Launch Segment

MAE 4160, 4161, 5160

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Today’s topics:

- Choosing a launch vehicle
- Basics mechanics of launch

Launch vehicle selection process

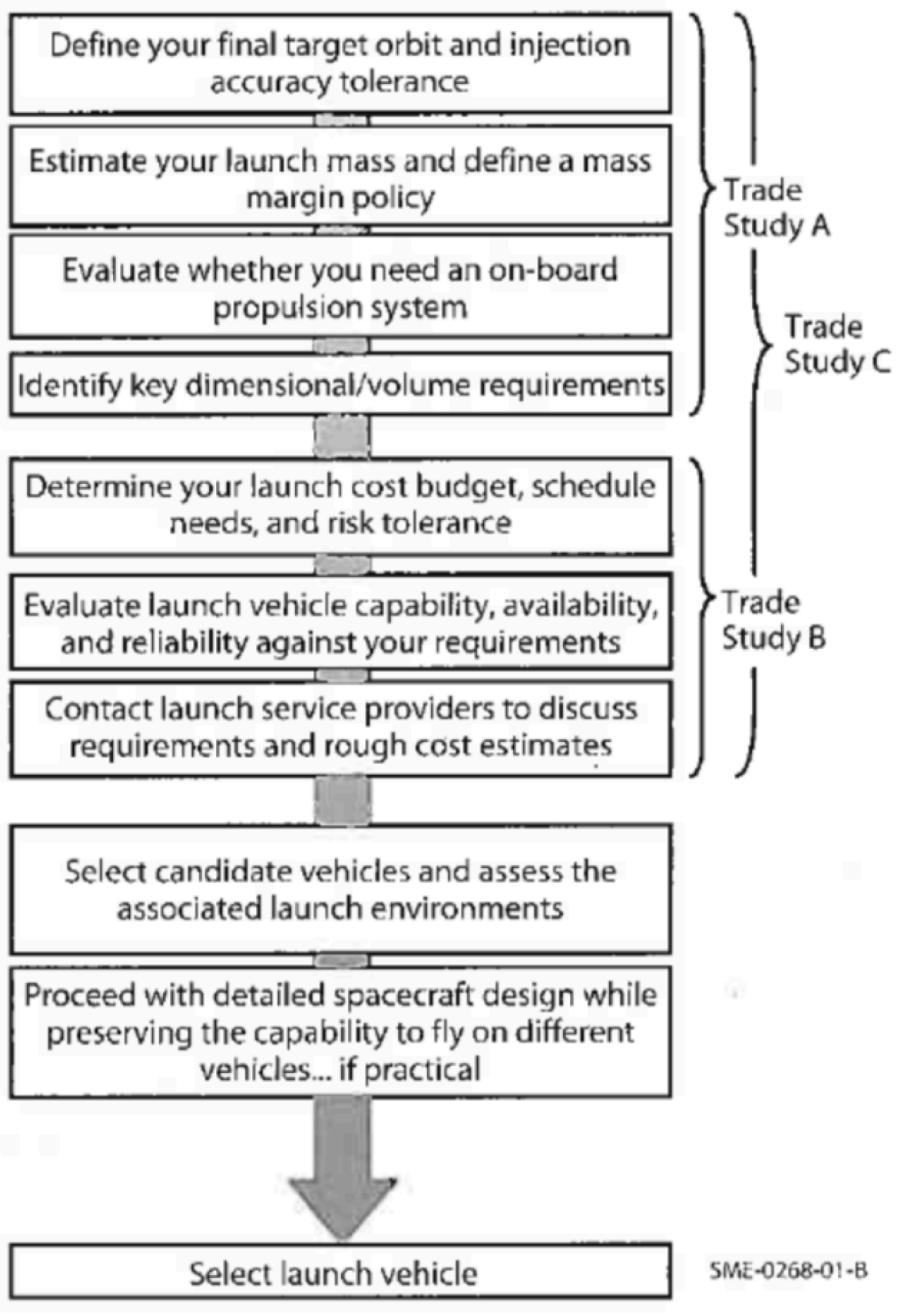

Fig. 26-4. Launch Vehicle Selection Process Flow.

	Vehicle - Nationality - Launch Site - Status	Kg to LEO		Vehicle - Nationality - Launch Site - Status	Kg to LEO
01	ITS - USA - Cape Canaveral Spaceport - In Development (SpaceX)	300000	30	Long March-2C - China - Taiyuan Spaceport - Operational	3850
02	NASA Space Launch System, Block 1B - USA - Cape Canaveral Spaceport - In Development	105000	31	Antares - USA - Mid-Atlantic Regional Spaceport - Operational	7000
03	New Glenn (3-Stage) - USA - Cape Canaveral Spaceport - In Development (Blue Origin)	100000	32	Cyclone-4 - Ukraine - TBD spaceports - In Development	5300
04	Falcon Heavy - USA - Cape Canaveral, Vandenberg, Boca Chica Spaceports - In Development	54400	33	Dnepr - Ukraine - Dombarovski & Baikonur Spaceports - Operational	4500
05	Delta-4 Heavy - USA - Cape Canaveral & Vandenberg Spaceports - Operational	28790	34	Naro-1 - South Korea - Naro Spaceport - Operational	100
06	Falcon-9 - USA - Cape Canaveral, Vandenberg, Boca Chica Spaceports - Operational	28000	35	Unha-3 - North Korea - Sohae Spaceport - Operational	100
07	Next-Gen Launcher - USA - Cape Canaveral Spaceport - Proposed (Orbital ATK)	TBD	36	Cosmos - Russia - Plesetsk Spaceport - Operational	1500
08	Delta-4 - USA - Cape Canaveral & Vandenberg Spaceports - Operational	9420	37	Vega - Europe - Kourou Spaceport - Operational	2150
09	Vulcan - USA - Cape Canaveral, Vandenberg - In Development (ULA)	31751	38	Rockot / Strela - Russia - Baikonur & Plesetsk Spaceports - Operational	1950
10	Angara-5 - Russia - Plesetsk, Baikonur & Vostochny Spaceports - In Development	28500	39	Long March-6 - China - Taiyuan - Operational	1500
11	Ariane-6 - Europe - Kourou Spaceport - In Development	TBD	40	Athena-2 - USA - Cape Canaveral & Kodiak Spaceports - Operational (2S model planned)	1896
12	Long March-5 - China - Wenchang Spaceport - Operational	25000	41	Minotaur C / Taurus - USA - Mid-Atlantic, Cape Canaveral & Vandenberg Spaceports - Operational	1458
13	Zenit - Ukraine/Russia - Sea Launch & Baikonur Spaceports - Operational	13740	42	Simorgh - Iran - Imam Khomeini Spaceport - In Development	150
14	Atlas-5 - USA - Cape Canaveral & Vandenberg Spaceports - Operational	18510	43	Shavit - Israel - Palmachim Spaceport - Operational	800
15	H-3 - Japan - Tanegashima Spaceport - In Development	TBD	44	Minotaur-4 & 5 - USA - Mid-Atlantic, Vandenberg & Kodiak Spaceports - Operational	1735
16	Long March-3B - China - Xichang Spaceport - Operational	12000	45	Epsilon - Japan - Uchinoura - Operational	1200
17	H-2B - Japan - Tanegashima Spaceport - Operational	19000	46	Firefly Alpha - USA - TBD spaceports - In Development	400
18	Ariane-5 - Europe - Kourou Spaceport - Operational	21000	47	Safir - Iran - Iran Space Center - Operational	50
19	Proton M - Russia - Baikonur Spaceport - Operational	23000	48	Long March-11 - China - Jiuquan - Operational	700
20	Long March-7 - China, Wenchang, Juiququn, Xichang, Taiyan Spaceports - Operational	13500	49	Athena-1c - USA - Cape Canaveral & Kodiak Spaceports - Operational	760
21	Athena-3 - USA - Cape Canaveral, Kodiak & Vandenberg Spaceports - Proposed	6000	50	Kuaizhou-2 - China - Jiuquan & mobile carrier - Operational	300
22	GSLV MK-2 - India - Sriharikota Spaceport - Operational	5000	51	Minotaur-1 & 2 - USA - Mid-Atlantic, Vandenberg & Kodiak Spaceports - Operational	560
23	Soyuz - Russia - Baikonur, Vostochny & Kourou Spaceports - Operational	7800	52	Electron - New Zealand - TBD spaceports - In Development	110
24	Soyuz-1 - Russia - Baikonur, Plesetsk & Vostochny Spaceports - Operational	2850	53	Super Strypi - USA - Barking Sands, Hawaii - In Development	320
25	Long March-4B - China, Wenchang, Juiququn, Xichang, Taiyan Spaceports - Operational	4200	54	Pegasus - USA - Multiple USA and international spaceports - Operational	450
26	PSLV - India - Sriharikota Spaceport - Operational	3800	55	LauncherOne - TBD spaceports - In Development	400
27	Angara-2 - Russia - Plesetsk, Baikonur & Vostochny Spaceports - In Development (successful test)	3360	56	Vector-H - USA - Cape Canaveral & Kodiak Alaska Spaceports - In Development	105
28	GSLV MK-3 - India - Sriharikota Spaceport - In Development (successful test flight)	8000	57	Aldan - Russia - TBD spaceports - Proposed	100
29	Proton Medium - Russia - Baikonur Spaceport - Proposed	TBD	58	SS-520 - Japan - Uchionoura - In Development	4

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Launch vehicle selection process

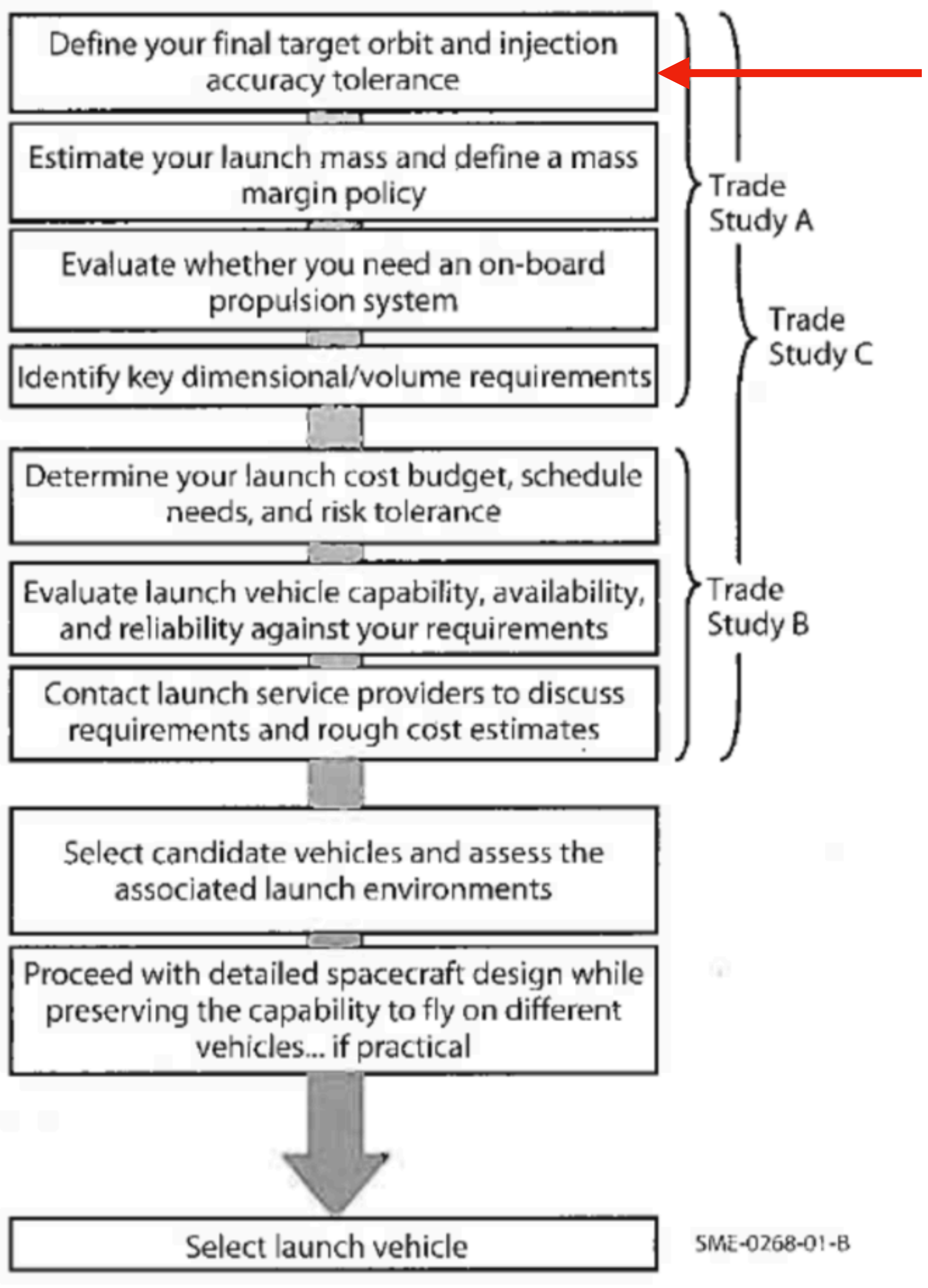


Fig. 26-4. Launch Vehicle Selection Process Flow.

