unison
TruePlanning for Cost Estimation

Model-based Cost Engineering Space Missions Estimating

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Agenda

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  - a. The PRICE Space Hardware Equipment Types
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  - a. The Space Missions Catalog
  - b. Cost Models / Results
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Executive Summary:
Two independent cost estimating methods in TruePlanning

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

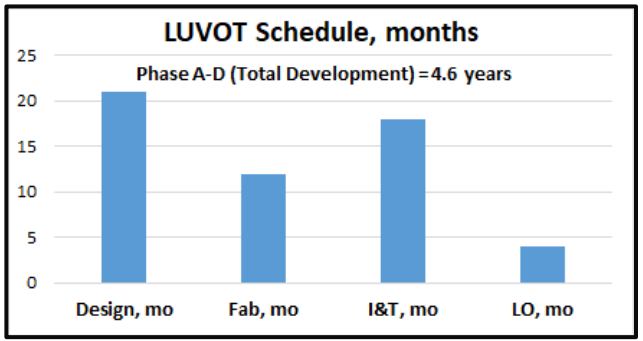
- Space Hardware Equipment Types
  - Best for DoD Service / Agency Space Missions, but very useful as a 'cross-check' for other estimating methods, including TruePlanning Space Missions
    - Flexible WBS outputs, including MIL-STD-881
    - Historical DoD Spacecraft Bus database

Case Study Overview

Case Study 1: LEO UV Optical Telescope (LUVOT)

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

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



Case Study 1: LUVOT Master Equipment List

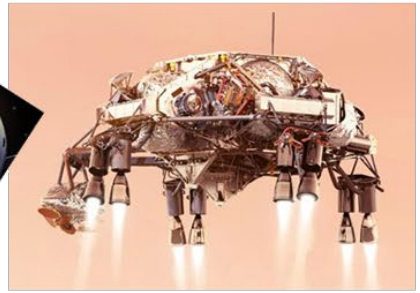
Subsystem/Component	Unit Mass, Current Best Estimate (CBE)	Flight Units	Flight Spares	EMs & Proto-types	Total Mass, CBE	Description (Vendor, Part #, Heritage Basis)	Other characteristics/issues (volume, power, other component-specific items)
TOTAL					**485.5**		
UVOT Spacecraft					**389.4**		
Structure							
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	Lightweighted 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	Lightweighted 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 Asembly 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
spider structure	0.8	4	1	1	3.0	Standard parts/processes, custom design	
heaters	0.4	4	1	1	1.6	Standard parts/processes, custom design	
telescope harnessing	0.5	4	1	1	2.0	Standard parts/processes, custom design	
kinematic mounts	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



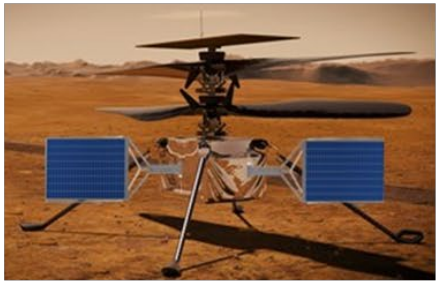
CRUISE STAGE

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

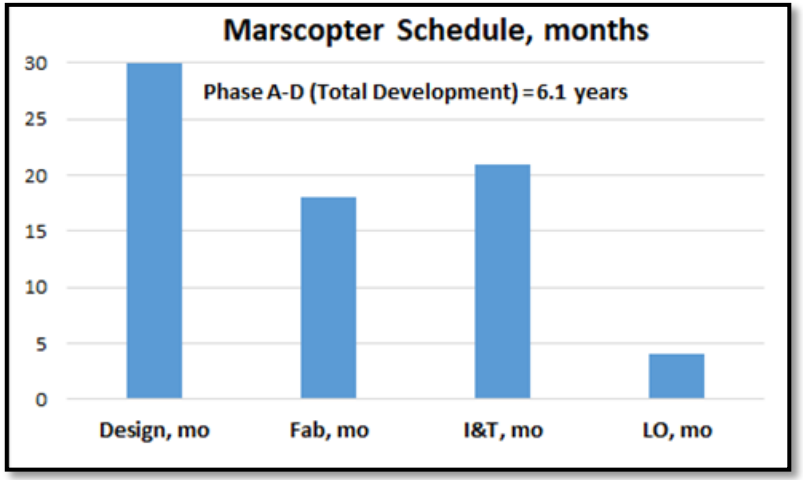
MARS HELICOPTER/LANDER

- 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					**515.2**				
Structure/Mechanical									
Primary Structure	35.0								
Top Deck	4.0	1	0	0	4.0			Custom design, standard materials/processes	Composite
Bottom Deck	4.0	1	0	0	4.0			Custom design, standard materials/processes	Composite
Struts	3.0	6	0	0	18.0			Custom design, standard materials/processes	Composite
Landing Legs	3.0	3	0	0	9.0			Custom design, standard materials/processes	Composite
Secondary Structures	24.0								
Brackets/Mounts	18.0	1	0	0	18.0			Custom design, standard materials/processes	Composite
Fasteners	6.0	1	0	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	0	0	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, Multi-junction
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	
Landing 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	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)
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	
Mechansims	15.0	1	0	0	15.0			COTS devices	
Balance Mass	5.0	1	0	0	5.0				Aluminum
Thermal Control									
MLI, Coatings	8.00	1	0	0	8.0			Modified design, standard materials/processes	
Temperature Sensors	0.20	10	0	0	2.0			Modified design, standard materials/processes	
Propulsion									
Fuel Tank	8.00	4	0	0	32.0			Mono-prop fuel tank	Titanium
TCM Thrusters	0.60	4	0	0	2.4			COTS items	
ACS Thrusters	0.40	8	0	0	3.2			COTS items	
Valves/Filters	3.00	1	0	0	3.0			Modified design, standard materials/processes	
Pressure Transducer	0.25	2	0	0	0.5			Modified design, standard materials/processes	
TCM Thruster Brackets	0.13	4	0	0	0.5			Modified design, standard materials/processes	
ACS Thruster Brackets	0.25	8	0	0	2.0			Modified design, standard materials/processes	
Brackets, Tubes, Fittings, etc	12.00	1	0	0	12.0			Modified design, standard materials/processes	

Case Study 2: Marscopter Master Equipment List

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)
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									
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	
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

