



Model-based Cost Engineering Space Missions Estimating

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Agenda

- I. Executive Summary: Two independent cost estimating methods in TruePlanning
- II. Case Study Overview (Two Case Studies)
- III. The PRICE Space Hardware Equipment Types and Resulting Cost Models
 - a. The PRICE Space Hardware Equipment Types
 - b. Cost Models / Results
- IV. The Space Missions Catalog and Resulting Cost Models
 - a. The Space Missions Catalog
 - b. Cost Models / Results
- V. Validation Study Results
 - a. Comparison of the Hardware Equipment Type and Space Missions Approaches / Results
 - b. Application Considerations



Executive Summary:

Two independent cost estimating methods in TruePlanning

- Space Missions (TPSM)
 - Best for NASA Projects
 - Estimates by NASA Mission Class
 - Default outputs in NASA Std. WBS format
 - Specific cost objects for Electric Propulsion, Ion Thrusters, Lasers, Parachutes, Radar Altimeters and Thermal Protection

Space Hardware Equipment Types

- Best for DoD Service / Agency Space Missions, but very useful as a 'cross-check' for other estimating methods, including TruePlanning Space Missions
 - Flexible WBS outputs, including MIL-STD-881
 - Historical DoD Spacecraft Bus database

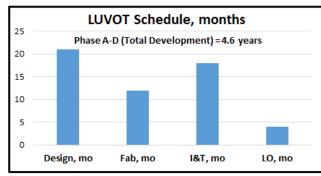
Case Study Overview

Case Study 1: LEO UV Optical

Telescope (LUVOT)

- Explorer-class UV telescope for Astrophysics
- LEO payload with commercial low-cost spacecraft
- Uses a cluster of 4 telescopes tuned to cover different ranges in the UV spectrum

MASS SUMMARY Subsystem/Component	Total Mass, CBE
TOTAL	485.5
UV Optical Telescope	96.1
UVOT Spacecraft	389.4





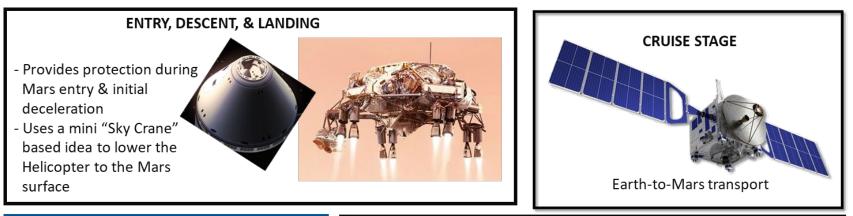


Case Study 1: LUVOT Master Equipment List

Subsystem/Component	Unit Mass, Current Best Estimate (CBE)	Flight Units	Flight Spares	EMs & Proto- types	Total Mass CBE	, Description (Vendor, Part #, Heritage Basis)	Other characteristics/issues (volume, power, other component-specific items)	Subsystem/Component	Unit Mass, Current Best Estimate (CBE)	Flight Units	Flight Spares	EMs & Proto- types	Total Mass CBE	, Description (Vendor, Part #, Heritage Basis)	Other characteristics/issues (volume, power, other component-specific items)
TOTAL					485.5			UV Optical Telescope					96.1		
UVOT Spacecraft					389.4			Telescope Optical Assembly							
Structure								Primary mirror	1.3	4	0	1	5.0	Lightweighted design, Adv Mat'l	25cm diameter
Primary Structure	90.0	1	0	0	90.0	Standard design	Aluminum	Primary mirror mounts	0.5	4	0	1	2.0	Modified past design	Titanium
Secondary Structure	25.0	1	0	0	25.0	Standard design	Aluminum	Secondary mirror	0.8	4	0	1	3.0	Lightweighted design, Adv Mat'l	12cm diameter
Gimbal	15.0	1	0	0	15.0	Modified from past program		Secondary mirror mounts	0.3	4	0	1	1.0	Modified past design	Titanium
Thermal				0				Detectors & Electronics							
Multi-Laver Insulation, Coatings	5.0	1	0	0	5.0	Standard materials, new design		Detectors, CCDs	1.0	4	4	4	4.0	CCDMart Part # 2021	
Heaters, Thermistors	2.0	1	0	0	2.0	Standard materials, new design		Readout Electronics	1.0	4	1	1	4.0	Modified Past Design	
Radiator	3.0	1	0	0	3.0	Minor mod of past design	Composite	Focal Plane Asembly Housing	1.5	4	1	1	6.0		Aluminum
ACS					0.0			Filter Wheel Assembly							
Coarse Sun Sensor	0.0	10	0	1	0.1			Entrance filters assembly	0.5	4	1	1	2.0	Minor mod from past design	
Inertial Reference Unit	2.0	3	0	1	6.0	COTS part		Filter wheel mechanism	0.8	4	1	1	3.0	Minor mod from past design	
Magnetometer	0.5	2	0	1	1.0	COTS part		shutter	0.5	4	1	1	2.0	Minor mod from past design	
Magnetic Torque Rod	1.5	3	0	1	4.5	COTS part		baffles	0.5	4	1	1	2.0	Minor mod from past design	
Star Tracker	5.0	2	0	1	10.0	Modified COTS part		secondary mirror	0.5	4	1	1	2.0	Minor mod from past design	
Reaction wheels	9.0	4	0	1	36.0	Modified standard design		focus mechanism	0.3	4	1	1	1.0	Minor mod from past design	
Power			-			0		image motion compensation actuators	2.0	4	1	1	8.0	Minor mod from past design	
Solar Array, Cells/Electrical	7.0	2	0	0	14.0	COTS cells, custom wiring	High efficiency, Multi-junction	Structure, Mechanical, Thermal							
Solar Array, Substrate/Structure	15.0	2	0	0	30.0	Modified past design	Composite	door Assembly	0.8	4	1	1	3.0	Minor mod from past design	
Solar Array Drives	5.0	2	0	0	10.0	Modified past design		door hinge assembly	0.5	4	1	1	2.0	Minor mod from past design	
Battery	40.0	1	1	1	40.0	Standard cells w/ new configuration	Li-lon, 80 Amp-hrs	aperture selector	0.5	1	1	1	0.5	COTS part	
Power Distribution Unit	20.0	1	0	1	20.0	Modified past design		Telescope Tube	4.0	4	1	1	16.0	New design	Composite
CDH									0.8	4	1	1	3.0	Standard parts/processes, custom	
Backplane	1.0	1	0	1	1.0	COTS part		spider structure						design	
Single Board Computer	0.8	1	0	1	0.8	COTS part w/ custom software	Rad750-based		0.4	4	1	1	1.6	Standard parts/processes, custom	
UL/DL Board	0.5	1	0	1	0.5	Modified past design		heaters						design	
Bus Control I/F Board	0.8	1	0	1	0.8	Modified past design			0.5	4	1	1	2.0	Standard parts/processes, custom	
ACS Electronics Board	0.8	1	0	1	0.8	Modified past design		telescope harnessing						design	
Gimbal Drive Board	0.5	1	0	1	0.5	Modified past design		kinematic mounts	0.8	12	3	3	9.0	Minor mod from past design	Aluminum
General Purpose Board	0.5	1	0	1	0.5	Modified past design		Electronics Box							
Power Control Unit	1.0	1	0	1	1.0	Modified past design		Control Electronics	0.5	1	0	1	0.5	COTS part w/ custom software	Rad750-based
Solid State Recorder	5.0	1	0	1	5.0	COTS part		Power Management	1.0	1	0	1	1.0	Modified past design	
Chassis	8.0	1	0	0	8.0	Modified past design		power switching card	1.0	1	0	1	1.0	Modified past design	
Communications								PCI backplane	0.5	1	0	1	0.5	COTS part	
X-band Transponder	3.0	2	0	1	6.0	COTS part		housing	7.0	1	0	1	7.0		Aluminum
Solid State Power Amplifier	3.0	4	0	1	12.0	COTS part		Harnessing	4.0	1	0	1	4.0	Custom harness, new design	
Antennas	1.0	4	0	1	4.0	Modified past design									
Misc RF Electronics	2.0	1	0	1	2.0	Standard design, modified COTS									
Waveguides/misc	5.0	1	0	1	5.0	Standard design, modified COTS									
Harness	30.0	1	0	0	30.0	Custom harness, modified design									



Case Study 2: Marscopter – Helicopter for Mars



- New Frontiers or Flagship-class mission to land & fly a medium-sized helicopter on Mars
- Uses MSL/Mars 2020 Sky Crane concept for entry, descent, & landing
- Primary power in flight at Mars is from batteries, which are recharged by deployed arrays when landed

MARS HELICOPTER/LANDER

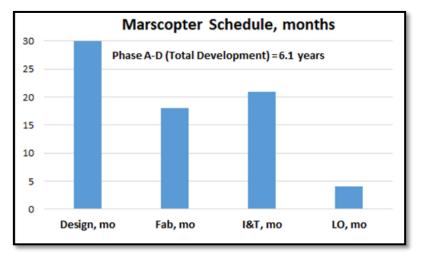
- Helicopter is powered by batteries during flight
- Solar Arrays are used when landed to recharge batteries between excursions
- Multiple excursions can be conducted;
 Lifetime driven by battery charge/discharge cycles





Case Study 2: Marscopter – Helicopter for Mars

MASS SUMMARY	Total
Subsystem/Component	Mass, CBE
TOTAL	2,228.9
PAYLOAD	87.9
Mapping Spectrometer	70.5
Visible Camera	7.9
Meteorological Suite	9.5
FLIGHT SYSTEM	1,625.8
Mars Helicopter/Lander	515.2
EDL Assembly	940.0
Cruise Stage	170.6





Case Study 2: Marscopter Master Equipment List

n	Unit Mass, Current Best Estimate (CBE)	Flight Units	Flight	EMs & Proto-	Total	Total Mass w/ Contingenc		Other characteristics/issues (volume, power, other component-specific issues)
Subsystem/Component	(CBE)	Units	Spares	types	Mass, CBE	 У	Description (Vendor, Part #, Heritage Basis)	items)
TOTAL					2,228.9			
FLIGHT SYSTEM					1,625.8			
Mars Helicopter/Lander					515.2			
Structure/Mechanical								
Primary Structure	35.0							
Top Deck	4.0	1	0	0	4.0		Custom design, standard materials/processes	Composite
Bottom Deck	4.0	1	0	0	4.0		Custom design, standard materials/processes	Composite
Struts	3.0	6	0	0	18.0		Custom design, standard materials/processes	Composite
Landing Legs	3.0	3	0	0	9.0		Custom design, standard materials/processes	Composite
Secondary Structures	24.0							
Brackets/Mounts	18.0	1	0	0	18.0		Custom design, standard materials/processes	Composite
Fasteners	6.0	1	0	ŏ	6.0		Custom design, standard materials/processes	Titanium
Mechanisms	30.0		v		0.0		Custom design, standard materials processes	Houmann
Landing Leg Lock	4.0	3	0	0	12.0		Custom design, standard materials/processes	Aluminum
Visible Camera Gimbal	6.0	1	0	0	6.0		Custom design, standard materials/processes	Aluminum
	6.0	1			6.0			
Mapping Spectrometer Cover	3.0	2	0	0	6.0		Custom design, standard materials/processes Custom design, standard materials/processes	Aluminum
Solar Array Deployment Device	3.0	2	0	0	6.0		Custom design, standard materials/processes	Auminum
Thermal Control								
Multi-Layer Insulation, Coatings, etc	10.0	1	0	0	10.0		Custom design, standard materials/processes	
Heaters	3.0	1	0	0	3.0		Custom design, standard materials/processes	
Power	0.0							
Solar Arrays	62.5							
SA Cells/Electrical	20.8	2	0	0	41.7		COTS cells, custom wiring	High elliciency, Mulu-
SA Substrate/Mechanical	10.4	2	0	0	20.8		Modified past design	Composite
Battery	200.0	1	1	1	200.0		Standard cells w/ new configuration	400 Amp-hr Li-ion
Power Supplies	8.0	1	0	1	8.0		Custom design, changes for HV operation	100 /010/11 6/1011
Power Management & Distribution	8.0	1	0	1	8.0		Custom design, changes for HV operation	
High Voltage Box	16.0		0	1	0.0		custom design, changes for HV operation	
HV Power Conversion System	9.0	1	0	1	9.0		Custom design, changes for HV operation	
HV Chassis/Frame	7.0	1	0	1	7.0		Custom design, standard materials/processes	Aluminum
Harnesses	30.0	1	0		30.0			Auminum
	30.0	1	0	0	30.0		Custom harness, modified design	
Guidance, Navigation, & Control	5.0				10.0		11.15.10070	
Inertial Measurement Unit	5.0	2	0	1	10.0		Modified COTS part	
Landing Altimeter	10.0	2	1	1	20.0		Custom design, changes for unique application	
Command & Data Handling	0.5						0070	De 1770 haved
RAD750 Single Board Computer	0.5	1	0	1	0.5		COTS part w/ application-specific software	Rad750-based
Payload Interface Card	0.5	1	0	1	0.5		Modified past design	
Other Cards	0.5	4	0	4	2.0		Modified past designs	
Communications	10						0070	
X-band Deep Space Transponder	4.0	2	0	1	8.0		COTS part	
Solid State Power Amplifier	3.0	2	0	1	6.0		COTS part	
High Gain Antenna	12.0							
HGA Dish	8.0	1	0	1	8.0		Modified past design	
HGA Support Structure	4.0	1	0	1	4.0		Modified past design	Composite
Low Gain Antennas	0.4	3	0	1	1.2		COTS part	
Misc RF Electronics	1.0	1	0	1	1.0		Modified design, standard materials/processes	
Waveguides	2.5	1	0	1	2.5		Modified design, standard materials/processes	
Helicopter								
Rotors	1.0	4	0	1	4.0		Custom lightweight design	Advanced composite
Rotors Support Structure	0.5	4	0	1	2.0		Custom housings	Titanium
Motor	4.0	4	1	1	16.0		Custom motor, New design	New technology
Motor Controller	3.0							
Motor Controller Electronics	2.0	1	0	1	2.0		Custom cards with heritage/modified devices	Rad750-based
Motor Controller Chassis/Box	1.0	1	0	1	1.0			Aluminum

Subsystem/Component	Current Best Estimate (CBE)	Flight Units	Flight Spares	EMs & Proto- types	Total Mass, CBE	Contingen	Total Mass wi Contingenc y	Description (Vendor, Part #, Heritage Basis)	characteristics/issues (volume, power, other component-specific items)
EDL Assembly					940.0				
Structures & Mechanisms									
Mini Sky Crane Primary Structure	150.0	1	0	0	150.0			Scaled-down heritage design	Aluminum
Mini Sky Crane Secondary Structure	50.0	1	0	0	50.0			Scaled-down heritage design	Aluminum
Heatshield Structure	75.0	1	0	0	75.0			Scaled-down heritage design	Aluminum
Heatshield TPS	300.0	1	0	0	300.0			Scaled-down heritage design	
Backshell Structure	50.0	1	0	0	50.0			Scaled-down heritage design	Aluminum
Backshell TPS	150.0	1	0	0	150.0			Scaled-down heritage design	
Parachute (w/ mortar)	75.0	1	1	1	75.0			Scaled-down heritage design	
Propulsion									
Thrusters	2.0	12	0	0	24.0			Multiple landing thruster clusters, COTS	
Propellant Tanks	25.0	2	0	0	50.0			Multiple custom tanks (for balance)	Titanium
Propulsion Lines/Valves/Filters	10.0	1	0	0	10.0			Modified design, standard materials/processes	
Avionics									
Inertial Measurement Unit	5.0	1	0	1	5.0			Modified COTS device	
Single Board Computer	1.0	1	0	1	1.0			COTS part w/ custom software	Rad750-based
Cruise Stage					170.6				
Structures & Mechanisms									
Primary Structure	75.0	1	0	0	75.0			Scaled heritage design	Aluminum-honeycom panels
Secondary Structure	10.0	1	0	0	10.0			Scaled heritage design	
Mechansims	15.0	1	0	0	15.0			COTS devices	
Balance Mass	5.0	1	0	0	5.0				Aluminum
Thermal Control									
MLI, Coatings	8.00	1	0	0	8.0			Modified design, standard materials/processes	
Temperature Sensors	0.20	10	0	0	2.0			Modified design, standard materials/processes	
Propulsion									
Fuel Tank	8.00	4	0	0	32.0			Mono-prop fuel tank	Titanium
TCM Thrusters	0.60	4	0	0	2.4			COTS items	
ACS Thrusters	0.40	8	0	0	3.2			COTS items	
Valves/Filters	3.00	1	0	0	3.0			Modified design, standard materials/processes	
Pressure Transducer	0.25	2	0	0	0.5			Modified design, standard materials/processes	
TCM Thruster Brackets	0.13	4	0	0	0.5			Modified design, standard materials/processes	
ACS Thruster Brackets	0.25	8	0	0	2.0			Modified design, standard materials/processes	
Brackets Tubes Fittings etc.	12.00	1	0	0	12.0			Modified design, standard materials/processes	

