Preliminary Cost Analysis

- Cost Sources
- Vehicle-level Costing Heuristics
- Applications
- Learning Curves
- Program-Level Analysis

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Cost Analysis

- Direct Costs - directly related to designing, testing, building, and operating the system
- Indirect Costs - required to do business, but not directly associated with development or operations
  - Management
  - Profit
  - Non-operational facilities
  - Overhead

Direct Cost Breakdown

- Non-recurring costs - only incurred once in program, such as design
- Recurring costs - reoccur throughout the life of the program
  - Per vehicle
  - Per flight
  - Per year

Nonrecurring Cost Sources

- Research
- Design
- Development
- Test and evaluation
- Facilities
- Tooling

Recurring Cost Sources

- Vehicle manufacturing
- Mission planning
- Pre-flight preparation and check-out
- Flight operations
- Post-flight inspection and refurbishment
- Range costs
- Consumables (e.g., propellants)
- Training

Refurbishment

- Cost associated with maintenance and upkeep on reusable vehicles between flights
- Refurbishment fraction f_R - fraction of first unit production cost that is required for average post-flight refurbishment
  - Airliner: ~0.001%
  - Fighter jet: ~0.01%
  - X-15: 3%
  - Shuttle: 6-20%
- Major contributor to space flight costs

Vehicle-Level Cost Estimating Relations

$$C\,(\$M) = a\left[m_i\langle kg\rangle\right]^b$$

Spacecraft Type	Nonrecurring a	Nonrecurring b	1st Unit Prod. a	1st Unit Prod. b
Launch Vehicle Stage	7.125	0.55	0.1693	0.662
Manned Spacecraft	18.06	0.55	0.5686	0.662
Unmanned Planetary	12.15	0.55	0.8818	0.662
Unmanned Earth Orbital	3.440	0.55	0.3908	0.662
Liquid Rocket Engine	28.78	0.55	0.1584	0.662
Scientific Instrument	1.840	0.50	0.2604	0.70

Implications of CERs

- Launch Vehicles
  - Nonrecurring $42K-$182K/kg inert mass
  - 1st Unit $3600-$10.7K/kg inert mass
- Manned Spacecraft
  - Nonrecurring $119K-$1.56M/kg inert mass
  - 1st Unit $13K-$90K/kg inert mass

Costing Applied to Launch Vehicle Design

Optimization Approach	ΔV Distribution (m/sec)	Gross Mass (kg)	Inert Masses (kg)	NR Cost ($M99)
Minimize Gross Mass	4600 4600	134,800	2,937 10,780 13,721	576 1177 1753
Minimize Inert Mass	3356 5844	139,000	2,066 11,123 13,189	474 1197 1672
Minimize Nonrecurring Cost	2556 6644	147,000	1,666 11,762 13,428	421 1235 1656
Single Stage to Orbit	9200	226,400	18,115	1566

