GAJAT
A Rapid Prototyping Mission Architecture Tool With Embedded Costing

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GAJAT

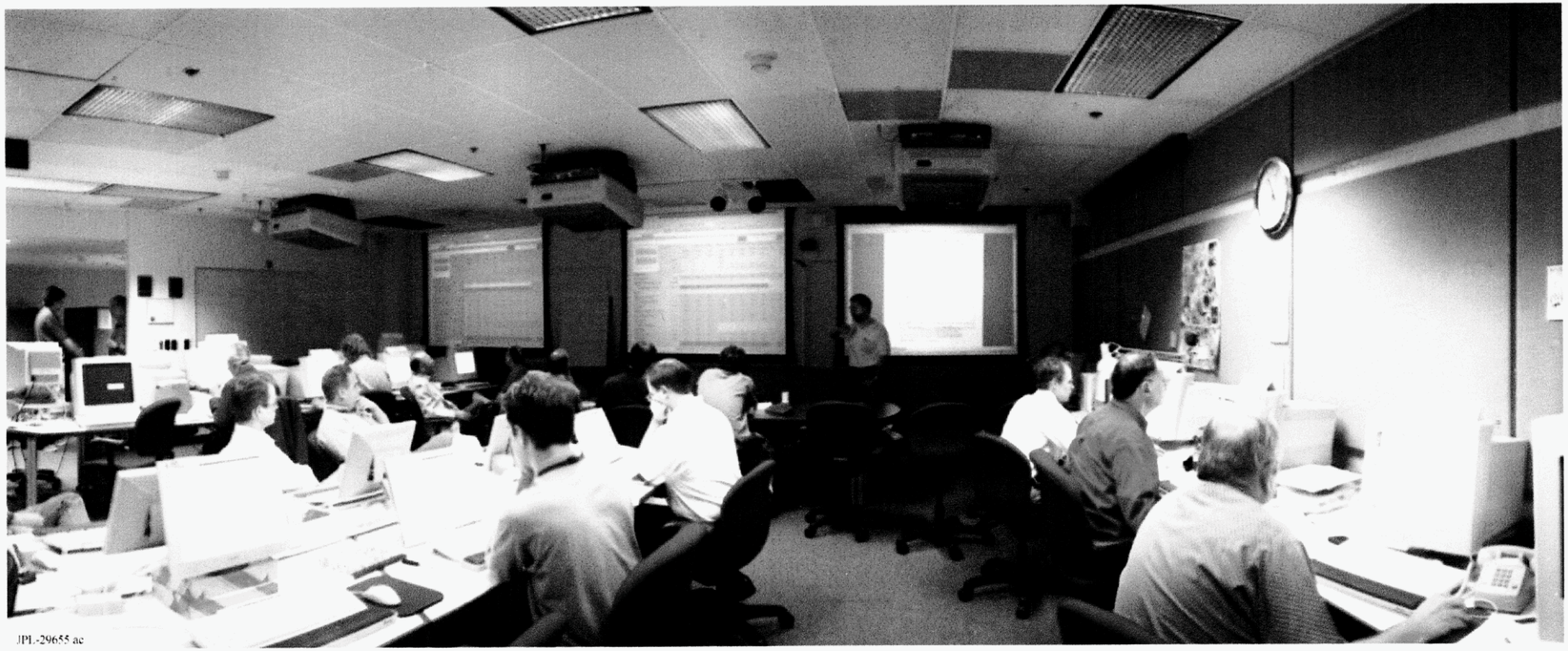
GAJAT Is a Near Earth Mission Architecture (NEMA) Rapid Prototyping Analysis Tool. It Was Designed To Be Operated by a Single Systems Engineer to Replicate the Mission Design Output of JPL's Team X.

Similar to Team X, GAJAT Provides Estimates For:

- The Overall Design of an Observatory With a Defined Payload [Instrument(s)]
- The Spacecraft Consumable Resources Required to Support the Mission Over Its Specified Operational Period
- The Minimum Launch Vehicle Capability Requirement
- The Ground Segment Requirements, and
- The Cost for Developing and Launching the Observatory (*Mission Development Cost*) and the Cost to Operate the System Over the Specified Operational Period (*Mission Operations Cost),* the Sum of These Two Being the *Total Mission Cost*.

Team X

Team X Is a Concurrent Engineering Environment in Which a Nominal 20 Engineering Specialist, Operating From a Common Date Base, Formulate the Design and Cost of a Mission Under Study.



