2nd ESA - CNES SPACE COST ENGINEERING CONFERENCE

Cost Estimating for a SmallSat-Dedicated Launch Vehicle in Korea

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About the authors

KARI: Korea Aerospace Research Institute

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Advise in Cost Estimating

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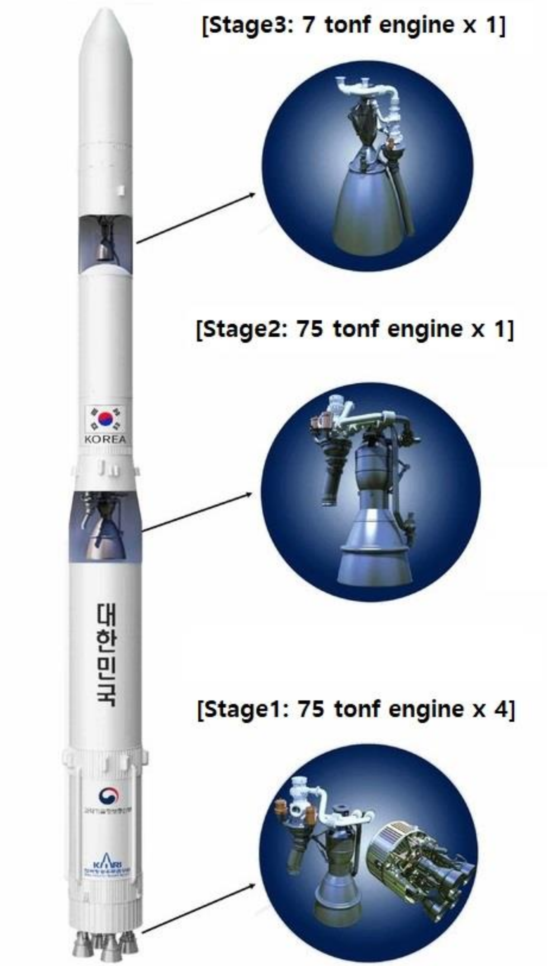
Contents

Nuri launch vehicle (KSLV-II)

- Indigenously designed and manufactured in Korea
- Performance: 1.5 tons to 700 km SSO (Sun Synchronous Orbit)
- Maiden Flight: scheduled for October in 2021
- Vehicle Characteristics

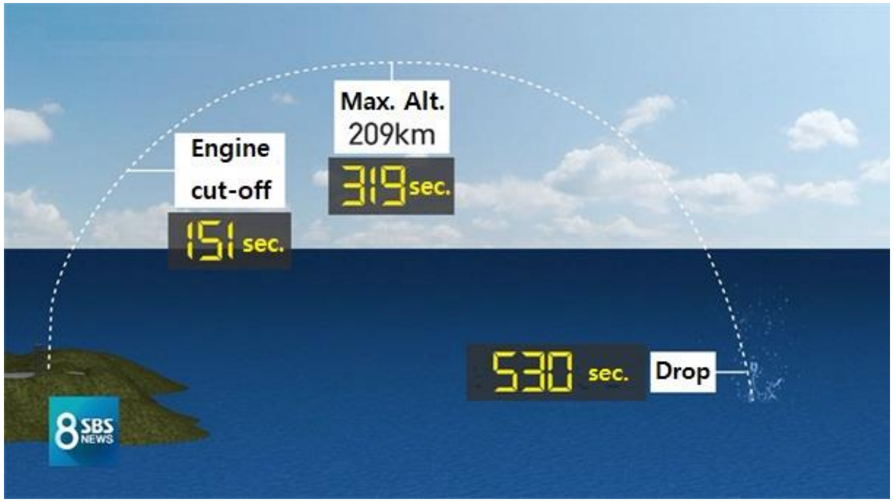
Parameter		Value
Gross Lift-Off Weight		200 ton
Height		47.5 m
Diameter		3.5 m / 2.6 m
Engines	Stage 1	75 tonf x 4 EA (300 tonf)
	Stage 2	75 tonf x 1 EA
	Stage 3	7 tonf x 1 EA
Propellant	Fuel	Kerosene
	Oxidizer	Liquid Oxygen



Test launch vehicle (TLV) of the Nuri Engine

- For verification of 75 tonf engine performance under launch environment
- Launch date: Nov. 28 2018 → Success
- 1st stage of TLV: similar to 2nd stage of Nuri
- Sub-orbital flight
- TLV Characteristics

Parameter	Value
GLOW	52 ton
Height	25.8 m
Diameter	2.6 m
Engine	75 tonf x 1 EA



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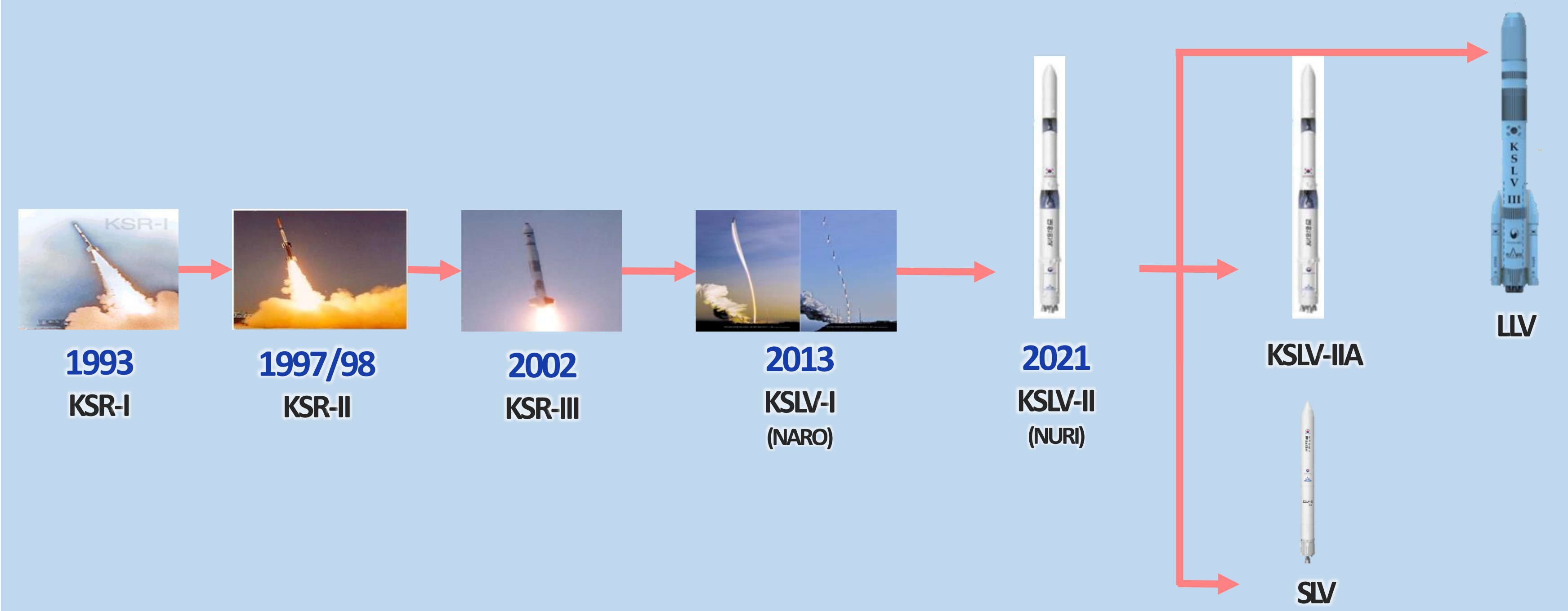
Master plan for launchers in Korea

