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National Aeronautics and Space Administration

Principles from Two Small SRM-Based Launcher Design/Developments

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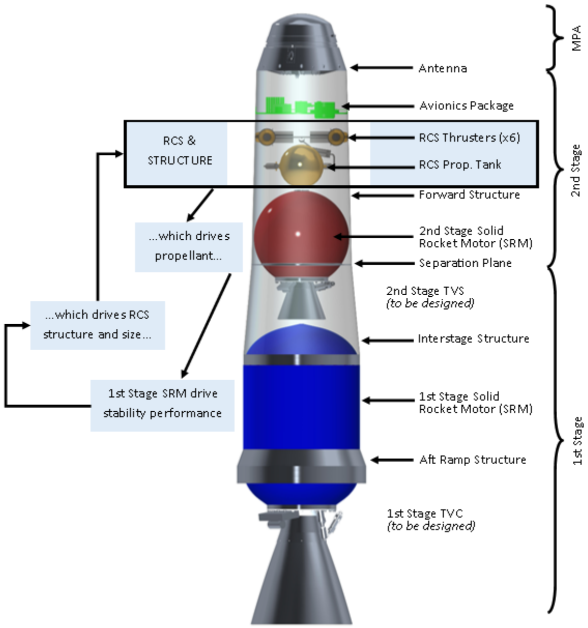
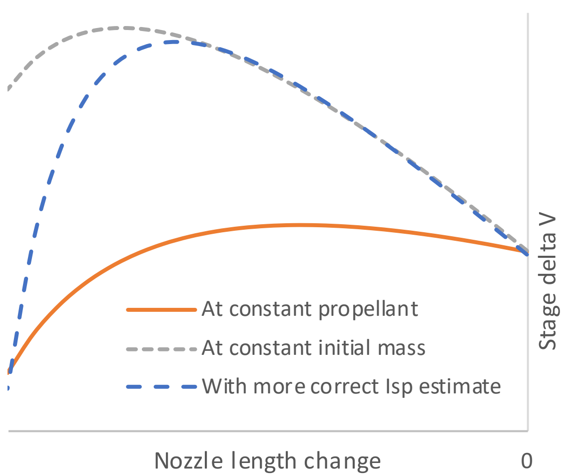
Trade studies have benefited from developments in understanding sensitivities and approximate modeling



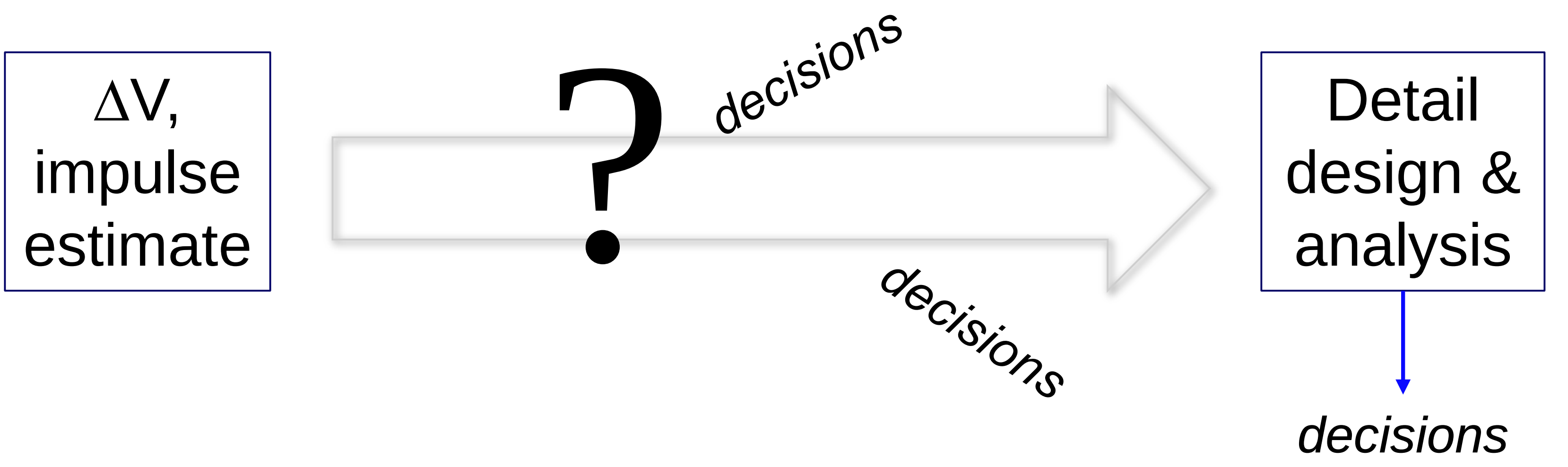
PRINCIPLE I: Identify mission-specific key design drivers — particularly interactions

