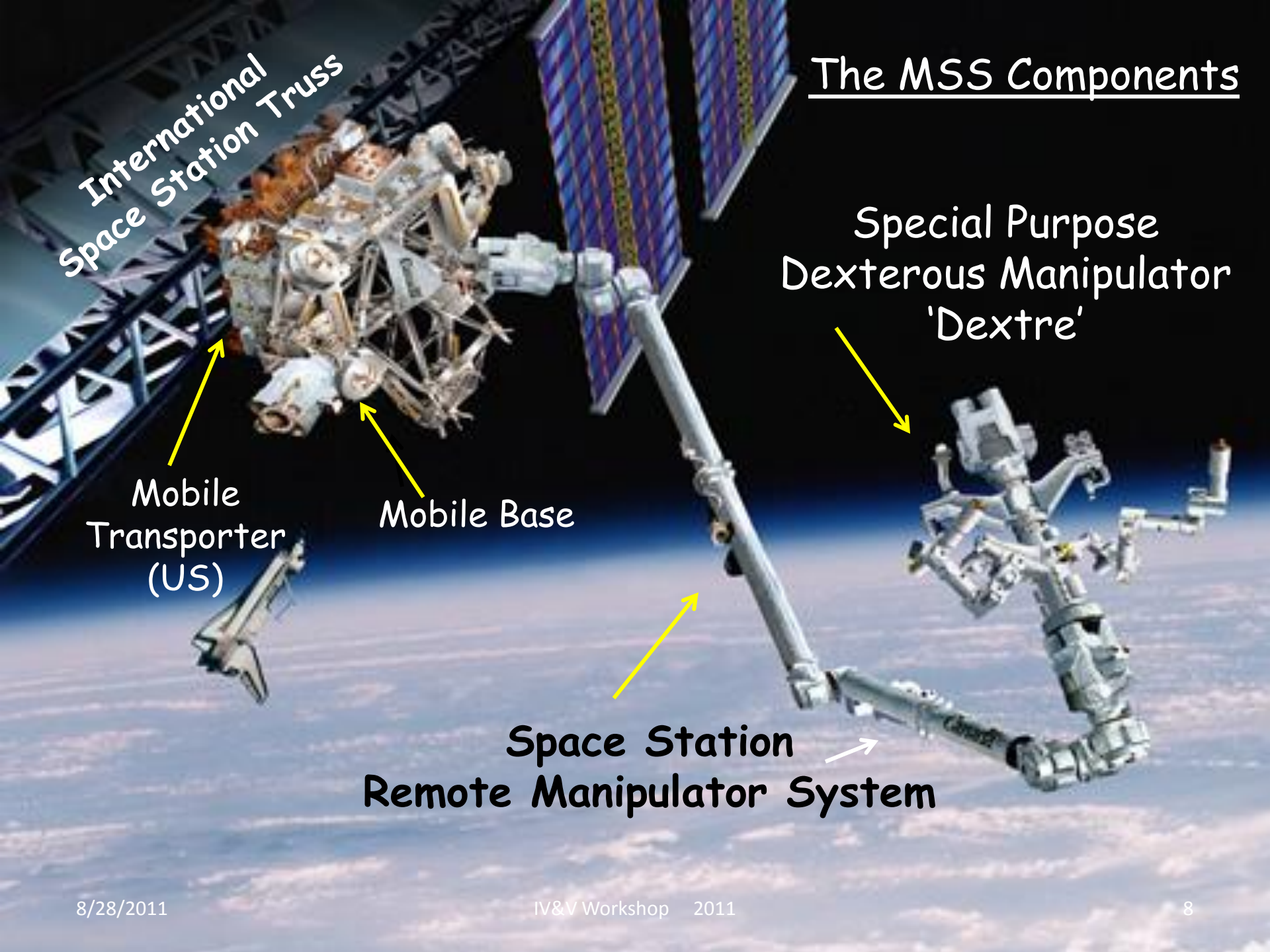
→ performs 'EVR' maintenance—the robotic approximation of astronaut EVA

# The International Space Station

MSS

357 feet long

Weight : 1,000,000 pounds



International  
Space Station Truss

# The MSS Components

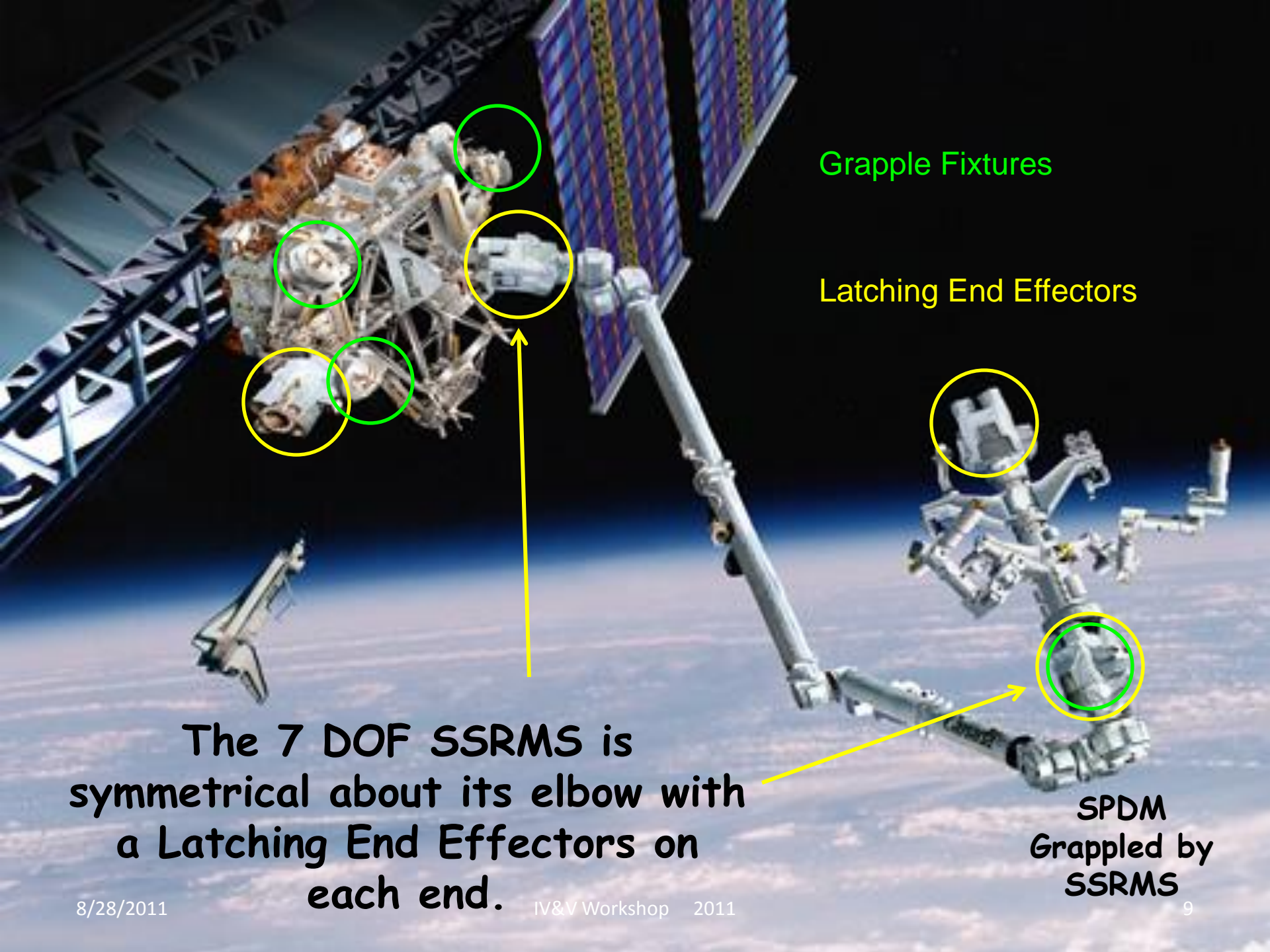
Special Purpose  
Dexterous Manipulator  
'Dextre'

