Reusable Lunar Lander

Agenda

- Introduction
- Mass Allocations and Equipment List
- Lander Schematics
- Flight One and Two Sequence
- Lunar Outpost Assembly Sequence and Crew Rotation
- Conclusion

Introduction:
Reusable Lander Concept

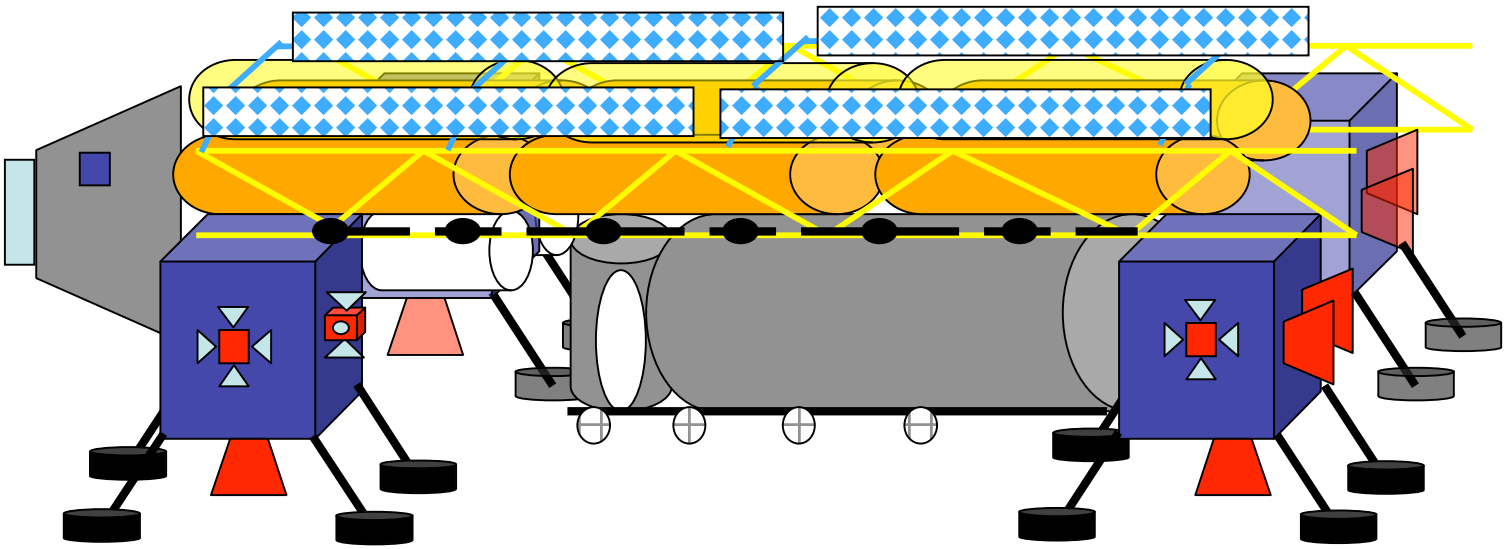
Concept

- Instead of abandoning the Lunar Lander after ascent each flight reuse for crew change out.
- Requires several development components.
  - Propellant Transfer Module
    - Provides Delta V to CEV for LOI since LSAM is no longer part of TLI stack
    - Provides Delta V to resupply Lander for descent and ascent
    - Provides Consumables to CEV and Lander
  - Lunar outpost modules that can be stowed in Lander
- Based off Single Stage, Dual Hab design
  - concept #2 Lunar Surface Access Module Study, RFT0020.05JSC

Phased In approach

- First flight consists of CEV and Lander
  - Lander performs LOI
  - Lander deploys first Outpost Module via attached Flat Bed Transport
- Second and subsequent flights consist of CEV, PTM and Outpost Modules/Resupplies
  - CEV performs LOI with prop from PTM

Lander



Mass Allocations: Equipment List

Mass Allocations

- Lander: 99,000 lb
  - Includes 10,000 outpost module capacity
- CEV: 50,000 lb
- PTM: 89,000 lb
  - Prop for CEV to perform LOI
  - Prop for Lander Descent and Ascent Resupply
  - Consumables for Lander
    - N2/O2 for cabin represses, Suit cooling H2O
- Outpost Module #X: 10,000 lb max

Propellant Mass Estimates (FWD)

	Lander Total	99000													
Gc =	32.174 ft/s^2														
												LO2 and Methane			
Propellant	Temp/Press	Density (lbm/ft^3)	MR	AR [6]	Rho_avg (lbm/ft^3)	Thrust (lbf)	ISP	CEV Mass (Wi) (lbm)	DV (fps)	Useable Prop [1] (%)	Margin [1] [2] (%)	Wp (lbm)	Ullage [3] (%)		
LO2 (OMS)	162R / 250 psia	62.11	3.4	150	44.99	900	362	149000	3600	98.0%	3.5%	41812.9	32310.0	5.3	
CH4 (OMS)	170R / 250 psia	23.22											9502.9	5.3	
LO2 (RCS)	162R / 250 psia	62.11	3.2	60	44.40	100	345	149000	0	100.0%	3.5%	0.0	0.0	5.3	
CH4 (RCS)	170R / 250 psia	23.22											0.0	5.3	

Total Propellant Weight	41812.9	4	tanks per propellant
Total Tank Weight	1615.4	8.31	[ft] NTO tank Length
Total Prop plus Tank Weight	43428.3	6.82	[ft] MMH tank length

LANDER PERFORMING LOI

Total Helium Weight	1313.4	1	tanks per propellant
Total Helium Tank Weight	1643.2	5.82	[ft] NTO He tank diameter
Total Helium plus Tank Wt	2956.5	5.37	[ft] MMH He tank diameter

Total He, Prop, & Tank Wt	**46384.8**
Lander Wet Mass Post LOI	**55873.7**

Gc =	32.174 ft/s^2														
												LO2 and Methane			
Propellant	Temp/Press	Density (lbm/ft^3)	MR	AR [6]	Rho_avg (lbm/ft^3)	Thrust (lbf)	ISP	CEV Mass (Wi) (lbm)	DV (fps)	Useable Prop [1] (%)	Margin [1] [2] (%)	Wp (lbm)	Ullage [3] (%)		
LO2 (OMS)	162R / 250 psia	62.11	3.4	150	44.99	900	362	55873.7	6200	98.0%	3.5%	24339.7	18807.9	5.3	
CH4 (OMS)	170R / 250 psia	23.22											5531.7	5.3	
LO2 (RCS)	162R / 250 psia	62.11	3.2	60	44.40	100	345	55873.7	0	100.0%	3.5%	0.0	0.0	5.3	
CH4 (RCS)	170R / 250 psia	23.22											0.0	5.3	

Total Propellant Weight	24339.7	2	tanks per propellant
Total Tank Weight	912.2	9.45	[ft] NTO tank Length
Total Prop plus Tank Weight	25251.9	7.72	[ft] MMH tank length

LANDER PERFORMING DESCENT

Total Helium Weight	764.5	1	tanks per propellant
Total Helium Tank Weight	1152.0	4.86	[ft] NTO He tank diameter
Total Helium plus Tank Wt	1916.5	4.48	[ft] MMH He tank diameter

Total He, Prop, & Tank Wt	**27168.4**
Lander Wet Mass Post Landing and post Module Deploy	**20769.5**
	10000

Gc =	32.174 ft/s^2														
												LO2 and Methane			
Propellant	Temp/Press	Density (lbm/ft^3)	MR	AR [6]	Rho_avg (lbm/ft^3)	Thrust (lbf)	ISP	CEV Mass (Wi) (lbm)	DV (fps)	Useable Prop [1] (%)	Margin [1] [2] (%)	Wp (lbm)	Ullage [3] (%)		
LO2 (OMS)	162R / 250 psia	62.11	3.4	150	44.99	900	362	20769.5	6200	98.0%	3.5%	9047.6	6991.3	5.3	
CH4 (OMS)	170R / 250 psia	23.22											2056.3	5.3	
LO2 (RCS)	162R / 250 psia	62.11	3.2	60	44.40	100	345	20769.5	0	100.0%	3.5%	0.0	0.0	5.3	
CH4 (RCS)	170R / 250 psia	23.22											0.0	5.3	

Total Propellant Weight	9047.6	1	tanks per propellant
Total Tank Weight	361.1	7.37	[ft] NTO tank Length
Total Prop plus Tank Weight	9408.7	6.08	[ft] MMH tank length

LANDER PERFORMING ASCENT

Total Helium Weight	284.2	1	tanks per propellant
Total Helium Tank Weight	603.5	3.49	[ft] NTO He tank diameter
Total Helium plus Tank Wt	887.6	3.22	[ft] MMH He tank diameter

Total He, Prop, & Tank Wt	**10296.3**
Lander Dry Mass (excludes Prop tanks)	**5150.5**

If estimates are correct only 5150 lb for all Lander systems except prop wet mass

Propellant Mass Estimates (Back)

Gc = 32.174 ft/s^2

Propellant	Temp/Press	Density (lbm/ft^3)	MR	AR [6]	Rho_avg (lbm/ft^3)	Thrust (lbf)	ISP	CEV Mass (Wf) (lbm)	DV (fps)	Useable Prop [1] (%)	Margin [1] [2] (%)	Wp (lbm)	Ullage [3] (%)	Volume (FT3)
LO2 (OMS	162R / 250 psia	62.11	3.4	150	44.99	900	362	20000	6250	98.0%	3.5%	14212.9	10982.7	5.3	186.20
CH4 (OMS	170R / 250 psia	23.22											3230.2	5.3	146.49
LO2 (RCS	162R / 250 psia	62.11	3.2	60	44.40	100	345	20000	0	100.0%	3.5%	0.0	0.0	5.3	0.00
CH4 (RCS	170R / 250 psia	23.22											0.0	5.3	0.00

LO2 and Methane

Total Propellant Weight	14212.9	3 tanks per propellant
Total Tank Weight	3819.2	27.36 [ft] NTO tank Length
Total Prop plus Tank Weight	18032.2	21.81 [ft] MMH tank length
Total Helium Weight	1225.2	1 tanks per propellant
Total Helium Tank Weight	1569.8	5.68 [ft] NTO He tank diameter
Total Helium plus Tank Wt	2795.1	5.25 [ft] MMH He tank diameter
Total He, Prop, & Tank Wt	**20827.2**	

Lander Performs Ascent
Lander RNDZ Burnout weight 20,000
Lander pre Ascent 35,438

Gc = 32.174 ft/s^2

Propellant	Temp/Press	Density (lbm/ft^3)	MR	AR [6]	Rho_avg (lbm/ft^3)	Thrust (lbf)	ISP	CEV Mass (Wf) (lbm)	DV (fps)	Useable Prop [1] (%)	Margin [1] [2] (%)	Wp (lbm)	Ullage [3] (%)	Volume (FT3)
LO2 (OMS	162R / 250 psia	62.11	3.4	150	44.99	900	362	45438	6250	98.0%	3.5%	32290.3	24951.6	5.3	423.02
CH4 (OMS	170R / 250 psia	23.22											7338.7	5.3	332.80
LO2 (RCS	162R / 250 psia	62.11	3.2	60	44.40	100	345	45438	0	100.0%	3.5%	0.0	0.0	5.3	0.00
CH4 (RCS	170R / 250 psia	23.22											0.0	5.3	0.00

LO2 and Methane

Total Propellant Weight	32290.3	3 tanks per propellant
Total Tank Weight	3819.2	27.36 [ft] NTO tank Length
Total Prop plus Tank Weight	36109.6	21.81 [ft] MMH tank length
Total Helium Weight	1225.2	1 tanks per propellant
Total Helium Tank Weight	1569.8	5.68 [ft] NTO He tank diameter
Total Helium plus Tank Wt	2795.1	5.25 [ft] MMH He tank diameter
Total He, Prop, & Tank Wt	**38904.6**	

Lander Performs Descent
Lander Payload 10,000
Lander Touchdown weight 45,438
Lander pre Deorbit Burn 78,954

Gc = 32.174 ft/s^2

Propellant	Temp/Press	Density (lbm/ft^3)	MR	AR [6]	Rho_avg (lbm/ft^3)	Thrust (lbf)	ISP	CEV Mass (Wf) (lbm)	DV (fps)	Useable Prop [1] (%)	Margin [1] [2] (%)	Wp (lbm)	Ullage [3] (%)	Volume (FT3)
LO2 (OMS	162R / 250 psia	62.11	3.4	150	44.99	900	362	128954	3600	98.0%	3.5%	46731.2	36110.4	5.3	612.21
CH4 (OMS	170R / 250 psia	23.22											10620.7	5.3	481.64
LO2 (RCS	162R / 250 psia	62.11	3.2	60	44.40	100	345	128954	0	100.0%	3.5%	0.0	0.0	5.3	0.00
CH4 (RCS	170R / 250 psia	23.22											0.0	5.3	0.00

LO2 and Methane

Total Propellant Weight	46731.2	3 tanks per propellant
Total Tank Weight	3819.2	27.36 [ft] NTO tank Length
Total Prop plus Tank Weight	50550.4	21.81 [ft] MMH tank length
Total Helium Weight	1225.2	1 tanks per propellant
Total Helium Tank Weight	1569.8	5.68 [ft] NTO He tank diameter
Total Helium plus Tank Wt	2795.1	5.25 [ft] MMH He tank diameter
Total He, Prop, & Tank Wt	**53345.4**	

Lander Performs LOI Burn
Trans Lunar Stack 176,910
Post LOI Burn 128,954
TLI Constraint 149,000
Lander Allocation 99000
Margin -27,910

Includes 50,000 for CEV

Lander Systems

- Propulsion
  - 4 +Z Direction 10Klb engines
    - Lunar Descent and Ascent
  - 4 +X Direction 10lkb engines
    - For LOI and Deorbit Burn
    - Allows for g loads eyeballs in for LOI
  - 4 RCS Quads located on Engine Pods
    - 870 lb engines for attitude control and translation
  - 4 RCS Tris located on Engine Pods
    - 870 lb engines for attitude control and translation
  - Tanks not optimized for size and shape
    - 3 He tanks
    - 7 Lox tanks
    - 7 CH4 tanks

