A Review of the NASA Space Shuttle and Human Space Flight Fixed and Variable Space Transportation System Costs

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The following review has been assembled to assist in understanding the topic of the NASA Space Shuttle fixed and variable space transportation systems costs. The data covered can reflect on the range of fixed and variable costs of new human space flight systems derived from Shuttle systems or more generally the existing human space flight systems, processes, infrastructure and contractors.

1. Space Shuttle Fixed Costs

The Space Shuttles "fixed costs" are an oft quoted number. The topic got increasing attention in the language of fixed, variable, marginal, average and related terminology in the early 1990's. The quote below from the 1993 General Accounting Office report "The Content and Uses of Shuttle Cost Estimates" places the Shuttles fixed costs at 90% of total yearly costs.

> For fiscal year 1993, NASA estimated the marginal cost savings associated with deleting a single flight at $44.4 million. Marginal cost includes consumable hardware and materials and personnel that can be added or removed with temporary adjustments in the flight rate. It does not include any of the fixed costs that are required if NASA is to maintain the capability to fly the shuttle eight or nine times per year. NASA says that these fixed costs account for about 90 percent of the total operations cost of a flight.

Almost all reference's since the early 1990's to the Shuttle's fixed costs, and likely the one above, have as a source a single study in 1991, the Shuttle Zero Base Cost Study. The entire document is available on the [1]web and totals hundreds of pages. There are key pieces of information in the study that can still be used to reflect on today's real-year fixed costs of the Space Shuttle. **Table 1** that follows is from this study. It reflects "zero base" costs, which are costs relative to the capability to launch just once per year.

Percents only										
	Flight Rate									
	1	2	3	4	5	6	7	8	9	10
Project	BASE 100%									
Launch Operations	100	108	115.1	150.4	160.7	169.4	199.7	211.8	216.2	220.3
External Tank	100	100	100	100	104.2	108.6	113.3	118.3	122.6	126.7
SRM	100	100	106.5	113.5	126.1	135.2	146.4	155.5	162.4	169.4
Mission Ops	100	104.1	107.6	110.2	115.4	119.3	125.5	128.7	131.6	133.8
Orbiter	100	101.9	104.7	116.6	122.7	126.5	136.2	139	142.6	144.6
Logistics	100	105.4	112.1	119.6	125.4	134.8	148.3	159.2	170.2	175.1
SRB	100	102.7	111.4	119.5	129.2	135.8	148.1	155.5	165.8	174.1
SSME	100	100	100	117.2	122.9	128.7	137.7	143.3	151	156.7
Program Office	100	101.2	103.6	107.7	112.8	118.9	123.9	128.7	133.5	137.8
Other										
Engineering	100	100.4	101.7	104.3	110	114	115	118.5	119.8	120.7
Flight Crew Ops	100	100	100	112.7	112.7	119.6	121.2	139.6	139.6	139.6
Payload Ops	100	100.7	177.5	210.6	226.8	269	273.9	278.9	297.9	305.6
Prop. Sys. Integ.	100	103.2	104.8	111.7	111.7	115.3	119.4	119.4	119.4	119.4
Space and Life Sci.	100	110.7	110.7	110.7	110.7	121.4	122.5	122.5	122.5	129.4

Table 1

[1] http://science.ksc.nasa.gov/shuttle/nexgen/Shuttle_ZB.htm

"Zero Base" costs and fixed costs should not be confused. The Zero Base value would be a capability to launch once, and any subsequent value assumes that the flight rate capability exists only up to that flight rate, and not above it. By way of example, a Zero Base cost at two flights per year would not include 3 Orbiter Processing Facilities, since only 1 would be required.

Nonetheless the Zero Base study can be used to reflect very well on the Shuttle's fixed and variable costs by reading the crucial **Figure 1** below.