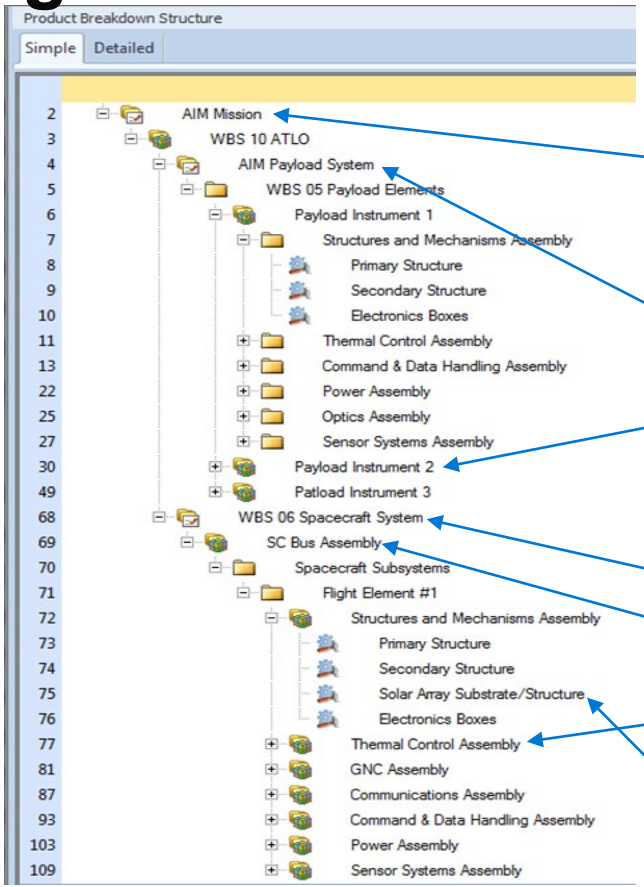
Payload / Instruments

- 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)

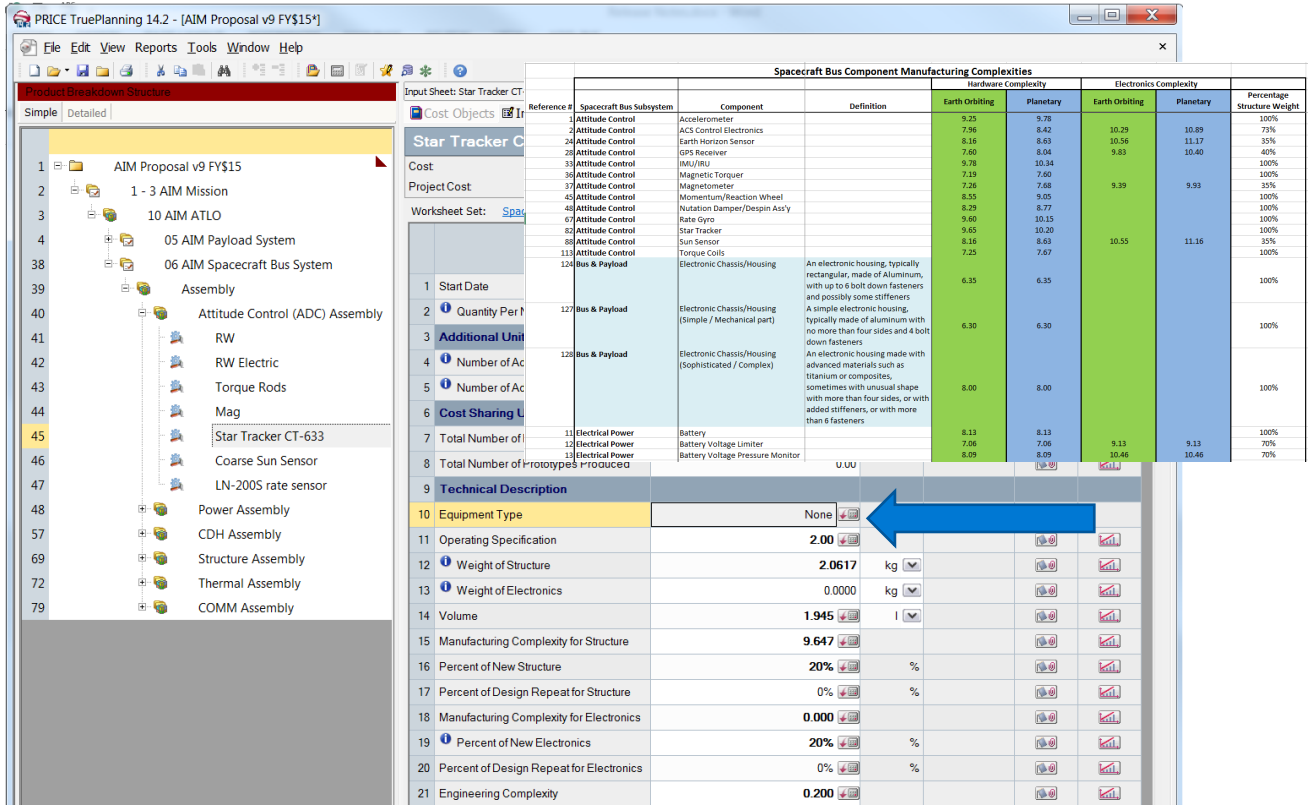
Building the Product Breakdown Structure



