



Model-based Cost Engineering Space Missions Estimating

Chris Price (Unison Cost Engineering)



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 / other 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

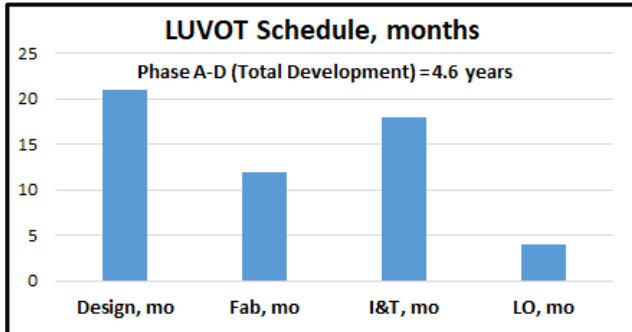
Case Study Overview



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)
TOTAL					485.5		
UVOT Spacecraft					389.4		
Structure							
Primary Structure	90.0	1	0	0	90.0	Standard design	Aluminum
Secondary Structure	25.0	1	0	0	25.0	Standard design	Aluminum
Gimbal	15.0	1	0	0	15.0	Modified from past program	
Thermal				0			
Multi-Layer Insulation, Coatings	5.0	1	0	0	5.0	Standard materials, new design	
Heaters, Thermistors	2.0	1	0	0	2.0	Standard materials, new design	
Radiator	3.0	1	0	0	3.0	Minor mod of past design	Composite
ACS							
Coarse Sun Sensor	0.0	10	0	1	0.1		
Inertial Reference Unit	2.0	3	0	1	6.0	COTS part	
Magnetometer	0.5	2	0	1	1.0	COTS part	
Magnetic Torque Rod	1.5	3	0	1	4.5	COTS part	
Star Tracker	5.0	2	0	1	10.0	Modified COTS part	
Reaction wheels	9.0	4	0	1	36.0	Modified standard design	
Power							
Solar Array, Cells/Electrical	7.0	2	0	0	14.0	COTS cells, custom wiring	High efficiency, Multi-junction
Solar Array, Substrate/Structure	15.0	2	0	0	30.0	Modified past design	Composite
Solar Array Drives	5.0	2	0	0	10.0	Modified past design	
Battery	40.0	1	1	1	40.0	Standard cells w/ new configuration	Li-Ion, 80 Amp-hrs
Power Distribution Unit	20.0	1	0	1	20.0	Modified past design	
CDH							
Backplane	1.0	1	0	1	1.0	COTS part	
Single Board Computer	0.8	1	0	1	0.8	COTS part w/ custom software	Rad750-based
UL/DL Board	0.5	1	0	1	0.5	Modified past design	
Bus Control I/F Board	0.8	1	0	1	0.8	Modified past design	
ACS Electronics Board	0.8	1	0	1	0.8	Modified past design	
Gimbal Drive Board	0.5	1	0	1	0.5	Modified past design	
General Purpose Board	0.5	1	0	1	0.5	Modified past design	
Power Control Unit	1.0	1	0	1	1.0	Modified past design	
Solid State Recorder	5.0	1	0	1	5.0	COTS part	
Chassis	8.0	1	0	0	8.0	Modified past design	
Communications							
X-band Transponder	3.0	2	0	1	6.0	COTS part	
Solid State Power Amplifier	3.0	4	0	1	12.0	COTS part	
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	

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)
UV Optical Telescope					96.1		
Telescope Optical Assembly							
Primary mirror	1.3	4	0	1	5.0	Lightweight design, Adv Mat'l	25cm diameter
Primary mirror mounts	0.5	4	0	1	2.0	Modified past design	Titanium
Secondary mirror	0.8	4	0	1	3.0	Lightweight design, Adv Mat'l	12cm diameter
Secondary mirror mounts	0.3	4	0	1	1.0	Modified past design	Titanium
Detectors & Electronics							
Detectors, CCDs	1.0	4	4	4	4.0	CCDMart Part # 2021	
Readout Electronics	1.0	4	1	1	4.0	Modified Past Design	
Focal Plane Assembly Housing	1.5	4	1	1	6.0		Aluminum
Filter Wheel Assembly							
Entrance filters assembly	0.5	4	1	1	2.0	Minor mod from past design	
Filter wheel mechanism	0.8	4	1	1	3.0	Minor mod from past design	
shutter	0.5	4	1	1	2.0	Minor mod from past design	
baffles	0.5	4	1	1	2.0	Minor mod from past design	
secondary mirror	0.5	4	1	1	2.0	Minor mod from past design	
focus mechanism	0.3	4	1	1	1.0	Minor mod from past design	
image motion compensation actuators	2.0	4	1	1	8.0	Minor mod from past design	
Structure, Mechanical, Thermal							
door Assembly	0.8	4	1	1	3.0	Minor mod from past design	
door hinge assembly	0.5	4	1	1	2.0	Minor mod from past design	
aperture selector	0.5	1	1	1	0.5	COTS part	
Telescope Tube	4.0	4	1	1	16.0	New design	Composite
	0.8	4	1	1	3.0	Standard parts/processes, custom design	
spider structure	0.4	4	1	1	1.6	Standard parts/processes, custom design	
heaters	0.5	4	1	1	2.0	Standard parts/processes, custom design	
telescope harnessing	0.8	12	3	3	9.0	Minor mod from past design	Aluminum
Electronics Box							
Control Electronics	0.5	1	0	1	0.5	COTS part w/ custom software	Rad750-based
Power Management	1.0	1	0	1	1.0	Modified past design	
power switching card	1.0	1	0	1	1.0	Modified past design	
PCI backplane	0.5	1	0	1	0.5	COTS part	
housing	7.0	1	0	1	7.0		Aluminum
Harnessing	4.0	1	0	1	4.0	Custom harness, new design	



Case Study 2: Marscopter – Helicopter for Mars

ENTRY, DESCENT, & LANDING

- Provides protection during Mars entry & initial deceleration
- Uses a mini “Sky Crane” based idea to lower the Helicopter to the Mars surface



CRUISE STAGE



Earth-to-Mars transport

- 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

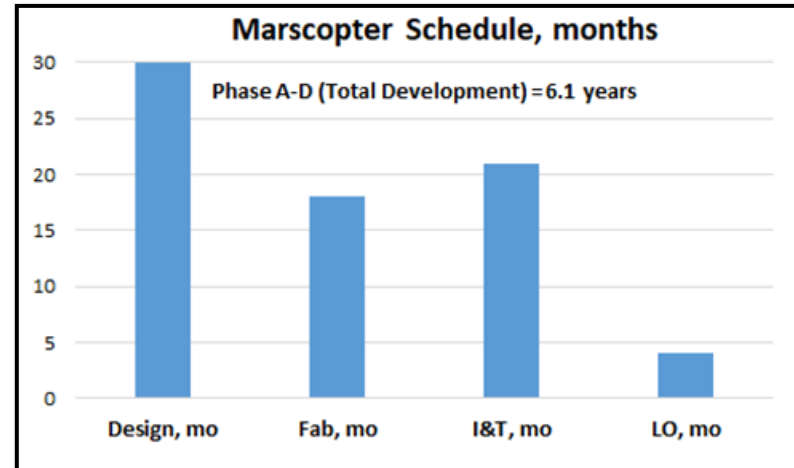
- Helicopter is powered by batteries during flight
- Solar Arrays are used when landed to recharge batteries between excursions
- Multiple excursions can be conducted; Lifetime driven by battery charge/discharge cycles