Case Study 2: Marscopter Master Equipment List

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Subsystem/Component	Current Best Estimate (CBE)	Flight Units	Flight Spares	EMs & Proto- types	Total Mass, CBE	Contingen	Total Mass w/ Contingenc y	Description (Vendor, Part #, Heritage Basis)	characteristics/issues (volume, power, other component-specific items)
PAYLOAD	(CBE)	onits	opares	ypes	Mass, CBE 87.9		7	Description (venuor, Parce, Hentage Basis)	nemsy
Mapping Spectrometer					70.5				
Spectrometer Assembly									
Optical elements	5.0	1	0	1	5.0			Optics use advanced materials/coatings w/ heritage	
Grating	2.0			1	2.0			Modified past design	
Filters	2.0	1	0	1	2.0			Modified past design	
Sensor, CCD	0.5	4	0	1	2.0			CCDMart Part # 1969	
Telescope Assembly	10.0								0
Main Body	10.0	1	0	1	10.0			Custom design, heritage processes/materials	Composite
Baffles	5.0	1	0	1	5.0			Modified past design	
Primary Mirror	4.0	1	0	1	4.0			Modified past design	
Scan Mirror								Ma diffe disease descine	Observation and a set in a
Scan Mirror Optics	2.0	1	0		2.0			Modified past design	Standard optics
Scan Mirror Actuator	1.0	1	0	1	1.0			Modified past design	O
Telescope Secondary Structure	5.0	1	0	1	5.0			Custom designs, heritage processes/materials	Composite
Scan Platform		4						Outra design hadres and the little	O
Scan Platform Structure	5.0	1	0	1	5.0			Custom design, heritage processes/materials	Composite
Scan Platform Motor	5.0	1	0	1	5.0			Modified past design	01
Scan Platform electronics	2.5	1	0	1	2.5			Modified past design	Standard microprocessor
Scan Platform cabling	1.0	1	0	1	1.0			Modified past design	moroprocessor
Thermal Control	1.0		v		1.0			mouned past design	
Multi-Layer Insulation/Coatings	4.0	1	0	1	4.0			Standard materials, new design	
Radiator	2.0	1	0	1	2.0			Custom design, heritage processes/materials	Composite
Temperature Sensors	1.0	1	ő	1	1.0			Standard materials, new design	Composite
Command & Data Handling	1.0				1.0			otanoura materialo, new acogri	
Read-Out Electronics	1.0	1	0	1	1.0			Modified COTS item with custom software	
Solid-state Memory	1.0	1	0	1	1.0			COTS item	
CDH Chassis	2.0	1	0	1	2.0			Modified past design	Aluminum
Power	2.0				2.0			mound past design	Fighting
Power Supplies	2.0	1	0	1	2.0			Modified past design	
Power Management & Distribution	2.0	1	ő	1	2.0			Modified past design	
Harnessing	4.0	1	0	1	4.0			Custom harness, new design	
Visible Camera	4.0				7.9			ousion numeros, nen uesign	
Housing	4.0	1	0	4	4.0			Custom design, heritage processes/materials	Composite
Primary Optic	2.0	1	0	1	2.0			Modified past design	Composite
Secondary Optics	0.5	1	0	1	0.5			Modified past design	
Detector, CCD	0.5	1	0	1	0.5			CCDMart Part # 1963	
Readout electronics	0.4	1	0	1	0.4			COTS item with custom programming	
Visible Camera Internal Harnessing	0.5	1	0	1	0.5			Modified past design	
Meteorological Suite	0.5		v		9.5			meaned post design	
Sensors					3.5				
Temperature Sensor	0.5	0	0		1.0			Modified past design	
	0.5	2		1					
Wind Sensor	0.5	2	0	1	1.0			Modified past design	
Pressure Sensor	0.5	2	0	1	1.0			Modified past design	
Seismometer	0.5	2	0	1	1.0			Custom design with new technology	
Electronics									
Readout Electronics	1.0	1	0	1	1.0			Modified past design	
Power Conditioning	1.5	1	0	1	1.5			Modified past design	
Power									
Power Conditioning	2.0	1	0	1	2.0			Modified past design	
Harpessing	1.0	4	0	4	1.0			Custom harness, new design	

The PRICE Space Hardware Equipment Types and Resulting Cost Models

Data Sources

The current Equipment Type calculator includes an updated table of TruePlanning manufacturing complexities using a combination of three sources:

- 1) PRICE KnowledgeNetwork (KN): Specific product information provided to PRICE Estimating Suite (PES) customers from approximately 1995 through 2005. KN is approximately 12,000 records of individual software and hardware product information for PES estimating purposes.
- 2) Spacecraft Bus Component Calibrations: Selected Unmanned Space Cost Model (USCOM) data dealing with spacecraft bus components, supplied to PRICE Systems by the US Air Force Space and Missile Command (SMC), sent to PRICE in April 2014.
- 3) Calibrated Complexity Values Embedded in PRICE tools: 30 years of heritage as some of the values originate with PES from its beginning in 1975. Since then, the content of the embedded tables has grown and matured and been inherited by TruePlanning.
- These three data sources contain publicly available as well a proprietary data. As a result, individual records of the sources are not used for table publication. Rather, statistical metrics are used to categorize component complexity values for estimating purposes. The average complexity over all instances of a component is used.

Space Equipment Types – 119 New Types + Legacy

Structures & Mechanisms

Actuator/Drive Ass'y Hinges Latch Mechanisms Pyrotechnics Pyrotechnics Ass'y Solar Array Yokes/Booms Structure, Panel Structure, Payload Structure, Primary Structure, Solar Sail Structure, Wheel

Thermal Control

Heat Pipes Heater/Thermistor/Thermostat Mirror Miscellaneous Passive Thermal MLI Blanket/Insulation/Paint/Shroud Optical Solar Reflector Radiators/Louvers

Altitude Control / GNC

Accelerometer ACS Control Electronics Earth Horizon Sensor GPS Receiver IMU/IRU Magnetic Torquer Magnetometer Momentum/Reaction Wheel Nutation Damper/Despin Ass'y Rate Gyro Star Tracker Sun Sensor Torque Coils

Propulsion

Filter Lines/Fittings.Latch/Isolation Valves Manifold Motor, Apogee Kick Motor. Solid Rocket Plumbing Plumbing, XIPS Power Processor Regulator Squib Valve, Fill/Drain Valve Tank, Auxilliary Tank, Chemical Tank. Flight System Tank. Helium Tank. Launch System Tank, Liquid Tank, Manned Space Mission Tank. MUPS Tank. Oxidizer/PMD Tank. Pressurant Tank, Propellant/Propulsion Tank, XIPS Thruster Module, Dual Thruster, ARCJET Thruster, Cold Gas Thruster, High Level Thruster. LAE Thruster, Liquid Thruster, Low Level Spin Control Thruster. REA Thruster, XIPS Thruster:.1 LB. - 110 LB. Transducer

Space Equipment Types – 119 New Types + Legacy

TT&C / C&DH / Communications

Antenna Antenna, Hi-Gain Antenna, Horn Antenna, Low-Gain/Medium Gain Antenna, Omni Antenna, S-Band Antenna, VHF Command Receiver Command Telemetry Unit Communication Security Data Handling Data Interface Data Recorder Demodulator Diplexer Filter/Coupler Frequency Downconverter Harness/Cabling/Waveguide Memory Modulator Oscillator/Clock Power Amplifier Premodulator Processor **RF** Distribution **RF** Ferrite Device **RF Plumbing** Signal Conditioner Signal Switch Spacecraft Control Processor **Thruster Firing Electronics** Transmitter Transponder Transponder Telemetry Unit TW/TA Valve Driver

Electrical Power Batterv **Battery Voltage Limiter Battery Voltage Pressure Monitor** Battery, NiH Cabling/Wiring Harness Ordnance/Charge Power Controller Power Conditioner/Controller **Power Control Electronics** Power Converter Power Dissipators/Shunts **Power Distribution Unit Power Regulator Power Supply Electronics** Solar Array Solar Array Drive Solar Array -GaAs Solar Array -Si Sauib Driver Switching Unit

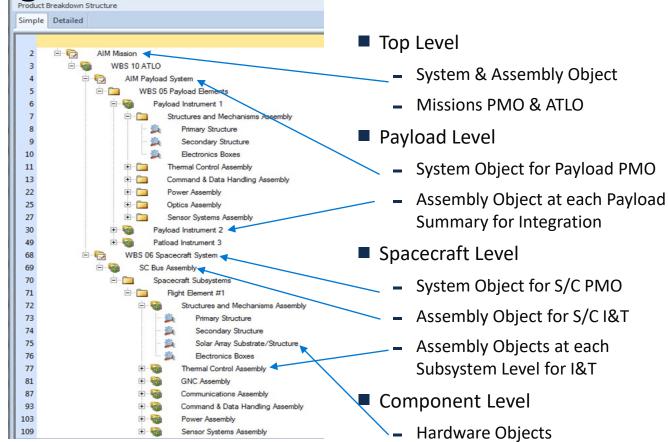
Payload / Instruments

Optics (Average Complexity) Digital/Analog Electronics Power Supply Electronics Power Connectors/Harnesses Optics (Simple) Optics (Complex Assy.) Digital/Analog Electronics (Simple Circuit) Digital/Analog Electronics (Complex Circuit) Sensor, Electronic, General

Payload and Bus

Electronic Chassis/Housing Electronic Chassis/Housing (Simple / Mechanical part) Electronic Chassis/Housing (Sophisticated / Complex)

Building the Product Breakdown Structure



Equipment Type Calculator:

Enhanced with Unmanned Space Mfg Complexities

	e Edit View Reports Tools Window Help 			· · · · ·	ecraft Bus Component Manuf	acturing Correla	vitier			
				Spac	ecrart Bus component Manuf		Complexity	Electronics	Complexity	
Produ	Ict Breakdown Structure	Input Sheet: Star Tracker CT	Reference # Spacecraft Bus Subsystem	n Component	Definition	Earth Orbiting	Planetary	Earth Orbiting	Planetary	Percentage Structure Weight
Simple	P Detailed	Cost Objects 🖬 Ir	1 Attitude Control	Accelerometer		9.25	9.78			100%
			2 Attitude Control	ACS Control Electronics		7.96	8.42	10.29	10.89	73%
		Star Tracker C	24 Attitude Control 28 Attitude Control	Earth Horizon Sensor GPS Receiver		8.16 7.60	8.63 8.04	10.56 9.83	11.17 10.40	35%
1	- 🗀 AIM Proposal v9 FY\$15	Cost	33 Attitude Control	IMU/IRU		9.78	10.34	5.05	10.40	100%
1			36 Attitude Control	Magnetic Torquer		7.19	7.60			100%
2	🖻 🔂 🛛 1 - 3 AIM Mission	Project Cost	37 Attitude Control 45 Attitude Control	Magnetometer Momentum/Reaction Wheel		7.26 8.55	7.68 9.05	9.39	9.93	35% 100%
		Worksheet Set: Space	45 Attitude Control	Nutation Damper/Despin Ass'y		8.29	8.77			100%
3	🖻 🍓 🛛 10 AIM ATLO	worksneet set: space	67 Attitude Control	Rate Gyro		9.60	10.15			100%
	D ATM Device of Contrast		82 Attitude Control	Star Tracker		9.65	10.20			100%
4	🗉 🔂 🛛 05 AIM Payload System		88 Attitude Control 113 Attitude Control	Sun Sensor Torque Coils		8.16 7.25	8.63 7.67	10.55	11.16	35%
38	🗄 🔞 06 AIM Spacecraft Bus System		124 Bus & Payload	Electronic Chassis/Housing	An electronic housing, typically	7.23	7.07			100%
50	- W OU AIM Spacectair bus system				rectangular, made of Aluminum,	6.35	6.35			100%
39	🖻 🍓 Assembly	1 Start Date			with up to 6 bolt down fasteners	0.55	0.55			100%
			127 Bus & Payload	Electronic Chassis/Housing	and possibly some stiffeners A simple electronic housing,					
40	🖹 🍘 🛛 Attitude Control (ADC) Assembly	2 🛈 Quantity Per N	127 Bus & Payload	(Simple / Mechanical part)	typically made of aluminum with					
41	- 🛸 RW	3 Additional Unit			no more than four sides and 4 bolt	6.30	6.30			100%
41	- 🙇 RW	5 Additional Onli			down fasteners					
42	RW Electric	4 🔍 Number of Ac	128 Bus & Payload	Electronic Chassis/Housing (Sophisticated / Complex)	An electronic housing made with advanced materials such as					
72	- Iteletite			(sophisticated / complex)	titanium or composites.					
43	- 🙇 Torque Rods	5 0 Number of Ac			sometimes with unusual shape	8.00	8.00			100%
					with more than four sides, or with					
44	🛁 Mag	6 Cost Sharing U			added stiffeners, or with more than 6 fasteners					
45	Star Tracker CT-633		11 Electrical Power	Battery	than o lasteners	8.13	8.13			100%
45	Star Tracker CT-035	7 Total Number of	12 Electrical Power	Battery Voltage Limiter		7.06	7.06	9.13	9.13	70%
46	Coarse Sun Sensor	8 Total Number of H	13 Electrical Power	Battery Voltage Pressure Monito	e	8.09	8.09	10.46	10.46	70%
		8 Total Number of P	fololypes Produced		0.00			KII.		
47	LN-200S rate sensor	9 Technical Desc	ription							
48	Power Assembly	10 Equipment Type			None 🚛					
57	🗉 🚳 CDH Assembly	11 Operating Specific	cation		2.00 🕡		1			
69	Structure Assembly	12 Ueight of Strue			2.0617 kg 💌					
72	🖲 🚳 Thermal Assembly	13 Ueight of Elec			0.0000 kg 💌					
79	COMM Assembly	14 Volume			1.945 🔎 🛛 💌					
		15 Manufacturing Cor	mplexity for Structure		9.647 🚛					
		16 Percent of New St			20% 🚛 %		(1 0			
			Repeat for Structure		0% 🔎 %		(\$0			
			mplexity for Electronics		0.000					
		19 Dercent of New			20% 🚛 %					
			Repeat for Electronics		0% 🔎 %					
		21 Engineering Com			0.200 🖌 🗐		1 0			

Equipment Type Calculator:

Completed Calculator Inputs

PRIC	CE TruePlanning 14.2 - [AIM Proposal v9 FY\$15*]					3
🖗 Ele	e <u>E</u> dit <u>V</u> iew Reports <u>T</u> ools <u>W</u> indow <u>H</u> elp					×
	- I m 4 X % % % A 11 1 6 6 8 8	A *	((Tables and Calculators		
Produ	ct Breakdown Structure	Input	Sheet: Star Tracker CT-633			
Simple	e Detailed		ost Objects 🖼 Input			
		St	ar Tracker CT-(The Equipment Type describes typical equipments that are of	commonly developed and produced.	
1 -	∃- 🗀 AIM Proposal v9 FY\$15	Cos		When you select an Equipment Type from the available value		
			ect Cost	Volume, Manufacturing Complexity for Structure, and Manufac research on equipment types. These values may be change		
2	🖻 🔂 1 - 3 AIM Mission		rksheet Set: Space v4			Show Descriptions
3	🖻 🗐 10 AIM ATLO		instruction oppice vi	Section Name	Input Field	in onow occurptions
4	🕀 🔄 05 AIM Payload System			Operating Environment	Unmanned Space - Earth Orbiting	
38	🖻 🛜 06 AIM Spacecraft Bus System			Function	Spacecraft Attitude Control V	
39	🖹 🍘 Assembly	1	Start Date	Equipment Type	Star Tracker	
40	Attitude Control (ADC) Assembly	2	Quantity Per Next	Total Weight	2.062	
41	- 🎉 RW	3	Additional Units	Heritage Structure	Copy/Build to Print	Copy refers to a component that is off
42	RW Electric	4	Number of Additic			
43	Torque Rods	5	Number of Additid			
44	Mag	6	Cost Sharing Units			
45	Star Tracker CT-633					
			Total Number of Proc	•		
46	Coarse Sun Sensor	8	Total Number of Prote			
47	LN-200S rate sensor	9	Technical Descrip		2.00	
48	Power Assembly	10	Equipment Type	Total Weight	2.062 kg	
57	🗉 🍓 CDH Assembly	11	Operating Specification	Weight of Structure Weight of Electronics	2.062 kg	
69	🗉 🍓 Structure Assembly	12	Weight of Structure	Volume	0.000 kg 3.218 l	
72	Thermal Assembly	13	Weight of Electror		9.647	
79	GOMM Assembly		Volume	Manufacturing Complexity for Electronics	0.000	
				Percent of New Structure	20.00% %	
			Manufacturing Compl	Percent of New Electronics	20.00% %	
		16	Percent of New Struct	Engineering Complexity	0.20	

The Space Missions Catalog and Resulting Cost Models



TruePlanning Space Missions (TPSM) History

1988 – 1992

- An improved method for estimating NASA Planetary missions was identified as a need to support the upcoming Discovery Program
- A new approach based on PRICE H was developed leveraging an extensive amount of past planetary data (going back to the early 1970s)

1992 – 2010

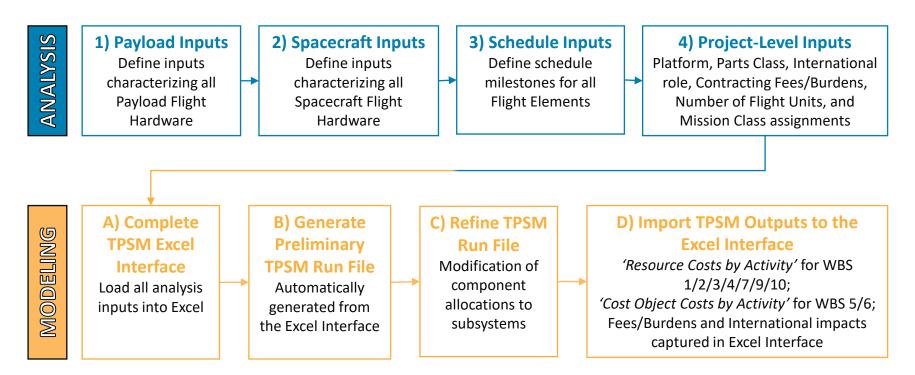
- The PRICE H approach was refined to include Earth orbiting missions in addition to Planetary
- Additional refinements were made to capture science instruments and approaches used by more recent missions
- Goal was to focus on perceived cost drivers versus non-causal options

2010 – Today

- Migrated methodology from PRICE H to TruePlanning
- Used to support multiple instrument and mission Standing Review Boards (SRBs) demonstrating accuracy and applicability throughout all mission development phases



TPSM Methodology Overview



TPSM Inputs

4 Analysis Steps Needed to Define Inputs:

- Step 1: Allocate all payload Master Equipment List (MEL) items to a subsystem & component type
- Step 2: Allocate all flight system MEL items to a subsystem & component
- Step 3: Define schedule milestones for each flight element and the individual instrument elements
- Step 4: Assign project-level inputs as needed





TPSM Components (Steps 1 & 2)

- TPSM builds up a cost estimate starting with definition of subsystems & components
- Each item in a MEL can be assigned to a 'Subsystem' and 'Component' using the Subsystems/Components shown here
- Subsystems can use items shown under a different subsystem, maximizing flexibility to track different project categorizations
- Instruments can use items in 'Optics' and Sensor Systems' as well as items from other Subsystems

ubsystem	Subsystem	Subsystem
Component	Component	Component
TRUCTURE & MECHANISMS	GUIDANCE, NAVIGATION, & CONTROI	L ENTRY & DESCENT
Primary Structure	Star Tracker	Themal Protection System *
Secondary Structure	Sun Sensor	Parachute *
Shielding	Reaction Wheel	1
Solar Array Substrate/Structure	Torque Rod	OPTICS
HGA Structure	Gimbals	Optical Bench
Electronics Boxes	IMU-Gyro	Optics
Mechanisms	Actuators	Gratings
Motor/Actuator	Radar Altimeter *	Filter Wheel
Booms	1	Optics Filters/Misc
		1
OBOTIC ARM	Transponder	SENSOR SYSTEMS
Robotic Arm - Limb	Transmitter	Laser *
Robotic Arm - Joint/Actuator	Amplifier	Sensors-Detectors
	Misc RF Electronics	CCD Detectors
HERMAL CONTROL	HGA	Magnetometer
MLI, Paints, Coatings	MGA/LGA	TOF Spectrometer
Heaters, RHUs, Thermostats	Waveguide/Comm Cabling	ESA sensor
Radiators/Louvers	1	Photodiode
Heat Pipes	COMMAND & DATA HANDLING	Bolometer
Cryocooler	Command/Data Processing	Ion Source
	Solid State Memory	Gamma Sensor
ROPULSION	1	Neutron Sensor
Propulsion Lines/Valves/Fittings	POWER	Dust Detector
Pressure Regulator	Power Management and Distribution	Readout Electronics
Tanks	Solar Cells/Electrical	1
Thrusters	Pyrotechnics	1
	Batteries	1
ECTRIC PROPULSION	Harness	1
Ion Thruster *	I	1
Power Processing Unit *	1	* Modeled using custom TPSM relationsh





TPSM Component Type Inputs (Steps 1 & 2)

- There can be up to 5 different type inputs tailored to each 'Component'
- The type inputs are generally arranged from lower cost (1) to higher cost (5)
- Component type inputs are used differently for each 'Component' and are used to estimate lowerlevel cost drivers (part volumes, electronics density, parts complexity, integration complexity, and others)