Lander Systems

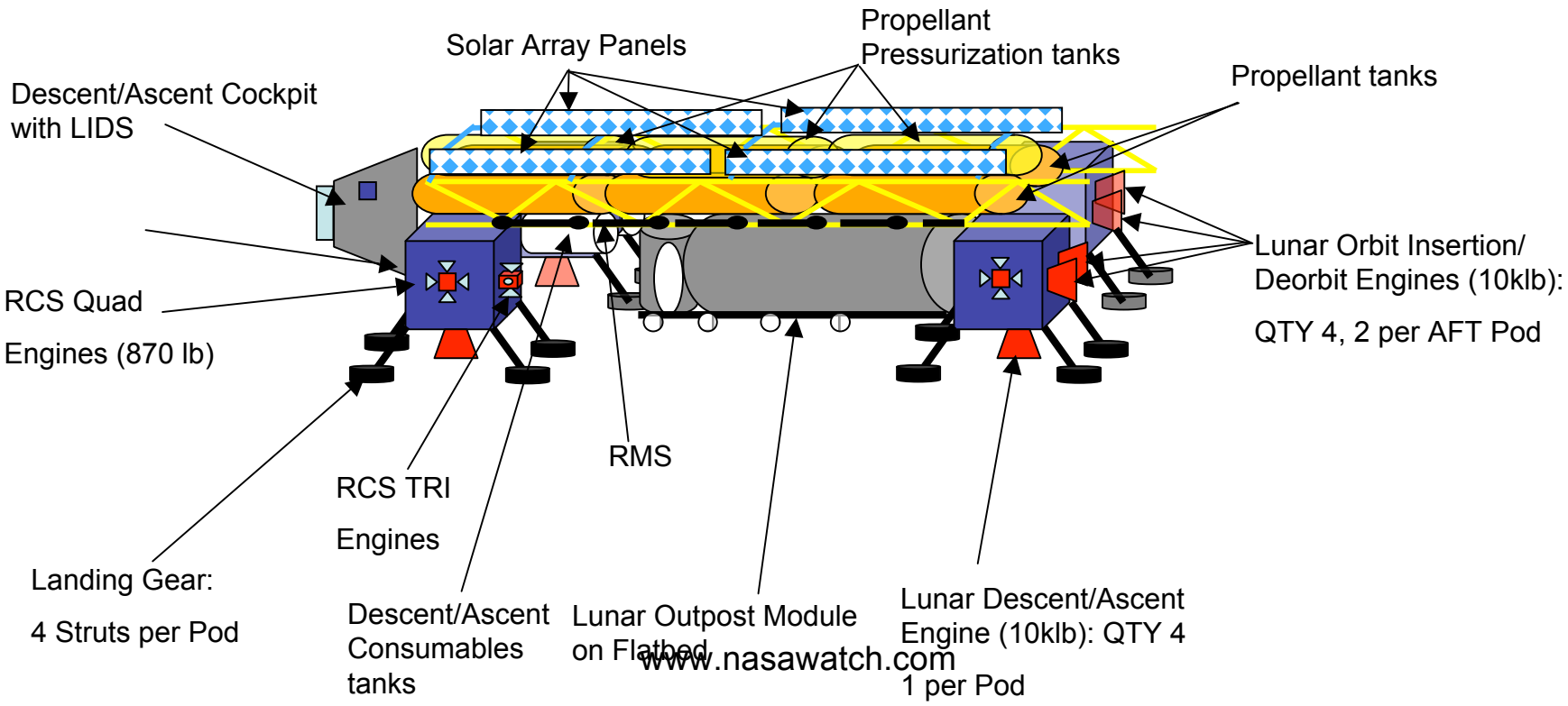
- GNC
  - 3 IMUs
  - 2 Star Camera for IMU alignments
  - RNDZ Sensors
    - IROC
    - SROC
    - LROC
    - Lidar
    - Aux Computers for image processing
    - Transponders for comm with CEV or outpost
    - Sensor redundancy is covered by the CEV that can rescue Lander for failed rndz
  - Descent Sensors
    - Ground Proximity sensors
    - Ground Radar
- Power
  - Solar Arrays
    - It may be possible to oversize solar arrays such that post landing crew can remove arrays for use in outpost solar array farm
  - Battery backup for night pass and supplement arrays during peak loading
  - Three redundant buses

Lander Systems

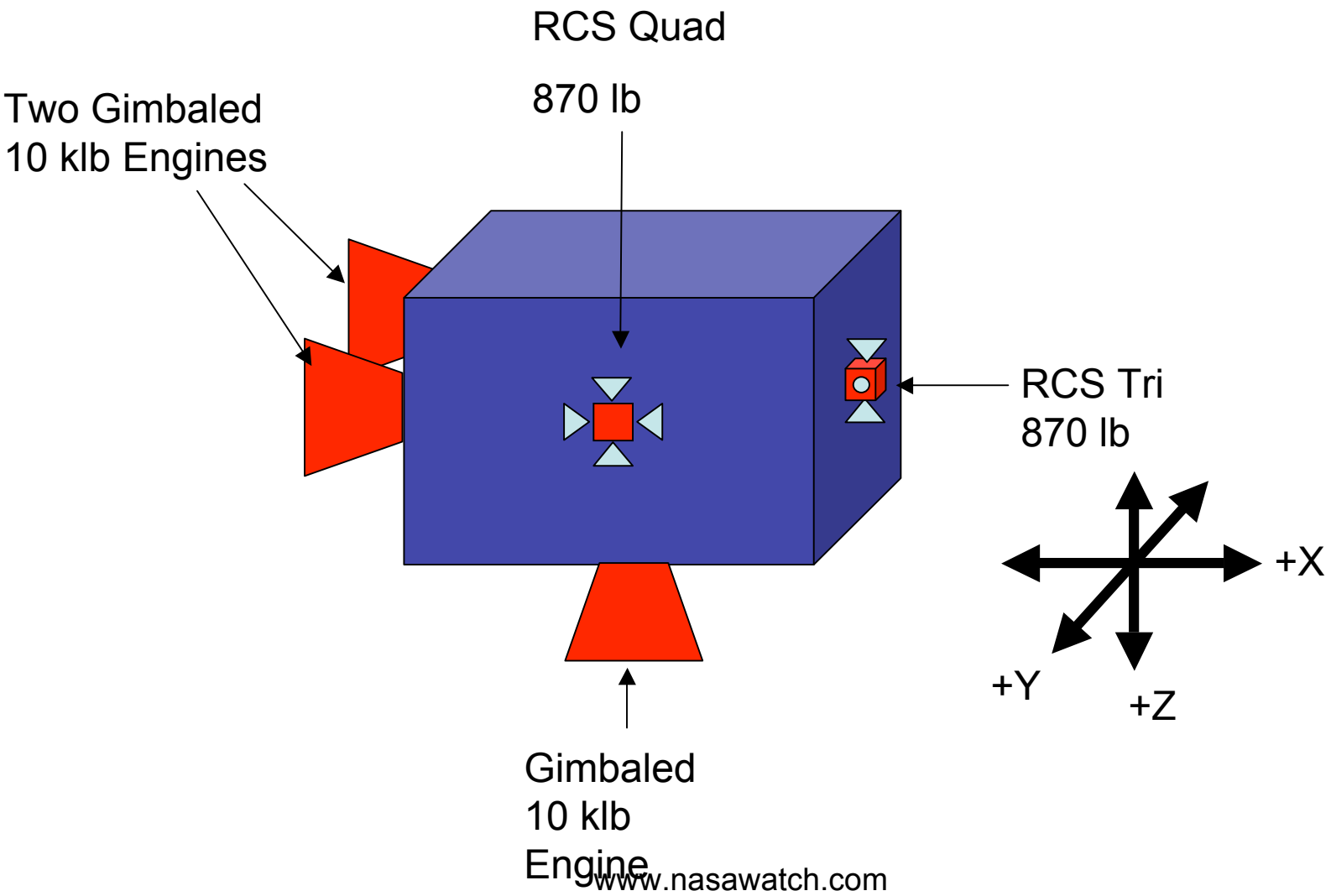
- DPS
  - 3 Computers
  - BIUS
  - AUX computers for rndz sensor navigation
  - 1553 Data Bus
- ECLSS
  - Consumables to support two cabin depress/repress cycles
    - Nominally should only require one depress post descent and then repress for ascent
  - Suit Cooling and Recharge capabilities
  - Resupply consumables from PTM

Lander Schematics

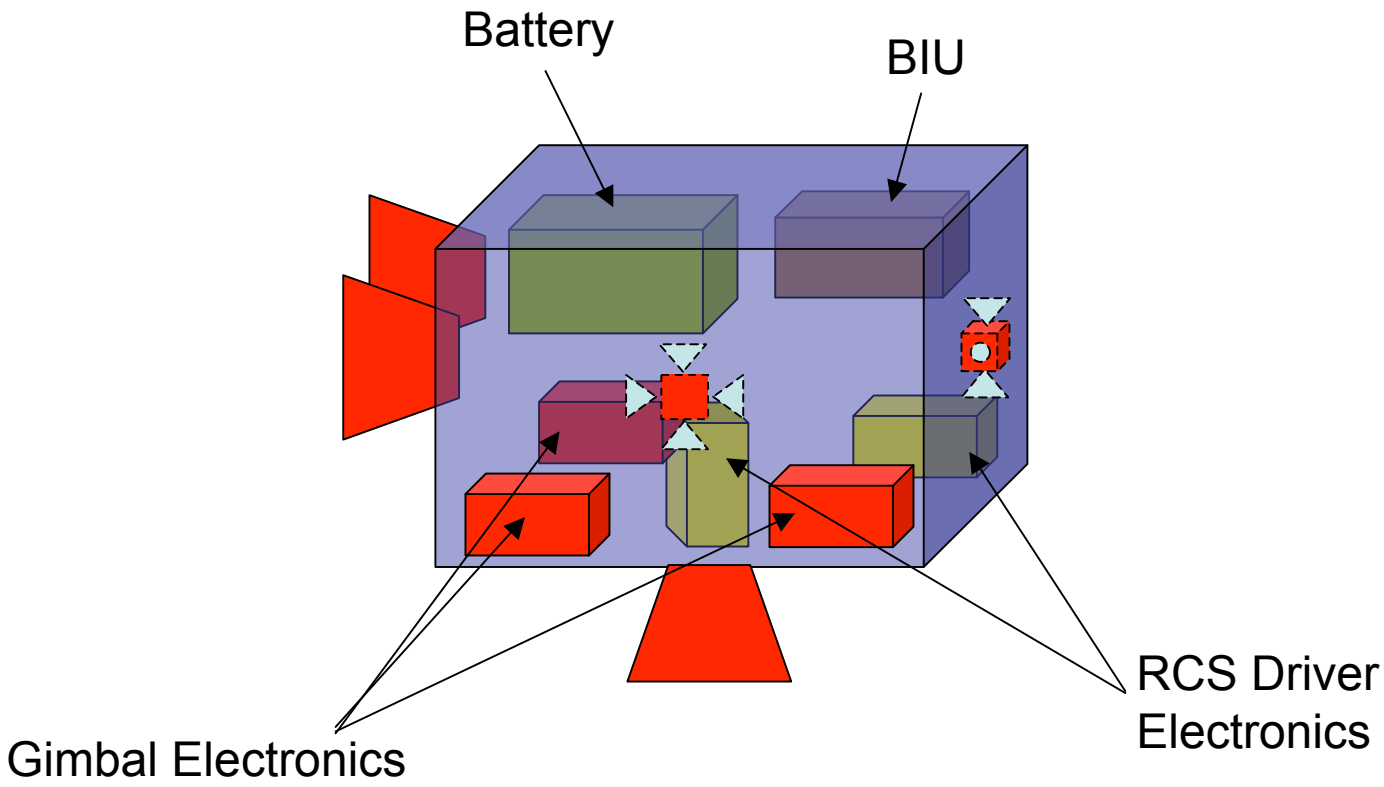
Lander


Solar Array Panels
Propellant
Pressurization tanks
Propellant tanks
Descent/Ascent Cockpit
with LIDS
Lunar Orbit Insertion/
Deorbit Engines (10klb):
QTY 4, 2 per AFT Pod
RCS Quad
Engines (870 lb)
RMS
RCS TRI
Engines
Landing Gear:
4 Struts per Pod
Descent/Ascent
Consumables
tanks
Lunar Outpost Module
on Flatbed
Lunar Descent/Ascent
Engine (10klb): QTY 4
1 per Pod
www.nasawatch.com