5000 kg payload, LOX/LH2 engines

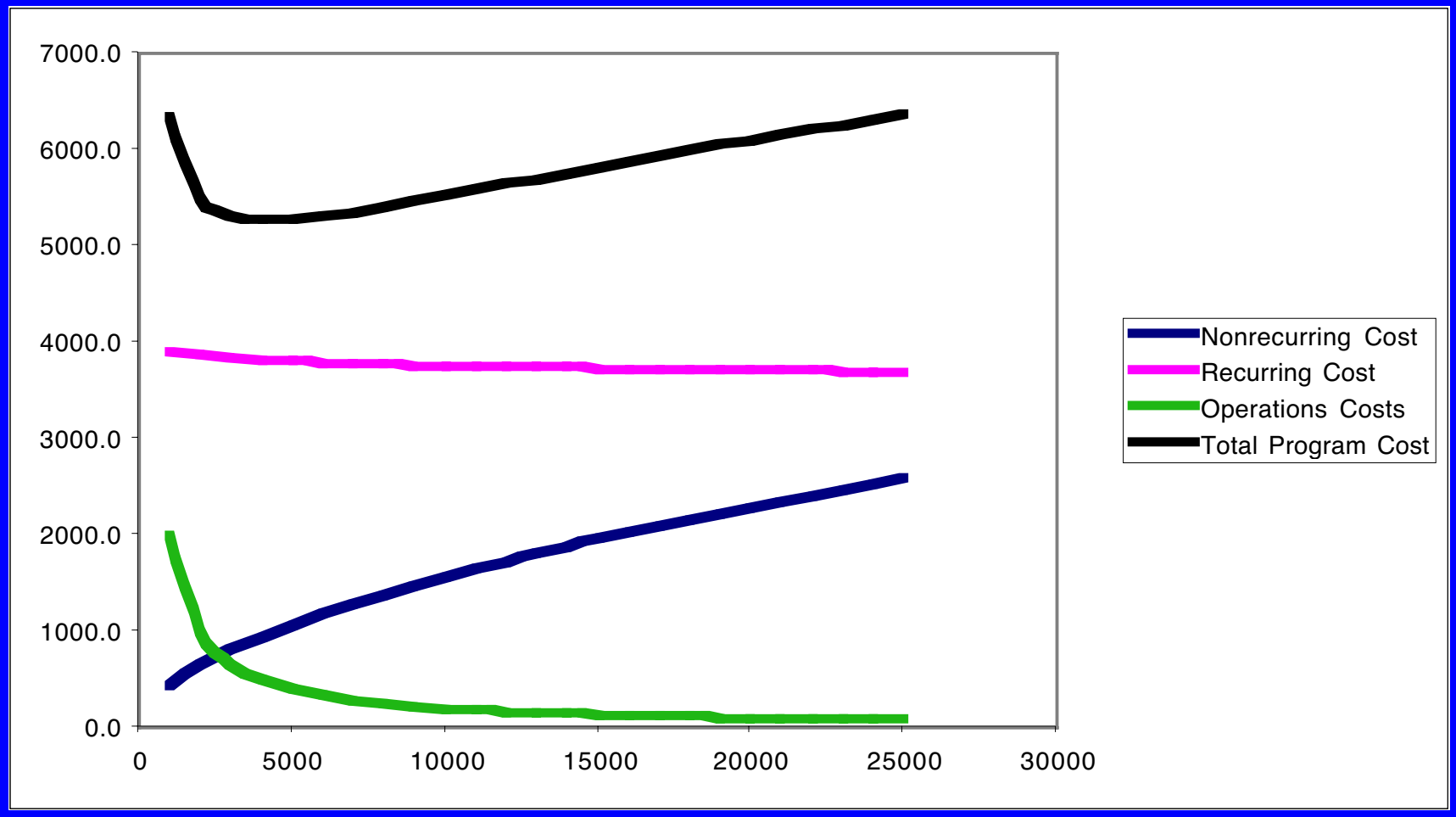
The Learning Curve

- The effort (time, cost, etc.) to perform a test decreases with repetition
- Crawford formulation: doubling the production run results in consistent fractional reduction of effort
  - "80% learning curve" - 2nd unit costs 80% of 1st, 4th is 80% of 2nd, 8th is 80% of 4th…
  - $C_n = C_1 \, n^p$
  - Average cost: $\overline{C}_n \approx C_1 \frac{n^p}{1+p}$