tructure					Type		-
	Component	Tech Parameter	1	2	3	4	5
	and Mechanisms						
P	Primary Structure	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Secondary Structure	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
		Material	Aluminum	Stainless Steel	Titanium		XX
5	Shielding					Other; High-Density	
s	Solar Array Substrate/Structure	Material	Aluminum	Honeycomb	Titanium	Composite	XX
F	High Gain Antenna Structure						
	Electronics Boxes	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Mechanisms	Complexity	Simple	Standard	Advanced	Very Advanced	XX
N	Motor-Actuator	Complexity	Simple	Standard	Advanced	Very Advanced	XX
8	Booms	Complexity	Simple	Standard	Advanced	Very Advanced	XX
ermal 0	Control						
	MU. Paints. Coatings						
	Heaters, RHUs, Thermostats	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
8	Radiators/Louvers	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Heat Pipes	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Cryocooler	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
opulsio	n						
	Propulsion - Lines/Valves/Fittings	Material	Aluminum	Staipless Steel	Titanium	Composite	XX
	Pressure Regulator - Transducer	Complexity	Simple	Standard	Advanced	Very Advanced	XX
T	Tanks	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
т	Thrusters	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Ion Thruster	Specific Impulse				n/a	
	Electric Propulsion Power Processing Unit	Maximum Power					
	d and Data Handling						
0	Command/Data Processing	Complexity	Simple, Non-	Most Microprocessors,	RAD750, PPC	Advanced Devices	XX
1			Programmable	8AD6000			
-	Collid Group Manager	Grandaut			Mandred Group h. 1	Consular Calif.	Ded Hand C
s	Solid State Memory	Complexity	XX	Simple Solid State	Nominal Space-based	Complex Solid State	Rad-Hard Comp
					Solid State		
mmvo	ications						
	Transponder	Frequency Band	UHF	S - band	X - band	Ka - band	Optical
	Transmitter	Frequency Band	UHF	S - band	X - band	Ka - band	Optical
1	Amplifier	Frequency Band	TWTA	UHF, Simple	S/X - band SSPA	Ka - band SSPA	Advanced Devi
	Miscellaneous RF Electronics	Frequency Band	UHF	S - band	X - band	Ka - band	Optical
•	High Gain Antenna	Frequency Band	UHF	S - band	X - band	Ka - band	Optical
1	Medium Gain Antenna/Low Gain Antenna	Frequency Band	UHF	S - band	X - band	Ka - band	Optical
							A 11 1
	Waveguides - Comm Cabling	Frequency Band	UHF	S - band	X - band	Ka - band	Optical
	e, Navigation and Control						
5	Star Tracker	Complexity	Simple	Standard	Advanced	Very Advanced	XX
5	Sun Sensor	Complexity	Simple	Standard	Advanced	Very Advanced	XX
	Reaction Wheel	compically	Simple	Standard	Hararcea		
	Torque Rod		n/a				n/a
6	Gimbals	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	IMU-Gyro						
	Actuators						
wer							
	Power Management and Distribution	Complexity	Simple or Large-Scale	Nominal Space-based	Complex Device, Adv	Very Complex Rad-	XX
F				Device		Hard Device	
\$							
	enter only following t	Constants.	Olline Calm Calls		Switching or I&T		104
	Solar Cells/Electrical	Complexity	Silicon Solar Cells	Multi-Junction	Multi-Junction and	Low Intensity and Low	XX
	Solar Cells/Electrical	Complexity	Silicon Solar Cells			Low Intensity and Low Temperature or	XX
	Solar Cells/Electrical	Complexity	Silicon Solar Cells		Multi-Junction and	Low Intensity and Low Temperature or	XX
s				Multi-Junction	Multi- Junction and High Efficiency	Low Intensity and Low Temperature or Advanced	
S	Pyrotechnics	Complexity	Simple	Multi-Junction Standard	Multi- Junction and High Efficiency Advanced	Low Intensity and Low Temperature or Advanced Very Advanced	XX
S P B	Pyrotechnics Batteries		Simple Non-rechargable	Multi-Junction	Multi- Junction and High Efficiency	Low Intensity and Low Temperature or Advanced	XX XX
S P B	Pyrotechnics Batteries	Complexity	Simple	Multi-Junction Standard	Multi- Junction and High Efficiency Advanced	Low Intensity and Low Temperature or Advanced Very Advanced	XX
S P B	Pyrotechnics Batteries Power Harness/Cabling	Complexity	Simple Non-rechargable	Multi-Junction Standard	Multi- Junction and High Efficiency Advanced	Low Intensity and Low Temperature or Advanced Very Advanced	XX XX
S P B P nsor Sy	Pyrotechnics Batteries Power Harness/Cabling systems	Complexity Chemistry	Simple Non-rechargable r/a	Multi-Junction Standard NiCd or NiH n/o	Multi- Junction and High Efficiency Advanced Li-ion n/a	Low Intensity and Low Temperature or Advanced Very Advanced Advanced Chemistry n/o	XX XX n/a
S P B P nsor Sy S	Pyrotechnics Batteries Power Harness/Cabling ystems Eensors/Detectors	Complexity Chemistry Complexity	Simple Non-rechargable n/a Simple	Multi-Junction Standard NiCd or NiH n/a Nominal	Multi- Junction and High Efficiency Advanced Li-ion n/a Complex	Low Intensity and Low Temperature or Advanced Very Advanced Advanced Chemistry n/a Very Complex	XX XX n/a XX
S P B P S S S	Pyrotechnics Batteries Power Harness/Cabling systems	Complexity Chemistry	Simple Non-rechargable n/o Simple Most Visible, Si-based	Multi-Junction Standard NiCd or NiH n/o Nominal Adv Vis, Most UV/IR	Multi- Junction and High Efficiency Advanced Li-ion n/a	Low Intensity and Low Temperature or Advanced Very Advanced Advanced Chemistry n/o	XX XX n/a
S P B P S S S	Pyrotechnics Batteries Power Harness/Cabling ystems Eensors/Detectors	Complexity Chemistry Complexity	Simple Non-rechargable n/a Simple	Multi-Junction Standard NiCd or NiH n/a Nominal	Multi- Junction and High Efficiency Advanced Li-ion n/a Complex	Low Intensity and Low Temperature or Advanced Very Advanced Advanced Chemistry n/a Very Complex	XX XX n/a XX
S P B P nsor Sy S C	Pyrotechnics Batteries Yower Harness/Cabling ystems Sensors/Detectors Charge Coupled Device Detectors	Complexity Chemistry Complexity Complexity	Simple Non-rechargable r/a Simple Most Visible, Si-based CCDs	Multi-Junction Standard NiCd or NiH n/a Nominal Adv Vis, Most UV/IR (HgCdTe)	Multi- Junction and High Efficiency Advanced Li-ion n/a Complex Adv Multi-Spectral	Low Intensity and Low Temperature or Advanced Very Advanced Advanced Chemistry n/o Very Complex Very Complex	XXX XXX n/a XXX XXX
S P Ensor Sy S C M	Pyrotechnics Batteries Power Harness/Cabling systems Gensors/Detectors Charge Coupled Device Detectors Magnotometer	Complexity Chemistry Complexity Complexity Complexity	Simple Non-rechargable Nost Visible, Si-based CCDs Simple/Standard	Multi-Junction Standard NiCd or NiH r//o Nominal Adv Vis, Most UV/IR (HgCdTe) Advanced	Multi- Junction and High Efficiency Advanced Li-ion n/a Complex Adv Multi-Spectral Very Advanced	Low Intensity and Low Temperature or Advanced Very Advanced Advanced Chemistry r/a Very Complex Very Complex Very Complex	XXX XXX n/a XXX XXX
S P B P S S C M	Pyrotechnics Batteries Yower Harness/Cabling ystems Sensors/Detectors Charge Coupled Device Detectors	Complexity Chemistry Complexity Complexity	Simple Non-rechargable r/a Simple Most Visible, Si-based CCDs	Multi-Junction Standard NiCd or NiH n/a Nominal Adv Vis, Most UV/IR (HgCdTe)	Multi- Junction and High Efficiency Advanced Li-ion n/a Complex Adv Multi-Spectral Very Advanced Customized/High	Low Intensity and Low Temperature or Advanced Very Advanced Advanced Chemistry n/o Very Complex Very Complex	XX XX n/a XX XX
S P B P P nsor Sy S C C M T	Protechnics Solaries Server Vances (Zobling Sensory Detectors Charge Coupled Device Detectors Charge Coupled Device Detectors Magnetometer Time Of Flight Spectrometer	Complexity Chemistry Complexity Complexity Complexity Complexity	Simple Non-rechargable r/a Most Visible, Si-based CCDs Simple/Standard Simple	Multi-Junction Standard NiCd or NiH n/o Adv Vis, Most UV/IR (HgCdT) Advanced Standard	Multi- Junction and High Efficiency Advanced Li-ion n/o Complex Adv Multi-Spectral Very Advanced Customized/High Performance	Low Intensity and Low Temperature or Advanced Very Advanced Advanced Chemistry r/o Very Complex Very Complex XX Advanced	XX XX n/a XX XX XX XX
S P Risor Sy S C M T	Protechnics Solaries Server Vances (Zobling Sensory Detectors Charge Coupled Device Detectors Charge Coupled Device Detectors Magnetometer Time Of Flight Spectrometer	Complexity Chemistry Complexity Complexity Complexity Complexity	Simple Non-rechargable r/a Most Visible, Si-based CCDs Simple/Standard Simple	Multi-Junction Standard NiCd or NiH r//o Nominal Adv Vis, Most UV/IR (HgCdTe) Advanced	Multi- Junction and High Efficiency Advanced Li-ion n/a Complex Adv Multi-Spectral Very Advanced Customized/High	Low Intensity and Low Temperature or Advanced Very Advanced Advanced Chemistry r/a Very Complex Very Complex Very Complex	XXX XXX n/a XXX XXX
P E Insor Sy C M T	Pyrotechnics Batteries Power Harness/Cabling systems Gensors/Detectors Charge Coupled Device Detectors Magnotometer	Complexity Chemistry Complexity Complexity Complexity	Simple Non-rechargable Nost Visible, Si-based CCDs Simple/Standard	Multi-Junction Standard NiCd or NiH n/o Adv Vis, Most UV/IR (HgCdT) Advanced Standard	Multi- Junction and High Efficiency Advanced Li-ion n/o Complex Adv Multi-Spectral Very Advanced Customized/High Performance Customized/High	Low Intensity and Low Temperature or Advanced Very Advanced Advanced Chemistry r/o Very Complex Very Complex XX Advanced	XX XX n/o XX XX XX XX
P B Insor Sy S C M T E	Pyrotechnics Batteries Overer Jimeser/Cabling Genory/Detectors Genory/Detectors Genory/Detectors Genory/Detectors Magnetometer Time of Flight Spectrometer Electro-Static Analyzer Sensor	Complexity Chemistry Complexity Complexity Complexity Complexity Complexity	Simple Non-rechargable N/S Simple Most Visible, Si-based CCDs Simple/Standard Simple Simple	Multi-Junction Standard NiCd or NiH <i>n/o</i> Nominal Adv Vis, Most UV/IR (HgCdTe) Advanced Standard Standard	Multi-Junction and High Efficiency Advanced Li-ion n/o Complex Adv Multi-Spectral Very Advanced Customized/High Performance Customized/High	Low Intensity and Low Temperature or Advanced Very Advanced Advenced Chemistry <i>r/o</i> Very Complex Very Complex XX Advanced Advanced	XX XX n/o XX XX XX XX
P B Insor Sy S C M T E	Protechnics Solaries Server Vances (Zobling Sensory Detectors Charge Coupled Device Detectors Charge Coupled Device Detectors Magnetometer Time Of Flight Spectrometer	Complexity Chemistry Complexity Complexity Complexity Complexity	Simple Non-rechargable r/a Most Visible, Si-based CCDs Simple/Standard Simple	Multi-Junction Standard NiCd or NiH n/o Adv Vis, Most UV/IR (HgCdT) Advanced Standard	Multi-Junction and High Efficiency Advanced Li-ion r/o Complex Adv Multi-Spectral Very Advanced Customized/High Performance Customized/High	Low Intensity and Low Temperature or Advanced Very Advanced Advanced Chemistry r/o Very Complex Very Complex XX Advanced	XX XX n/o XX XX XX XX
P B P nsor Sy S C M T E	Pyrotechnics Batteries Overer Jimeser/Cabling Genory/Detectors Genory/Detectors Genory/Detectors Genory/Detectors Magnetometer Time of Flight Spectrometer Electro-Static Analyzer Sensor	Complexity Chemistry Complexity Complexity Complexity Complexity Complexity	Simple Non-rechargable N/S Simple Most Visible, Si-based CCDs Simple/Standard Simple Simple	Multi-Junction Standard NiCd or NiH <i>n/o</i> Nominal Adv Vis, Most UV/IR (HgCdTe) Advanced Standard Standard	Multi-Junction and High Efficiency Advanced Li-ion n/o Complex Adv Multi-Spectral Very Advanced Customized/High Performance Customized/High	Low Intensity and Low Temperature or Advanced Very Advanced Advenced Chemistry <i>r/o</i> Very Complex Very Complex XX Advanced Advanced	xx xx n/o xx xx xx xx xx xx
P B P nsor Sy S C M T E F	Pyrotechnics Batteries Overer Jimeser/Cabling Genory/Detectors Genory/Detectors Genory/Detectors Genory/Detectors Magnetometer Time of Flight Spectrometer Electro-Static Analyzer Sensor	Complexity Chemistry Complexity Complexity Complexity Complexity Complexity Complexity	Simple Non-rechargable rechargable Simple Most Visible, Si-based CCDs Simple/Standard Simple Simple	Multi-Junction Standard NiCd or NiH <i>n/o</i> Nominal Adv Vis, Most UV/IR (HgCdTe) Advanced Standard Standard	Multi-Junction and High Efficiency Advanced Li-ion r/o Complex Adv Multi-Spectral Very Advanced Customized/High Performance Customized/High	Low Intensity and Low Temperature or Advanced Very Advanced Advenced Chemistry <i>r/o</i> Very Complex Very Complex XX Advanced Advanced	xx xx n/o xx xx xx xx xx xx
P B P nsor Sy S C M T E F	Pyrotechnics Batteries Dever Fanness/Cabling Dever Fanness/Cabling Deverse/Deverse Deverse/Deverse Deverse/Deverse Charge Coupled Device Detectors Magnetometer Time Of Flight Sportometer Electro-Static Analyzer Sensor Photodiode	Complexity Chemistry Complexity Complexity Complexity Complexity Complexity	Simple Non-rechargable N/S Simple Most Visible, Si-based CCDs Simple/Standard Simple Simple	Multi-Junction Standard NiCd or NiH Adv Vis, Most UV/IR (HgCdTe) Advanced Standard Standard Standard	Multi-Lunction and High Efficiency Advanced Li-Jon r//o Complex Adv Multi-Spectral Very Advanced Customized/High Performance Customized/High Performance Customized/High	Low intensity and Low Temperature or Advanced Very Advanced Advanced Chemistry //© Very Complex Very Complex XX Advanced Advanced Advanced	xx xx n/a xx xx xx xx xx xx xx xx
S P P nsor Sy C C M T E P P E E E E E E E E E E E E E E E E	Pyrotechnics Batteries Dever Fanness/Cabling Events Protection Charge Coupled Device Detectors Charge Coupled Device Detectors Charge Coupled Device Detectors Charge Coupled Device Detectors Detectors Static Analyzer Sensor Photodiode Biolometer	Complexity Chemistry Complexity Complexity Complexity Complexity Complexity Complexity Complexity	Simple Non-rechargable r/d Simple Most Visible, Si-based CCDS Simple/Standard Simple Simple Simple Simple	Multi-Junction Standard NiCd or NiH Nominal Adv Vis, Most UV/IR (HgCTe) Advanced Standard Standard Standard Standard	Multi-Junction and High Efficiency Lison Complex Adv Multi-Speetral Very Advanced Customized/High Performac Customized/High Performac Customized/High Performac Customized/High Performac	Low Intensity and Low Temperature or Advanced Very Advanced Advanced Chemistry Very Complex Very Complex Very Complex Advanced Advanced Advanced Advanced	xx xx n/e xx xx xx xx xx xx xx xx xx xx
S P P P P P S S C C M T T E E P P E E E	Pyrotechnics Batteries Dever Fanness/Cabling Dever Fanness/Cabling Charge Coupled Device Detectors Magnetometer Time Of Flight Sportometer Electro-Static Analyzer Sensor Photodiode	Complexity Chemistry Complexity Complexity Complexity Complexity Complexity Complexity	Simple Non-rechargable rechargable Simple Most Visible, Si-based CCDs Simple/Standard Simple Simple	Multi-Junction Standard NiCd or NiH Adv Vis, Most UV/IR (HgCdTe) Advanced Standard Standard Standard	Multi-Junction and High Efficiency Livian Advanced Livian Complex Adv Multi-Spectral Very Advanced Customized/High Performance Customized/High Performance Customized/High	Low intensity and Low Temperature or Advanced Very Advanced Advanced Chemistry //© Very Complex Very Complex XX Advanced Advanced Advanced	xx xx n/a xx xx xx xx xx xx xx xx
S P B F P S S C C M T T T E E E E E	Pyrotechnics Batteries Dever Fanness/Cabling Events Protection Charge Coupled Device Detectors Charge Coupled Device Detectors Charge Coupled Device Detectors Charge Coupled Device Detectors Detectors Static Analyzer Sensor Photodiode Biolometer	Complexity Chemistry Complexity Complexity Complexity Complexity Complexity Complexity Complexity	Simple Non-rechargable r/d Simple Most Visible, Si-based CCDS Simple/Standard Simple Simple Simple Simple	Multi-Junction Standard NiCd or NiH Nominal Adv Vis, Most UV/IR (HgCTe) Advanced Standard Standard Standard Standard	Multi-Junction and High Efficiency Lison Complex Adv Multi-Speetral Very Advanced Customized/High Performac Customized/High Performac Customized/High Performac Customized/High Performac	Low Intensity and Low Temperature or Advanced Very Advanced Advanced Chemistry Very Complex Very Complex Very Complex Advanced Advanced Advanced Advanced	xx xx n/a xx xx xx xx xx xx xx xx xx xx
2 9 8 9 7 1 1 5 7 7 7 7 7 7 7 8 8 8 8	Pyrutechnics Batteries Batteries Dever Janesu/Cabling ennour)Detectors Angencometer Time of Flight Spactrometer Electro Static Analyzer Sensor Photodiode Bolometer Intodiode	Complexity Chemistry Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity	Simple Non-rechargable Ards Simple Simple/Standard Simple/Standard Simple Simple Simple Simple Simple Simple	Multi-Junction Standard Nicd or NiH Adv Vis, Most UV/IR (HgCato Standard Standard Standard Standard	Multi-Junction and High Efficiency Liven More Complex Adv Multi-Spectral Very Advanced Customized/High Performace Customized/High Performace Customized/High Performace Customized/High Performace Customized/High Performace Customized/High Performace Customized/High Performace Customized/High Performace Customized/High	Low Intensity and Low Temperature or Advanced Very Advanced Advanced Chemistry Net Very Complex Very Complex Very Complex Very Complex Advanced Advanced Advanced Advanced	xx xx n/a xx xx xx xx xx xx xx xx xx xx
2 9 8 9 7 1 1 5 7 7 7 7 7 7 7 8 8 8 8	Pyrotechnics Batteries Dever Fanness/Cabling Events Protection Charge Coupled Device Detectors Charge Coupled Device Detectors Charge Coupled Device Detectors Charge Coupled Device Detectors Detectors Static Analyzer Sensor Photodiode Biolometer	Complexity Chemistry Complexity Complexity Complexity Complexity Complexity Complexity Complexity	Simple Non-rechargable r/d Simple Most Visible, Si-based CCDS Simple/Standard Simple Simple Simple Simple	Multi-Junction Standard NiCd or NiH Nominal Adv Vis, Most UV/IR (HgCTe) Advanced Standard Standard Standard Standard	Multi-Junction and High Efficiency Lion of Complex Adv Multi-Spectral Very Advanced Customized/High Performance Customized/High Performance Customized/High Performance Customized/High Performance Customized/High	Low Intensity and Low Temperature or Advanced Very Advanced Advanced Chemistry Very Complex Very Complex Very Complex Advanced Advanced Advanced Advanced	xx xx n/e xx xx xx xx xx xx xx xx xx xx xx xx xx
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S P P P P P P P P S C C C C R F F F E E E F C C C C C C C C C C C C C	Pyrotechnics anterins extern stems stems binny/Detectors Gauge Coupled Device Detectors Magnotometer Time Of Flight Spectrometer Time Of Flight Spectrometer Biestro Static Analyzer Sensor Pilotdolog Biometer ton Source Gaunna Sensor	Complexity Chemistry Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity	Simple Non-rechargable Ards Simple Shabad CCDs Simple/Standard Simple Simple Simple Simple Simple Simple Simple Simple	Multi-Junction Standard Nicd or NiH Adv Vis, Most UV/JR (HigG16) Standard Standard Standard Standard Standard	Multi-Junction and High Efficiency Lion Advanced Lion Adv Multi-Spectral Very Advanced Coustonized/High Performance Custonized/High Performance Custonized/High Performance Custonized/High Performance Custonized/High Performance	Low Intensity and Low Temperature or Advanced Very Advanced Advanced Chemistry Net Very Complex Very Complex Very Complex Very Complex Very Complex Advanced Advanced Advanced Advanced Advanced	۵۲۲ ۵۲۲ ۵۲۲ ۵۲۲ ۵۲۲ ۵۲۲ ۵۲۲ ۵۲۲ ۵۲۲ ۵۲۲
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S B B B C C C C C C C C C C C C C C C C	Pyrotechnics Batteries Batteries Dever Fanesu/Cabling Charge Coupled Device Detectors Charge Coupled Device Detectors Sectors Static Analyzer Sensor Photodiode Biolometer Consore Gamma Sensor Neutron Sensor	Complexity Chemistry Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity	Simple Non-rechargabe Aria Simple Most Visible, Shased COS Simple/Standard Simple Simple Simple Simple Simple Simple	Multi-Junction Standard Nicio er Niti Advi Yus, Hoori UV/R Advorsed Standard Standard Standard Standard Standard Standard Standard Standard Advorsed	Multi-Junction and High Efficiency Liven Advanced Liven Adv Multi-Spectral Very Advissectal Very Advissectal Very Advissectal Very Advissectal Performace Customized/High Performance Customized/High Performance Customized/High Performance Customized/High Performance	Low Intensity and Low Temperature or Advanced Very Advanced Comment Very Complex Very Complex Very Complex Very Complex Advanced Advanced Advanced Advanced Advanced Advanced	۲۵۲ ۲۵۲ ۲۵۳ ۲۵۶ ۲۵۶ ۲۵۶ ۲۵۶ ۲۵۵ ۲۵۵ ۲۵۵ ۲۵۵ ۲۵۵ ۲۵۵
2 8 8 8 9 7 5 5 7 7 7 7 7 8 8 8 8 8 8 8 8 8 8 8 8	Protechnics Batteries Survey Parentecklang Charge Couled Device Detectors Magnetometer Timo of Flight Spectrometer Electro-Static Analyzer Sensor Photodode Bolometer Bolometer Could Sensor Could Sensor Neutron Sensor Duck Detector Neutron Sensor	Complexity Chemistry Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity	Simple Non-rechargable r/s Most Visible, S-based Simple/Standard Simple Simple Simple Simple Simple Simple Simple	Multi-Junction Standard Nicd or Niti- Nominal Advits, Most UV/IR Advanced Standard Standard Standard Standard Standard Standard Standard Standard	Multi-Junction and High Efficiency Lion Advanced Lion Adv Multi-Speetral Very Advanced Customized/High Performance Customized/High Performance Customized/High Performance Customized/High Performance Customized/High Performance Customized/High Performance Customized/High Performance Customized/High Performance Customized/High Performance Customized/High Performance	Low Intensity and Low Temperature or Advanced Very Advanced Communication Very Complex Very Complex Advanced Advanced Advanced Advanced Advanced Advanced Advanced	x0x x0x x0x x0x x0x x0x x0x x0x x0x x0x
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S P P P P P S C C C M T T F P R R R R R R R R R R R R R R R R R R	Protechnics Batteries Survey Parentecklang Charge Couled Device Detectors Magnetometer Timo of Flight Spectrometer Electro-Static Analyzer Sensor Photodode Bolometer Bolometer Could Sensor Could Sensor Neutron Sensor Duck Detector Neutron Sensor	Complexity Chemistry Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity	Simple Non-rechargabe Aria Simple Most Visible, Shased COS Simple/Standard Simple Simple Simple Simple Simple Simple	Multi-Junction Standard Nicio er Niti Advi Yus, Hoori UV/R Advorsed Standard Standard Standard Standard Standard Standard Standard Standard Advorsed	Multi-Junction and High Efficiency Liven Advanced Liven Adv Multi-Spectral Very Advissectal Very Advissectal Very Advissectal Very Advissectal Performace Customized/High Performance Customized/High Performance Customized/High Performance Customized/High Performance	Low Intensity and Low Temperature or Advanced Very Advanced Comment Very Complex Very Complex Very Complex Very Complex Advanced Advanced Advanced Advanced Advanced Advanced	۲۵۲ ۲۵۲ ۲۵۳ ۲۵۳ ۲۵۶ ۲۵۶ ۲۵۶ ۲۵۵ ۲۵۵ ۲۵۵ ۲۵۵ ۲۵۵ ۲۵۵
S P P E P P P S C C M T T E E P P C C C C C C C C C C C C C C C C	Protechnics atteries Over Fannes/Cabling Course Courses/Cabling Course Course Courses Course Course Courses Caused Courses Adapted Device Detectors Charge Courses Protocolode Biolometer Protocolode Biolometer Source Biolometer Courses Biolometer Courses Biolometer Courses Biolometer Courses Biolometer Courses Biolometer Data Detector Data Detector Biological Courses Biological Courses Biolo	Complexity Chemistry Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity	Simple Non-rechargate Aria Simple Most Visible, Si-based CCD Simple/Standard Simple Simple Simple Simple Simple Simple Simple	Multi-Junction Standard Niccle or Nith or Norminal Adv Vis, Moor (JV)/In Yidonneed Standard Standard Standard Standard Standard Advanced Standard	Multi-Lucción and High Efficiency Market Complex Complex Advanced Custonized/High Performance Custonized/High Performance Custonized/High Performance Custonized/High Performance Custonized/High Performance Custonized/High Performance Custonized/High Performance Custonized/High Performance Custonized/High Performance	Low Intensity and Gam Temperature or Advanced Way Advanced Way Complex Way Complex Way Complex Way Complex Way Complex Way Complex Way Complex Advanced Advanced Advanced Advanced Advanced Way Monced	xx xx n/a xx xx xx xx xx xx xx xx xx xx xx xx xx
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P P P P P P P S S C C M T T E E P P E E E E E E E E E E E S C C C C C C C C	Parotechnics Brotechnics Brower Farness/Cabling Drever Farness/Cabling Charge Coupled Device Detectors Charge Coupled Device Detectors Charge Coupled Device Detectors Biometer Photodiode Biometer Biometer Charge Coupled Device Detectors Biometer Charge Coupled Device Detectors Biometer Charge Coupled Device Detectors Biometer Charge Coupled Device Detectors Coupled Detector Charge Detector Charge Device Detectors Caser	Complexity Chemistry Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity	Simple Non-rechargate Area Simple Most Visible, St-based CCDs Simple/Standard Simple Simple Simple Simple Simple Simple Simple Simple Mode Atturnium	Multi-Junction Standard Niccl or Nith System AdvVis, Most UV/IR (HgCrtis) Standard Standard Standard Standard Standard Standard Standard Standard Standard	Multi-Junction and High Efficiency Complex Advanced Links Advanced Advanced Complex Advanced Contonical/high Performance Contonical/high Perfo	Low Intensity and Low Temperature or Advanced Very Advanced Advanced communi- Very Complex Very Complex Advanced Advanced Advanced Advanced Advanced Advanced Advanced Composite Very Advanced	XX N/a N/a XX XX XX XX XX XX XX XX XX X
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S P E Ennsor Syy S C C C E E E E E E E E E E E E E C	Aprilemins Batterins Stems Stems Stems Stems Stems Charge Coubing Charge Coubing Charge Coubing Charge Coubing Stems Time Of Flight Spectrometer Time Of Flight Spectrometer Stems Stem	Complexity Clemitary Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity	Simple Non-rechargele Simple Most Visible, Shaaed Simple Simple Simple Simple Simple Simple Simple Simple Simple Simple Simple Simple Automitian Simple	Multi-Junction Nicd or Nith Nicd or Nith Nicd or Nith Nick of Nith Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard	Multi-Junction and High Efficiency of the second second second second second second second second second second second second second Performance Catorinical/High Performance Catorinical/High Performance Catorinical/High Performance Catorinical/High Performance Catorinical/High Performance Catorinical/High Performance Second Secon	Low Intensity and Low Temperature or Advanced Very Advanced Advanced Cuentry Very Complex Very Complex Advanced Advanced Advanced Advanced Advanced Advanced Advanced Composite	
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S P P P P P S S C C C C C C C C C C C C	Pyrotechnics atteries	Complexity Clemitary Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity	Simple Non-rechargele Simple Most Visible, Shaaed Simple Simple Simple Simple Simple Simple Simple Simple Simple Simple Simple Simple Aluminum	Multi-Junction Nicd or Nith Nicd or Nith Nicd or Nith Nick of Nith Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard	Multi-Junction and High Efficiency of the second second second second second second second second second second second second second Performance Catorinical/High Performance Catorinical/High Performance Catorinical/High Performance Catorinical/High Performance Catorinical/High Performance Catorinical/High Performance Second Secon	Low Intensity and Low Temperature or Advanced Very Advanced Advanced Cuentry Very Complex Very Complex Advanced Advanced Advanced Advanced Advanced Advanced Advanced Composite	
S P P P P P P P C C C C C C C C C C C C	Pyrotechnics atteries	Complexity Clemitary Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity Complexity	Simple Non-rechargele Simple Most Visible, Shaaed Simple Simple Simple Simple Simple Simple Simple Simple Simple Simple Simple Simple Aluminum	Multi-Junction Nicd or Nith Nicd or Nith Nicd or Nith Nick of Nith Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard	Multi-Junction and High Efficiency of the second second second second second second second second second second second second second Performance Catorinical/High Performance Catorinical/High Performance Catorinical/High Performance Catorinical/High Performance Catorinical/High Performance Catorinical/High Performance Second Secon	Low Intensity and Low Temperature or Advanced Very Advanced Advanced Cuentry Very Complex Very Complex Advanced Advanced Advanced Advanced Advanced Advanced Advanced Composite	

