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Human Spaceflight Value Study

Was the Shuttle a Good Deal?

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Purpose

- **Examine the Space Shuttle Program Relative to its Goals and Objectives, other Human Space Flight Programs, and Measures of Economic Effectiveness**

Was the Shuttle Program a "Good Value" for the American Taxpayer?

What Lessons Learned can be Drawn to make Future Exploration Architectures more Cost Effective?

Outline

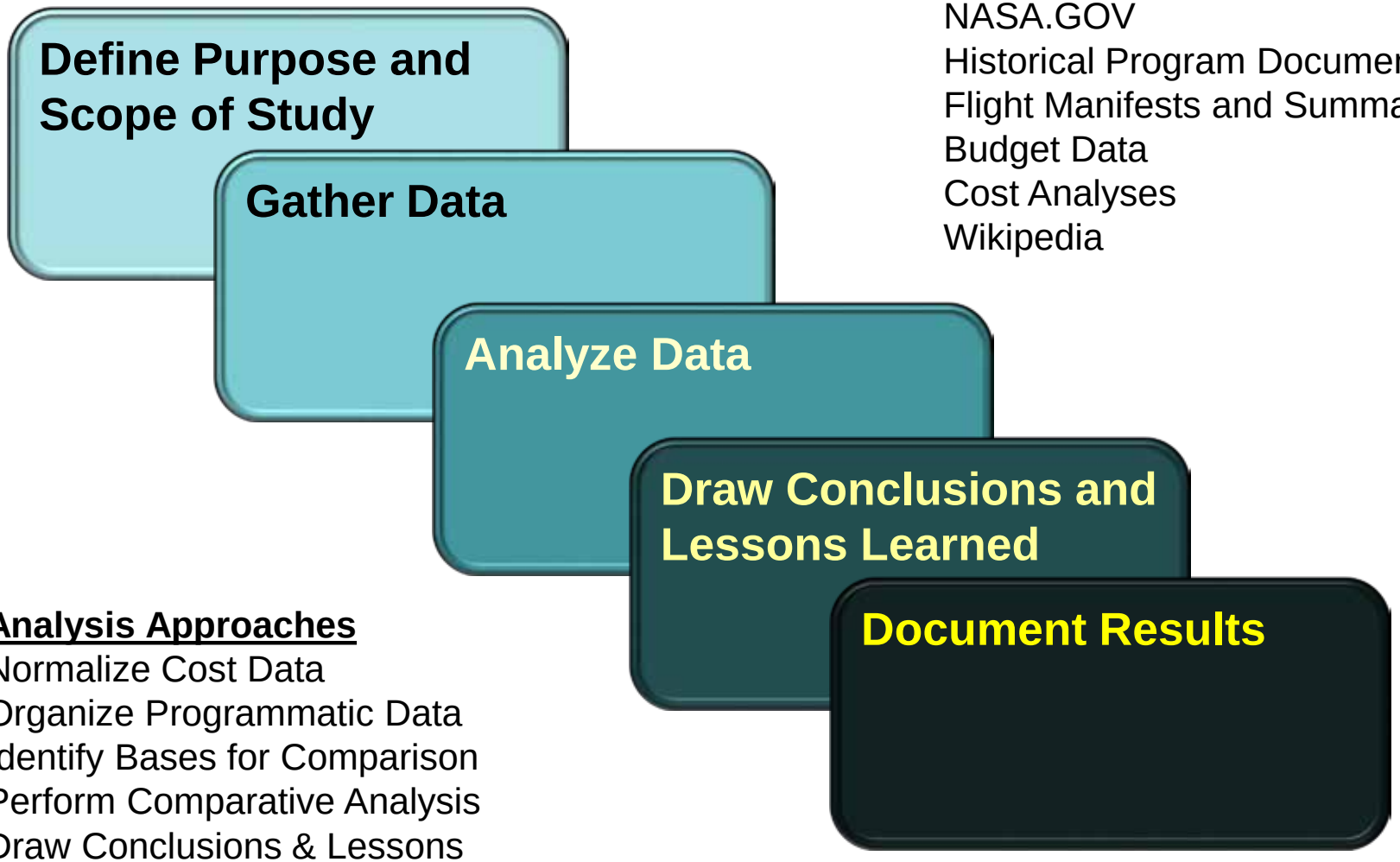
- Purpose
- Scope and Approach
- Ground Rules and Assumptions
- Overview of NASA Human Spaceflight Programs
- Comparative Assessment
- Heritage Issues
- Value Assessment
- Lessons Learned

Scope

- **Focus on the Space Shuttle Program**
  - Goals and Objectives
  - Accomplishments
  - Costs
- **Comparative Programs**
  - Mercury
  - Gemini
  - Apollo
  - Skylab

- **ISS Not Included in Analysis**
  - On-going Program
  - Complexity of International Partner Contributions

Approach



Data Sources

NASA.GOV
Historical Program Documents
Flight Manifests and Summaries
Budget Data
Cost Analyses
Wikipedia

Analysis Approaches

Normalize Cost Data
Organize Programmatic Data
Identify Bases for Comparison
Perform Comparative Analysis
Draw Conclusions & Lessons
Identify Issues and Concerns

Ground Rules & Assumptions

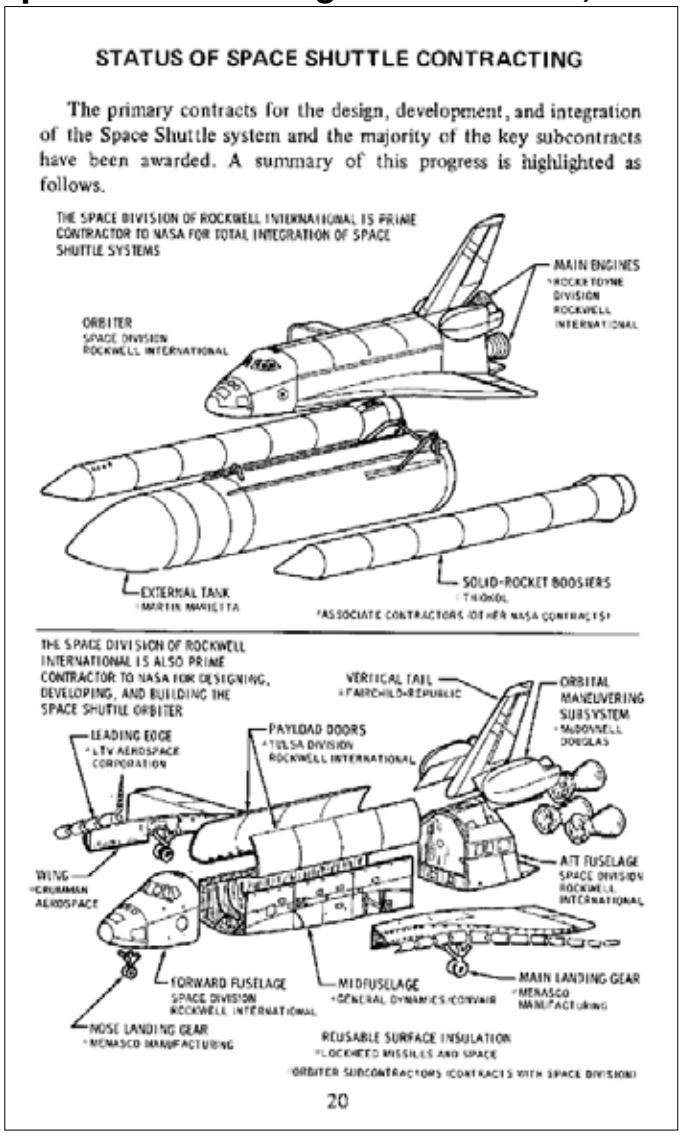
- **All Cost Data Normalized to FY12$ using the NASA New Start Inflation Index Titled "NASA FY11 Inflation Tables to be Used in FY12"**
- **Budget Data Includes all Design & Development, Testing, Flight Hardware, Launch & Mission Operations, and Retirement**
- **No Adjustments to the Budget/Cost Data for Heritage, Program Content, Full Cost Accounting, Number of Test Flights, etc.**
- **Only Crewed Missions included in the Calculation of Metrics**
- **For each Mission, Days in Orbit Equals Mission Duration**
  - Mission Duration Equals Time from Launch to Landing
- **ISS Shuttle Missions where Crew Size Changed - Time in Orbit Calculated as:**
  - Initial Crew Size x (Launch until shuttle leaves ISS) + Return Crew Size x (Departure from ISS until landing)