JPL-29655 ac

GAJAT Mission Design (Technical Outputs Summary)

GAJAT Provides Technical Estimates For:

- **Observatory Dry & Wet Masses**
- **Subsystems Masses**
- **Solar Array (Hi/lo Technology) Size & Articulation Requirements**
- **Battery Am-hr Capacity, DOD and Spacecraft Voltage**
- **Data Storage (SSR) Volume**
- **Command, Telemetry & Science Downlink Data Rates & Link Margin Analyses Based On:**
  - Data Volume
  - Error Protection Coding
  - Ground Station Antenna Elevation Angle
  - Ground Station Antenna Diameter
  - Ground Station & Observatory Antenna Pointing Errors
  - Transmission Band(s) & Protocols (CCSDS Packetization, TDM, etc.)
  - Antenna Types – HGA, MGA, LGA (Omni)
- **Propulsion Requirements For:**
  - Orbit Maintenance
  - Correction for L/V Orbit Insertion Errors (Altitude & Inclination)
  - De-orbit
- **Required Number of Ground Station/TDRS & Contact Times for Downlinking of Science Data & for Performing Command Generation and Housekeeping Telemetry Collection**
- **ACS Minimum Reaction Wheel & Torque Rod Sizes**
- **Launch Vehicle Selection With Launch Mass Margin**

GAJAT Mission Design (Cost Outputs Summary)

GAJAT Provides Cost Estimates For:

- **Mission Development Cost**
  - Phase A
  - Phase B
  - Phase C/D, The Observatory Development & Associated Programmatic Cost
  - The Spacecraft Bus
  - The Assembly, Test, Launch and On-orbit Checkout (ATLO)
  - Subsystems
  - Solar Array (Hi/lo Technology) & Articulation
  - Data Storage (SSR) Volume
- **Mission Operations Cost**
- **Total Mission Cost**

GAJAT Data Input Sets

Mission Data Input
- Mission Duration
- Orbit Requirements
- Mass Reserves
- Cost Reserves
- Deorbit Requirements

Payload Resource Req. w/% Contingency Input
- Mass
- Power
- Data Rate
- Operate time in Sun light/Eclipse
- Estimated Cost (Year of estimate)

Solar Array & Battery Inputs
- S/A Technology
- Alpha & Beta Angle
- Articulation
- Bus Voltage
- Battery DOD
- Initial On-Orbit deployment time

Spacecraft Bus Power Initial Estimates & % Contingency Input
- ACS
- C&DH
- Comms w/S-band & X-band D/L time/orbit
- Propulsion
- Thermal
- Harness Loss
- Power

D/L Link Analysis Input
- Science D/L Type (S, X, K)
- RF Outputs per D/L
- Transmit Antennas Beamwidths
- Desired Bit Error Rate
- Error Protection Coding Type(s)
- Data Formatting
- Gnd Std Elevation Angle
- Gnd Std Antenna Diameter
- Gnd Std & S/C Antenna Pointing Error

Data Storage & Gnd Station Inputs
- Number of required orbits of storage
- S/C & P/L Housekeeping Data Requirements
- Data storage capacity contingency
- D/L Data Rate
- Gnd Station Contact Opportunities/Orbit
- D/L Data Rate to satisfy Gnd Station Contacts and Data Volume

Reaction Wheel, Torque Bar & Delta V Inputs
- S/C Slew Time & Angle
- SS & Peak RW Speed
- Estimated X, Y & Z Size of Deployed S/C
- L/V Injection Error

GAJAT C&DH Subsystem Outputs

Payload Resource Req. w/% Contingency Input
- Mass
- Power
- Data Rate
- Operate time in Sun light/Eclipse
- Estimated Cost (Year of estimate)

Data Storage & Gnd Station Analysis Outputs & Inputs
- Number of required orbits of storage
- S/C & P/L Housekeeping Data Requirements
- Data storage capacity contingency

C&DH Requirements Analysis & Outputs
- S/C & P/L Housekeeping Cmd & Tlm Data Rates
- Scince D/L Data Rates
- Data storage (SSR) capacity & contingency
- Min. Gnd Station Contact times per Orbit
- SSR Cost

Note: Red Text Within the Input Boxes Is the Input to the Next Analysis.

GAJAT Comms & Gnd Std Subsystems Outputs

C&DH Requirements Analysis & Outputs

- S/C & P/L Housekeeping Cmd & Tlm Data Rates
- Science Data Rates
- Data storage capacity & contingency
- Min. Gnd Station Contact times per Orbit
- SSR Cost

D/L Link Analysis & Inputs

- Science D/L Type (S, X, K)
- RF Outputs per D/L
- Transmit Antennas Beamwidths
- Desired Bit Error Rate
- Error Protection Coding Type(s)
- Data Formatting
- Gnd Std Elevation Angle
- Gnd Std Antenna Diameter
- Gnd Std & S/C Antenna Pointing Error

Comms & Gnd Std Req. Requirements Analysis & Outputs

Comms

- Cmd, Tlm & Science Link Types (S, X, K)
- Data Rates
- RF Power Outputs per Link
- Transmit Antennas Beamwidths
- Bit Error Rates
- Error Protection Coding Type(s)
- Data Formatting
- Max. allowable S/C Antenna Pointing error

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Gnd Std

- Min. Gnd Std Elevation Angle
- Min.Gnd Std Antenna Diameter
- Max. allowable Gnd Std Antenna Pointing Errors
- Min. Gnd Station Contact times per Orbit
- Link Margins

Note: Red Text Within the Input Boxes Is the Input to the Next Analysis.