- 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

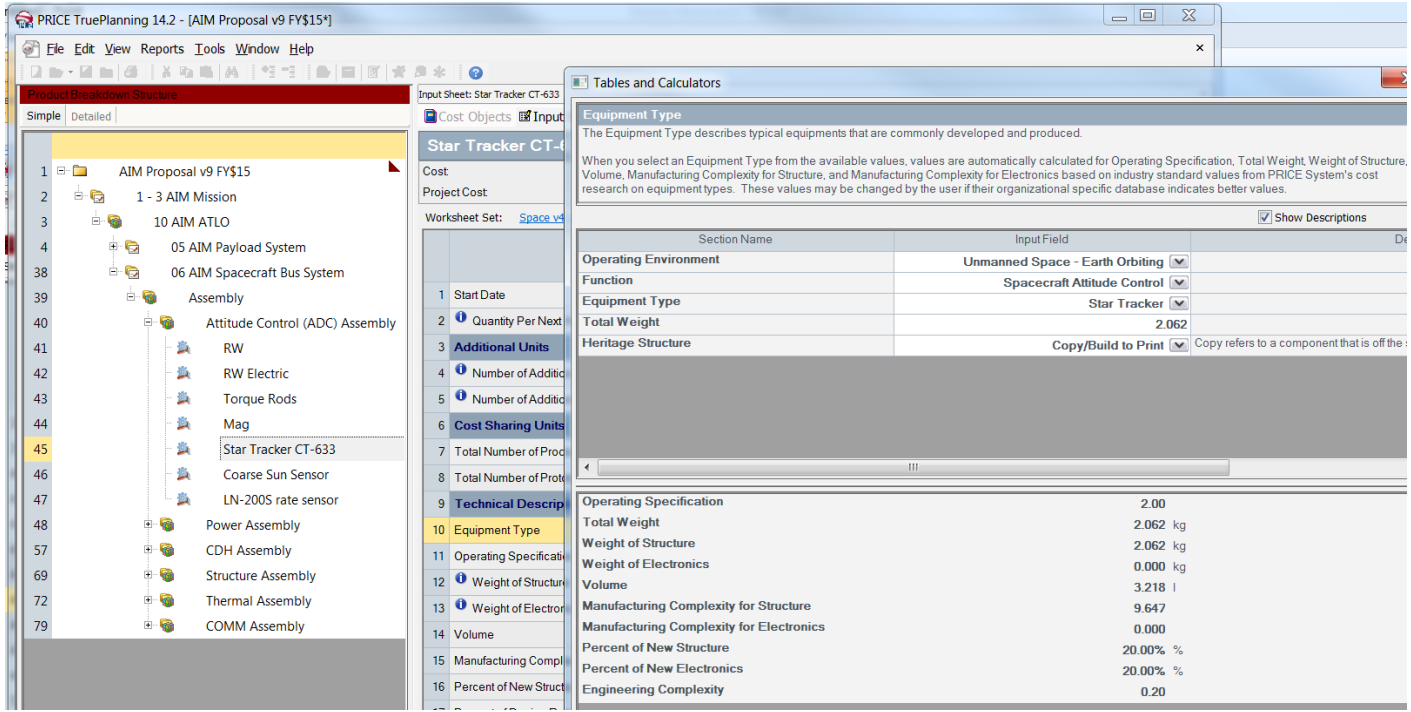


Spacecraft Bus Component Manufacturing Complexities

Reference #	Spacecraft Bus Subsystem	Component	Definition	Hardware Complexity: Earth Orbiting	Hardware Complexity: Planetary	Electronics Complexity: Earth Orbiting	Electronics Complexity: Planetary	Percentage Structure Weight
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		8.16	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		7.19	7.60			100%
37	Attitude Control	Magnetometer		7.26	7.68	9.39	9.93	35%
45	Attitude Control	Momentum/Reaction Wheel		8.55	9.05			100%
48	Attitude Control	Nutation Damper/Despin Ass'y		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 Calculator:

Completed Calculator Inputs



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)

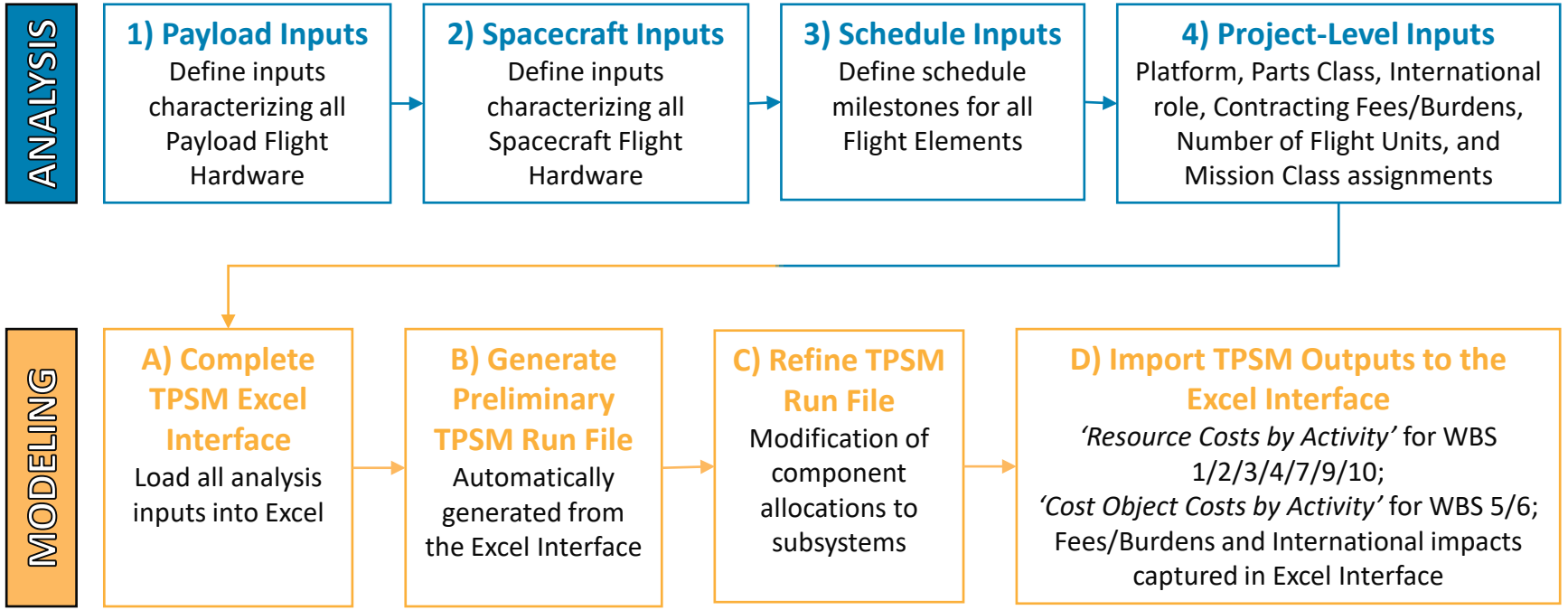
1992 – 2010

- 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 / *Component*
STRUCTURE & MECHANISMS
Primary Structure
Secondary Structure
Shielding
Solar Array Substrate/Structure
HGA Structure
Electronics Boxes
Mechanisms
Motor/Actuator
Booms
ROBOTIC ARM
Robotic Arm - Limb
Robotic Arm - Joint/Actuator
THERMAL CONTROL
MLI, Paints, Coatings
Heaters, RHUs, Thermostats
Radiators/Louvers
Heat Pipes
Cryocooler
PROPULSION
Propulsion Lines/Valves/Fittings
Pressure Regulator
Tanks
Thrusters
ELECTRIC PROPULSION
Ion Thruster *
Power Processing Unit *

Subsystem / *Component*
GUIDANCE, NAVIGATION, & CONTROL
Star Tracker
Sun Sensor
Reaction Wheel
Torque Rod
Gimbals
IMU-Gyro
Actuators
Radar Altimeter *
COMMUNICATIONS
Transponder
Transmitter
Amplifier
Misc RF Electronics
HGA
MGA/LGA
Waveguide/Comm Cabling
COMMAND & DATA HANDLING
Command/Data Processing
Solid State Memory
POWER
Power Management and Distribution
Solar Cells/Electrical
Pyrotechnics
Batteries
Harness

Subsystem / *Component*
ENTRY & DESCENT
Themal Protection System *
Parachute *
OPTICS
Optical Bench
Optics
Gratings
Filter Wheel
Optics Filters/Misc
SENSOR SYSTEMS
Laser *
Sensors-Detectors
CCD Detectors
Magnetometer
TOF Spectrometer
ESA sensor
Photodiode
Bolometer
Ion Source
Gamma Sensor
Neutron Sensor
Dust Detector
Readout Electronics

** Modeled using custom TPSM relationships*

TPSM Component Type Inputs (Steps 1 & 2)