Data Sources

Engineering Cost Office

- **Human Spaceflight Mission Data**
  - NASA.GOV
  - Wikipedia
- **Historical Program Data**
  - NASA.GOV
  - REDSTAR Library
- **Budget/Cost Data**
  - Official NASA Budget Documents
  - NASA Historical Records
  - Program Operating Plans
  - REDSTAR Library

Space Shuttle Program Overview, 1974



Mercury

- **Objectives**
  - Place a Manned Spacecraft in Orbital Flight Around the Earth
  - Investigate Man's Performance Capabilities and His Ability to Function In the Environment of Space
  - Recover the Man and the Spacecraft Safely
- **Major Achievements**
  - First American in Space (May 5, 1961)
  - First Orbital Flight (February 20, 1962)

Gemini
(1 of 2)

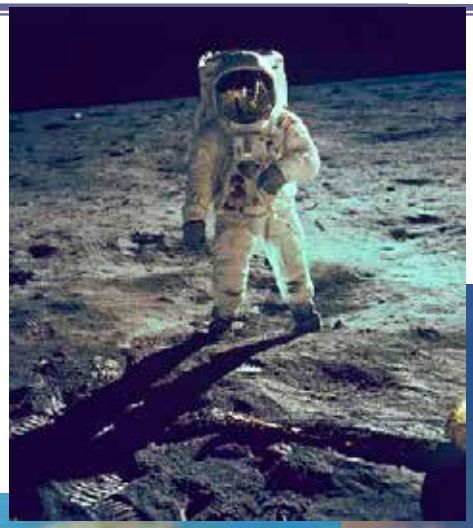
- **Major Objectives**
  - To subject two men and supporting equipment to long duration flights -- a requirement for projected later trips to the moon or deeper space
  - To effect rendezvous and docking with other orbiting vehicles, and to maneuver the docked vehicles in space, using the propulsion system of the target vehicle for such maneuvers
  - To perfect methods of reentry and landing the spacecraft at a pre-selected land-landing point (Cancelled)
  - To gain additional information concerning the effects of weightlessness on crew members and to record the physiological reactions of crew members during long duration flights

Gemini
(2 of 2)

- **Notable (US) Achievements**
  - First Two Person Crew
  - First Long Duration Space Flight (14 Days)
  - First Rendezvous and Docking
  - Two Crewed Spacecraft in Orbit (Gemini VII & Gemini VI A)
  - First Spacewalk
  - First Flight Computer

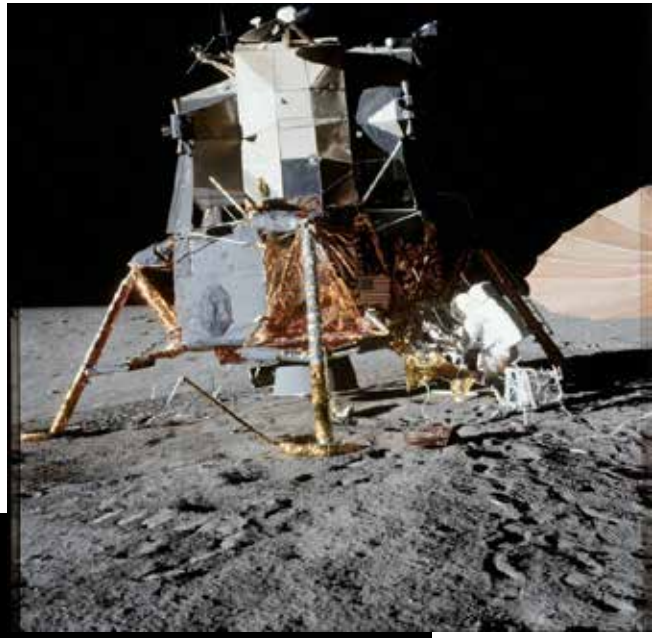
Apollo
(1 of 2)

- **Major Objectives**
  - To put Man on the Moon and Return him Safely to Earth
  - To Establish the Technology to Meet Other National Interests in Space
  - To Achieve Preeminence in Space For the United States
  - To Carry Out a Program of Scientific Exploration Of the Moon
  - To Develop Man's Capability to Work In the Lunar Environment

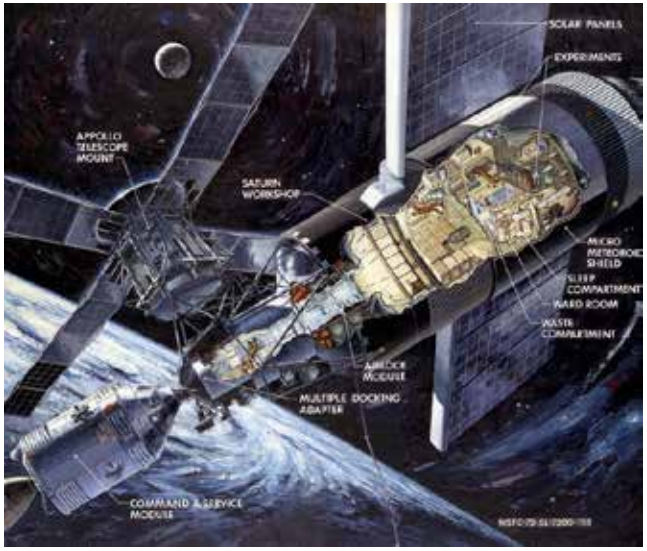


Apollo
(2 of 2)

- **Significant Achievements**
  - First Human Landing on the Moon
  - First Operations in Lunar Orbit
  - First 3 Person Crew
  - First Human Launch from the Moon
  - Human Lunar EVA's
  - Return of Lunar Samples



Skylab



- **Objectives**
  - To Prove that Humans Could Live and Work in Space for Extended Periods
  - To Expand our Knowledge of Solar Astronomy Well Beyond Earth-Based Observations
- **Notable Achievements**
  - First US Space Station
  - Three Long Duration Missions
  - Highly Successful Solar Observation Program
  - First EVA Repair

The Shuttle Decision

- **Reusable Space Vehicles had been Discussed Since the 1920's**
  - **Werner Von Braun** and other Space Pioneers Developed Notional Concepts
- **Aeronautics Research in the 1950's and 1960's Laid the Foundation**
- **High Cost of Expendable Launch Systems made Reusable seem like a Logical Choice**
- **September 1969: President Nixon's Space Task Group Recommends a Reusable Launch Vehicle**
- **January 5, 1972: President Nixon Gives the Go-Ahead for the Shuttle Program**

TABLE 0.1: SPACE TRANSPORTATION SYSTEMS COST SUMMARY (1)

(Millions of Undiscounted 1970 Dollars)

Modified NASA and DoD Baseline
514 Space Shuttle Flights (1979-1990)

	Current Expendable	New Expendable	TAOS Space Shuttle and Tug
EXPECTED LAUNCH VEHICLE COSTS			
Non-Recurring Costs (FY1972-87)	1,620	2,000	7,450
Recurring Costs (FY1977-1990)	10,600	8,760	4,800
Total Launch Costs	12,000	11,000	12,000
EXPECTED PAYLOAD COSTS (SATELLITES)			
RDT&E (FY1975-1990)	11,000	10,600	9,880
Recurring Costs (FY1976-1990)	18,800	18,400	12,700
Total Payload Costs	30,000	29,000	23,000
EXPECTED TOTAL SPACE PROGRAM COSTS	42,000	40,000	35,000