GAJAT Power Subsystem Outputs

Mission Data Input
- Mission Duration
- Orbit Requirements
- Mass Reserves
- Cost Reserves
- Deorbit Requirements

C&DH Requirements Analysis & Outputs
- Data storage capacity & contingency

Payload Resource Req. w/% Contingency Input
- Mass
- Power
- Data Rate
- Operate time in Sun light/Eclipse
- Estimated Cost (Year of estimate)

Comms & Gnd Std Req. Requirements Analysis & Outputs
- RF Power Outputs per Link
- Min. Gnd Station Contact times per Orbit

Solar Array & Battery Inputs
- S/A Technology
- Alpha & Beta Angle
- Articulation
- Bus Voltage
- Battery DOD
- Initial On-Orbit deployment time

Spacecraft Bus Power Initial Estimates & % Contingency Input
- ACS
- C&DH
- Comms w/S-band & X-band D/L time/orbit
- Propulsion
- Thermal
- Harness Loss
- Power

Power Subsystem Requirements Analysis & Outputs

Solar Array
- Technology
- BOL & EOL Pwr
- Size – m^2
- Cost
- Mass
- P/L Orbital Avg Pwr
- Bus Orbital Avg Pwr

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Battery
- Voltage
- Amp-hr Capacity
- DoD

Note: Red Text Within the Input Boxes Is the Input to the Next Analysis.

GAJAT ACS & Power Subsystems Outputs

Mission Data Input
- Mission Duration
- Orbit Requirements
- Mass Reserves
- Cost Reserves
- Deorbit Requirements

Reaction Wheel, Torque Bar & Delta V Inputs
- S/C Slew Time & Angle
- SS & Peak RW Speed
- Estimated X, Y & Z Size of Deployed S/C
- L/V Injection Error

ACS & Propulsion Subsystem Requirements Analysis & Outputs

ACS
- Min.ACS Wheels size, mass & pwr
- Min. Torque Bar size

&

Propulsion
- Propulsion Mass for:
  - Atmospheric Drag Makeup
  - L/V Injection Errors
  - Deorbit
- Propulsion Tank & associated mounting hardware mass

Note: Red Text Within the Input Boxes Is the Input to the Next Analysis.

Bus Cost Algorithm

Payload Resource Req. w/% Contingency Input
- Mass
- Power
- Data Rate
- Operate time in Sun light/Eclipse
- Estimated Cost (Year of estimate)

→

P/L Mass Fraction Estimator
1–100 kg → 30%
101-400kg → 45%
401-1000kg → 55%
>1000kg → 60%

→

P/L Mass Fraction to Spacecraft Dry Mass Estimator

↓

Initial Estimate of:
- **Spacecraft Dry Mass w/contingency**
- **Subsystem Masses based on a % allocation of S/C dry mass**

ACS, C&DH, Power & Propulsion Subsystem Requirements Analysis & Outputs (mass)

→

Spacecraft Dry Mass w/contingency
Subsystem Allocations Adjusted For Sizing of:
Pwr Subsystem S/A
C&DH Subsystem SSR
Prop. Subsystem ΔV Req.
ACS Subsystem wheels

→

Mass to S/C Bus Cost Estimator
1-100kg → mass * K1
101-400 → mass * K2
401-1000 → mass * K3
>1000 → mass * K4

→

Initial S/C Bus Cost Estimate

Note: Red Text Within the Input Boxes Is the Input to the Next Analysis.

GAJAT Observatory Mass Summary Output Sheet

Spacecraft	Nominal % of SC (Dry)	Actual % of SC (Dry)	Mass (kg)	Optional Input
				If you wish to over-ride the nominal mass fractions (MF), enter the desired MF (% of SC dry) in this column.
Payload				
Payload Total			1200.0	
Payload Total	**43.4%**	**60.0%**	**1200.0**	
Payload Mass Fraction		60.0%		
Bus Total Mass	**56.6%**	**40.0%**	**800**	
Spacecraft Total (Dry)			**2000**	
Bus				
ACS	6.7%	4.7%	94.7	
CDH	1.8%	1.3%	25.4	
PWR	14.9%	10.5%	210.6	
Prop	4.1%	2.9%	58.0	4.1%
Structure	21.0%	14.8%	345.8	
S/C Adapter	1.9%	1.3%	26.9	
Cabling	3.8%	2.7%	53.7	
Telecom	1.0%	0.7%	14.1	
Thermal	3.0%	2.1%	42.4	
Bus Total	**58.2%**	**41.1%**	**872**	4.1%
Spacecraft Total (Dry)			**2072**	
Bus Mass Contingency		30.0%	261	
Payload Mass Contingency		30.0%	360	
Spacecraft w/Contingency		**30.0%**	**2693**	
Propellant & Pressurant		8.3%	243	
Solid Rocket Motor Mass (kg)			0	
Spacecraft Total (Wet)			**2936**	
Launch Mass			**2936**	
Launch Vehicle Capability			**3100**	
Delta II - 79				
Launch Vehicle Margin			**164**	
Launch Vehicle Margin (%)			5.3%	