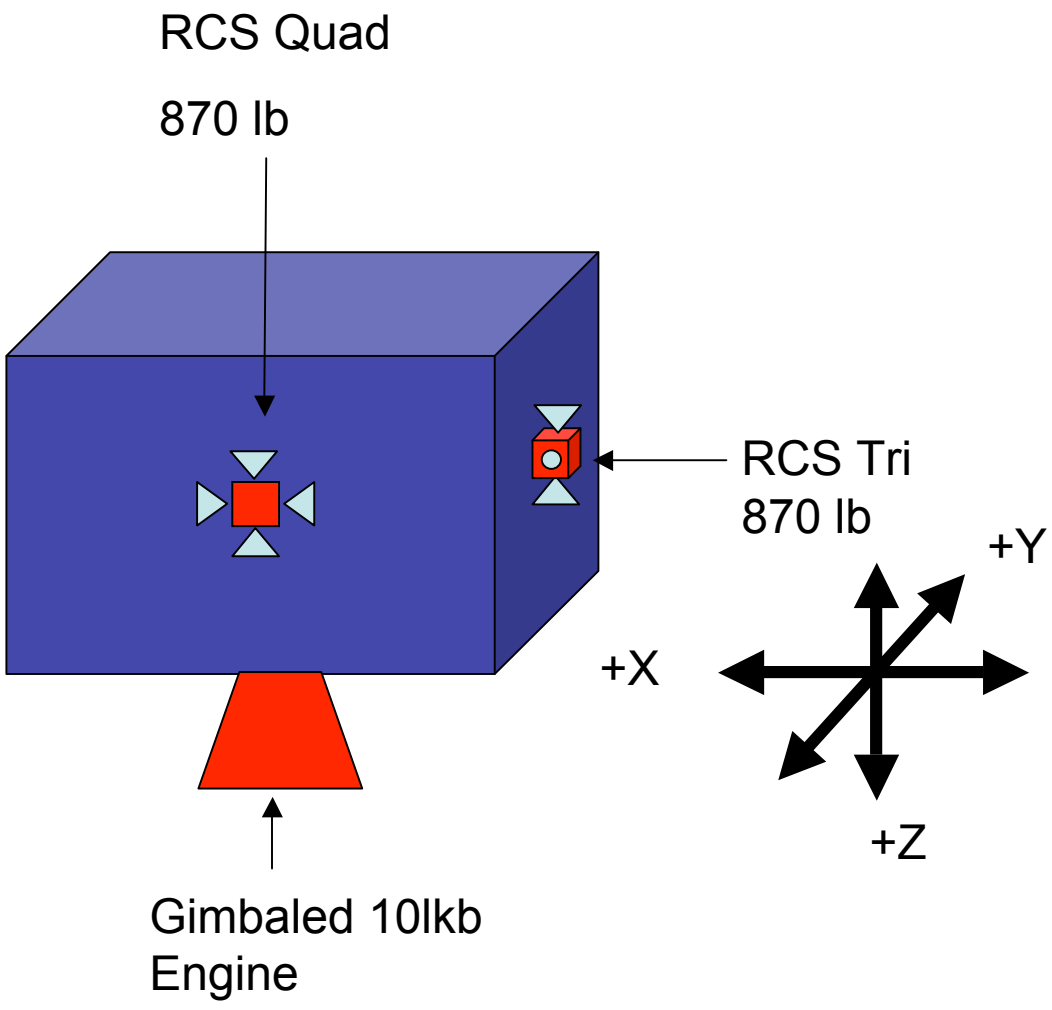
AFT Engine Pods



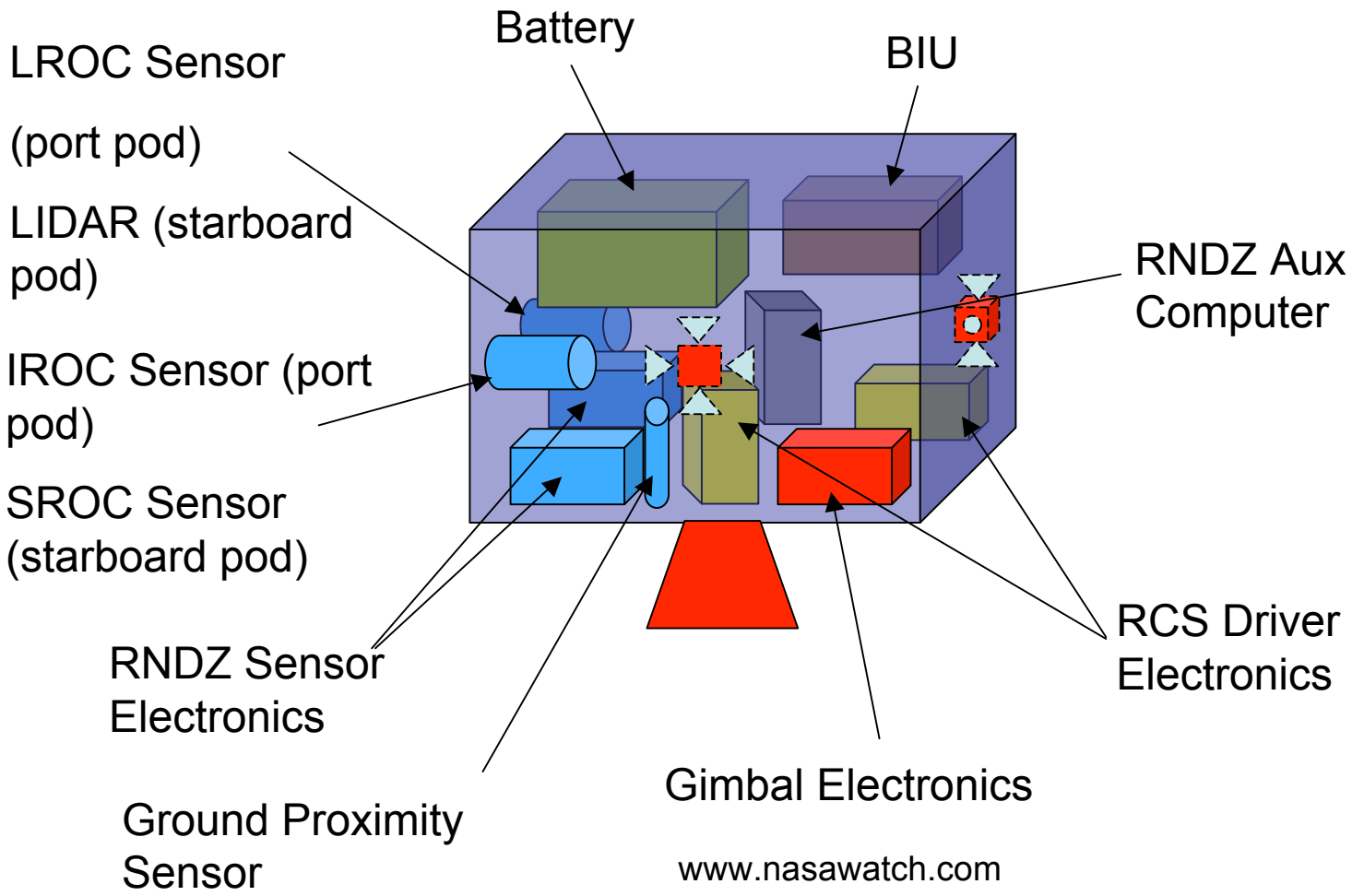
AFT Engine Pods Internal



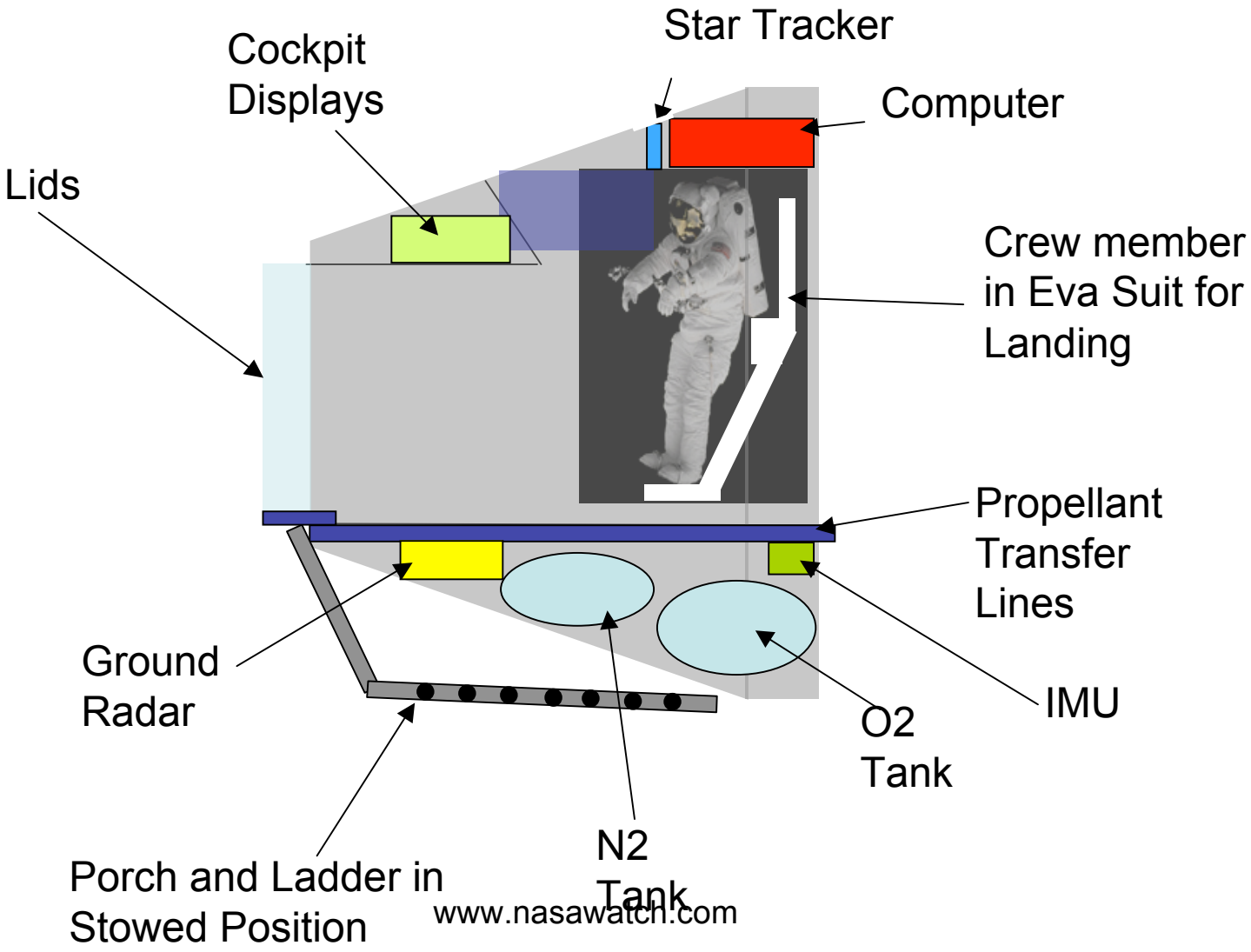
FWD Engine Pods



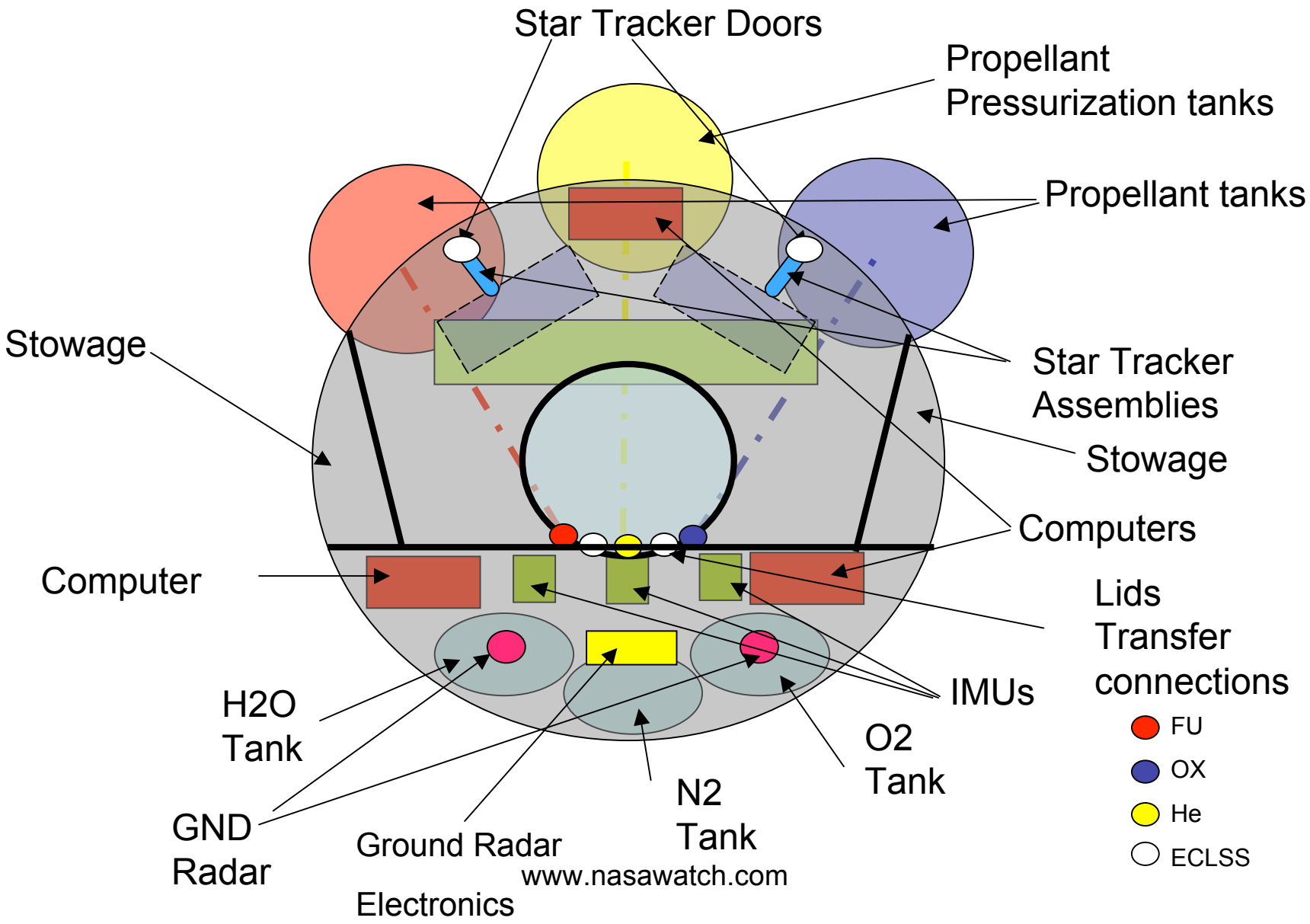
FWD Engine Pods Internal



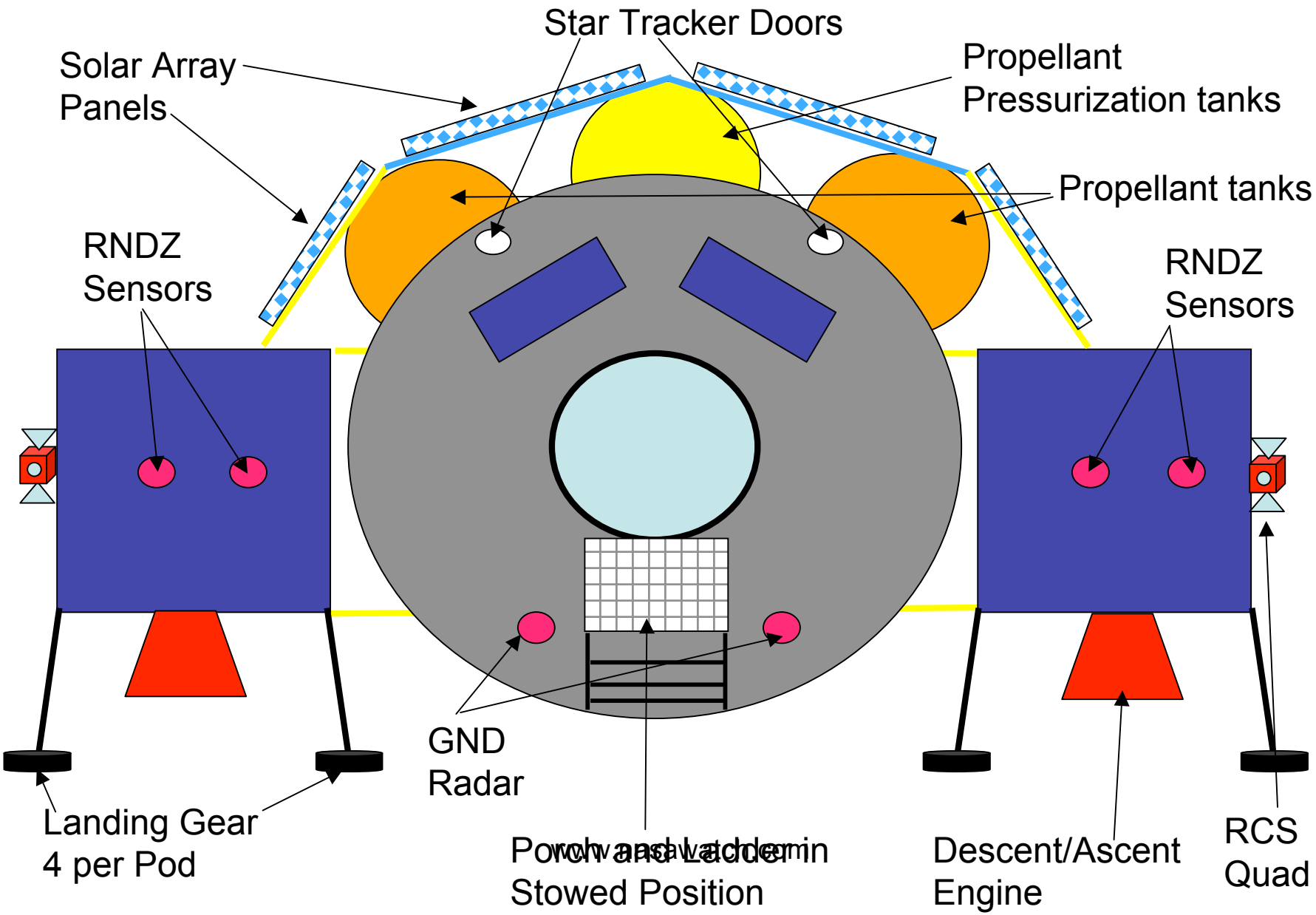
Cockpit Internal Side View



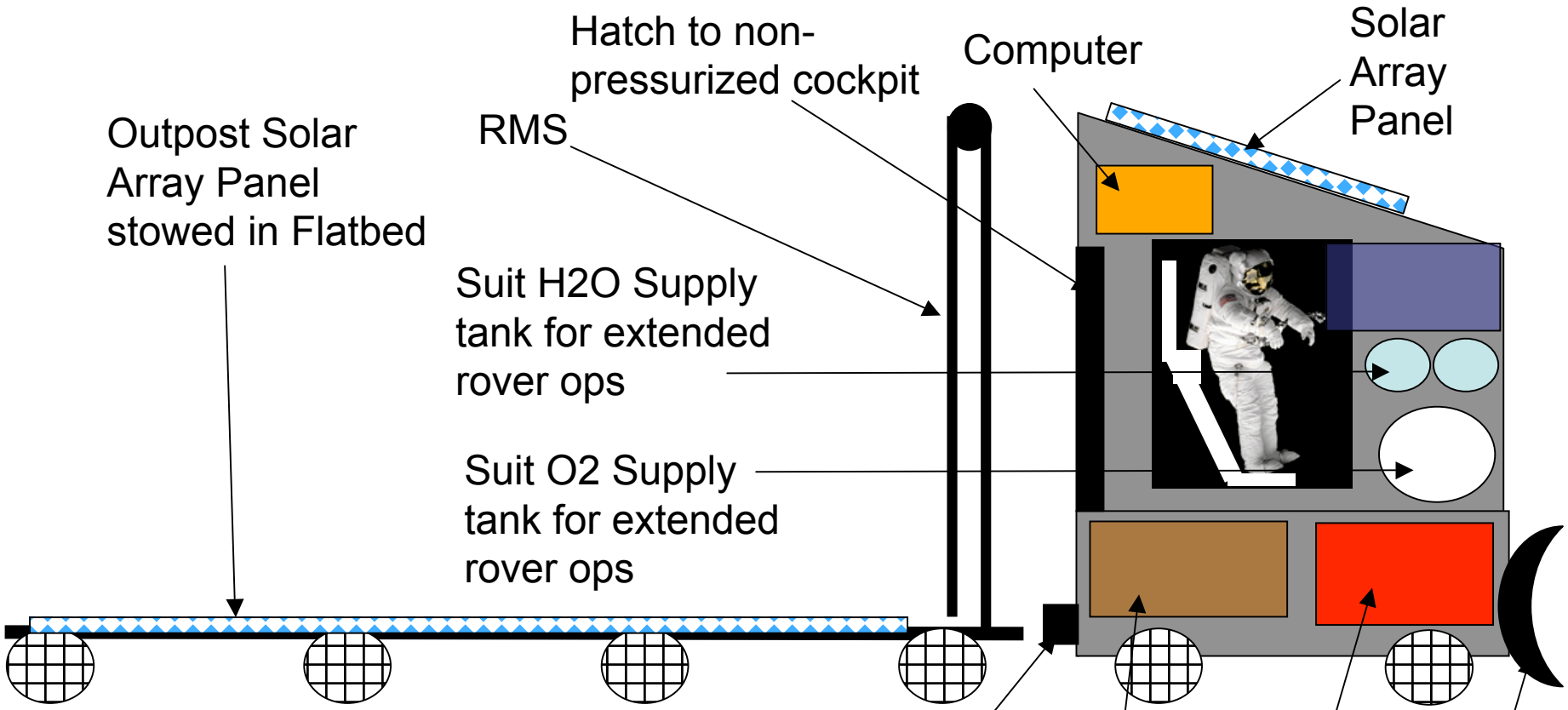
Cockpit Forward Facing



Lander Forward Facing

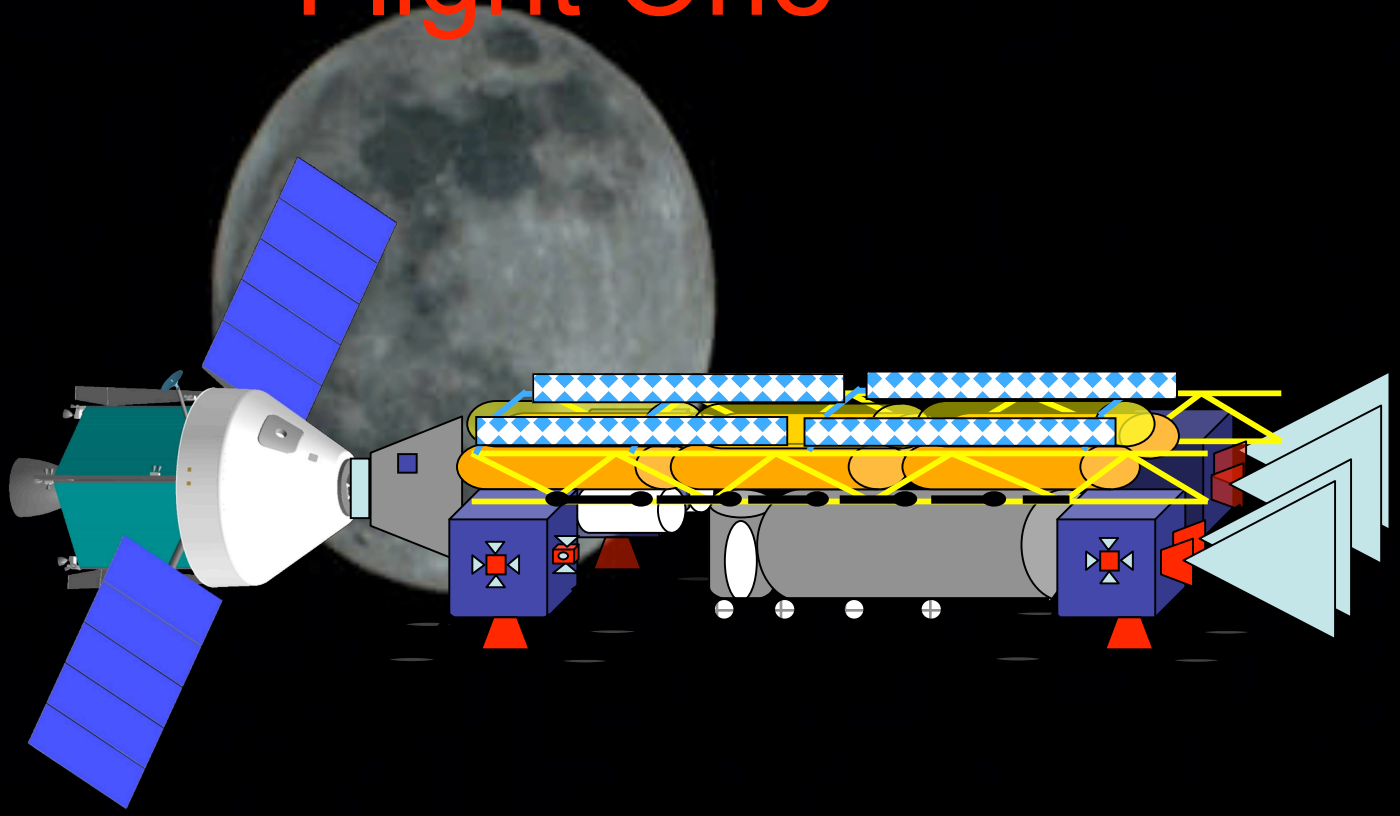


Flat bed Transport



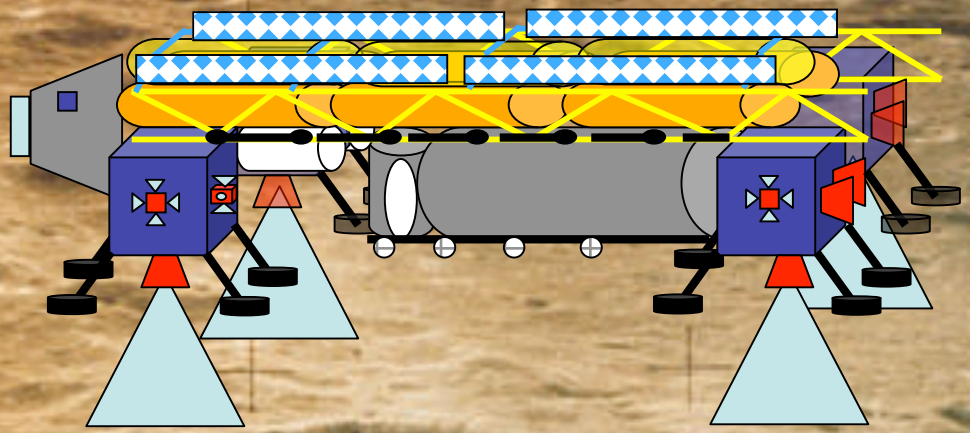