Where do you need to go? How sloppy are you willing to be? Liquid second-stages will always be more precise than solid-fuel kick-motor second stages, at cost of price and payload mass.

The closer a launch vehicle can get you to your target orbit, the lower your requirement for onboard propulsion.

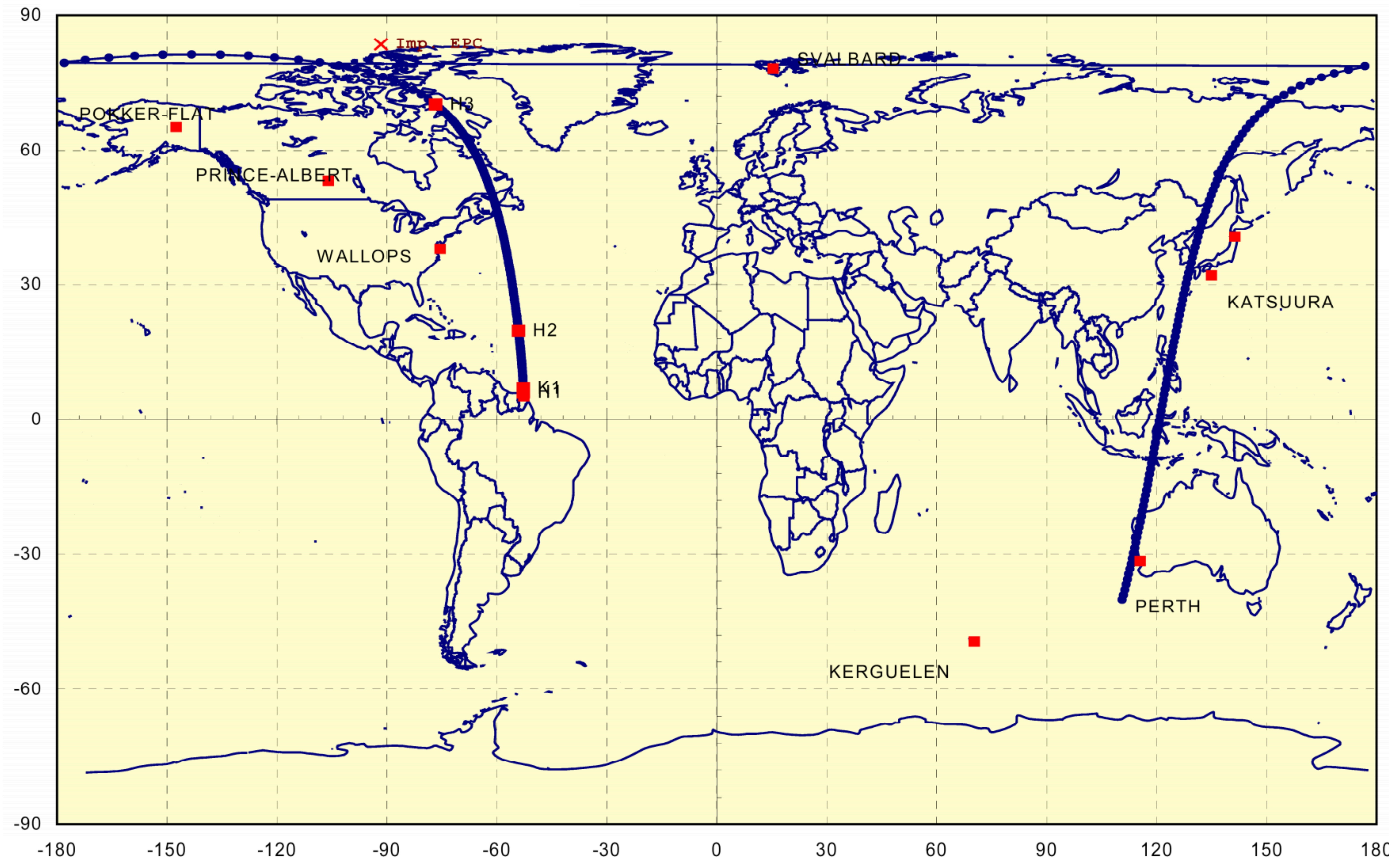


Figure 2.4.2.a – Ariane 5 typical SSO - Ground track

The following table gives the typical standard deviation (1 sigma) for standard GTO and for SSO.

Standard GTO (6°)

a	semi-major axis (km)	40
e	eccentricity	$4.5\ 10^{-4}$
i	inclination (deg)	0.02
ωp	argument of perigee (deg)	0.2
Ω	ascending node (deg)	0.2

Leading to:

- standard deviation on apogee altitude 80 km
- standard deviation on perigee altitude 1.3 km

Typical SSO (800 km – 98.6 °)

a	semi-major axis (km)	2.5
e	eccentricity	$3.5\ 10^{-4}$
i	inclination (deg)	0.04
Ω	ascending node (deg)	0.03

Launch vehicle selection process

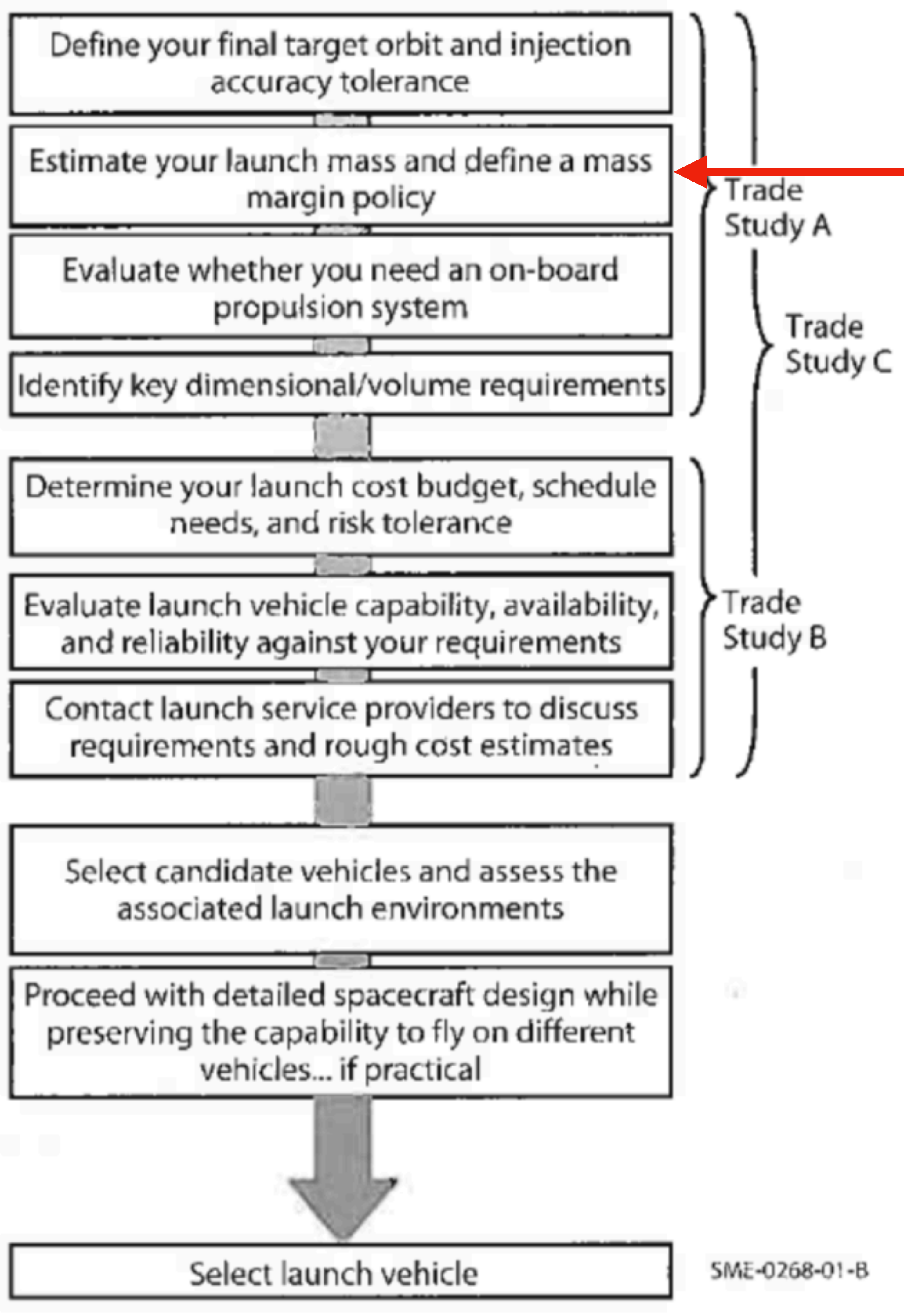


Fig. 26-4. Launch Vehicle Selection Process Flow.

What dry mass do you require? Add 20-30 percent margin.

What propellant mass do you require? Add 3σ margin.

Expect the launch vehicle provider to include a significant amount of margin for themselves which is *not yours to use*.