- Classified to three different sizes based on payload weight
  - SmallSat-dedicated launch vehicle (SLV): 500 kg to SSO
  - Medium-class launch vehicle (MLV): 2,500 kg to SSO
  - Large-class launch vehicle (LLV): 3,000 kg to GTO (Geostationary Transfer Orbit)



Space Launchers Roadmap of Korea

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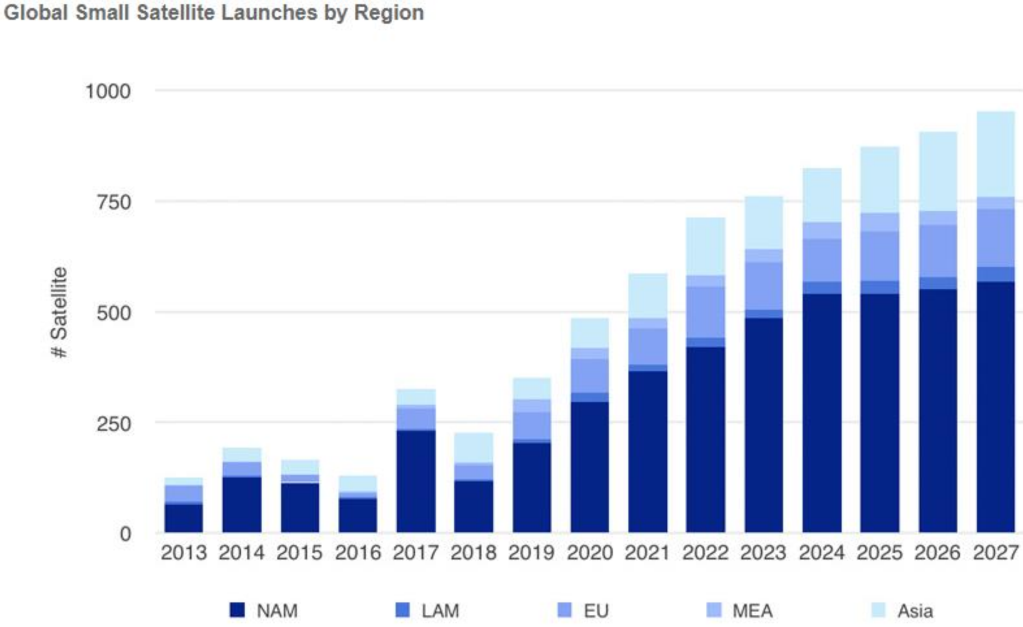
SmallSat-dedicated Launch Vehicle (SLV)

- To respond increasing demand for SmallSat-dedicated launch service
  - Launch frequency – high
  - Price per launch - low



Source: NSR (https://apscc.or.kr/2019-2/)

- Performance: 500 kg to 500 km SSO
- Target cost < 15M USD
- Propulsion system
  - Stage 1: Improved engine from 75 tonf Kerosene/LOX engine of Nuri
  - Stage 2: Newly developed 3 tonf LCH4/LOX engine

SmallSats-dedicated Launch Vehicle (a Concept)

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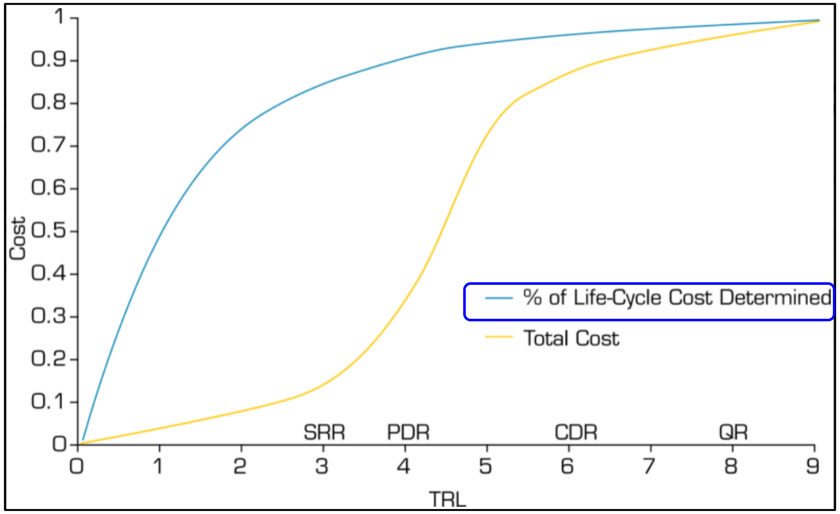
Contents

Why cost estimating?

- Cost estimating is used to
  - Sizing your project office team
  - Affordability studies
  - …
- Why is cost estimating important?
  - Early-phase cost estimates are used in a decision-making for project feasibility.
  - Cost can be used as a design variable or objective for optimization.
    - ✓ Minimize cost or Maximize return
  - Most costs are frozen in early phase.

    → Early estimating is important.

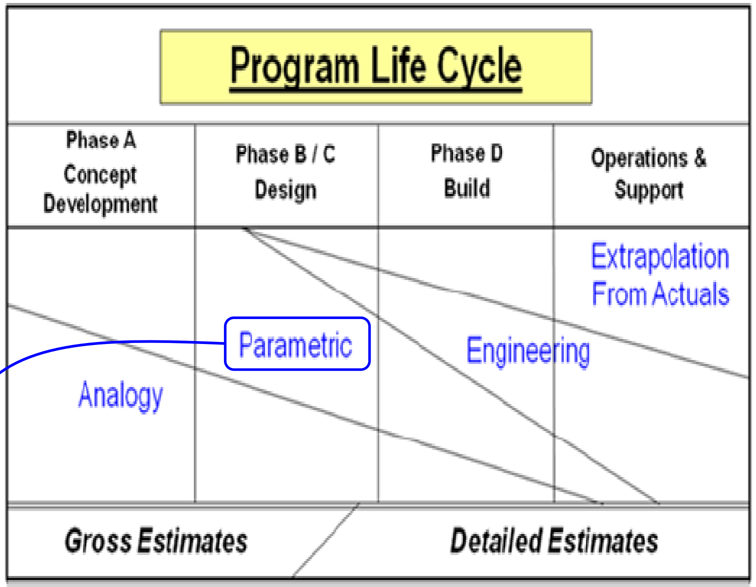


(Blair JC, Ryan RS, Schutzenhofer LA, Humphries WR, inventors; Vehicle Design Process: Characterization, Technical Integration, and Lessons. 2001 May 1.)

- Reasonable and transparent cost estimate is needed.