(1) Source: Adapted from Aerospace Corporation and Contractor Data

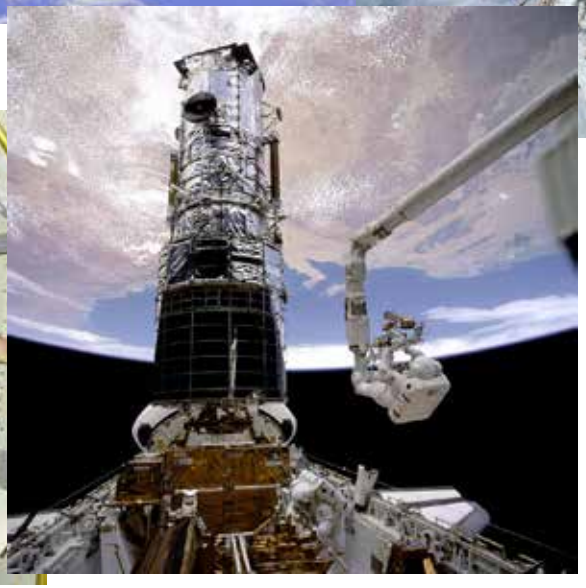
From ***Economic Analysis of the Space Shuttle*** by the Advanced Technology Economics Group at Mathematica, January 31, 1972

The Space Shuttle

- **Objectives**
  - Provide a Low-Cost Economical Space Transportation System
  - An Operating Mode Geared to Reduce Costs an Order of Magnitude Below Present Operating Costs
  - A Flexible Capability to Support a Variety of Payloads and Missions
  - An Airline-Type Operation for Passengers and Cargo Transport
  - A Reusable System with High Launch Rate Capability and Short Turn-Around and Reaction Times

Space Shuttle Achievements

- **First Reusable Crew Launch System**
- **Satellite Servicing and Repair**
- **Satellite Capture and Return**
- **EVA Construction Tests**
- **First Free-Flying Astronaut**
- **Numerous Science Experiments**
  - Spacelab
  - Astro-1
  - Mid-Deck Science
  - etc.

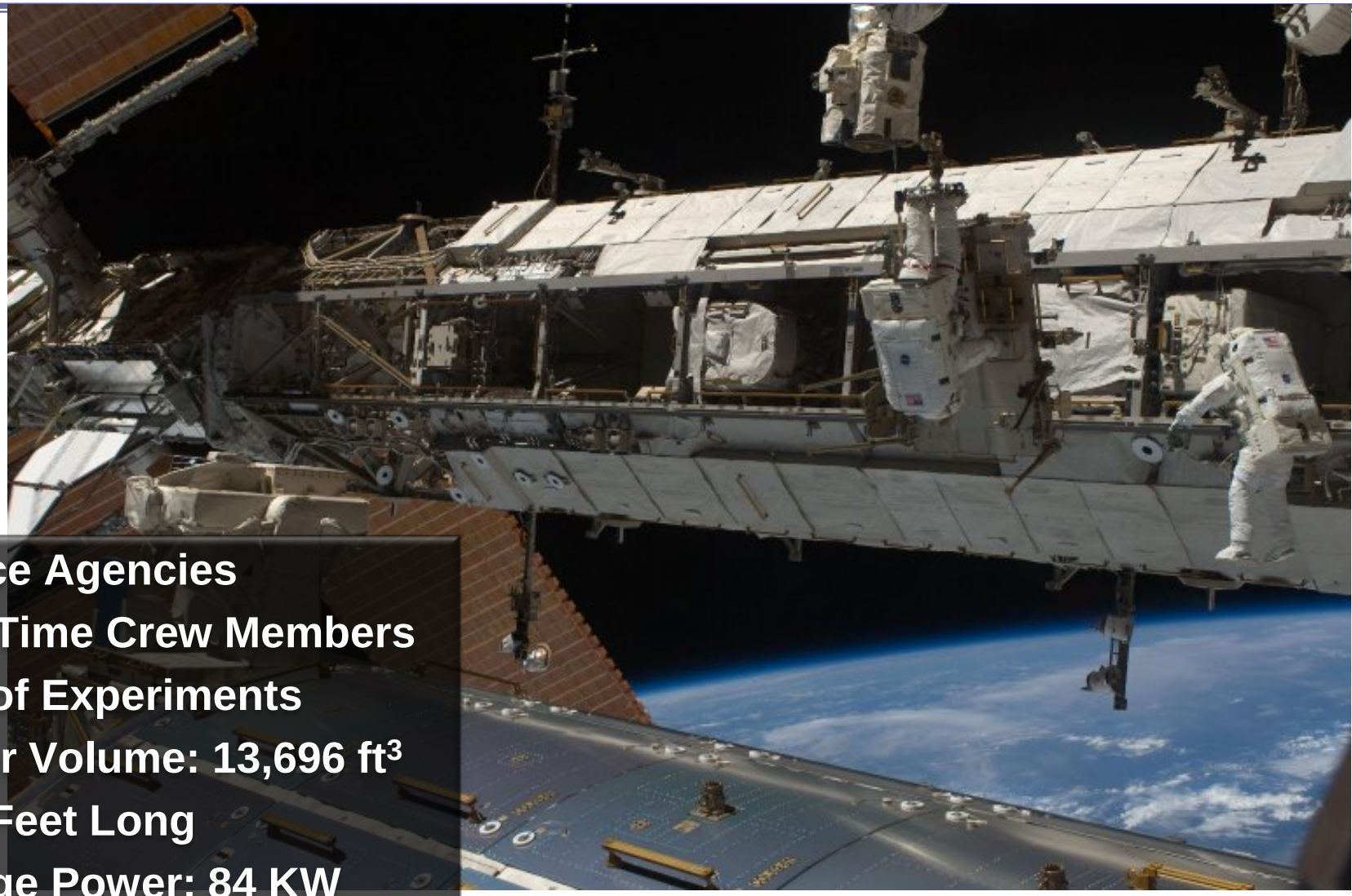


ISS Construction

Engineering Cost Office

- Largest Structure ever Built in Space
- 37 Shuttle Flights for Assembly and Servicing
- 108 EVA's Performed During Assembly
- 12.5 Years to Complete On-Orbit Assembly

The International Space Station



- 5 Space Agencies
- 6 Full Time Crew Members
- 100's of Experiments
- Interior Volume: 13,696 ft^3
- 357.5 Feet Long
- Average Power: 84 KW
- Mass on Orbit: 861,804 lb.

Comparative Analysis

- **Budget**
- **Number of Missions and Flight Rate**
- **Cost per Crewed Mission**
- **Cost per Person Day in Space**

Person Days in Space = Number of Astronauts * Total Mission Time (Launch to Landing)

- **Example: Gemini IV**
  - Number of Astronauts: **2**
  - Total Mission Time: **4 Days, 1 hour, 56 minutes, 12 Seconds** (**4.08 Days in Decimal**)
  - Person Days in Space = **2 * 4.08 = 8.16**