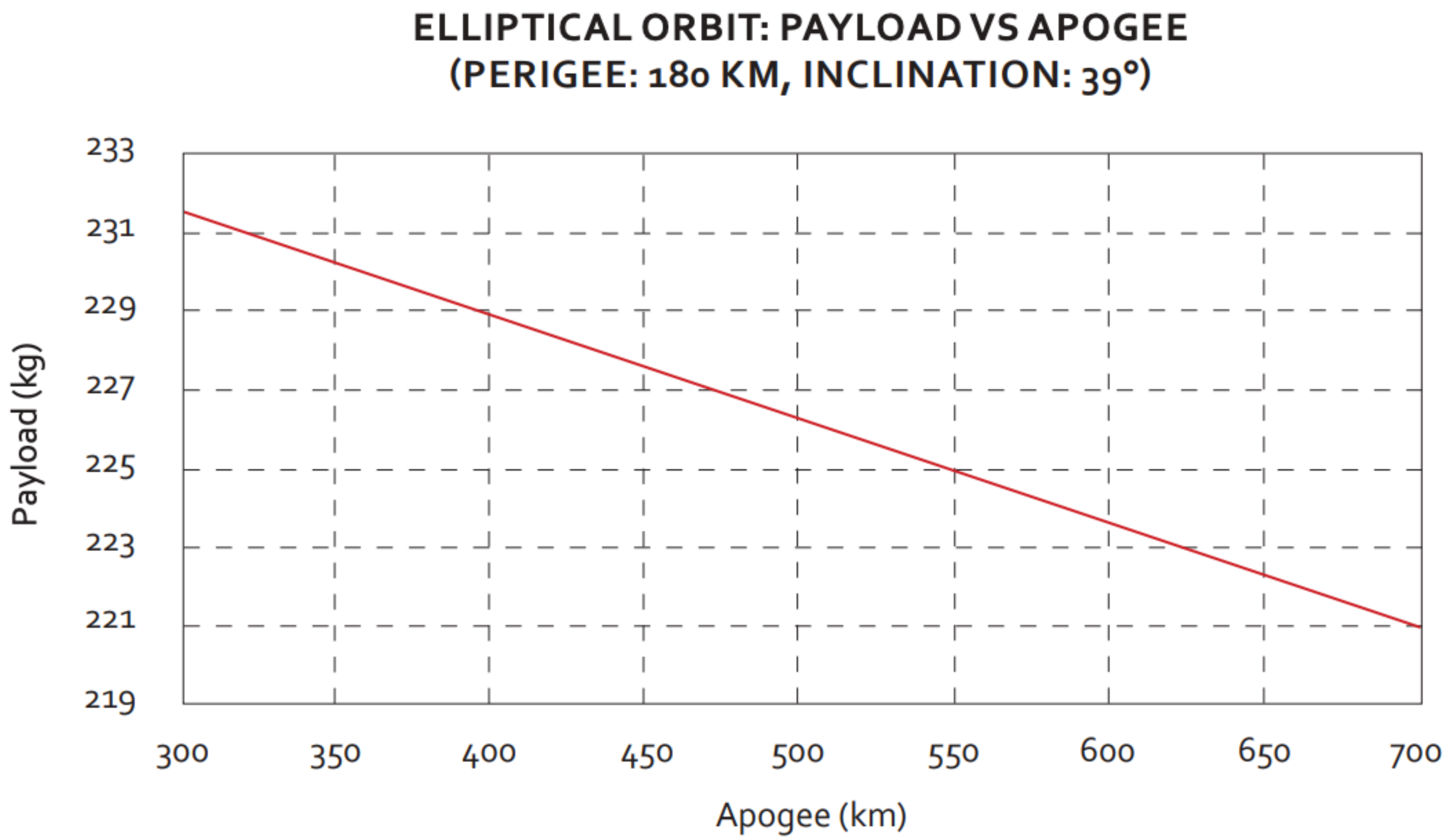
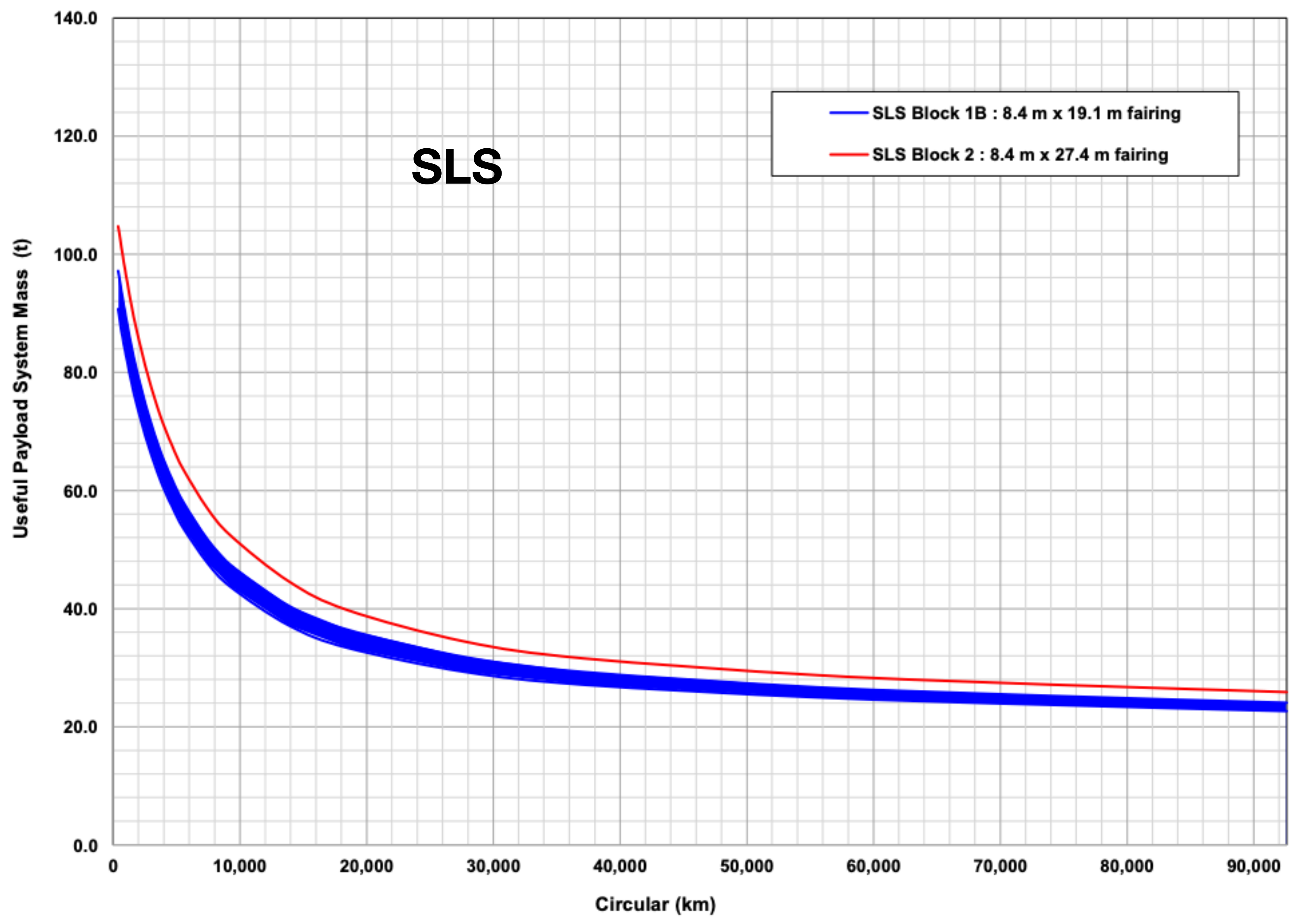


Figure 17 Performance to a 180 km Perigee at 39° Inclination Elliptical Orbit

APOGEE (KM)	PAYLOAD MASS (KG)
300	**231**
400	**229**
500	**226**
600	**224**
700	**221**

Table 8 Performance to a 180 km Perigee at 39° Inclination Elliptical Orbit

Electron

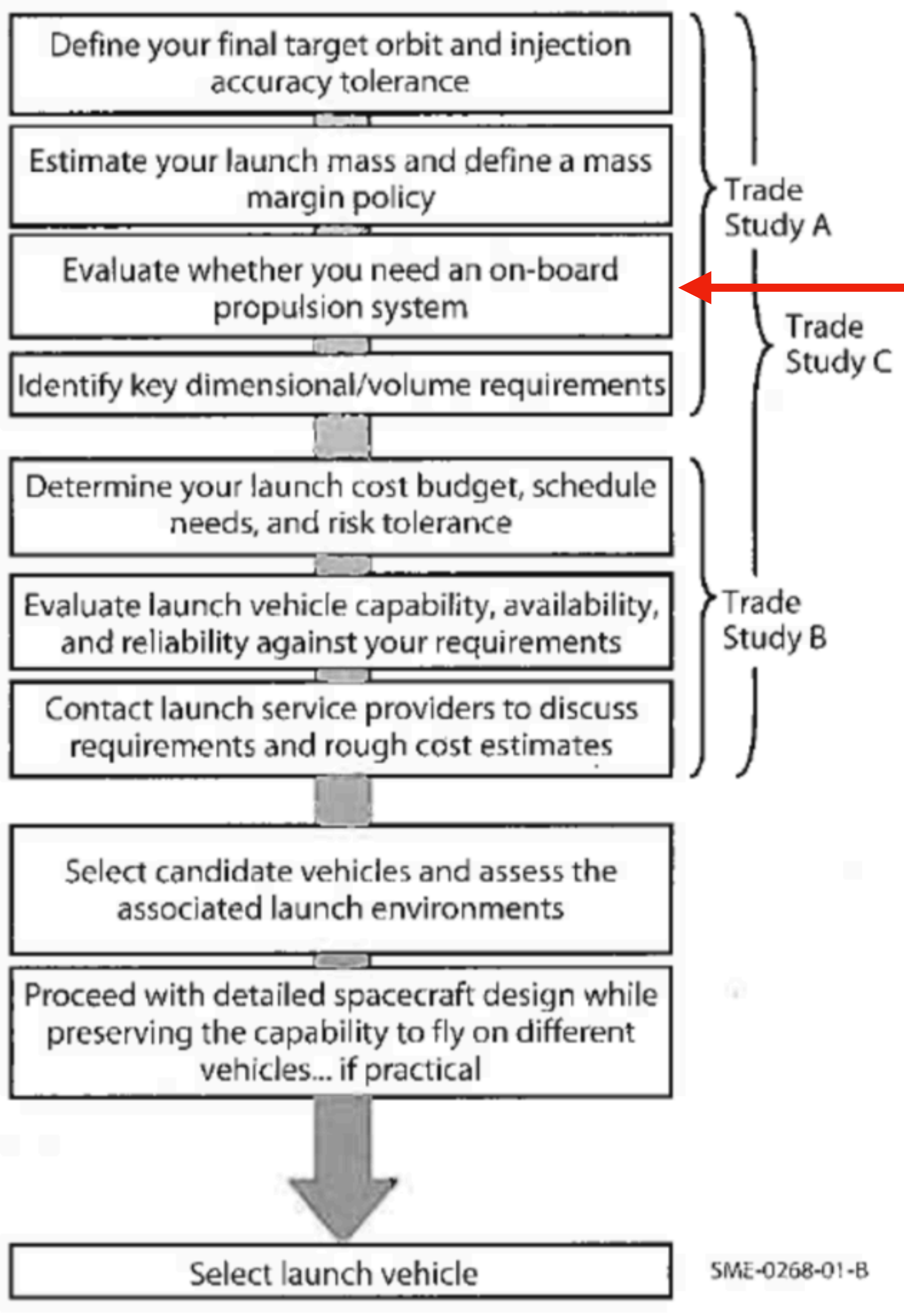


Useful Payload System Mass (t) with 8.4m Diamter Fairing

Apogee (km)	SLS Block 1B 19.1 m Fairing (t)		SLS Block 2 27.4 m Fairing (t)	Apogee (km)	SLS Block 1B 19.1 m Fairing (t)		SLS Block 2 27.4 m Fairing (t)	Apogee (km)	SLS Block 1B 19.1 m Fairing (t)		SLS Block 2 27.4 m Fairing (t)
	Min.	Max.			Min.	Max.			Min.	Max.	
407	90.7	97.2	104.7	2778	67.5	72.9	79.1	18520	33.3	36.4	39.7
556	88.2	95.0	102.5	3704	61.9	66.8	72.8	27780	29.3	31.8	34.4
741	85.9	92.5	99.9	4630	57.3	61.9	67.6	37040	27.1	29.3	31.6
926	83.8	90.2	97.5	5556	53.6	57.9	63.5	55560	25.0	26.7	28.7
1111	81.7	88.1	95.2	7408	47.8	51.8	57.1	74080	23.7	25.2	27.1
1482	78.0	84.1	91.0	9260	43.7	47.4	52.4	92600	22.7	24.1	25.9
1852	74.6	80.5	87.2	13890	37.1	40.4	44.5				

https://en.wikipedia.org/wiki/Comparison_of_orbital_launch_systems

Launch vehicle selection process



Couples with final orbit and injection accuracy tolerance.