$$p = \frac{\log\left(C_2 / C_1\right)}{\log(2)}$$

Cost and Learning Effects

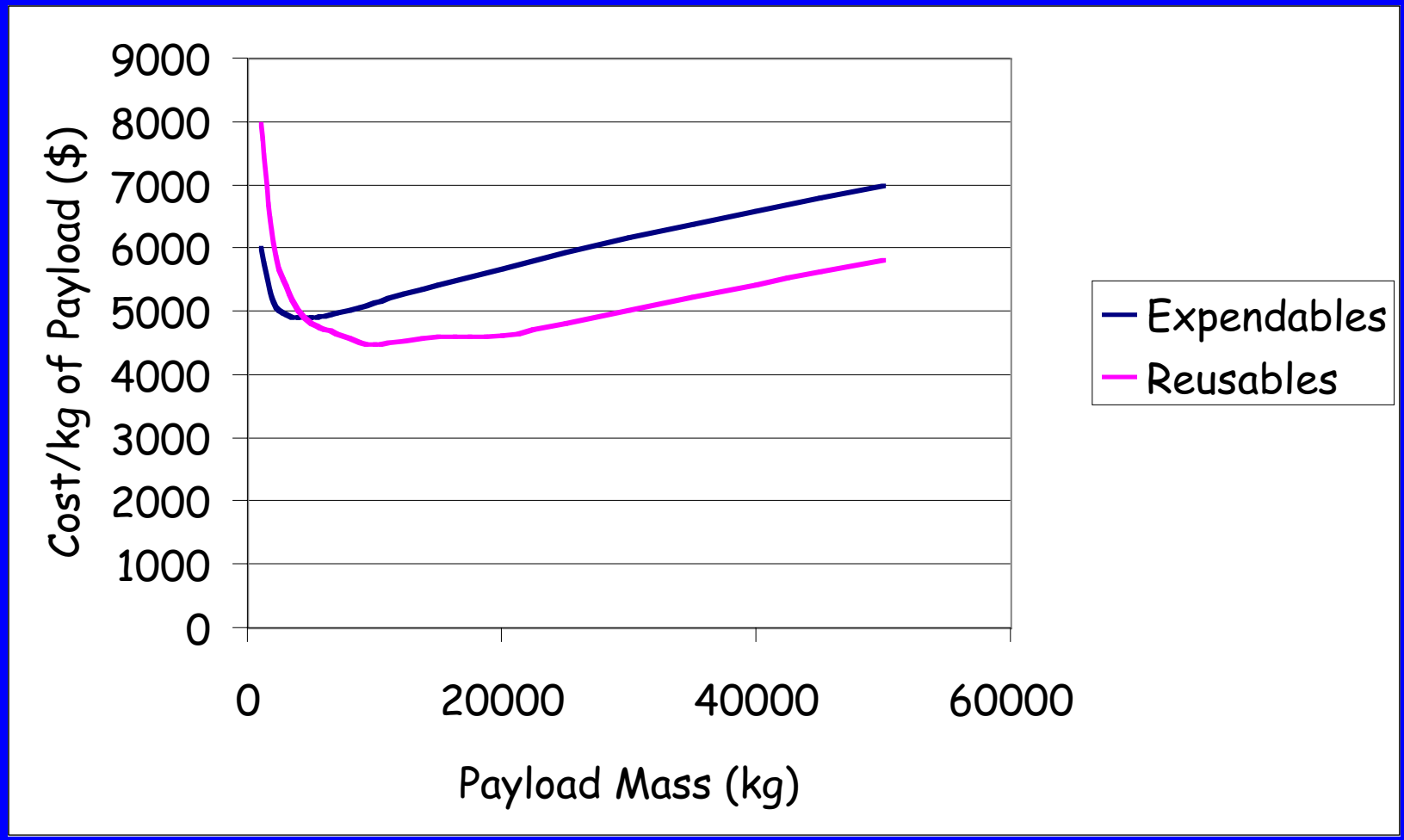
Total Program Payload Mass = 1,000,000 kg



Payload Mass per Flight (kg)

Expendable/Reusable Trade Study

Total Market to Orbit=1,000,000 kg



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Vehicle Inert Masses

	Baseline	LLO Case	
Boost Stage	2300	2300	
Descent Stage	2700	2493	
Ascent Stage	1084	993	
TEI Stage		618	
Crew Cabin	3229	4114	
Entry Systems			
Totals	9313	10518	

All masses in kg

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Nonrecurring Costs

	Baseline	LLO Case	
Boost Stage	503.2	503.2	
Descent Stage	549.6	526.0	
Ascent Stage	332.7	317.0	
TEI Stage		244.2	
Crew Cabin	1537	1756	
Entry Systems			
Totals	2923	3347	