Derived from P/L Mass Fraction Estimator – see VG #11

Manual adjustments can be made by systems engineer based on experience by inputting changes in light green cells.

Actual Mass = 2967kg

GAJAT Observatory Cost Output Sheet (w/o Cost Reserves)

Fiscal Year Estimates	2000
	($M)
AURA Observatory Cost	
WBS Element Total Adjusted to Fiscal Year	**$661.4**
AURA Payload - Instrument(s)	$460.4
Bus	$167.7
ATLO	$33.3

Si Solar Array Cost =	$11.5 M
GaAs Solar Array Cost =	$8.6 M
C&DH SSR Cost =	$0.9 M
Suggested Power Cost =	$10.1 M

Fiscal Year Estimates	2003		
AURA Observatory	($M)		
WBS Elements	1st Mission	Optional Cost Input to adjust cost based on mission unique areas	
Element Total	**$722.7**		
AURA Observatory	**$686.3**		
Spacecraft Bus	**$181.0**		**$183.2**
S/C Bus Management	$9.2		5.1%
S/C Bus Engineering	$3.2		1.8%
ACS	$54.0		29.8%
Power	$10.2	10.2	4.4%
Propulsion	$10.2		5.6%
Structures	$7.6		4.2%
Thermal	$3.7		2.0%
Telecom	$34.2		18.9%
C&DH	$25.8		14.2%
Harness	$1.1		0.6%
C&DH Software	$17.5		9.7%
Testbeds	$6.6		3.6%
Payload - Instrument(s)	**$503.1**		**100.0%**
ATLO	**$36.4**		5.3%
System-Level A,I&T	$28.8		79.3%
Mechanical Build-Up	$7.5		20.7%
Launch and Orbital Ops		Included in ATLO	100.0%
		ATLO Total:	**36.35**
Burden & Fee		Included in Subsystem Costs	