Fig. 26-4. Launch Vehicle Selection Process Flow.

Launch vehicle selection process

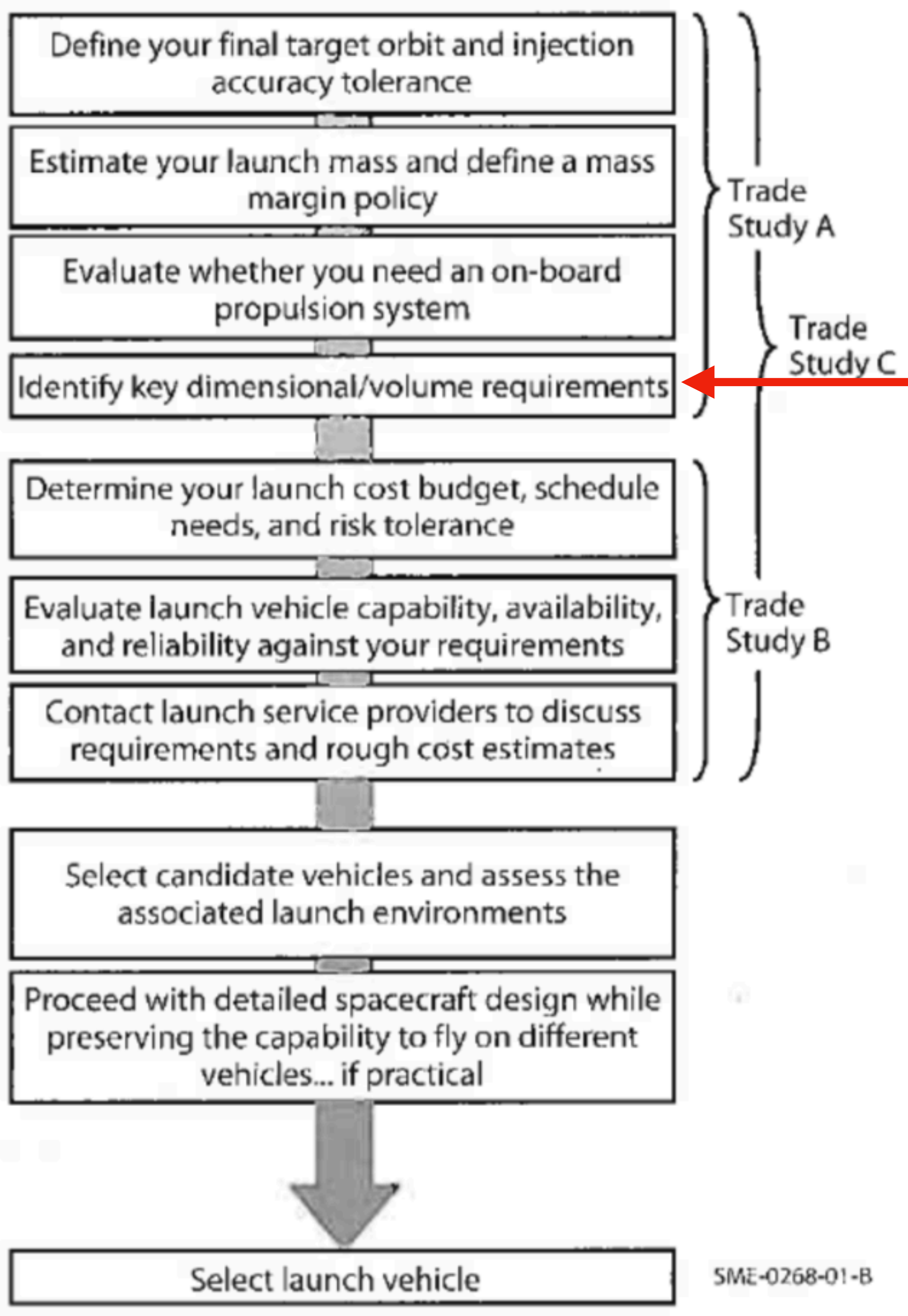


Fig. 26-4. Launch Vehicle Selection Process Flow.

Do you have strict volumetric requirements (optics, heat shield, etc.)? This may place constraints on your launch vehicle choices with regard to payload envelope in the fairing.

Expect to pay more for more volume. SMAD claims a cost increase for NASA of $14-68M for moving from a 4m diameter payload fairing to a 5m diameter fairing.

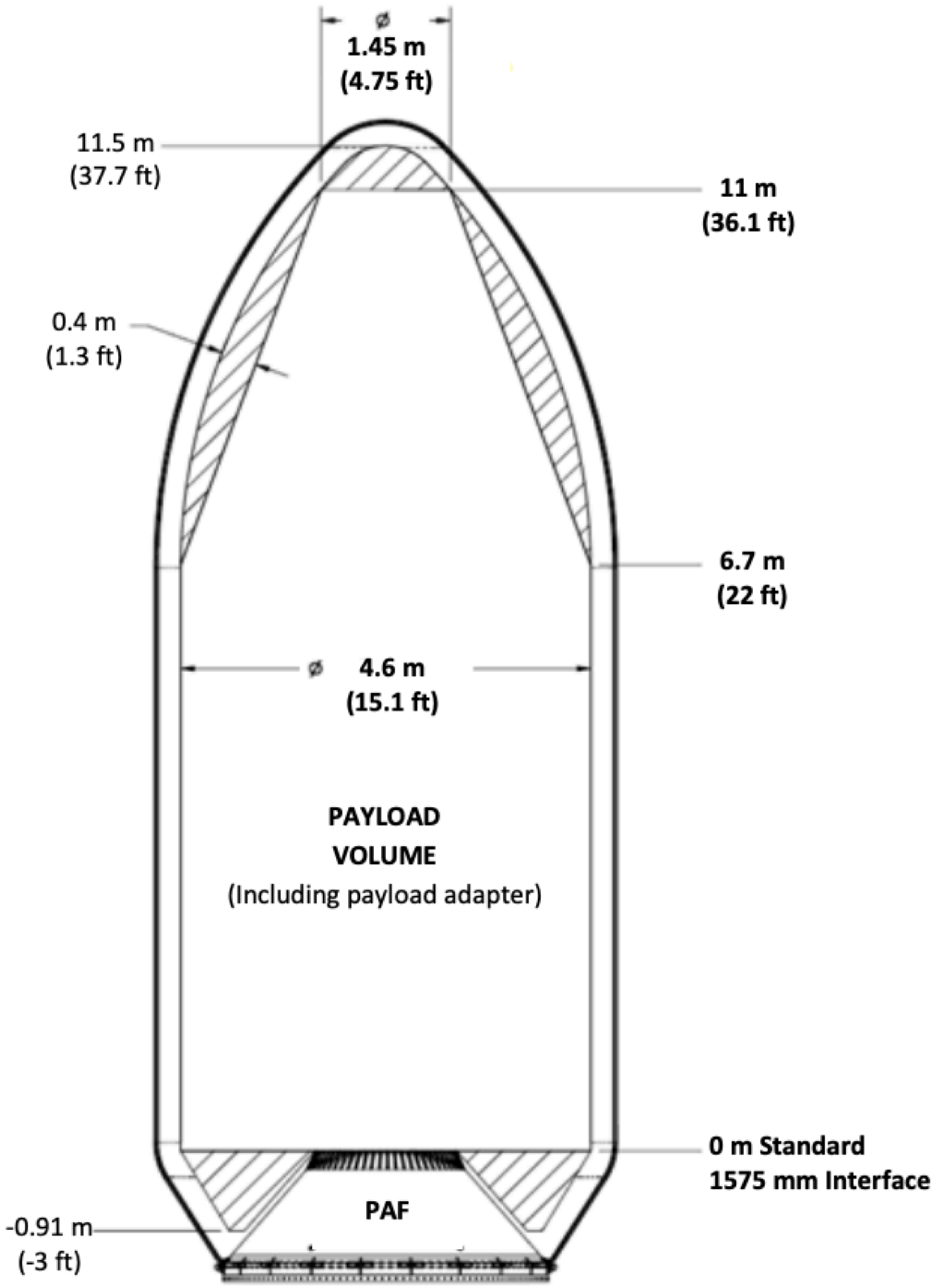


Figure 5-1: Falcon fairing and payload dynamic envelope[2], meters (feet)