All costs in $M

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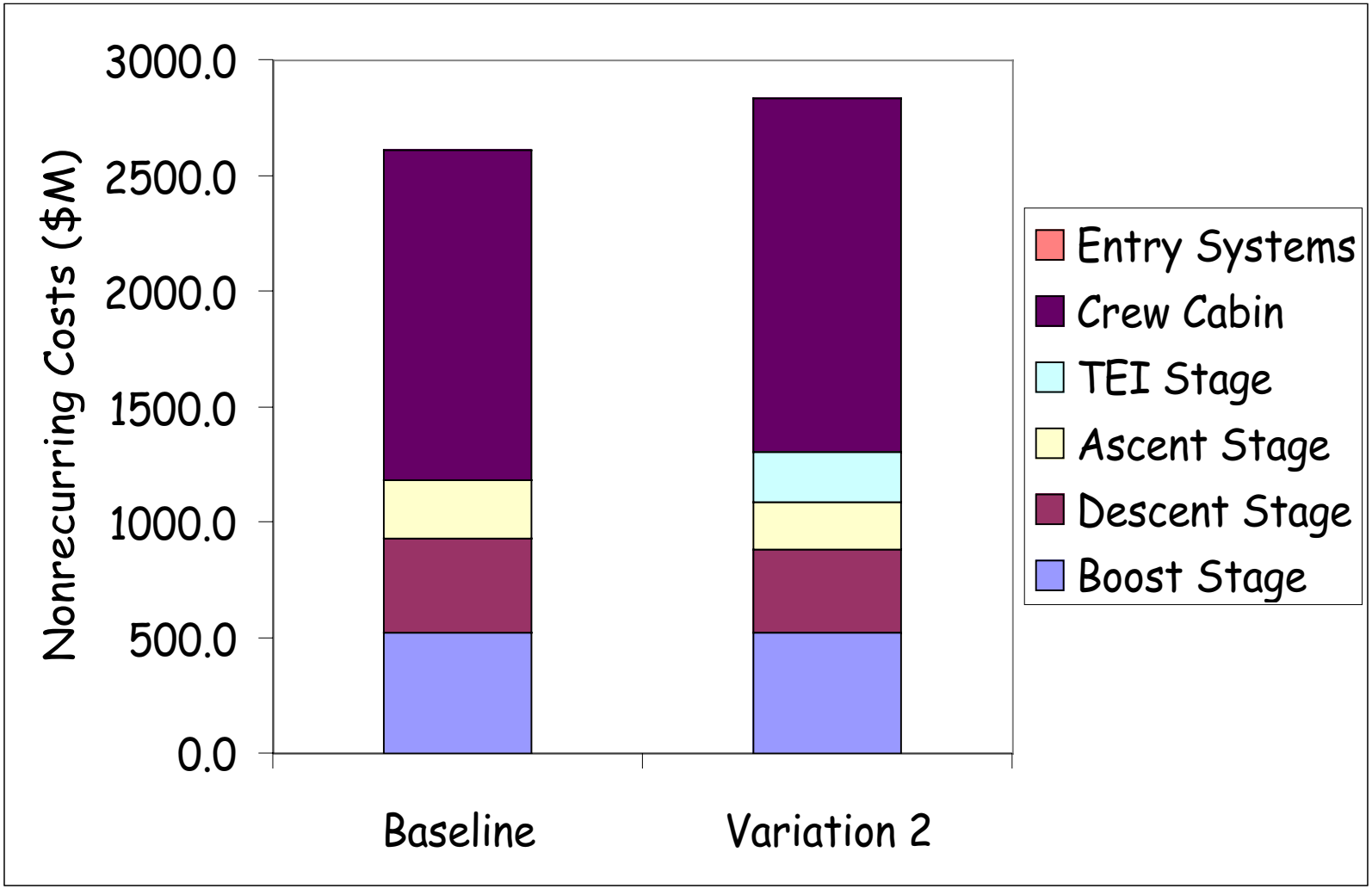
Nonrecurring Cost Comparison



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First Unit Production Costs

	Baseline	LLO Case	
Shuttle Launch	300	300	
Delta IVH	150	150	
Boost Stage	28.5	28.5	
Descent Stage	31.6	30.0	
Ascent Stage	17.3	16.3	
TEI Stage		11.9	
Crew Cabin	119.6	140.4	
Totals	647	677	