Heritage Issues

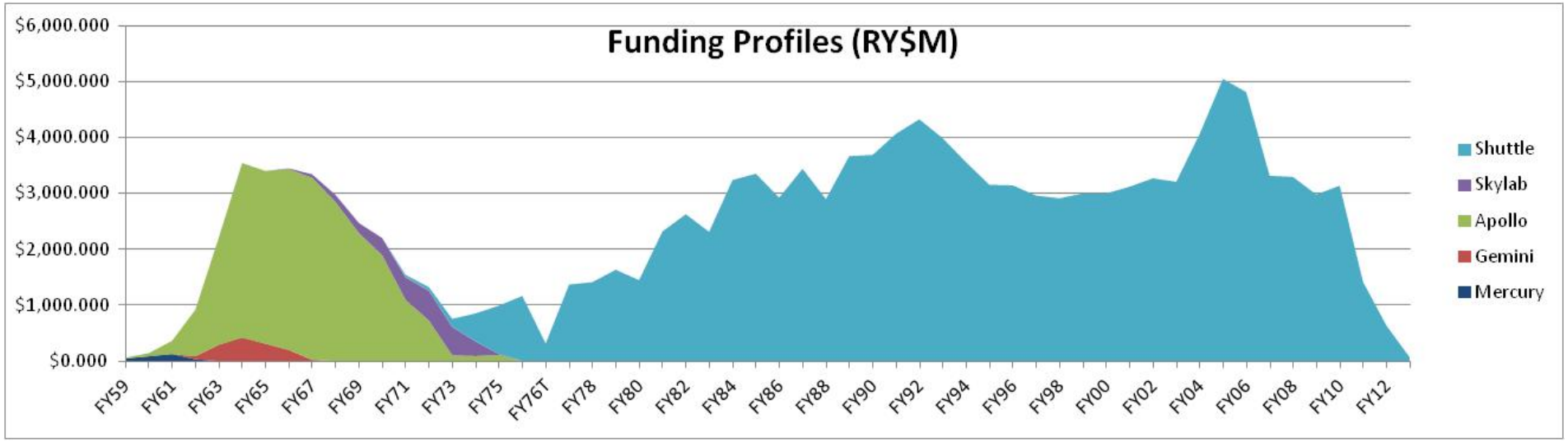
- **Mercury and Gemini used Existing Ballistic Missiles and Air Force Launch Facilities**
  - **Mercury: Redstone and Atlas**
  - **Gemini: Titan II**
  - **Vehicles Human Rated at NASA Expense**

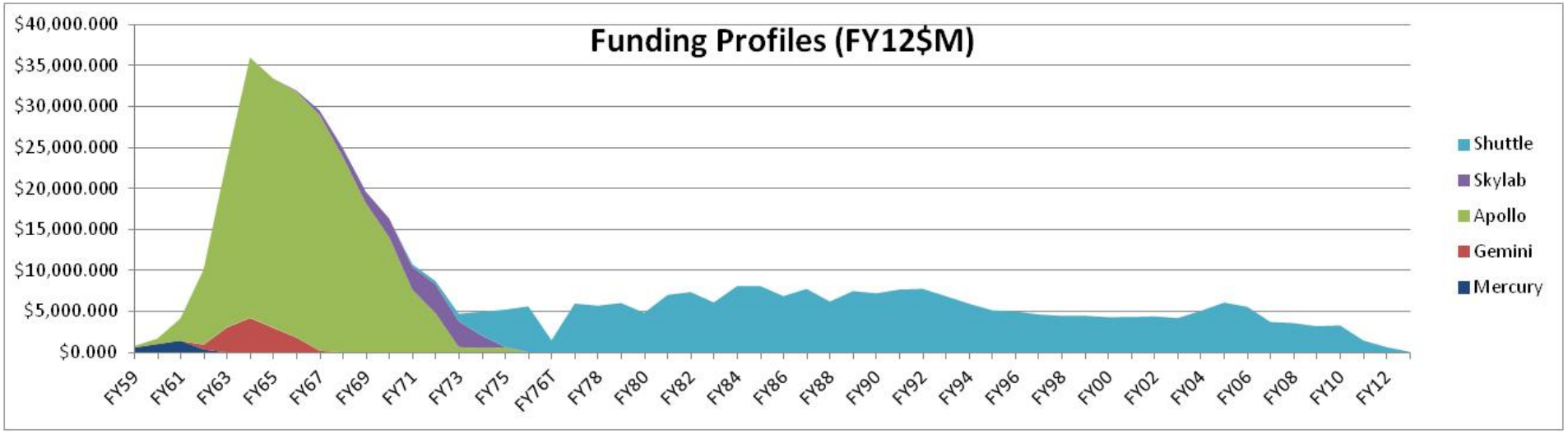
- **Apollo Program was Almost all New**
  - **New Launch Vehicles and Facilities**
  - **Human Exploration (Beyond LEO) Capability**
  - **Lunar Lander**

- **Skylab had Extensive Heritage from Apollo**
  - **Used Existing Saturn Launch Vehicles**
  - **Modified Apollo Capsules for Longer Duration Flight**
  - **Saturn V S-IVB Stage used for Orbital Workshop Structure**

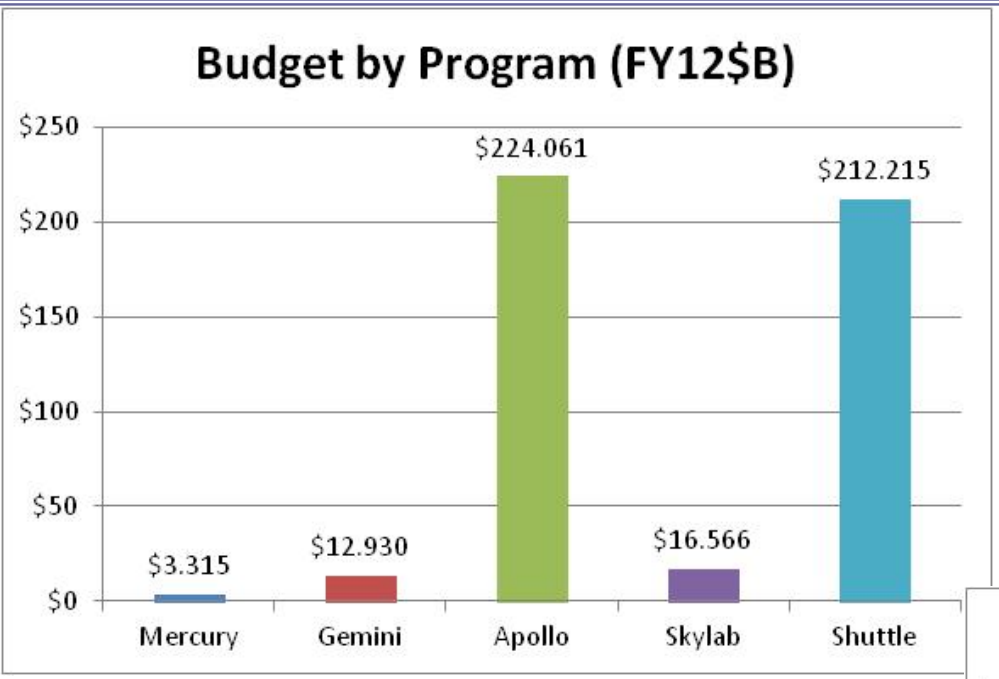
- **Space Shuttle used a Mixture of New Flight Hardware and New, Existing, and Modified Facilities**