Case Study 2: Marscopter – Helicopter for Mars

MASS SUMMARY	
Subsystem/Component	Total 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

Subsystem/Component	Unit Mass, Current Best Estimate (CBE)	Flight Units	Flight Spares	EMs & Proto-types	Total Mass, CBE	Contingency %	Total Mass w/ Contingency	Description (Vendor, Part #, Heritage Basis)	Other characteristics/issues (volume, power, other component-specific items)
TOTAL					2,228.9				
FLIGHT SYSTEM					1,625.8				
Mars Helicopter/Lander Structure/Mechanical					515.2				
Primary Structure	35.0								
Top Deck	4.0	1			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	0	6.0			Custom design, standard materials/processes	Titanium
Mechanisms	30.0								
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
Mapping Spectrometer Cover	6.0	1	0	0	6.0			Custom design, standard materials/processes	Aluminum
Solar Array Deployment Device	3.0	2	0	0	6.0			Custom design, standard materials/processes	Aluminum
Thermal Control									
Multi-Layer Insulation, Coatings, etc	10.0	1			10.0			Custom design, standard materials/processes	
Heaters	3.0	1	0	0	3.0			Custom design, standard materials/processes	
Power									
Solar Arrays	62.5								
SA Cells/Electrical	20.8	2	0	0	41.7			COTS cells, custom wiring	high efficiency, waste-reduction
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	
Power Management & Distribution	8.0	1	0	1	8.0			Custom design, changes for HV operation	
High Voltage Box	16.0								
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	0	30.0			Custom harness, modified design	
Guidance, Navigation, & Control									
Inertial Measurement Unit	5.0	2	0	1	10.0			Modified COTS part	
Commanding Altimeter	10.0	2	1	1	20.0			Custom design, changes for unique application	
Command & Data Handling									
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	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	Contingency %	Total Mass w/ Contingency	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-honeycomb panels
Secondary Structure	10.0	1	0	0	10.0			Scaled heritage design	
Mechanisms	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

Subsystem/Component	Current Best Estimate (CBE)	Flight Units	Flight Spares	EMs & Proto-types	Total Mass w/ Contingency %	Description (Vendor, Part #, Heritage Basis)	characteristics/issues (volume, power, other component-specific items)
PAYLOAD					87.9		
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	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							
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	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	
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	
Thermal Control							
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	0	1	1.0	Standard materials, new design	
Command & Data Handling							
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							
Power Supplies	2.0	1	0	1	2.0	Modified past design	
Power Management & Distribution	2.0	1	0	1	2.0	Modified past design	
Harnessing	4.0	1	0	1	4.0	Custom harness, new design	
Visible Camera					7.9		
Housing	4.0	1	0	1	4.0	Custom design, heritage 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	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	
Harnessing	1.0	1	0	1	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
TWTA
Valve Driver

Electrical Power

Battery
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
Squib Driver
Switching Unit

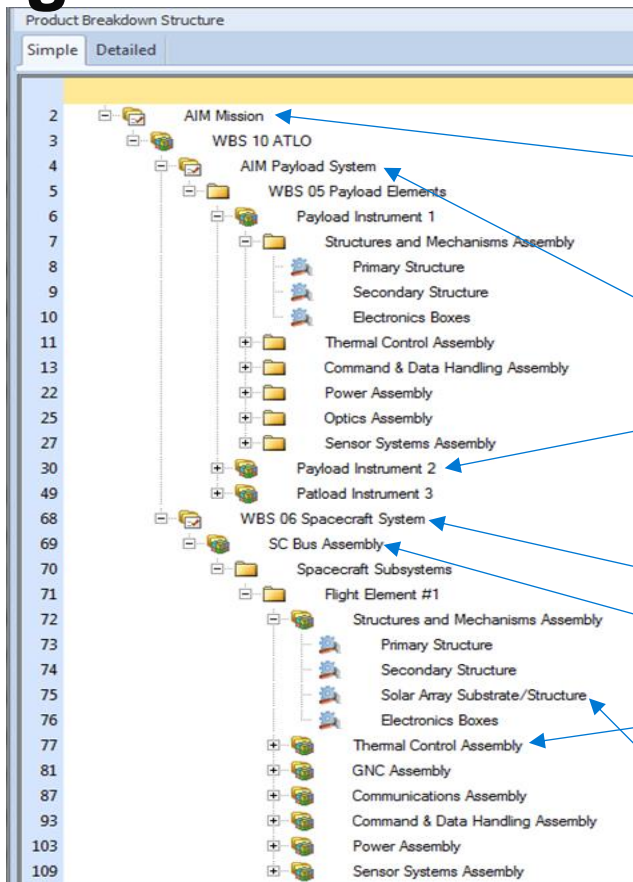
Payload / Instruments

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



■ Top Level

- System & Assembly Object
- Missions PMO & ATLO

■ Payload Level

- 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

Equipment Type Calculator:

Enhanced with Unmanned Space Mfg Complexities

PRICE TruePlanning 14.2 - [AIM Proposal v9 FY\$15]