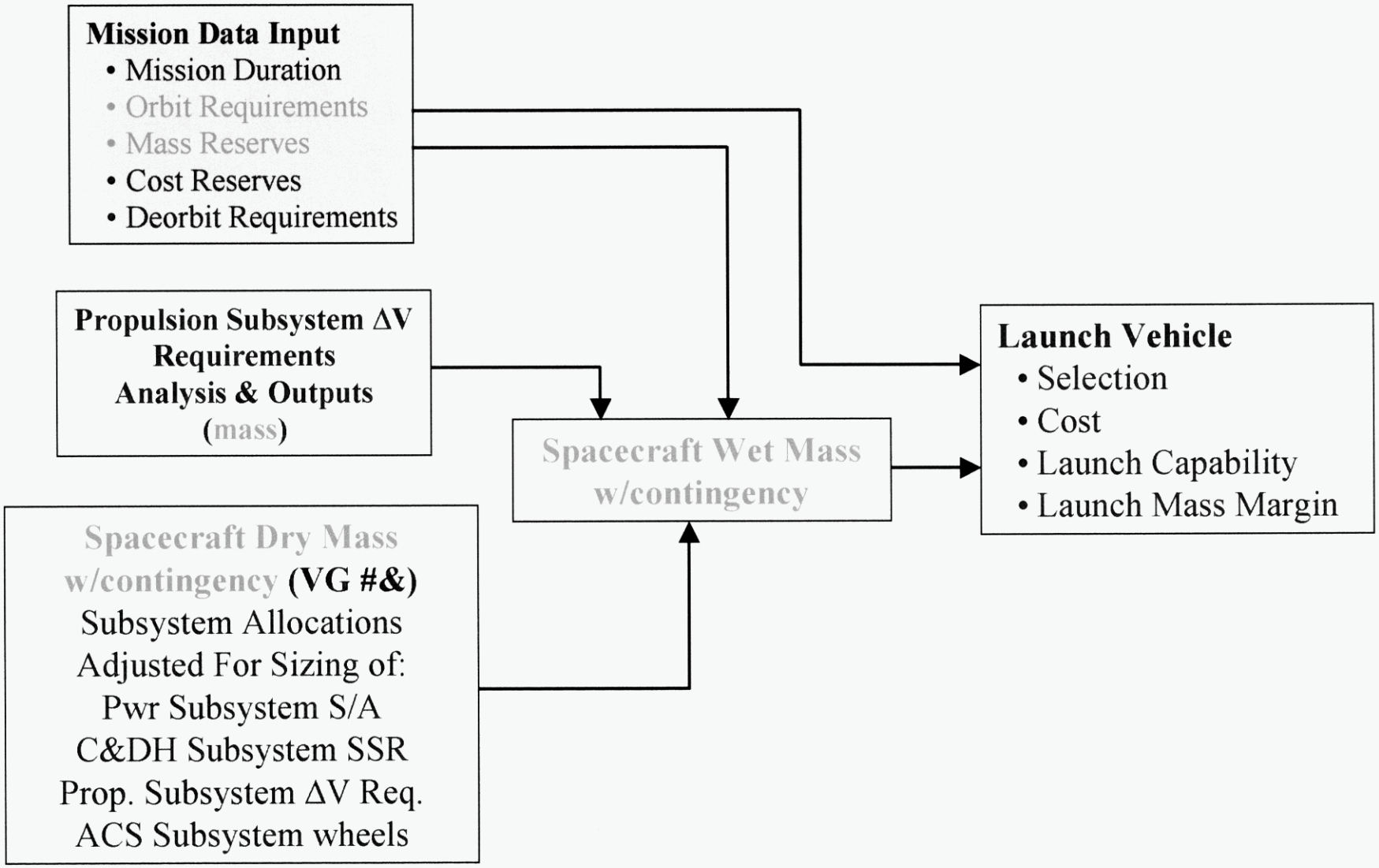
See VG #11

See VG #11, Data Input Sets – P/L Resource Req.

Manual adjustments can be made by systems engineer based on experience by inputting changes in light green cells.