Cost estimation methods

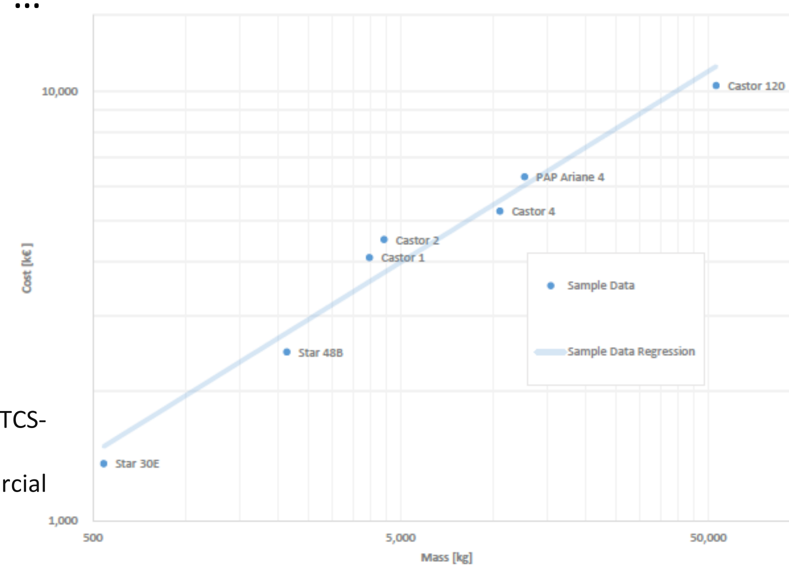
- Methods



(NASA(2015), “NASA Cost Estimating Handbook(Ver 4.0)”)

- Parametric method ($C = f(p_1, p_2, \ldots, p_n)$)
  - Using the relationship between inputs & cost in previous programs
  - Usually mass is used as an input.

- Tools
  - TRANSCOST (Koelle)[1]
  - Unmanned Space Vehicle Cost Model (NASA)
  - Small Satellite Cost Model (NASA)
  - Drenthe’s model (ESA)[2]
  - SPICE 6 (ESA)
  - RACE (ESA)
  - TruePlanner (commercial)
  - SEER-H (commercial)
  - …



(Drenthe, N. T. “SOLSTICE: Small Orbital Launch Systems, a Tentative Initial Cost Estimate.” (2016).)

[1]Koelle, D. E.: Handbook of cost engineering and design of space transportation systems. Number TCS-TR-200, 8.2 edition, TransCostSystems (TCS), Ottobrunn Germany, October, 2013.
[2]Drenthe, N. T., Zandbergen, B. T. C., Curran, R., & Van Pelt, M. O.: Cost estimating of commercial smallsat launch vehicles. Acta Astronautica, Vol. 155, pp. 160-169, 2019.

Drenthe's model

- Small Orbital Launch Systems, a Tentative Initial Cost Estimate (SOLSTICE)
  - New method to estimate costs of small and commercial launch vehicles

- Six phase estimate

① T1 (Flight Unit cost)

✓ T1 = FM1 (Manufacturing) + Management + Product Assurance

✓ T1 = aM^b [k€]

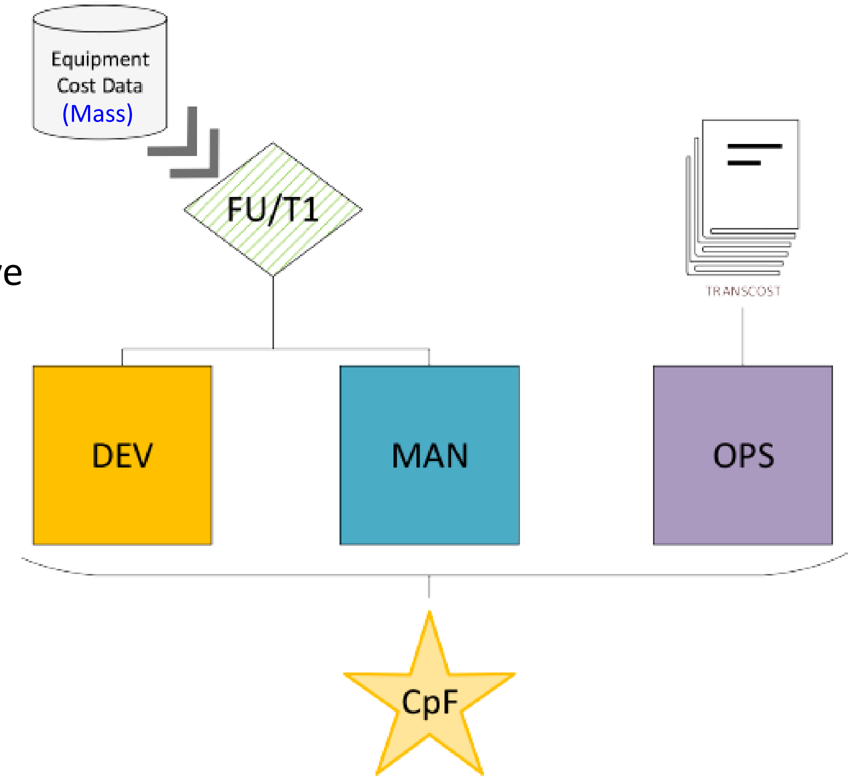
② Development cost – Using T1

③ Manufacturing cost – Using learning curve

④ Operating cost – Using TRANSCOST

⑤ Cost per Flight (CpF)

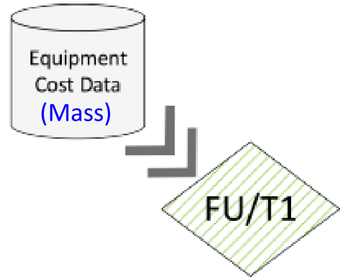
⑥ Price per Flight (PpF)



CpF estimating process

① T1 (Flight Unit Cost)

- T1 = aM^b [k€]