Mobile  
Transporter  
(US)

Mobile Base

Space Station  
Remote Manipulator System





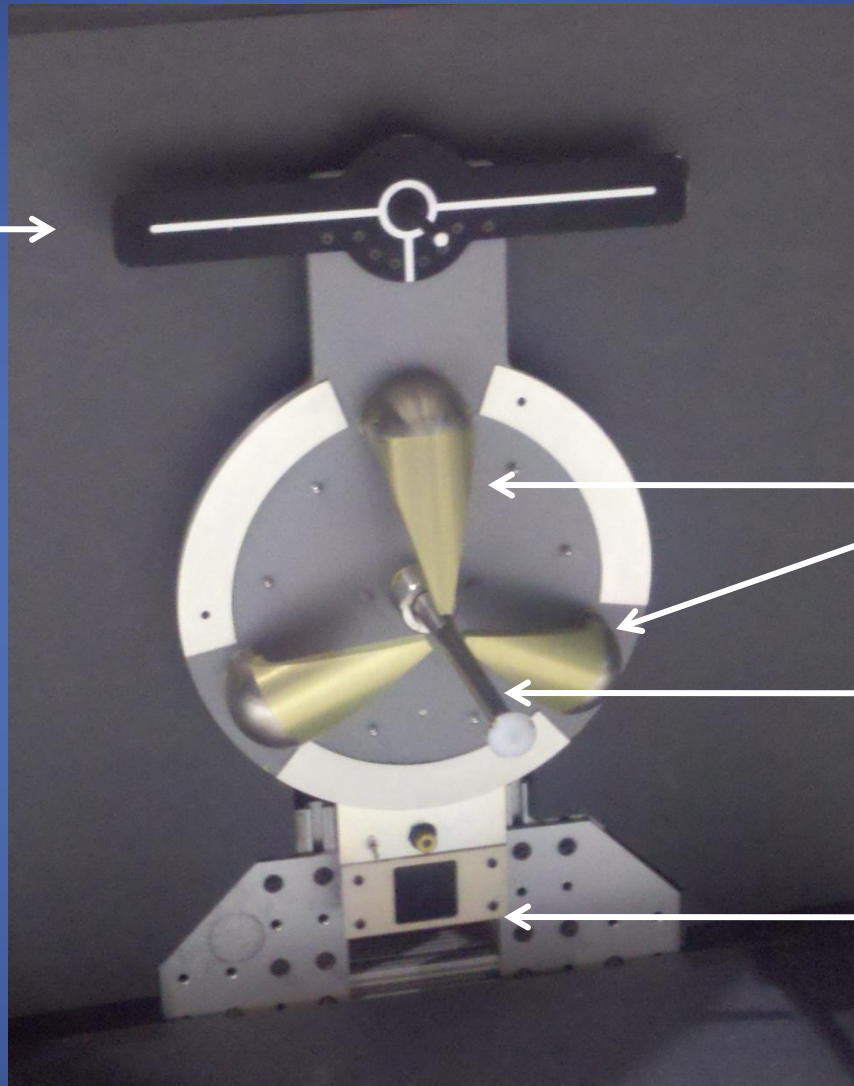
Grapple Fixtures

Latching End Effectors

The 7 DOF SSRMS is symmetrical about its elbow with a Latching End Effectors on each end.