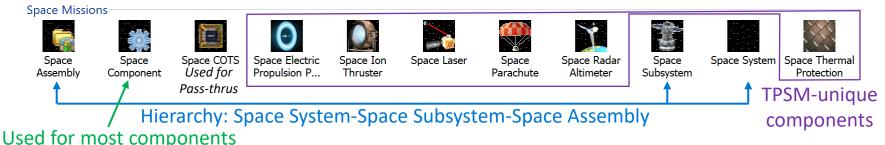


TPSM Component Type Input Matrix (Steps 1 & 2)

					Type		
Subsys	Component	Tech Parameter	1	2	3	4	5
Structu	e and Mechanisms						
	Primary Structure	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Secondary Structure	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Shielding	Material	Aluminum	Stainless Steel	Titanium	Other; High-Density	XX
	Solar Array Substrate/Structure	Material	Aluminum	Honeycomb	Titanium	Composite	XX
	High Gain Antenna Structure		n/a	n/a	n/a	n/a	n/a
	Electronics Boxes	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Mechanisms	Complexity	Simple	Standard	Advanced	Very Advanced	XX
	Motor-Actuator	Complexity	Simple	Standard	Advanced	Very Advanced	XX
	Booms	Complexity	Simple	Standard	Advanced	Very Advanced	XX
Therma	l Control						
	MLI, Paints, Coatings		n/a	n/a	n/a	n/a	n/a
	Heaters, RHUs, Thermostats	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Radiators/Louvers	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Heat Pipes	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Cryocooler	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
Propuls	ion						
	Propulsion - Lines/Valves/Fittings	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Pressure Regulator - Transducer	Complexity	Simple	Standard	Advanced	Very Advanced	XX
	Tanks	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Thrusters	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Ion Thruster	Specific Impulse	n/a	n/a	n/a	n/a	n/a
	Electric Propulsion Power Processing Unit	Maximum Power	n/a	n/a	n/a	n/a	n/a
Comma	nd and Data Handling						
	Command/Data Processing	Complexity	Simple, Non- Programmable	Most Microprocessors, RAD6000	RAD750, PPC	Advanced Devices	XX
	Solid State Memory	Complexity	xx	Simple Solid State	Nominal Space-based Solid State	Complex Solid State	Rad-Hard Comple
Commu	nications						
	Transponder	Frequency Band	UHF	S - band	X - band	Ka - band	Optical
	Transmitter	Frequency Band	UHF	S - band	X - band	Ka - band	Optical
	Amplifier	Frequency Band	TWTA	UHF, Simple	S/X - band SSPA	Ka - band SSPA	Advanced Device
	Miscellaneous RF Electronics	Frequency Band	UHF	S - band	X - band	Ka - band	Optical
	High Gain Antenna	Frequency Band	UHF	S - band	X - band	Ka - band	Optical

	Medium Gain Antenna/Low Gain Antenna	Frequency Band	UHF	S - band	X - band	Ka - band	Optical
	Waveguides - Comm Cabling	Frequency Band	UHF	S - band	X - band	Ka - band	Optical
Guidan	ce, Navigation and Control						
	Star Tracker	Complexity	Simple	Standard	Advanced	Very Advanced	XX
	Sun Sensor	Complexity	Simple	Standard	Advanced	Very Advanced	XX
	Reaction Wheel		n/a	n/a	n/a	n/a	n/a
	Torque Rod		n/a	n/a	n/a	n/a	n/a
	Gimbals	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	IMU-Gyro		n/a	n/a	n/a	n/a	n/a
	Actuators		n/a	n/a	n/a	n/a	n/a
Power							
	Power Management and Distribution	Complexity	Simple or Large-Scale	Nominal Space-based Device	Complex Device, Adv Switching or I&T	Very Complex Rad- Hard Device	XX
	Solar Cells/Electrical	Complexity	Silicon Solar Cells	Multi-Junction	Multi- Junction and High Efficiency	Low Intensity and Low Temperature or Advanced	xx
	Pyrotechnics	Complexity	Simple	Standard	Advanced	Very Advanced	XX
	Batteries	Chemistry	Non-rechargable	NiCd or NiH	Li-ion	Advanced Chemistry	XX
	Power Harness/Cabling		n/a	n/a	n/a	n/a	n/a
Sensor	Systems						
	Sensors/Detectors	Complexity	Simple	Nominal	Complex	Very Complex	XX
	Charge Coupled Device Detectors	Complexity	Most Visible, Si-based CCDs	Adv Vis, Most UV/IR (HgCdTe)	Adv Multi-Spectral	Very Complex	xx
	Magnetometer	Complexity	Simple/Standard	Advanced	Very Advanced	XX	XX
	Time Of Flight Spectrometer	Complexity	Simple	Standard	Customized/High Performance	Advanced	XX
	Electro-Static Analyzer Sensor	Complexity	Simple	Standard	Customized/High Performance	Advanced	xx
	Photodiode	Complexity	Simple	Standard	Customized/High Performance	Advanced	XX
	Bolometer	Complexity	Simple	Standard	Customized/High Performance	Advanced	XX
	Ion Source	Complexity	Simple	Standard	Customized/High Performance	Advanced	xx
	Gamma Sensor	Complexity	Simple	Standard	Customized/High Performance	Advanced	xx
	Neutron Sensor	Complexity	Simple	Standard	Customized/High Performance	Advanced	xx
	Dust Detector	Complexity	Simple/Standard	Advanced	Very Advanced	XX	XX
	Read Out Electronics	Complexity	Simple	Standard	Advanced	Very Advanced	XX
	Laser		n/a	n/a	n/a	n/a	n/a
Optics							
	Optical Bench	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Optics	Complexity	Simple	Standard	Advanced	Very Advanced	XX
	Gratings	Complexity	Simple	Standard	Advanced	Very Advanced	XX
	Filter Wheel	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Optic Filters/Miscellaneous	Complexity	Simple	Standard	Advanced	Very Advanced	XX
Robotic	Arm						
	Robotic Arm - Limb	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Robotic Arm - Joint-Actuator	Complexity	Simple	Standard	Advanced	Very Advanced	XX

TPSM Space Missions Objects



- These are the TPSM Objects
- Each Flight Element and Instrument is represented by a 'Space System" that is made up of 'Space Assemblies'
- 'Space Component' is used for most items
- 'Space COTS' can be used for pass-thrus
- There are 7 component types that have TPSM-unique estimates PPUs and Thrusters for Ion Propulsion, Lasers, Radar Altimeters, Parachutes (including mortar), and TPS; These items have inputs tailored to capture their associated cost drivers



TPSM Schedule Milestones (Step 3)

- Projects are organized into 4 phases:
 - DESIGN + FABRICATION + I&T + LAUNCH OPS
- 5 milestones are used to define these phases
 - Authority to Proceed (typically start of Phase B)
 - Critical Design Review (CDR); DESIGN = CDR ATP
 - Systems Integration Review (SIR); FABRICATION = SIR CDR
 - Pre-Ship Review (PSR); I&T = SIR PSR
 - On-orbit Checkout (OOCO); LAUNCH OPS = OOCO PSR
- Schedule inputs can be refined in TPSM
 - Typically, dates for Instrument & Subsystem (latest component) deliveries to System I&T are used in place of SIR



TPSM Project-Level Inputs (Step 4)

There are 7 Project-Level Inputs:

- Platform: Earth Orbiting (= Near Earth) or Planetary
- Parts Class: S, S1, B, B1, B2, D; These classifications relate to parts quality, where S/S1 are the highest quality parts, B/B1/B2 include COTS items with varying levels of qualification, and D covers purchases from Home Depot or Radio Shack
- International: Yes or No; If there is international contributions to any of the space flight elements, costs are added to the management, systems engineering, and mission assurance functions to capture associated complexities (this is added outside TPSM)
- Contracting Fees & Burdens: These have been stripped from the data used to develop TPSM and need to be added to the estimate (this is added outside TPSM)
- Number of Flight Units: The MEL should represent a single flight unit for each element, and multiple units is captured here
- Mission Class: A/B or C/D; This drives the percentages used for PM, SE, MA, MOS/GDS, & I&T

TPSM Output (Step D)

- High-level TPSM outputs are shown here along with their associated estimating methodology
- •TPSM Results using "Cost Object Costs by Activity" are used to populate WBS 5 & 6 costs; Output for individual Flight Elements and Instruments can be copied into Excel
- •TPSM results using "Resource Costs by Activity" are used to populate WBS 1/2/3/4/7/9/10

