

Model-based Cost Engineering Space Missions Estimating

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Agenda

- I. Case Study Overview (Two Case Studies)
- II. The PRICE Space Hardware Equipment Types and Resulting Cost Models
 - a. The PRICE Space Hardware Equipment Types
 - b. Cost Models / Results
- III. The Space Missions Catalog and Resulting Cost Models
 - a. The Space Missions Catalog
 - b. Cost Models / Results
- IV. Validation Study Results
 - a. Comparison of the Hardware Equipment Type and Space Missions Approaches / Results
 - b. Application Considerations
 - c. Validation Study Results (forthcoming)

Case Study Overview

Presented at the 2022 ICEAA Professional Developmen 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	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					200 4	1		Telescope Optical Assembly					The bar as		
ovor spacecrait			-		303.4		the second second second second	Primary mirror	1.3	4	0	1	5.0	Lightweighted design, Adv Mat'l	25cm diameter
Structure Drimony Chrystere	000		0	ó	00.0	Searcherd design	Aluminum	Primary mirror mounts	0.5	4	0	1	2.0	Modified past design	Titanium
Primary Structure	90.0		0	0	90.0	Standard design	Aluminum	Secondary mirror	0.8	4	0	1	3.0	Lightweighted design, Adv Mat'l	12cm diameter
Secondary Structure	25.0	1	0	0	25.0	Standard design	Adminum	Secondary mirror mounts	0.3	4	0	1	1.0	Modified past design	Titanium
Gimbal	15.0		0	0	15.0	Modified from past program		Detectors & Electronics					1.00		and the second s
Inermal				0		and the second second		Detectors CCDs	1.0	4	4	4	4.0	CCDMart Part # 2021	
Multi-Layer Insulation, Coatings	5.0	1	0	0	5.0	Standard materials, new design		Readout Electronics	1.0	4	1	1	4.0	Modified Past Design	
Heaters, Thermistors	2.0	1	0	0	2.0	Standard materials, new design	0	Focal Plane Asembly Housing	1.5	4	1	1	6.0	in second second	Aluminum
ACS	3.0	1	0	0	3.0	Minor mod of past design	Composite	Filter Wheel Assembly	1.0					in the second second	
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	20	3	0	1	60	COTS part		Filter wheel mechanism	0.8	4	1	1	3.0	Minor mod from past design	
Magnetometer	0.5	2	0	1	10	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	50	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	0.0	1.1			00.0			image motion compensation actuators	2.0	4	1	1	8.0	Minor mod from past design	
Solar Array Cells/Electrical	70	2	0	0	14.0	COTS cells, custom wiring	High efficiency, Multi-junction	Structure, Mechanical, Thermal		1.1.1					
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-Ion, 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	20.0				20.0	and a second second		Telescope Tabe	0.8	4	1	1	3.0	Standard parts/processes, custom	
Backplane	10	1	0	1	1.0	COTS part	1.	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	and the second se	heaters	1.1.1	1.1			1.1.1.1	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							20.40 Arr
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	0.0							PCI backplane	0.5	1	0	1	0.5	COTS part	
X-band Transponder	30	2	0	1	60	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 barness modified design									

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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

	Unit Mass, Current Best Estimate	Flight	Flight	EMs & Proto-	Total Mass w/ Total Contingen Contingen		Other characteristics/issues (volume, power, other component-specific	Subsystem/Component	Current Best Estimate (CBE)	Flight	Flight	EMs & Proto-	Total Mans, CBE	Total Mase wi Contingen Contingen	s Description (Vendor, Part 8, Heritage Basis)	characteristics/issues (volume, power, other component-specific items)
Subsystem/Component	(CBE)	Units	Spares	types	Mass, CBE cy % y	Description (Vendor, Part #, Heritage Basis)	items)	EDI Assembly	1000)		opares	- opes	940 0	44 1	outplot (terror, rate, renarge data)	incinity
TOTAL					2,228.9	the second se		Structures & Mechanisms					0.00.0		and the second se	
FLIGHT SYSTEM					1,625.8			Mini Sky Crane Primary Structure	150.0	1	0	0	150.0		Scaled down heritage design	Aluminum
Mars Helicopter/Lander					515.2			Hini Sky Grane Primary Subcidie	60.0	1		0	60.0		Scaled down nemage design	Ananan
Structure/Mechanical								Structure	50.0	1.8	0	0	30.0		Scaled-down heritage design	Aluminum
Primary Structure	35.0							Heatshield Structure	75.0	1	0	0	75.0		Scaled down heritage design	Aluminum
(interior) of the second	40	1.1			4.0	and the second se		Heatshield TPS	300.0	1	0	0	300.0		Scaled down heritage design	2000 million and
Top Deck	4.0		1.4		4.9	Custom design, standard materials/processes	Composite	Backshell Structure	50.0		0	0	50.0		Scaled drive heritage design	Aluminum
	1.00		0	0	1	Children and the state of the state of the state		Backshell TDC	160.0		0		160.0		Scaled down heritage design	Andiminant
Bottom Deck	4.0	1	0	0	4.0	Custom design, standard materials/processes	Composite	Barashida (ud modar)	75.0	1.4			75.0		Scaled down heritage design	
Struts	3.0	6	0	0	18.0	Custom design, standard materials/processes	Composite	Parachule (writtonar)	15.0			1	15.0		Scaled-uowin nemage design	
Landing Legs	3.0	3	0	0	9.0	Custom design, standard materials/processes	Composite	Propulsion			1.	1.1.2				
Secondary Structures	24.0				2.2			Infusters	2.0	12	0	0	24.0		Multiple landing thruster clusters, CO15	The second
Brackets/Mounts	18.0	1	0	0	18.0	Custom design, standard materials/processes	Composite	Propellant Lanks	25.0	2	0	0	50.0		Multiple custom tanks (for balance)	1 (tanium
Fasteners	6.0	1	0	0	6.0	Custom design, standard materials/processes	Titanium	Propulsion Lines/Valves/Filters	10.0	1	0	0	10.0		Modified design, standard materials/processes	
Mechanisms	30.0							Avionics			And a second		-		foreiter unseine en an	
Landing Leg Lock	4.0	3	0	0	12.0	Custom design, standard materials/processes	Aluminum	Inertial Measurement Unit	5.0	1	0	1	5.0	K	Modified COTS device	
Visible Camera Gimbal	6.0	1	0	0	6.0	Custom design, standard materials/processes	Aluminum	Single Board Computer	1.0	1	0	1	1.0	6	COTS part w/ custom software	Rad750-based
Manning Spectrometer Cover	60	1	0	0	6.0	Custom design standard materials/processes	Aluminum	the second se			1		1 start			
Solar Array Deployment Device	3.0	2	0	ů.	6.0	Custom design standard materials/processes	Aluminum	Cruise Stage					170.6			
Thermal Control	2.0				0.0	Content design, standard material aprovesses	- Subministra	Structures & Mechanisms	1.000						and the second se	
Multi-Lawer Insulation Coations	10.0	4	1.00		10.0			Primary Structure	75.0	1	1.1		75.0	1	Scaled heritage design	Aluminum-honeycon
ate	10.0	1		0	10.0	Custom design, standard materials/processes		Primary Subcrute	1.00		0	0	10.00		Scaled heritage design	panels
Heatere	3.0	1	0	0	30	Custom design standard materials/processes		Secondary Structure	10.0	1	0	0	10.0		Scaled heritage design	
Power	5.0	1.00			5.0	Coston design, standard materials processes		Mechansims	15.0	1	0	0	15.0	K	COTS devices	
Color Arrows	62.6					a state of the second se	and the second sec	Balance Mass	5.0	1	0	0	5.0	ř		Aluminum
CA Colle/Flootical	02.0				44.7	COTP and a sustain wide a	right eniciency, while-	Thermal Control			1.00				at the second se	
SA CensiElectrical	20.0	2	0	0	41.7	COTS cells, custom wining	innetion	MLI, Coatings	8.00	1	0	0	8.0	E .	Modified design, standard materials/processes	
SA Substrate/Mechanical	10.4	4	0	0	20.8	Modified past design	Composite	Temperature Sensors	0.20	10	0	0	2.0	ř.	Modified design, standard materials/processes	
Battery	200.0	1	1	1 1	200.0	Standard cells w new configuration	400 Amp-nr Li-ion	Propulsion	1.2.2.2.1						and a first of the second s	
Power Supplies	8,0	1	0	1	8.0	Custom design, changes for HV operation		Fuel Tank	8.00	4	0	0	32.0		Mono-prop fuel tank	Titanium
Power Management & Distribution	8.0	1	0	1	8.0	Custom design, changes for HV operation		TCM Thrusters	0.60	4	0	0	24		COTS items	
High Voltage Box	16.0	1.1	1.6.2		1.25	and the second second second second		ACS Thrusters	0.40	8	0	0	32		COTS items	
HV Power Conversion System	9.0	1	0	1	9.0	Custom design, changes for HV operation	A 100 100	Valves/Filters	3.00	1	0	0	3.0		Modified design, standard materials/processes	
HV Chassis/Frame	7.0	1	0	1	7.0	Custom design, standard materials/processes	Aluminum	Pressure Transducer	0.25	2	0	0	0.5		Modified design standard materials/processes	
Harnesses	30.0	1	0	0	30.0	Custom harness, modified design		TCM Thruster Brackete	0.13	4	0	, i	0.5		Modified design standard materials/processes	
Guidance, Navigation, & Control	1.6.4				100.2	and an and a second secon		ACS Thruster Brackets	0.25	8	0	0	20		Modified design, standard materials/processes	
Inertial Measurement Unit	5.0	2	0	1	10.0	Modified COTS part		Roo Infusiel Dischers	12.00	1	0		120		Modified design, standard materials processes	
Landing Altimeter	10.0	2	1	1	20.0	Custom design, changes for unique application		BLACKEDS THOPS FILLERDS FILL	1 12.00		U U		16.3		Interesting design, standard materials processes	
Command & Data Handling						A CONTRACTOR OF A CONTRACT OF A CONTRACT OF	A CONTRACTOR OF THE									
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																
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	80	1	0	4	80	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	12	COTS part	and the second									
Misc RE Electronics	10	1	0	1	10	Modified design standard materials/processes										
Wayanidas	25	1	0		25	Modified docing standard materials/monoscor										
Helisepter	2.0		0		2.5	incomes weather, arannairs materialary/ocesses										
Deter	10				10	Custom Settle sight design	Advision description									
Rolors	1.0		0	1 1	4.0	Custom tightweight desigh	Advanced composite									
Rotors Support Structure	0.5	4	0	1	2.0	Custom nousings	iitanium									
Motor	4.0	4	1	1	16.0	Custom motor, New design	New technology									
Motor Controllier	3.0		1.00			in the second	0.000									
Motor Controller Electronics	2.0	1	0	1	2.0	Custom cards with heritage/modified devices	Rad750-based									