PRINCIPLE II: Agility — don't lock down your derived requirements early



PRINCIPLE III: Use multi-fidelity tools as needed to support decisions

Improve "understanding value generated per modeling effort cost." → enabling decisions



Launch Vehicle Architectures considered

			2-stage MAV	4-stage CEL
	Payload Target	kg	16	10
	Injected Mass	kg	64	24
	Total/nth stage DV	m/s	3990 / 1690	9300 / 3110
Stage k	Non-prop inerts	kg	34	2
	inert	kg	14	12
	propellant	kg	54	51
	Comments		Accuracy-driven	Inert Mass-driven, burntime-limited
Stage k-1	Non-prop inerts	kg	14	28
	inert	kg	46	25
	propellant	kg	216	226
	Comments		Boost-sustain reqd	Burntime-limited, control systems here
Stage k-2	Non-prop inerts	kg		10
	inert	kg		77
	propellant	kg		540
	Stage k-3 propellant	kg		650
	Comments			Set by partner

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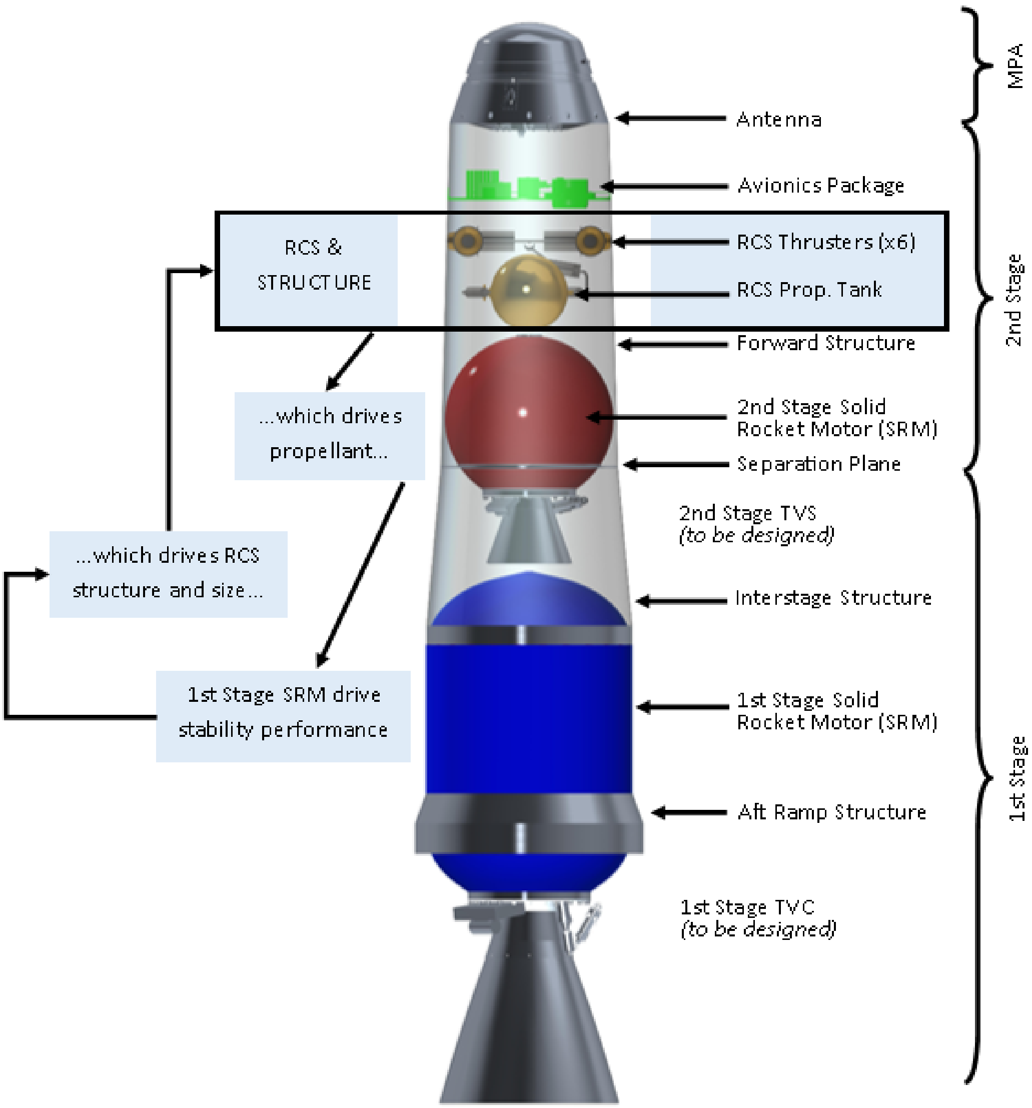
PRINCIPLE I: MAV and CEL have different mission values, which drives different decisions