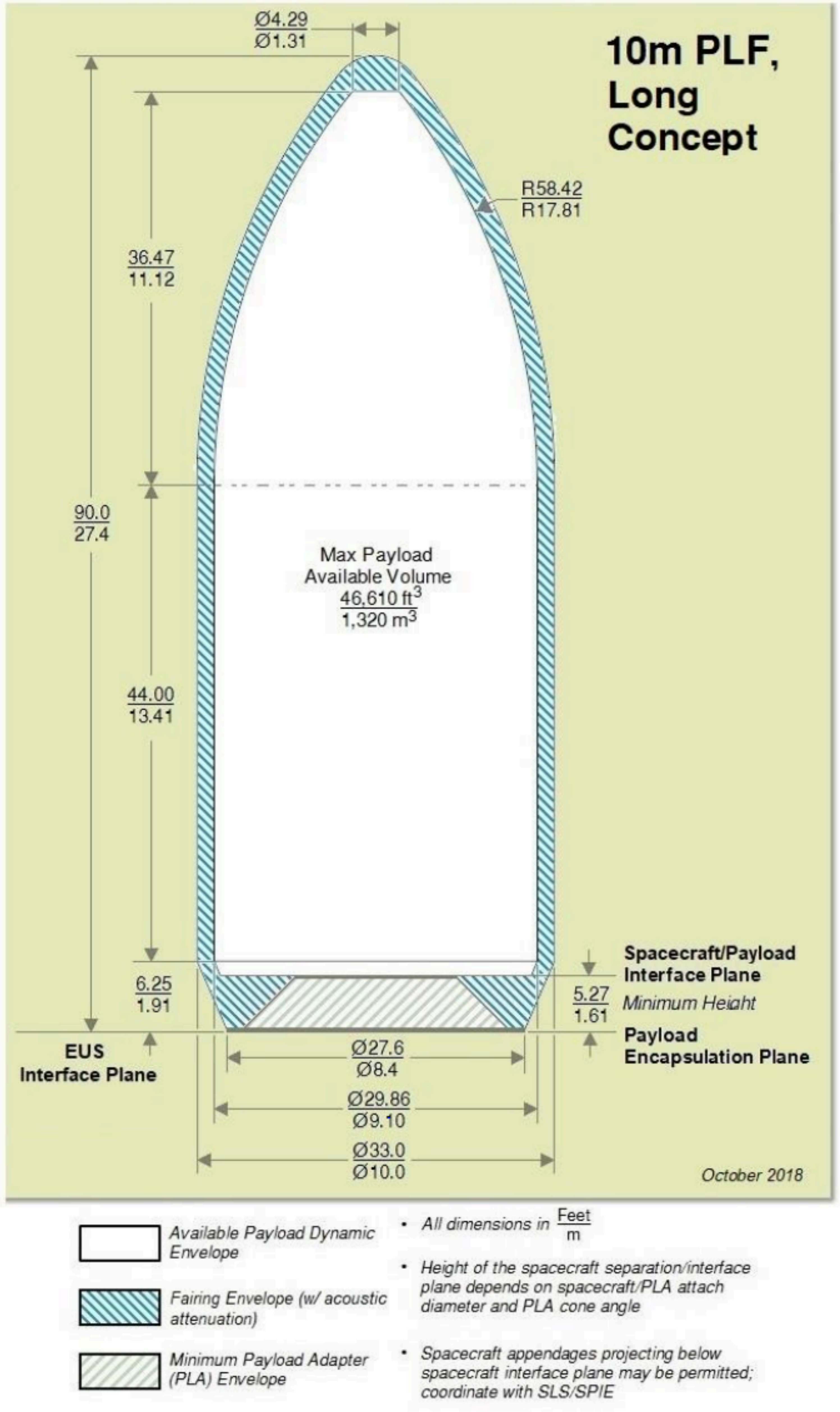


Figure 6-9. Composite 10m PLF, Long Concept

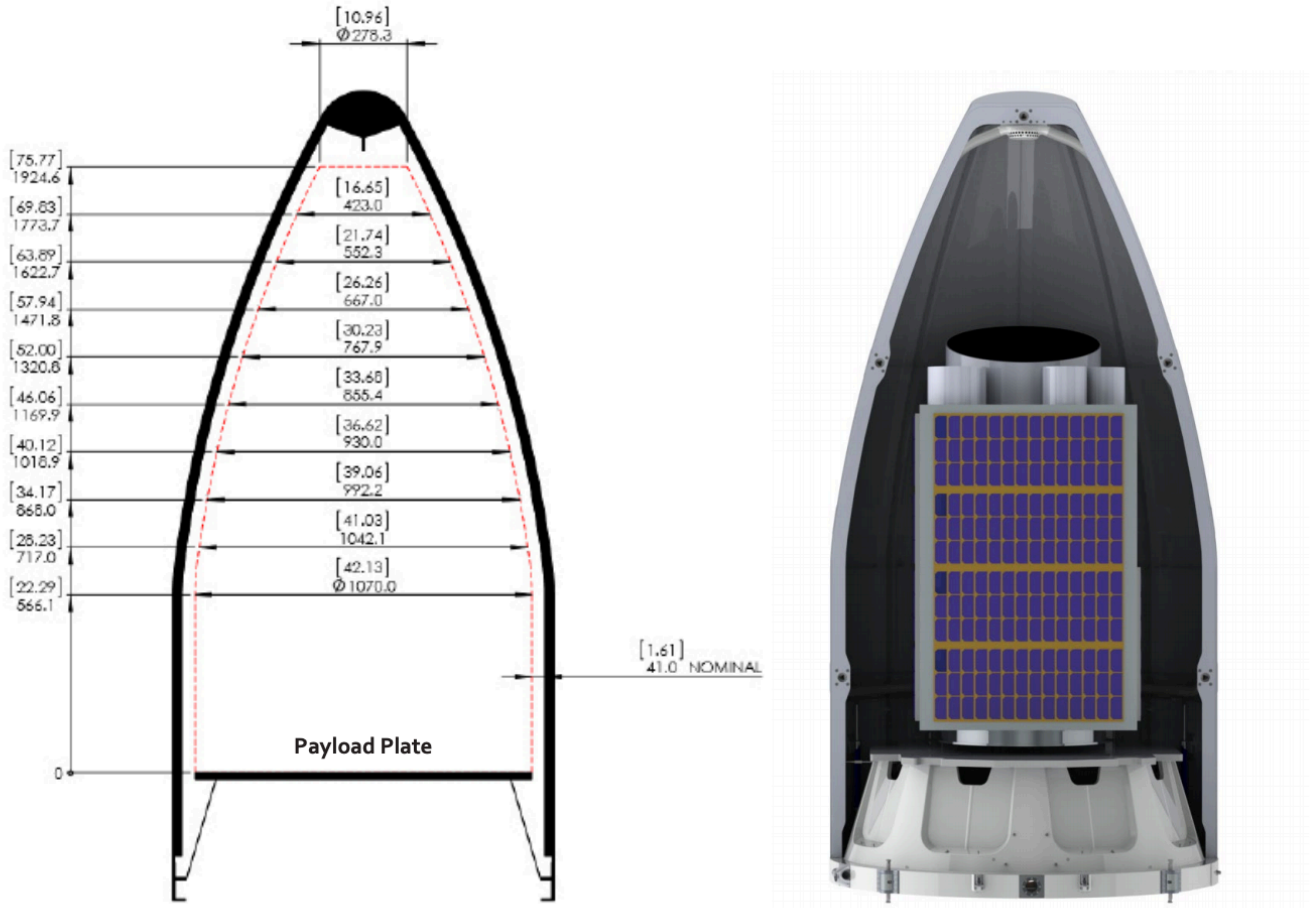


Figure 7 Fairing capacity & sample configuration inside of the fairing

Launch vehicle selection process

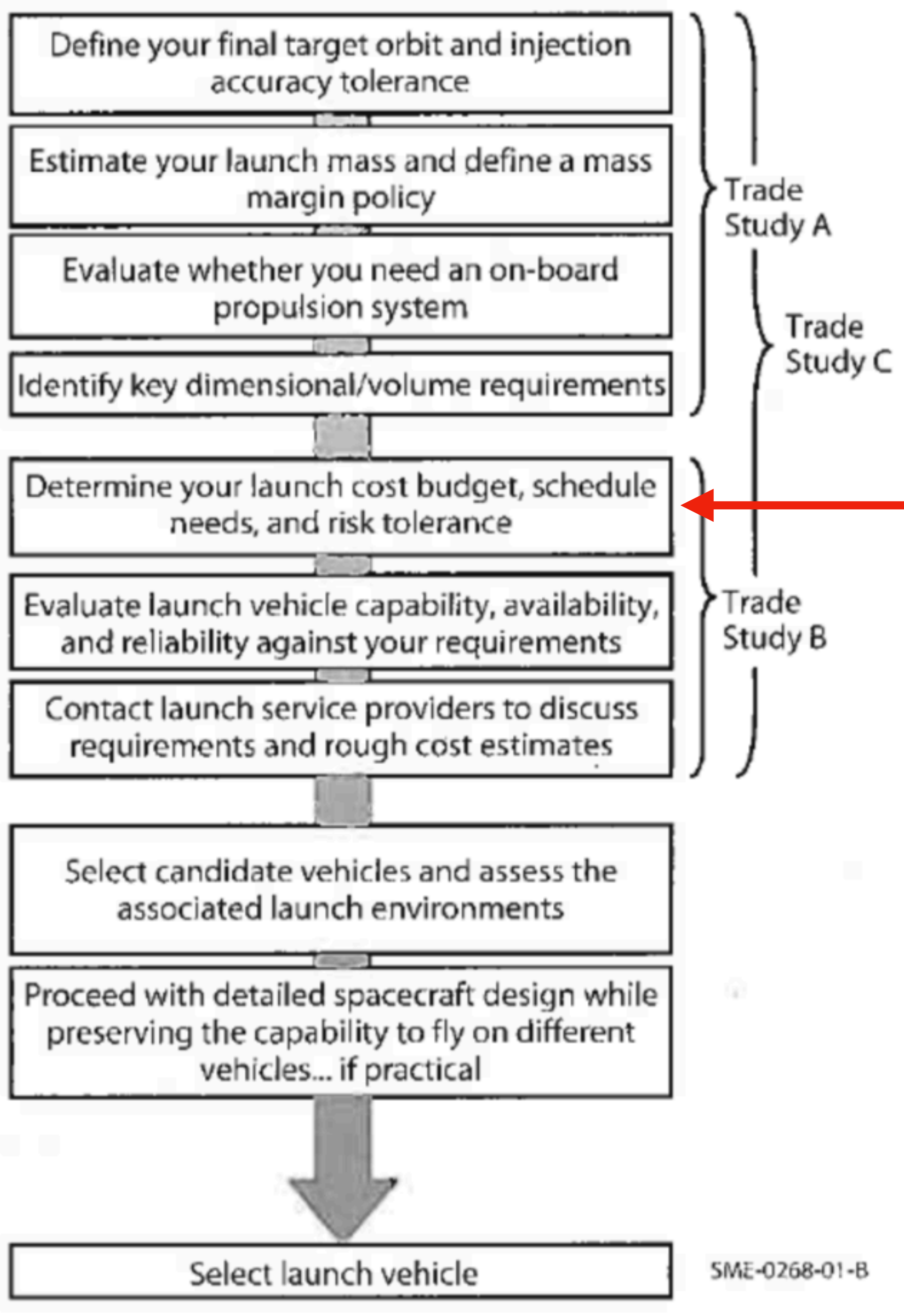
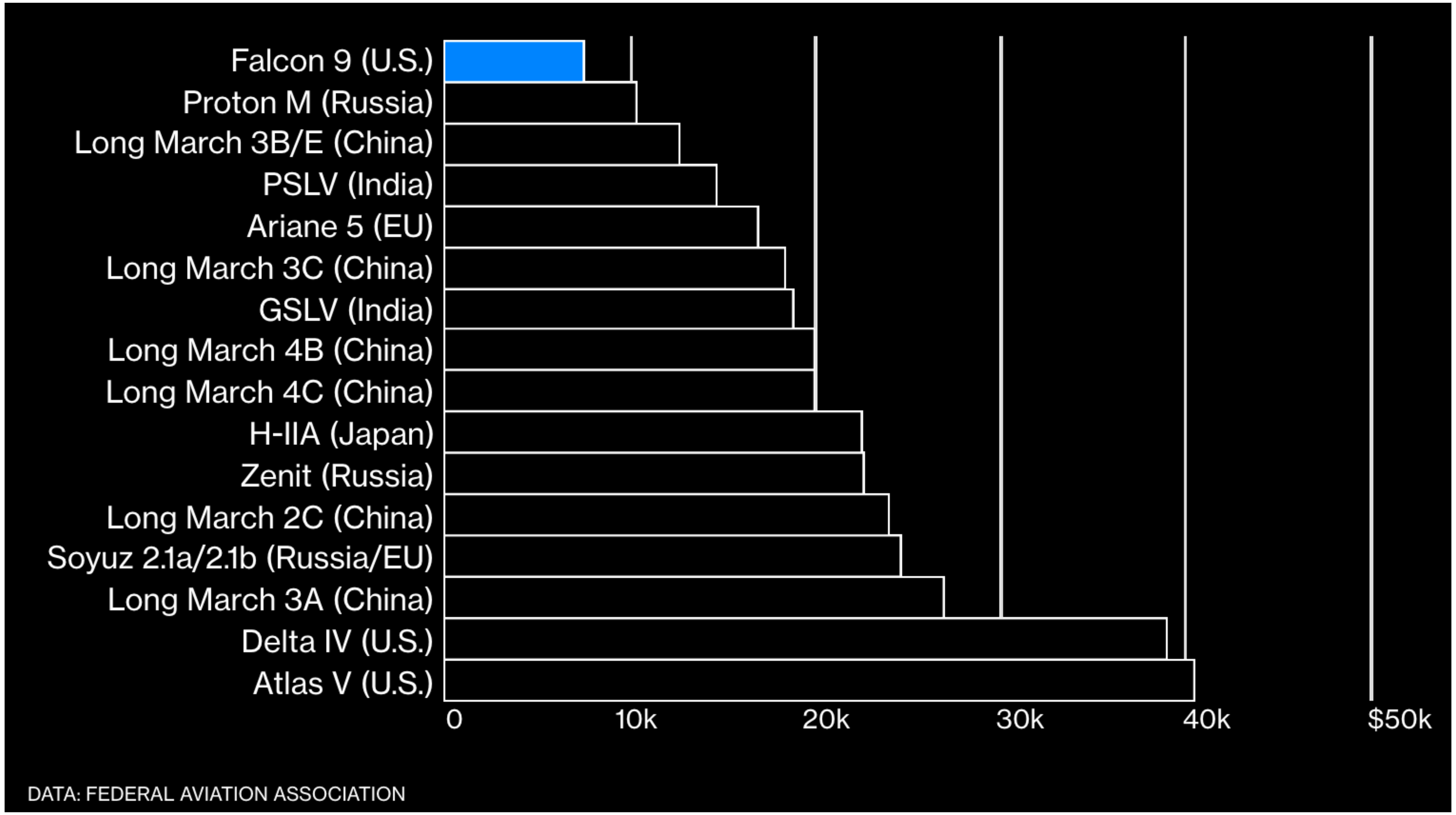


Fig. 26-4. Launch Vehicle Selection Process Flow.