Mission	Name							
WBS	RY\$K	DES	FAB	I&T	LOCO	TOTAL		
1	PM					0		
2	SE			ated as "wra	•	0		
3	MA	driven	by the Missi (A/B o	on Risk Class ר כ (ח)	input	0		
4	SciTm		(7,00	10/0/	-	0		
5	Pyld	0	0	0	0	0		
	Instrument 1							
	Instrument 2							
	Instrument 3			Subsyste				
	Instrument 4	Estimated directly in factors used to TPSM (with applicable estimate Instrument- Project-level inputs) level costs during I&T						
	Instrument 5							
	Instrument 6	FIOJECTIE	verinputsj					
	Instrument 7			and L				
	Instrument 8							
	Instr PM/SE/MA	Portion of W	/BS 1/2/3 esti	mate can be r	moved here			
	Instr I&T/GSE	Portion of	WBS 10 estim	ate can be m	oved here			
6	S/C	0	0	0	0	0		
	Flight System 1			Subsyste	em-level			
	Flight System 2	Estimated	directly in	factors				
	Flight System 3	TPS <mark>M (</mark> with	n applicable	estimate In	strument-			
	Flight System 4	Project-le	vel inputs)	level costs	during I&T			
	Flight System 5	and LOCO						
	S/C PM/SE/MA	Portion of WBS 1/2/3 estimate can be moved here						
	S/C I&T/GSE	Portion of	WBS 10 estim	ate can be m	oved here			
7/9	MOS/GDS	These item	ns are estima	ated as "wra	p" factors	0		
10	I&T	driven	by the Missi	on Risk Class	input	0		
	TOTAL	0	0	0	0	0		



Case Study 1: LUVOT (Step 1)

			# OF UNIT	S	FLIGHT	HARDWAR	E MASSES	OTHER CO	MPONENT INFORMATION	TPSM COST	MODEL INPUTS			
Subsystem/Component	Unit Mass, Current Best Estimate (CBE)	Flight Units	Flight Spares	EMs & Proto- types	Total Mass, CBE		Total Mass w/ Contingency	r Description (Vendor, Part #, Heritage Basis)	Other characteristics/issues (volume, power, other component- specific items)	Heritage	New or Advanced Tech	Subsys	Comp	Туре
UVOT Telescope Optical Assembly					11.00	#####								
Primary mirror	1.25	4	0	1	5.00			Lightweighted design, Adv Mat'l	25cm diameter	Major Mod		Optics	Optics	3
Primary mirror mounts	0.50	4	0	1	2.00			Modified past design	Titanium	Minor Mod		Optics	Optical Bench	3
Secondary mirror	0.75	4	0	1	3.00			Lightweighted design, Adv Mat'l	12cm diameter	Major Mod		Optics	Optics	3
Secondary mirror mounts	0.25	4	0	1	1.00			Modified past design	Titanium	Minor Mod		Optics	Optical Bench	3
Detectors/Electronics					14.00	#####								
Detectors, CCDs	1.00	4	4	4	4.00			CCDMart Part # 2021		Сору		Sensor Systems	narge Coupled Device Detect	etc 2
Readout Electronics	1.00	4	1	1	4.00			Modified Past Design		Minor Mod		Sensor Systems	Read Out Electronics	2
Focal Plane Asembly Housing	1.50	4	1	1	6.00			······································	Aluminum	New	Stru	cture and Mechan	Electronics Boxes	1
Filter Wheel Assembly					20.00	#####								
Entrance filters assembly	0.50	4	1	1	2.00			Minor mod from past design		Minor Mod		Optics	Optic Filters/Miscellaneous	s 2
Filter wheel mechanism	0.75	4	1	1	3.00			Minor mod from past design		Minor Mod	Stru	ture and Mechan	Mechanisms	2
shutter	0.50	4	1	1	2.00			Minor mod from past design		Minor Mod		Optics	Optic Filters/Miscellaneous	s 2
baffles	0.50	4	1	1	2.00			Minor mod from past design		Minor Mod		Optics	Optic Filters/Miscellaneous	
secondary mirror	0.50	4	1	1	2.00			Minor mod from past design		Minor Mod		Optics	Optics	2
focus mechanism	0.25	4	1	1	1.00			Minor mod from past design		Minor Mod	Guidan	e. Navigation and	Actuators	1
image motion compensation actuators	2.00	4	1	1	8.00			Minor mod from past design		Minor Mod	Guidan	e, Navigation and	Actuators	1
Structure, Mechanical, & Thermal					37.10	-54%	17.00							
door Assembly	0.75	4	1	1	3.00			Minor mod from past design		Minor Mod	Stru	ture and Mechan	Mechanisms	2
door hinge assembly	0.50	4	1	1	2.00			Minor mod from past design		Minor Mod	Stru	cture and Mechan	Mechanisms	2
aperture selector	0.50	1	1	1	0.50			COTS part		Сору		Optics	Optic Filters/Miscellaneous	s 2
Telescope Tube	4.00	4	1	1	16.00			New design	Composite	New		Optics	Optical Bench	4
spider structure	0.75	4	1	1	3.00			Standard parts/processes, custom design		Major Mod	Stru	cture and Mechan	Mechanisms	2
heaters	0.40	4	1	1	1.60			Standard parts/processes, custom design		Major Mod		Thermal Control	Heaters, RHUs, Thermostat	ts 3
telescope harnessing	0.50	4	1	1	2.00			Standard parts/processes, custom design		Major Mod		Power	Power Harness/Cabling	1
kinematic mounts	0.75	12	3	3	9.00			Minor mod from past design	Aluminum	Minor Mod	Stru	cture and Mechan	Secondary Structure	1
UVOT Electronics Box					10.00	#####								
Control Electronics	0.50	1	0	1	0.50	0%	0.00	COTS part w/ custom software	Rad750-based	Minor Mod	Comr	nand and Data Ha	Command/Data Processing	1 3
Power Management	1.00	1	0	1	1.00	0%	0.00	Modified past design		Minor Mod		Power	ver Management and Distrib	ou 2
power switching card	1.00	1	0	1	1.00	0%	0.00	Modified past design		Minor Mod	Comr	nand and Data Ha	Command/Data Processing	2 2
PCI backplane	0.50	1	0	1	0.50	0%	0.00	COTS part		Сору	Comr	nand and Data Ha	Command/Data Processing	8 1
housing	7.00	1	0	1	7.00	0%	0.00		Aluminum	Minor Mod	Stru	cture and Mechan	Electronics Boxes	1
Harness					4.00	#####								
Harnessing	4.00	1	0	1	4.00			Custom harness, new design		New		Power	Power Harness/Cabling	1

Case Study 1: LUVOT (Step 2)

			# OF UNIT	s	FLIGHT	HARDWAR	E MASSES	OTHER COMPONE	NT INFORMATION	TPSM COST MODEL	INPUTS			
Subsystem/Component	Unit Mass, Current Best Estimate (CBE)	Flight Units	Flight Spares	EMs & Proto- types	Total Mass, CBE	Contingen	Total Mass w/ Contingency	Description (Vendor, Part #, Heritage Basis)	Other characteristics/issues (volume, power, other component-specific items)	Heritage	New or Advanced Tech	Subsys	Comp	Type
LUVOT Spacecraft					389.4	######								
Structure					130.0									
Primary Structure	90.0	1	0	0	90.0			Standard design	Aluminum	Minor Mod		Structure and Mechanisms	Primary Structure	1
Secondary Structure	25.0	1	0	Ő	25.0			Standard design	Aluminum	Minor Mod		Structure and Mechanisms	Secondary Structure	1
Gimbal	15.0	1	0	0	15.0			Modified from past program	, danman	Minor Mod		Structure and Mechanisms	Gimbals	1
Thermal	10.0				10.0			mouniou nom puot program					Simbalo	
Multi-Laver Insulation, Coatings	5.0	1	0	0	5.0			Standard materials, new design		New		Thermal Control	MLI, Paints, Coatings	1
Heaters, Thermistors	2.0	1	0	0	2.0			Standard materials, new design		New		Thermal Control	Heaters, RHUs, Thermostats	3
Radiator	3.0	1	0	0	3.0			Minor mod of past design	Composite	Minor Mod		Thermal Control	Radiators/Louvers	4
ACS	5.0	1	0	0	57.6			Willior mod or past design	Composite	WINDI WIDU		mermarcontrol	Radiators/Louvers	
Coarse Sun Sensor	0.0	10	0	4	0.1					Сору		Guidance, Navigation and Contr	Sun Sensor	2
Inertial Reference Unit	2.0	3	0	1	6.0			COTS part		Сору		Guidance, Navigation and Contr Guidance, Navigation and Contr		1
Magnetometer	0.5	2	0	4	1.0			COTS part		Сору		Sensor Systems	Magnetometer	1
Magnetic Torque Rod	1.5	3	0	1	4.5			COTS part		Сору		Guidance, Navigation and Contr		1
Star Tracker	5.0	2	0	1	10.0			Modified COTS part		Minor Mod		Guidance, Navigation and Contr Guidance, Navigation and Contr		2
Reaction wheels	9.0	2	0	1	36.0			Modified standard design		Minor Mod				2
Power	9.0	4	0		114.0			woomed standard design		WINOr Woo		Guidance, Navigation and Contr	Reaction wheel	1
Solar Array, Cells/Electrical	7.0	2	0	0	114.0				Link officiants, Markinsonian	Minor Mod		Power	Solar Cells/Electrical	3
	7.0	2	0	0	30.0			COTS cells, custom wiring	High efficiency, Multi-junction	Minor Mod		Structure and Mechanisms		3
Solar Array, Substrate/Structure	5.0	2	0	0				Modified past design	Composite	Minor Mod Minor Mod			Solar Array Substrate/Structure	4
Solar Array Drives		2	0	0	10.0			Modified past design				Guidance, Navigation and Contr		1
Battery	40.0	1	1	1	40.0			Standard cells w/ new configuration	Li-Ion, 80 Amp-hrs	Minor Mod		Power	Batteries 1	3
Power Distribution Unit	20.0	1	0	1	20.0			Modified past design		Minor Mod		Power	Power Management and Distribution	2
CDH					18.8							-		-
Backplane	1.0	1	0	1	1.0			COTS part	-	Сору		Command and Data Handling	Command/Data Processing 8	1
Single Board Computer	0.8	1	0	1	0.8			COTS part w/ custom software	Rad750-based	Minor Mod		Command and Data Handling	Command/Data Processing 1	3
UL/DL Board	0.5	1	0	1	0.5			Modified past design		Minor Mod		Command and Data Handling		2
Bus Control I/F Board	0.8	1	0	1	0.8			Modified past design		Minor Mod		Command and Data Handling		2
ACS Electronics Board	0.8	1	0	1	0.8			Modified past design		Minor Mod		Command and Data Handling	Command/Data Processing 4	2
Gimbal Drive Board	0.5	1	0	1	0.5			Modified past design		Minor Mod		Command and Data Handling		2
General Purpose Board	0.5	1	0	1	0.5			Modified past design		Minor Mod		Command and Data Handling		2
Power Control Unit	1.0	1	0	1	1.0			Modified past design		Minor Mod		Command and Data Handling		2
Solid State Recorder	5.0	1	0	1	5.0			COTS part		Сору		Command and Data Handling	Solid State Memory 1	3
Chassis	8.0	1	0	0	8.0			Modified past design		Minor Mod		Structure and Mechanisms	Electronics Boxes	1
Communications					29.0									
X-band Transponder	3.0	2	0	1	6.0			COTS part		Сору		Communications	Transponder 1	3
Solid State Power Amplifier	3.0	4	0	1	12.0			COTS part		Сору		Communications	Amplifier 1	3
Antennas	1.0	4	0	1	4.0			Modified past design		Minor Mod			1edium Gain Antenna/Low Gain Antenn	1 3
Misc RF Electronics	2.0	1	0	1	2.0			Standard design, modified COTS		Minor Mod		Communications	Miscellaneous RF Electronics	3
Waveguides/misc	5.0	1	0	1	5.0			Standard design, modified COTS		Minor Mod		Communications	Waveguides - Comm Cabling	3
Harness	30.0	1	0	0	30.0			Custom harness, modified design		Major Mod		Power	Power Harness/Cabling	1

Case Study 1: LUVOT (Steps 3 & 4)

				Deliver to	Ship to Launch		On-Orbit Chect-
	Phase B start	PDR ¹	CDR	System I&T	Site	Launch	Out (L+30d)
Project	1/2/2022	11/17/2022	10/2/2023	10/1/2024	4/2/2026	8/1/2026	8/31/2026
LUVOT Spacecraft	1/2/2022	11/17/2022	10/2/2023	10/1/2024	4/2/2026	8/1/2026	8/31/2026
UVOT Telescope Optical	1/2/2022	11/17/2022	10/2/2023	10/1/2024	4/2/2026	8/1/2026	8/31/2026
Detectors/Electronics	1/2/2022	11/17/2022	10/2/2023	10/1/2024	4/2/2026	8/1/2026	8/31/2026
Filter Wheel Assembly	1/2/2022	11/17/2022	10/2/2023	10/1/2024	4/2/2026	8/1/2026	8/31/2026
Structure, Mechanical, &	1/2/2022	11/17/2022	10/2/2023	10/1/2024	4/2/2026	8/1/2026	8/31/2026
UVOT Electronics Box	1/2/2022	11/17/2022	10/2/2023	10/1/2024	4/2/2026	8/1/2026	8/31/2026
Harness	1/2/2022	11/17/2022	10/2/2023	10/1/2024	4/2/2026	8/1/2026	8/31/2026

	Platform ("EO" or "P")		Internatio nal ("Y" or "N")	Contractin g Fee	Contract Monitor Burden	# of Flight Units	Notes	Mission Class
LUVOT Spacecraft	Р	В	Ν			1		Class C/D
UVOT Telescope Optical Assemb	Р	S1	N			1		Class C/D
Detectors/Electronics	Р	S1	Ν			1		
Filter Wheel Assembly	Р	S1	Ν			1		
Structure, Mechanical, & Therm	Р	S1	Ν			1		
UVOT Electronics Box	Р	S1	Ν			1		
Harness	Р	S1	Ν			1		



Case Study 1: LUVOT (Step D – Output)

Case S	tudy 1: LUVOT					
RY\$K		DES	FAB	1&T	LOCO	TOTAL
1	PM	2,303	11,131	1,210	266	14,910
2	SE	2,861	3,277	998	321	7,458
3	MA	1,960	3,517	2,084	442	8,003
4	SciTm	389	2,454	1,957	476	5,277
5	Pyld	14,814	19,357	6,179	1,151	41,501
	UVOT Telescope Assembly	1,374	1,509	407	108	3,398
	Detectors/Electronics	4,019	9,472	2,847	570	16,908
	Filter Wheel Assembly	1,968	4,329	757	114	7,168
	Structure, Mechanical, & Thermal	2,625	2,064	666	149	5,503
	UVOT Electronics Box	4,250	1,939	1,332	186	7,708
	Harness	579	45	170	23	817
	Instr PM/SE/MA					0
	Instr I&T/GSE					0
6	s/c	35,761	23,647	11,766	2,051	73,225
	LUVOT S/C	35,761	23,647	11,766	2,051	73,225
	S/C PM/SE/MA					0
	S/C I&T/GSE					0
7/9	MOS/GDS	490	2,959	3,080	631	7,160
10	I&T	3,566	7,008	7,936	674	19,184
	TOTAL	62,145	73,350	35,211	6,012	176,718



■ Case Study 1: LUVOT (TruePlanning Output)