SPDM Grappled by SSRMS

3  
Dimensional  
Alignment  
Target



Grapple  
Fixture

3  
Pawls

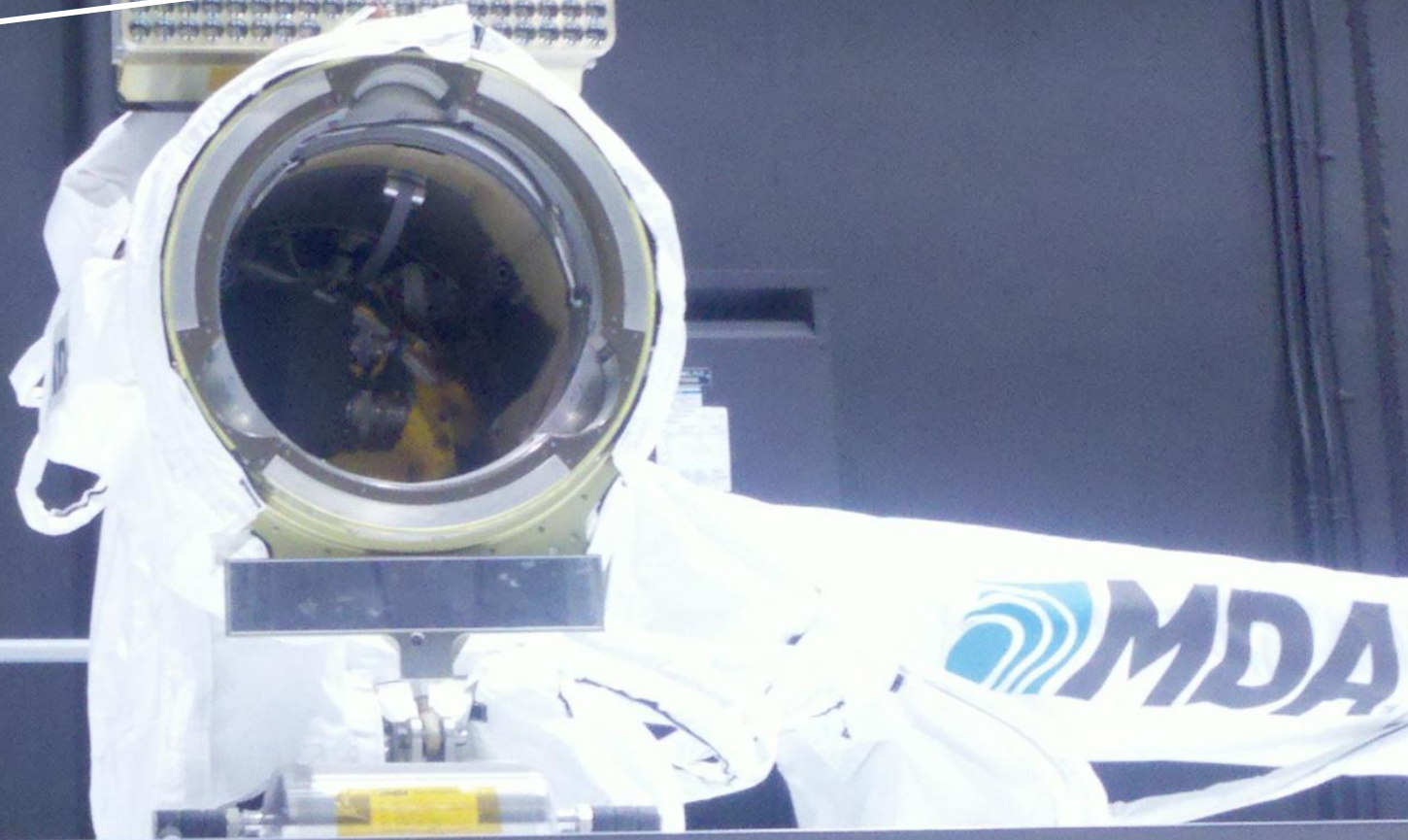
Grappling  
Pin

Power &  
Data  
Connectors

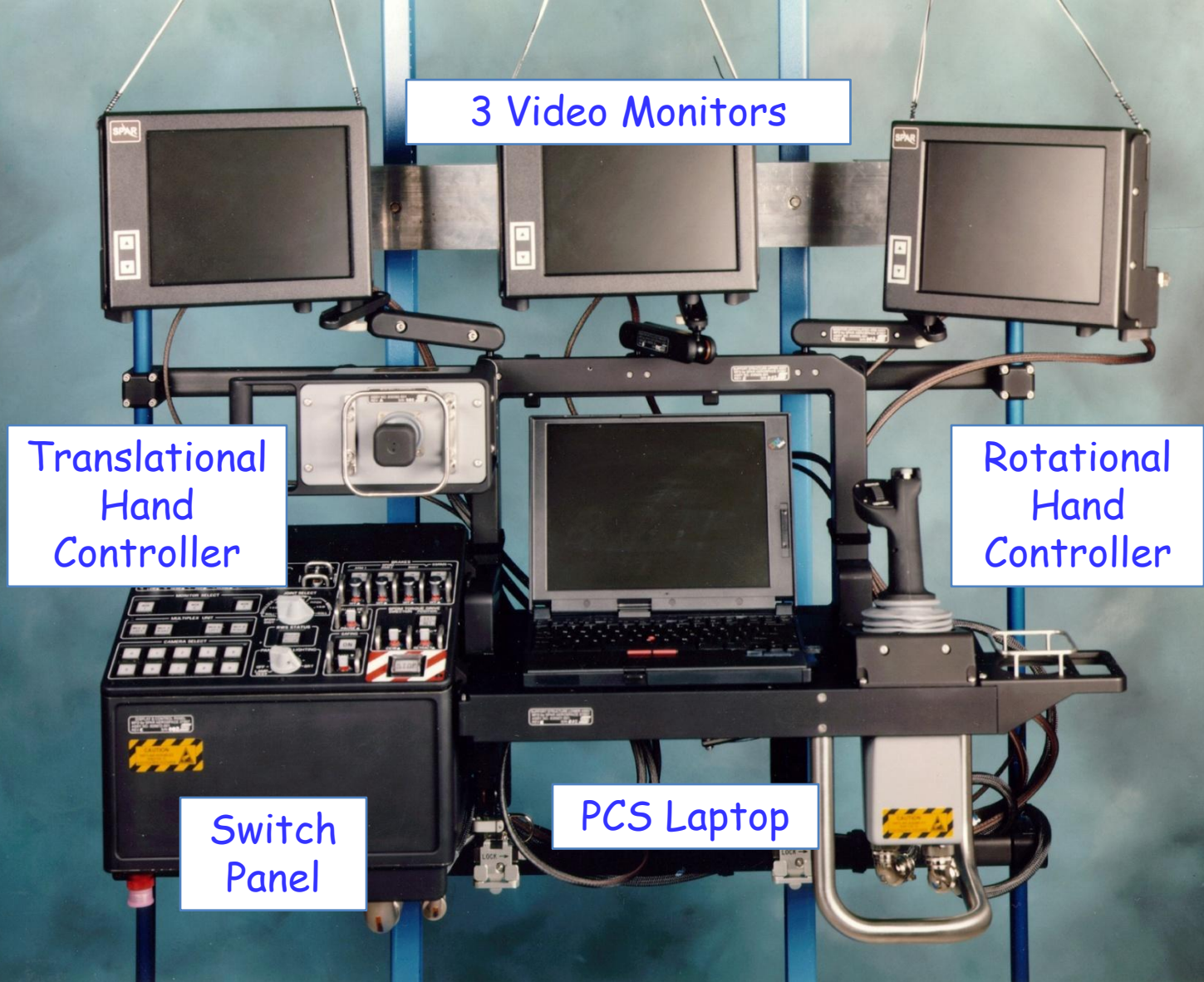


# ISS MSS Power Data Grapple Fixture Ground Mockup

LED  
Illumination  
& TV  
Camera



ISS SSRMS End Effector Ground Mockup



ISS Robotic Work Station is used to control the MSS over the ISS data network.  
The MSS can also be controlled from the ground.



Canadian Astronaut Julie Payette operating the ISS Robotic Work Station in a ground laboratory.



US Astronaut Leroy Chou operating the Robotic Work Station onboard the ISS.

Safety for astronauts & spacecraft dictates very careful mission planning of all paths of movement of a manipulator and its payload.

This is typically begun with kinematic analysis of the manipulator and its workspace configuration using high definition computer graphics models.

These procedures are refined through the use of dynamic engineering simulations.

Flight procedures are wrung out in Systems Test Facilities & Crew Trainers such as full cockpit Simulators, Neutral Buoyancy, and Virtual Reality immersion trainers.

Post flight crew debriefs provide feedback on process.

All MSS software was developed by Canada with no NASA IV&V performed until 2008, when 3 displays requirements documents (~3,000 pages total) for the MSS were transferred to NASA responsibility.

IV&V reviews all changes to the 3 documents.

- Software Change Requests
- Redlines to the documents

IV&V also supports reviews of

- Unit Tests of the changes,
- Formal Qualification Testing (FQT)
- Change request prioritization for the Portable Computing System software builds



## Requirements Change Drivers:

- Functional Errors
- ISS Configuration Changes
- Planned Improvements
- Documentation Updates

## Nature of Issues Found IV&V:

- Text 'typos' & contextual content
- Incomplete or incorrect graphic figures
- Missing footnotes, & graphic figures
- Non-deleted requirements, figures, & footnotes
- Incorrect expected test values

MSS displays are in the Portable Computing System (PCS).

Currently consist of 382 windows

Each window has textual and graphic requirements for

Function &

Size, colors, text and icon format, and screen locations for

- Labels
- Graphic figures
- Status data fields
- Command buttons
- Navigation buttons (to & from other windows).