Cost is coupled with required payload to orbit, maturity of the launch service provider (risk), and uniqueness of requirements.

These are *contractual agreements*. Neither the launch provider nor the payload provider is allowed to arbitrarily change launch dates without protracted negotiation and (usually) an incurred cost.

Dollars/kg to GTO (2018)



https://www.bloomberg.com/graphics/2018-rocket-cost/

Launch vehicle selection process

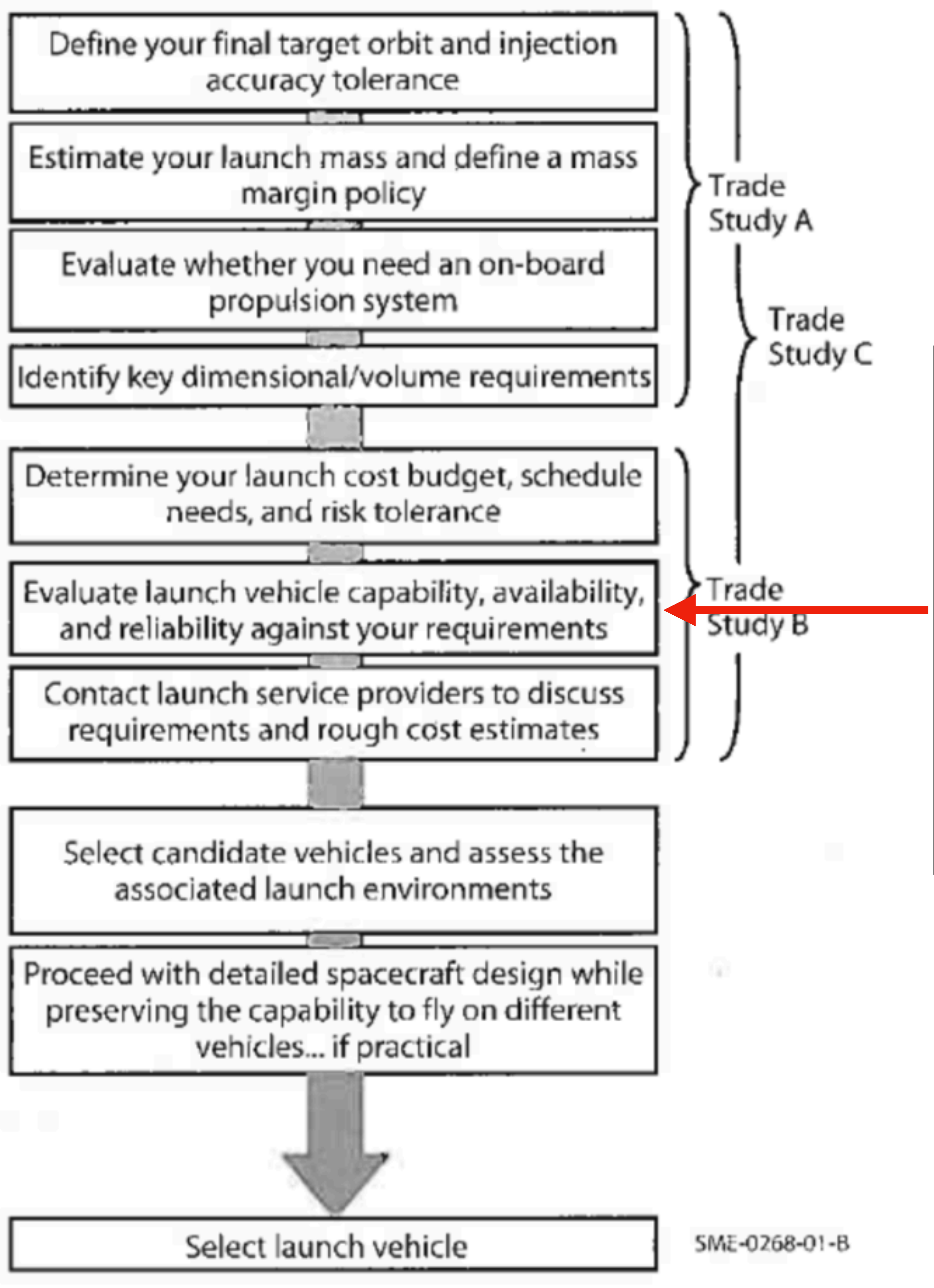


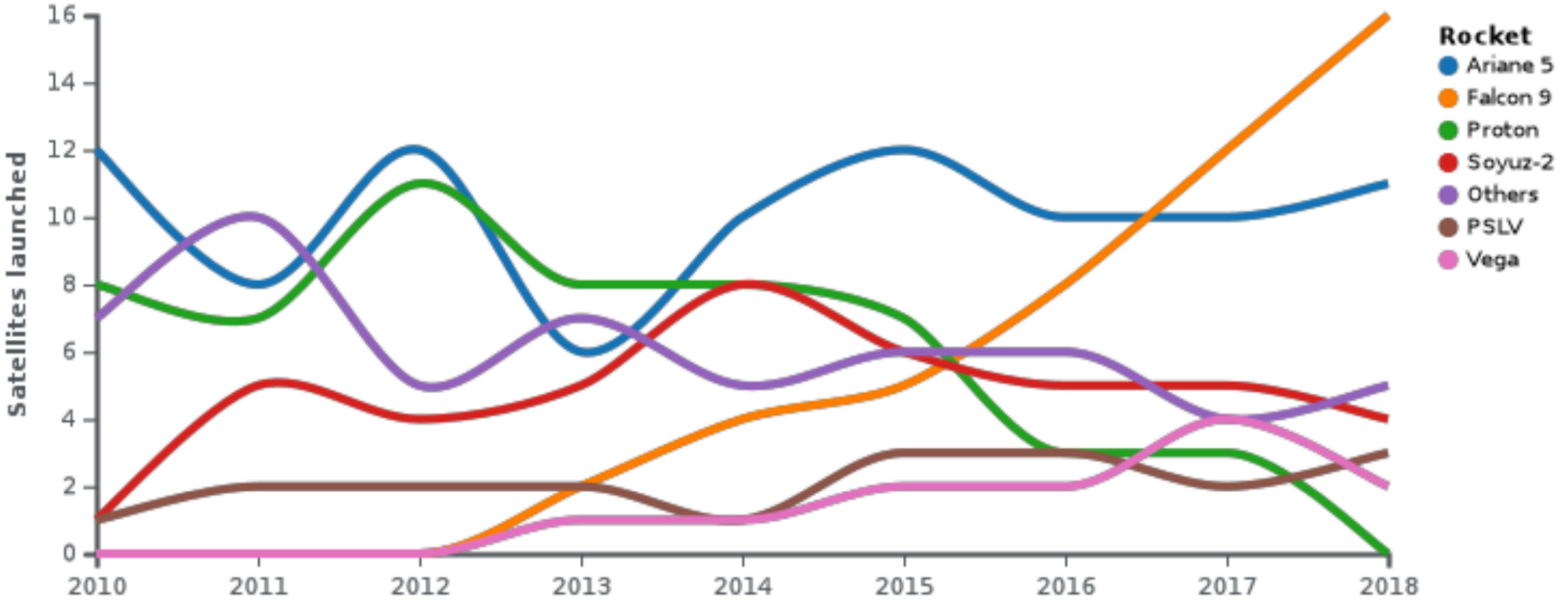
Fig. 26-4. Launch Vehicle Selection Process Flow.

Capability: can the launch vehicle perform in accordance with your requirements (mass, injection, etc.)? Launch locations place limitations on achievable inclinations.

Reliability affects availability. A failure must be investigated, which takes time and can introduce manifest backup. In general, delays are shorter for launch providers with a longer history of successful launches.

Table 26.2. Reliability Experience of Launch Vehicles as of December 31, 2010.

Launch Vehicle	No. of Successful Launches	Total No. of Launches	R
Atlas V	23	23	1.000
Delta II	163	165	0.988
Delta IV	15	15	1.000
Falcon 1	2	5	0.400
Falcon 9	2	2	1.000
Minotaur I	9	9	1.000
Minotaur IV	2	2	1.000
Pegasus XI	37	40	0.925
Space Shuttle	130	132	0.985
Taurus	6	8	0.750
Long March 2C/D	46	46	1.000
Long March 3A/B/C	36	38	0.947
Long March 4	22	22	1.000
Ariane 5	52	55	0.945
PSLV	17	18	0.944
GSLV	4	7	0.571
Shavit	6	9	0.667
H-IIA	17	18	0.944
H-IIB	2	2	1.000
Dnepr	15	16	0.938
Proton (since 1970)	321	348	0.922
Rockot	16	17	0.941
Soyuz	1654	1753	0.944
Zenit	28	30	0.933



(from Prof. Selva's slides)