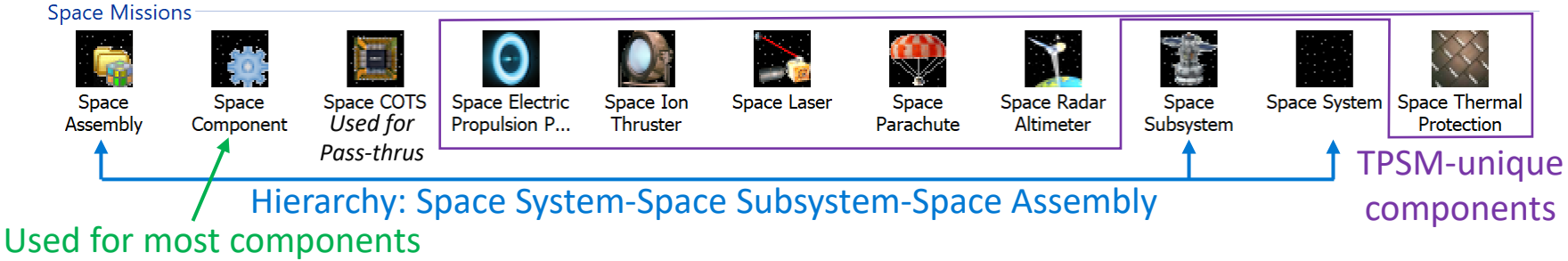
- There can be up to 5 different type inputs tailored to each ‘Component’
- The type inputs are generally arranged from lower cost (1) to higher cost (5)
- Component type inputs are used differently for each ‘Component’ and are used to estimate lower-level cost drivers (part volumes, electronics density,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

Subsys	Component	Tech Parameter	Type 1	2	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
	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		n/a	n/a	n/a	n/a	n/a
	Heaters, RHUs, Thermostats	*Material*	Aluminum	Stainless Steel	Titanium	Composite	XX
	Radiators/Louvers	*Material*	Aluminum	Stainless Steel	Titanium	Composite	XX
	Heat Pipes	*Material*	Aluminum	Stainless Steel	Titanium	Composite	XX
	Cryocooler	*Material*	Aluminum	Stainless Steel	Titanium	Composite	XX
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	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		n/a	n/a	n/a	n/a	n/a
	Torque Rod		n/a	n/a	n/a	n/a	n/a
	Gimbals	*Material*	Aluminum	Stainless Steel	Titanium	Composite	XX
	IMU-Gyro		n/a	n/a	n/a	n/a	n/a
	Actuators		n/a	n/a	n/a	n/a	n/a
Power							
	Power Management and Distribution	*Complexity*	Simple or Large-Scale	Nominal Space-based Device	Complex Device, Adv Switching or I&T	Very Complex Rad-Hard Device	XX
	Solar Cells/Electrical	*Complexity*	Silicon Solar Cells	Multi-Junction	Multi- Junction and High Efficiency	Low Intensity and Low Temperature or Advanced	XX
	Pyrotechnics	*Complexity*	Simple	Standard	Advanced	Very Advanced	XX
	Batteries	*Chemistry*	Non-rechargable	NiCd or NiH	Li-Ion	Advanced Chemistry	XX
	Power Harness/Cabling		n/a	n/a	n/a	n/a	n/a
Sensor Systems							
	Sensors/Detectors	*Complexity*	Simple	Nominal	Complex	Very Complex	XX
	Charge Coupled Device Detectors	*Complexity*	Most Visible, Si-based CCDs	Adv Vis, Most UV/IR (HgCdTe)	Adv Multi-Spectral	Very Complex	XX
	Magnetometer	*Complexity*	Simple/Standard	Advanced	Very Advanced	XX	XX
	Time Of Flight Spectrometer	*Complexity*	Simple	Standard	Customized/High Performance	Advanced	XX
	Electro-Static Analyzer Sensor	*Complexity*	Simple	Standard	Customized/High Performance	Advanced	XX
	Photodiode	*Complexity*	Simple	Standard	Customized/High Performance	Advanced	XX
	Bolometer	*Complexity*	Simple	Standard	Customized/High Performance	Advanced	XX
	Ion Source	*Complexity*	Simple	Standard	Customized/High Performance	Advanced	XX
	Gamma Sensor	*Complexity*	Simple	Standard	Customized/High Performance	Advanced	XX
	Neutron Sensor	*Complexity*	Simple	Standard	Customized/High Performance	Advanced	XX
	Dust Detector	*Complexity*	Simple/Standard	Advanced	Very Advanced	XX	XX
	Read Out Electronics	*Complexity*	Simple	Standard	Advanced	Very Advanced	XX
	Laser		n/a	n/a	n/a	n/a	n/a
Optics							
	Optical Bench	*Material*	Aluminum	Stainless Steel	Titanium	Composite	XX
	Optics	*Complexity*	Simple	Standard	Advanced	Very Advanced	XX
	Gratings	*Complexity*	Simple	Standard	Advanced	Very Advanced	XX
	Filter Wheel	*Material*	Aluminum	Stainless Steel	Titanium	Composite	XX
	Optic Filters/Miscellaneous	*Complexity*	Simple	Standard	Advanced	Very Advanced	XX
Robotic Arm							
	Robotic Arm - Limb	*Material*	Aluminum	Stainless Steel	Titanium	Composite	XX
	Robotic Arm - Joint-Actuator	*Complexity*	Simple	Standard	Advanced	Very Advanced	XX

TPSM Component Type Input Matrix (Steps 1 & 2)