Flight Sequence:
Flights Ones and Two

Flight One



Lander performs Lunar Orbit Insertion
with 4 AFT Engines

Flight One



Lander Lands on surface

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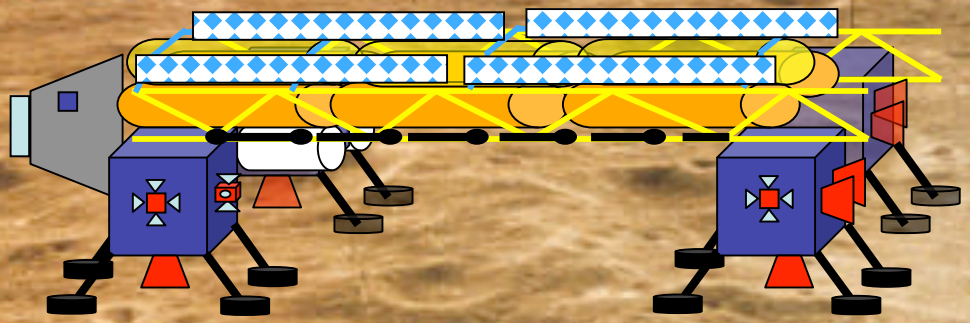
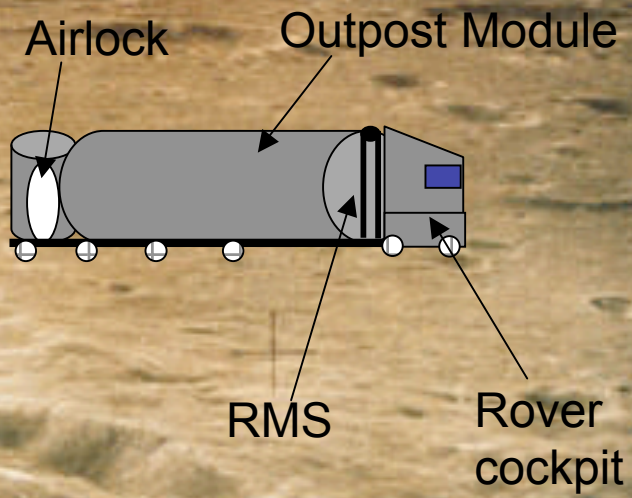
Flight One





Lander Releases Outpost Module and flat bed

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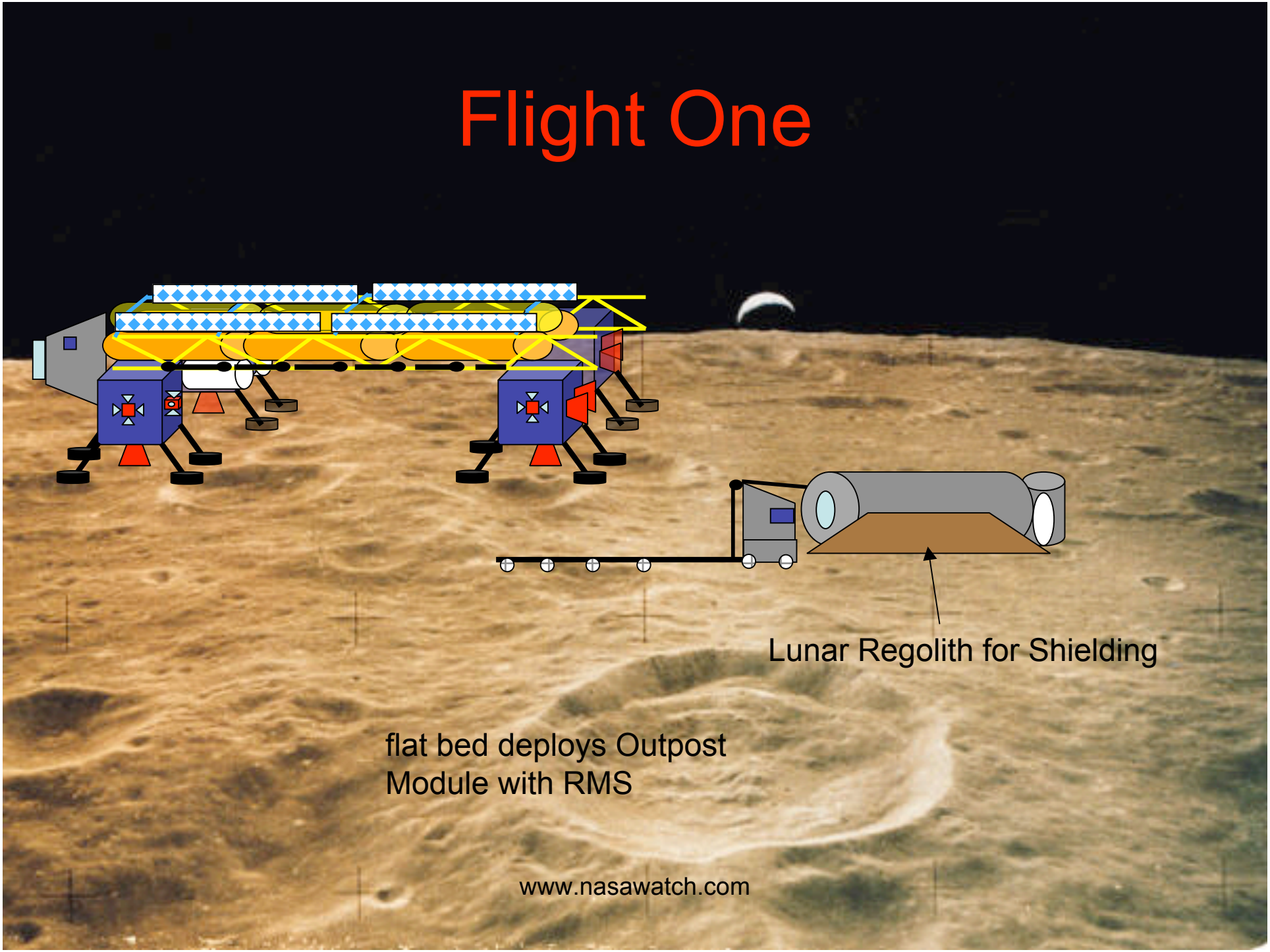
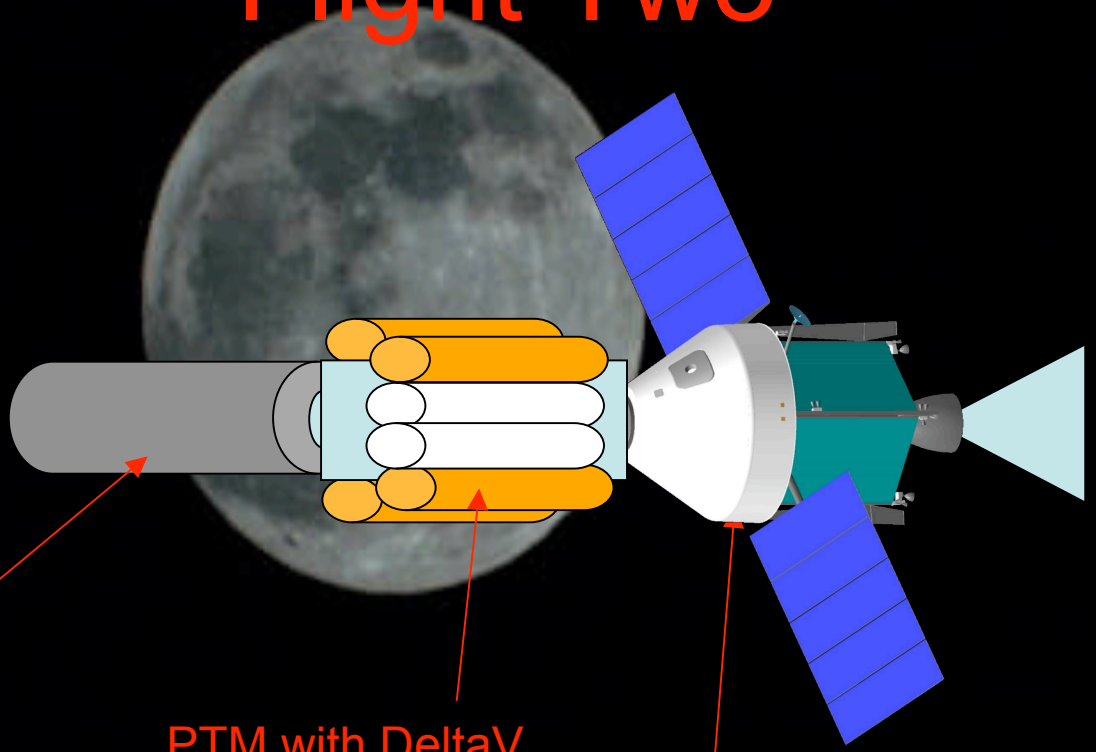
Flight One