Launch vehicle selection process

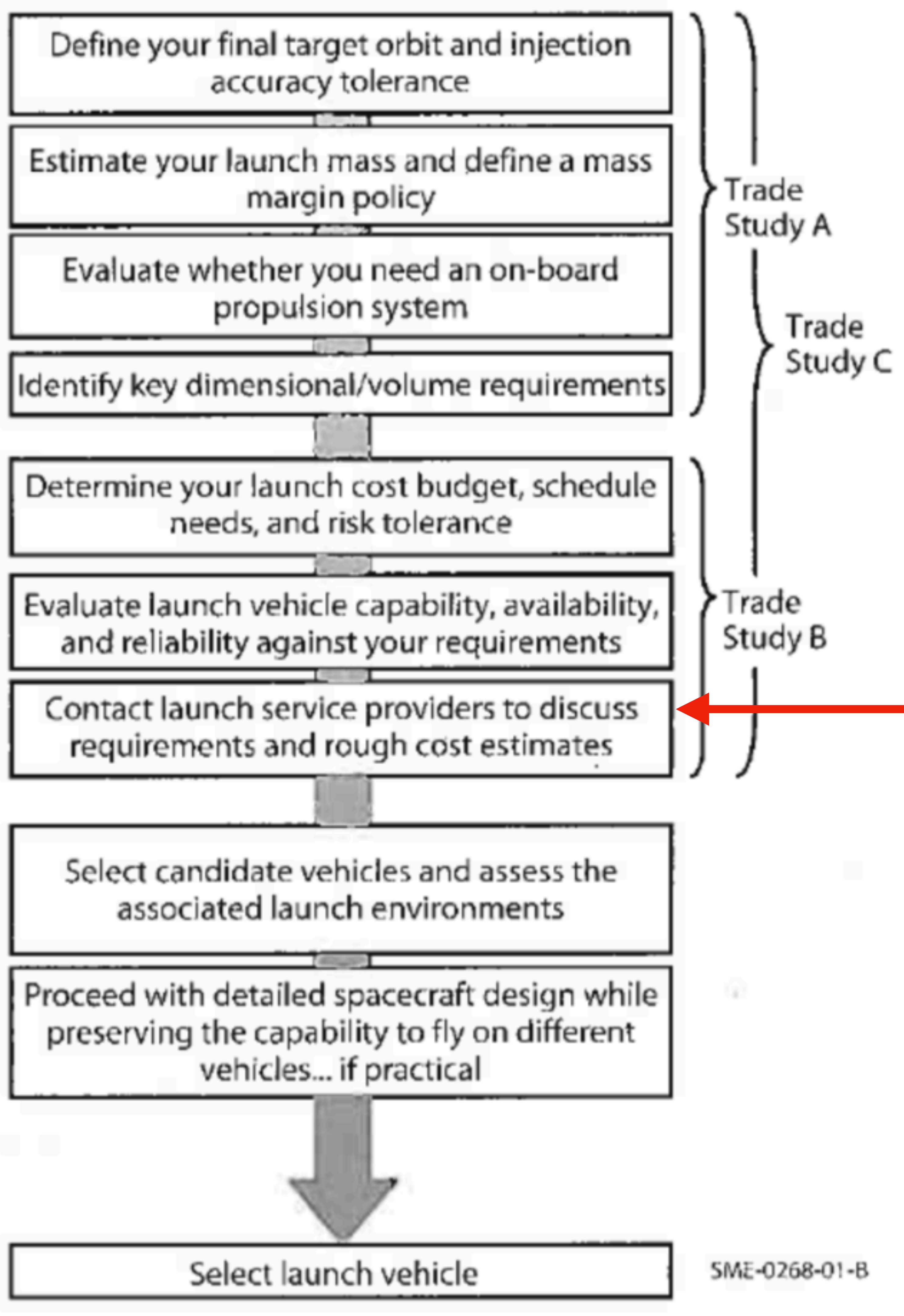


Fig. 26-4. Launch Vehicle Selection Process Flow.

All previous steps are "homework" before starting negotiation with the launch service provider.

Launch vehicle selection process

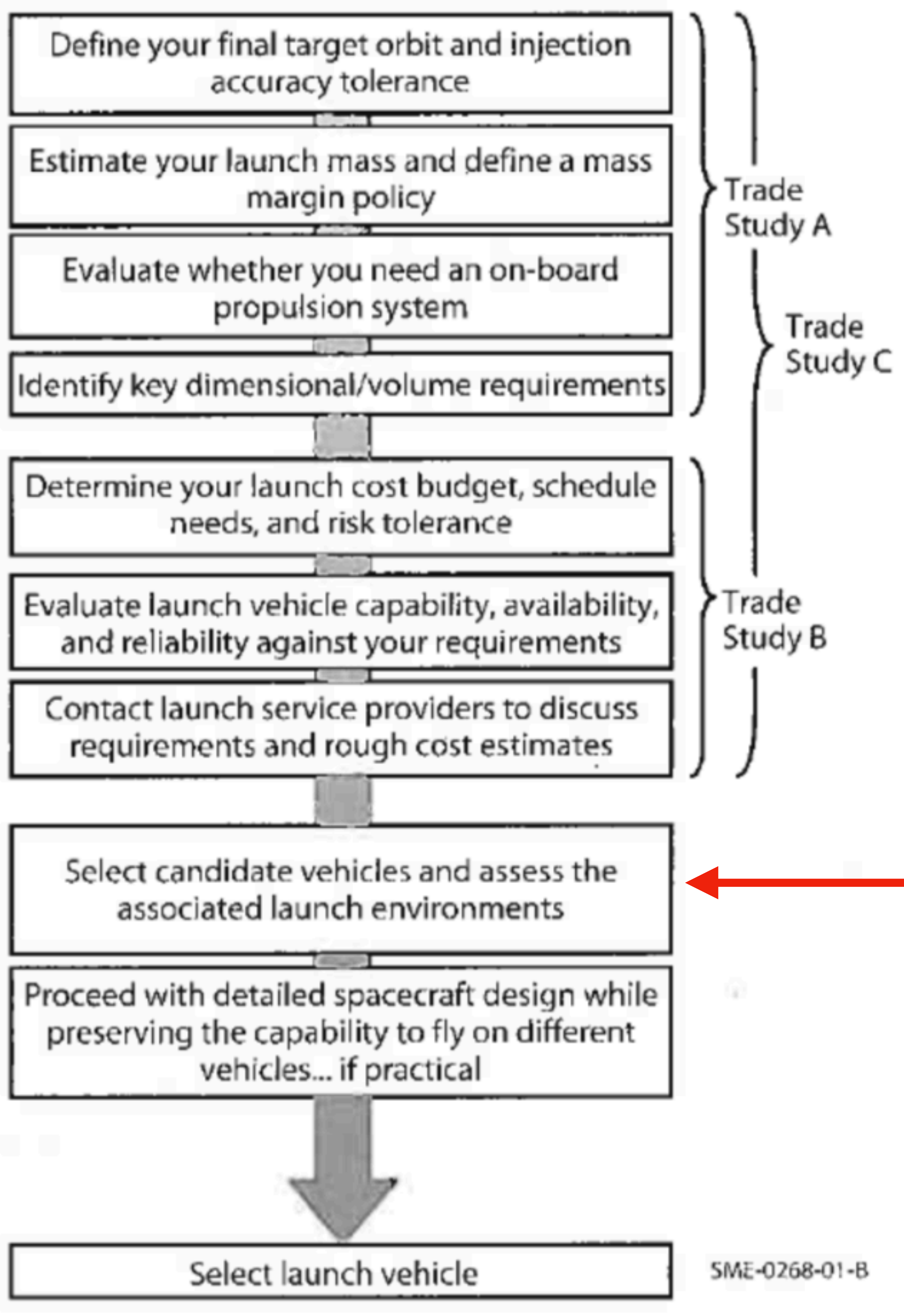
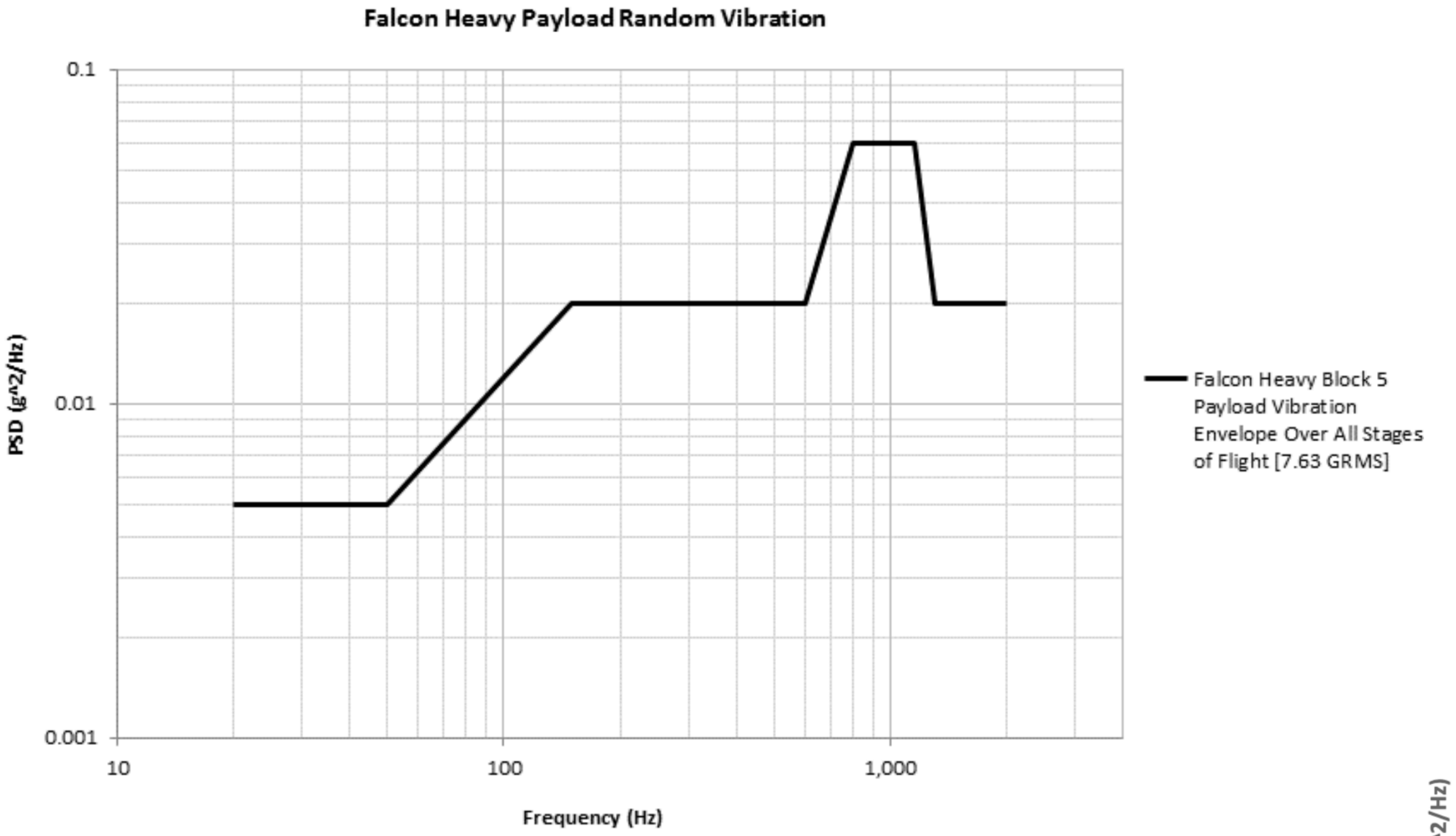


Fig. 26-4. Launch Vehicle Selection Process Flow.

Vibration, shock, acoustics, coupled loads, thermal, electromagnetic. These could affect the structure of your spacecraft, nature/configuration of solar panels and instruments, etc.

Seek out not less than 2 candidates that can do the job within cost, schedule, and risk tolerance.