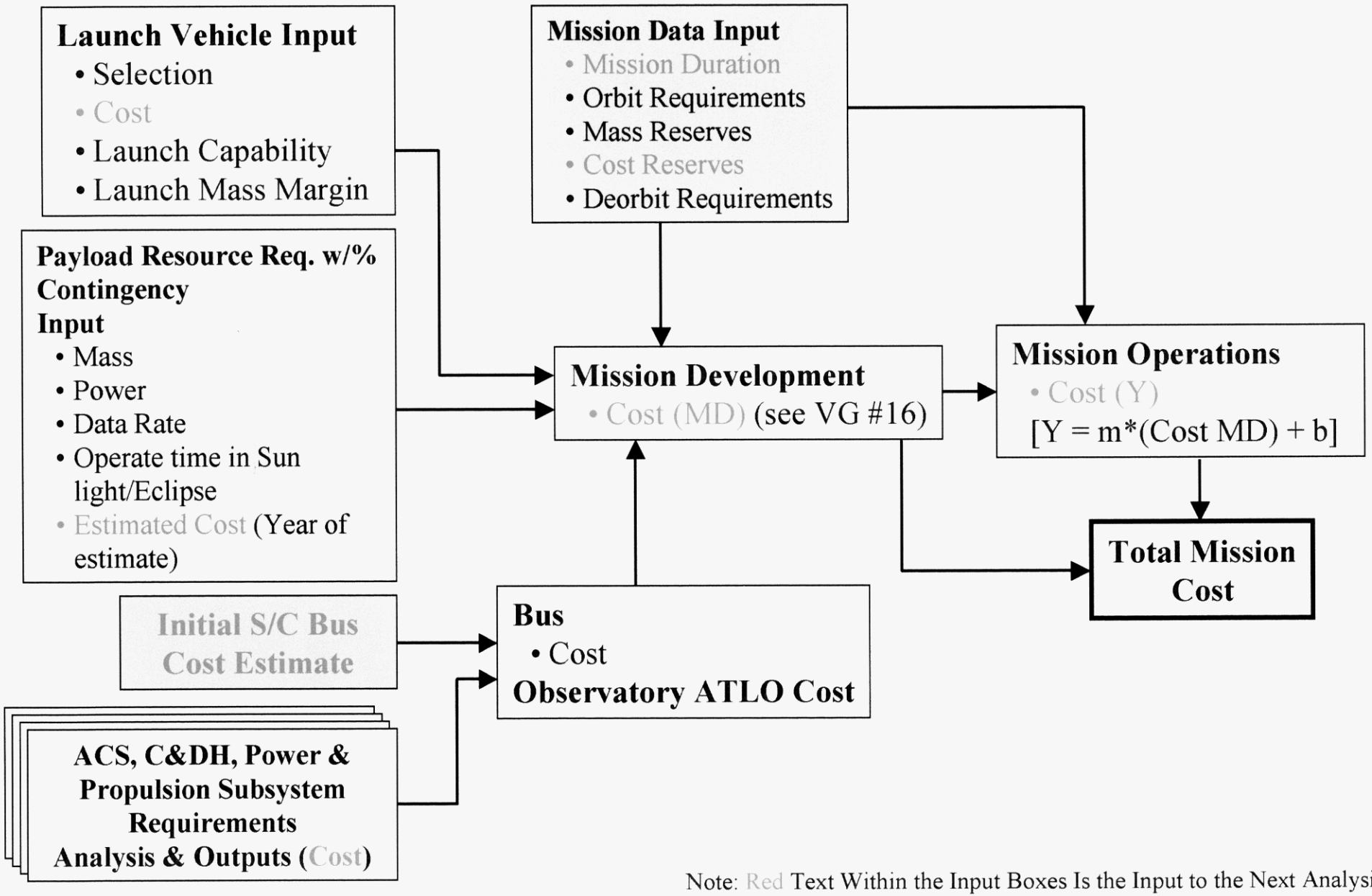
Derived S/C Bus Cost

GAJAT Launch Vehicle Determination



Note: Red Text Within the Input Boxes Is the Input to the Next Analysis.

Total Mission Cost Algorithm



Note: Red Text Within the Input Boxes Is the Input to the Next Analysis.

GAJAT Mission Development Cost Output Sheet (w/30% Cost Reserves)

Fiscal Year Estimates		2000
AURA	Mission Development Cost Range	$M
	High	$1,389.6
	Mid	$1,158.0
	Low	$1,042.2

Fiscal Year Estimates		2003
AURA	Mission Development Cost Range	$M
	High	$1,518.5
	Mid	$1,265.4
	Low	$1,138.9

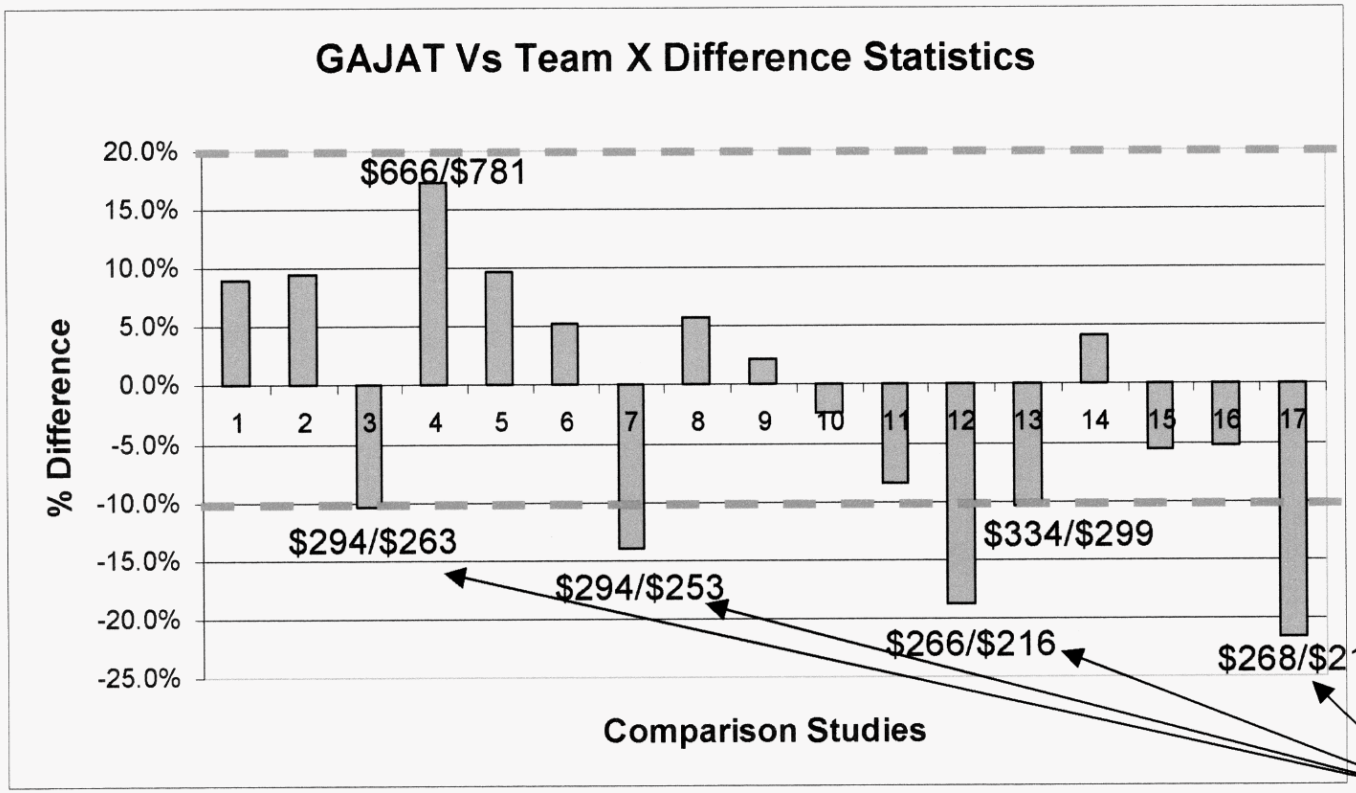
WBS Elements		1st Mission
AURA	Mission Development Cost	$1,265.4
	Phase A Total	$6.7
	Phase B Total	$34.8
	Phase C/D Total	$1,123.7
	Development Total	$1,165.2
	Project Managemnt	$24.5
	Project Manager & Staff	$24.5
	Project System Engineering	$36.6
	Project System Engineering	$12.0
	Mission & Navigation Engineering	$6.5
	Project S/W Eng	$3.6
	EEIS	$1.2
	Information System & Communications	$3.1
	Configuration Management	$3.1
	Planetary Protection	$0.0
	Launch approval	$1.1
	Launch system integration	$2.9
	Project V&V	$3.1
	Mission Assurance	$28.3
	Science	$25.2
	Science Team	$25.2
	Observatory/Spacecraft	$722.7
	Bus	$183.2
	Instrument	$503.1
	ATLO	$36.4
	Prepare for Mission Ops	$27.2
	Other	
	Reserves (A,B,C,D, Outreach)	$272.4
	Outreach	$15.1
	Solid Rocket Motor	$0.0
	Launch Vehicle	$85.0
	*Based on the following LV:	Delta II - 79
	Reserves	30.0%