Case Study 2: Marscopter Master Equipment List

Subsystem/Component	Current Best Estimate (CBE)	Flight	Flight	EMs & Proto- types	Total Con Mass.CBE c	Total Mass w/ tingen Contingenc	Description (Vendor, Part #, Heritage Basis)	characteristics/issues (volume, power, other component-specific items)
PAYLOAD					87.9			
Manalas Casadasastas					70.5			
Mapping Spectrometer					10.5			
Spectrometer Assembly			1	1.1.1			6 . F	
Optical elements	5.0	1	0	1	5.0		Optics use advanced materials/coatings w/ heritage	
Grating	2.0	1	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					10000		and the second se	and the second se
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								
Scan Mirror Optics	2.0	1	0	1	2.0		Modified past design	Standard optics
Scan Mirror Actuator	1.0	1	0	1	1.0		Modified past design	
Telescope Secondary Structure	5.0	1	0	1	5.0		Custom designs, heritage processes/materials	Composite
Scan Platform								
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	
	1				1			Standard
Scan Platform electronics	2.5	1	0	1	2.5		Modified past design	microprocessor
Scan Platform cabling	1.0	1	0	1	1.0		Modified past design	
Thermal Control								
Multi-Laver 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	0	1	1.0		Standard materials, new design	
Command & Data Handling							and a second	
Read-Out Electronics	1.0	1	0	1	1.0		Modified COTS item with custom software	
Solid.state Memory	10	1	0	1	10		COTS item	
CDH Chassis	2.0	1	0	4	2.0		Modified past design	Aluminum
Power	2.0	-			2.0		instanted blief geothin	Future
Downer Supplier	20		0		20		Modified part design	
Power Supplies	2.0	-	0	1	2.0		Modified past design	
Hampersing	4.0		0	1.4	4.0		Custom barness, new design	
Hamessing	4,0		0	1.1.1	7 70		Custom namess, new design	
visible camera					7.9			0
Housing	4.0	1	0	1	4.0		Custom design, nentage processes/materials	Composite
Primary Optic	2.0	1	0	1.	2.0		Modified past design	
Secondary Optics	0.5	1	0	1	0.5		Modified past design	
Detector, CCD	0.4	1	0	1	0.4		CCDMart Part # 1963	
Readout electronics	0.5	1	0	1	0.5		COTS item with custom programming	
Visible Camera Internal Harnessing	0.5	1	0	1	0.5		Modified past design	
Meteorological Suite					9.5			
Sensors								
Temperature Sensor	0.5	2	0	1	1.0		Modified past design	
Wind Sensor	0.5	2	0	1	1.0		Modified past design	
Pressure Sensor	0.5	2	0	1	10		Modified past design	
Colomometer	0.0	2	0	1	1.0		Custom design with new technology	
Seismometer	0.5	2	0	1	1.0		Cusion design with new rechnology	
Electronics			in the second		1.4		induite the transmission	
Readout Electronics	1.0	1	0	1	1.0		Modified past design	
Power Conditioning Power	1.5	1	0	1	1.5		Modified past design	
Power Conditioning	2.0	1	0	1	2.0		Modified past design	
Hamossing	10	1	0	1	10		Custom harness, new design	

The PRICE Space Hardware Equipment Types and Resulting Cost Models

Presented Dtata2Sourcesnal Development & Training Workshop: www.iceaaonline.com/pit2022

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, Liguid 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

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

Electrical Power

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 Productal Breakdown Structure aaonline.com/pit2022



- Missions PMO & ATIO
- System Object for Payload PMO
- Assembly Object at each Payload Summary for Integration
- Spacecraft Level
 - System Object for S/C PMO
 - Assembly Object for S/C I&T
 - Assembly Objects at each Subsystem Level for I&T
- Component Level
 - Hardware Objects

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Enhanced with Unmanned Space Mfg Complexities

	· 🖬 🖬 🖓 🖓	ABER	2011年 13		Spac	ecraft Bus Compon	ent Manufacturing Comple	xities	I flashe in a	Complexity	1
a designation of the	Broukelown Manufacture		Input Sheet: Star Tracker CT-				Larth Orbiting	Planetary	Electronics	Planatary	Percentage
Simple	Detailed		Star Tracker O	1 Attitude Control 2 Attitude Control 24 Attitude Control	Accelerometer ACS Control Electronics Earth Horizon Sensor	Dennico	9-25 7.96 8.16	9.78 8.42 8.63	10.29 10.56	10.09	100% 73% 35%
1 = 2 3	AIM Proposal	v9 FY\$15.	Cost ProjectCost Worksheet Set: Spor	28 Attitude Control 33 Attitude Control 39 Attitude Control 37 Attitude Control 45 Attitude Control 48 Attitude Control 48 Attitude Control 47 Attitude Control	GPS Receiver UNL//RV Magnetic Torquer Magnetometer Momentum/Reaction Wheel Nutation Damper/Despin Ass'y Rate Gyro		7,60 9,78 7,19 7,26 8,55 8,29 9,60	8.64 10.34 7.68 9.05 8.77 10.15	5.05	30.40	40% 100% 100% 100% 100% 100%
4 38 39	05 Al Carlo	M Payload System M Spacecraft Bus System isembly	1 Start Date	82 Attitude Control 88 Attitude Control 113 Attitude Control 124 Bus & Payload	Star Tracker Sun Senior Torque Colls Electronic Chassis/Housing	An electronic housing rectangular, made of with up to 6 bolt dow and possible some th	3.60 8.16 7.25 6 typically Aluminum, m fasteries filenees	10.20 8.51 7.67 6.35	20.55	11.18	100% 35% 100% 100%
40 41 42	e 😼	Attitude Control (ADC) Assembly RW RW Electric	2 O Quantity Per M 3 Additional Unit 4 O Number of Ad	127 Bus & Payload	Electronic Chassis/Housing (Simple / Mechanical part) Electronic Chassis/Housing (Sophisticated / Complex)	A simple electronic h typically made of alu no more than four sid down fasteniars An electronic housing advanced materials s	ousing, minum with 6.30 ses and 4 bolt 6.30 g made with 1 with as	6.87			600%
43 44	4 4	Torque Rods Mag	5 O Number of Ac 6 Cost Sharing U			titanium or composit sometimes with unur with more than four added stiffeners, or than 6 fasteners	ies, sual shape 8.00 sides, or with with more	8.00			100%
45	4	Star Tracker CT-633 Coarse Sun Sensor	7 Total Number of 8 Total Number of Pro	11 Electrical Power 12 Electrical Power 13 Electrical Power 14 Electrical Power 10 TPC B 1º TO GUCE G	Battery Battery Voltage Limiter Battery Voltage Pressure Monito	0.00	# 13 7.06 8.09	8.13 7.08 6.29 (948)	6.13 30.46 MIL	9.13 30.46	100% 70% 70%
4/	P.	LN-200S rate sensor	9 Technical Descrip	otion							
48	18 · 🌚	Power Assembly	10 Equipment Type			None 43					
57	E - 🔞	CDH Assembly	11 Operating Specificat	ion		2.00 🐖		100	1		
69	(E) 📷	Structure Assembly	12 • Weight of Structu	re		2.0617	kg 💌	19.0	M1		
72	10	Thermal Assembly	13 ¹ Weight of Electro	nics		0.0000	kg 🚾	10.0	M		
79	3 Q	COMM Assembly	14 Volume			1.945 🚛	1.	10-0			
			15 Manufacturing Comp	lexity for Structure		9.647 🚛		100	K		
			16 Percent of New Struc	ture		20% 🚛	%	100	M.		
			17 Percent of Design Re	epeat for Structure		0% 🚛	%	100	1		
			18 Manufacturing Comp	lexity for Electronics		0.000		146			
			19 0 Percent of New E	lectronics		20% 🚛	%	140	1		
			20 Percent of Design Re	apeat for Electronics		0% 🚛	%	100			
			21 Engineering Comple			0 200 000		100	1		