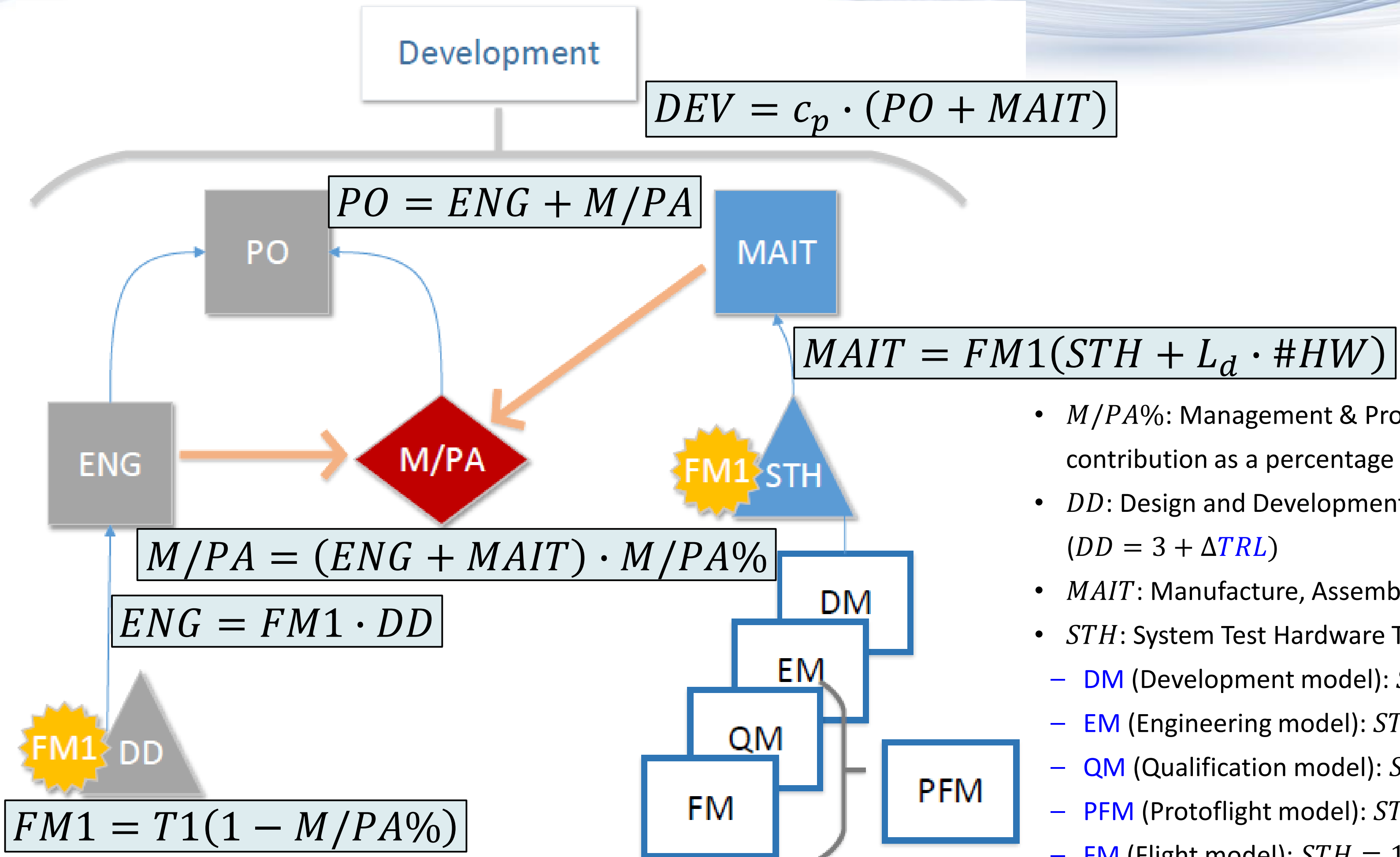
Equipment Element Name	Regression			NAFCOM		Used
	a value	*b* value	RSE/CMA	*a* value	*b* value	
Solid Casing, including solid propellant	90.72782	0.44422	12.9%	321.12767	0.30	Regression
Pressurizant Tank	19.99465	0.71253	27.6%	22.21748	0.70	Regression
Fuel Tank	19.99465	0.71253	27.6%	22.21748	0.70	Regression
Oxidizer Tank	19.99465	0.71253	27.6%	22.21748	0.70	Regression
Thrust Cone	2.79930	0.91199	12.6%	9.39259	0.70	Regression
Skirt	2.79930	0.91199	12.6%	9.39259	0.70	Regression
Thermal Control	2.79930	0.91199	12.6%	9.39259	0.70	Regression
Engine(s)	31.48271	0.78811	35.8%	322.07959	0.50	Regression
Thrust Vector Control	33.90978	0.60977	13.7%	35.44885	0.60	Regression
Pressurization System	11.50618	1.06948	49.8%	72.19775	0.60	Regression
Pipes	8.95877	0.68815	34.3%	8.96336	0.70	Regression
Valves	8.95877	0.68815	34.3%	8.96336	0.70	Regression
Stage Harness	27.45211	0.44623	34.9%	14.20721	0.75	Regression
Payload Adapter	124.86209	0.31031	13.0%	26.01794	0.70	Regression
Payload Fairing	4.09558	0.96587	9.2%	23.59239	0.70	Regression
Comms			*One data point only*	51.11253	0.80	NAFCOM
Power	56.13918	0.66916	*Two points*	42.01174	0.80	NAFCOM
Data Handling	141.82428	0.79249	16.3%	141.68203	0.80	Regression
GNC	69.05491	0.82458	23.8%	72.86034	0.80	Regression
Avionics Harness	27.45211	0.44623	34.9%	14.20721	0.75	Regression
Attitude Control Module	44.04074	1.06207	88.6%	257.84198	0.75	Regression
Interstage Structure	6.70369	0.68041	19.3%	6.16655	0.70	Regression

- Drenthe's model: <u>*can*</u> estimate equipment elements' cost

  (TRANSCOST: <u>*cannot*</u> estimate equipment elements' cost)

Drenthe, N. T., Zandbergen, B. T. C., Curran, R., & Van Pelt, M. O.: Cost estimating of commercial smallsat launch vehicles. Acta Astronautica, Vol. 155, pp. 160-169, 2019.