File Edit View Reports Tools Window Help

Product Breakdown Structure

Simple Detailed

1 AIM Proposal v9 FY\$15

2 1 - 3 AIM Mission

3 10 AIM ATLO

4 05 AIM Payload System

38 06 AIM Spacecraft Bus System

39 Assembly

40 Attitude Control (ADC) Assembly

41 RW

42 RW Electric

43 Torque Rods

44 Mag

45 Star Tracker CT-633

46 Coarse Sun Sensor

47 LN-2005 rate sensor

48 Power Assembly

57 CDH Assembly

69 Structure Assembly

72 Thermal Assembly

79 COMM Assembly

Input Sheet: Star Tracker CT

Cost Objects

Star Tracker C

Cost

Project Cost

Worksheet Set: Sp8

1 Start Date

2 Quantity Per Unit

3 Additional Unit

4 Number of Ac

5 Number of Ac

6 Cost Sharing Unit

7 Total Number of

8 Total Number of

9 Technical Description

10 Equipment Type

11 Operating Specification

12 Weight of Structure

13 Weight of Electronics

14 Volume

15 Manufacturing Complexity for Structure

16 Percent of New Structure

17 Percent of Design Repeat for Structure

18 Manufacturing Complexity for Electronics

19 Percent of New Electronics

20 Percent of Design Repeat for Electronics

21 Engineering Complexity

Spacecraft Bus Component Manufacturing Complexities

Reference #	Spacecraft Bus Subsystem	Component	Definition	Hardware Complexity		Electronics Complexity		Percentage Structure Weight
				Earth Orbiting	Planetary	Earth Orbiting	Planetary	
1	Attitude Control	Accelerometer		9.25	9.78			100%
2	Attitude Control	ACS Control Electronics		7.96	8.42	10.29	10.89	73%
24	Attitude Control	Earth Horizon Sensor		8.18	8.63	10.56	11.17	35%
28	Attitude Control	GPS Receiver		7.60	8.04	9.83	10.40	40%
33	Attitude Control	IMU/IRU		9.78	10.34			100%
36	Attitude Control	Magnetic Torquer		7.13	7.60			100%
37	Attitude Control	Magnetometer		7.26	7.68			35%
43	Attitude Control	Momentum/Reaction Wheel		8.55	9.05	9.39	9.93	100%
48	Attitude Control	Nutation Damper/Despin Assy		8.29	8.77			100%
67	Attitude Control	Rate Gyro		9.60	10.15			100%
82	Attitude Control	Star Tracker		9.65	10.20			100%
88	Attitude Control	Sun Sensor		8.16	8.63	10.55	11.16	35%
113	Attitude Control	Torque Coils		7.25	7.67			100%
124	Bus & Payload	Electronic Chassis/Housing	An electronic housing, typically rectangular, made of Aluminum, with up to 6 bolt down fasteners and possibly some stiffeners	6.35	6.35			100%
127	Bus & Payload	Electronic Chassis/Housing (Simple / Mechanical part)	A simple electronic housing, typically made of aluminum with no more than four sides and 4 bolt down fasteners	6.30	6.30			100%
128	Bus & Payload	Electronic Chassis/Housing (Sophisticated / Complex)	An electronic housing made with advanced materials such as titanium or composites, sometimes with unusual shape with more than four sides, or with added stiffeners, or with more than 6 fasteners	8.00	8.00			100%
11	Electrical Power	Battery		8.13	8.13			100%
12	Electrical Power	Battery Voltage Limiter		7.06	7.06	9.13	9.13	70%
13	Electrical Power	Battery Voltage Pressure Monitor		8.09	8.09	10.46	10.46	70%

Equipment Type: None

Operating Specification: 2.00

Weight of Structure: 2.0617 kg

Weight of Electronics: 0.0000 kg

Volume: 1.945 l

Manufacturing Complexity for Structure: 9.647

Percent of New Structure: 20%

Percent of Design Repeat for Structure: 0%

Manufacturing Complexity for Electronics: 0.000

Percent of New Electronics: 20%

Percent of Design Repeat for Electronics: 0%

Engineering Complexity: 0.200

Equipment Type Calculator:

Completed Calculator Inputs

The screenshot displays the PRICE TruePlanning 14.2 software interface for the [AIM Proposal v9 FY\$15*] project. The main window is divided into several panes:

- Product Breakdown Structure:** A tree view on the left showing the hierarchy of the AIM Proposal v9 FY\$15. The selected item is "Star Tracker CT-633" under the "06 AIM Spacecraft Bus System" > "Assembly" > "Attitude Control (ADC) Assembly".
- Input Sheet: Star Tracker CT-633:** A central pane showing the input fields for the selected item. The "Equipment Type" field is highlighted in yellow.
- Tables and Calculators:** A pane on the right showing the calculated values for the selected item.

The "Equipment Type" section includes a description: "The Equipment Type describes typical equipments that are commonly developed and produced. When you select an Equipment Type from the available values, values are automatically calculated for Operating Specification, Total Weight, Weight of Structure, Volume, Manufacturing Complexity for Structure, and Manufacturing Complexity for Electronics based on industry standard values from PRICE System's cost research on equipment types. These values may be changed by the user if their organizational specific database indicates better values."

The "Equipment Type" table shows the following values:

Section Name	Input Field
Operating Environment	Unmanned Space - Earth Orbiting
Function	Spacecraft Attitude Control
Equipment Type	Star Tracker
Total Weight	2.062
Heritage Structure	Copy/Build to Print

The "Technical Description" table shows the following values:

Section Name	Value
Operating Specification	2.00
Total Weight	2.062 kg
Weight of Structure	2.062 kg
Weight of Electronics	0.000 kg
Volume	3.218 l
Manufacturing Complexity for Structure	9.647
Manufacturing Complexity for Electronics	0.000
Percent of New Structure	20.00%
Percent of New Electronics	20.00%
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

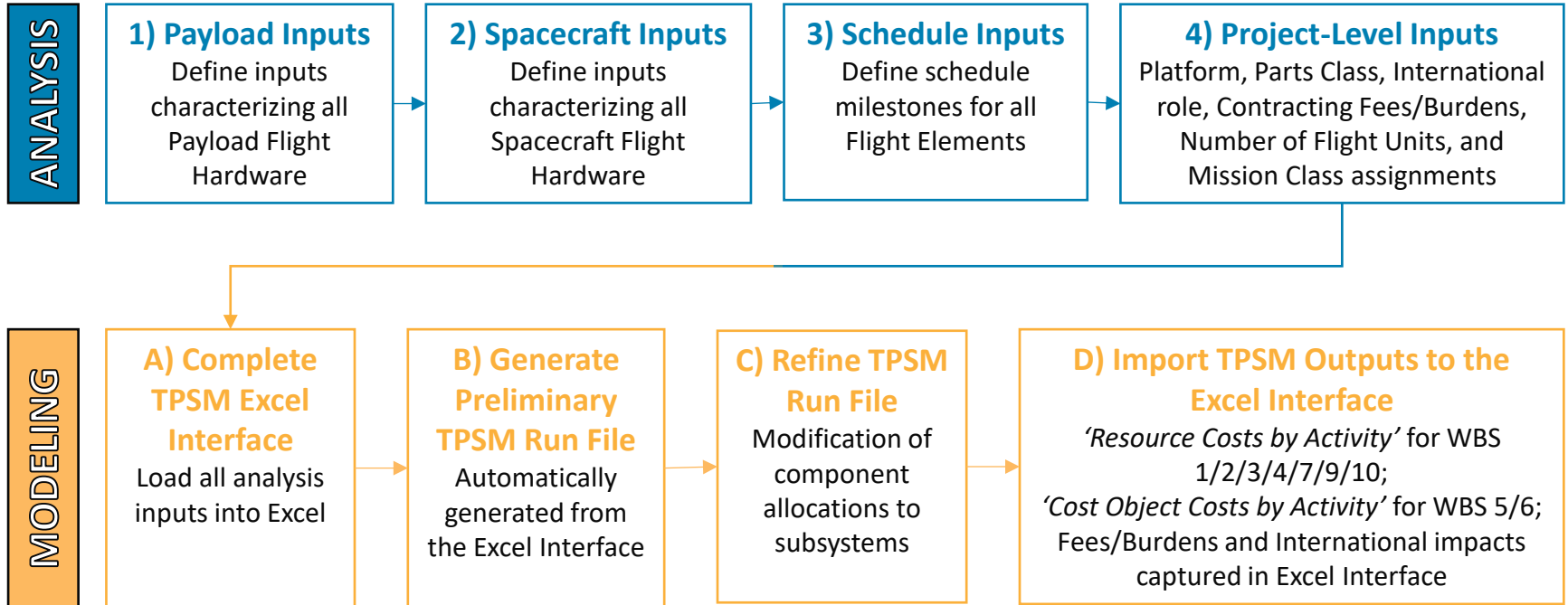
- The PRICE H approach was refined to include Earth orbiting missions in addition to Planetary
- Additional refinements were made to capture science instruments and approaches used by more recent missions
- Goal was to focus on perceived cost drivers versus non-causal options