Funding Profiles



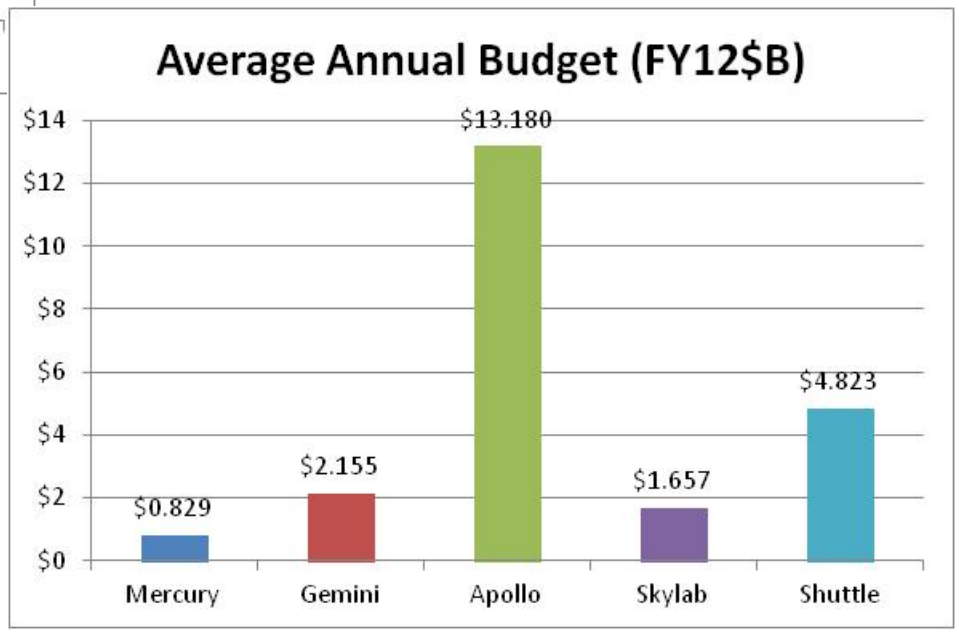


Total Program Budgets

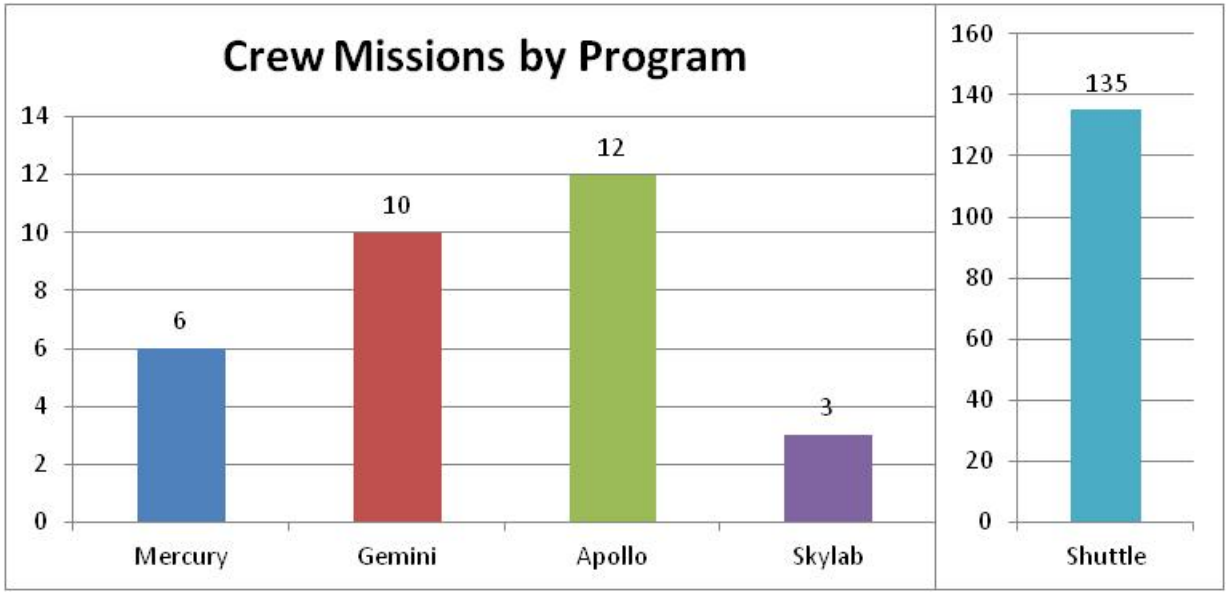


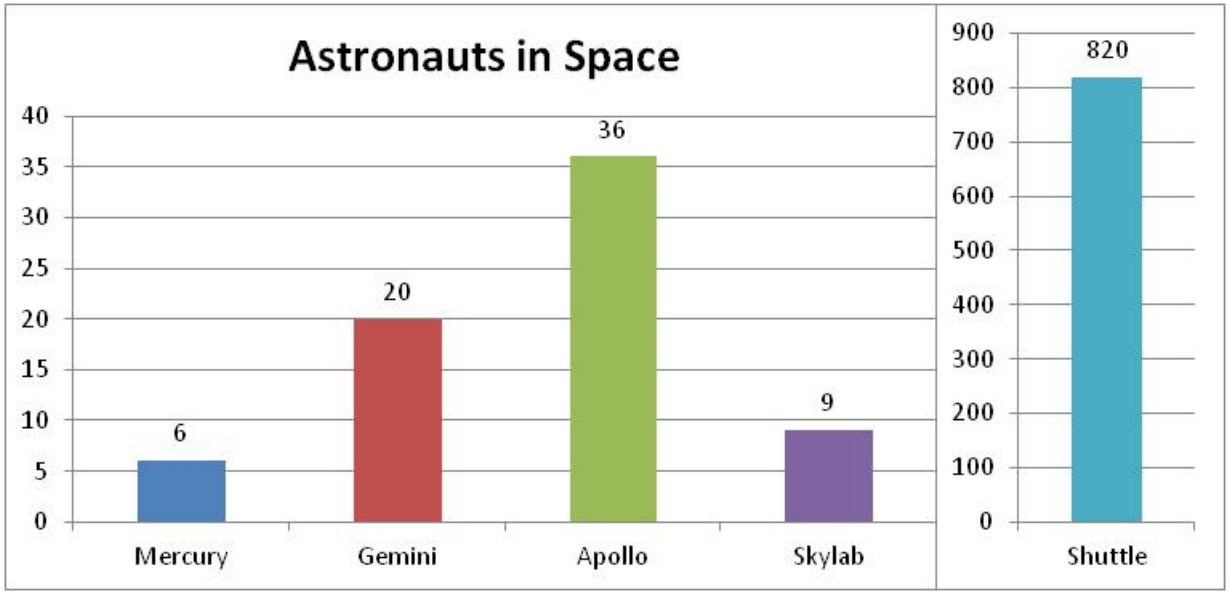
- Apollo was All New Ground and Flight Hardware Systems
- Shuttle Flew for 30 Years

- Mercury & Gemini were Short-Term, Focused Programs
- Skylab had Significant Heritage from Apollo