Lunar Regolith for Shielding
flat bed deploys Outpost
Module with RMS
www.nasawatch.com

Flight Two



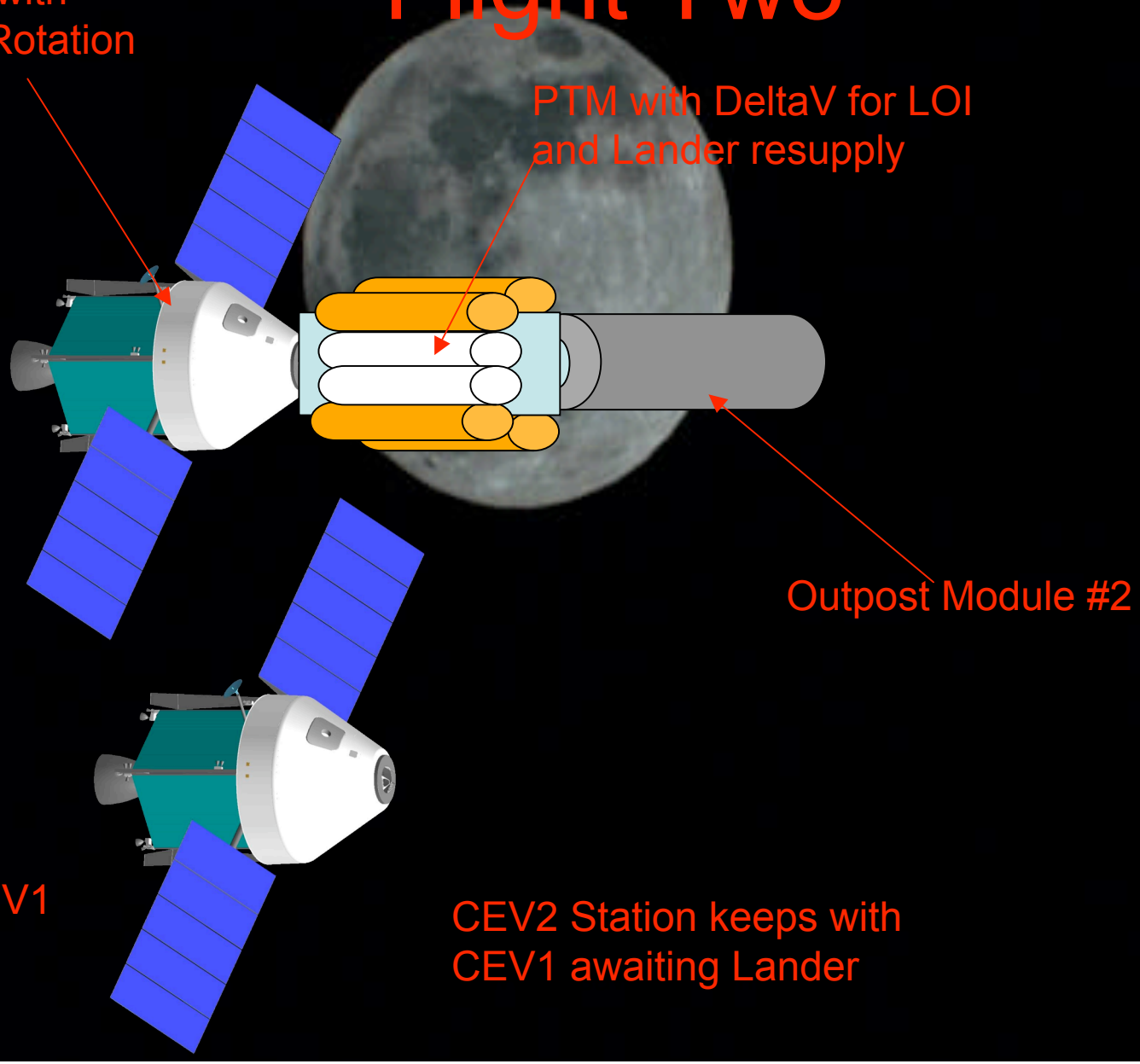
Outpost Module #2

PTM with DeltaV
for LOI and Lander
resupply

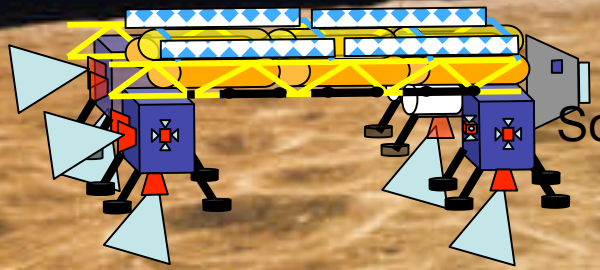
CEV2 with
Crew Rotation

CEV2 Performs Lunar orbit
Insertion

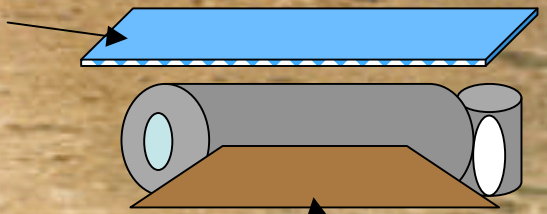
Flight Two


CEV2 with
Crew Rotation
PTM with DeltaV for LOI
and Lander resupply
Outpost Module #2
CEV1
CEV2 Station keeps with
CEV1 awaiting Lander

Flight One Termination



Solar Array Farm



Lunar Regolith for Shielding

Crew egresses outpost and takes off in Lander

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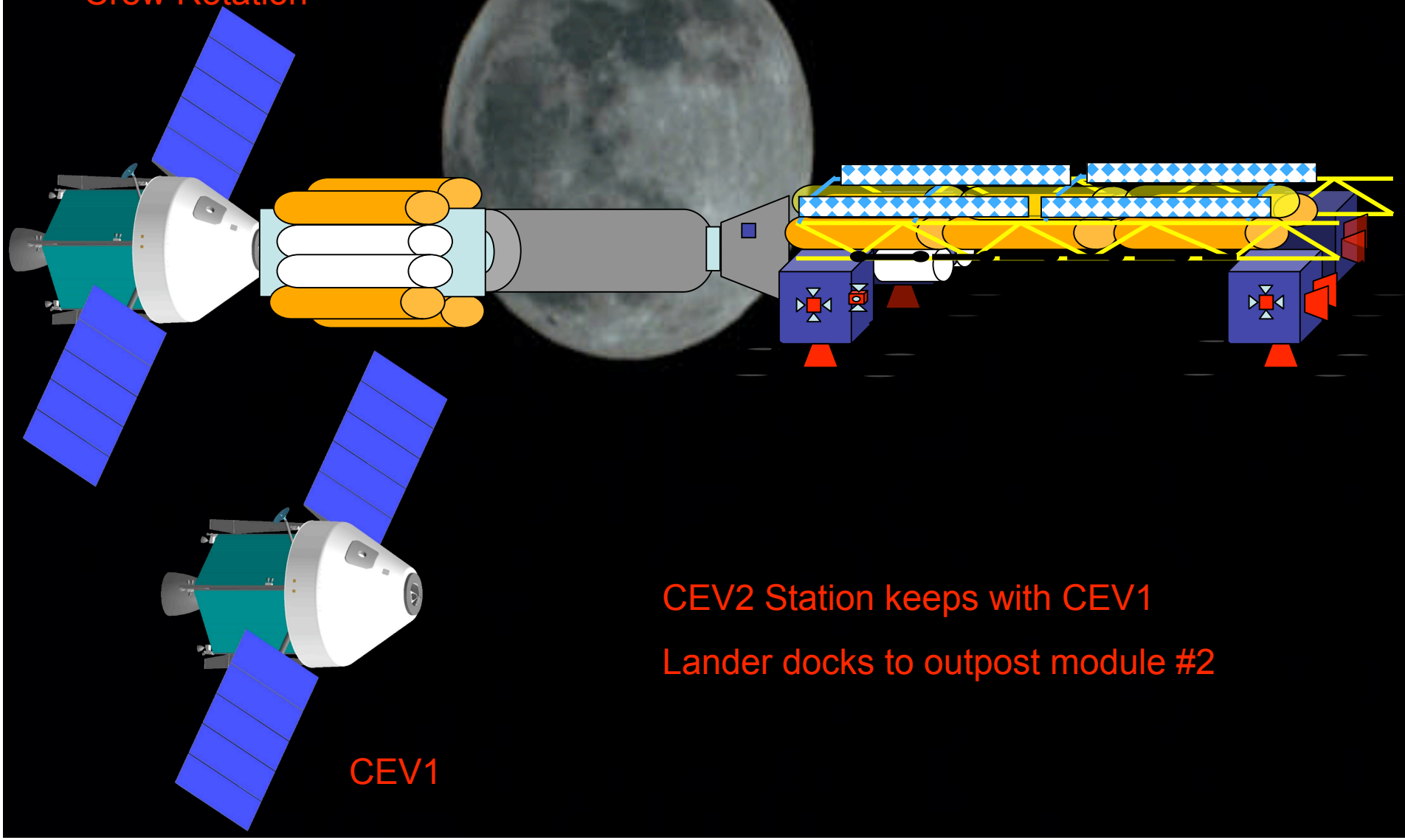
Crew Rotation