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

Subsystem	Subsystem	Subsystem
Component	Component	Component
STRUCTURE & MECHANISMS	GUIDANCE, NAVIGATION, & CONTROL	ENTRY & DESCENT
Primary Structure	Star Tracker	Thermal Protection System *
Secondary Structure	Sun Sensor	Parachute *
Shielding	Reaction Wheel	
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		Optics Filters/Misc
	COMMUNICATIONS	
ROBOTIC ARM	Transponder	SENSOR SYSTEMS
Robotic Arm - Limb	Transmitter	Laser *
Robotic Arm - Joint/Actuator	Amplifier	Sensors-Detectors
	Misc RF Electronics	CCD Detectors
THERMAL CONTROL	HGA	Magnetometer
MLI, Paints, Coatings	MGA/LGA	TOF Spectrometer
Heaters, RHUs, Thermostats	Waveguide/Comm Cabling	ESA sensor
Radiators/Louvers		Photodiode
Heat Pipes	COMMAND & DATA HANDLING	Bolometer
Cryocooler	Command/Data Processing	Ion Source
	Solid State Memory	Gamma Sensor
PROPULSION		Neutron Sensor
Propulsion Lines/Valves/Fittings	POWER	Dust Detector
Pressure Regulator	Power Management and Distribution	Readout Electronics
Tanks	Solar Cells/Electrical	
Thrusters	Pyrotechnics	
	Batteries	
ELECTRIC PROPULSION	Harness	
Ion Thruster *		
Power Processing Unit *		

* 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 lower-level cost drivers (part volumes, electronics density, parts complexity, integration complexity, and others)

Subsys	Component	Tech Parameter	1	2	Type 3	4	5
Structure 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	n/a
	Electronic 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
	Thermal Control	n/a	n/a	n/a	n/a	n/a	n/a
Propulsion	MLI, Paints, Coatings	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Heaters, RHUs, Thermostats	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Radiators/Coolers	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Heat Pipes	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Cryocooler	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	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
Command and Data Handling	Electric Propulsion Power Processing Unit	Maximum Power	n/a	n/a	n/a	n/a	n/a
	Command/Data Processing	Complexity	Simple, Non-Programmable	Most Microprocessors, RAD1000	RAD750, PPC	Advanced Devices	XX
	Solid State Memory	Complexity	XX	Simple Solid State	Nominal Space-based Solid State	Complex Solid State	Rad-Hard Complex
	Communications	Frequency Band	UHF	S - band	X - band	Ka - band	Optical
	Transponder	Frequency Band	UHF	S - band	X - band	Ka - band	Optical
	Amplifier	Frequency Band	UHF	S - band	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
Guidance, 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	n/a
	Torque Rod	n/a	n/a	n/a	n/a	n/a	n/a
	Gimbals	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	MLU-Gyro	n/a	n/a	n/a	n/a	n/a	n/a
	Actuators	n/a	n/a	n/a	n/a	n/a	n/a
	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
Sensor Systems	Batteries	Chemistry	Non-rechargeable	NiCd or NiH	Li-ion	Advanced Chemistry	XX
	Power Harness/Cabling	n/a	n/a	n/a	n/a	n/a	n/a
	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
Optics	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	n/a
	Optical Bench	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
	Optics	Complexity	Simple	Standard	Advanced	Very Advanced	XX
	Gratings	Material	Aluminum	Stainless Steel	Advanced	Very Advanced	XX
	Optic Fibers/Miscellaneous	Complexity	Simple	Standard	Advanced	Very Advanced	XX
	Robotic Arm	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
Robotic Arm	Robotic Arm - Limb	Complexity	Simple	Standard	Advanced	Very Advanced	XX
	Robotic Arm - Joint-Actuator	Complexity	Simple	Standard	Advanced	Very Advanced	XX

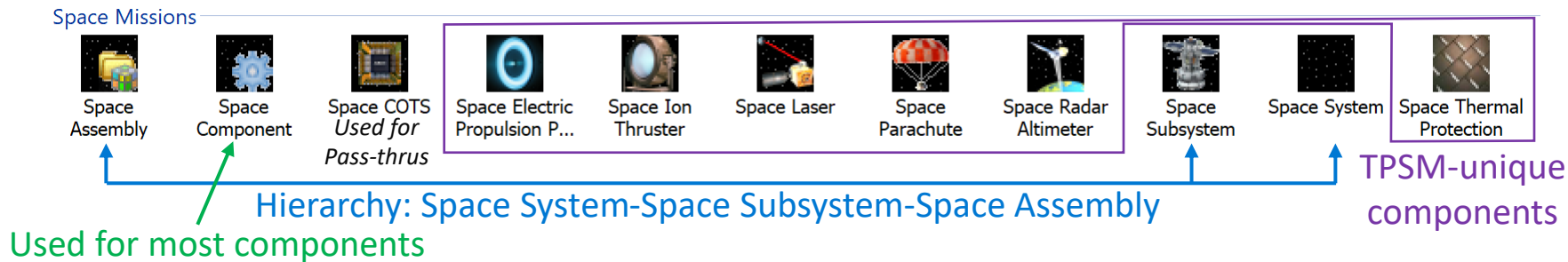
TPSM Component Type Input Matrix (Steps 1 & 2)