	Cost objects an input sheet a Attin	outes 💷 Results 🖂 Cha	rt 🛄 Metrics	🗷 Schedule 🛛	Uncertainty A	Analysis	
	C:\Users\mkjac\OneDrive\Documents\T	SMruns\LUVOT.tpprj			ء 🛱 k	🗎 🍰 🦕 Re	source Costs by Activity
C:\Users\mkjaclOneDrive\Documents\TPSMruns\LUVOT.tpprj	Cost:		100.00% Labor P	Requirement:			653,843.53 h
- Spacecraft	Project Cost:			Labor Requirem	ent:		653,843.53 h
WBS 6 Spacecraft Subsystems				•	A	Laurah	
E LUVOT Spacecraft	C:\Users\mkjac\OneDrive\Documents\TF	SMruns\L			Integration	Operations	
Structures and Mochanisms	- [System Holder] Costs : C:/Users/mkja Currency in USD (Currency in USD (S) (c\OneDrive\Documents\TPS as spent)	SMruns\LUVOT.tp	pprj - [System Fo	ider]		
Structures and Mechanisms Assembly							
Primary Structure							
- Secondary Structure							
Gimbal							
Thermal Control		8,003,334					
Thermal Control Assembly	5 04. Science/Technology	5,276,775	389,438				
	9 10c. Ground Support	4,337,065	1,202,447	2,188,817	807,742	138,059	
			0				
				0			
	12 Assembly Integration and Test	17,945,485			17,945,485		
	13 Launch Operation	3,201,348				3,201,348	
	14 Design Engineering			402,057			
	15 Project Systems Engineer	408,206	408,206				
	16 Support Engineering	20,208,948	15,248,289	4,960,659			
	17 Test Engineering	7,627,066	1,557,797	6,069,268			
	18 Assembler	6,631,051	1,175,961	5,455,090			
	19 Material	11,744,439	2,755,919	8,988,520			
	20 Tooling and Test Engineering	8,730,142	589,950	8,140,192		_	
	21 Tooling and Test Material	1,345,445	401,168	944,278			
	22 Manufacturing Engineering	4,483,422		4,483,422			
	23 Fabricator	3,560,934		3,560,934			
	24 System Engineering	2,259,365	2,259,365				
	25 Contractor	0	0	0			
	26 Total	176,717,614	62,144,969	73,350,052	35,211,018	6,011,575	
Gimbal Drive Board							
	Spacecraft Spacecraft UUWS 6 Spacecraft Subsystems UUVOT Spacecraft UUVOT Spacecraft UUVOT Spacecraft UUVOT Structures and Mechanisms Primary Structure Primary Structure Primary Structure Secondary Structure Termal Control Thermal Control	Spaces Project Cost: Wilds 6 spaces Project Cost: Wilds 6 spaces Project Cost: Output Spaces Co	Spectral Project Cost: 9 T27 77 941 Image: Spectral biologistems: Cost: 9 T27 77 941 Image: Spectral biologistems: Cost: Cost: Cost: Image: Spectral biologistems: Cost: Cost: Cost: Cost: Image: Spectral biologistems: Cost: Cost: <td>Spectrot Project Cost 117177781 Project Cost VidS Spectrot VidS Spectrot</td> <td>Dispensition Project Chil: 11/0.7.17.4 Pages Lako Registration W18 Sepassent Babyame Visioname Set Construction Visioname Set Construction<td>□ ○ 100 1000000000000000000000000000000000000</td><td>□ 0: 197.77.4 10.00% List Page.set ■ V98.4 Space-set 0.4xystem 0: 197.77.4 10.00% List Page.set ■ V98.4 Space-set 0.4xystem 0: 100%</td></td>	Spectrot Project Cost 117177781 Project Cost VidS Spectrot VidS Spectrot	Dispensition Project Chil: 11/0.7.17.4 Pages Lako Registration W18 Sepassent Babyame Visioname Set Construction Visioname Set Construction <td>□ ○ 100 1000000000000000000000000000000000000</td> <td>□ 0: 197.77.4 10.00% List Page.set ■ V98.4 Space-set 0.4xystem 0: 197.77.4 10.00% List Page.set ■ V98.4 Space-set 0.4xystem 0: 100%</td>	□ ○ 100 1000000000000000000000000000000000000	□ 0: 197.77.4 10.00% List Page.set ■ V98.4 Space-set 0.4xystem 0: 197.77.4 10.00% List Page.set ■ V98.4 Space-set 0.4xystem 0: 100%

Case Study 2: Marscopter (Step 1)

			# OF UNIT	s	FLIGHT	HARDWARE	MASSES	OTHER COMPONENT INFORM	TION	TPSM COST	MODEL INPUTS			
Subsystem/Component	Unit Mass, Current Best Estimate (CBE)	Flight Units	Flight Spares	EMs & Proto- types	Total Mass, CBE		Total Mass w/ Contingency	Description (Vendor, Part #, Heritage Basis)	Other characteristics/issues (volume, power, other component-specific items)	Heritage	New or Advanced Tech	Subsys	Comp	Туре
Mapping Spectrometer	1/			41.00	70.50			. ,		Tieritage		canoyo	oomp	.,,,,,,
					70.50	*****								
Spectrometer Assembly														
Optical elements	5.00	1	0	1	5.00			Optics use advanced materials/coatings w/ heritage		Major Mod		Optics	Optics	3
Grating	2.00	1	0	1	2.00			Modified past design		Minor Mod		Optics	Optic Filters/Miscellaneous	
Filters	2.00	1	0	1	2.00			Modified past design		Minor Mod		Optics	Optic Filters/Miscellaneous	
Sensor, CCD	0.50	4	0	1	2.00			CCDMart Part # 1969		Сору		Sensor Systems	harge Coupled Device Detect	tc 3
Telescope Assembly														
Main Body	10.00	1	0	1	10.00			Custom design, heritage processes/materials	Composite	New		Optics	Optical Bench	4
Baffles	5.00	1	0	1	5.00			Modified past design		Minor Mod		Optics	Optic Filters/Miscellaneous	5 2
Primary Mirror	4.00	1	0	1	4.00			Modified past design		Minor Mod		Optics	Optics	3
Scan Mirror														
Scan Mirror Optics	2.00	1	0	1	2.00			Modified past design	Standard optics	Minor Mod		Optics	Optics	2
Scan Mirror Actuator	1.00	1	0	1	1.00			Modified past design		Minor Mod	Guidance	e, Navigation and		1
Telescope Secondary Structure	5.00	1	0	1	5.00			Custom designs, heritage processes/materials	Composite	New		ture and Mechan		4
Scan Platform	0.00		, i		0.00				poone		Siluc			1
Scan Platform Structure	5.00	1	0	1	5.00			Custom design, heritage processes/materials	Composite	New	Strue	ture and Mechan	Primary Structure	4
Scan Platform Motor	5.00	4	0	4	5.00			Modified past design	Composite	Minor Mod		ture and Mechan		
Scan Platform electronics	2.50	1	0	1	2.50			Modified past design	Standard microprocessor	Minor Mod			Command/Data Processing	1 2
Scan Platform cabling	1.00		0		1.00			Modified past design	Standard microprocessor	Minor Mod	Comm	Power	Power Harness/Cabling	1 4
	1.00		0		1.00			wodnied past design		Wilhor Wood		Power	Power Harness/Cabling	-
Thermal Control	1.00				1.00									
Multi-Layer Insulation/Coatings	4.00	1	0	1	4.00			Standard materials, new design		New		Thermal Control	MLI, Paints, Coatings	1
Radiator	2.00	1	0	1	2.00			Custom design, heritage processes/materials	Composite	New		Thermal Control	Radiators/Louvers	4
Temperature Sensors	1.00	1	0	1	1.00			Standard materials, new design		New		Thermal Control	Heaters, RHUs, Thermostat	ts 3
Command & Data Handling														
Read-Out Electronics	1.00	1	0	1	1.00			Modified COTS item with custom software		Major Mod		Sensor Systems		3
Solid-state Memory	1.00	1	0	1	1.00			COTS item		Сору		and and Data Ha		3
CDH Chassis	2.00	1	0	1	2.00			Modified past design	Aluminum	Minor Mod	Struc	ture and Mechan	 Electronics Boxes 	1
Power														
Power Supplies	2.00	1	0	1	2.00			Modified past design		Major Mod		Power	ver Management and Distrib	u 2
Power Management & Distribution	2.00	1	0	1	2.00			Modified past design		Major Mod		Power	ver Management and Distrib	u 2
Harnessing	4.00	1	0	1	4.00			Custom harness, new design		New		Power	Power Harness/Cabling	1
Visible Camera					7.90	#####								
Housing	4.00	1	0	1	4.00			Custom design, heritage processes/materials	Composite	New		Optics	Optical Bench	4
Primary Optic	2.00	1	ŏ	1	2.00			Modified past design	Composite	Minor Mod		Optics	Optical Denoti	2
Secondary Optics	0.50	1	0	1	0.50			Modified past design		Minor Mod		Optics	Optics	2
Detector, CCD	0.40	1	0	1	0.40			CCDMart Part # 1963		Copy			harge Coupled Device Detect	tc 2
Readout electronics	0.50	4	0	4	0.50					Minor Mod				10 2
Visible Camera Internal Harnessing	0.50	1	0	1	0.50			COTS item with custom programming Modified past design		Minor Mod		Sensor Systems Power	Power Harness/Cabling	2
Visible Camera Internal Harnessing	0.50	1	0	1	0.50			Modified past design		Minor Mod		Power	Power Harness/Cabling	1
Meteorological Suite					9.50	#####								
Sensors														
Temperature Sensor	0.50	2	0	1	1.00			Modified past design		Minor Mod		Sensor Systems	Sensors/Detectors	1
Wind Sensor	0.50	2	0	1	1.00			Modified past design		Minor Mod		Sensor Systems	Sensors/Detectors	1
Pressure Sensor	0.50	2	0	1	1.00			Modified past design		Minor Mod		Sensor Systems	Sensors/Detectors	1
Seismometer	0.50	2	0	1	1.00			Custom design with new technology		New	New	Sensor Systems	Sensors/Detectors	2
Electronics														
Readout Electronics	1.00	1	0	1	1.00			Modified past design		Minor Mod		Sensor Systems	Read Out Electronics	2
Power Conditioning	1.50	1	0	1	1.50			Modified past design		Minor Mod			ver Management and Distrib	u 2
Power			, v		1.00								Distribution	
Power Conditioning	2.00	1	0	1	2.00			Modified past design		Minor Mod		Power	ver Management and Distrib	
Harnessing	1.00	1	0	4	1.00			Custom harness, new design		New		Power	Power Harness/Cabling	4
namessing	1.00	1	0	1	1.00			Custom namess, new design		New		Power	Power marness/Cabling	1



Case Study 2: Marscopter (Step 2)