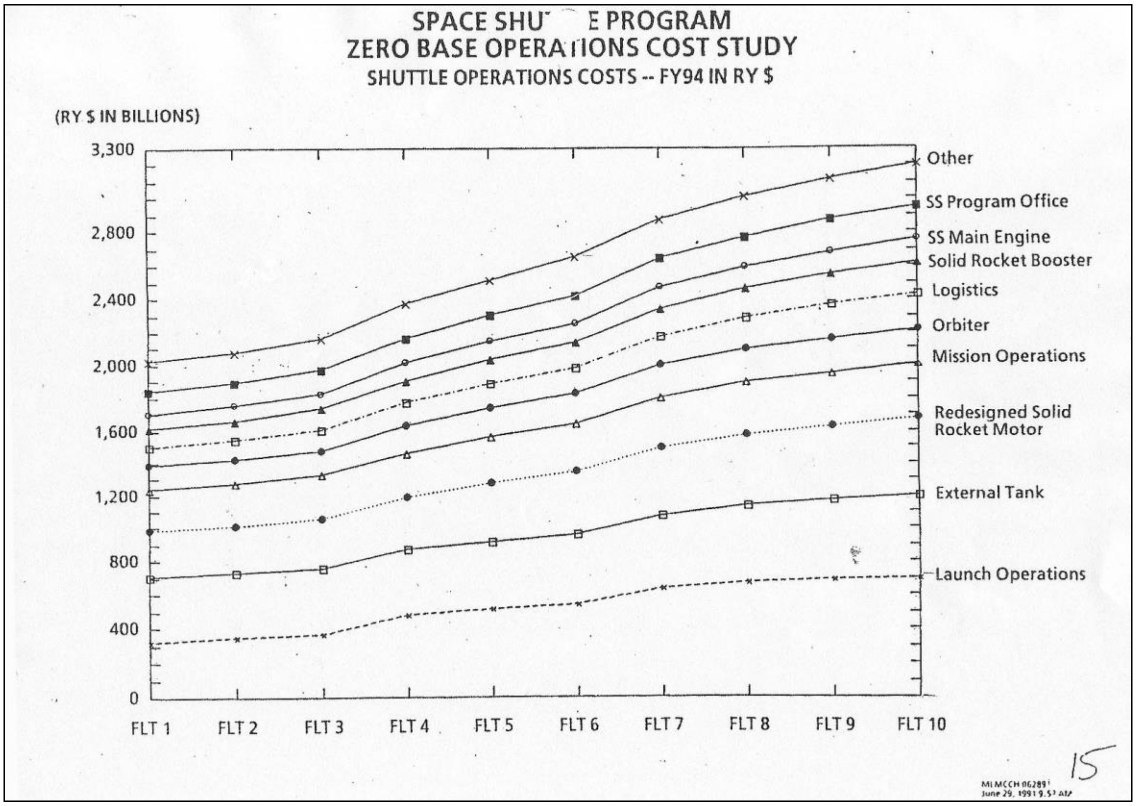

Figure 1

Knowing that history has born out over 100 flights that the truest flight rate capability of the Space Shuttle is close to five flights per year, without stressing the current systems and processes as usual, then **Figure 1** would indicate zero base costs at about 80% of total costs. That would be the above intersection of ~$2,500M at 5 flights vs. the ~$2,000M yearly for just the first flight. To further refine towards a fixed and variable concept it can be assumed that the derived variable cost total between five flights and one flight, about $500M (back then, in 1994 dollars), can be divided over the 4 ensuing flights to yield a variable cost of about $125M a flight. Zero flights, usually associated with fixed costs, would then have come out back then to $1,875M a year, with variable costs per flight, up to a 5 flight a year capability, at $125M a flight. Fixed costs would be 1,875 / 2,500 or **75% of total yearly costs.**

2. Updating Previous Study Values to Today

In terms of ratios the major assumptions that would allow using this older data point today, in lieu of repeating the study, would include:

- Assume that evolving changes in the vehicle and infrastructure technology have just replaced past functions in new ways
- Assume that evolving contractual changes have just replaced past functions affecting any totals but not ratios
- Assume the persistence of the functions drives the fixed to variable cost ratios

(These assumptions are tested further ahead.)

For today's budget the Space Shuttle value and the Space Flight Support (SFS) values can be taken from recent NASA e-budget system data as shown below in **Table 2**. SFS being accounted for separately is one change since the 1990's and it can be excluded here as being a general function that Human Space Flight would have to support in any architectural rendition in the future unless it is specifically reinvented.