Subsys	Component	Tech Parameter	1	2	Type	3	4	5
Structure 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	Material	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
Thermal Control								
	MLI, Paints, Coatings	Material	n/a	n/a	n/a	n/a		n/a
	Heaters, RHJs, 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
Propulsion								
	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
	Electric Propulsion Power Processing Unit	Maximum Power	n/a	n/a	n/a	n/a		n/a
Command 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
Communications								
	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
Guidance, Navigation and Control						
Star Tracker	Complexity	Simple	Standard	Advanced	Very Advanced	XX
Sun Sensor	Complexity	Simple	Standard	Advanced	Very Advanced	XX
Reaction Wheel	Material	n/a	n/a	n/a	n/a	n/a
Torque Rod	Material	n/a	n/a	n/a	n/a	n/a
Gimbals	Material	Aluminum	Stainless Steel	Titanium	Composite	XX
IMU-Gyro	Material	n/a	n/a	n/a	n/a	n/a
Actuators	Material	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 IBT	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-rechargeable	NiCd or NiH	Li-ion	Advanced Chemistry	XX
Power Harness/Cabling	Material	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	Material	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 – PPU 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	RYŠK	DES	FAB	I&T	LOCO	TOTAL
	1	PM	These items are estimated as "wrap" factors driven by the Mission Risk Class input (A/B or C/D)				0
	2	SE					0
	3	MA					0
	4	SciTm					0
	5	Pyld	0	0	0	0	0
		Instrument 1	Estimated directly in TPSM (with applicable Project-level inputs)		Subsystem-level factors used to estimate Instrument-level costs during I&T and LOCO		0
		Instrument 2					0
		Instrument 3					0
		Instrument 4					0
		Instrument 5					0
		Instrument 6					0
		Instrument 7					0
		Instrument 8					0
		Instr PM/SE/MA	Portion of WBS 1/2/3 estimate can be moved here				0
		Instr I&T/GSE	Portion of WBS 10 estimate can be moved here				0
	6	S/C	0	0	0	0	0
		Flight System 1	Estimated directly in TPSM (with applicable Project-level inputs)		Subsystem-level factors used to estimate Instrument-level costs during I&T and LOCO		0
		Flight System 2					0
		Flight System 3					0
		Flight System 4					0
		Flight System 5					0
		S/C PM/SE/MA	Portion of WBS 1/2/3 estimate can be moved here				0
		S/C I&T/GSE	Portion of WBS 10 estimate can be moved here				0
	7/9	MOS/GDS	These items are estimated as "wrap" factors driven by the Mission Risk Class input				0
	10	I&T					0
	TOTAL		0	0	0	0	0



Case Study 1: LUVOT (Step 1)

Subsystem/Component	Unit Mass, Current Best Estimate (CBE)	# OF UNITS			FLIGHT HARDWARE MASSES			OTHER COMPONENT INFORMATION		TPSM COST MODEL INPUTS				
		Flight Units	Flight Spares	EMs & Proto-types	Total Mass, CBE	Contingency %	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
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		Sensor Systems	Large Coupled Device Detect	2
Readout Electronics	1.00	4	1	1	4.00			Modified Past Design		Minor Mod		Sensor Systems	Read Out Electronics	2
Focal Plane Assembly Housing	1.50	4	1	1	6.00				Aluminum	New		Structure 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	2
Filter wheel mechanism	0.75	4	1	1	3.00			Minor mod from past design		Minor Mod		Structure and Mechan	Mechanisms	2
shutter	0.50	4	1	1	2.00			Minor mod from past design		Minor Mod		Optics	Optic Filters/Miscellaneous	2
baffles	0.50	4	1	1	2.00			Minor mod from past design		Minor Mod		Optics	Optic Filters/Miscellaneous	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		Structure and Mechan	Mechanisms	2
door hinge assembly	0.50	4	1	1	2.00			Minor mod from past design		Minor Mod		Structure and Mechan	Mechanisms	2
aperture selector	0.50	1	1	1	0.50			COTS part		Copy		Optics	Optic Filters/Miscellaneous	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		Structure and Mechan	Mechanisms	2
heaters	0.40	4	1	1	1.60			Standard parts/processes, custom design		Major Mod		Thermal Control	Heaters, RHUs, Thermostats	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		Structure 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		Command and Data Ha	Command/Data Processing	1
Power Management	1.00	1	0	1	1.00	0%	0.00	Modified past design		Minor Mod		Power	Power Management and Distribu	2
power switching card	1.00	1	0	1	1.00	0%	0.00	Modified past design		Minor Mod		Command and Data Ha	Command/Data Processing	2
PCI backplane	0.50	1	0	1	0.50	0%	0.00	COTS part		Copy		Command and Data Ha	Command/Data Processing	8
housing	7.00	1	0	1	7.00	0%	0.00		Aluminum	Minor Mod		Structure 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)

Subsystem/Component	Unit Mass, Current Best Estimate (CBE)	# OF UNITS			FLIGHT HARDWARE MASSES			OTHER COMPONENT INFORMATION		TPSM COST MODEL INPUTS				
		Flight Units	Flight Spares	EMs & Proto- types	Total Mass, CBE	Contingen- cy %	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	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									
Multi-Layer 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					57.6									
Coarse Sun Sensor	0.0	10	0	1	0.1					Copy		Guidance, Navigation and Contr	Sun Sensor	2
Inertial Reference Unit	2.0	3	0	1	6.0			COTS part		Copy		Guidance, Navigation and Contr	IMU-Gyro	1
Magnetometer	0.5	2	0	1	1.0			COTS part		Copy		Sensor Systems	Magnetometer	1
Magnetic Torque Rod	1.5	3	0	1	4.5			COTS part		Copy		Guidance, Navigation and Contr	Torque Rod	1
Star Tracker	5.0	2	0	1	10.0			Modified COTS part		Minor Mod		Guidance, Navigation and Contr	Star Tracker	2
Reaction wheels	9.0	4	0	1	36.0			Modified standard design		Minor Mod		Guidance, Navigation and Contr	Reaction Wheel	1
Power					114.0									
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		Guidance, 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									
Backplane	1.0	1	0	1	1.0			COTS part		Copy		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									
X-band Transponder	3.0	2	0	1	6.0			COTS part		Copy		Communications	Transponder 1	3
Solid State Power Amplifier	3.0	4	0	1	12.0			COTS part		Copy		Communications	Amplifier 1	3
Antennas	1.0	4	0	1	4.0			Modified past design		Minor Mod		Communications	Medium 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)

	Phase B start	PDR ¹	CDR	Deliver to System I&T	Ship to Launch Site	Launch	On-Orbit Check-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")	Parts Class (S,S1,B,B1, B2,D)	International ("Y" or "N")	Contracting Fee	Contract Monitor Burden	# of Flight Units	Notes	Mission Class
LUVOT Spacecraft	P	B	N			1		Class C/D
UVOT Telescope Optical Assembly	P	S1	N			1		Class C/D
Detectors/Electronics	P	S1	N			1		
Filter Wheel Assembly	P	S1	N			1		
Structure, Mechanical, & Thermal	P	S1	N			1		
UVOT Electronics Box	P	S1	N			1		
Harness	P	S1	N			1		



Case Study 1: LUVOT (Step D – Output)

Case Study 1: LUVOT		DES	FAB	I&T	LOCO	TOTAL
RYSK						
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)

PRICE TruePlanning 16.2 - [LUVOT.tppj]