Each window has tabular specs for context of all

- Status data
- Command signals

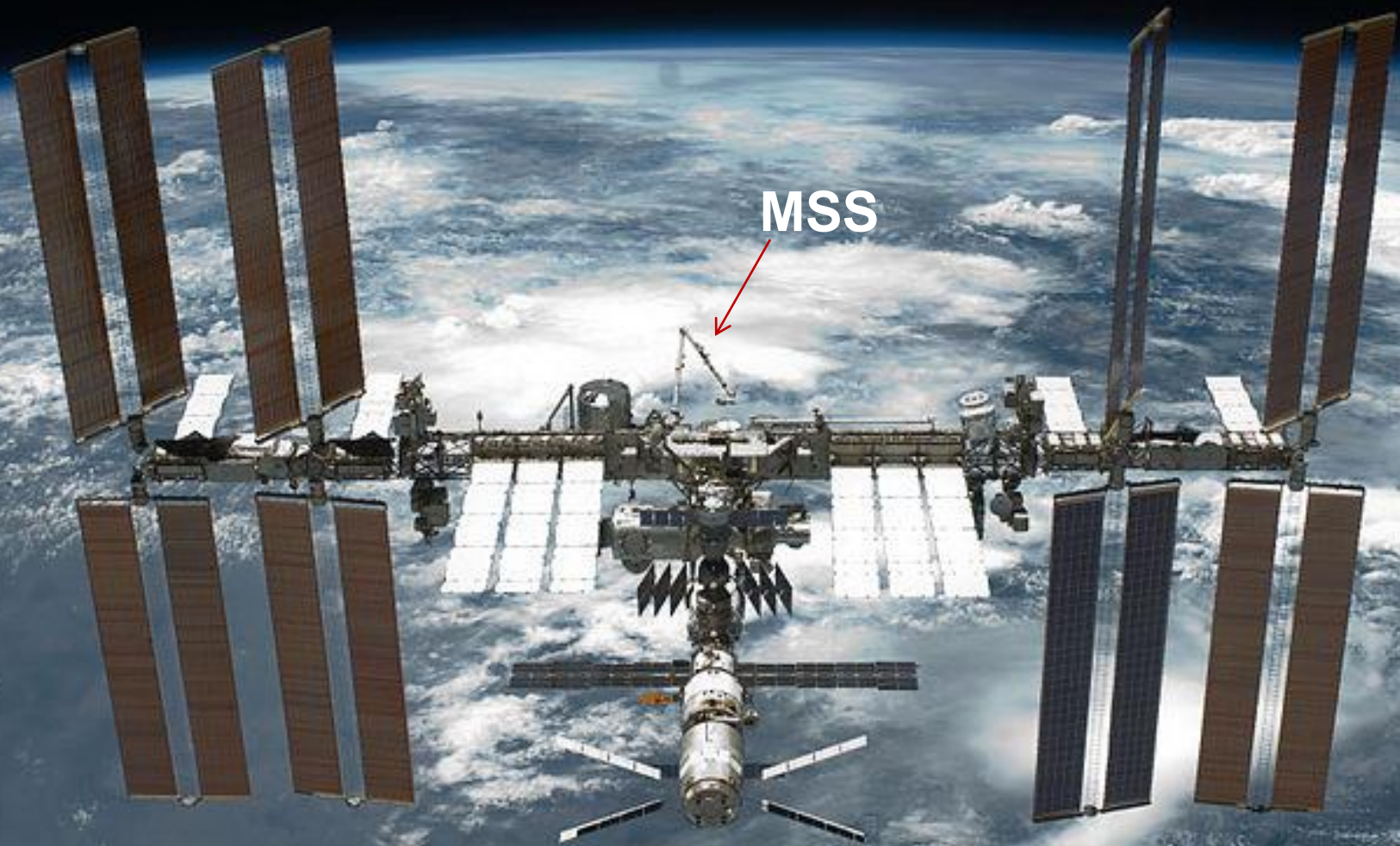
(Each of which has a unique identification number.)

# The MSS Displays & Parameters Summary

	Display Pages	Status Data	Command Signals	Total Parameters
MT/MBS	79	486	1221	1707
SSRMS	121	1751	2535	4286
SPDM	182	n/a	n/a	n/a

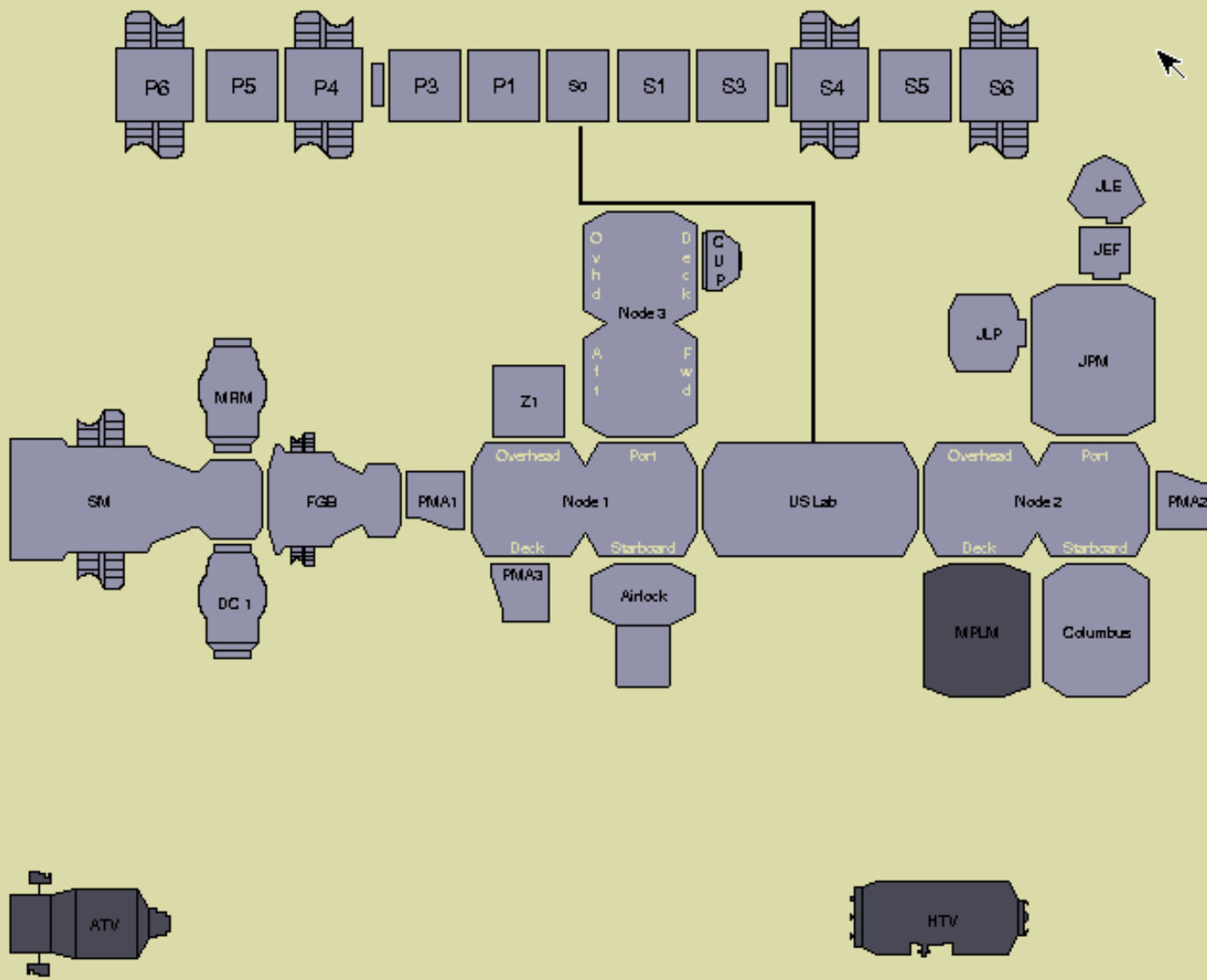
ISS MSS SCRs Reviewed by IV&V (issues reported)	2008	2009	2010	2011
MT		3 ( 3)		1
MBS	2	2 ( 2)		
SSRMS		13 ( 4)	9 (1)	18
SPDM		11 ( 7)	1	2
<b>Totals 62 (17)</b>	<b>2</b>	<b>29 (16)</b>	<b>10 (1)</b>	<b>21</b>
Unit Tests			7 (3)	2
Formal Qualification Tests			6	6
Build Prioritizations				12
<b>Totals 33 (3)</b>	<b>0</b>	<b>0</b>	<b>13 (3)</b>	<b>20</b>