Subsys	Component	Tech Parameter	Type 1	2	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
	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		n/a	n/a	n/a	n/a	n/a
	Heaters, RHUs, Thermostats	*Material*	Aluminum	Stainless Steel	Titanium	Composite	XX
	Radiators/Louvers	*Material*	Aluminum	Stainless Steel	Titanium	Composite	XX
	Heat Pipes	*Material*	Aluminum	Stainless Steel	Titanium	Composite	XX
	Cryocooler	*Material*	Aluminum	Stainless Steel	Titanium	Composite	XX
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	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		n/a	n/a	n/a	n/a	n/a
	Torque Rod		n/a	n/a	n/a	n/a	n/a
	Gimbals	*Material*	Aluminum	Stainless Steel	Titanium	Composite	XX
	IMU-Gyro		n/a	n/a	n/a	n/a	n/a
	Actuators		n/a	n/a	n/a	n/a	n/a
Power							
	Power Management and Distribution	*Complexity*	Simple or Large-Scale	Nominal Space-based Device	Complex Device, Adv Switching or I&T	Very Complex Rad-Hard Device	XX
	Solar Cells/Electrical	*Complexity*	Silicon Solar Cells	Multi-Junction	Multi- Junction and High Efficiency	Low Intensity and Low Temperature or Advanced	XX
	Pyrotechnics	*Complexity*	Simple	Standard	Advanced	Very Advanced	XX
	Batteries	*Chemistry*	Non-rechargable	NiCd or NiH	Li-ion	Advanced Chemistry	XX
	Power Harness/Cabling		n/a	n/a	n/a	n/a	n/a
Sensor Systems							
	Sensors/Detectors	*Complexity*	Simple	Nominal	Complex	Very Complex	XX
	Charge Coupled Device Detectors	*Complexity*	Most Visible, Si-based CCDs	Adv Vis, Most UV/IR (HgCdTe)	Adv Multi-Spectral	Very Complex	XX
	Magnetometer	*Complexity*	Simple/Standard	Advanced	Very Advanced	XX	XX
	Time Of Flight Spectrometer	*Complexity*	Simple	Standard	Customized/High Performance	Advanced	XX
	Electro-Static Analyzer Sensor	*Complexity*	Simple	Standard	Customized/High Performance	Advanced	XX
	Photodiode	*Complexity*	Simple	Standard	Customized/High Performance	Advanced	XX
	Bolometer	*Complexity*	Simple	Standard	Customized/High Performance	Advanced	XX
	Ion Source	*Complexity*	Simple	Standard	Customized/High Performance	Advanced	XX
	Gamma Sensor	*Complexity*	Simple	Standard	Customized/High Performance	Advanced	XX
	Neutron Sensor	*Complexity*	Simple	Standard	Customized/High Performance	Advanced	XX
	Dust Detector	*Complexity*	Simple/Standard	Advanced	Very Advanced	XX	XX
	Read Out Electronics	*Complexity*	Simple	Standard	Advanced	Very Advanced	XX
	Laser		n/a	n/a	n/a	n/a	n/a
Optics							
	Optical Bench	*Material*	Aluminum	Stainless Steel	Titanium	Composite	XX
	Optics	*Complexity*	Simple	Standard	Advanced	Very Advanced	XX
	Gratings	*Complexity*	Simple	Standard	Advanced	Very Advanced	XX
	Filter Wheel	*Material*	Aluminum	Stainless Steel	Titanium	Composite	XX
	Optic Filters/Miscellaneous	*Complexity*	Simple	Standard	Advanced	Very Advanced	XX
Robotic Arm							
	Robotic Arm - Limb	*Material*	Aluminum	Stainless Steel	Titanium	Composite	XX
	Robotic Arm - Joint-Actuator	*Complexity*	Simple	Standard	Advanced	Very Advanced	XX

TPSM Space Missions Objects



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

TPSM Schedule Milestones (Step 3)

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

TPSM Project-Level Inputs (Step 4)

There are 7 Project-Level Inputs:

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

TPSM Output (Step D)

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

Mission Name

WBS	*RY$K*	DES	FAB	I&T	LOCO	TOTAL
1	PM	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 Units	Flight Spares	EMs & Proto-types	FLIGHT HARDWARE MASSES: Total Mass, CBE	Contingency %	Total Mass w/ Contingency	OTHER COMPONENT INFORMATION: Description (Vendor, Part #, Heritage Basis)	Other characteristics/issues (volume, power, other component-specific items)	TPSM COST MODEL INPUTS: 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	harge Coupled Device Detecto	2
Readout Electronics	1.00	4	1	1	4.00			Modified Past Design		Minor Mod		Sensor Systems	Read Out Electronics	2
Focal Plane Asembly Housing	1.50	4	1	1	6.00				Aluminum	New		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	3
Power Management	1.00	1	0	1	1.00	0%	0.00	Modified past design		Minor Mod		Power	ver 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	2
PCI backplane	0.50	1	0	1	0.50	0%	0.00	COTS part		Copy		Command and Data Ha	Command/Data Processing 8	1
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)

		# OF UNITS			FLIGHT HARDWARE MASSES			OTHER COMPONENT INFORMATION		TPSM COST MODEL INPUTS				
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)	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)

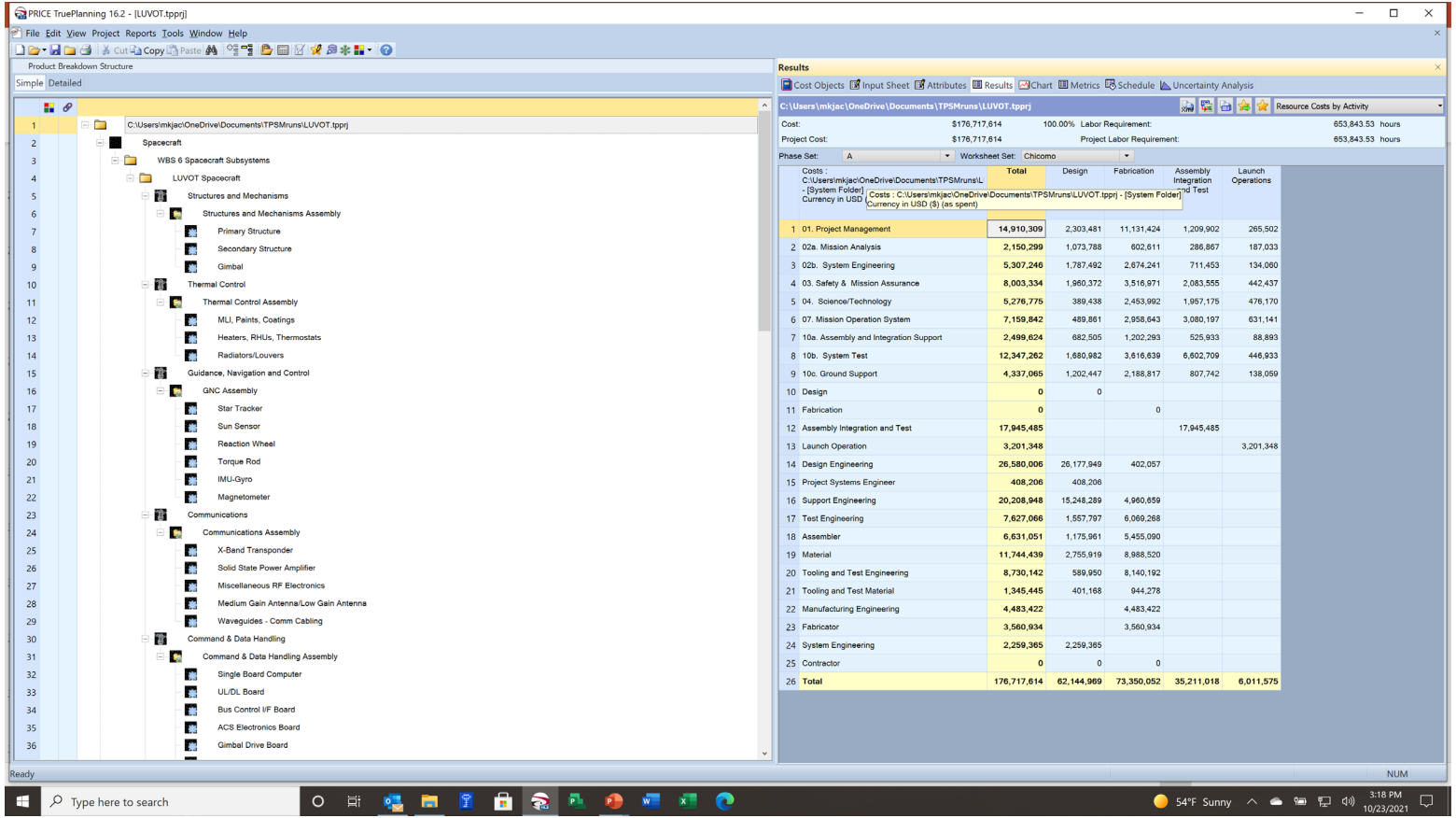
	Phase B start	PDR [1]	CDR	Deliver to System I&T	Ship to Launch Site	Launch	On-Orbit Chect-Out (L+30d)
Project	1/2/2022	11/17/2022	10/2/2023	10/1/2024	4/2/2026	8/1/2026	8/31/2026
LUVOT Spacecraft	1/2/2022	11/17/2022	10/2/2023	10/1/2024	4/2/2026	8/1/2026	8/31/2026
UVOT Telescope Optical /	1/2/2022	11/17/2022	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 Assemb	P	S1	N			1		Class C/D
Detectors/Electronics	P	S1	N			1		
Filter Wheel Assembly	P	S1	N			1		
Structure, Mechanical, & Therm	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						
RY$K		DES	FAB	I&T	LOCO	TOTAL
1	PM	2,303	11,131	1,210	266	**14,910**
2	SE	2,861	3,277	998	321	**7,458**
3	MA	1,960	3,517	2,084	442	**8,003**
4	SciTm	389	2,454	1,957	476	**5,277**
5	Pyld	14,814	19,357	6,179	1,151	**41,501**
	UVOT Telescope Assembly	1,374	1,509	407	108	**3,398**
	Detectors/Electronics	4,019	9,472	2,847	570	**16,908**
	Filter Wheel Assembly	1,968	4,329	757	114	**7,168**
	Structure, Mechanical, & Thermal	2,625	2,064	666	149	**5,503**
	UVOT Electronics Box	4,250	1,939	1,332	186	**7,708**
	Harness	579	45	170	23	**817**
	Instr PM/SE/MA					**0**
	Instr I&T/GSE					**0**
6	S/C	35,761	23,647	11,766	2,051	**73,225**
	LUVOT S/C	35,761	23,647	11,766	2,051	**73,225**
	S/C PM/SE/MA					**0**
	S/C I&T/GSE					**0**
7/9	MOS/GDS	490	2,959	3,080	631	**7,160**
10	I&T	3,566	7,008	7,936	674	**19,184**
	TOTAL	**62,145**	**73,350**	**35,211**	**6,012**	**176,718**