② Development cost – Using T1

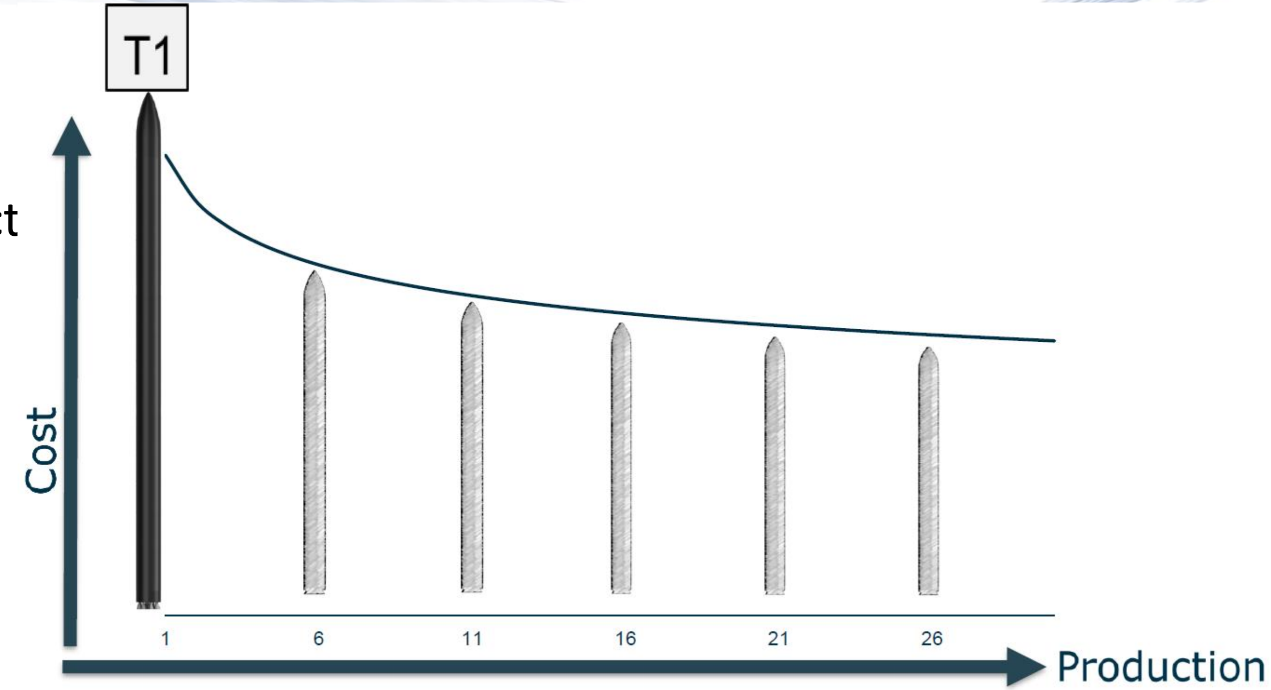


Development cost estimating process

- $M/PA\%$: Management & Product Assurance contribution as a percentage
- DD: Design and Development T1 equivalent ($DD = 3 + \Delta TRL$)
- $MAIT$: Manufacture, Assembly, Integration and Test
- STH: System Test Hardware T1 equivalent
  - DM (Development model): $STH = 0.3$
  - EM (Engineering model): $STH = 1.3$
  - QM (Qualification model): $STH = 1.3$
  - PFM (Protoflight model): $STH = 1.5$
  - FM (Flight model): $STH = 1$ (reference)
- L_d: Development cost improvement/learning factor
- $\#HW$: Number of hardware elements
- PO: Project office cost
- c_p: Cost reduction factor

③ Manufacturing cost – Using learning curve

- T1: First unit cost
- If hundreds are manufactured, you expect to see improvements in efficiency!



- Two typically applied learning curves:
  - Wright
  - Crawford (used in Drenthe's model)

$$n\text{-th unit cost: } C_N = T1 \cdot n^{\frac{ln(p)}{ln(2)}}$$

p: Cost improvement factor

Drenthe, N. T. "SOLSTICE: Small Orbital Launch Systems, a Tentative Initial Cost Estimate." (2016).

④ Operating cost – Using TRANSCOST

- Direct operating costs (DOC) - relating to launch itself
- Indirect operating costs (IOC) - commercialization costs

DOC	Cost-Estimating Relationship (CER)
Ground Operations	$8M_0^{0.67}L^{-0.9}N^{0.7}f_v f_c f_4 f_8 f_{11}$ [WYr]
Propellant Cost	$\frac{M_p}{r+1}c_f + \frac{r\cdot M_p}{r+1}c_{ox} + M_{pres}\cdot c_{pres}$ [€]
Flight and Mission Operations	$20(\sum Q_N)L^{-0.65}f_4 f_8$ [WYr]
Transportation Costs	$T_S M_0$ [WYr]
Fees and Insurance Costs	Insurance + Launch site fee + Payload charge site fee
IOC	$(33S+32)L^{-0.379}$ [WYr]

M_0: Lift-off Weight [ton]

M_{pres}: Pressurizant mass [kg]

N: Number of stages

f_4: Cost reduction factor

f_{11}: Commercial factor

c_f: Fuel cost per kilogram [€/kg]

c_{pres}: Pressurizant cost per kilogram [€/kg]

T_S: Transportation cost to launch site per kilogram [€/kg]

M_p: Propellant mass [kg]

L: Launches per year

f_c: Assembly and integration factor

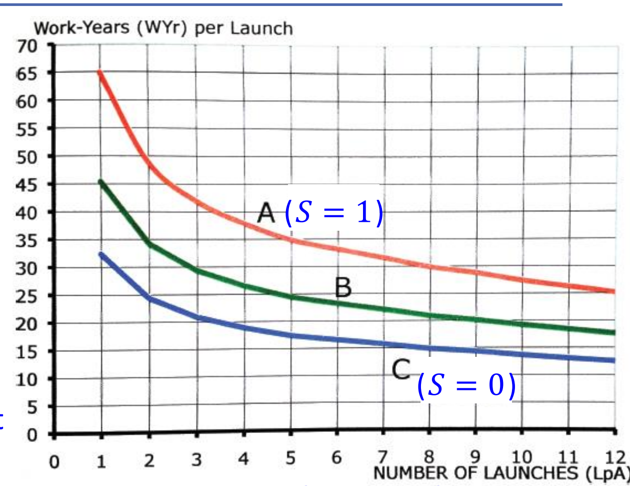
f_8: Country productivity factor

r: Mixture ratio

c_{ox}: Oxidizer cost per kilogram [€/kg]

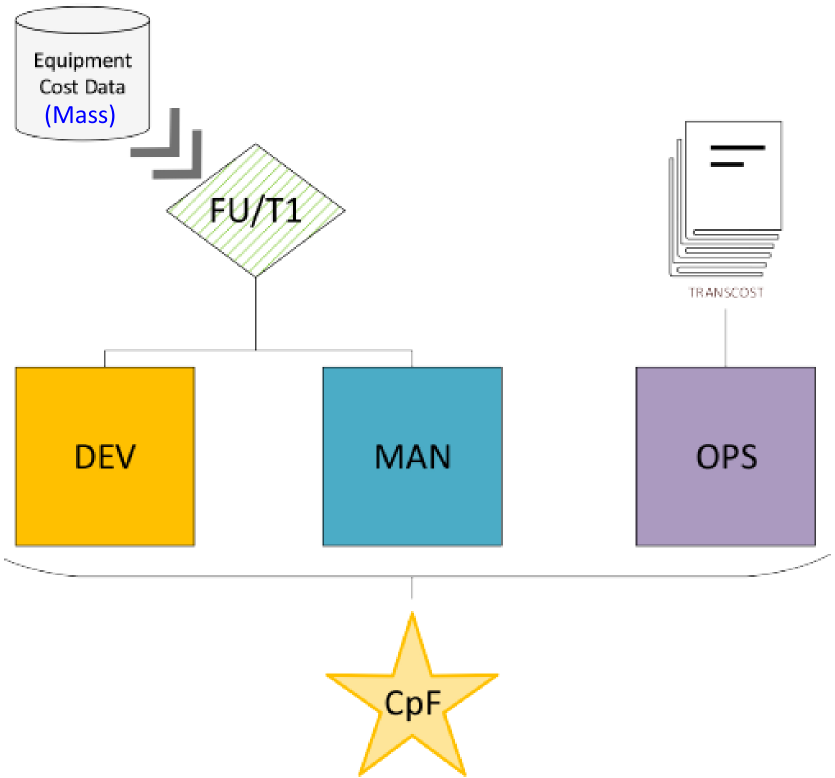
Q_N: Vehicle complexity factor

S: Percent of work subcontracted out



IOC as a function of L

⑤ Cost per Flight (CpF)