All costs in $M

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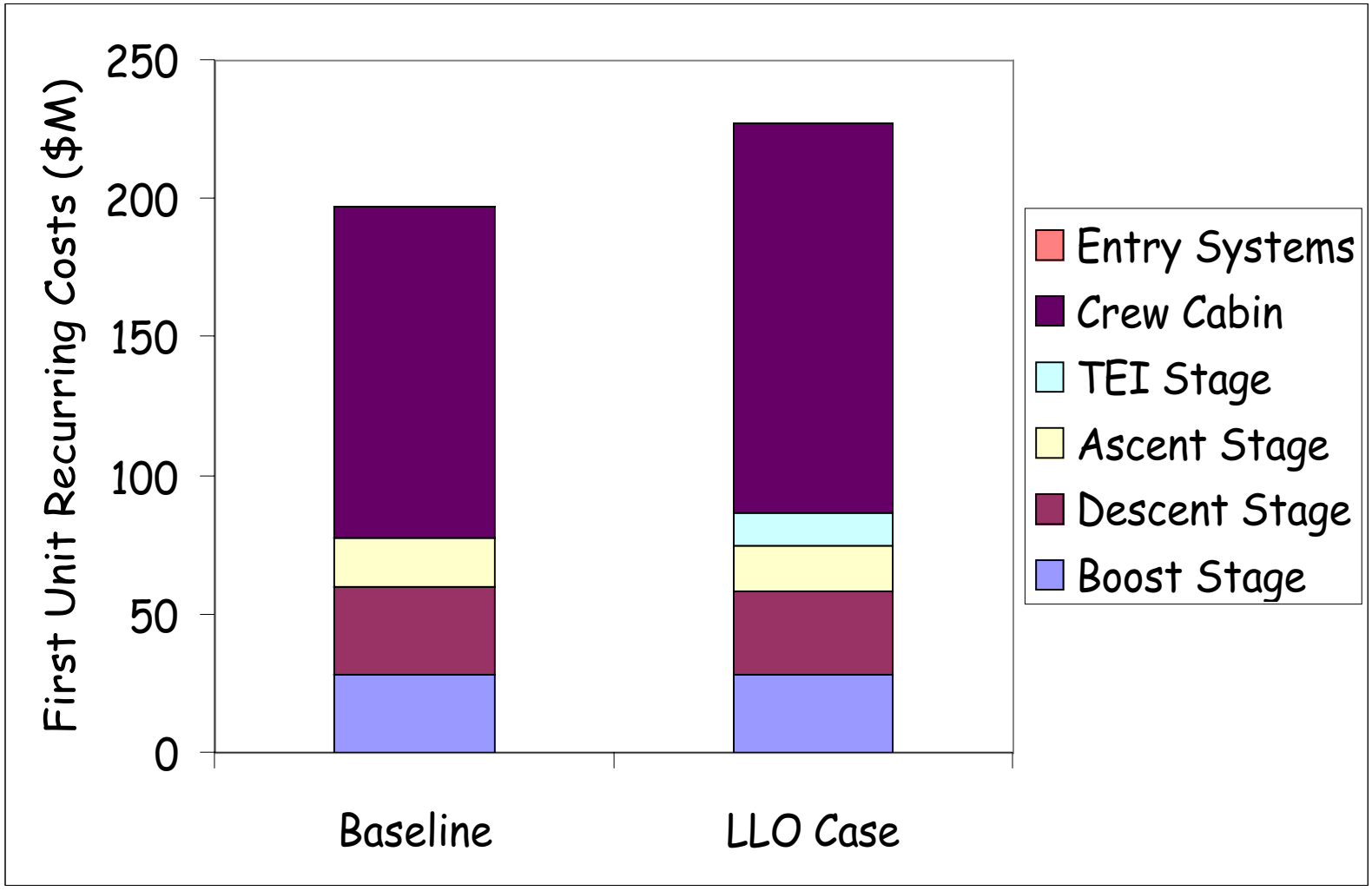
First Unit Cost Comparison



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Project Diana Mission Models

- **Single Mission Model**
  - One all-up lunar flight
  - Single crew cabin, ascent/descent stages
  - Three boost stages, four launch vehicles
- **Apollo Comparison Model**
  - One orbital test flight (crew module, ascent/descent stages)
  - One high orbital mission (above + one boost stage)
  - One lunar orbital rehearsal mission
  - Seven lunar landing missions

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Single Mission Model Cost Summary

Baseline Case

	Number	Nonrecurring Cost ($M)	First Unit Cost ($M)	Recurring Cost ($M)	Totals
Shuttle Launch	1		300	300	300
Delta IVH	4		150	600	600
Boost Stages	4	503.2	28.45	71.26	574.5
Descent Stage	1	549.6	31.64	31.64	581.2
Ascent Stage	1	332.7	17.29	17.29	350
TEI Stage	1	0.0	0.00	0.00	0
Crew Cabin	1	1537	120	120	1657
Totals		2923	647	1140	4062

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Production for Apollo Case

	Earth Orbit	High Orbit	Lunar Orbit	Lunar Landing	Totals
Shuttle Launch	1	1	1	7	10
Delta IVH	0	1	4	28	33
Boost Stages	0	1	4	28	33
Descent Stage	1	1	1	7	10
Ascent Stage	1	1	1	7	10
TEI Stage	1	1	1	7	10
Crew Cabin	1	1	1	7	10

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Apollo Mission Model Cost Summary

Baseline Case

	Number	Nonrecurring Cost ($M)	First Unit Cost ($M)	Recurring Cost ($M)	Totals
Shuttle Launch	10		300	3000	3000
Delta IVH	33		150	4950	4950
Boost Stages	33	503.2	28.45	428.8	932
Descent Stage	10	549.6	31.64	200.3	750
Ascent Stage	10	332.7	17.29	109.5	442
TEI Stage	0	0.0	0.00	0.0	0
Crew Cabin	10	1537	119.6	757.4	2295
Totals		2923	647	9446	12369