			# OF UNIT	8	FLIGHT H	ARDWARE	MASSES	OTHER COMPONENT INF	ORMATION	TPSM COST MODEL	NPUTS			
	Unit Mass, Current Best Estimate	Flight	Flight	EMs & Proto-	Total Mass,	Contingen	Total Mass		Other characteristics/issues (volume,		New or Advanced			
Subsystem/Component	Estimate (CBE)	Flight Units	Spares	types	CBE	cy %	Contingenc	y Description (Vendor, Part #, Heritage Basis)	power, other component-specific items)	Heritage	Tech	Subsys	Comp	Туре
Marscopter					515.20	#####						· · · · ·		
Structure/Mechanical														
Primary Structure							120.8							
Top Deck	4.00	1	0	0	4.0			Custom design, standard materials/processes	Composite	New		Structure and Mechanisms	Primary Structure	4
Bottom Deck	4.00	1	0	0	4.0			Custom design, standard materials/processes	Composite	New		Structure and Mechanisms	Primary Structure	4
Struts	3.00	6	0	0	18.0			Custom design, standard materials/processes	Composite	New		Structure and Mechanisms	Primary Structure	4
Landing Legs	3.00	3	0	0	9.0			Custom design, standard materials/processes	Composite	New		Structure and Mechanisms	Primary Structure	4
Secondary Structures														
Brackets/Mounts	18.00	1	0	0	18.0			Custom design, standard materials/processes	Composite	New		Structure and Mechanisms	Secondary Structure	4
Fasteners	6.00	1	0	0	6.0			Custom design, standard materials/processes	Titanium	New		Structure and Mechanisms	Secondary Structure	- 4
Mechanisms														
Landing Leg Lock	4.00	3	0	0	12.0			Custom design, standard materials/processes	Aluminum	New		Structure and Mechanisms	Mechanisms	1
Visible Camera Gimbal	6.00	1	0	0	6.0			Custom design, standard materials/processes	Aluminum	New		Structure and Mechanisms	Mechanisms	2
Mapping Spectrometer Cover	6.00	1	0	0	6.0			Custom design, standard materials/processes	Aluminum	New		Structure and Mechanisms	Mechanisms	1
Solar Array Deployment Device	3.00	2	0	0	6.0			Custom design, standard materials/processes	Aluminum	New		Structure and Mechanisms	Mechanisms	2
Thermal Control	10.00		0	0	10.0					Minor Mod		Thermal Control	MUL Driver Original	
Multi-Layer Insulation, Coatings, etc Heaters	3.00	1	0	0	3.0			Custom design, standard materials/processes		Minor Mod		Thermal Control Thermal Control	MLI, Paints, Coatings	1
Power	3.00	1	0	0	3.0			Custom design, standard materials/processes		Minor Mod		Thermal Control	Heaters, RHUs, Thermostats	3
Solar Arrays	-													
SA Cells/Electrical	20.83	2	0	0	41.7			COTS cells, custom wiring	High efficiency, Multi-junction	Minor Mod		Power	Solar Cells/Electrical	
SA Cells/Electrical SA Substrate/Mechanical	20.83	2	0							Minor Mod				3
SA Substrate/Mechanical Battery	200.00	2	0	0	20.8 200.0			Modified past design Standard cells w/ new configuration	Composite 400 Amp-hr Li-ion	Malor Mod		Structure and Mechanisms Power	Solar Array Substrate/Structure Batteries 1	-
Battery Power Supplies	200.00	1	0	1	200.0			Standard cells w/ new configuration Custom design, changes for HV operation	400 Amp-nr Li-Ion	Major Mod Major Mod	New	Power	Batteries 1 Power Management and Distribution	3
Power Supplies Power Management & Distribution	8.00		0	1	8.0			Custom design, changes for HV operation Custom design, changes for HV operation		Major Mod Major Mod	New	Power	Power Management and Distribution Power Management and Distribution	3
Power Management & Distribution High Voltage Box	8.00	1	U	1	8.0			Cusion design, changes for HV operation		Major Mod	new	Power	Power Management and Distribution	5
High Voltage Box HV Power Conversion System	9.00		0		9.0			Custom design, shappen for bill and the		New	New	Power	Deuter Management and Distance	
HV Power Conversion System HV Chassis/Frame		1	0	1	9.0			Custom design, changes for HV operation	Aluminum	Minor Mod	new	Structure and Mechanisms	Power Management and Distribution Electronics Boxes	5
HV Chassis/Frame Hamesses	7.00		0	1	7.0			Custom design, standard materials/processes	Auminum					1
Guidance, Navigation, & Control	30.00	1	U	U	30.0			Custom harness, modified design		Major Mod		Power	Power Harness/Cabling	1
Guidance, Navigation, & Control	5.00	2	0	4	10.0			Madified COTP and		Minor Mod		Cuidence Mexication or 10	INIL Core	
Inertial Measurement Unit Landing Altimeter	5.00	2	0	1	20.0			Modified COTS part Custom design, changes for unique application		Minor Mod		Guidance, Navigation and Contr Guidance, Navigation and Contr	IMU-Gyro Space Radar Altimeter	1
Command & Data Handling	10.00	2	1	1	20.0			Custom design, changes for unique application		New		Guidance, Navigation and Contr	Space Radar Altimeter	1
Command & Data Handling	0.50		0		0.5			0070	Rad750-based	Minor Mod	New	Command and Data Handling	Command/Data Processing 1	
RAD750 Single Board Computer Pavload Interface Card	0.50	1	0	1	0.5			COTS part w/ application-specific software Modified past design	Rad/50-based	Minor Mod	New	Command and Data Handling Command and Data Handling	Command/Data Processing 1 Command/Data Processing 2	3
Other Cards	0.50	1		4	2.0					Minor Mod		Command and Data Handling Command and Data Handling	Command/Data Processing 2 Command/Data Processing 3	2
Communications	0.50	4	0	4	2.0			Modified past designs		Minor Mod		Command and Data Handling	Command/Data Processing 3	2
	4.00	2	0					0070		Minor Mod		Communications.	Transmission	
X-band Deep Space Transponder Solid State Power Amplifier	3.00	2	0	1	8.0			COTS part COTS part		Minor Mod		Communications	Transponder 1 Amplifier 1	3
High Gain Antenna	3.00	6	U	1	6.0			COTS part		Minor Mod		Communications	Amplitier 1	3
HGA Dish	8.00		0		8.0			Modified past design		Minor Mod		Communications	High Gain Antenna	
HGA Dish HGA Support Structure	4.00	1	0	1	4.0			Modified past design	Composite	Minor Mod		Structure and Mechanisms	High Gain Antenna High Gain Antenna Structure	3
Low Gain Antennas	0.40	3	0	4	1.2			COTS part	Composite	Minor Mod			tedium Gain Antenna/Low Gain Antenn	
Misc RF Electronics	1.00		0	1	1.2			Modified design, standard materials/processes		Minor Mod		Communications	Miscellaneous RF Electronics	2
Waveguides	2.50		0		2.5			Modified design, standard materials/processes		Minor Mod		Communications	Waveguides - Comm Cabling	3
Helicopter	2.00		0		2.0			woulded design, standard materials/processes		MILLOT MOD		Communications	waveguides - Commicability	
Rotors	1.00		0	4	4.0			Custom lightweight design	Advanced composite	New	New	Structure and Mechanisms	Primary Structure	
Rotors Support Structure	0.50	4	0	1	2.0			Custom housings	Titanium	New	INCW	Structure and Mechanisms	Secondary Structure	2
Motor	4.00	4	1	1	16.0			Custom motor. New design	New technology	New	New	Structure and Mechanisms	Motor-Actuator	3
Motor Controller	4.00	4			10.0			Castom motor, New design	New technology	New	IVEW	Sudctore and Mechanisms	Woldr-Actuator	3
Motor Controller Electronics	2.00	1	0	1	2.0			Custom cards with heritage/modified devices	Rad750-based	Major Mod		Command and Data Handling	Command/Data Processing 1	2
Motor Controller Chassis/Box	1.00	1	ő	1	1.0			Coston carda wan nenagemounes dencea	Aluminum	Minor Mod		Structure and Mechanisms	Electronics Boxes	1
EDL					940.00	#####								
Structures & Mechanisms	450.05				450.5			Oralis d davas hardware davies	4 h	11.1.1.1.1.1		Observations and Marshar 1	0	
Mini Sky Crane Primary Structure	150.00	1	0	0	150.0			Scaled-down heritage design	Aluminum	Major Mod		Structure and Mechanisms	Secondary Structure	1
Mini Sky Crane Secondary Structure	50.00	1	0	0	50.0			Scaled-down heritage design	Aluminum	Major Mod		Structure and Mechanisms	Secondary Structure	1
Heatshield Structure Heatshield TPS	75.00	1	0	0	75.0			Scaled-down heritage design Scaled-down heritage design	Aluminum	Major Mod Minor Mod		Structure and Mechanisms Structure and Mechanisms	Secondary Structure	1
		1	0	0									TPS	1
Backshell Structure	50.00	1	0	0	50.0			Scaled-down heritage design	Aluminum	Major Mod		Structure and Mechanisms	Secondary Structure	1
Backshell TPS	150.00	1	0	0	150.0			Scaled-down heritage design		Minor Mod Major Mod		Structure and Mechanisms	TPS	1
Parachute (w/ mortar) Propulsion	75.00	1	1	1	75.0			Scaled-down heritage design		Major Mod		Structure and Mechanisms	Parachute	1
	2.00	12	0	0	24.0			Multiple landing thruster clusters, COTS		Came		Propulsion	Thrusters 1	
Thrusters Propellant Tanks	2.00	12	0	0	24.0			Multiple landing thruster clusters, COTS Multiple custom tanks (for balance)	Titanium	Copy		Propulsion	Thrusters 1 Tanks 1	3
Propulsion Lines/Valves/Filters	25.00	4	0	0	10.0			Multiple custom tanks (for balance) Modified design, standard materials/processes	i namulii	Major Mod		Propulsion	Propulsion - Lines/Valves/Fittings	3
Avionics	10.00	1	0	U	10.0			Modified design, standard materials/processes		Major Mod		Propulsion	Propulsion - Lines/Valves/Fittings	
Inertial Measurement Unit	5.00		0		5.0			Modified COTS device		Minor Mod		Guidance, Navigation and Contr	IMU-Gyro	
Single Board Computer	1.00	1	0	1	1.0			COTS part w/ custom software	Rad750-based	Minor Mod		Command and Data Handling	Command/Data Processing 1	2
	1.00				1.0			COTO part w custom software	Naur So-based	initial mod		Command and Data Handling	Command Data Processing 1	
Cruise Stage					170.60	#####								
Structures & Mechanisms														
Primary Structure	75.00	1	0	0	75.0			Scaled heritage design	Aluminum-honeycomb panels	Minor Mod		Structure and Mechanisms	Primary Structure	1
Secondary Structure	10.00	1	0	0	10.0			Scaled heritage design		Minor Mod		Structure and Mechanisms	Secondary Structure	1
Mechansims	15.00	1	0	0	15.0			COTS devices		Copy		Structure and Mechanisms	Mechanisms	1
Balance Mass	5.00	1	0	0	5.0				Aluminum	Minor Mod		Structure and Mechanisms	Secondary Structure	1
Thermal Control														
MLI, Coatings	8.00	1	0	0	8.0			Modified design, standard materials/processes		Major Mod		Thermal Control	MLI, Paints, Coatings	1
Temperature Sensors	0.20	10	0	0	2.0			Modified design, standard materials/processes		Major Mod		Thermal Control	Heaters, RHUs, Thermostats	3
Propulsion														
Fuel Tank	8.00	4	0	0	32.0			Mono-prop fuel tank	Titanium	Сору		Propulsion	Tanks 1	3
Trajectory Correction Maneuver thrusters	0.60	4	0	0	2.4			COTS items		Copy		Propulsion	Thrusters 1	3
Attitude Control System thrusters	0.40	8	0	0	3.2			COTS items		Сору		Propulsion	Thrusters 2	3
	3.00	1	0	0	3.0			Modified design, standard materials/processes		Major Mod		Propulsion	Propulsion - Lines/Valves/Fittings	3
Valves/Filters	0.25	2	0	0	0.5			Modified design, standard materials/processes		Major Mod		Propulsion	Pressure Regulator - Transducer	3
Pressure Transducer										Major Mod		Structure and Mechanisms		1
Pressure Transducer TCM Thruster Brackets	0.13	4	0	0	0.5			Modified design, standard materials/processes					Secondary Structure	
Pressure Transducer TCM Thruster Brackets ACS Thruster Brackets	0.13 0.25	4	0	Ō	2.0			Modified design, standard materials/processes		Major Mod		Structure and Mechanisms	Secondary Structure	1
Pressure Transducer TCM Thruster Brackets	0.13	4 8 1												1

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Case Study 2: Marscopter (Steps 3 & 4)

				Deliver to	Ship to Launch		On-Orbit Chect-
	Phase B start	PDR ¹	CDR	System I&T	Site	Launch	Out (L+30d)
Project	1/2/2022	4/3/2023	7/2/2024	1/1/2026	10/1/2027	1/31/2028	3/1/2028
Marscopter	1/2/2022	4/3/2023	5/17/2024	12/16/2025	10/1/2027	1/31/2028	3/1/2028
EDL	1/2/2022	4/3/2023	6/2/2024	12/16/2025	10/1/2027	1/31/2028	3/1/2028
Cruise Stage	1/2/2022	4/3/2023	5/2/2024	12/16/2025	10/1/2027	1/31/2028	3/1/2028
Mapping Spectrometer	1/2/2022	4/3/2023	4/2/2024	12/1/2025	10/1/2027	1/31/2028	3/1/2028
Visible Camera	1/2/2022	4/3/2023	4/2/2024	12/1/2025	10/1/2027	1/31/2028	3/1/2028
Meteorological Suite	1/2/2022	4/3/2023	4/2/2024	12/1/2025	10/1/2027	1/31/2028	3/1/2028

	Platform	(S,S1,B,B1,		Contractin		# of Flight		
	("EO" or "P")	B2,D)	"N")	g Fee	Burden	Units	Notes	Mission Class
Marscopter	Р	S1	Ν			1		Class A/B
EDL	P	S1	Ν			1		
Cruise Stage	Р	S1	Ν			1		
Mapping Spectrometer	Р	S1	N			1		Class A/B
Visible Camera	P	S1	Ν			1		
Meteorological Suite	Р	S1	Ν			1		

Case Study 2: Marscopter (Step D – Output)

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Case Stud	ly 2: Marscopter					
RY\$K		DES	FAB	1&T	LOCO	TOTAL
1	PM	26,759	79, <mark>0</mark> 69	9,171	1,827	116,826
2	SE	29,081	21,849	6,842	1,781	59,553
3	MA	22,773	24,982	15,793	3,045	66,593
4	SciTm	1,562	3,687	4,751	1,148	11,148
5	Pyld	49,627	23,362	15,000	2,776	90,765
	Mapping Spectrometer	26,208	13,226	7,625	1,380	48,439
	Visible Camera	5,609	2,702	1,617	333	10,261
	Meteorological Suite	17,810	7,434	5,759	1,063	32,066
	Instr PM/SE/MA					0
	Instr I&T/GSE					0
6	s/c	293,749	174,586	75,679	11,914	555,929
	Marscopter	134,510	76,193	44,849	8,037	263,589
	EDL	147,475	94,286	28,555	3,515	273,830
	Cruise Stage	11,764	4,107	2,276	363	18,510
	S/C PM/SE/MA					0
	S/C I&T/GSE					0
7/9	MOS/GDS	3,794	14,011	15,564	2,896	36,265
10	I&T	34,126	41,749	56,785	4,118	136,777
	TOTAL	461,470	383,295	199,586	29,506	1,073,857

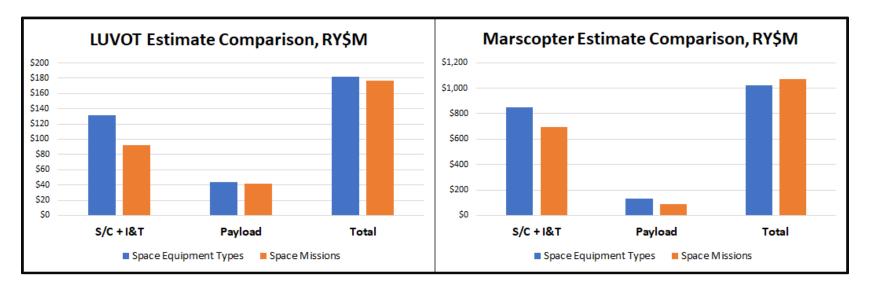
Case Study 2: Marscopter (TruePlanning Output)

uct Breakdown Structure	Results								
Detailed	Cost OL	ects 📝 Inp	out Sheet 🖪	Attributes	Results 🖂 C	hart 🔟 Metric	s 🗟 Schedule 🛛	Uncertainty Analysis	
8	C:\Users\m	C:\Users\mkjac\OneDrive\Documents\TPSMruns\Marscopter.tpprj					🔝 🙀 🖮 🍁 😭 Resource Costs by Activity		
C:\Users\mkjac\OneDrive\Documents\TPSMruns\Marscopter.tpprj	Cost:					100.00% Labor Requirement:		2,233,330.87	
Spacecraft	Project Cost			\$1,073,856,938		Project Labor Requirement:		2,233,330.87	
- 🔁 WBS 6 Spacecraft Subsystems	Phase Set:	A	Total	Work Design	sheet Set: Chi Fabrication	Assembly	• Launch		
- CONTER FLIGHT SYSTEM	ChUse		Total	Design	Paphcation	Integration	Operations		
Structures and Mechanisms	- (Sysi Folder					and Test			
E Structures and Mechanisms Assembly	Curret	i/ae					_		
Primary Structure	1 01. Pr	ject 11	6,826,333	26,758,974	79,069,326	9,170,579	1,827,453		
Secondary Structure	2 02a. N	ssio 1	3,477,414	8,315,954	2,853,667	1,449,560	858,233		
HGA Support Structure	3 026.	yste 4	6,075,939	20,764,859	18,995,814	5,392,534	922,733		
Solar Array Substrate/Structure	4 03. Se	ety & 6	6,592,915	22,773,160	24,981,935	15,792,523	3,045,297		
HV Electronics Chassis/Frame	5 04. S	ence 1	1,148,100	1,561,684	3,686,623	4,751,341	1,148,451		
Landing Leg Lock	6 07. Mi	sion 3	6,264,939	3,793,731	14,010,660	15,564,448	2,896,100		
Visible Camera Gimbal	7 10a.A	sem 1	4,044,600	5,285,661	5,693,461	2,657,578	407,900		
Mapping Spectrometer Cover	8 106.5	yste 9	8,339,622	19,527,556	25,689,904	50,045,918	3,076,244		
Solar Array Deployment Device	9 10c. C	ound 2	4,392,589	9,312,358	10,365,148	4,081,575	633,508		
Thermal Control	10 Design		0	0					
Thermal Control Assembly	11 Fabric	tion	0		0				
MLI, Paints, Coatings	12 Assen	oly In 9	0,679,782			90,679,782			
Heaters, RHUs, Thermostats	13 Launo	Ope 1	4,689,939				14,689,939		
Guidance, Navigation and Control	14 Desig	Engi 12	3,223,731	121,941,044	1,282,687				
GNC Assembly	15 Project	Syst	1,210,766	1,210,766					
Inertial Reference Unit	16 Suppo	t Eng 8	1,755,304	69,031,181	12,724,123				
Landing Radar Altimeter	17 Test E	gine 1	8,768,867	4,175,869	14,592,998				
Communications	18 Assen	bler 1	6,187,575	3,150,215	13,037,360				
Communications Assembly	19 Materi	1 2	6,324,975	6,819,865	19,505,110				
X-band Deep Space Transponder	20 Toolin	and 1	4,017,994	2,140,996	11,876,998				
X-band Power Amplifier	21 Toolin		2,001,475	1,328,923	672,553				
Miscellaneous RF Electronics	22 Manut		4,439,937		14,439,937				
High Gain Antenna	23 Fabric		8,552,349		8,552,349				
Low Gain Antennas	24 System		8,022,230	8,022,230					
Waveguides - Comm Cabling	24 System 25 Contra		0	0,022,230	0				
E T	25 CONT			125,555.046	0				
Command & Data Handling Assembly	20 NORM		1,264,513	120,000,040	101,264,513				
RAD750 Single Board Computer	27 Recur 28 Total			464 470 070		199,585,837	20 505 850		
Payload I/F Card	28 100	1,0	1/3,656, 4	401,470,072	363,295,169	199,565,837	29,505,860		
Other Cards									
Power	v								

Validation Study Results

TP Result Comparisons

• Result comparisons from the 2 different approaches are shown here:



Application Considerations

Space Missions (TPSM)

- Best for NASA Projects
 - Estimates by NASA Mission Class
 - Default outputs in NASA Std. WBS format
 - Specific cost objects for Electric Propulsion, Ion Thrusters, Lasers, Parachutes, Radar Altimeters and Thermal Protection

Space Hardware Equipment Types

- Best for DoD Service / Agency Space Missions, but very useful as a 'cross-check' for other estimating methods, including TruePlanning Space Missions
 - Flexible WBS outputs, including MIL-STD-881
 - Historical DoD Spacecraft Bus database

Q and A

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