Program Metrics

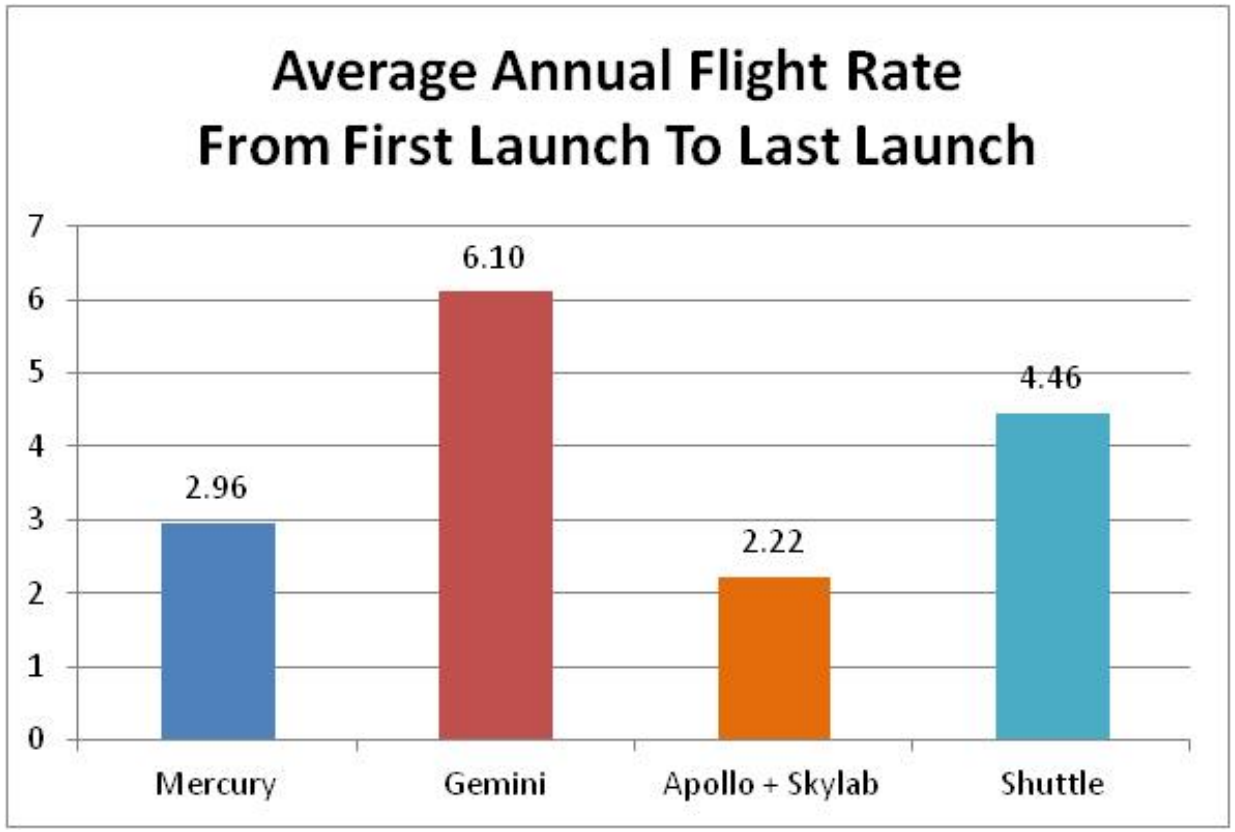




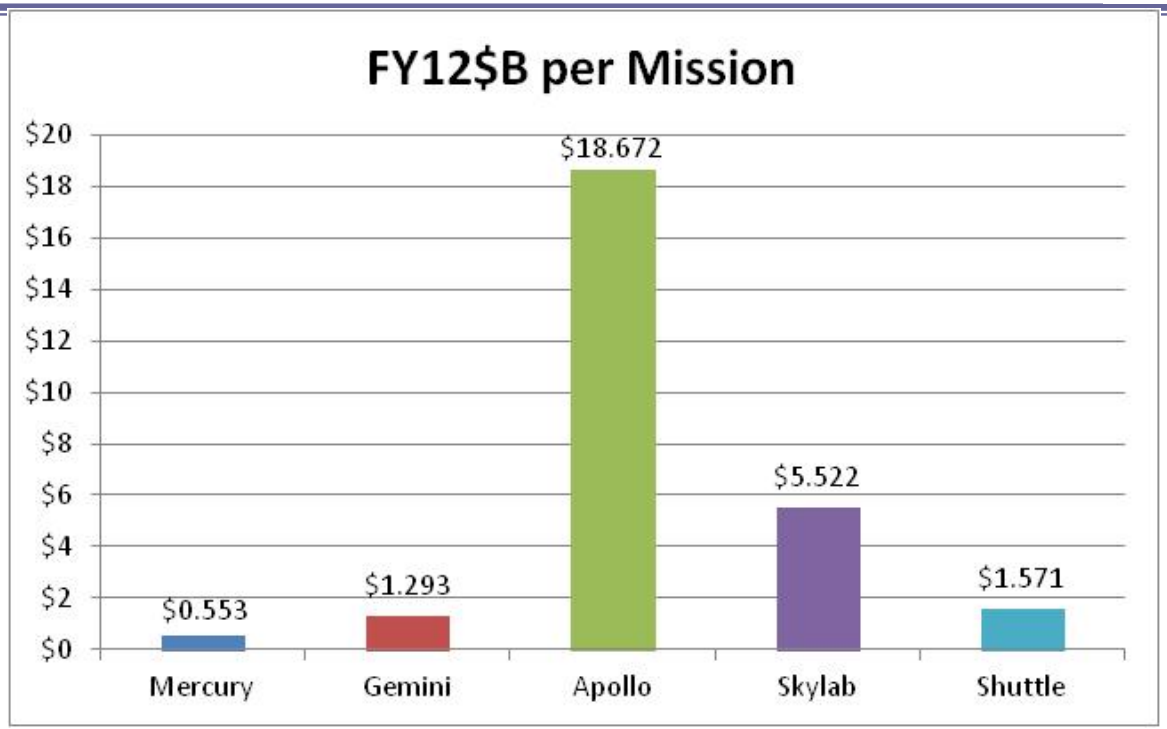
- ***Shuttle put more Astronauts in Space on more Flights than any other Launch System in History***
- **Note: Did not Adjust Shuttle Numbers for Non-US Astronauts or Repeat Flyers**

Flight Rate

- **Shuttle Sustained almost 4.5 Flights per Year from 1981 to 2011**
- **Gemini was Rapid Development Program to "Catch Up" in the Space Race and Support Apollo**