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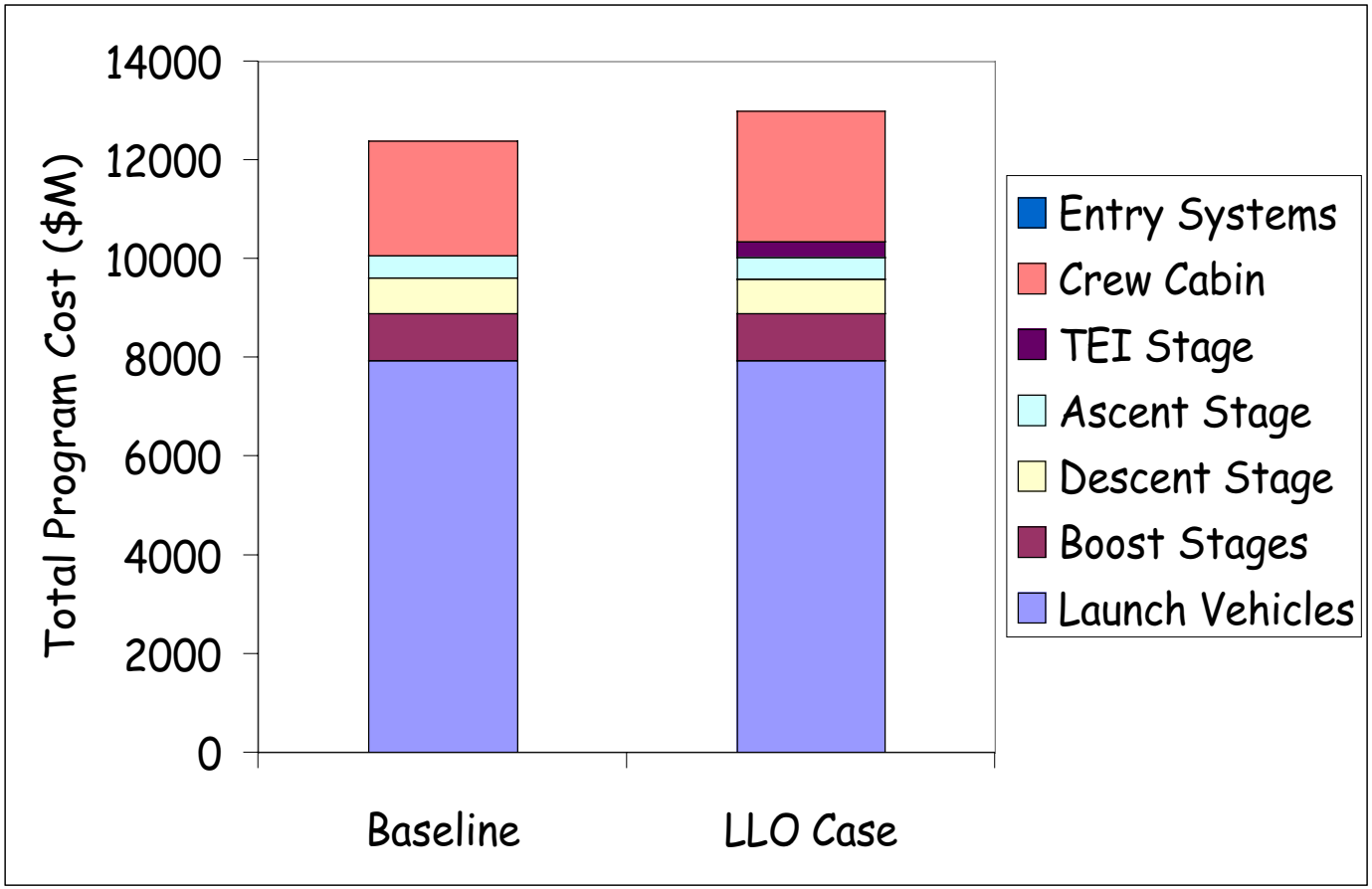
Apollo Model Cost Comparisons



Web-Based Costing References

- NASA Cost Estimation Web Site
  http://www.jsc.nasa.gov/bu2/index.html
- Vehicle-Level Costing Models
  http://www.jsc.nasa.gov/bu2/SVLCM.html
- Inflation Adjustment
  http://www.jsc.nasa.gov/bu2/inflate.html
- Learning Curves
  http://www.jsc.nasa.gov/bu2/learn.html