These cost are derived from Observatory Cost, and when added to the Observatory Cost & L/V Cost produce the Mission Development Cost

L/V cost - manual input from L/V Determination – VG #14

Mission Data Input

GAJAT Analyses of 17 Team X Studies Comparative Analysis Statistics



GAJAT algorithms incorporate the use of an RSDO Catalog bus, which produces a lower overall mission cost for smaller spacecraft missions whereas Team X's approach is a first build every time.

Note: (1) Team X / GAJAT Analysis Results Comparisons are in $M
(2) Red Dashed Lines is Team X Cost Analysis Error Band

GAJAT is a Rapid Prototyping Productivity Tool

Team X Cost = 17 Studies X 17 Seats/study X 8 hrs/study = 2,312
GAJAT Cost = 17 Studies X 1 Seat/study X 0.5 hr/study = 8.5

GAJAT Analysis Carrying 30% Reserves Existing Satellite

Results for Mission:	XYZ

Mission Cost	2003		2000
Mission Development - High Estimate	$1,518.5	$M	$1,389.6
Mission Development - Mid-Range Estimate	**$1,265.4**	**$M**	**$1,158.0**
Mission Development - Low Estimate	$1,138.9	$M	$1,042.2
Payload - Instrument(s)	$503.1	$M	$460.4
Spacecraft (Bus, Instrument, ATLO)	$722.7	$M	$661.4
Bus + ATLO	$219.6	$M	$201.0
Reserves (A,B,C,D, Outreach)	$272.4	$M	$249.3
Outreach	$15.1	$M	$13.9
Mission Ops Cost (Mid-Range Estimate)*	**$141.1**	**$M**	**$129.1**
Mission Cost - Mid-Range Estimate*	**$1,406.5**	**$M**	**$1,287.1**

* Does not include Science Team and Data Processing Costs

31% > XYZ actual of 4600

Solar Array and Battery Size			
SA	**GaAs**	**Si**	**Units**
Solar Array Output at EOL	**6042.3**	**6042.3**	**watts**
Solar Array BOL	6857.7	7220.5	watts
Array Size	**27.1**	**55.1**	**m^2**
Total S/A System Mass	72.1	147.9	kg
Total Solar Array Cost	8.6	11.5	$M
Battery			**Units**
Battery Amp-Hour Capacity	233.8		Amp-hrs
Orbital Average S/C Bus Power w/Reserves	**1916.5**		**watts**

Payload (P/L) Power		
	Allocation	
Payload Energy Total - During Sun Light	1637.6	watt-hrs
Payload Energy Total - During Eclipse	868.9	watt-hrs
P/L Pwr w/Reserves - Orbital Average	**1521.0**	**watts**

SSR Sizing		
Total Data Volume per Orbit	34.8	Gbits
SSR Storage Capacity	34.8	Gbits
Downlink Data Volume Capacity Per Orbit	42.0	Gbits

RSDO Catalog Bus Availability for this mission.

There is no RSDO Catalog Bus Available for this mission.