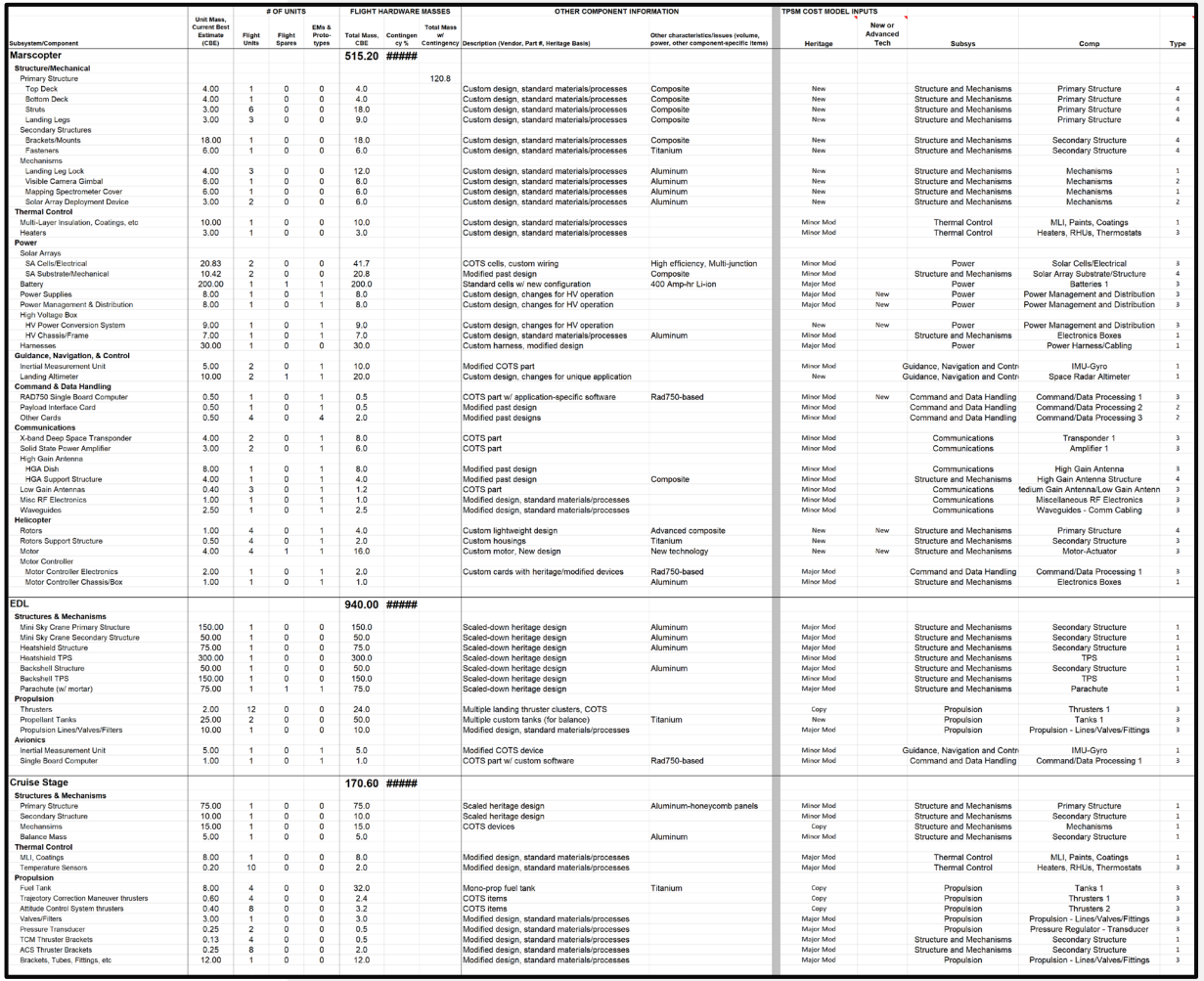
Case Study 1: LUVOT (TruePlanning Output)