CpF estimating process

$$CpF_a = \frac{DEV}{N_a} + MAN_a + OPS$$

CpF_a: Average CpF

MAN_a: Average manufacturing cost

N_a: Number of flights over which the development charge is spread

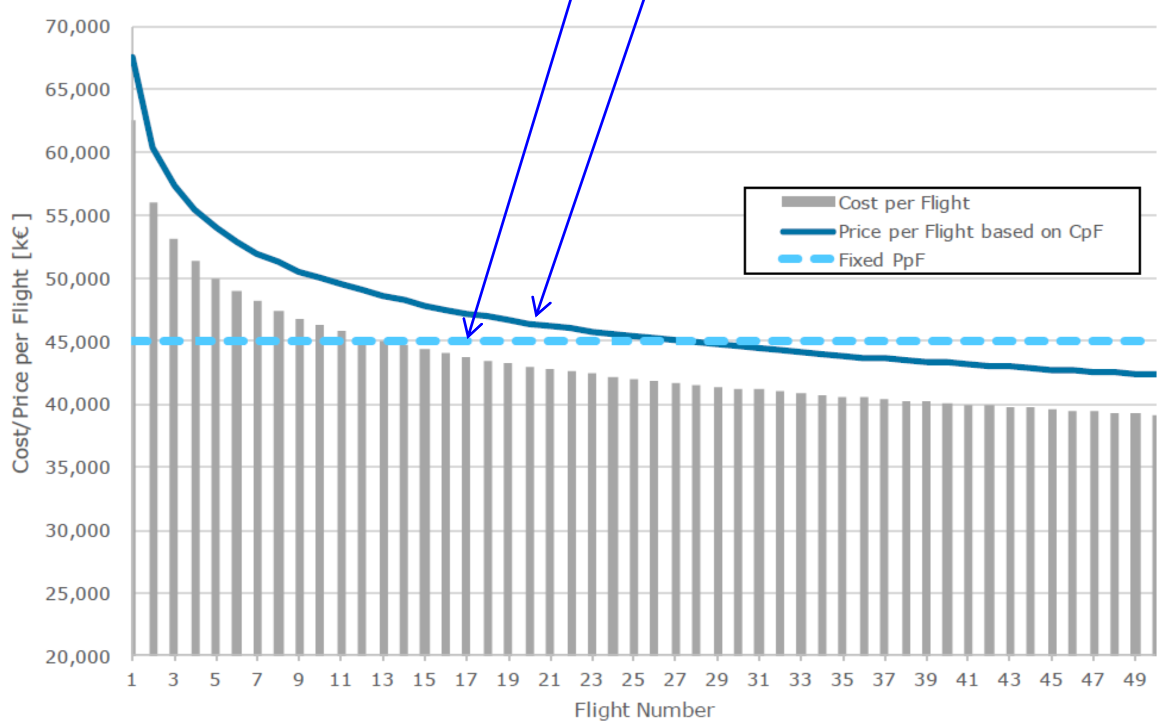
- DEV of the Falcon 1 was fully covered by NASA.

→ DEV should not be included in the CpF.

$$CpF_a = \frac{DEV}{N_a} + MAN_a + OPS$$

⑥ Price per Flight (PpF)

- PpF
  - Cost-based Pricing
    - PpF based on CpF
    - Fixed PpF
      - Break-even Fixed PpF
      - Net Present Value Analysis (Consider the time-value of money)
  - Competition-based Pricing
  - Demand-based Pricing



CpF & PpF based on CpF & Fixed PpF

Contents

① T1 (Flight Unit Cost)

$$T1 = aM^b f_8 \ [k€]$$

$f_8 = 0.56$ is used to consider the country productivity of Korea

Unit	Equipment	Part	Part ID	Mass (kg)	Number	T1 (k€)
Stage 2	**----liquid stage ---**			**520**		**2,123**
	Solid Casing		S-SC-	-	-	
	Pressurizant Tank		S-PT-	20	1	95
	Fuel Tank		S-FT-	115	1	329
	Oxidizer Tank		S-OT-	115	1	329
	Stage Structures					
		Thrust Cone	S-SS-TRC	8	1	10
		Skirt	S-SS-SKI	23	1	27
		Thermal Control	S-SS-THM	13	1	16
	Engine(s)		S-EN-	120	1	767
	Thrust Vector Control		S-TV-	30	1	151
	Pressurization System		S-PS-	35	1	289
	Pipes & Valves					
		Pipes	S-PV-PIP	15	1	32
		Valves	S-PV-VAL	15	1	32
	Stage Harness		S-SH-	10.8	1	44
Interstage						
	Interstage Structures		**I-IS-**	**308**	**1**	**185**
Stage I&T	**Stage I&T**		**I&T**	**3.20%**	**1**	**68**
Stage 1	**----liquid stage ---**			**4,017**		**10,391**
	Solid Casing		S-SC-	-	-	-
	Pressurizant Tank		S-PT-	256	1	582
	Fuel Tank		S-FT-	468	1	895
	Oxidizer Tank		S-OT-	655	1	1137
	Stage Structures					
		Thrust Cone	S-SS-TRC	282	1	269
		Skirt	S-SS-SKI	768	1	671
		Thermal Control	S-SS-THM	179	1	178
	Engine(s)		S-EN-	834	1	3535
	Thrust Vector Control		S-TV-	130	1	369
	Pressurization System		S-PS-	262	1	2489
	Pipes & Valves					
		Pipes	S-PV-PIP	100	1	119
		Valves	S-PV-VAL	50	1	74
	Stage Harness		S-SH-	31.9	1	72
Payload				**310**		**709**
	Payload Adapter		P-PA-	10	1	143
	Payload Fairing		P-PF-	300	1	566
Avionics				**142**		**2,331**
	Avionics					
		Comms	A-AV-COM	8.7	1	162
		Power	A-AV-PWR	31.2	1	368
		Data Handling	A-AV-DHL	23.6	1	973
		GNC	A-AV-GNC	36.2	1	746
		Avionics Harness	A-AV-HNS	42.7	1	82
Attitude Control						
	Attitude Control Module		C-AC-	-		-
						-
I&T				**3.20%**		**430**
	Stage Integration & Test		I&T		1	333
	PAA I&T		I&T-P-		1	97
M&PA				**5.30%**		
Total						16,238

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② Development cost

$$FM1 = T1(1 - M/PA\%)$$

$$ENG = FM1 \cdot DD$$

$$MAIT = FM1(STH + L_d \cdot \#HW)$$

$$M/PA = (ENG + MAIT) \cdot M/PA\%$$

$$PO = ENG + M/PA$$

$$DEV = c_p \cdot (PO + MAIT)$$

Parameter		Assumptions	Note
$M/PA\%$	Management & Product Assurance contribution as a percentage	5.3%	
DD	**Design and Development T1 Equivalent**	**5**	**TRL of the launch vehicle would need to be increased from 7 to 9, DD' = DD + ∆TRL = 3+2 = 5.**
STH	**System Test Hardware T1 Equivalent**	**3.1**	**DM(0.3)+EM(1.3)+PFM(1.5)**
$\#HW$	Number of hardware elements	1	
L_d	Development cost improvement/learning factor	1	
c_p	Cost reduction factor	0.97	

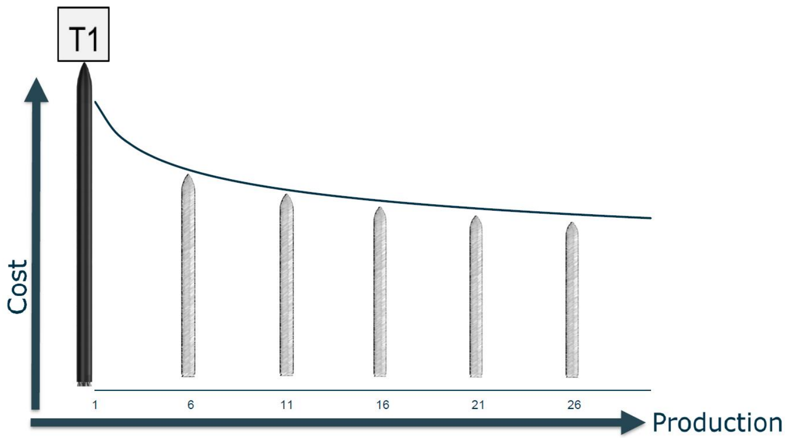
- TRL = 7 is assumed.
- Assumed as DM+EM+PFM