# The International Space Station





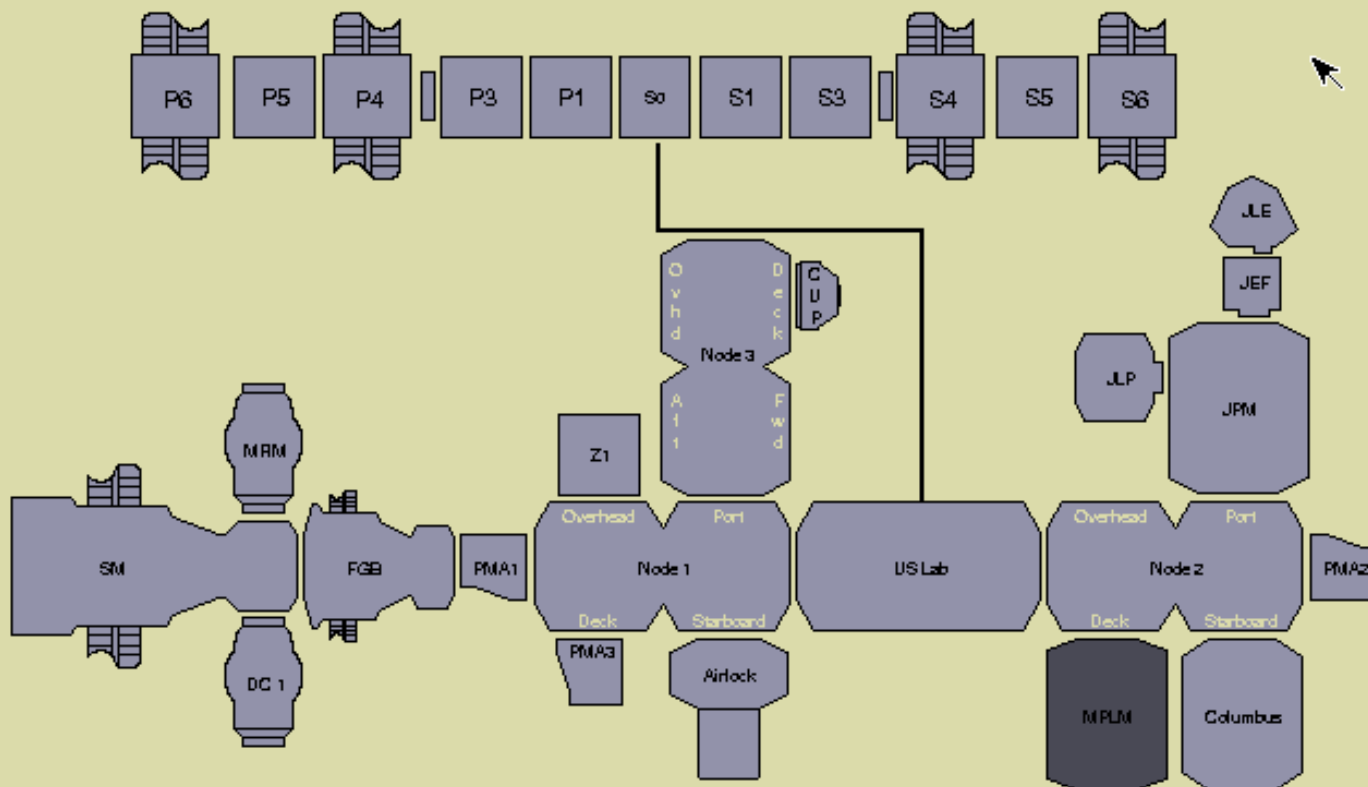
- Clone
- 
- APV
- Fire Summ
- Rapid Depress
- Voice Status
- Cmd Log
- Error Log



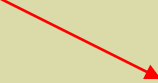
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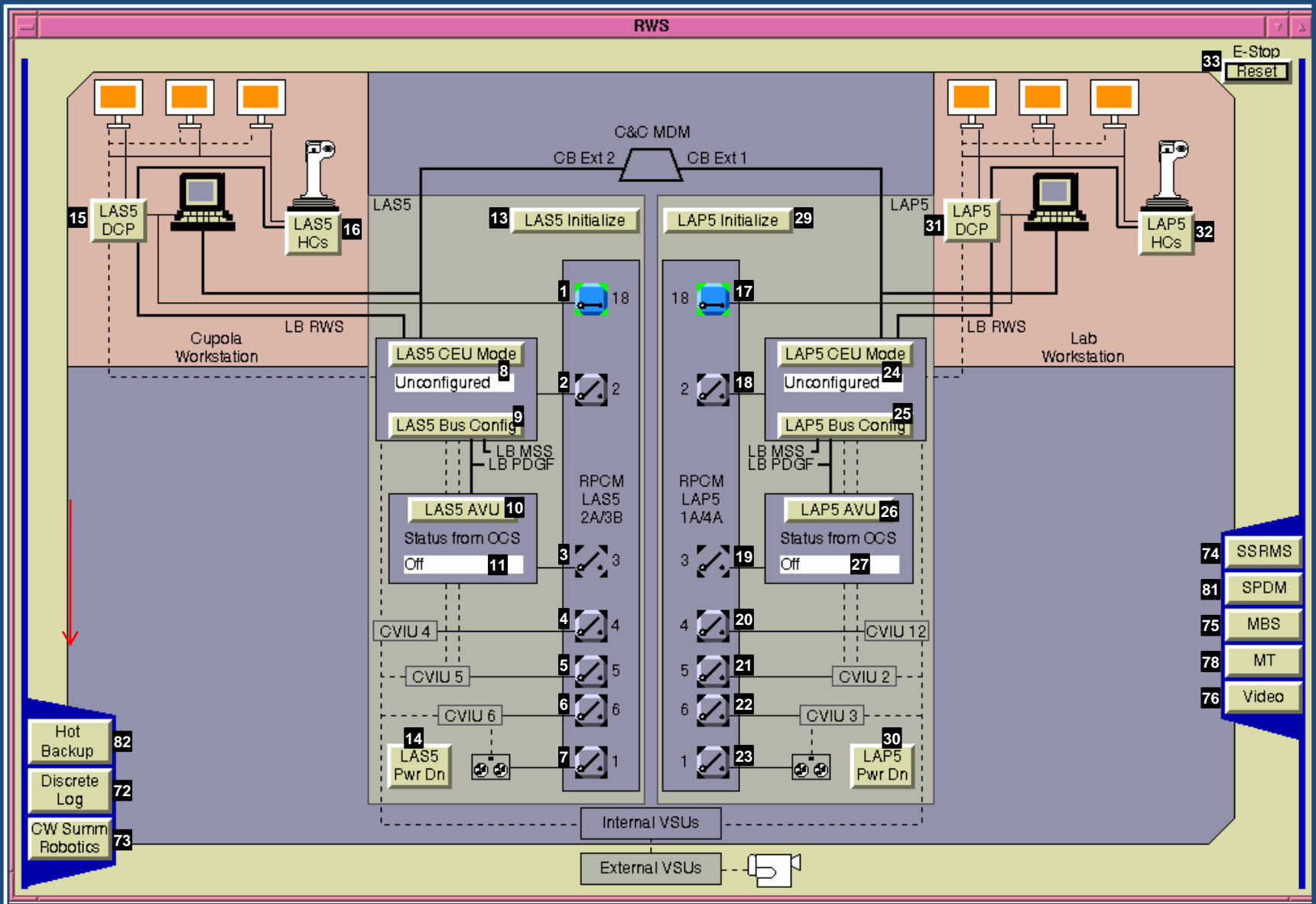
- Clone
- 
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Robotics Nav Button