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	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
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	arge Coupled Device Detecto	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	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	ver Management and Distribu	2
Power Management & Distribution	2.00	1	0	1	2.00			Modified past design		Major Mod		Power	ver 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	arge Coupled Device Detecto	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	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	ver Management and Distribu	2
Power														
Power Conditioning	2.00	1	0	1	2.00			Modified past design		Minor Mod		Power	ver 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 Units	# OF UNITS: Flight Spares	# OF UNITS: EMs & Proto-types	FLIGHT HARDWARE MASSES: Total Mass, CBE	FLIGHT HARDWARE MASSES: Contingency %	FLIGHT HARDWARE MASSES: Total Mass w/ Contingency	OTHER COMPONENT INFORMATION: Description (Vendor, Part #, Heritage Basis)	OTHER COMPONENT INFORMATION: Other characteristics/issues (volume, power, other component-specific items)	TPSM COST MODEL INPUTS: Heritage	TPSM COST MODEL INPUTS: New or Advanced Tech	TPSM COST MODEL INPUTS: Subsys	TPSM COST MODEL INPUTS: Comp	TPSM COST MODEL INPUTS: Type
Marscopter					**515.20**	**#####**								
Structure/Mechanical														
Primary Structure							120.8							
Top Deck	4.00	1	0	0	4.0			Custom design, standard materials/processes	Composite	New		Structure and Mechanisms	Primary Structure	4
Bottom Deck	4.00	1	0	0	4.0			Custom design, standard materials/processes	Composite	New		Structure and Mechanisms	Primary Structure	4
Struts	3.00	6	0	0	18.0			Custom design, standard materials/processes	Composite	New		Structure and Mechanisms	Primary Structure	4
Landing Legs	3.00	3	0	0	9.0			Custom design, standard materials/processes	Composite	New		Structure and Mechanisms	Primary Structure	4
Secondary Structures														
Brackets/Mounts	18.00	1	0	0	18.0			Custom design, standard materials/processes	Composite	New		Structure and Mechanisms	Secondary Structure	4
Fasteners	6.00	1	0	0	6.0			Custom design, standard materials/processes	Titanium	New		Structure and Mechanisms	Secondary Structure	4
Mechanisms														
Landing Leg Lock	4.00	3	0	0	12.0			Custom design, standard materials/processes	Aluminum	New		Structure and Mechanisms	Mechanisms	1
Visible Camera Gimbal	6.00	1	0	0	6.0			Custom design, standard materials/processes	Aluminum	New		Structure and Mechanisms	Mechanisms	2
Mapping Spectrometer Cover	6.00	1	0	0	6.0			Custom design, standard materials/processes	Aluminum	New		Structure and Mechanisms	Mechanisms	1
Solar Array Deployment Device	3.00	2	0	0	6.0			Custom design, standard materials/processes	Aluminum	New		Structure and Mechanisms	Mechanisms	2
Thermal Control														
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	3
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														
HV Power Conversion System	9.00	1	0	1	9.0			Custom design, changes for HV operation		New	New	Power	Power Management and Distribution	3
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 Contr	IMU-Gyro	1
Landing Altimeter	10.00	2	1	1	20.0			Custom design, changes for unique application		New		Guidance, Navigation and Contr	Space Radar Altimeter	1
Command & Data Handling														
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
High Gain 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	ledium Gain Antenna/Low Gain Antenn	3
Misc 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
Rotors Support Structure	0.50	4	0	1	2.0			Custom housings	Titanium	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														
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	3
Motor Controller Chassis/Box	1.00	1	0	1	1.0				Aluminum	Minor Mod		Structure and Mechanisms	Electronics Boxes	1
EDL					**940.00**	**#####**								
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		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		Minor Mod		Guidance, Navigation and Contr	IMU-Gyro	1
Single Board Computer	1.00	1	0	1	1.0			COTS part w/ custom software	Rad750-based	Minor Mod		Command and Data Handling	Command/Data Processing 1	3
Cruise Stage					**170.60**	**#####**								
Structures & Mechanisms														
Primary Structure	75.00	1	0	0	75.0			Scaled heritage design	Aluminum-honeycomb panels	Minor Mod		Structure and Mechanisms	Primary Structure	1
Secondary Structure	10.00	1	0	0	10.0			Scaled heritage design		Minor Mod		Structure and Mechanisms	Secondary Structure	1
Mechansims	15.00	1	0	0	15.0			COTS devices		Copy		Structure and Mechanisms	Mechanisms	1
Balance Mass	5.00	1	0	0	5.0				Aluminum	Minor Mod		Structure and Mechanisms	Secondary Structure	1
Thermal Control														
MLI, Coatings	8.00	1	0	0	8.0			Modified design, standard materials/processes		Major Mod		Thermal Control	MLI, Paints, Coatings	1
Temperature Sensors	0.20	10	0	0	2.0			Modified design, standard materials/processes		Major Mod		Thermal Control	Heaters, RHUs, Thermostats	3
Propulsion														
Fuel Tank	8.00	4	0	0	32.0			Mono-prop fuel tank	Titanium	Copy		Propulsion	Tanks 1	3
Trajectory Correction Maneuver thrusters	0.60	4	0	0	2.4			COTS items		Copy		Propulsion	Thrusters 1	3
Attitude Control System thrusters	0.40	8	0	0	3.2			COTS items		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)