	A	C	D
1	Subtotals and Grand totals do not include Workforce Totals and subtotals may not sum precisely due to rounding.	PY (2008)	2009 Pres Bud
2	Science	$4,760.5	$4,460.3
4239	Aeronautics Research	$573.6	$508.2
4681	Exploration Systems	$3,311.3	$3,512.4
4682	Constellation Systems	$2,683.8	$3,056.1
4683	Constellation Systems Program	$2,553.3	$2,883.0
5266	Commercial Crew and Cargo	$130.5	$173.0
5298	Advanced Capabilities	$627.5	$456.3
5299	Human Research Program	$153.6	$155.9
5450	Exploration Technology Development	$286.9	$244.1
6720	Prometheus Power and Propulsion	$0.0	$0.0
6727	Reimbursables Exploration Systems	$0.0	$0.0
6739	Space Operations	$5,488.5	$5,823.7
6740	Space Shuttle	$3,310.0	$2,997.8
6741	Space Shuttle Program	$3,310.0	$2,997.8
7259	International Space Station	$1,687.4	$2,062.1
7499	Space and Flight Support (SFS)	$491.1	$763.9
7500	Space Communications and Navigation	$304.1	$583.1
7755	Human Space Flight Operations	$0.0	$0.0
7782	Launch Services	$105.6	$100.1
7849	Rocket Propulsion Test	$72.7	$72.1
7905	Crew Health & Safety	$8.7	$8.6
7916	Reimbursables Space Operations	$0.0	$0.0
7928	Education	$147.7	$116.5
9503	Cross-Agency Support	$3,328.8	$3,383.2
12273	Inspector General	$32.6	$35.5
12283			

Table 2

The Space Shuttle's 2008 budget value in direct program dollar accounting would be \$3,310M a year. The value for 2009 is not used as it is already starting to reflect reduced costs as the retirement of the Space Shuttle approaches.

The Space Shuttle's fixed and variable cost in 2008 dollars, using a \$3.3B a year budget would be:

- If 5 flights per year –
- If in FY 2008 dollars -
- Then, total Space Shuttle budget = $3.3B in direct program accounting
- **Fixed Cost = 75% = $2.5B/year**
- Total Variable Cost = 25% = $825M/year
- **Variable Cost *Average* per Flight = $165M a flight**

3. Testing Assumptions

The assumptions used above can be partly tested to show how an old studies ratio set still applies to the question of the Space Shuttles fixed and variable costs. There are a handful of major changes in accounting, dollars and process from the early 1990's to today:

- Switchover to "full cost accounting" in the late 1990's.
  i. Fewer civil servants booked for as directly charging to the Space Shuttle program, all other's moved off
- Creation of the United Space Alliance (USA)
- Flight Rate
- Inflation
- Switchover to "direct program dollar" accounting in 2008/2009

Without detailing the mathematics, if an analyst were using the older FY 1994 cost data to predict FY 02 cost data, post USA, post getting into full cost accounting, knowing only 2 things - the drop in flight rate capability, and the drop in civil servants, and adjusting for inflation, the analyst would achieve a result that's 99% of the actual data (under-estimating). This implies that the savings achieved in the Space Shuttle in the late 1990's were a result primarily of off-loading 3,700 civil servants (moved to other programs, especially the International Space Station) and of the reduction in steady flight rate to 4 per year (also freeing funds for the ISS). Assuming any other factors, such as efficiency in the consolidation to USA, would throw the estimate off the actual data. This supports the steadiness assumed in the system processes, functions and behavior inherent in the prior assumptions. The switchover to "direct program dollar" accounting is a last adjustment, simply subtracting the percent of Cross Agency Support (CAS) / Center Management and Operations assigned overhead reflected as already removed in **Table 2**.

4. Are the Space Shuttle's Fixed and Variable Costs also the Costs of any Shuttle-Derived System?

An alternate view of the Space Shuttle's costs is shown below in **Table 3**. This view is un-official, a merger and filling in of the matrix from assorted sources with assorted modifications and guesstimates. The data for KSC and Florida is the best in absolute values as that has been a focus of this operations analyst.

What composes the Shuttle $3.3 Billion/year for Operations & Production? Sums>	$ 3,361 ↓	JSC $ 1,709	MSFC $ 1,030	KSC $ 519	<Sum $ 3,257
Florida: Ground Operations at the Kennedy Space Center					
F1-Space Flight Operations Contract, United Space Alliance Ground Operations (Lockheed-Martin & Boeing), managed by JSC		$ 403			
F2-Space Flight Operations Contract, United Space Alliance, NASA Shuttle Logistics Depot (Cape Canaveral) (Lockheed-Martin & Boeing), managed by JSC		$ 144			
F3-Space Flight Operations Contract, United Space Alliance Solid Rocket Booster Assembly/Refurbishment Facility & Related (Lockheed-Martin & Boeing), managed by MSFC			$ 124		
F4-KSC, all other Ground Operations				$ 519	
Total>	**$ 1,190**				
Texas: Mission Operations at the Johnson Space Center					
T1-Space Flight Operations Contract, United Space Alliance Mission & Flight Operations (Lockheed-Martin & Boeing), managed by JSC		$ 729			
T2-JSC, all other Mission & Flight Operations		$ 432			
Total>	**$ 1,161**				
Utah: Reusable Solid Rocket Motors and Boosters, ATK Launch Systems Group					
U1-Solid Rocket Booster (excluding f3 above), Reusable Solid Rocket Motor			$ 329		
Total>	**$ 329**				
Louisiana: External Tanks from the Michoud Assembly Facility, Lockheed-Martin					
L1-External tank project, production			$ 330		
Total>	**$ 330**				
California: Space Shuttle Main Engines, United Technologies Corp. / Rocketdyne.					
C1-Engines, hardware & support			$ 124		
Total>	**$ 124**				
Alabama: Launch Vehicle Project at the Marshall Space Flight Center					
A1-Propulsion & other NOT in f3, u1, L1, or c1. Note, u1, L1, and c1 already include MSFC center per se, civil servants et al.			$ 124		
Total>	**$ 124**				
Washington D.C.: NASA Headquarters contribution					
W1-Portion assignable to Space Shuttle, actual total is $341M/yr.	$ 70				
Total>	**$ 70**				
Other:					
O1-Mississippi: Engine Test Project, Stennis Space Center	**$ 29**				
O2-California: Flight Test Project, Dryden Flight Research Center	**$ 4**				