Mars Ascent Vehicle (MAV):	**Cubesat Earth Launcher (CEL):**
limit GLOM, overall length, diameter	limit individual stage length, diameter
have high reliability	limit max acceleration
limit orbital uncertainty	have low cost
launch to a single orbit	attempt medium reliability
	allow launch to multiple orbits

"derived architectural decisions"

Use pedigreed, refined motor manufacturer/methods	Use "low-cost" small manufacturer
use thrust vector controlled motors plus RCS system	invoke spin-stabilization with steering between burns
	design to "bend the cost-performance curve"
	Optimize for mass by putting control system on 3rd stage instead of upper stage
Drives saving 2nd stage mass at the expense of 1st stage mass	max accel proves a driving limitation

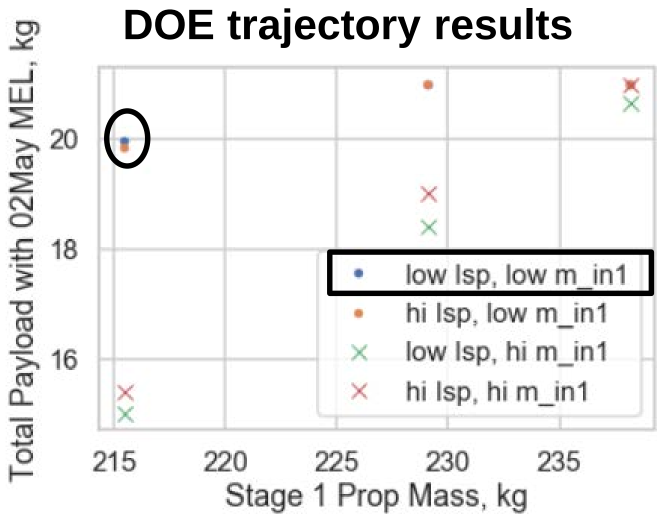
MAV architecture drove key interaction between Stage 1 motor and RCS on Stage 2



- Pushed SRM1 burn time longer than typical to limit RCS size
- Survey of existing motors
  - STAR15G to stretch and scale
  - boost-sustain motor will have a lower mass fraction
  - Previous efforts had defined full end-burning motors, which had an even lower mass fraction.
- Understand effect of motor gross parameters on burn times and thrust levels.
- Look at grain design features that could generate a boost-sustain and further customize.