Click here to return to Data Input Sheet: Data Input

Mass with Reserves		
Payload	1560	kg
Total SC (dry)	2693	kg
Total SC (wet)	**2936**	**kg**

1% < XYZ actual of 2967

Link Margin		S1	S2	S3	X
		Cmd Uplink	Tlm Downlink	Low Rate Downlink	High Rate Downlink
Transmit Antenna Gain	(dB)		-0.5	N/A	18.6
Eb/No	(dB)	51.9	40.3	N/A	21.1
Required Eb/No	(dB)	10.5	10.5	N/A	10.5
Coding Gain	(dB)	5.4	5.4	N/A	2.4
Link Margin	**(dB)**	**46.8**	**35.2**	**N/A**	**13.0**

Reaction Wheels		
Angular Momentum	4.627	N-m-s
Req. Slew Torque	0.308	N-m
SC Inertia	31809.7	kg-m^2
Ixx	25937.1	kg-m^2
Iyy	18107.0	kg-m^2
Izz	31809.7	kg-m^2
Wheel types available for this mission:		
	2-Type E	4-Type E
	8-Type E	

View Mag Torquers Selection on Mag Torquers Page

Launch Vehicle		
LV Selected:	**Delta II - 79**	
LV Cost:	**$85**	$M
LV Capability:	**3100**	kg
LV Margin:	**164**	kg

Optional L/V Input Selected

GAJAT Analysis Carrying 0% Reserves Existing Satellite

Results for Mission:	XYZ

Mission Cost	2003		2000
Mission Development - High Estimate	$1,118.7	$M	$1,023.8
Mission Development - Mid-Range Estimate	**$932.3**	**$M**	**$853.1**
Mission Development - Low Estimate	$839.0	$M	$767.8
Payload - Instrument(s)	$503.1	$M	$460.4
Spacecraft (Bus, Instrument, ATLO)	$676.3	$M	$619.0
Bus + ATLO	$173.3	$M	$158.6
Reserves (A,B,C,D, Outreach)	$0.0	$M	$0.0
Outreach	$8.4	$M	$7.7
Mission Ops Cost (Mid-Range Estimate)*	**$88.7**	**$M**	**$81.2**
Mission Cost - Mid-Range Estimate*	**$1,021.0**	**$M**	**$934.4**

* Does not include Science Team and Data Processing Costs

12% < XYZ actual of 4600

Solar Array and Battery Size			
SA	**GaAs**	**Si**	**Units**
Solar Array Output at EOL	**4053.8**	**4053.8**	**watts**
Solar Array BOL	4600.9	4844.3	watts
Array Size	**18.2**	**37.0**	**m^2**
Total S/A System Mass	49.5	100.4	kg
Total Solar Array Cost	6.0	7.9	$M
Battery			**Units**
Battery Amp-Hour Capacity	156.8		Amp-hrs
Orbital Average S/C Bus Power w/Reserves	**1136.2**		**watts**

Payload (P/L) Power		
	Allocation	
Payload Energy Total - During Sun Light	1259.7	watt-hrs
Payload Energy Total - During Eclipse	668.4	watt-hrs
P/L Pwr w/Reserves - Orbital Average	**1170.0**	**watts**

SSR Sizing		
Total Data Volume per Orbit	34.8	Gbits
SSR Storage Capacity	34.8	Gbits
Downlink Data Volume Capacity Per Orbit	42.0	Gbits

RSDO Catalog Bus Availability for this mission.

There is no RSDO Catalog Bus Avalilable for this mission.

Click here to return to Data Input Sheet: Data Input

Mass with Reserves		
Payload	1200	kg
Total SC (dry)	2050	kg
Total SC (wet)	**2237**	**kg**

25% < XYZ actual Of 2967

Link Margin					
		S1	S2	S3	X
		Cmd Uplink	Tlm Downlink	Low Rate Downlink	High Rate Downlink
Transmit Antenna Gain	(dB)		-0.5	N/A	18.6
Eb/No	(dB)	51.9	40.3	N/A	21.1
Required Eb/No	(dB)	10.5	10.5	N/A	10.5
Coding Gain	(dB)	5.4	5.4	N/A	2.4
Link Margin	**(dB)**	**46.8**	**35.2**	**N/A**	**13.0**

Reaction Wheels		
Angular Momentum	3.524	N-m-s
Req. Slew Torque	0.235	N-m
SC Inertia	24232.2	kg-m^2
Ixx	19758.5	kg-m^2
Iyy	13793.7	kg-m^2
Izz	24232.2	kg-m^2
Wheel types available for this mission:		
		Type E
	2-Type E	4-Type E
	8-Type E	

View Mag Torquers Selection on Mag Torguers Page

Launch Vehicle		
LV Selected:	**Delta II - 79**	
LV Cost:	**$85**	$M
LV Capability:	**3100**	kg
LV Margin:	863	kg

Optional L/V Input Selected