Presented Ecoppendie SyperCatculator. www.iceaaonline.com/pit2022

Completed Calculator Inputs

RICE TruePlanning 14.2 - [AIM Proposal v9 FY\$15*]			- D 2	3
Ele Edit View Reports Tools Window Help				×
Re-Red FORM 15 BES	1 # K @	Tables and Calculators		
Product Breakdown Structure	Input Sheet: Star Tracker CT-633			
Simple Detailed	Cost Objects 🖼 Input	Equipment Type		
	Star Tracker CT-(The Equipment Type describes typical equipments that	are commonly developed and produced.	
1 = AIM Proposal v9 FY\$15	Cost	When you select an Equipment Type from the available	values, values are automatically calculated for Operating Spe	sification. Total Weight, Weight of Structure
	Project Cost	research on equipment types. These values may be cha	anged by the user if their organizational specific database indi	cates better values.
	Worksheet Set: Space v4			Show Descriptions
4 OF AIM Davland System		Section Name	Input Field	De
		Operating Environment	Unmanned Space - Earth Orbiting 💌	
38 = 🕢 06 AIM Spacecraft Bus System		Function	Spacecraft Attitude Control	
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 the
42 RW Electric	4 0 Number of Additio			
43 Torque Rods	5 0 Number of Additio			
44 🎽 Mag	6 Cost Sharing Units			
45 Star Tracker CT-633	7 Total Number of Proc			
46 Coarse Sun Sensor	8 Total Number of Prote	•	m	
47 LN-200S rate sensor	9 Technical Descrip	Operating Specification	2.00	
48 🖲 🚱 Power Assembly	10 Equipment Type	Total Weight	2.062 kg	
57 CDH Assembly	11 Operating Specification	Weight of Structure	2.062 kg	
69 The Structure Assembly	11 Operating Specification	Weight of Electronics	0.000 kg	
72 Thermal Assembly	12 Weight of Structure	Volume	3.218	
Tz Thermal Assembly	13 Ueight of Electron	Manufacturing Complexity for Structure	9.647	
79 COMM Assembly	14 Volume	Manufacturing Complexity for Electronics	0.000	
Concernence of the second s	15 Manufacturing Compl	Percent of New Structure	20.00% %	
	16 Percent of New Struct	Engineering Complexity	20.00% %	
		Lighteening 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
RUCTURE & MECHANISMS	GUIDANCE, NAVIGATION, & CONTROL	ENTRY & DESCENT
Primary Structure	Star Tracker	Themal Protection System *
Secondary Structure	Sun Sensor	Parachute *
Shielding	Reaction Wheel	1
Solar Array Substrate/Structure	Torque Rod	DPTICS
HGA Structure	Gimbals	Optical Bench
Electronics Boxes	I IMU-Gyro	Optics
Mechanisms	Actuators	Gratings
Motor/Actuator	Radar Altimeter *	Filter Wheel
Booms	1 C	Optics Filters/Misc
2000	COMMUNICATIONS	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	I HGA	Magnetometer
MLI, Paints, Coatings	I MGA/LGA	1 TOF Spectrometer
Heaters, RHUs, Thermostats	Waveguide/Comm Cabling	ESA sensor
Radiators/Louvers		Photodiode
Heat Pipes	COMMAND & DATA HANDLING	Bolometer
Cryocooler	Command/Data Processing	I Ion Source
and the second	Solid State Memory	1 Gamma Sensor
ROPULSION		Neutron Sensor
Propulsion Lines/Valves/Fittings	POWER	Dust Detector
Pressure Regulator	Power Management and Distribution	Readout Electronics
Tanks	Solar Cells/Electrical	1
Thrusters	Pyrotechnics	î
	Batteries	Ĩ.
LECTRIC PROPULSION	1 Harness	ĩ
Ion Thruster *	1	Î.
Power Processing Unit *	1	1 * Modeled using custom TPSM relationships

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)