Table 3

The answer to the question "are the Space Shuttle's fixed and variable costs also the costs of any Shuttle-derived system?" is more "yes" to the extent more of the existing Shuttle assets above are used, carrying in existing Shuttle processes, flight hardware suppliers and methods, with associated reliabilities, infrastructure and functions.

5. Closing

The notions of the Space Shuttle's "fixed costs" can be thought of with some out-of-the-box perspectives that deserve more attention than the time available to address these here:

One-the fixed costs we call Shuttle are really Human Space Flights, a way of doing business, related to ANY Shuttle-like system, supply chain, or human systems, to the degree these are not re-imagined.

Two-fixed costs are mostly a system of processes driven mostly by contractor in-direct functions from requirements generation to requirements fulfillment. Touch labor that touches flight hardware is the smaller part of any contractor workforces. The majority of the contractor resources are in-direct, where the money is. And contractors are the bulk of costs. So consider these fixed costs of processes, not just hard infrastructure ownership.

Third-NASA overhead is no longer in current program accounting. The soup-to-nuts enabling support services in NASA are no longer in direct program dollar budgets. Rather these items such as procurement, finance, information technology, security, general facilities one step removed from flight hardware processing sites, human resources, and safety and mission assurance are under Cross Agency Support (CAS) and Center Management and Operations (CMO) as revealed also in **Table 2**. So the Shuttles fixed costs are not primarily due to NASA / federal base support, a common misperception.

Fourth-Utilization has been left unaddressed. Fixed costs can be a strength, a valuable asset, ready to produce for only marginally more than is already a given. The behavior of fixed costs, and contractor's processes and their infrastructure, in this respect must develop some out-of-the-box thinking, such as how to ramp up production of flight elements of sufficient internal commonality to avoid multiplying fixed costs. This would be done while exploiting the benefits to flight rate and exploration of relatively low variable costs. This commonality trade space is usually opposed to optimization of individual flight elements for performance. This need not be the case. Related to commonality is the concept of amortization, the use of existing external capabilities that are not owned nor used exclusively by NASA. The Commercial Orbital Transportation Services (COTS) concept relates to the former as would the use of any Expendable Launch Vehicles. Yet the degree to which optimization and customization result in exclusive use or full ownership of unique assets (flight or ground) will determine the degree to which the quandary of high fixed costs again arises.

About the Author

Mr. Zapata has worked with NASA at the Kennedy Space Center since 1988. In that time he has held responsibility for Shuttle systems including the Shuttle External Tank and the Shuttle cryogenic propellant loading systems, as related flight and ground propulsion systems. Starting in the mid 90's he began work to translate the operations experience into improvements in flight and ground system designs for achieving improvements in ground operations processing from landing through launch, in all aspects from direct to in-direct operations. He participated in the Explorations Systems Architecture Study or "ESAS" contributing launch and landing ground operations cost estimates and integrating the KSC cost estimates into the ESAS life-cycle cost analysis.

Most recently Mr. Zapata is performing (1) strategic Constellation and NASA agency level future scenario analysis and (2) analysis supporting the Constellation Standing Review Board, by providing independent analysis of the KSC ground operations project.

Mr. Zapata looks forward to the day when access to space is safe, routine and affordable as a result of taking advantage of, quantifying and understanding the experience and lessons of past and current space transportation systems operations.

For related material see: http://science.ksc.nasa.gov/shuttle/nexgen/rlvhp.htm