CEV2 with
Crew Rotation



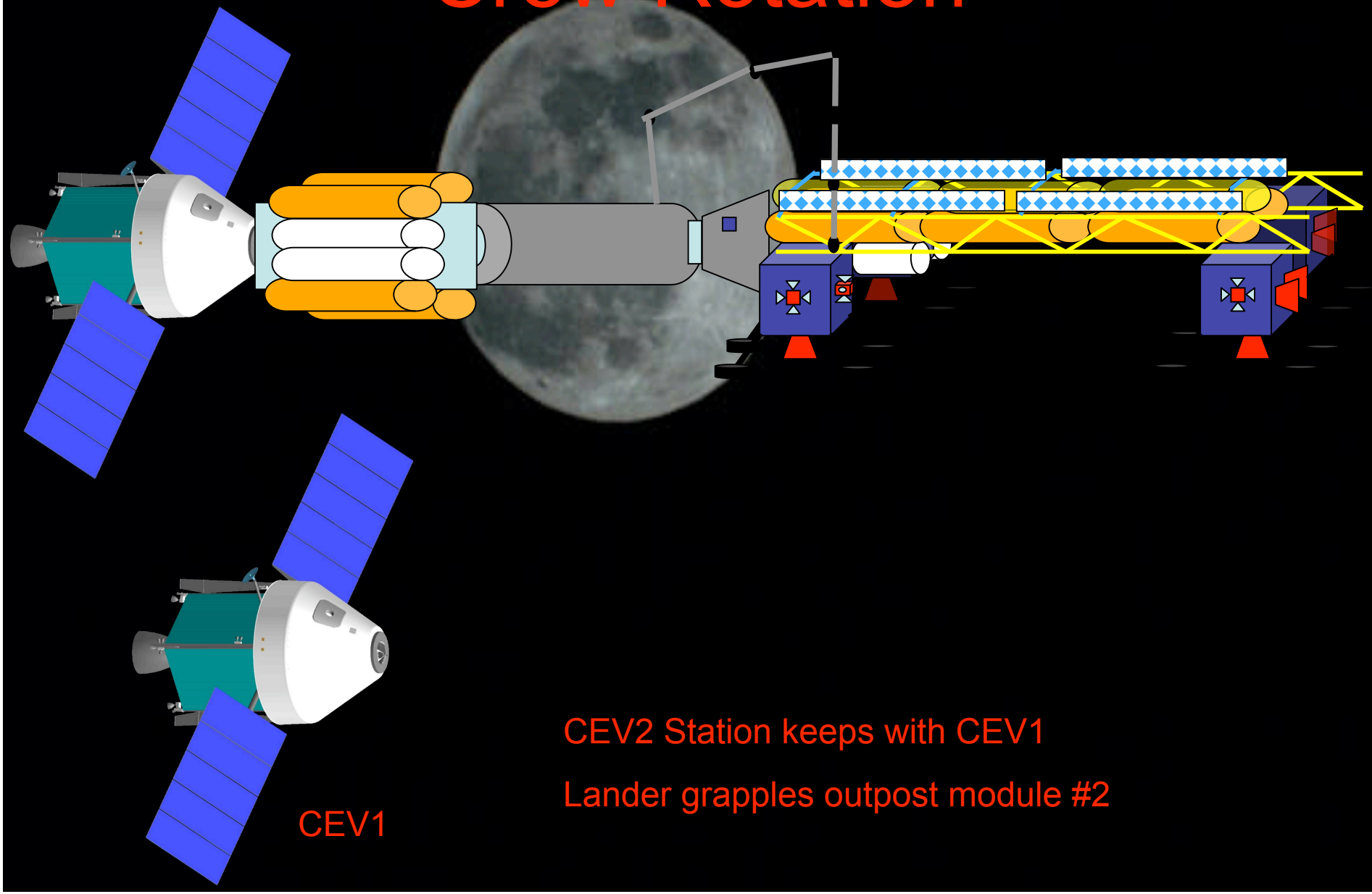
CEV2 Station keeps with CEV1

Lander docks to outpost module #2

CEV1

Crew Rotation

CEV2 with
Crew Rotation

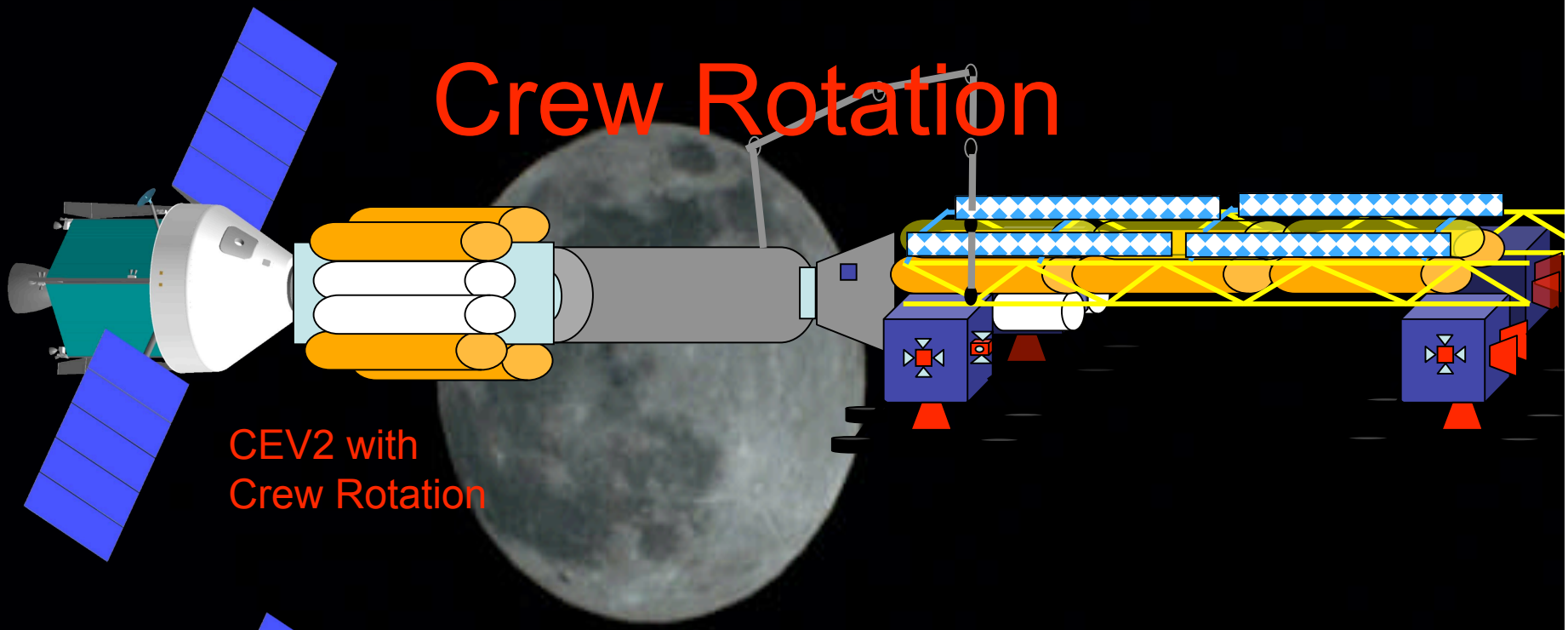


CEV1

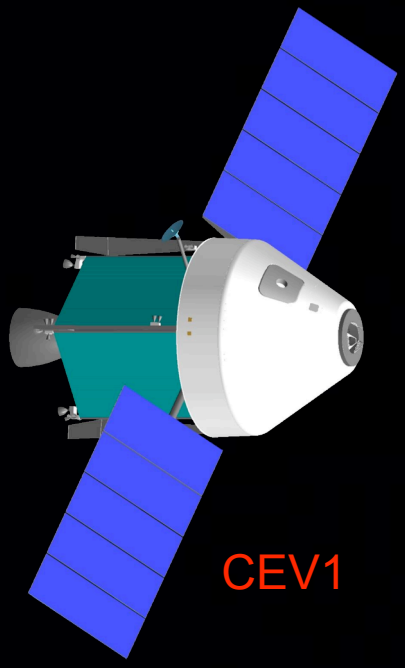
CEV2 Station keeps with CEV1

Lander grapples outpost module #2

Crew Rotation



CEV2 with
Crew Rotation

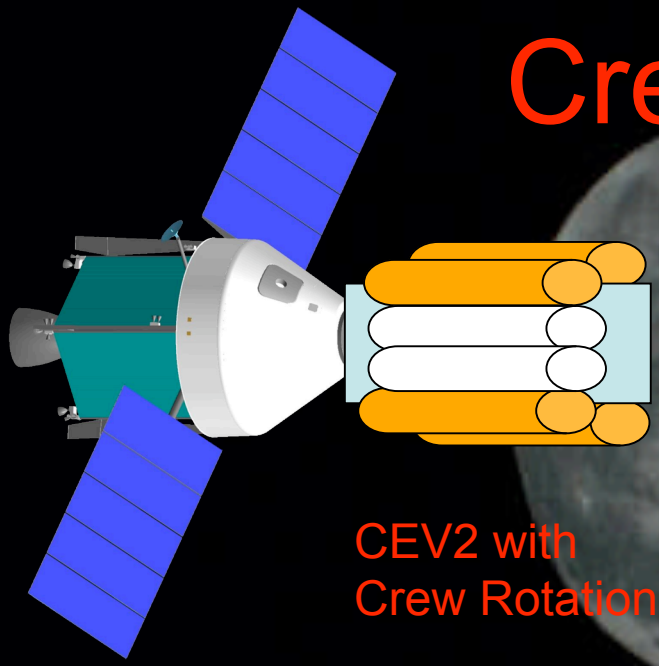


CEV1

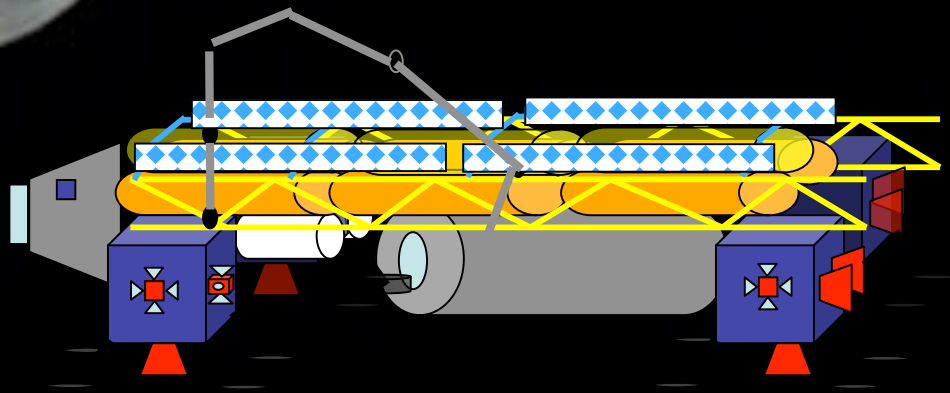
CEV2 Station keeps with CEV1

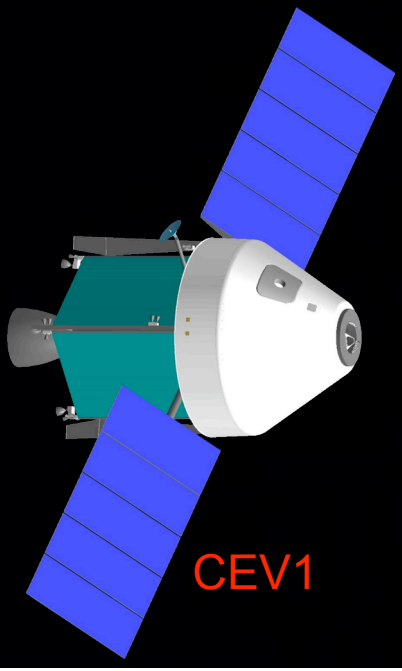
Lander with outpost module #2 grappled undocks at PTM separation plane