Unit	Equipment	Part	T1 (k€)	Development Phase (k€)					
				FM1	ENG	MAIT	M/PA	PO	DEV
Stage 2	**----liquid stage ---**		**2,123**	**2,011**	**10,053**	**8,243**	**970**	**11,022**	**18,687**
	Solid Casing								
	Pressurizant Tank		95	90	448	368	43	491	833
	Fuel Tank		329	312	1,559	1,278	150	1,709	2,897
	Oxidizer Tank		329	312	1,559	1,278	150	1,709	2,897
	Stage Structures								
		Thrust Cone	10	10	49	41	5	54	92
		Skirt	27	26	130	106	12	142	241
		Thermal Control	16	15	77	63	7	84	143
	Engine(s)		767	726	3,632	2,979	350	3,983	6,753
	Thrust Vector Control		151	143	715	587	69	784	1,330
	Pressurization System		289	273	1,367	1,121	132	1,499	2,541
	Pipes & Valves								
		Pipes	32	31	153	126	15	168	285
		Valves	32	31	153	126	15	168	285
	Stage Harness		44	42	210	172	20	230	391
Interstage									
	Interstage Structures		**185**	176	**878**	**720**	**85**	**962**	**1,631**
Stage I&T	**Stage I&T**		**68**	64	**322**	**264**	**31**	**353**	**598**
Stage 1	**----liquid stage ---**		**10,391**	**9,840**	**49,202**	**40,346**	**4,746**	**53,948**	**91,465**
	Solid Casing		-	-	-	-	-	-	-
	Pressurizant Tank		582	551	2,756	2,260	266	3,022	5,123
	Fuel Tank		895	848	4,238	3,475	409	4,647	7,878
	Oxidizer Tank		1137	1,077	5,386	4,416	520	5,905	10,012
	Stage Structures								
		Thrust Cone	269	255	1,275	1,046	123	1,398	2,371
		Skirt	671	636	3,178	2,606	307	3,485	5,908
		Thermal Control	178	168	841	690	81	922	1,564
	Engine(s)		3535	3,348	16,739	13,726	1,615	18,354	31,118
	Thrust Vector Control		369	349	1,747	1,432	169	1,915	3,247
	Pressurization System		2489	2,357	11,784	9,663	1,137	12,921	21,906
	Pipes & Valves								
		Pipes	119	113	565	463	55	620	1,050
		Valves	74	70	351	288	34	384	652
	Stage Harness		72	68	341	280	33	374	634
Payload			**709**	**672**	**3,358**	**2,754**	**324**	**3,682**	**6,243**
	Payload Adapter		143	135	676	555	65	742	1,258
	Payload Fairing		566	536	2,682	2,199	259	2,940	4,985
Avionics			**2,331**	**2,208**	**11,038**	**9,051**	**1,065**	**12,103**	**20,520**
	Avionics								
		Comms	162	153	766	628	74	840	1,423
		Power	368	349	1,744	1,430	168	1,913	3,243
		Data Handling	973	921	4,606	3,777	444	5,050	8,562
		GNC	746	707	3,534	2,898	341	3,875	6,570
		Avionics Harness	82	78	389	319	37	426	722
Attitude Control									
	Attitude Control Module		-	-	-	-	-	-	-
			-	-	-	-	-	-	-
I&T			**430**	**407**	**2,035**	**1,669**	**196**	**2,231**	**3,783**
	Stage Integration & Test		333	315	1,574	1,291	152	1,726	2,927
	PAA I&T		97	92	461	378	44	505	856
M&PA									**7,575**
	Total		**16,238**						**150,503**

③ Manufacturing cost

$$n\text{-th unit cost: } C_N = T1 \cdot n^{\frac{ln(p)}{ln(2)}}$$

$p = 0.9$ (cost improvement factor)



Unit	Equipment	Part	T1 (k€)	Manufacturing (k€)	
				(50U)	(1U)
Stage 2	**----liquid stage ---**		**2,123**	**68,239**	**1,365**
	Solid Casing				
	Pressurizant Tank		95	3,042	61
	Fuel Tank		329	10,580	212
	Oxidizer Tank		329	10,580	212
	Stage Structures				
		Thrust Cone	10	336	7
		Skirt	27	879	18
		Thermal Control	16	523	10
	Engine(s)		767	24,658	493
	Thrust Vector Control		151	4,856	97
	Pressurization System		289	9,280	186
	Pipes & Valves				
		Pipes	32	1,040	21
		Valves	32	1,040	21
	Stage Harness		44	1,426	29
Interstage					
	Interstage Structures		**185**	**5,957**	**119**
Stage I&T	**Stage I&T**		**68**	**2,184**	**44**
Stage 1	**----liquid stage ---**		**10,391**	**333,991**	**6,680**
	Solid Casing		-		
	Pressurizant Tank		582	18,709	374
	Fuel Tank		895	28,768	575
	Oxidizer Tank		1137	36,560	731
	Stage Structures				
		Thrust Cone	269	8,657	173
		Skirt	671	21,575	432
		Thermal Control	178	5,710	114
	Engine(s)		3535	113,630	2,273
	Thrust Vector Control		369	11,858	237
	Pressurization System		2489	79,992	1,600
	Pipes & Valves				
		Pipes	119	3,835	77
		Valves	74	2,380	48
	Stage Harness		72	2,317	46
Payload			**709**	**22,795**	**456**
	Payload Adapter		143	4,592	92
	Payload Fairing		566	18,203	364
Avionics			**2,331**	**74,930**	**1,499**
	Avionics				
		Comms	162	5,197	104
		Power	368	11,842	237
		Data Handling	973	31,263	625
		GNC	746	23,990	480
		Avionics Harness	82	2,637	53
Attitude Control					
	Attitude Control Module		-		
			-		
I&T			**430**	**13,815**	**276**
	Stage Integration & Test		333	10,688	214
	PAA I&T		97	3,127	63
M&PA				**27,661**	**553**
Total			**16,238**	**549,572**	**10,991**

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④ Operating cost (1/2)

(1) Ground Operations

Parameter	Value	Note
M_0 (ton)	53.32	Lift-off weight
L	7	Launches per year
N	2	Number of stages
f_v	0.9	Vehicle type factor 1st stage (kerosene): fv=0.8, 2nd stage (methane): fv=1 → fv=(0.8+1)/2=0.9
f_c	0.7	Assembly and integration factor (Horizontal assembly and checkout, transport to pad, erection)
f_4	0.64	Cost reduction factor (p=0.9, 50 units, SOLSTICE[3] Appendix F)
f_8	0.56	Country productivity factor
f_{11}	0.55	Commercial factor (SOLSTICE[3] Table 5.2)
M₩/WYr	167	
₩/€	1,350	
Ground Operations (k€)	499.6	$8M_0^{0.67}L^{-0.9}N^{0.7}f_v f_c f_4 f_8 f_{11}$ [WYr]

(2) Propellant Cost

		Value	Note
Propellant Cost per kg (€/kg)	kerosene	1.11	YK-D80N (1,500₩/kg)(1€/1350₩)
	methane	0.741	
	LOX	0.126	
	He	124	=(30,000₩/m3)(1m3/l000L)(1L/0.1786g)(1000g/1kg)(1€/1350₩)
Mass (kg)	kerosene	12,838	
	methane	1,079	
	LOX	33,452	
	He	77	
Propellant Cost (k€)	kerosene	14.3	
	methane	0.8	
	LOX	4.2	
	He	9.6	
	Total	28.9	

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[3] Drenthe, N. T. "SOLSTICE: Small Orbital Launch Systems, a Tentative Initial Cost Estimate." (2016).