().etu	Workshop:	WWW	1ceaa	online	com/	p1f20	22
D	Himary Structure	Material	Aluminorit	Starreet Stee	Unamicien	Composite	XX
	Secondary Structure	Material	Aluminum	Stainless Steel	Titamum	Composite	AX.
	shelding	Macersol	Aluminum	Stamless Steel	Titanium	Other; High-Density	A.C.
	Solar Array Substrate/Structure	Material	Aluminum	Honeycomb	Titanium	Composite	xe
	High Gain Antenna Structure	Territory .				A	
	Electronics Bowes	Material	Aluminum	Stainess Steel	Tilanum	Composite	AN
	Mechanismo	Complexity	Simple	Scandard	Advanced	very Accariced	
	Motor-Actuator	complexity	Simple	scandard	Advanced	very novanced	
	Booms .	Complexity	Subs	Scandard	Advanced	very Advanced	AR
Therma	al Control						
	MU, Paints, Coatings	100 million 100 million	.00				1000
	Heaters, RHUs, Thermostats	Material	Aluminum	Stainless Steel	Titanium	Composite	AX
	RedutoryLouvers	Material	Autonum	Stanwess steel	Internum	Composite	
	Heat Pipes	Material	Aluminum	Stansess Steel	titanium	Composite	AX.
	Cryecoster	Material	Auminum	Stamess Steel	Tritemum	Composite	AK .
Propula	sion						
	Propulsion - Lines/Valves/Fittings	Material	Aluminum	Stainless Steel	Titanium	Composite	**
	Pressure Regulator - Transducer	Complexity	Simple	Standard	Advanced	Very Advanced	AX
	Tanks	Material	Auminum	Stainless Steel	Titanium	Composite	XX
	Thrusters	Material	Auminum	Stainless Steel	Titanium	Composite	XX
	Ion Thruster	Specific Impulse	0.000				
	Electric Propulsion Power Processing Unit	Maximum Power	100				
Commi	and and Data Handling	1.000	and the second sec				
	Command/Data Processing	Complexity	Simple, Non- Programmable	Most Microprocessors, RAD6000	RAD750, PPC	Advanced Devices	XX
	Solid State Memory	Complexity		Simple Solid State	Nominal Space-based Solid State	Complex Solid State	Rad-Hard Complex
Comm	unications						
	Transponder	Frequency Rand	UHE	5 - band	X - band	Ka - band	Optical
	Transmitter	Frequency Band	UHH	5 - band	X - band	Ka - band	Optical
	Amplifier	Frequency Rand	TWTA	UHF, Simple	S/X - band SSPA	Ka - band SSPA	Advanced Device
	Miscellaneous RF Electronics	Frequency Road	UHF	5 - band	Xiband	Ka - band	Optical
	High Gain Antenna	Frequency Band	UH#	5 - band	X - bend	Ka - band	Optical
	Medium Gain Antenna/Low Gain Antenna	Frequency Band	UHP	5 - band	X - band	Ka - band	Optical
	Waveguides - Comm Cabling	Frequency Band	UHF	5 - band	X-band	Ka - band	Optical
Guidan	ce, Navigation and Control						
	Star Tracker	Complexity	Simple	Standard	Advanced	Very Advanced	AX
	Sun Sensor	Complexity	Simple	Standard	Advanced	Very Advanced	XXX
	Reaction Wheel		e				
	Torque Rod	 An annual sector 					
	Gimbals	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	IMU-Gyro		10				
	Actuators						
Power							
	Power Management and Distribution	Complexity	Simple or Large-Scale	Nominal Space-based	Complex Device, Adv	Very Complex Rad-	AX.
			Sector Sector	Device	Switching or IST	Hard Device	
	Solar Celli/flectrical	Complexity	Silicon Solar Cells	Multi-Junction	Multi-Junction and High Efficiency	Low Intensity and Low Temperature or	xx
			-	1000	10.00	Advanced	
	Pyrotechnics	Complexity	Simple	Standard	Advanced	Very Advanced	AX.
	Batteries	Chemistry	Non-rechargable	NICd or NIH	Li-ion	Advanced Chemistry	AK.
	Power harness/Cabling		1.0				
Sensor	Systems						
	Sensors/Decectors	Complexity	Simple	Nominal	Complex	Very Complex	AV.
	Charge Coupled Device Detectors	complexity	Most visible, sebased	ADV VIL, MOST UV/IN	Adv Multi-opectral	very complex	
	Adv	Constants	CLUS .	(Hguete)	March Barren C.	20	-
	magnetometer	comprexity	bimpre/Standard	Asyanced	very Advanced	AX	ALC: NO
	Time Of Hight Spectrometer	Complexity	Simple	Standard	Eustomized/High Ferformance	Advanced	
	Electro-Static Analyzer Sensor	Complexity	Simple	Standard	Customized/High Ferformance	Advanced	AX
	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 Reformance	Advanced	88
	Gamma Sensor	Complexity	Simple	Standard	Customized/High Performance	Advanced	**
	Neutron Sensor	Complexity	Simple	Standard	Customized/High	Advanced	xx
	Dust Detector	Complexity	SameRanded	Advanced	Very Advanced	17	
	Read Out Electronics	Complexity	Cracia	Grandarid	Advanced	Very Advanced	
	These out Decembers	compressly	ampre	Standard	Advances	sery resarced	
Detics	Contract of the second s		1910				
where	Outland Barets	Advanced	thermore	description Stand	Thursday	Committee	-
	Challes -	-anare/sal	finite.	(traded	Advaced	View Advanced	
	Graties	Compressity	Simple	Standard	Advanced	Very Advanced	
	Elfar Mhard	Material	All uninum	Steleloss Stori	Titleium	Composite	
	Ontir Elbara Miscellaneour	Complexity	Carola	Standard	Advanted	Man Advance	
Babari	A A see	Complexity	2 mpsi	standard	Asvances	very novanced	**
musices:	Patrici dana Limita	Manager	Al entaine	Etablicare Eta	Tituchist	Compatible	-
	managers comit - Limits	and ends	Polar Service III	JARLANDS SCORE	* Carriers	Composite	

TPSMathonponent*ional Development & Training Workshop: www.iceaaonline.com/pit2022 Type Input Matrix (Steps 1 & 2)

					Type		
Subsys	Component	Tech Parameter	1	2	3	4	5
Structur	e and Mechanisms		100 C	and the second second	and the second	and the second second	
	Primary Structure	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Secondary Structure	Material	Aluminum	Stainless Steel	Titanlum	Composite	XX
	Shielding	Material	Aluminum	Stainless Steel	Titanium	Other; High-Density	XX
	Solar Array Substrate/Structure	Material	Aluminum	Honeycomb	Titanlum	Composite	XX
	High Gain Antenna Structure			11/0			
	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	Control						
	MLI, Paints, Coatings			-10/10	ale		
	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	lon						
	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					
	Electric Propulsion Power Processing Unit	Maximum Power				-1/10	
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 Complex
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 Bond	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
	Managaridan Campa Cabling	Company Rand	1195	C band	Y hand	Ki hand	Outlead
Guidan	waveguides - commicating	Prequency bunu	OHP	5 · Warru	A - Dania	Na - Danu	opucar
ousuan	Ce, Navigation and Control	Constants	Finals	freedowd	Advanta	Main Advanced	
1.1	star tracker	Complexity	Simple	Scandard	Advanced	very Advanced	-
1.1	Sun Sensor	Complexity	Simple	Standard	Advanced	very Advanced	AA.
1.000	Reaction Wheel		-040			10/11	
	Torque Rod	and the second			-0.0		
	Gimbals	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	IMU-Gyro			100		n/m	100
	Actuators		104	100			
Power			1				
	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/Cabline						
Sensor	Sustems						
Jenno	Farran Matastar	Complatini	finale	Manual	Complan	Mana Consulari	-
1.11	Charge Coupled David Datasters	Complexity	Mast Maible El.bared	Adultin Ment In/AB	Adv Multi Screetical	Very Complex	
	charge coupled bevice betectors	complexity	CCDs	(HgCdTe)	How more spectral	very complex	
	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	××.
	Ion Source	Complexity	Simple	Standard	Customized/High Performance	Advanced	xx
	Gamma Sensor	Complexity	Simple	Standard	Customized/High Performance	Advanced	
	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	**
1997	lacer	compressiy	Sumpris			res production of the	Car.
Ontice	case						
Optics							100
1.2	Optical Bench	Material	Auminum	staimess steel	Titanium	Composite	XX
	optics	Complexity	Simple	Standard	Advanced	very Advanced	XX
1 14	Gratings	Complexity	Simple	Standard	Advanced	Very Advanced	XX
	Filter Wheel	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
1.1.1	Optic Filters/Miscellaneous	Complexity	Simple	Standard	Advanced	Very Advanced	XX
Roboti	c 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

WBS	RY\$K	DES	FAB	1&T	LOCO	TOTAL
1	PM					0
2	SE	These item	hu the Missi	ated as "wra	ip" factors	0
3	MA	unven	(A/B o	r C/D)	sinput	0
4	SciTm		(14			0
5	Pyld	0	0	0	0	0
	Instrument 1					
	Instrument 2				1.1.1	
	Instrument 3	1.000		Subsyst	em-level	
	Instrument 4	Estimated	directly in	factors	used to	
	Instrument 5	Project-le	vel inputs)	level costs	during 1&T	
	Instrument 6	rojectie	vermputsj	and I	OCO	
	Instrument 7			di		
	Instrument 8					
	Instr PM/SE/MA	Portion of W	/BS 1/2/3 esti	imate can be	moved here	
	Instr I&T/GSE	Portion of	WBS 10 estim	nate can be m	noved here	
6	s/c	0	0	0	0	0
	Flight System 1			Subsyste	em-level	
	Flight System 2	Estimated	directly in	factors	used to	
	Flight System 3	TPSM (with	n applicable	estimate In	nstrument-	
	Flight System 4	Project-le	vel inputs)	level costs	during I&T	
	Flight System 5			and I	LOCO	
	S/C PM/SE/MA	Portion of W	/BS 1/2/3 esti	imate can be	moved here	
	S/C I&T/GSE	Portion of	WBS 10 estim	nate can be m	noved here	
7/9	MOS/GDS	These item	ns are estima	ated as "wra	p" factors	0
10	1&T	driven	by the Missi	on Risk Class	s input	0
	TOTAL	0	0	0	0	0