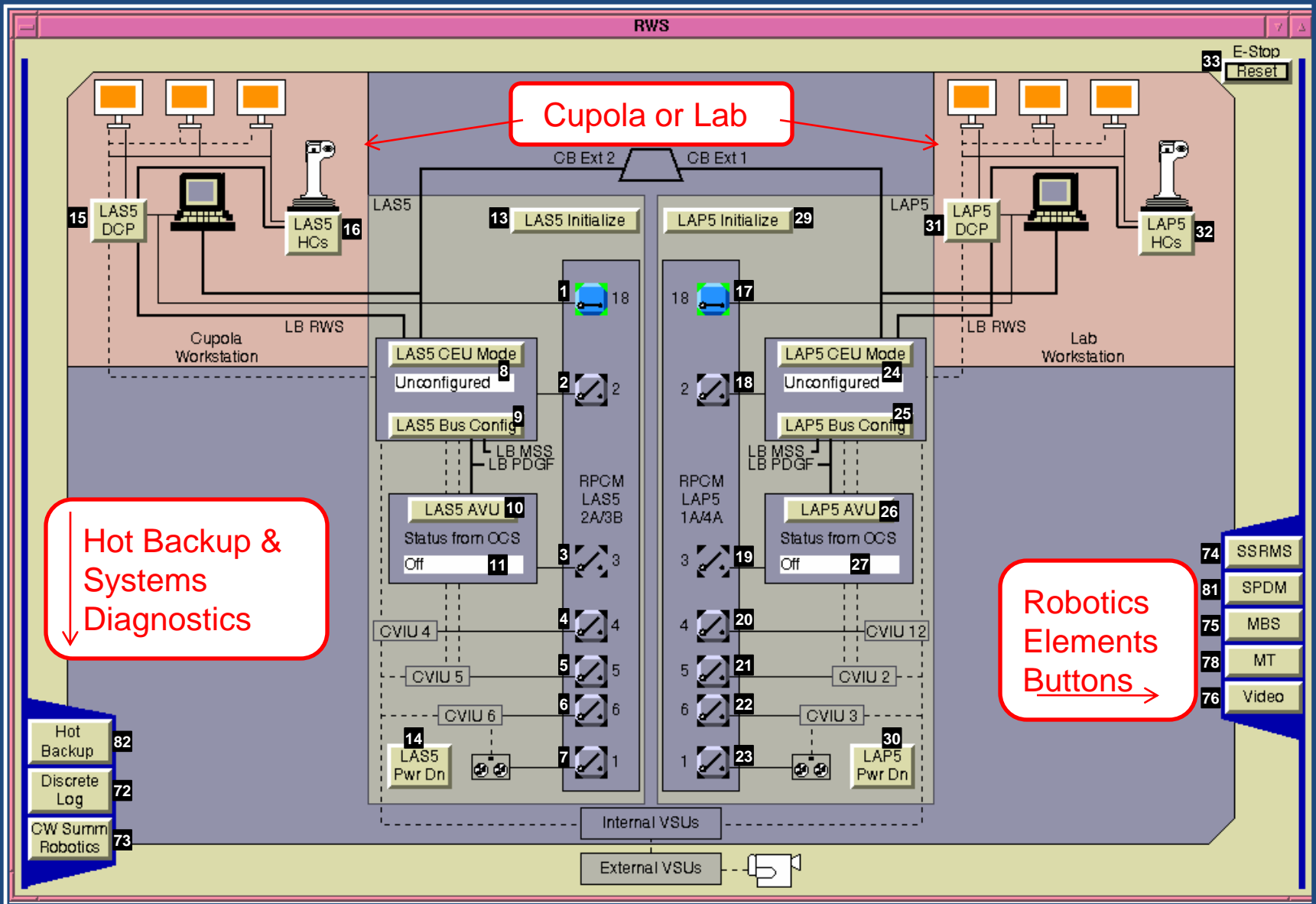


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ISS Robotics Work Station window





ISS Robotics Work Station window

# Control Modes

E Stop

SSRMS

The screenshot displays the SSRMS control interface with the following components:

- Control Modes:** FOR Auto, FOR OCAS, Joint Auto, Joint OCAS, Manual (selected), Single, Pitch Plane, Standby, Limp.
- MSS Safing:** Safed
- Joint Angles (deg):** SR (-159.0), SY (43.2), SP (-41.1), EP (44.7), WP (-104.0), WY (144.5), WR (97.5).
- End Effectors:** Base LEE A, Tip LEE.
- Active Manipulator:** SSRMS
- Active Effector:** SSRMS Tip LEE
- Positioning:** Rate (cm/s) XYZ, X, Y, Z, Pitch, Yaw, Roll.
- Buttons:** DOUG, Targets, Overlay, Rate, Diagnostic, Thermal, Discrete Log, CW Summ Robotics, RWS, SPDM, MBS, MT, Video, Thrusters, Mech, Brake Override, Checkpoint Data.

Red callout boxes provide additional information:

- Shoulder:** Roll, Yaw, Pitch
- Elbow:** Pitch
- Wrist:** Pitch, Yaw, Roll
- Base End Effector:** (points to Base LEE A)
- Tip End Effector:** (points to Tip LEE)

Joint angles are collectively labeled as **< Joint Angles >**.