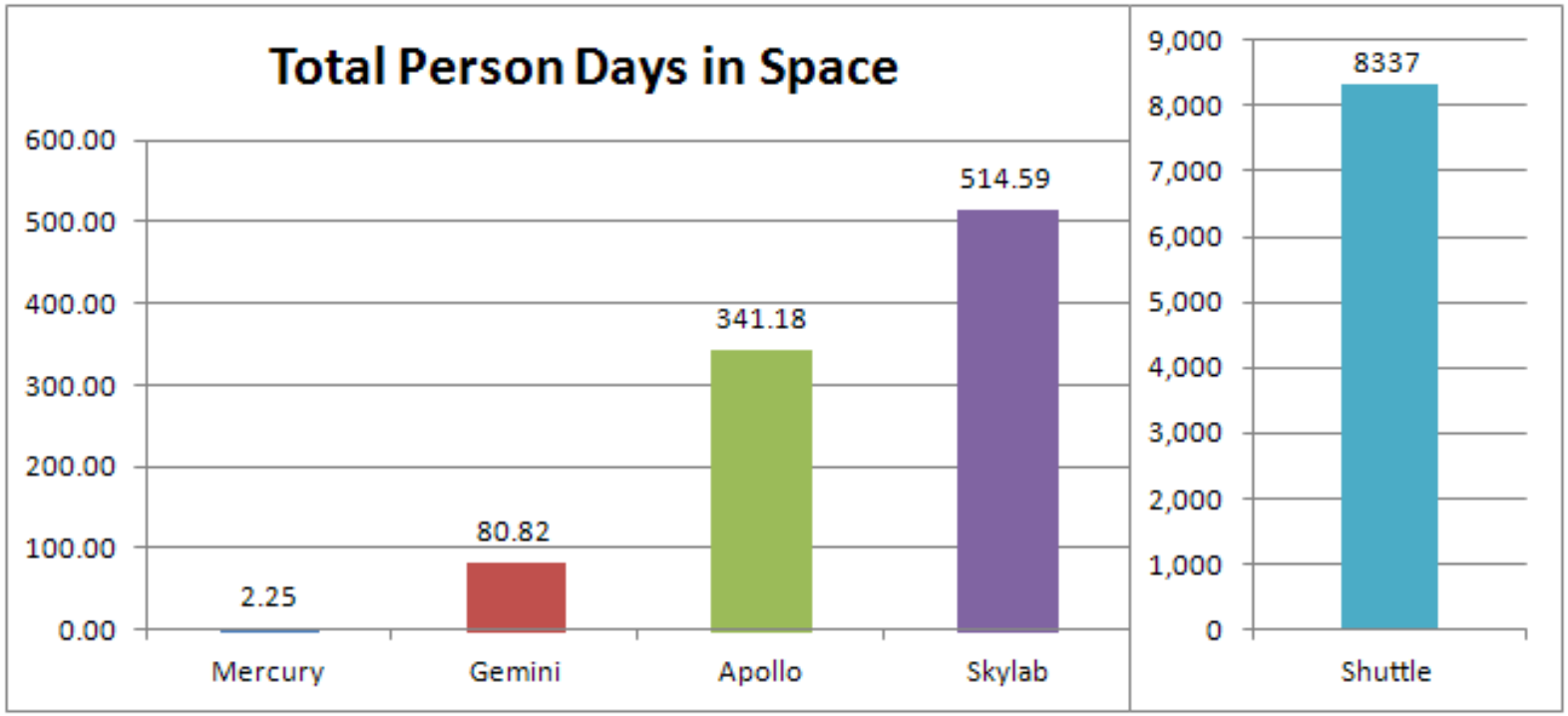
Cost per Crewed Mission



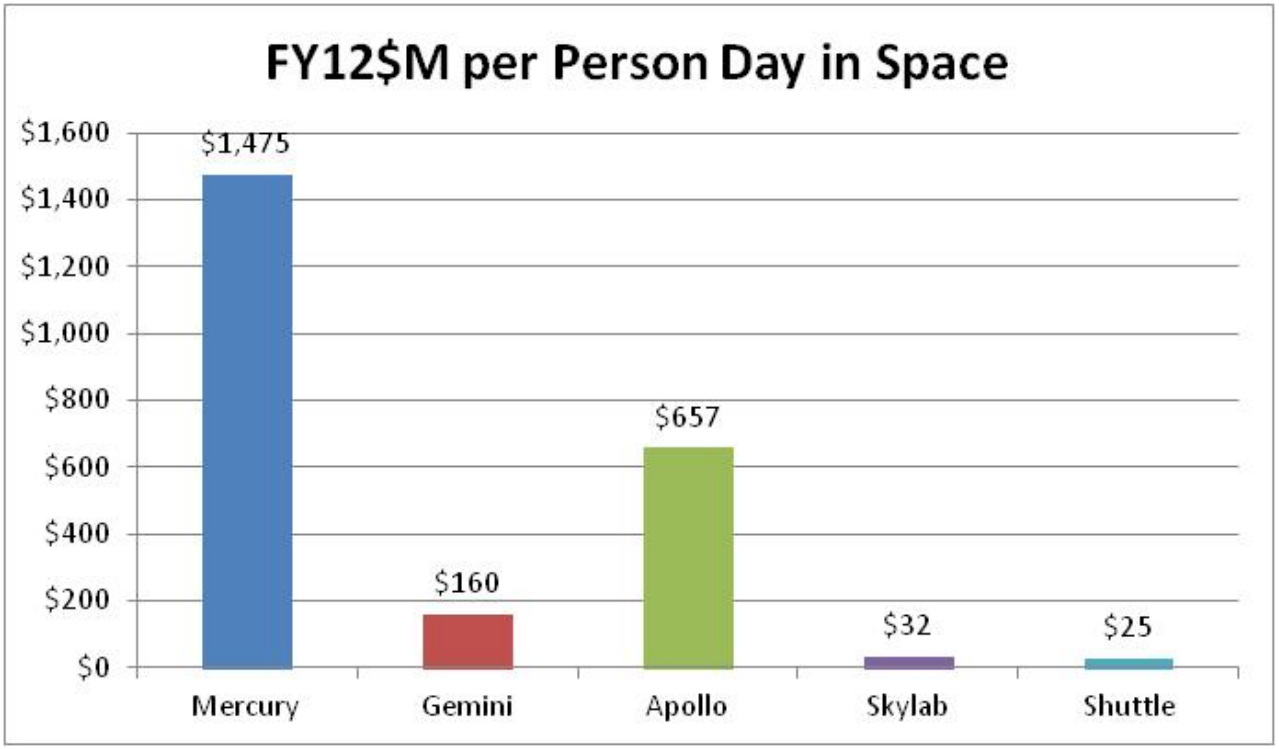
- **Mercury was Low Cost but Limited Capability**
- **Gemini was a Tightly Focused, High Flight Rate Program**
- **Apollo Architecture Highly Capable and High Cost**
  - Cost would have Decreased with more Missions
- **Skylab had only 3 Missions**
- **Shuttle Cost per Mission Reflects 30 Year Lifetime and Flight Rate**

Person Days in Space

- **Shuttle Increased US Human Spaceflight Experience by Almost a Factor of 9**
- **From 1961 to 1975, the US Averaged 67 Person Days in Space per Year**
- **From 1981 to 2011, the Shuttle Program Averaged 278 Person Days in Space per Year**



Cost per Person Day in Space



- **Shuttle was the Lowest Cost to Put One Person in Space for One Day**
- **Low Cost of Skylab shows the Value of Heritage and of a Continuous Orbiting Outpost**

Was Shuttle a Good Value?

- **Pro**
  - Provided Opportunity for ***Extensive Human Space Flight Experience*** over a ***Wide Range of Missions***
  - ISS Construction and Maintenance
  - Science Return (Spacelab, HST, etc.)
  - ***Lowest Cost*** on a per Person Day in Space Basis
- **Con**
  - Failed to Deliver Anticipated ***Flight Rate and Cost Savings***
  - Could not Support Human Exploration
  - Two ***Loss of Crew*** Failures

YES!

Shuttle Expanded Our Knowledge of Human Space Flight for the Lowest Cost per Astronaut of Any NASA Program

Lessons Learned

- **Amortize the Development Cost**
  - Buy it Once and Use it as Long as Possible
- **Reusability can Yield Cost Savings**
- **Carefully Trade Flexibility versus Dedicated System**
- **Recognize the Experimental Nature (and Associated High Cost) of Human Space Flight**
- **Plan in Crew Safety from the Beginning**
- **Only Promise what You can Deliver**

Conclusion

- **The Space Shuttle Achieved *Numerous Human Spaceflight Firsts***
  - **Reusability, On-Orbit Satellite Retrieval and Repair, Biological and Material Science Experiments, International Diplomacy, etc.**
- **The Space Shuttle was a *Marvel of Aerospace Engineering and Science***
  - **Lox/Hydrogen Propulsion, Thermal Protection Systems, Avionics Architecture, Aero Thermal Sciences, etc.**
- **The Space Shuttle is the most *Cost Effective US Human Launch System yet Developed***

The Space Shuttle was a Stunning Technical Achievement and a Major Advancement in Human Space Flight!