File Edit View Project Reports Tools Window Help

Product Breakdown Structure

Simple Detailed

C:\Users\mkjac\OneDrive\Documents\TPSMun\LUVOT.tppj

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

Spacecraft

WBS 6 Spacecraft Subsystems

LUVOT Spacecraft

Structures and Mechanisms

Structures and Mechanisms Assembly

Primary Structure

Secondary Structure

Gimbal

Thermal Control

Thermal Control Assembly

MLI, Paints, Coatings

Heaters, RHUs, Thermostats

Radiators/Louvers

Guidance, Navigation and Control

GNC Assembly

Star Tracker

Sun Sensor

Reaction Wheel

Torque Rod

IMU-Gyro

Magnetometer

Communications

Communications Assembly

X-Band Transponder

Solid State Power Amplifier

Miscellaneous RF Electronics

Medium Gain Antenna/Low Gain Antenna

Waveguides - Comm Cabling

Command & Data Handling

Command & Data Handling Assembly

Single Board Computer

UL/DL Board

Bus Control I/F Board

ACS Electronics Board

Gimbal Drive Board

Results

Cost Objects Input Sheet Attributes Results Chart Metrics Schedule Uncertainty Analysis

C:\Users\mkjac\OneDrive\Documents\TPSMun\LUVOT.tppj

Cost: \$176,717,614 100.00% Labor Requirement: 653,843.53 hours

Project Cost: \$176,717,614 Project Labor Requirement: 653,843.53 hours

Phase Set: A Worksheet Set: Chismo

Costs: C:\Users\mkjac\OneDrive\Documents\TPSMun\LUVOT.tppj - [System Folder] Currency in USD

Costs: C:\Users\mkjac\OneDrive\Documents\TPSMun\LUVOT.tppj - [System Folder] Currency in USD (\$ as spent)

	Total	Design	Fabrication	Assembly Integration and Test	Launch Operations
01. Project Management	14,910,309	2,303,481	11,131,424	1,209,902	265,502
02a. Mission Analysis	2,150,299	1,073,788	602,611	286,867	187,033
02b. System Engineering	5,307,246	1,787,492	2,674,241	711,453	134,060
03. Safety & Mission Assurance	8,003,334	1,960,372	3,516,971	2,083,555	442,437
04. Science/Technology	5,276,775	389,438	2,453,992	1,957,175	478,170
07. Mission Operation System	7,159,842	489,861	2,958,643	3,080,197	631,141
10a. Assembly and Integration Support	2,499,624	682,505	1,202,293	525,933	88,893
10b. System Test	12,347,262	1,680,962	3,616,639	6,602,709	446,933
10c. Ground Support	4,337,065	1,202,447	2,188,817	807,742	138,059
Design	0	0			
Fabrication	0		0		
Assembly Integration and Test	17,945,485			17,945,485	
Launch Operation	3,201,348				3,201,348
Design Engineering	26,580,006	26,177,949	402,057		
Project Systems Engineer	408,206	408,206			
Support Engineering	20,208,948	15,248,289	4,960,659		
Test Engineering	7,627,066	1,557,797	6,069,268		
Assembler	6,631,051	1,175,961	5,455,090		
Material	11,744,439	2,755,919	8,988,520		
Tooling and Test Engineering	8,730,142	589,950	8,140,192		
Tooling and Test Material	1,345,445	401,168	944,278		
Manufacturing Engineering	4,483,422		4,483,422		
Fabricator	3,560,934		3,560,934		
System Engineering	2,259,365	2,259,365			
Contractor	0	0	0		
Total	176,717,614	62,144,969	73,350,052	35,211,018	6,011,575

Ready

NUM

Type here to search

54°F Sunny 3:18 PM 10/23/2021



Case Study 2: Marscopter (Step 1)

Subsystem/Component	Unit Mass, Current Best Estimate (CBE)	# OF UNITS			FLIGHT HARDWARE MASSES			OTHER COMPONENT INFORMATION		TPSM COST MODEL INPUTS				
		Flight Units	Flight Spares	EMs & Proto- types	Total Mass, CBE	Contingen- cy %	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
Mapping Spectrometer					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	2
Filters	2.00	1	0	1	2.00			Modified past design		Minor Mod		Optics	Optic Filters/Miscellaneous	2
Sensor, CCD	0.50	4	0	1	2.00			CCDMart Part # 1969		Copy		Sensor Systems	Large Coupled Device Detector	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	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, Navigation and Structure and Mechan	Actuators	1
Telescope Secondary Structure	5.00	1	0	1	5.00			Custom designs, heritage processes/materials	Composite	New		Structure and Mechan	Secondary Structure	4
Scan Platform														
Scan Platform Structure	5.00	1	0	1	5.00			Custom design, heritage processes/materials	Composite	New		Structure and Mechan	Primary Structure	4
Scan Platform Motor	5.00	1	0	1	5.00			Modified past design		Minor Mod		Structure and Mechan	Motor-Actuator	2
Scan Platform electronics	2.50	1	0	1	2.50			Modified past design	Standard microprocessor	Minor Mod		Command and Data Ha	Command/Data Processing 1	2
Scan Platform cabling	1.00	1	0	1	1.00			Modified past design		Minor Mod		Power	Power Harness/Cabling	1
Thermal Control														
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, Thermostats	3
Command & Data Handling														
Read-Out Electronics	1.00	1	0	1	1.00			Modified COTS item with custom software		Major Mod		Sensor Systems	Read Out Electronics	3
Solid-state Memory	1.00	1	0	1	1.00			COTS item		Copy		Command and Data Ha	Solid State Memory 1	3
CDH Chassis	2.00	1	0	1	2.00			Modified past design	Aluminum	Minor Mod		Structure and Mechan	Electronics Boxes	1
Power														
Power Supplies	2.00	1	0	1	2.00			Modified past design		Major Mod		Power	Power Management and Distribu	2
Power Management & Distribution	2.00	1	0	1	2.00			Modified past design		Major Mod		Power	Power Management and Distribu	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	0	1	2.00			Modified past design		Minor Mod		Optics	Optics	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		Sensor Systems	Large Coupled Device Detector	2
Readout electronics	0.50	1	0	1	0.50			COTS item with custom programming		Minor Mod		Sensor Systems	Read Out Electronics	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		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		Power	Power Management and Distribu	2
Power														
Power Conditioning	2.00	1	0	1	2.00			Modified past design		Minor Mod		Power	Power Management and Distribu	2
Harnessing	1.00	1	0	1	1.00			Custom harness, new design		New		Power	Power Harness/Cabling	1



Case Study 2: Marscopter (Step 2)