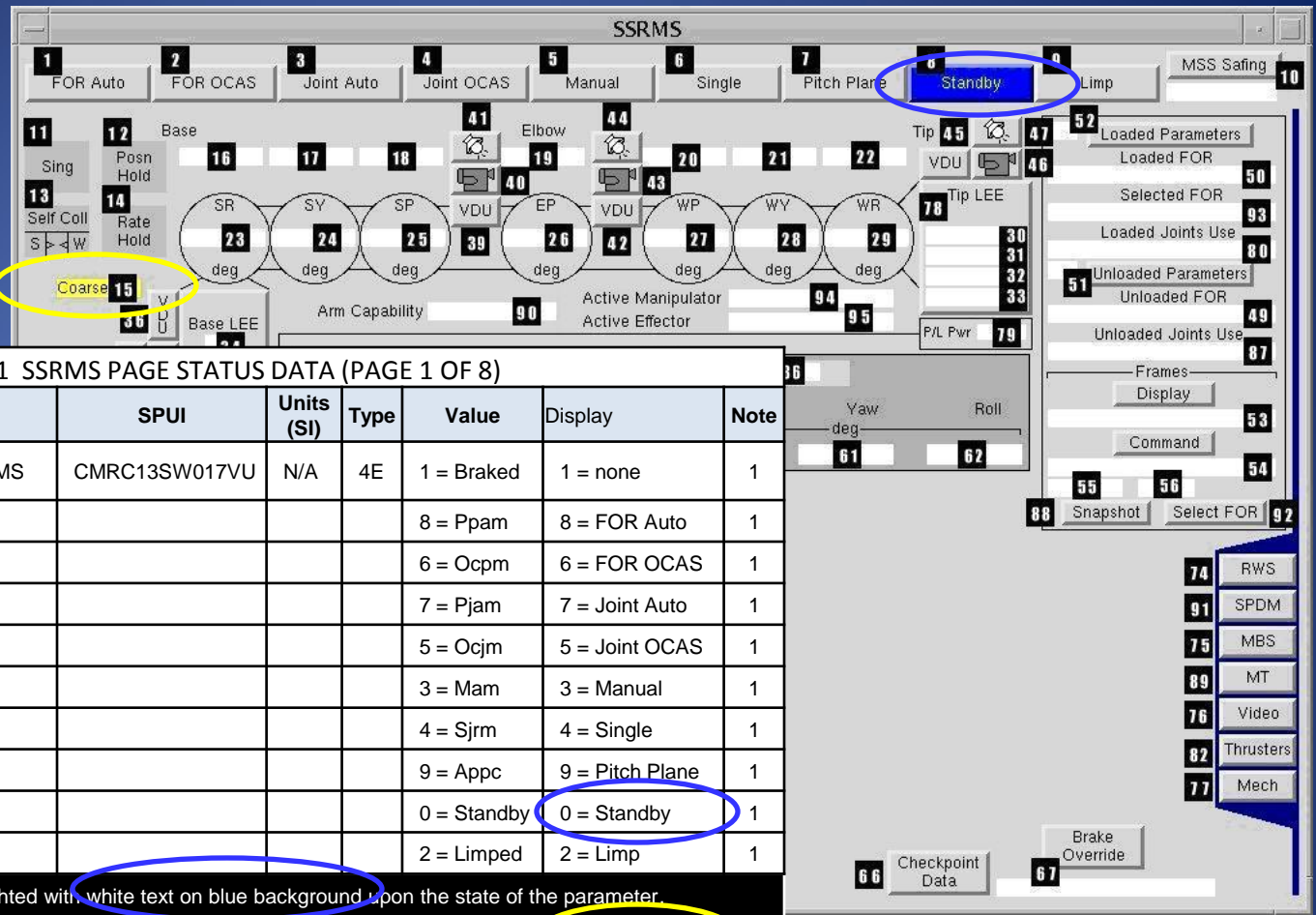


TABLE 3.3.1.2-1 SSRMS PAGE STATUS DATA (PAGE 1 OF 8)

Device Identifier	Ops Name	SPUI	Units (SI)	Type	Value	Display	Note
	MSS_OCS_Manipulator_Mode_SSRMS	CMRC13SW017VU	N/A	4E	1 = Braked	1 = none	1
1					8 = Ppam	8 = FOR Auto	1
2					6 = Ocpm	6 = FOR OCAS	1
3					7 = Pjam	7 = Joint Auto	1
4					5 = Ocjm	5 = Joint OCAS	1
5					3 = Mam	3 = Manual	1
6					4 = Sjrm	4 = Single	1
7					9 = Appc	9 = Pitch Plane	1
8					0 = Standby	0 = Standby	1
9					2 = Limped	2 = Limp	1

Note 1. The appropriate mode button is highlighted with white text on blue background upon the state of the parameter.

15	SSRMS_JEUs_Vernier_Bus	CMRC13SW00MKU	N/A	1E	0 = Coarse	0 = "Coarse"	13
					1 = Vernier	1 = "Vernier"	
	SSRMS_Invalid_Vernier_Coarse_Selection	CMRC13SW0B6SJ	N/A	1E	0 = False	0 = "Coarse" or "Vernier"	
					1 = True	1 = "Invalid"	

Note 13. The background color is yellow when SSRMS\_JEUs\_Vernier\_Bus is Coarse or SSRMS\_Invalid\_Vernier\_Coarse\_Selection is True. If SSRMS\_Invalid\_Vernier\_Coarse\_Selection is True, "Invalid" is displayed; otherwise, SSRMS\_JEUs\_Vernier\_Bus determines the text displayed.

ISS SSRMS window and Status Data table excerpt from SSP 50337-01-ANX PCS R13

**Mobile Transporter**

The interface displays a track with segments 1 through 10. Segment 4 is highlighted in blue. An "EMERGENCY STOP" button is located below the track. A coordinate system shows +Y pointing left and +Z pointing down.

**MT Mode Panel:**

- MT Mode: Disabled
- Position: 287.0 cm
- Position Data Valid:
- Velocity: ERR! cm/s
- Destination WS: 0
- Positioned over WS:
- Latched for SSRMS:  4 of 4
- Latched Data Valid:
- EXT Comm Fail: 1  2
- MT Reject Cmd Cnt: 0
- Pri EXT Frame Cnt: 11

**Component Diagram:**

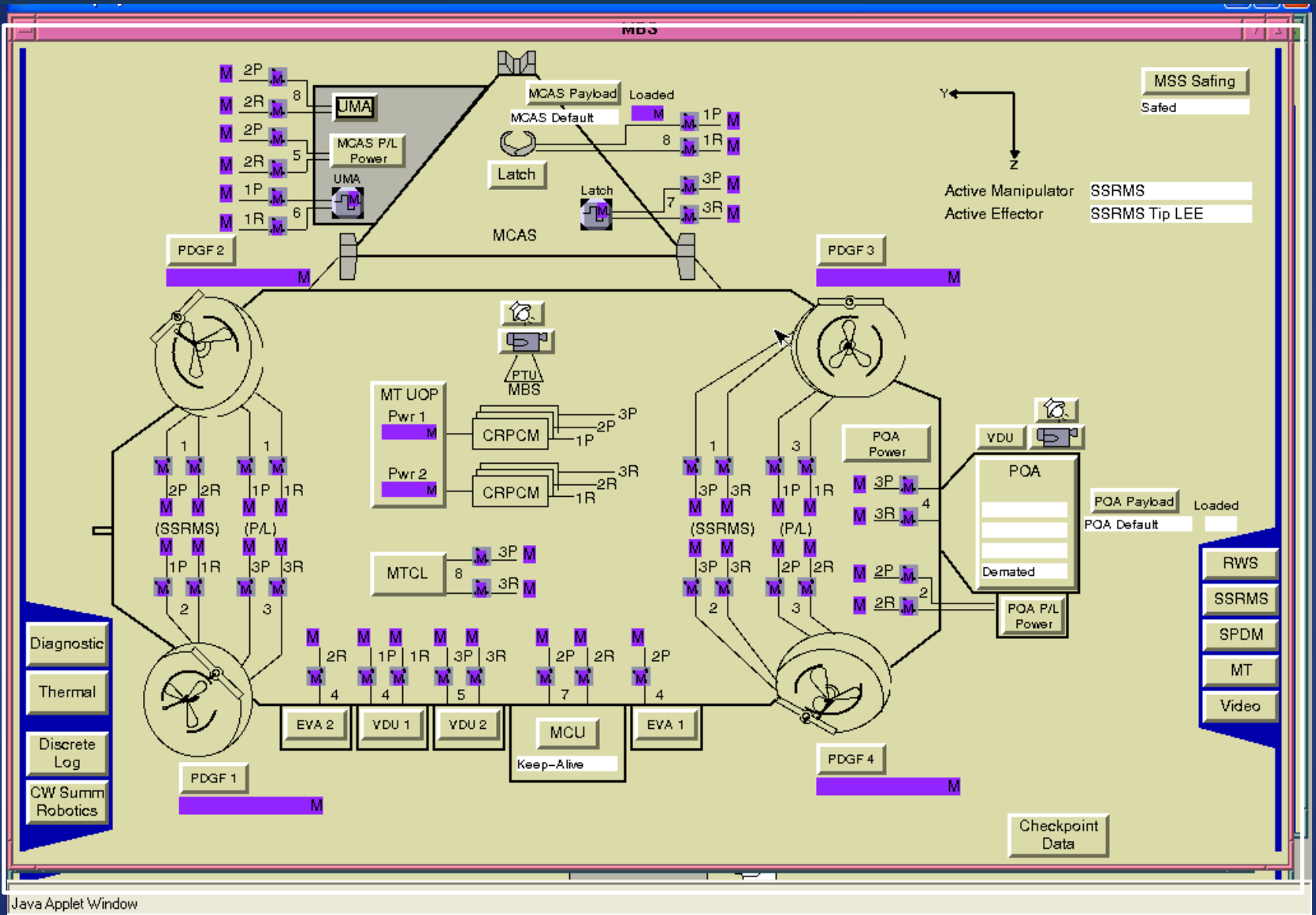
The diagram shows the internal components of the Mobile Transporter (MT):

- MT:** Contains sub-components like LTU3, RPCM MT-4B, and RPCM MT-3A.
- LDU:** Contains TD2, ED2, ED1, and TD1.
- IUA1:** Connected to TUS1 and TUS2.
- Amp1/Amp2:** Contain MT LB A and MT LB B.
- MSS LB A/B:** Motor speed sensors.
- UMA1/UMA2:** Undercarriage motor assemblies.
- RSU1/RSU2:** Remote sensor units.
- LTU1-4:** Local transport units.
- TUS1/TUS2:** Transporter units.
- TUS1 Cut/TUS2 Cut:** Cut-off switches.