Case Study 1: LUVOT (Step 1)

	and the second s		# OF UNIT	5	FLIGHT	HARDWARE	MASSES	OTHER CO	MPONENT INFORMATION	TPSM COS	T MODEL INPUTS			
Subsystem/Component	Unit Mass, Current Best Estimate (CBE)	Flight Units	Flight Spares	EMs & Proto- types	Total Mass, CBE	Contingen cy %	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		Copy	5	ensor Systems	arge Coupled Device Detec	etc 2
Readout Electronics	1.00	4	1	1	4.00			Modified Past Design		Minor Mod	5	ensor Systems	Read Out Electronics	z
Focal Plane Asembly Housing	1.50	4	1	1	6.00				Aluminum	New	Struct	ure 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/Miscellaneou	us 2
Filter wheel mechanism	0.75	4	1	1	3.00			Minor mod from past design		Minor Mod	Struct	are and Mechan	Mechanisms	2
shutter	0.50	4	1	1	2.00			Minor mod from past design		Minor Mod		Optics	Optic Filters/Miscellaneou	JS 2
baffles	0.50	4	1	1	2.00			Minor mod from past design		Minor Mod		Optics	Optic Filters/Miscellaneou	is 2
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	Guidance	Navigation and	Actuators	1
image motion compensation actuators	2.00	4	1	1	8.00			Minor mod from past design		Minor Mod	Guidance	, 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	Struct	ure and Mechan	Mechanisms	2
door hinge assembly	0.50	4	1	1	2.00			Minor mod from past design		Minor Mod	Struct	ure and Mechan	Mechanisms	2
aperture selector	0.50	1	1	1	0.50			COTS part		Сору		Optics	Optic Filters/Miscellaneou	JS 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	Struct	ure and Mechan	Mechanisms	2
heaters	0.40	4	1	1	1.60			Standard parts/processes, custom design		Major Mod	1	hermal Control	Heaters, RHUs, Thermosta	ats 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	Struct	ure 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	Comma	nd and Data Ha	Command/Data Processing	01 3
Power Management	1.00	1	0	1	1.00	0%	0.00	Modified past design	Contraction of the second s	Minor Mod	i e e contra	Power	ver Management and Distri	ibu z
power switching card	1.00	1	0	1	1.00	0%	0.00	Modified past design		Minor Mod	Comma	nd and Data Ha	Command/Data Processing	g 2 2
PCI backplane	0.50	1	0	1	0.50	0%	0.00	COTS part		Copy	Comma	nd and Data Ha	Command/Data Processing	08 1
housing	7.00	1	0	1	7.00	0%	0.00	(and a field	Aluminum	Minor Mod	Struct	ure and Mechan	Electronics Boxes	1
Harness					4.00	#####	1	1						-
Harnessing	4.00	1	0	1	4.00			Custom harness, new design		New		Power	Power Harness/Cabling	1

Case Study 1: LUVOT (Step 2)

	and the second		# OF UNIT:	s	FLIGHT	HARDWARE MASSES	OTHER COMPONE	INT INFORMATION	TPSM COST MODEL	INPUTS			
Subsystem/Component	Unit Mass, Current Best Estimate (CBE)	Flight	Flight Spares	EMs & Proto- types	Total Mass, CBE	Total Mass Contingen w/ cy % Contingency	Description (Vendor, Part #, Heritage Basis)	Other characteristics/issues (volume, power, other component-specific items)	Heritage	New or Advanced Tech	Subsys	Comp	Туре
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	0	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		Minor Mod		Structure and Mechanisms	Gimbals	1
Thermal					10.0		in a set of poor program.		and a start				-
Multi-Laver Insulation Coatings	5.0	1	0	0	5.0		Standard materials, new design		New		Thermal Control	MLL Paints Coatings	1
Heaters Thermistors	2.0	1	0	0	2.0		Standard materials, new design		New		Thermal Control	Heaters RHUs Thermostats	3
Radiator	30	1	0	0	30		Minor mod of past design	Composite	Minor Mod		Thermal Control	Radiators/Louvers	4
ACS				-	57.6		initial files of part of age.	- enipeenie	and a second second				
Coarse Sun Sensor	0.0	10	0	1	0.1				Copy	G	uidance Navigation and Contr	Sun Sensor	2
Inertial Reference Unit	2.0	3	0	1	6.0		COTS part		Copy	G	uidance, Navigation and Contro	IMU-Gyro	1
Magnetometer	0.5	2	0	1	1.0		COTS part		Conv		Sensor Systems	Magnetometer	1
Magnetic Torque Rod	1.5	3	0	1	4.5		COTS part		Copy	G	uidance Navigation and Contro	Torque Rod	1
Star Tracker	5.0	2	0	1	10.0		Modified COTS part		Minor Mod	G	uidance, Navigation and Contr	Star Tracker	2
Reaction wheels	9.0	4	0	1	36.0		Modified standard design		Minor Mod	G	uidance. Navigation and Control	Reaction Wheel	1
Power			-		114.0		a contraction of the second seco						
Solar Array, Cells/Electrical	7.0	2	0	0	14.0		COTS cells, custom wiring	High efficiency, Multi-junction	Minor Mod		Power	Solar Cells/Electrical	3
Solar Array, Substrate/Structure	15.0	2	0	0	30.0		Modified past design	Composite	Minor Mod		Structure and Mechanisms	Solar Array Substrate/Structure	4
Solar Array Drives	5.0	2	0	0	10.0		Modified past design		Minor Mod	G	uidance, Navigation and Contr	Actuators	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								1000
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	Command/Data Processing 2	2
Bus Control I/F Board	0.8	1	0	1	0.8		Modified past design		Minor Mod		Command and Data Handling	Command/Data Processing 3	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	Command/Data Processing 5	2
General Purpose Board	0.5	1	0	1	0.5		Modified past design		Minor Mod		Command and Data Handling	Command/Data Processing 6	2
Power Control Unit	1.0	1	0	1	1.0		Modified past design		Minor Mod		Command and Data Handling	Command/Data Processing 7	2
Solid State Recorder	5.0	1	0	1	5.0		COTS part		Copy		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		and the second sec						
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		Communications	ledium Gain Antenna/Low Gain Antenn	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

		Parts Class	Internatio		Contract			
	Platform	(S,S1,B,B1,	nal ("Y" or	Contractin	Monitor	# of Flight		
	("EO" or "P")	B2,D)	"N")	g Fee	Burden	Units	Notes	Mission Class
LUVOT Spacecraft	Р	В	Ν			1		Class C/D
UVOT Telescope Optical Assemb	Р	S1	Ν			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	Study 1: LUVOT					
RYSK	<	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				1.11	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	1.1.2.2.1				0
	S/C I&T/GSE					0
7/9	MOS/GDS	490	2,959	3,080	631	7,160
10	1&T	3,566	7,008	7,936	674	19,184
	TOTAL	62,145	73,350	35,211	6,012	176,718

Presented at the 2022 ICEAA Professional Development & Training Workshop: www.iceaaonline.com/pit2022 Case Study 1: LUVOT (TruePlanning Output)