Crew Rotation



CEV2 with
Crew Rotation





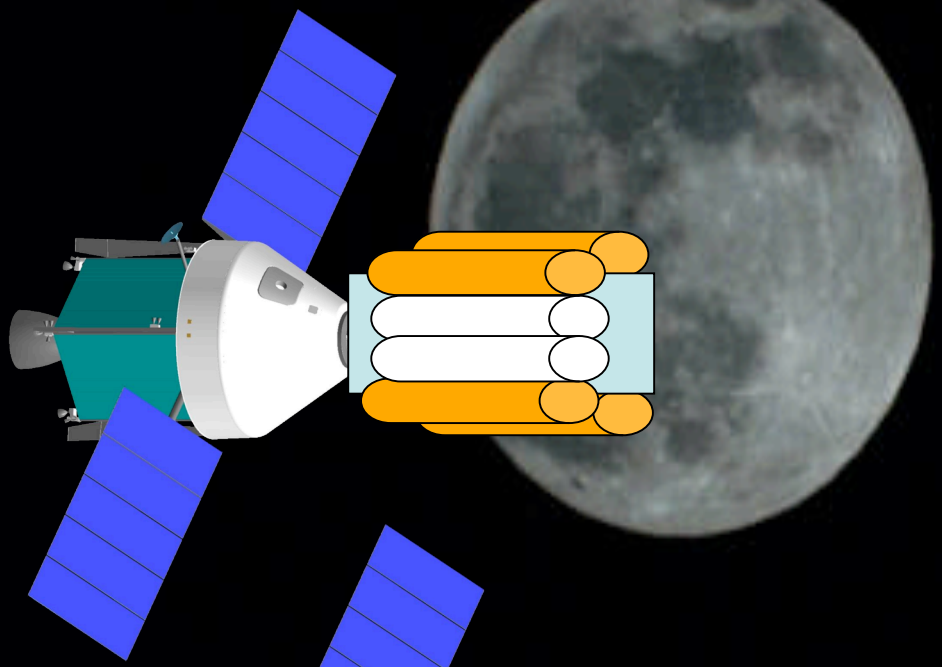
CEV1

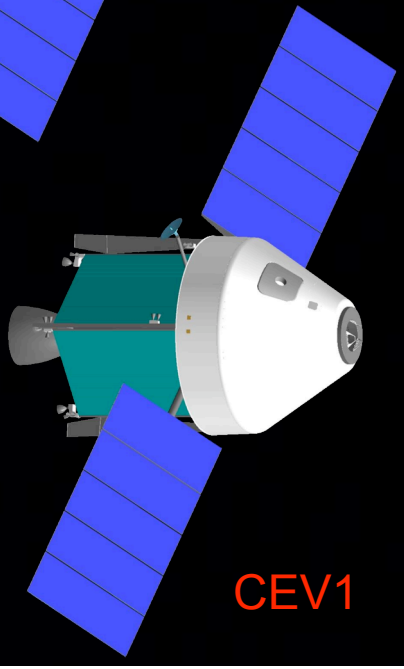
CEV2 Station keeps with CEV1

Lander stows outpost module #2

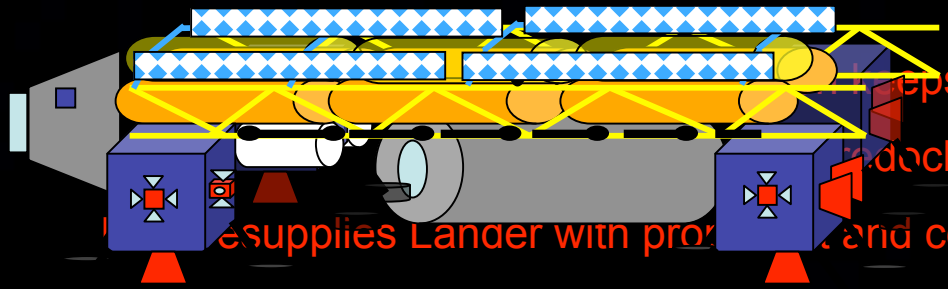
CEV2 with
Crew Rotation

Crew Rotation





CEV1



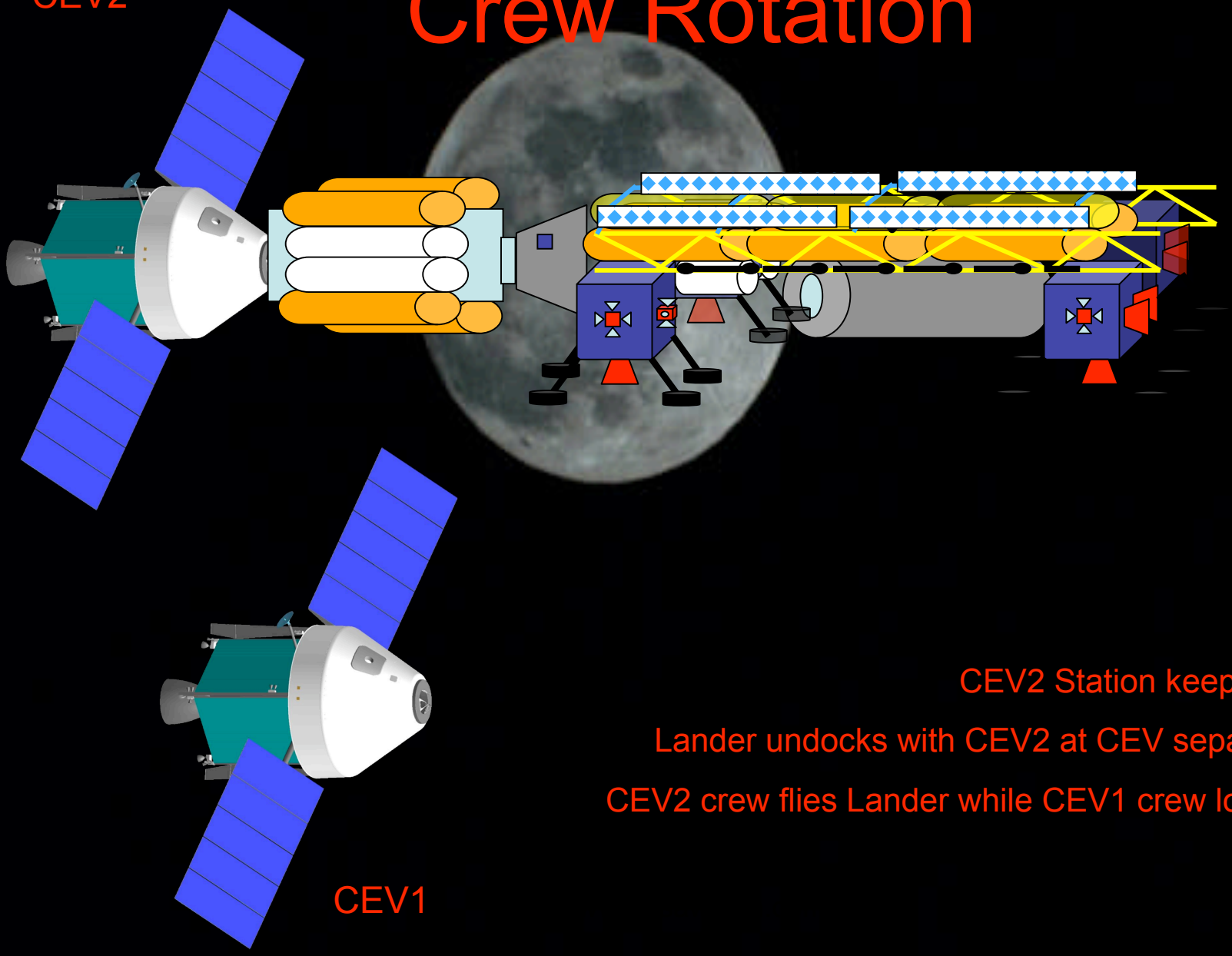
eps with CEV1

docks with PTM

esupplies Lander with pro[illegible] and consumables

CEV2 crew modes CEV2 to loiter and ingresses PTM

Crew Rotation



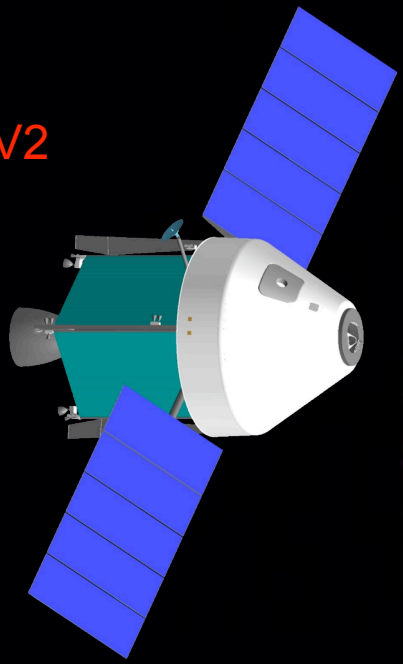
CEV2 Station keeps with CEV1

Lander undocks with CEV2 at CEV separation plane

CEV2 crew flies Lander while CEV1 crew loiters in PTM

Crew Rotation

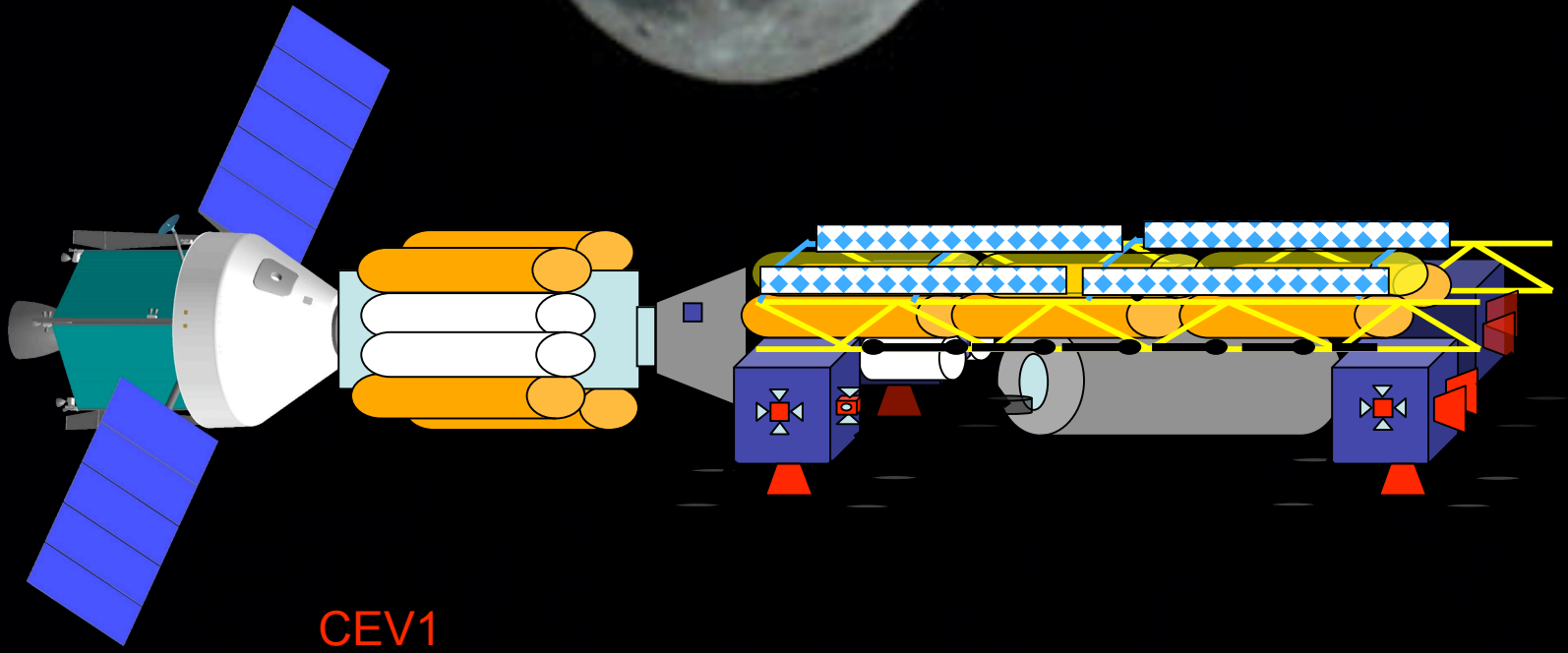
CEV2



CEV2 Station keeps with CEV1

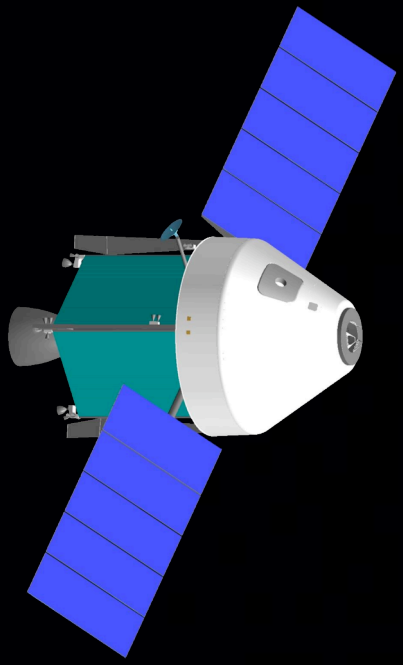
Lander docks with CEV1 with PTM attached

CEV1 crew powers up CEV1

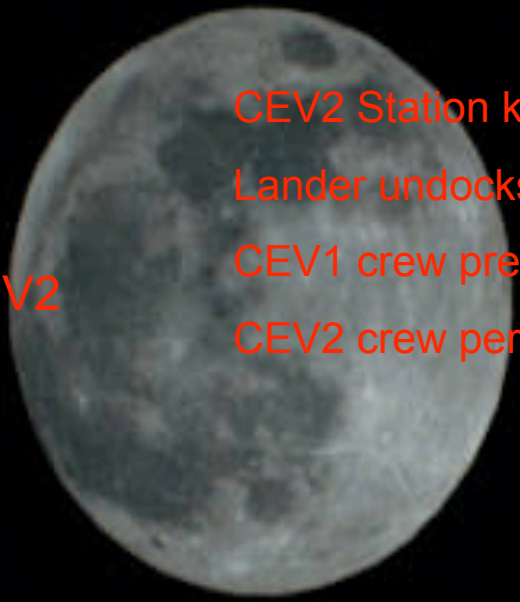


CEV1

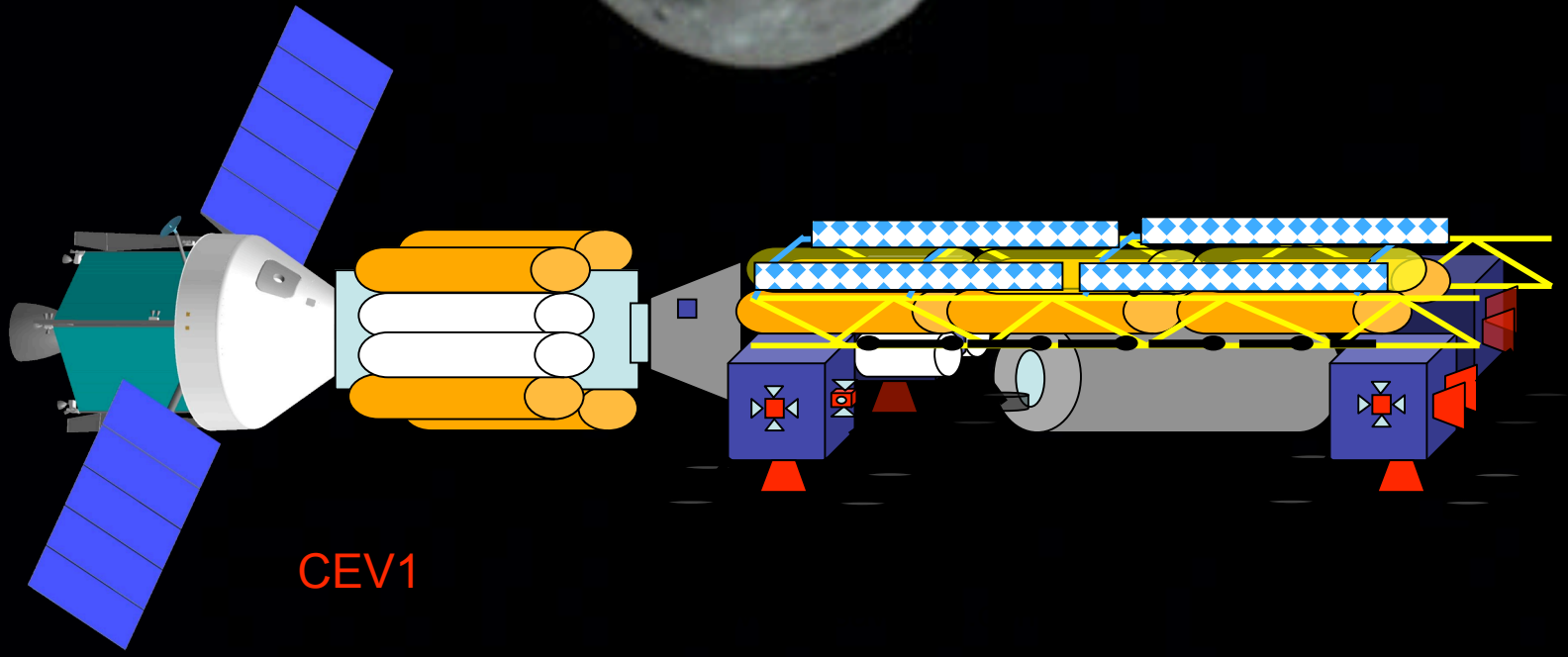
Crew Rotation



CEV2

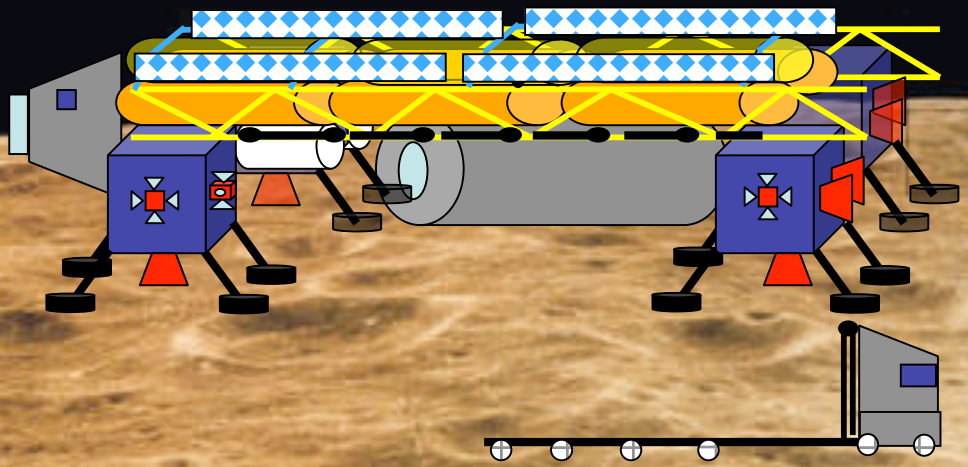


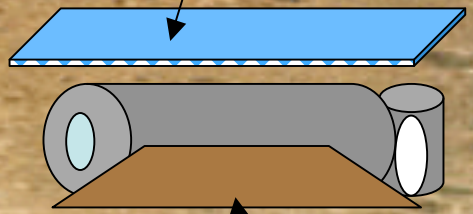
- CEV2 Station keeps with CEV1
- Lander undocks with CEV1 at PTM separation plane
- CEV1 crew preps CEV1 for TEI
- CEV2 crew performs Lunar Descent in Lander