PRINCIPLE II: Agility with requirements — keep trading, and characterizing sensitivities.

- Be skeptical of requirements early
- “early and often,” identify of interactions between (traditionally separated) disciplines and components.
- Let analysts to be designers and designers to be (0th-order, anyway) analysts
- one pass through the integrated design assessment is unlikely to yield the perfect answer.



Provides delta propellant mass as function of other things

	coef	std err	t	P>|t|	[0.025	0.975]
Intercept	280.8219	3.657	76.794	0.000	273.070	288.574
M_Margin	3.8693	0.108	35.784	0.000	3.640	4.098
ctrl_mcase	17.5663	0.766	22.939	0.000	15.943	19.190
ctrl_Isp	-1.6724	0.596	-2.805	0.013	-2.936	-0.408
mp2_lbm	-0.6376	0.033	-19.123	0.000	-0.708	-0.567

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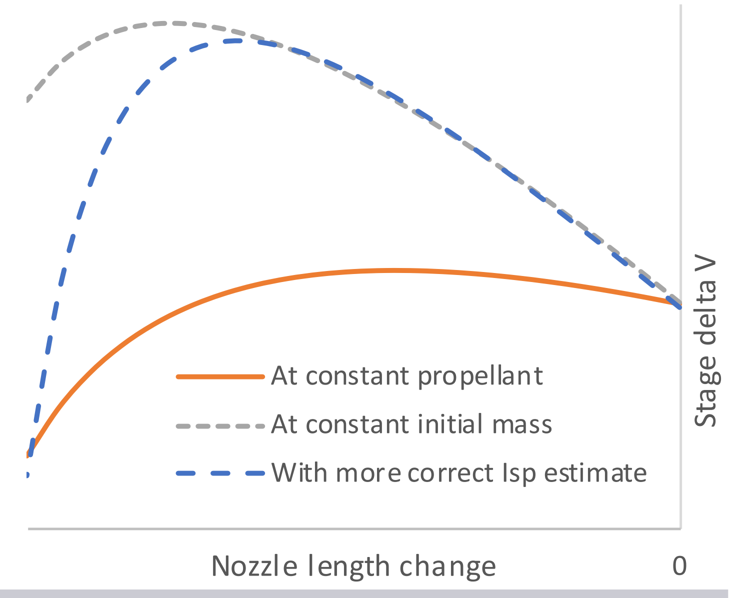
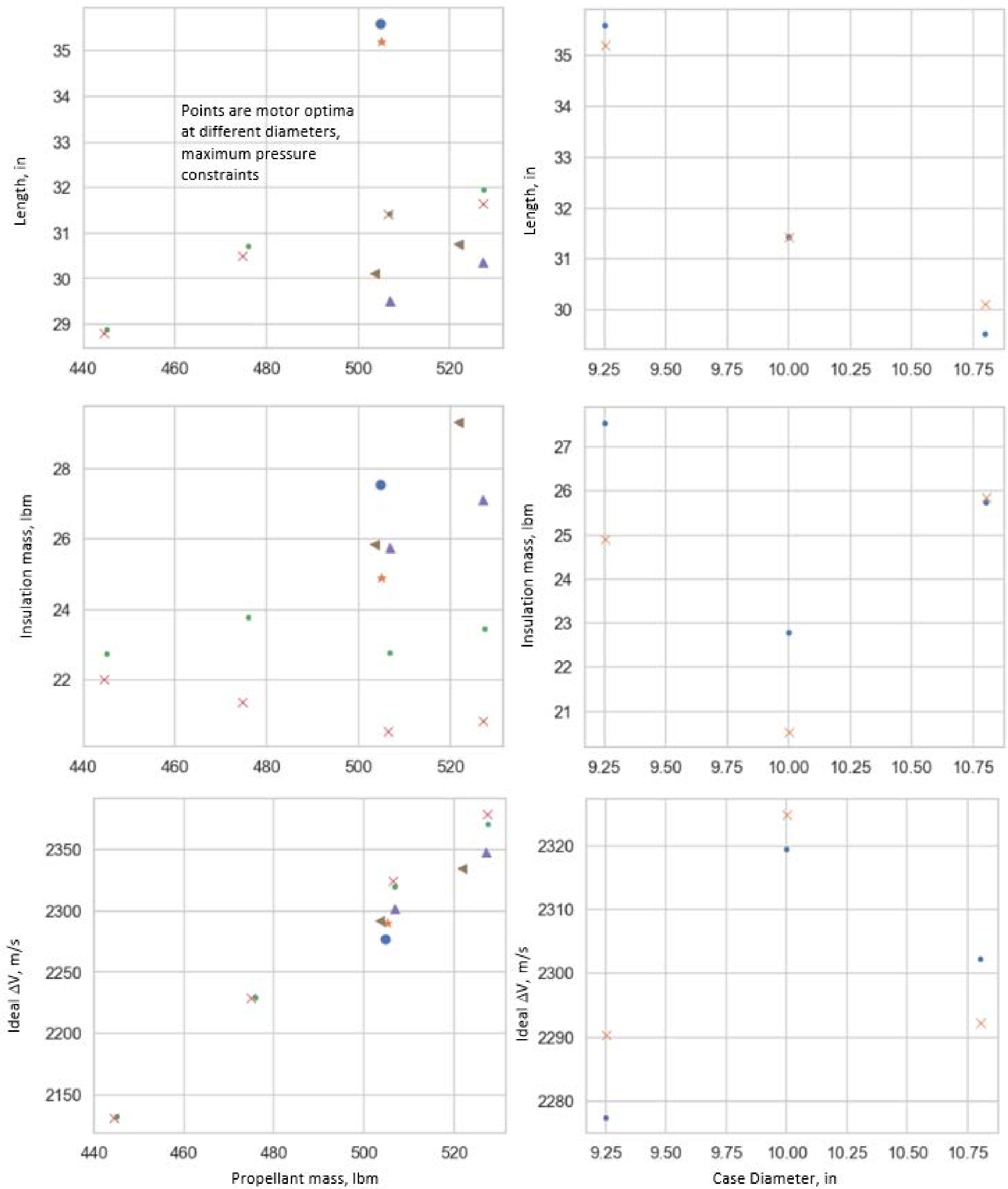
PRINCIPLE III: Use multi-fidelity tools: MAV Custom Fidelity Ladder