uet Bewikdown Structure Defailed	Results	F Input Sheet F Attributes B Re	sult PlChart	EN Motrice E	R Schedule M	Uncertainty A	Analysic	
E Ø	· Cillbers (miller)	OneDrive Documents \ TPSMruns \ LU	VOT. toori				Resource	e Costs by Activity
1 C:Users/mkiaciOneOnive/Documents/TPSMruns/LUVOT top)	Cost	\$176,717.6	14 100	00% Labor R	equirement:	AND DES C		653,843.53 hou
2 - Speccraft	Project Cost.	\$176,717,6	14	Project	Labor Requirem	int		653,843.53 hou
3 🔅 🛅 WBS 6 Spacecraft Subsystems	Phase Sec.	A Workshee	et Set: Chicomo					
4 LUVOT Speceoraft	Costs : C:Users'mki	laciOneDrive/Documents\TPSMruns\L	Total	Design	Fabrication	Assembly	Launoh Operations	
5 Structures and Mechanisms	- (System Fo	kider] Costs : C:\Users'mkjaclOneDrive/D	ocuments TPSM	runs'LUVOT.tp	prj - [System Fol	der] d Test	1000	
6 E Structures and Mechanisms Assembly		Currency in USD (\$) (as spent)				_		
7 Primary Structure	1 01. Project N	Managemént	14,910,309	2,303,481	11,131,424	1,209,902	265,502	
8 Secondary Structure	2 02a. Mission	Analysis	2,150,299	1.073,788	602,611	286,867	187.033	
9 Gimbal	3 02b. System	n Engineering	5,307,246	1,787,492	2,674,241	711,453	134.000	
10 E Thermal Control	4 03. Safety &	Mission Assurance	8,003,334	1,960,372	3,516,971	2,083,555	442,437	
11 📄 💽 Thermal Control Assembly	5 04. Science	Technology	5,276,775	389,438	2,453,992	1,957,175	476.170	
12 MLI, Paints, Coatings	6 07 Mission 0	Operation System	7,159,842	489,851	2,958,643	3,080,197	631,141	
13 Heaters, RHUs, Thermostats	7 10a. Assemb	bly and integration Support	2,499,624	682,505	1,202,293	525,933	88,893	
14 Radiators/Louvers	8. 10b. System	n Test	12,347,262	1,680,982	3,616,639	6,602,709	446.933	
15 Guidance, Navigation and Control	9 10c. Ground	Support	4,337,065	1,202,447	2,188,817	807,742	138,059	
16 GNC Assembly	10 Design		0	0				
17 Star Tracker	11 Fabrication		0		0		_	
18 Sun Sensor	12. Assembly Int	tegration and Test	17,945,485			17,945,485		
19 Reaction Wheel	13 Launch Oper	ration	3,201,348				3,201,348	
20 Torque Rod	14 Design Engr	neering	26,580,006	25,177,949	402,057			
21 MU-Gyro	15 Project Syste	ems Engineer	408,206	408,206				
22 Magnetometer	16 Support Engl	ineering	20,208,948	15,248,289	4,950,659		_	
23 Communications	17 Test Enginee	ening	7,627,066	1.557,797	6,069,268			
24 Communications Assembly	18 Assembler		6,631,051	1,175,961	5,455,090			
25 X-Band Transponder	19 Material		11,744,439	2,755,919	8,988,520			
26 Solid State Power Amplifier	20. Tooling and	Test Engineering	8,730,142	589,950	8,140,192			
27 Miscellaneous RF Electronics	21 Tooling and	Test Material	1,345,445	401,168	944,278		_	
28 Medium Gain Antenna/Low Gain Antenna	22 Manufacturin	ng Engineering	4,483,422		4,483,422			
29 Waveguides - Comm Cabling	23 Fabricator		3,560,934		3,560,934			
30 Command & Data Handling	24 System Engl	ineering .	2,259,365	2,259,365				
31 Command & Data Handling Assembly	25 Contractor		0	0	0			
32 Single Board Computer	26 Total		176,717,614	62,144,969	73,350,052	35,211,018	6,011,575	
33 ULIDL Board			-					
34 Bus Control VF Board								
35 ALIS Electronics Board								
30 Gimbel Drive Board								

Case Study 2: Marscopter (Step 1)

	Sector 10.2		# OF UNIT	s	FLIGHT	HARDWAR	E MASSES	OTHER COMPONENT INFORM	ATION	TPSM COST	MODEL INPUTS			
Subsystem/Component	Current Best Estimate (CBE)	Flight	Flight	EMs & Proto-	Total Mass	Contingen	Total Mass w/	Description (Vendor, Part & Ventage Basis)	Other characteristics/issues (volume, power, other component-specific items)	Haritana	New or Advanced	Subsys	Comp	Type
Manning Spectrometer					70 50								A DOF	
Papetrameter Assembly					10.00			the second se						
opectrometer Assembly	5.00			1.1	6.00			Online was adverted an abula before the set had been				Outles	Cation	
Optical elements	5.00		0	1.1	5.00			Optics use advanced materials/coatings w/ heritage		major mod		Optics	Optics	100
Grading	2.00	1	0	1	2.00			Modified past design		Minor Mod		Optics	Optic Filters/Miscellaneou	6 4
Filters	2.00	1	0	1	2.00			Modified past design		Minor Med		Optics	Optic Filters/Miscellaneou	15 2
Sensor, CCD	0.50	4	0	1	2.00			CCDMart Part # 1969		Copy	Se	insor Systems	s sarge Coupled Device Deter	ctc 3
Telescope Assembly	1				1.1.1.1.			and a local provide the second states of		and the second second				
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/Miscellaneou	15 2
Primary Mirror	4.00	1	0	1	4.00			Modified past design		Minor Mod		Optics	Optics	3
Scan Mirror					1.1.1.1			The second s						
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,	Navigation an	d Actuators	1
Telescope Secondary Structure	5.00	1	0	1	5.00			Custom designs, heritage processes/materials	Composite	New	Structur	e and Mecha	n Secondary Structure	4
Scan Platform	1000									1.000				
Scan Platform Structure	5.00	1	0	1	5.00			Custom design heritage processes/materials	Composite	New	Structur	e and Mecha	n Primary Structure	4
Scan Platform Motor	5.00	1	0		5.00			Modified past design	o o inposito	Minor Mod	Structure	e and Mecha	n Motor-Actuator	2
Scan Platform electronica	2.50	1.1	o.		2.50			Modified past design	Standard microprocessor	Minor Mod	Comman	d and Data H	aCommand/Data Processing	.1 .2
Scan Platform cabling	1.00	1	0		1.00			Modified past design	Standard microprocessor	Minor Mod	Comman	Dawor	Power Harness/Cabling	10.2
Scan Flauorin cabling	1.00	1.4	0		1.00			mouniou past design		reactor most		Power	Power marriess Cabing	- 1
the fill and insulation Castings	4.00		0		4.00			Chandred materials new design		Alaria		ama Cantra	MIL Dainty Castings	
Multi-Layer insulation/Coatings	4,00	1.2	0	1.1	4.00			Standard materials, new design	Comparis	inew .	The	ermal Contro	MLI, Paints, Coatings	1.2
Radiator	2.00		0		2.00			Custom design, heritage processes/materials	Composite	New	10	ermai Contro	Radiators/Louvers	
Temperature Sensors	1.00	3	0		1.00			Standard materials, new design		New	10	ermai Contro	Heaters, RHUS, Thermosta	115 3
Command & Data Handling			1.12		1.1.1.1			and the state of the state that the		10000			and an arrest of the	
Read-Out Electronics	1.00	1	0	1	1.00			Modified COTS item with custom software		Major Mod	Se	insor Systems	s Read Out Electronics	3
Solid-state Memory	1.00	1	0	1	1.00			COTS item		Copy	Comman	d and Data H	a Solid State Memory 1	3
CDH Chassis	2.00	1	0	1	2.00			Modified past design	Aluminum	Minor Mod	Structur	e and Mecha	n Electronics Boxes	1
Power					10.00			Ale and a start share		and the second second				
Power Supplies	2.00	1	0	1	2.00			Modified past design		Major Mod		Power	ver Management and Distril	bu 2
Power Management & Distribution	2.00	1	0	1	2.00			Modified past design		Major Mod		Power	ver Management and Distril	bu 2
Harnessing	4.00	1	0	1	4.00			Custom harness, new design		New		Power	Power Harness/Cabling	1
Visible Camera					7.90	######		a contract of the second second second						
Housing	4.00	1	0	1	4.00			Custom design, heritage processes/materials	Composite	New		Optics	Optical Bench	4
Primary Optic	2.00	1	0	1	2.00			Modified past design		Minor Mod		Optics	Optics	2
Secondary Ontics	0.50	1	0	1	0.50			Modified past design		Minor Mod		Ontics	Ontics	2
Detector, CCD	0.40	1	0	1	0.40			CCDMart Part # 1963		Copy	Se	nsor System	sharpe Coupled Device Deter	etc 2
Readout electropics	0.50	1	0	1	0.50			COTS item with custom programming		Minor Mod	Se	nsor System	Read Out Electronics	2
Visible Camera Internal Hamessing	0.50	1	Ō	1	0.50			Modified past design		Minor Mod		Power	Power Harness/Cabling	1
Meteorological Suite	-		_	_	9.50	######								
Canadra					0.00	annan								
Sensors	0.50				1.00			Mode down down			0	and Parton	Concern Detectors	
Temperature Sensor	0.50	2	0	1.1	1.00			Modified past design		Minor Mod	50	nsor Systems	Sensors/Detectors	
wind Sensor	0.50	4	0	1	1.00			Modified past design		Minor Mod	50	insor Systems	s Sensors/Detectors	
Pressure Sensor	0.50	2	0	1	1.00			Modified past design		Minor Mod	Se	insor Systems	s Sensors/Detectors	
Seismometer	0.50	2	0		1.00			Custom design with new technology		New	New Se	insor Systems	s Sensors/Detectors	2
Electronics			1.1		1.00			and a second second		Sec. 2010.				100
Readout Electronics	1.00	1.2	0	1	1.00			Modified past design		Minor Mod	Se	insor Systems	Read Out Electronics	2
Power Conditioning	1.50	1	0	1	1.50			Modified past design		Minor Mod		Power	ver Management and Distril	bu 2
Power	2.672				1.00			N.S. Sauchar		and the second				
Power Conditioning	2.00	1	0	1	2.00			Modified past design		Minor Mod		Power	ver Management and Distril	bu z
Harnessing	1.00	1	0	1	1.00			Custom harness, new design		New		Power	Power Harness/Cabling	1
rianiesofig	1.00		0		1.00			Custom namess, new design		New		Power	eower marness/Cabling	