Backup

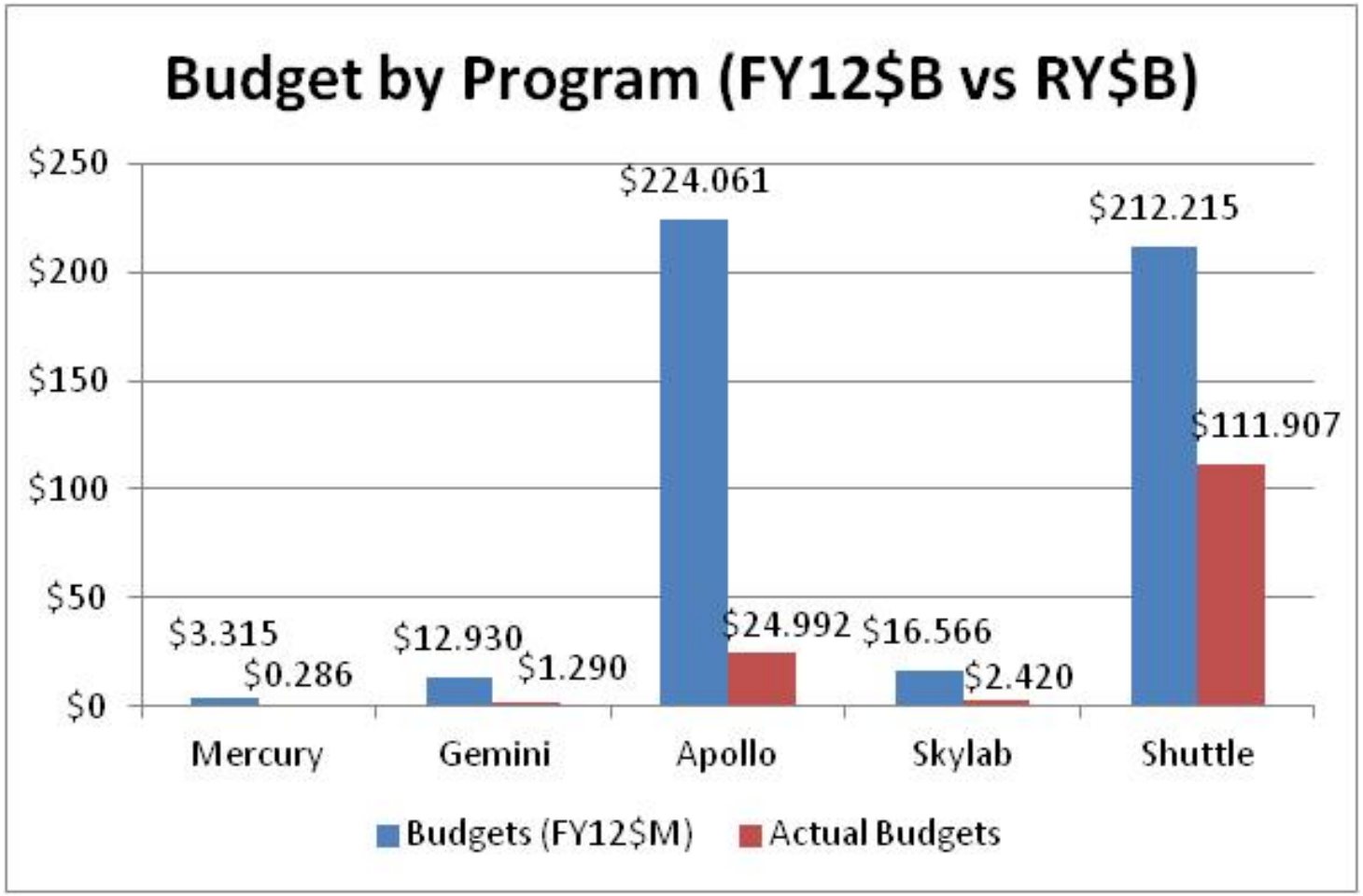
Gemini Person Days in Space

Missions	# of Astronauts	Days	hours	minutes	seconds	Total in days	Person Days in Orbit
Gemini III	2	0	4	52	31	0.20	0.41
Gemini IV	2	4	1	56	12	4.08	8.16
Gemini V	2	7	22	55	14	7.96	15.91
Gemini VII	2	13	18	35	1	13.77	27.55
Gemini VI A	2	1	1	51	24	1.08	2.15
Gemini VIII	2	0	10	41	26	0.45	0.89
Gemini IX-A	2	3	0	20	50	3.01	6.03
Gemini X	2	2	22	46	39	2.95	5.90
Gemini XI	2	2	23	17	8	2.97	5.94
Gemini XII	2	3	22	34	31	3.94	7.88
Total	**20**	**35**	**123**	**407**	**236**	**40.41**	**80.82**

Summary Metrics

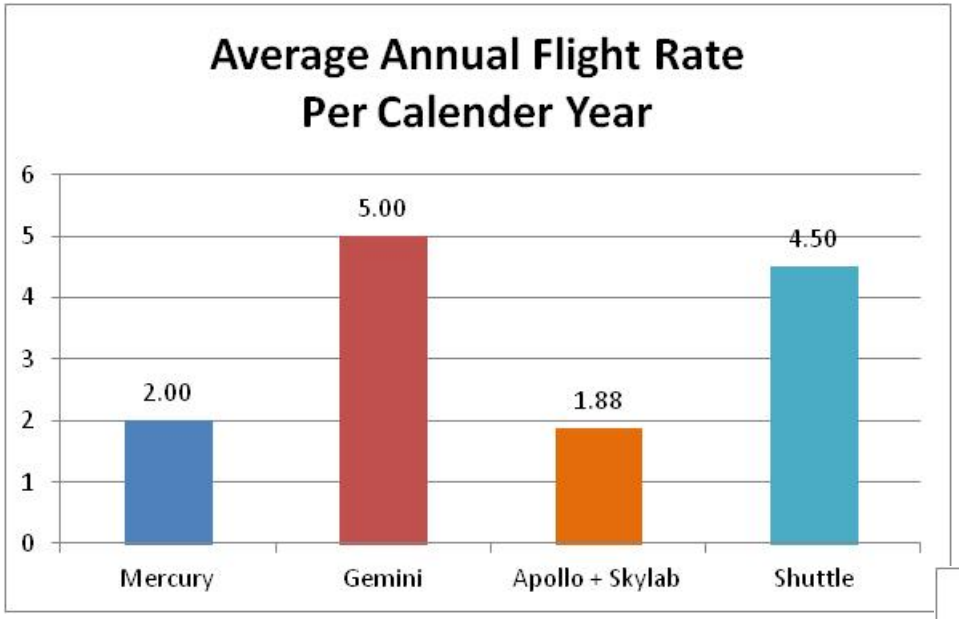
Program	Astronauts	Missions with Astronauts	Person Days in Orbit
Mercury	6	6	2.25
Gemini	20	10	80.82
Apollo	36	12	331.81
Skylab	9	3	514.59
Shuttle	820	135	8337.53
Total	**891**	**166**	**9267.00**

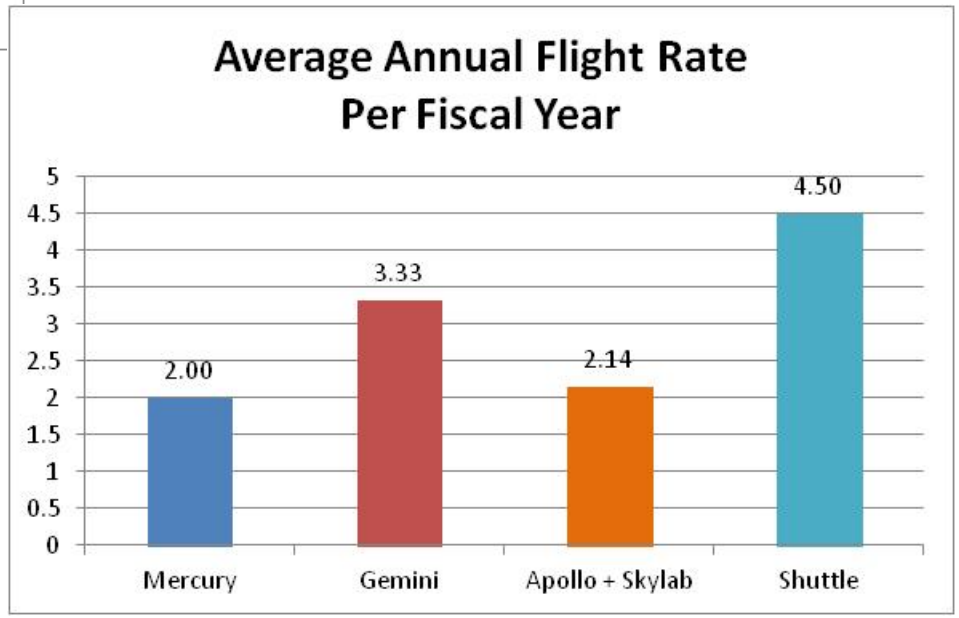
Total Program Budgets (RY$ VS FY12$)



Other Annual Flight Rates

Engineering Cost Office





Example Calculations

- **Cost per Crewed Mission**

  Formula: Cost per Mission = Total Budget / Number of Crewed Missions

  Example: Gemini

  - Total Gemini Budget: **$12.930 FY12$B**
  - Total # of Crewed Missions: **10**
  - Cost per Mission = **$12.930 / 10 = $1.293 FY12$B**

- **Cost per Person Day in Space**

  Formula: Person Days in Space = Number of Astronauts * Total Mission Time (Launch to Landing)

  Example: Gemini IV

  - Number of Astronauts: **2**
  - Total Mission Time: **4 Days, 1 hour, 56 minutes, 12 Seconds (4.08 Days in Decimal)**
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