**Control Panels:**

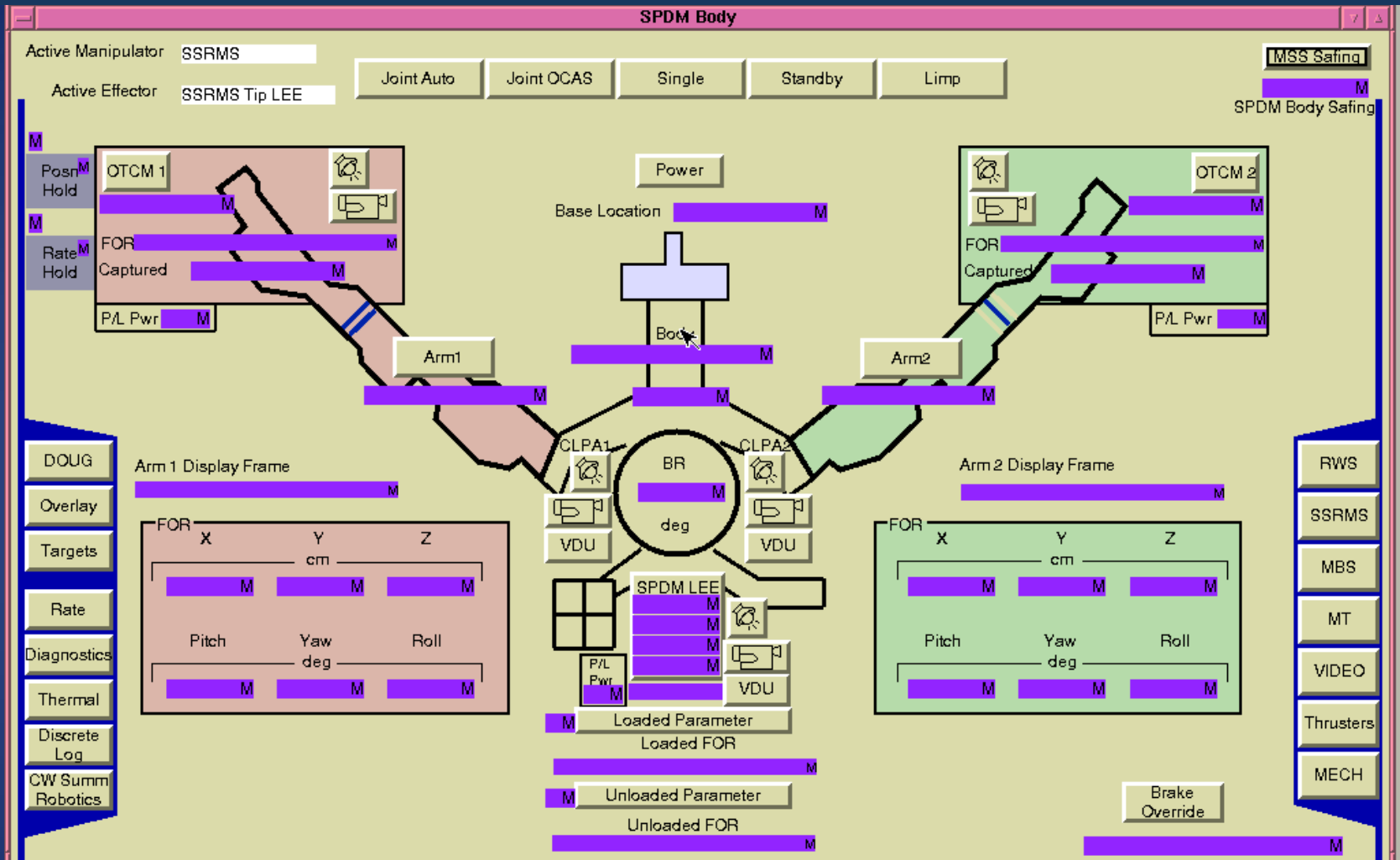
- Left Panel:** Auto Translate, Manual Translate, MT Mode, Init Frame, Power, Thermal, Worksite Power, IMCA BIT Results, IMCA Cmd State, IMCA Data State State, Auto Safing.
- Right Panel:** RWS, SSRMS, MBS, Video, Thruster.

MT App Cmd Resp:



Java Applet Window

# ISS Mobile Base System window



ISS SPDM Body window

PCS Display #8

SPDM Arm1

FOR Auto | FOR OCAS | Joint Auto | Joint OCAS | Manual | Single | Pitch Plane | Standby | Limp | MSS Safing

Arm 1 State

SPDM Arm1 Safing

OTCM 1

Active Manipulator: SSRMS  
Active Effector: SSRMS Tip

Rate cm/s

	X	Y	Z	$\Sigma$ XYZ	Pitch	Yaw	Roll
FOR	M	M	M	M	M	M	M
FMA	M	M	M	M	M	M	M
POHS	M	M	M	M	M	M	M

Backup Drive Unit 1 | Checkpoint data 1 | Brake Override

24 of 24 - Clipboard  
Item not Collected: Delete

ISS SPDM Arm1 window

PCS Display #8

SPDM Arm2

FOR Auto | FOR OCAS | Joint Auto | Joint OCAS | Manual | Single | Pitch Plane | Standby | Limp | MSS Safing

Arm 2 State

OTCM 2

SPDM Arm2 Safing

SPDM Arm2 OTCM

OTCM Mode

Backdrive

OTCM Mechanisms

Arm 2 FMS

OTCM Gripper

Umbilical

Socket Drive

Advance

Torquer

Turn Count

Torque (Nm)

Target Torque

RPM

CCW Max

Actual

CW Max

Parameters Override 2

RMCT 2 Operations

SPDM Arm2 Safing

Loaded Parameters

Loaded FOR

Joint Use

Loaded File Use

Unloaded Parameters

Unloaded FOR

Joint Use

Unloaded File Use

Frames

Display

Command

Snapshot

Set SSRMS FOR

RWS

SSRMS

MBS

MT

VIDEO

Thrusters

Brake

Java Applet Window

ISS SPDM Arm 2 window with OTCM popup invoked



ISS Assembly operations have been exceptionally successful by having onboard astronauts execute scripted moves of payloads using the SSRMS.

Recently-initiated Maintenance operations with the SPDM (DEXTRE) have successfully used ground issued sequence commands.

It is likely that the number of onboard SPDM displays will be reduced.

IV&V of the Canadian ISS MSS onboard displays has been presented.

Scope is limited to 'one end' of the MSS, but is critical for system integrity.

State of the art for operational robots for manned spaceflight.

Illustrates how complex these systems are.

Questions ?