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Case Study 2: Marscopter (Step 2)

Marscepter 1 ct 1	ere pr				515.20 What	8 Wollionop		o aa o m		ere only pr		
Structure/Mechanical					desc 1	Contraction of the second s						
Primary Structure	10000				120.8	and a set of the set of the set of the set of the	Acres 61				and an and the second second second	
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
Struta	3.00	6	0	0	18.0	Custom design, standard materials/processes	Composite	New		Structure and Mechanisms	Primary Structure	
Landing Legs	3.00	3	0	0	9/0	Custom design, standard materials/processes	Composite	New		conucture and Mechanisms	Primary Structure	
Brockets Minutes	18.00				18.0	Custom dasian standard materials in-	Composite	New		Charles and Hack-sizes	Canondary Charthur	
Enthesis	6.00	1.2		0	60	Custom design, standard materials processes	Tracker	New		Structure and Machanisms	Secondary Structure	1.2
Herbert	0.00				0.0	Costom breigh, standard materialis processes	1 starsets	(ALL)		Saucrare and wecharterns	Secondary Structure	
Landing Lord	400	1.	0	.0	12.0	Custom design standard materials howeverses	Abarrant	New		Structure and Machanisma	Mortaniama	
Visible Camera Gimbal	8.00	1	0	ő	8.0	Custom design, standard materials processes	Aluminum	New		Structure and Mechanisms	Mechanisms	2
Nanning Snectrometer 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												
Multi-Layer Insulation, Coatings, etc.	10.00	1	0	0	10.0	Custom design, standard materials/processes		Minor Mod.		Thermal Control	MLI, Paints, Coatings	1
Heaters	3.00	1	0	0	3.0	Custom design, standard materials/processes		Minor Mod		Thermal Control	Heaters, RHUs, Thermostate	
Power						and the second						
Solar Arrays						and a state of the second	and an and the strength of					
SA Cells/Electrical	20.83	2	0	0	41.7	COTS cells, custom writing	High efficiency, Multi-junction	Minor Mod		Power	Solar Cells/Electrical	
SA Substrate Mechanical	t0.42	-2	0	0	20.8	Modified past design	Composite	Minor Mod		Structure and Mechanisms	Solar Array Substrate/Structure	4
Banery	200.00	1	1	1.1	200.0	standard cells winew configuration	400 Amp-hr Li-Ion	Major Mod	100	Power	Batteries 1	
Power subjetos	8.00	1	0	1.1	8.0	Custom design, changes for HV operation	and the second se	Major Mod	TOPW.	Power	Power stanagement and Distribution	
How Webser Bro	8.00	1	0		0,0	Concern betright, changes for HV operation		Major Mox	(NEW)	Power	Power stanagement and Listribution	
HU Brass Constitution Publish	0.00	1.4			9.0	Custom design changes for bill provides		New	New	Drawne	Brane Management and Catchedon	1.1
NV Crassis/France	7.00	1	0	1.1	70	Custom design, changes tor his operation	Aluminum	Minor Mod		Ometion and Machaniama	Electropics Boxes	1
Hamassas	30.00	÷	0	0	30.0	Custom barness, modified design		Major Mod		Power	Power Harnoss Cables	
Guidance, Navigation, & Control	an ord					Contraction internet design		traffe traffe		- uner	. Since it an instance cause if	
Inertial Measurement Unit	5.00	2	0		10.0	Modified COTS part		Minor Mid		Guidance, Navigation and Contri	IMU-Gwo	-1
Landing Altimeter	10.00	2	1	1	20.0	Custom design, changes for unique application		New		Guidance, Navigation and Contri	Space Radar Altimeter	1
Command & Data Handling											Sector Contraction Contraction	
RAD750 Single Board Computer	0.50	1	0	1	0.5	COTS part w/ application-specific software	Rad750-based	Minor Mod	New	Command and Data Handling	Command Data Processing 1	1
Payload interface Card	0.50	1	0		0.5	Modified past design		Minor Mod		Command and Data Handling	Command Data Processing 2	z
Other Cards	0.50	4	0	4.	2.0	Modified past designs		Minor Mod		Command and Data Handling	Command Data Processing 3	z
Communications	1.1.1.1		1.01	1000		and the second se				and the second se		- 14
X-band Deep Space Transponder	4.00	2	0	1.1	8.0	COTS part		Minor Mod		Communications	Transponder 1	1
Solid State Power Amplifier	3.00	2	0	1	6.0	COTS part		Minor Mod		Communications	Amplifier 1	
High Gan Antenna	6.00					Madded and desire		Anna March		Communication -	High Cais Asterno	1.2
HOA Formed Providence	8.00		0		4.0	Modified past design	Company	Manage Model		Communications	High Cain Antonna	
Low Cale Anternas	0.40	4		1.4	8.2	COTS and	Composite	Minor Mod		Communications	Ingli Gain America Studure	
Miss BF Electronice	1.00	1		1.4	10	Modified design, standard materials		Minor Mod		Communications	Miscellaneous RE Electronics	
Minary intern	2.50	1	0	1.21	25	Motified design, standard materials processes		Minor Mad		Communications	Waynoughts - Comm Cables	1.1
Helicopter	4,94		W.	1.0	6.0	movinov volegn, stancaro matoriais processes	10.0 Total 1	Million Mod		Communications	manegulass - Comm Cabling	
Bothins	1.00		ė.		40	Custom Inhteeinht design	Advanced composite	New	No.	Structure and Machinesians	Drimary Structure	
Rotars former file in an	0.50	2	0	1.2	2.0	Custom Ignitieght design	Tranium	New		Church use and Hachanisme	Cacapitary Structure	- 21
Motor Depyton Drockare	4.00	4		1.4	16.0	Custom motor New design	New technology	New	New	Structure and Machanisms	Motor Astuator	1.1
Moher Controller	4.00	100			10.0	contract interest of the state of the	tere (cc.) (cm/g)			Statistic and methodship	And the residence	
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	
Motor Controller Chassis Box	1.00		0	1	1.0		Auminum	Minor Mod		Structure and Mechanisms	Electronics Boxes	1
			-									-
DL		-			940.00 ######							
Structures & Mechanisms	1000					the state of the s						
Mini Sky Crane Primary Structure	150.00	1	0	0	150.0	Scaled-down heritage design	Aluminum	Major Med		Structure and Mechanisms	Secondary Structure	1
Mini Sky Crane Secondary Structure	50.00	1.1	0	0	50.0	Scaled-down heritage design	Alumnum	Major Mod		Structure and Mechanisms	Secondary Structure	1
Heatshield Structure	75.00	1	0	0	75.0	Scaled-down heritage cesion	Aluminum	Major Mod		Structure and Mechanisms	Secondary Structure	1
Heatshield TPS	300.00	7	0	0	300.0	Scaled-down heritage design		Minor Mod		Structure and Mechanisms	TPS	1
Backshell Structure	50.00	1	0	0	50.0	Scaled-down heritage design	Auminum	Major Mod		Structure and Mechanisms	Secondary Structure	1
Becksholl TPS	150.00	1	0	0	150.0	Scaled-down heritage design		Minue Mod		Structure and Mechanisms	TPS	1
Parachute (w'mortar)	75.00	4	1		75.0	Scaled-down heritage design		Major Mod		Structure and Mechanisms	Parachute	1
Proputsion												
Thrusters	2.00	12	0	0	24.0	Multiple landing thruster clusters, COTS	and and	Copy		Propulsion	Thrusters 1	
Propelant Tanks	25.00	2	0	0	50.0	Multiple custom tanks (for balance)	Titanium	New		Propulsion	Tanks 1	1.1
Propulsion Lines/Valves/Filters	10.00	1	0	0	10.0	Modified design, standard materials/processes		Major Mod		Propulsion	Propulsion - Lines/Valves/Fittings	
Avionics			1.1		5.45			1.000		A STATE OF STATES		
Inertial Measurement Unit	5.00	1	0	1.3.1	5.0	Modified COTS device		Minor Mod		Guidance, Navigation and Contri	IMU-Gyro	1
Single Board Computer	1.00	1	Q	- t	1.0	COTS part w/ custom software	Rad750-based	Minor Mod		Command and Data Handling	Command Data Processing 1	
Couldes Planes	-		_	-	120.00							
ruise Stage					170.60 #####							
Structures & Mechanisms						a supervised and	- 10					
Primary Structure	75.00	1	0	0	75.0	Scaled heritage design	Aluminum-honeycomb panels	Minor Mod		Structure and Mechanisms	Primary Structure	T
Secondary Structure	10.00	1	0	0	10.0	Scaled heritage design		Minor Mod		Structure and Mechanisms	Secondary Structure	
Mechanismis	15.00	1	0	0	15.0	COTS devices		Sope		Structure and Mechanisms	Mechanisms	
Balance Mass	5.00	1	0	0	5.0	the second se	Aluminum	Minor Mod		Structure and Mechanisms	Secondary Structure	3
Thermal Control				100	1.1.1	Andread all states and a state state of the	and the second sec	10000				
MLI, Coamps	8.00	1	0	0	8.0	Modified design, standard materials/processes		Major Mod		Thermal Control	MLI, Paints, Coatings	1
emperatule Sensors	0.20	10	0	0	2.0	skoaitea odsign, standard materials/processes		Major Mod		Thermal Control	Heaters, RHUs, Thermostals	
Propulsion	0.00		0		12.0	Manage array dated bank	Thusbas	free.		Property law	Tente 1	
Fuel Falls	8,00	4	0	0	32.0	Mono-prop fuel tank	1.tanutin	Dopy		Propulsion	Tanks 1	
Tagectory Correction Maneuver Brusters	0.60	4	0	0	24	COTS items		Copy		Propulsion	Thrusters 1	- 5 -
Annual Control by start Prusters	0.40		0	0	32	COID RETS		Lopy		Propulsion	Inrusters 2	
Province Transmission	3.00	1	0	0	3.0	Modified design, standard materials/processes		Major Mod		Propulsion	Propulsion - Lines/Valves/Fittings	1.2.1
rressore rismourer	0.25	2	0	0	0.5	Mounto obsign, standard materials processes		Major Mod		Propulsion Structure and Manhorizon	Pressure Regulator - transducer	1.1
Trible Theoreman Delivery and	1 10 10 10 10				M-14	movines seagh, asandard materials processes		sector seco		secure and secondrisms	Secondary Scructure	
TCM Thruster Brackets ACS Thruster Brackets	0.25	8		.0	2.0	Modified design standard materials incorrect		Site or Site		Children and Machanisme	Secondary Structure	
TCM Thruster Brackets ACS Thruster Brackets	0.25	8	0	0	2.0	Modified design, standard materials/processes		Major Mod		Structure and Mechanisms	Secondary Structure	1