④ Operating cost (2/2)

Total Operations (average)

	Costs [k€]	Note
(1) Ground Operations	499.6	
(2) Propellant Cost	28.9	
$\sum Q_N$	0.8	Q_N: vehicle complexity factor (liquid engine: Q_N=0.4/ea)
(3) Flight and Mission Operations	201.1	$20(\sum Q_N)L^{-0.65} f_4 f_8$ [WYr]
(4) Transportation Cost	160.2	SOLSTICE[3] Table 5.2: T_S = 5.365 €kg^{-1} considering f_8(country productivity correction factor)
(5) Fees and Insurance Costs	481.5	- Launch site fees = (4.5x10^8₩)(1€/1350₩)(1k€/1000€) = 333.33 k€ - Public damage insurance = (2x10^8₩)(1€/1350₩)(1k€/1000€) = 148.15 k€ - The payload charge site fee is assumed to be included in the launch site fees.
(6) DOC	**1,371.2**	(1)+…+(5)
(7) IOC	**2,283.9**	IOC=(33S+32)$L^{-0.379}$ [WYr], S(Percent of work subcontracted out)=0.2
(8) Operating Cost	**3,655.1**	(6)+(7)
(9) First Production Unit (T1)	16,237.7	
(10) Average Production Unit	10,991.4	p(cost improvement factor)=0.9, 50 units

⑤ CpF & ⑥ PpF

Estimated by referring to research conducted by Hanwha Aerospace (Gyu-Jin Jung, Won Choi, Byung-Yong Park, Ho-Woon Lee). Hanwha Aerospace

Summary (Average, 50 units)

Costs	Drenthe's model	TRANSCOST 8.2	Note
(11) Development Cost [k€]	150,502.5	279,262.3	p(cost improvement factor)=0.9, 50 units
(10) Average Manufacturing Cost [k€]	10,991.4	6,280.7	
	75%	63%	(10)/(12)
(8) Operating Cost [k€]	3,655.1	3,655.1	
	25%	37%	(8)/(12)
(12) CpF [k€]	**14,646.6**	**9,935.9**	Development Costs are not included. (refer to Falcon 1)
(13) PpF[%] [k€]	15,818.3	10,730.7	CpF×1.08
(14) CpF/kg [k€/kg]	25.7	17.4	payload = 570 kg
(15) PpF/kg [k€/kg]	27.8	18.8	

- Estimated CpF < Target CpF (15M USD ≈ 17,700 k€, (1.18 €/USD))
- Why are the estimated development costs different by the two methods?
  - TRANSCOST does not consider manufacturing PFM instead of QM/FM.
  - The initial TRL in TRANSCOST can be lower than 7. (So, DEV. of TRANSCOST is larger.)
- Why are the estimated manufacturing costs different by the two methods?
  - It can be related to that unit of Drenthe's model is k€, which is different from WYr of TRANSCOST.
    - ✓ Assume that the unit of Drenthe's model is WYr like TRANSCOST, and manufactured in Korea.
    - → (10,991 k€)/(286.425 k€/WYr)(167e6 ₩/WYr)/(1,350e3 ₩/k€) = 4,747 k€ (Difference is reduced.)

Drenthe, N. T. "SOLSTICE: Small Orbital Launch Systems, a Tentative Initial Cost Estimate." (2016).

⑤ CpF & ⑥ PpF

Summary (Average, 50 units)

Costs	Drenthe's model	TRANSCOST 8.2	Note
(10) Average Manufacturing Cost [k€]	10,991.4	6,280.7	p(cost improvement factor)=0.9, 50 units
	75%	63%	(10)/(12)
(8) Operating Cost [k€]	3,655.1	3,655.1	
	25%	37%	(8)/(12)
(12) CpF [k€]	**14,646.6**	**9,935.9**	Development Costs are not included. (refer to Falcon 1)
(13) PpF[%] [k€]	15,818.3	10,730.7	CpF×1.08
(14) CpF/kg [k€/kg]	25.7	17.4	payload = 570 kg
(15) PpF/kg [k€/kg]	27.8	18.8	

✓ Assume that the unit of Drenthe's model is WYr like TRANSCOST, and manufactured in Korea.

→ (10,991 k€)/(286.425 k€/WYr)(167e6 ₩/WYr)/(1,350e3 ₩/k€) = 4,747 k€ (Difference is reduced.)

Drenthe: "As SOLSTICE CERs were developed in a European context, it was deemed appropriate to correct manufacturing costs for the Korean context in which SLV will be developed.
Therefore, the Euro cost values from SOLSTICE were converted to workyear, and then to Korean Won using local workyear costs."

Summary (Average, 50 units)

Costs	Drenthe's model	TRANSCOST 8.2	Note
(10) Average Manufacturing Cost [k€]	4,747.1	6,280.7	p(cost improvement factor)=0.9, 50 units
	56%	63%	(10)/(12)
(8) Operating Cost [k€]	3,655.1	3,655.1	
	44%	37%	(8)/(12)
(12) CpF [k€]	**8,402.2**	**9,935.9**	Development Costs are not included. (refer to Falcon 1)
(13) PpF[%] [k€]	9,074.4	10,730.7	CpF×1.08
(14) CpF/kg [k€/kg]	14.7	17.4	payload = 570 kg
(15) PpF/kg [k€/kg]	15.9	18.8	

Contents

Summary and Future works

- SmallSat-dedicated Launch Vehicle (SLV) in Korea
  - Performance: 500 kg to 500 km SSO
  - Stage 1: Improved engine from 75 tonf kero/LOX engine of Nuri
  - Stage 2: Newly developed 3 tonf LCH4/LOX engine
- Drenthe's model
  - Parametric method to estimate costs of small and commercial launch vehicles
- We estimated the cost of the SLV using Drenthe's model and TRANSCOST.
- Future works
  - Consider different TRLs for each equipment (Drenthe's suggestion)
  - More study including uncertainty analysis
  - Estimate cost for new design (Stage 1: 2 LCH4/LOX engines, Stage 2: 1 LCH4/LOX engine)
  - Estimate the cost-reduction effect of adopting new technologies (such as additive manufacturing, autonomous ground launch operation, friction stir welding for tank production, and integrated and miniaturized avionics.)

Thank you for your attention!

If you have any questions, please ask them now or send us (shchoi@kari.re.kr or Nigel.Drenthe@esa.int) an email.
We will answer your questions as soon as possible.