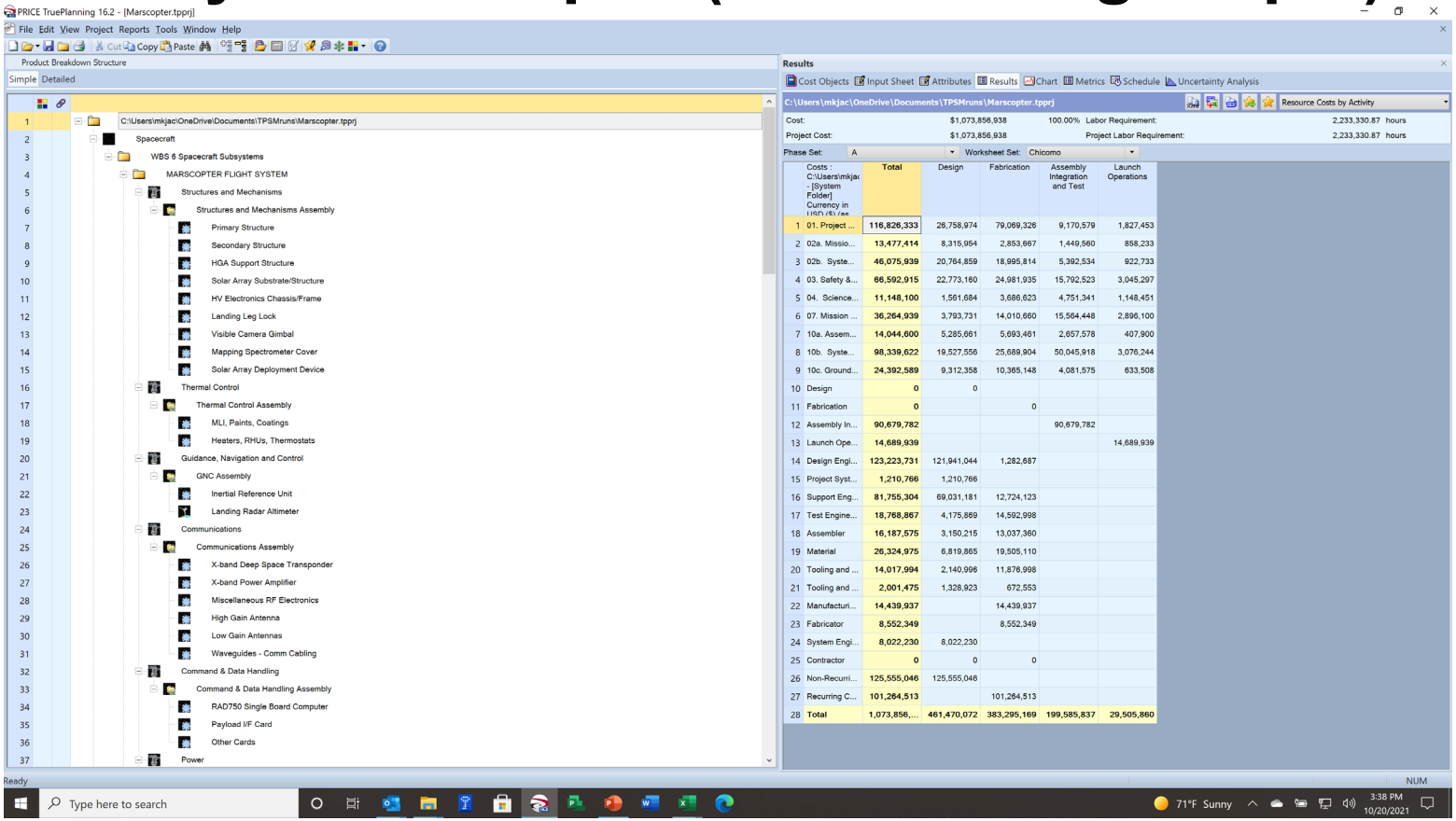
	Phase B start	PDR [1]	CDR	Deliver to System I&T	Ship to Launch Site	Launch	On-Orbit Chect-Out (L+30d)
Project	1/2/2022	4/3/2023	7/2/2024	1/1/2026	10/1/2027	1/31/2028	3/1/2028
Marscopter	1/2/2022	4/3/2023	5/17/2024	12/16/2025	10/1/2027	1/31/2028	3/1/2028
EDL	1/2/2022	4/3/2023	6/2/2024	12/16/2025	10/1/2027	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						
RY$K		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)

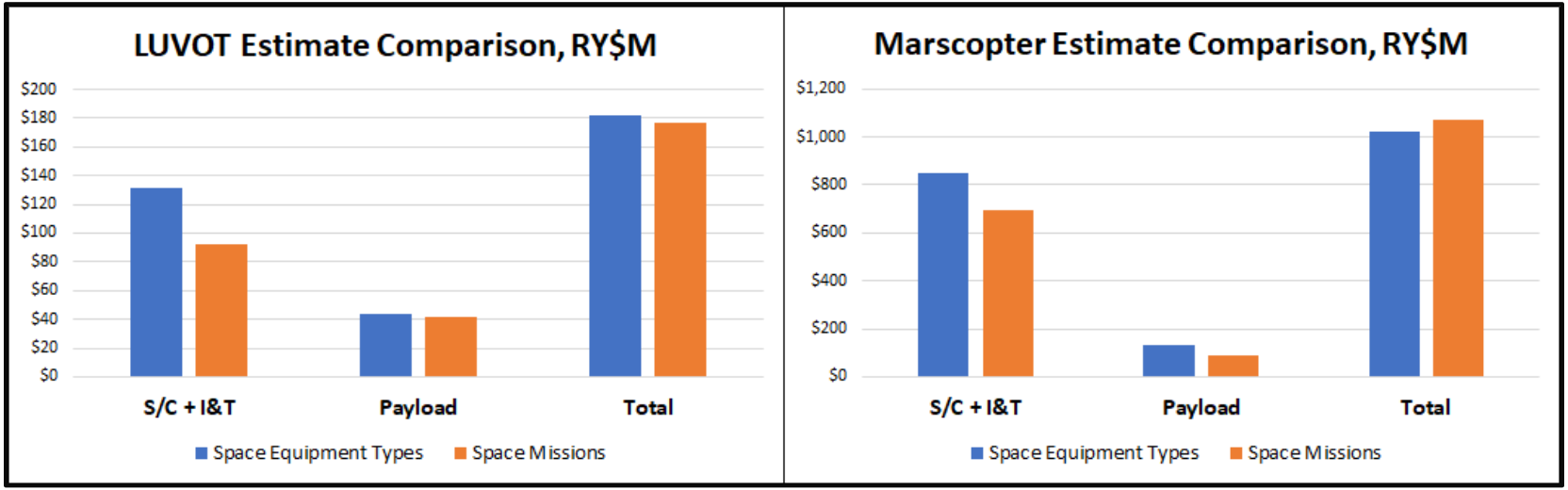


	Costs : C:\Users\mkjac - [System Folder] Currency in USD ($) as	Total	Design	Fabrication	Assembly Integration and Test	Launch Operations
1	01. Project ...	116,826,333	26,758,974	79,069,326	9,170,579	1,827,453
2	02a. Missio...	13,477,414	8,315,954	2,853,667	1,449,560	858,233
3	02b. Syste...	46,075,939	20,764,859	18,995,814	5,392,534	922,733
4	03. Safety &...	66,592,915	22,773,160	24,981,935	15,792,523	3,045,297
5	04. Science...	11,148,100	1,561,684	3,686,623	4,751,341	1,148,451
6	07. Mission ...	36,264,939	3,793,731	14,010,660	15,564,448	2,896,100
7	10a. Assem...	14,044,600	5,285,661	5,693,461	2,657,578	407,900
8	10b. Syste...	98,339,622	19,527,556	25,689,904	50,045,918	3,076,244
9	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	16,187,575	3,150,215	13,037,360		
19	Material	26,324,975	6,819,865	19,505,110		
20	Tooling and ...	14,017,994	2,140,998	11,876,998		
21	Tooling and ...	2,001,475	1,328,923	672,553		
22	Manufacturi...	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-Recurri...	125,555,046	125,555,046			
27	Recurring C...	101,264,513		101,264,513		
28	Total	1,073,856,...	461,470,072	383,295,169	199,585,837	29,505,860

Validation Study Results

TP Result Comparisons

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



Application Considerations

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

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

Q and A