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	<mark>6/</mark> 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 ("EO" or "P")	Parts Class (S,S1,B,B1, B2,D)	Internatio nal ("Y" or "N")	Contractin g Fee	Contract Monitor Burden	# of Flight Units	Notes	Mission Class
Marscopter	Р	S1	N			1		Class A/B
EDL	Р	S1	N			1		
Cruise Stage	Р	S1	N			1		
Mapping Spectrometer	Р	S1	N			1		Class A/B
Visible Camera	P	S1	N			1		
Meteorological Suite	P	S1	N			1		

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Case Study 2: Marscopter (Step D – Output)

RY\$K	and a second string of the out	DES	FAB	1&T	LOCO	TOTAL
1	PM	26,759	79,069	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 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	1.1.1.1.1.1.1				0
·	S/C I&T/GSE	1.1	· · · · ·			0
7/9	MOS/GDS	3,794	14,011	15,564	2,896	36,265
10	1&T	34,126	41,749	56,785	4,118	136,777
	TOTAL	461,470	383,295	199,586	29,506	1,073,857



Presented at the 2022 ICEAA Professional Development & Training Workshop: www.iceaaonline.com/pit2022 Case Study 2: Marscopter (TruePlanning Output)

sakdown Structure	Results						
ailed	Cost Objects	Input Sheet	🖻 Attributes 🔳	Results 🖾 🛛	hart. 🖪 Metric	s 🖾 Schedule 🔼	Uncertainty Analysis
9	Chilsters\mkjac\	Decline Declim	ents\TPSMruns\	Marscopter.tp	er)		🚔 🙀 🍓 🎓 Resource Costs by Activity
C1Users/mkjaciOneDrive/Documents/TPSMruns/Marscopter.tpprj	Cost:		\$1,073,85	6,938	100.00% Labo	r Requirement.	2,233,330.87 ho
B Spacecraft	Project Cost:		\$1,073.85	8,938	Proje	ect Labor Requirement	nt: 2,233,330.87 ho
😑 🚞 🛛 WBS 6 Spacecraft Subsystems	Phase Set.		* Works	theet Set: Chi	0000		
E D MARSCOPTER FLIGHT SYSTEM	Costs - C:Users/mkj	Total	Design	Fabrication	Integration	Operations	
Structures and Mechanisms	- [System Folder]				and Test		
- Structures and Mechanisms Assembly	Currency in LISD (5) (an						
Primary Structure	1 01. Project	116,826,333	26,758,974	79,069,326	9,170,579	1,827,453	
Secondary Structure	2 02a Missio.	13,477,414	8,315,954	2,853,667	1,449,560	858,233	
HGA Support Structure	3 02b. Syste	46,075,939	20,764,859	18,995,814	5,392,534	922,733	
Solar Array Substrate/Structure	4 03 Satety &	66,592,915	22,773,160	24,981,935	15,792,523	3,045,297	
HV Electronics Chassis/Frame	5 04. Science.	11,148,100	1,561,684	3,686,623	4,751,341	1,148,451	
Landing Leg Lock	6 07. Mission .	36,264,939	3,793,731	14,010,660	15,564,448	2,896,100	
Visible Camera Gimbal	7 10a. Assem.	14,044,600	5,285,661	5,093,461	2,057.578	407,900	
Mapping Spectrometer Cover	8 10b. Syste	98,339,622	19,527,556	25,689,904	50,045,918	3,076,244	
Solar Array Deployment Device	9 10c. Ground.	24,392,589	9,312,358	10,365,148	4,081,575	633,508	
Thermal Control	10 Design	0	0				
Thermal Control Assembly	11 Fabrication	0		0		_	
MU, Paints, Coatings	12 Assembly In.	90,679,782			90.679.782		
Heaters, RHUs, Thermostats	13 Launch Ope	14,689,939				14,689,939	
Guidance, Navigation and Control	14 Design Engl.	123,223,731	121,941,044	1,282,687			
E ONC Assembly	15 Project Syst.	1,210,766	1,210,766			_	
inertial Reference Unit	16 Support Eng.	81,755,304	69,031,181	12,724,123		_	
Landing Radar Altimeter	17 Test Engine.	18,768,867	4,175,869	14,592,098		_	
Communications	18 Assembler	16,187,575	3,150,215	13,037,360		_	
- Communications Assembly	19 Material	26,324,975	6.819.865	19,505,110		_	
X-band Deep Space Transponder	20 Tooling and	14.017.994	2,140,998	11.876.998			
X-band Power Amplifier	21 Tooling and	2,001,475	1.328.923	672,553		_	
Miscellaneous RF Electronics	22 Manufacturi.	14,439,937		14,439,937			
High Gain Antenna	23 Fabricator	8,552,349		8,552,349			
Low Gain Anterinas	24 Sustem Engl	8,022,230	8,022,230				
Waveguides - Comm Cabling	25 Contractor	0	0	0			
Command & Data Handling	26 Non-Recuri	125.555.046	125.555.046				
Command & Data Handling Assembly	27 Becuring C	101,264,513		101,264,513			
RAD750 Single Board Computer	29 Total	1 073 856	461 470 072	383 295 169	199 585 837	29 505 860	
Payload IF Card	20 100					11,000,000	
Other Cards							
Power	~						

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Validation Study Results

TP Result Comparisons

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



Application²Considerations^{nt & Training Workshop: www.iceaaonline.com/pit2022}

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
 - Flexible WBS outputs, including MIL-STD-881
 - Historical DoD Spacecraft Bus database

Q and A