CEV1

Flight Two Lunar Surface





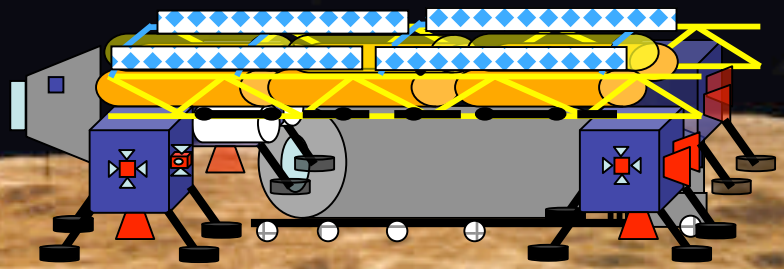
Solar Array Farm

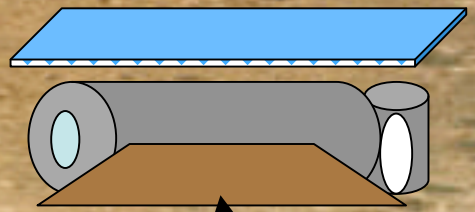
Lunar Regolith for Shielding

Crew egresses Lander and ingresses flat Bed

www.nasawatch.com

Flight Two Lunar Surface





Lunar Regolith for Shielding

Flat bed extracts Outpost Module #2 from Lander

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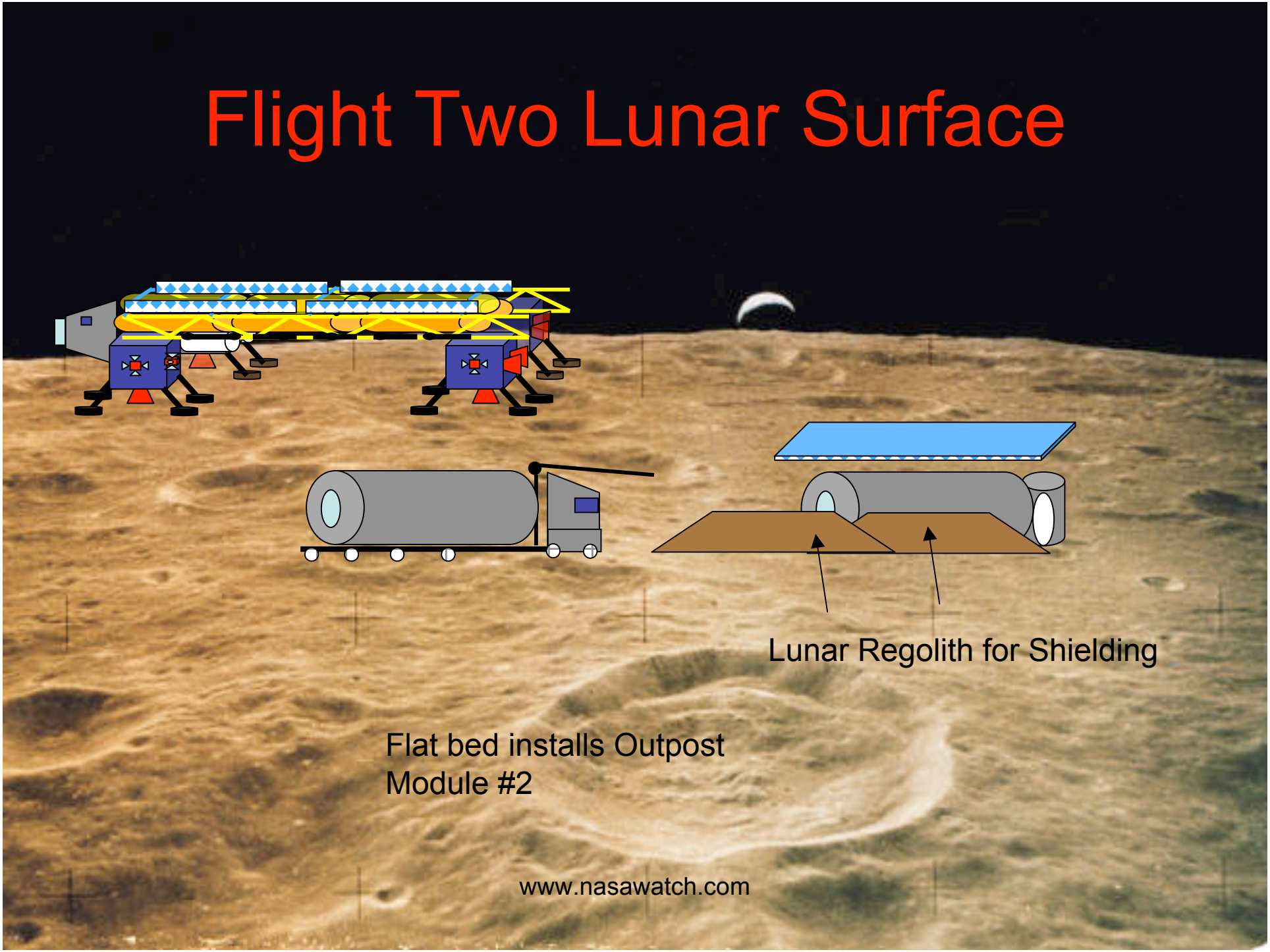
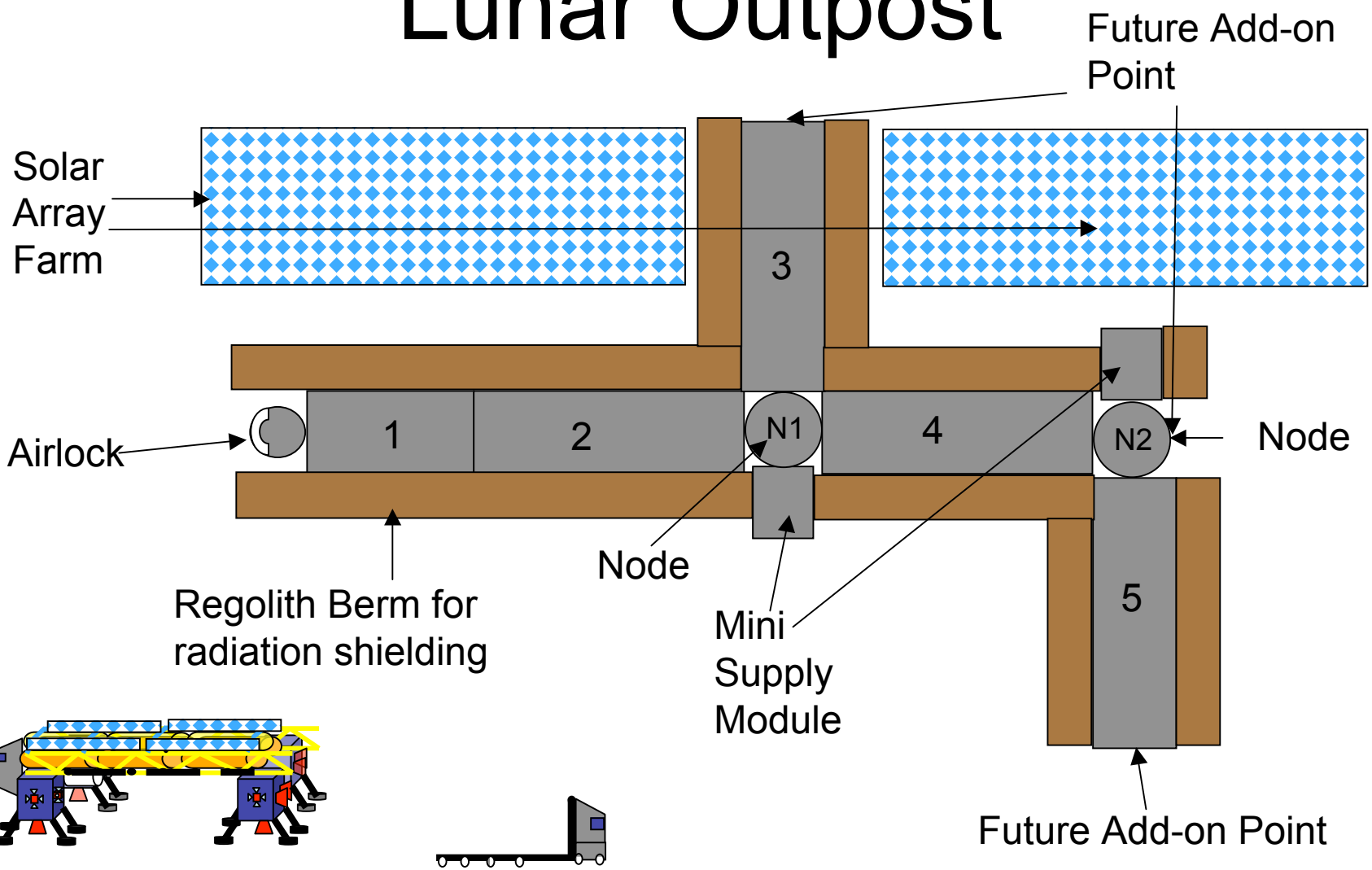
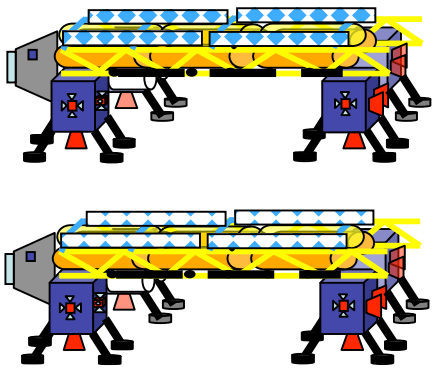
Flight Two Lunar Surface

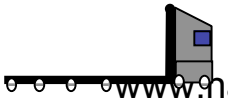


Lunar Outpost:
Assembly Sequence and Crew Rotation

Lunar Outpost

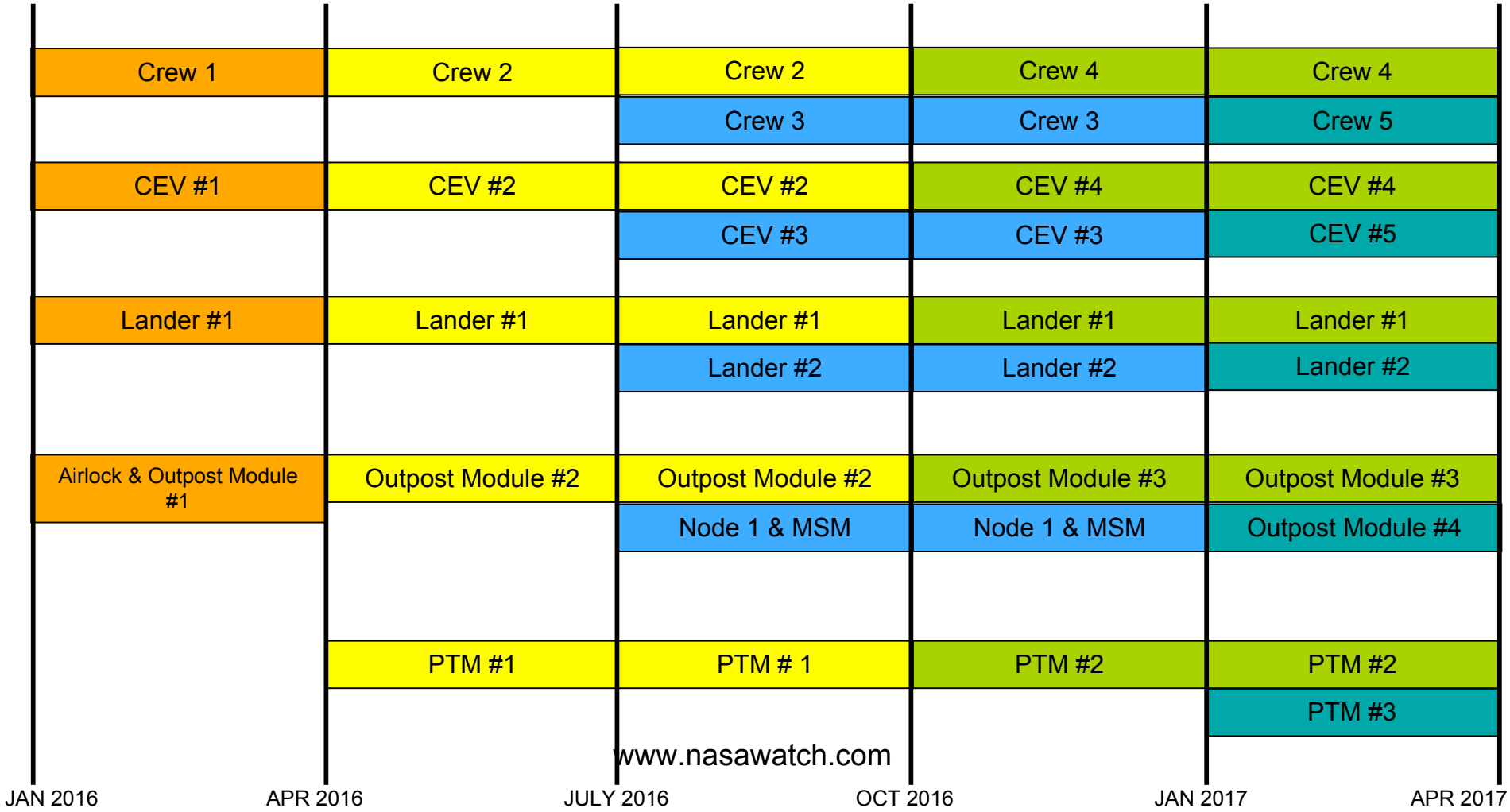




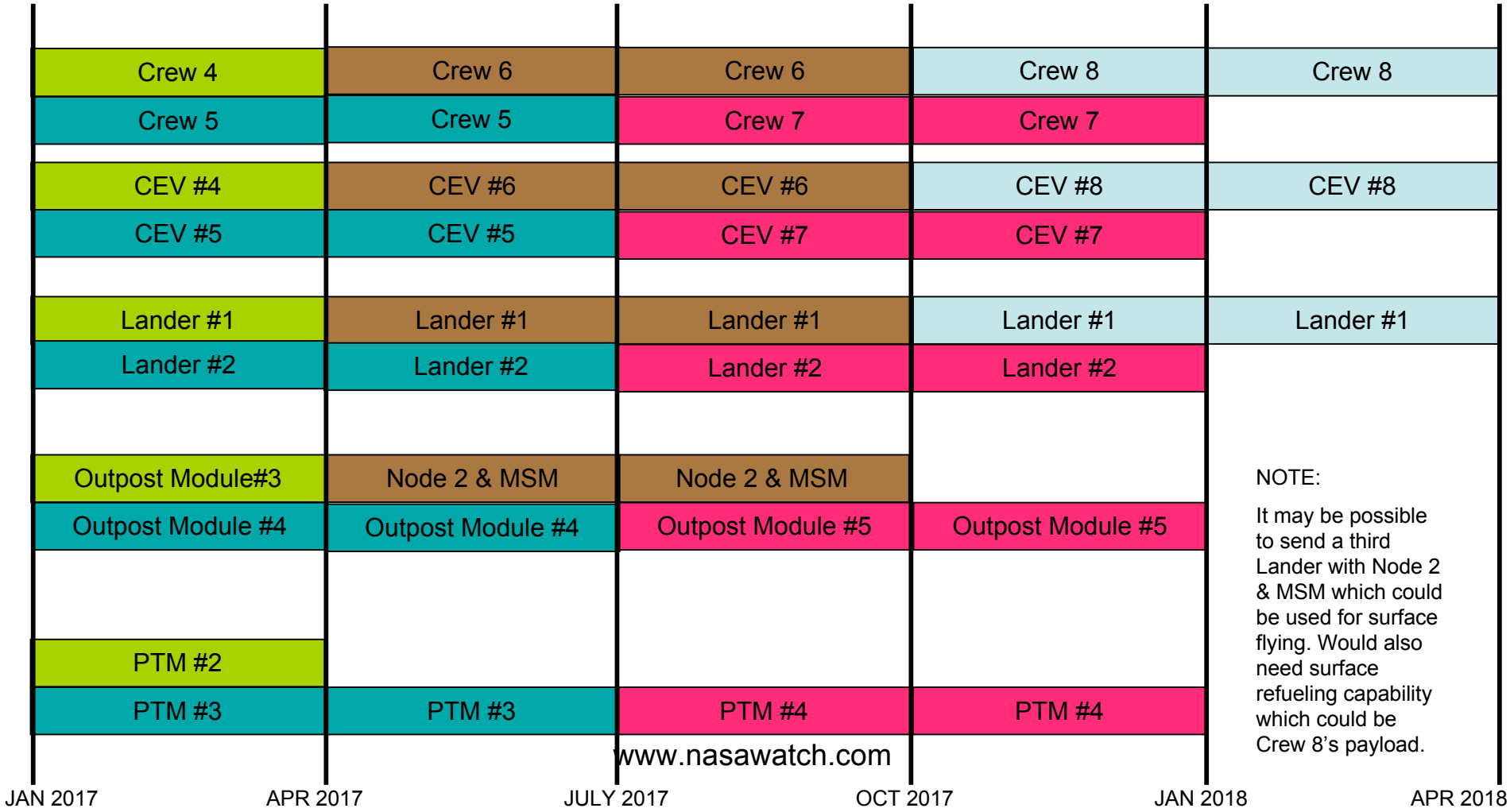


Two Landers allows 8 person Outpost crew rotating 4 crew members every 3 months

Assembly Sequence and Crew Rotations [Jan 2016-April 2017]



Assembly Sequence and Crew Rotations [Jan 2017-April 2018]



NOTE:

It may be possible to send a third Lander with Node 2 & MSM which could be used for surface flying. Would also need surface refueling capability which could be Crew 8's payload.

Conclusion

Total Mass Rollup

- Prop Dry: 10,000 lb excluding valves/manifolds
- GNC: 100 lb
- DPS: 200 lb excluding wiring
- Power: 2,000 lb
- LIDS: 1,000 lb
- Crew: 1,280 lb (4 crew, suits and accommodations)
- RMS: 1000 lb
- ECLSS: ?
- Structure: ?
- ATCS: ?
- Total: CBE 20,000 (15,580 + ?) not including 10,000 for OM (outpost module)
- Lander total:
  - CBE+ OM+PROP (fwd) = 107500 (8,500 Negative Margin)
    - Prop wet mass for Lander: ~77500
  - CBE+ OM+PROP (Back) = 126,910 (28,000 Negative Margin)
    - Prop wet mass for Lander: ~96,910

Conclusion

- Reusable Lander is Not closed Design
  - Significant Negative Margin (8,500-28,000)
- Limits of current design
  - Based on limited tools from Smart Buyer Effort
    - Prop Sizing Generic 6.xls for prop budget
    - CEV SBT Master Workbook for equipment mass
  - Based on limited engineering development
    - MOD notional concept based on Smart Buyer experience
- Is concept viable?
  - Necessitates further study