Subsystem/Component	Unit Mass, Current Best Estimate (CBE)		# OF UNITS		FLIGHT HARDWARE MASSES		OTHER COMPONENT INFORMATION		TPSM COST MODEL INPUTS		Subsys	Comp	Type
	Flight Units	Flight Spares	EMs & Proto-type	Total Mass, Contingency @ 3%	Total Mass w/ Contingency	Description (Vendor, Part #, Heritage Basis)	Other characteristics/issues (volume, power, other component-specific items)	Heritage	New or Advanced Tech				
Marscopter													
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													
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, Thermostats	1	
Power													
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	3	
SA Substrate/Mechanical	10.42	2	0	0	20.8	Modified past design	Composite	Minor Mod		Structure and Mechanisms	Solar Array Substrate/Structure	4	
Battery	200.00	1	1	1	200.0	Standard cells w/ new configuration	400 Amp-hr Li-ion	Major Mod		Power	Batteries 1	3	
Power Supplies	8.00	1	0	1	8.0	Custom design, changes for HV operation		Major Mod	New	Power	Power Management and Distribution	3	
Power Management & Distribution	8.00	1	0	1	8.0	Custom design, changes for HV operation		Major Mod	New	Power	Power Management and Distribution	3	
High Voltage Box								New	New	Power	Power Management and Distribution	3	
HV Power Conversion System	9.00	1	0	1	9.0	Custom design, changes for HV operation				Structure and Mechanisms	Electronics Boxes	1	
HV Chassis/Frame	7.00	1	0	1	7.0	Custom design, standard materials/processes	Aluminum	Minor Mod		Structure and Mechanisms	Electronics Boxes	1	
Harnesses	30.00	1	0	0	30.0	Custom harness, modified design		Major Mod		Power	Power Harness/Cabling	1	
Guidance, Navigation, & Control													
Inertial Measurement Unit	5.00	2	0	1	10.0	Modified COTS part		Minor Mod		Guidance, Navigation and Control	IMU-Gyro	1	
Landing Attitude	10.00	2	1	1	20.0	Custom design, changes for unique application		New		Guidance, Navigation and Control	Space Radar Attitude	1	
Command & Data Handling													
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	3	
Payload Interface Card	0.50	1	0	1	0.5	Modified past design		Minor Mod		Command and Data Handling	Command/Data Processing 2	2	
Other Cards	0.50	4	0	4	2.0	Modified past designs		Minor Mod		Command and Data Handling	Command/Data Processing 3	2	
Communications													
X-band Deep Space Transponder	4.00	2	0	1	8.0	COTS part		Minor Mod		Communications	Transponder 1	3	
Solid State Power Amplifier	3.00	2	0	1	6.0	COTS part		Minor Mod		Communications	Amplifier 1	3	
HGA Antenna													
HGA Dish	8.00	1	0	1	8.0	Modified past design		Minor Mod		Communications	High Gain Antenna	3	
HGA Support Structure	4.00	1	0	1	4.0	Modified past design	Composite	Minor Mod		Structure and Mechanisms	High Gain Antenna Structure	4	
Low Gain Antennas	0.40	3	0	1	1.2	COTS part		Minor Mod		Communications	Medium Gain Antenna/Low Gain Antenn	3	
Mini RF Electronics	1.00	1	0	1	1.0	Modified design, standard materials/processes		Minor Mod		Communications	Miscellaneous RF Electronics	3	
Waveguides	2.50	1	0	1	2.5	Modified design, standard materials/processes		Minor Mod		Communications	Waveguides - Comm Cabling	3	
Helicopter													
Rotors	1.00	4	0	1	4.0	Custom lightweight design	Advanced composite	New	New	Structure and Mechanisms	Primary Structure	4	
Rotor Support Structure	4.00	4	0	1	2.0	Custom housings	Titanium	New	New	Structure and Mechanisms	Secondary Structure	3	
Motor	4.00	4	1	1	16.0	Custom motor, new design	New technology	New	New	Structure and Mechanisms	Motor-Actuator	3	
Motor Controller	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	3	
Motor Controller Electronics	1.00	1	0	1	1.0	Custom cards with heritage/modified devices	Aluminum	Minor Mod		Structure and Mechanisms	Electronics Boxes	1	
EDL													
Structures & Mechanisms													
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	75.00	1	0	0	75.0	Scaled-down heritage design	Aluminum	Major Mod		Structure and Mechanisms	Secondary Structure	1	
Heatshield TPS	300.00	1	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	Aluminum	Major Mod		Structure and Mechanisms	Secondary Structure	1	
Backshell TPS	150.00	1	0	0	150.0	Scaled-down heritage design		Minor Mod		Structure and Mechanisms	TPS	1	
Parachute (w/ mortar)	75.00	1	1	1	75.0	Scaled-down heritage design		Major Mod		Structure and Mechanisms	Parachute	1	
Propulsion													
Thrusters	2.00	12	0	0	24.0	Multiple landing thruster clusters, COTS		Copy		Propulsion	Thrusters 1	3	
Propellant Tanks	25.00	2	0	0	50.0	Multiple custom tanks (for balance)	Titanium	New	New	Propulsion	Tanks 1	3	
Propulsion Lines/Valves/Filters	10.00	1	0	0	10.0	Modified design, standard materials/processes		Major Mod		Propulsion	Propulsion - Lines/Valves/Fittings	3	
Avionics													
Inertial Measurement Unit	5.00	1	0	1	5.0	Modified COTS device	Rad750-based	Minor Mod		Guidance, Navigation and Control	IMU-Gyro	1	
Single Board Computer	1.00	1	0	1	1.0	COTS part w/ custom software		Minor Mod		Command and Data Handling	Command/Data Processing 1	3	
Cruise Stage													
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	
Mechanisms	15.00	1	0	0	15.0	COTS devices	Copper	Minor Mod		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	1	
Propulsion													
Fuel Tank	8.00	4	0	0	32.0	Mono-prop fuel tank	Titanium	Copy		Propulsion	Tanks 1	3	
Trajectory Correction Manoeuvr 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		Copy		Propulsion	Thrusters 2	3	
Valves/Filters	3.00	1	0	0	3.0	Modified design, standard materials/processes		Major Mod		Propulsion	Propulsion - Lines/Valves/Fittings	3	
Pressure Transducer	0.25	2	0	0	0.5	Modified design, standard materials/processes		Major Mod		Propulsion	Pressure Regulator - Transducer	3	
TCM Thruster Brackets	0.13	4	0	0	0.5	Modified design, standard materials/processes		Major Mod		Structure and Mechanisms	Secondary Structure	1	
ACS Thruster Brackets	0.25	8	0	0	2.0	Modified design, standard materials/processes		Major Mod		Structure and Mechanisms	Secondary Structure	1	
Brackets, Tubes, Fittings, etc	12.00	1	0	0	12.0	Modified design, standard materials/processes		Major Mod		Propulsion	Propulsion - Lines/Valves/Fittings	3	



Case Study 2: Marscopter (Steps 3 & 4)

	Phase B start	PDR ¹	CDR	Deliver to System I&T	Ship to Launch Site	Launch	On-Orbit Check-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 ("EO" or "P")	Parts Class (S,S1,B,B1, B2,D)	International ("Y" or "N")	Contracting Fee	Contract Monitor Burden	# of Flight Units	Notes	Mission Class
Marscopter	P	S1	N			1		Class A/B
EDL	P	S1	N			1		
Cruise Stage	P	S1	N			1		
Mapping Spectrometer	P	S1	N			1		Class A/B
Visible Camera	P	S1	N			1		
Meteorological Suite	P	S1	N			1		