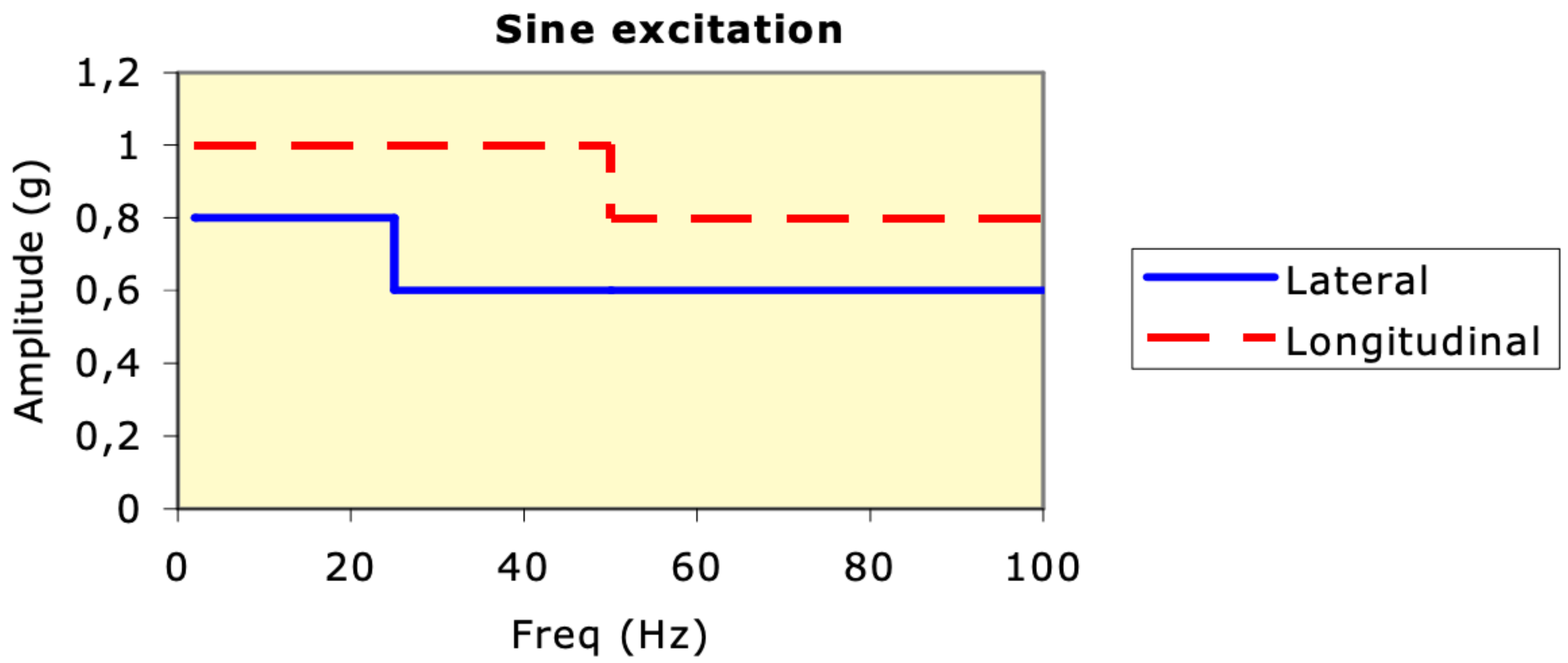


Table 3.2.3.a - Sine excitation at spacecraft base

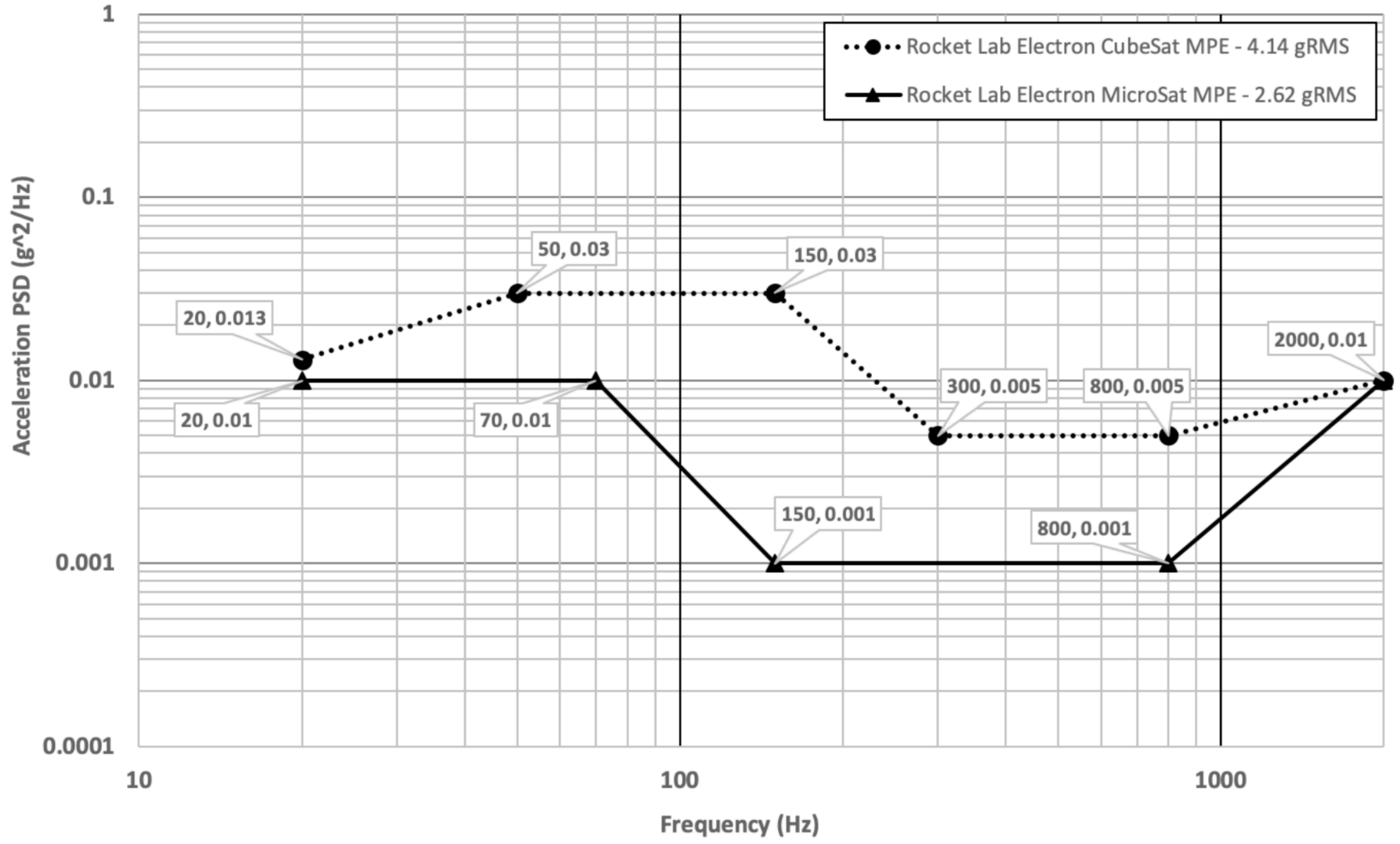


Figure 14 Electron Random Vibration MPE

Launch vehicle selection process

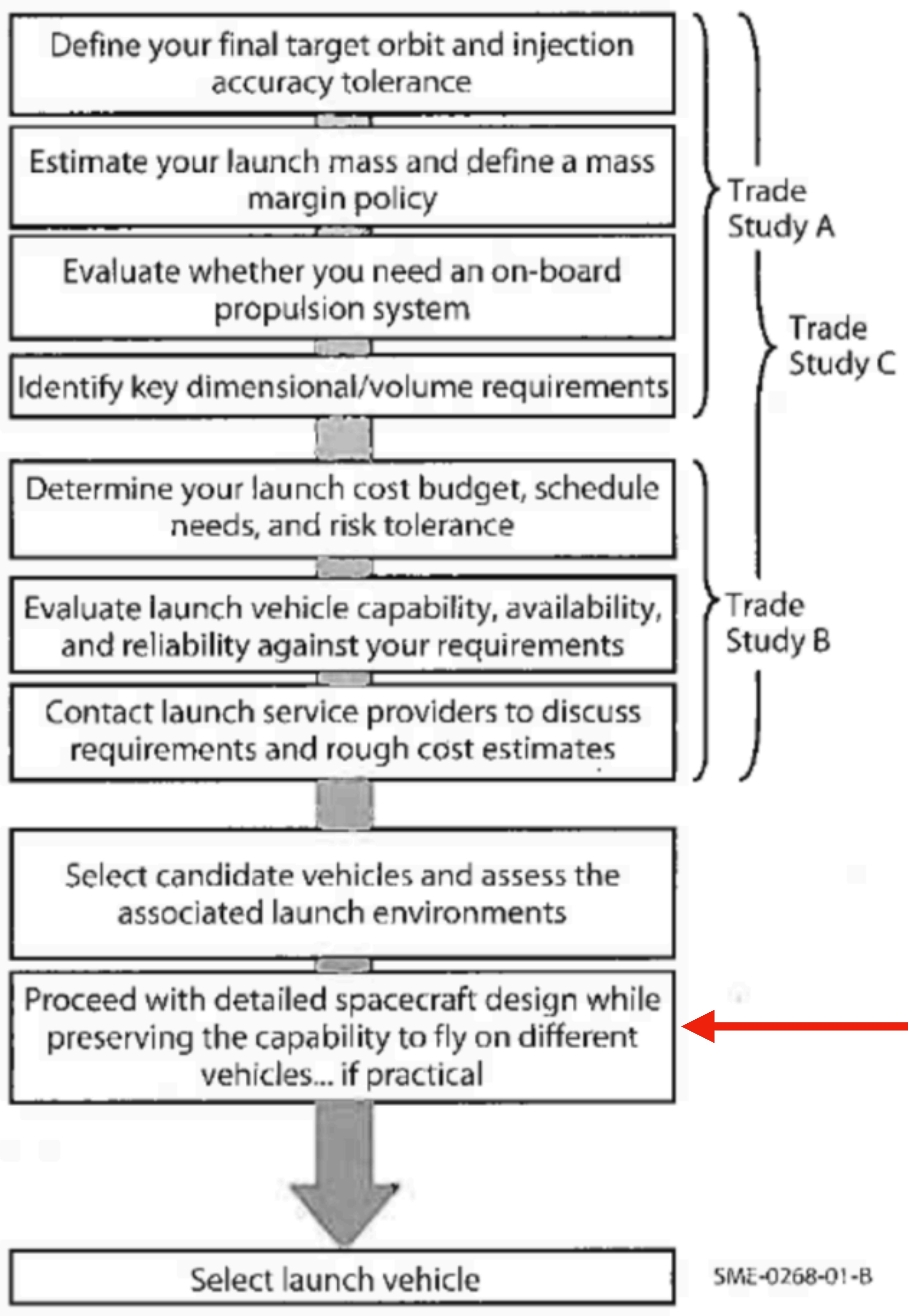


Fig. 26-4. Launch Vehicle Selection Process Flow.

Good idea to maintain at least 2 candidates thru PDR.

Basic mechanics of launch

- A $t-+$10-15 sec, control of the rocket is given to onboard flight computers
- The vehicle begins to rise painfully slowly
- Vehicle clears the tower, pitches over, and begins a downrange trajectory
- Max-Q achieved as the vehicle goes supersonic
- Vehicle may drop a stage at this point, trajectory control may become closed-loop
- Drop the fairing
- Send a wakeup signal to the spacecraft
- Deploy the spacecraft, and get away

/// PAYLOAD SEPARATION
/// FAIRING SEPARATION
/// FLIP MANEUVER
Cold gas thrusters flip first stage
/// STAGE SEPARATION
First stage has left Earth's atmosphere
/// BOOSTBACK BURN
Engines light to bring in trajectory toward landing site
/// GRID FINS DEPLOY
/// ENTRY BURN
Engines light again to slow down first stage
/// ASCENT
/// AERODYNAMIC GUIDANCE
Grid fins steer lift produced by first stage
/// LAUNCH
/// VERTICAL LANDING
Engines light one final time bringing first stage to precision landing
/// "JUST READ THE INSTRUCTIONS"
Autonomous Spaceport Drone Ship

/// PAYLOAD SEPARATION
/// FAIRING SEPARATION
/// FLIP MANEUVER
Cold gas thrusters flip first stage
/// FLIP MANEUVER
BOOSTER
/// BOOSTBACK BURN
/// BOOSTBACK BURN
Engines light to bring in trajectory toward landing site
/// GRID FINS DEPLOY
/// STAGE SEPARATION
First stage has left Earth's atmosphere
BOOSTER
/// ENTRY BURN
/// ENTRY BURN
Engines light again to slow down first stage
/// BOOSTER SEPARATION
/// AERODYNAMIC GUIDANCE
Grid fins steer lift produced by first stage
/// ASCENT
/// AERODYNAMIC GUIDANCE
/// FAIRING RECOVERY
/// LAUNCH
/// VERTICAL LANDING
Engines light one final time bringing first stage to precision landing
/// VERTICAL LANDING LZ-1
/// "OF COURSE I STILL LOVE YOU"
Autonomous Spaceport Drone Ship