ENAE 483/788D LECTURE #07
(COST ESTIMATING RELATIONS) PROBLEMS – FALL, 2024

We are going to use the NASA SVLCM costing model (in the lecture notes) to estimate the costs of the New Glenn launch vehicle from Blue Origin. Use the following parameters in the analysis: *Note: in this problem set, as throughout the course, "MT" refers to metric tons, or 1000 kg.*

Parameter	First Stage	Second Stage
Specific impulse (sec)	327.5	356
Total stage mass (MT)	1025	375
Inert mass (MT)	102.5	18.75
Payload to LEO (MT)	–	45

(1) Calculate the nonrecurring costs for each of the two stages.

From page 13 of the slides, $c_{NR} = 12.73 m_{in}^{0.55}$ *for launch vehicles, where the units of* m_{in} *are kilograms. (Note that the values in the problem set table are given in metric tons, or thousands of kilograms.) This gives values of* $c_{NR}(1ststage) = \boxed{\$7257M}$*, and* $c_{NR}(2ndstage) = \boxed{\$2851M}$*, for a total nonrecurring cost of $10,110M. It's worth noting that this would be the estimate for NASA developing this vehicle; Blue Origin is likely spending significantly less.*

(2) Assume the development of the vehicle took six years. Find the year-by-year costs using a beta function with $c_f = 0.45$ and $P_k = 0.55$.

$$A = \frac{(1-P_k)(c_f - 0.1875)}{0.625} = \frac{(1-0.55)(0.45-0.1875)}{0.625} = 0.1890$$
$$B = P_k \frac{c_f - 0.1875}{0.3125} = 0.55\frac{0.45-0.1875}{0.3125} = 0.4620$$
$$C(\tau) = 10\tau^2(1-\tau)^2(A + B\tau) + \tau^4(5-4\tau)$$

Year	τ	$C(\tau)$	Cumulative Cost, \$M	Yearly Cost, \$M
1	0.1667	0.0547	552.4	552.4
2	0.3333	0.2147	2,170.	1,617
3	0.5	0.45	4,548	2,379
4	0.6667	0.7063	7,139	2,591
5	0.8333	0.9145	9,243	2,104
6	1	1	10,110	864.4

(3) Calculate the first unit production costs for each of the two stages.

From page 13 of the notes, $c_{R1} = 0.3024 m_{in}^{0.662}$ *for launch vehicles, where the units of* m_{in} *are kilograms. This gives values of* $c_{R1}(1^{st}stage) = \boxed{\$627.6M}$*, and* $c_{R1}(2^{nd}stage) = \boxed{\$203.8M}$*, for a total first unit production cost of $831.4M for the first launch vehicle set.*

(4) For an 85% learning curve, calculate the production costs (unit by unit) for the first 5 vehicles.

$$p = \frac{\ln LC}{\ln 2} = \frac{\ln 0.85}{\ln 2} = -0.2345$$

$$C_n = C_1 * n^p$$

Production #	LC fraction	1^{st} Stage Cost ($M)	2^{nd} Stage Cost ($M)	Launch Vehicle Cost ($M)
1	1	627.6	203.9	831.5
2	0.85	533.5	173.3	706.7
3	0.7729	485.1	157.6	642.6
4	0.7225	453.4	147.3	600.7
5	0.6867	430.3	139.8	570.1

Note that the discount is distributive, so it can be applied to the cost of each individual stage's production, or it can be applied to the overall launch vehicle production (both stage costs summed).

(5) Assume for this problem that the New Glenn is expendable. For simple break-even, how much would you have to charge per flight to amortize both the nonrecurring and recurring costs over the first five vehicles?

The total recurring cost over the 5 vehicles is $3,352M, so adding in the nonrecurring cost of $10,110M the total cost is $13,460M. Spread across the 5 flights of the expendable vehicles, that works out to **$2,692M/flt** *or* **$59,820/kg of payload**.

(6) The New Glenn first stage is designed to be reusable. Assume the refurbishment fraction is f_R=0.03. What is the simple break-even cost over 25 missions assuming each first stage flies five times?

$$c_{refurb} = f_R * c_{R,1} = 0.03 * (627.6) = \$18.83M/flt$$

(Note that we only refurbish the first stage, and that the refurbishment cost does not follow a learning curve.) The costs for the first six years are as they were in (2). With the learning curve for production costs as per (4), we can calculate the total production costs of the 5 first and 25 second stages, as well as the refurbishment costs for the 20 first stage re-flights after the 5 newly produced first stages fly once without refurbishment. This is included in Table 1.

Given these costs for the first and second stage production, 20 refurbishments of the first stages (since they each exit production ready to fly for a first time), and the nonrecurring costs from (1), the total program cost with reusability comes to $16,030M, which equates to **$641.2M/flt** *or* **$14,250K/kg** *of payload.*

Table 1. Detail for (6)

Unit number	c_R Stage 1 (\$M)	c_{refurb} Stage 1 (\$M)	c_R Stage 2 (\$M)
1	627.6		203.8
2	533.5		173.3
3	485.1		157.6
4	453.4		147.3
5	430.3		139.8
6		18.83	133.9
7		18.83	129.2
8		18.83	125.2
9		18.83	121.8
10		18.83	118.8
11		18.83	116.2
12		18.83	113.8
13		18.83	111.8
14		18.83	109.8
15		18.83	108.0
16		18.83	106.4
17		18.83	104.9
18		18.83	103.5
19		18.83	102.2
20		18.83	101.0
21		18.83	99.84
22		18.83	98.73
23		18.83	97.73
24		18.83	96.76
25		18.83	95.84
Totals	2,530	376.6	3,017

(7) Assume as per (2) the development of New Glenn took six years, that the production costs for the first stages are all paid in year 7, and that the cost for each second stage is paid in the year in which it flies. Refurbishment costs for the first stage are also paid in the year of flight. There are 5 flights/year in each of years 7-11 in which you pay production costs for the expendable second stages (with learning curve as per (5)) and refurbishment as necessary for the first stages (no learning effects on refurbishment). What is the total cost in each year of the program from 1-11?
Included in Table 2

(8) At a 10% discount rate, what is the net present value in year 0 for each of the costs you calculated in (7)?
Included in Table 2

TABLE 2. Detail for (7 and 8)

Year	NRE Cost ($M)	Stage Production Cost ($M)	Stage 1 Refurb ($M)	Total Annual Costs ($M)	NPV ($M)
1	552.4			552.4	502.2
2	1617			1617	1337
3	2379			2379	1787
4	2591			2591	1770.
5	2104			2104	1306
6	864.4			864.4	487.9
7		3352	94.14	3352	1720.
8		625.9	94.14	723.0	337.3
9		559.6	94.14	653.7	277.2
10		518.0	94.14	612.2	236.0
11		488.9	94.14	583.1	204.4
Totals	10,110	5,547	376.6	16,030	9,965