Case Study 2: Marscopter (Step D – Output)

Case Study 2: Marscopter							
	RYŠK		DES	FAB	I&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					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)

PRICE TruePlanning 16.2 - [Marscopter.tpprj]

File Edit View Project Reports Tools Window Help

Product Breakdown Structure

Simple Detailed

C:\Users\mkjac\OneDrive\Documents\TPSMrns\Marscopter.tpprj

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37

Spacecraft

WBS # Spacecraft Subsystems

MARSCOPTER FLIGHT SYSTEM

Structures and Mechanisms

Structures and Mechanisms Assembly

Primary Structure

Secondary Structure

HGA Support Structure

Solar Array Substrate/Structure

HV Electronics Chassis/Frame

Landing Leg Lock

Visible Camera Gimbal

Mapping Spectrometer Cover

Solar Array Deployment Device

Thermal Control

Thermal Control Assembly

MLI, Paints, Coatings

Heaters, RHUs, Thermostats

Guidance, Navigation and Control

GNC Assembly

Inertial Reference Unit

Landing Radar Altimeter

Communications

Communications Assembly

X-band Deep Space Transponder

X-band Power Amplifier

Miscellaneous RF Electronics

High Gain Antenna

Low Gain Antennas

Waveguides - Comm Cabling

Command & Data Handling

Command & Data Handling Assembly

RAD750 Single Board Computer

Payload I/F Card

Other Cards

Power

Results

Cost Objects Input Sheet Attributes Results Chart Metrics Schedule Uncertainty Analysis

C:\Users\mkjac\OneDrive\Documents\TPSMrns\Marscopter.tpprj

Cost: \$1,073,856,938 100.00% Labor Requirement: 2,233,330.87 hours

Project Cost: \$1,073,856,938 Project Labor Requirement: 2,233,330.87 hours

Phase Set: A Worksheet Set: Chicomo

	Costs C:\Users\mkjac\OneDrive\Documents\TPSMrns\Marscopter.tpprj [System Folder] Currency in USD (\$)	Total	Design	Fabrication	Assembly Integration and Test	Launch Operations
01. Project ...	116,826,333	26,758,874	79,069,326	9,170,579	1,827,453	
02a. Missio...	13,477,414	8,315,954	2,853,667	1,449,560	858,233	
02b. Syste...	46,075,939	20,764,859	18,995,814	5,392,534	922,733	
03. Safety &...	66,592,915	22,773,180	24,981,935	15,792,523	3,045,297	
04. Science...	11,148,100	1,561,684	3,686,623	4,751,341	1,148,451	
07. Mission ...	36,264,939	3,793,731	14,010,660	15,564,448	2,896,100	
10a. Assem...	14,044,600	5,285,661	5,693,461	2,657,578	407,900	
10b. Syste...	98,339,622	19,527,556	25,689,904	50,045,918	3,076,244	
10c. Ground...	24,392,589	9,312,358	10,365,148	4,081,575	633,508	
10. Design	0	0				
11. Fabrication	0	0				
12. Assembly In...	90,679,782			90,679,782		
13. Launch Ope...	14,689,939					14,689,939
14. Design Engi...	123,223,731	121,941,044	1,282,687			
15. Project Syst...	1,210,766	1,210,766				
16. Support Eng...	81,755,304	69,031,181	12,724,123			
17. Test Engine...	18,768,867	4,175,869	14,592,998			
18. Assembler	16,167,575	3,150,215	13,037,360			
19. Material	26,324,975	6,819,865	19,505,110			
20. Tooling and ...	14,017,994	2,140,996	11,876,998			
21. Tooling and ...	2,001,475	1,328,923	672,553			
22. Manufactur...	14,439,937		14,439,937			
23. Fabricator	8,552,349		8,552,349			
24. System Engi...	8,022,230	8,022,230				
25. Contractor	0	0	0			
26. Non-Recurit...	125,555,046	125,555,046				
27. Recurring C...	101,264,513		101,264,513			
28. Total	1,073,856,938	461,470,072	383,295,169	199,585,837	29,505,860	

NUM

Ready

Type here to search

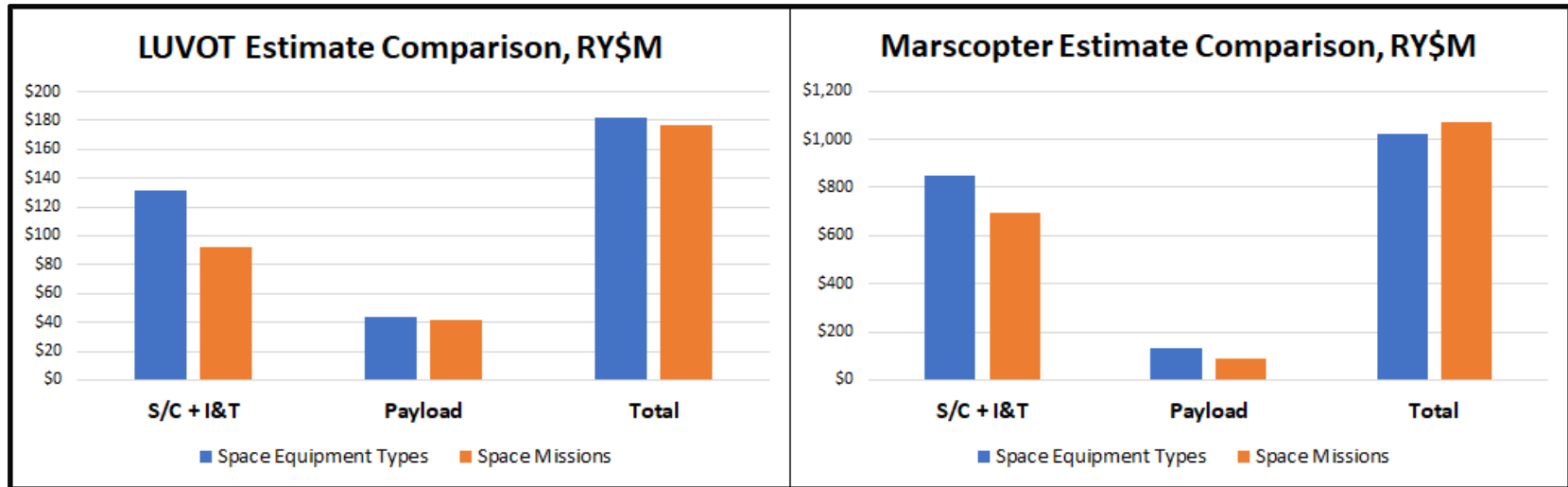
71°F Sunny 3:38 PM 10/20/2021

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 / other 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