	MAV steps of increased fidelity	MAV application
4	- consider mass on multiple stages and solve for max payload (or minimum GLOM) at constant ΔVs - know likely payload mass and maximize ΔV OR set ΔV and maximize payload mass - estimate Isp of expansion ratio calibrated to reference - estimate "local" inert mass change per unit propellant mass change - estimate structural thicknesses/materials Model length, diameter range from a baseline	 shorten 2nd stage nozzle to maximize ΔV
3	all-solids modified by features similar to certain motors	calibrate to catalog boost-sustain motor
2	all-solids mass modeling	too small for 0.9
1	textbook or searched mass fraction and Isp to use	use 0.9 prop mass fraction

PRINCIPLE III: MAV Ladder

	MAV steps of increased fidelity	MAV application
6	- then, running propellant grain designs, what is the best at each setting? - first, understand what are the gross effects consider effect of pressure on case, insulation and nozzle masses, and Isp	Compute consistent set of grain designs at different diameters, pressures, and propellant masses
5	Develop more particular design constraints	quantify “boost-sustain-ness”



PRINCIPLE III: Use multi-fidelity tools: CEL Custom Fidelity Ladder

	CEL steps of increased fidelity	CEL application
6	Develop more particular design constraints B	Optimize ins/nozzle contours
5	- balance diameter-driven masses with other constraints - generate full grain designs to test ability to customize for acceleration Develop more particular design constraints A	Get the most out of the upper stage, which was found to be most driven by constraints
4	- model across multiple stages: solve for max payload assuming constant total DV - estimate Isp of ER calibrated to reference - estimate lengthening/ shortening of all stages Model nozzle/stage mass, Isp to trade	updates marginal inert mass per unit propellant mass, then enables multi-stage trades
3	all-solids modified by features similar to certain motors	heavier because of acceleration constraint
2	all-solids mass modeling	also be at the lower end for “affordable”
1	Textbook/searched mass fraction and Isp to use	

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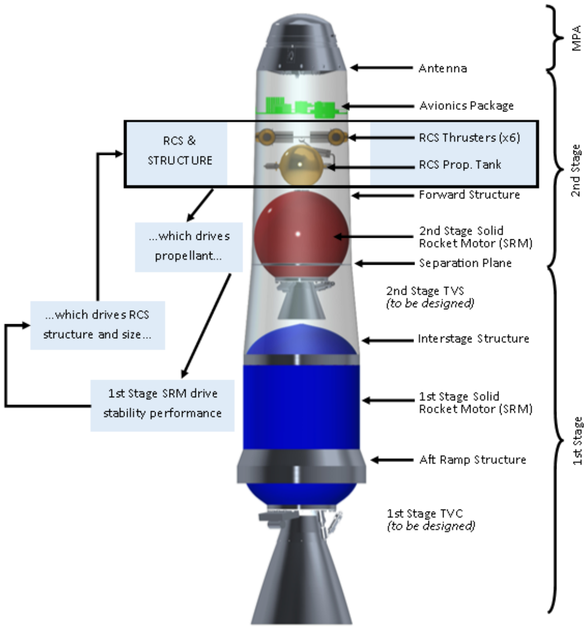
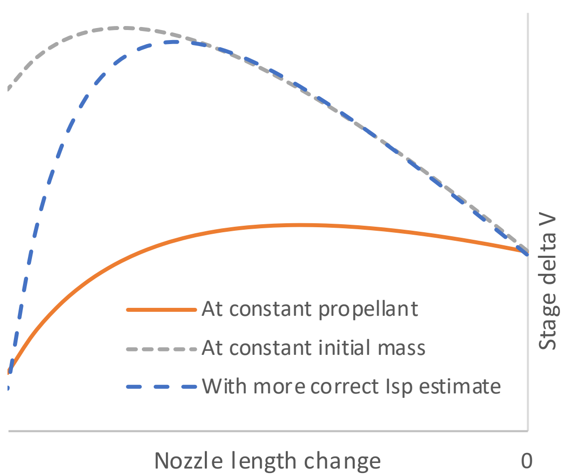


PRINCIPLE I: Identify mission-specific key design drivers — particularly interactions (and focus knowledge-development on those).

PRINCIPLE II: Agility — don't lock down your derived requirements early — keep trading, and characterizing sensitivities



PRINCIPLE III: Use multi-fidelity tools to improve "understanding value generated per modeling effort cost."

Questions??

Nomenclature

Nomenclature

Isp	specific impulse
ΔV	change in velocity
A_t	throat area
C_f	thrust coefficient
F	thrust
k	number of stages in the vehicle
m	mass
m_p	propellant mass
$\dot{m}$	mass flow rate
n	burn rate exponent
P	pressure
P_{ref}	reference pressure
$\dot{r}$	burn rate
$\dot{r}_{ref}$	reference burn rate
t	time

Acronyms/Abbreviations

CEL	Cubesat Earth Launcher
ERO	Earth Return Orbiter
GLOM	gross liftoff mass
MAV	Mars Ascent Vehicle
MSR	Mars Sample Retrieval
RCS	reaction control system
SRL	Sample Retrieval Lander
SRM	solid rocket motor

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