Das Marsprojekt × Mars DRA 5.0 × Starship = ?

Nov 11, 2026 · v0.2.4, by RocketAnaglyph

A technically plausible plan outline for a crewed landing on Mars in 2035. It's only just technically plausible because the only US company capable of its implementation has its dance card fully booked with Starshield and Artemis commitments, and there is no hope of a separate budget for it. So this must be strictly relegated to the category of Starship fan fiction: what could have been if COVID-19 hadn't decimated the nation's Leydig cells, and what could still be if all ZBO cryogen designs prove impractical.

Overview

The overall scheme is broadly analogous to NASA's Mars DRA 5.0 (with addenda), albeit with several major departures. This is a family of distinct yet related vehicles: MTVs (Mars Transport Vehicles), MDVs (Mars Descent Vehicles) and MDAVs (Mars Descent/Ascent Vehicles). All vehicles use Starship-derived technology and are boosted to orbit atop a SuperHeavy, are refueled in orbit by tanker Starships, but will ultimately be expended. The Mars-orbiting/landing/return propulsion systems are based on common, non-cryogenic, space-storable propellants (preferred: ethane/MON-25, but MMH/MON-25 is more likely), likely requiring the development of one new, possibly hypergolic engine. No ISRU is required. The systems are electric-pumped into COPV reservoirs from which the engines are then pressure fed (like SuperDracos - we're calling these UltraDracos). It is hoped that these reservoirs can also function as "header" tanks for the flip maneuver.

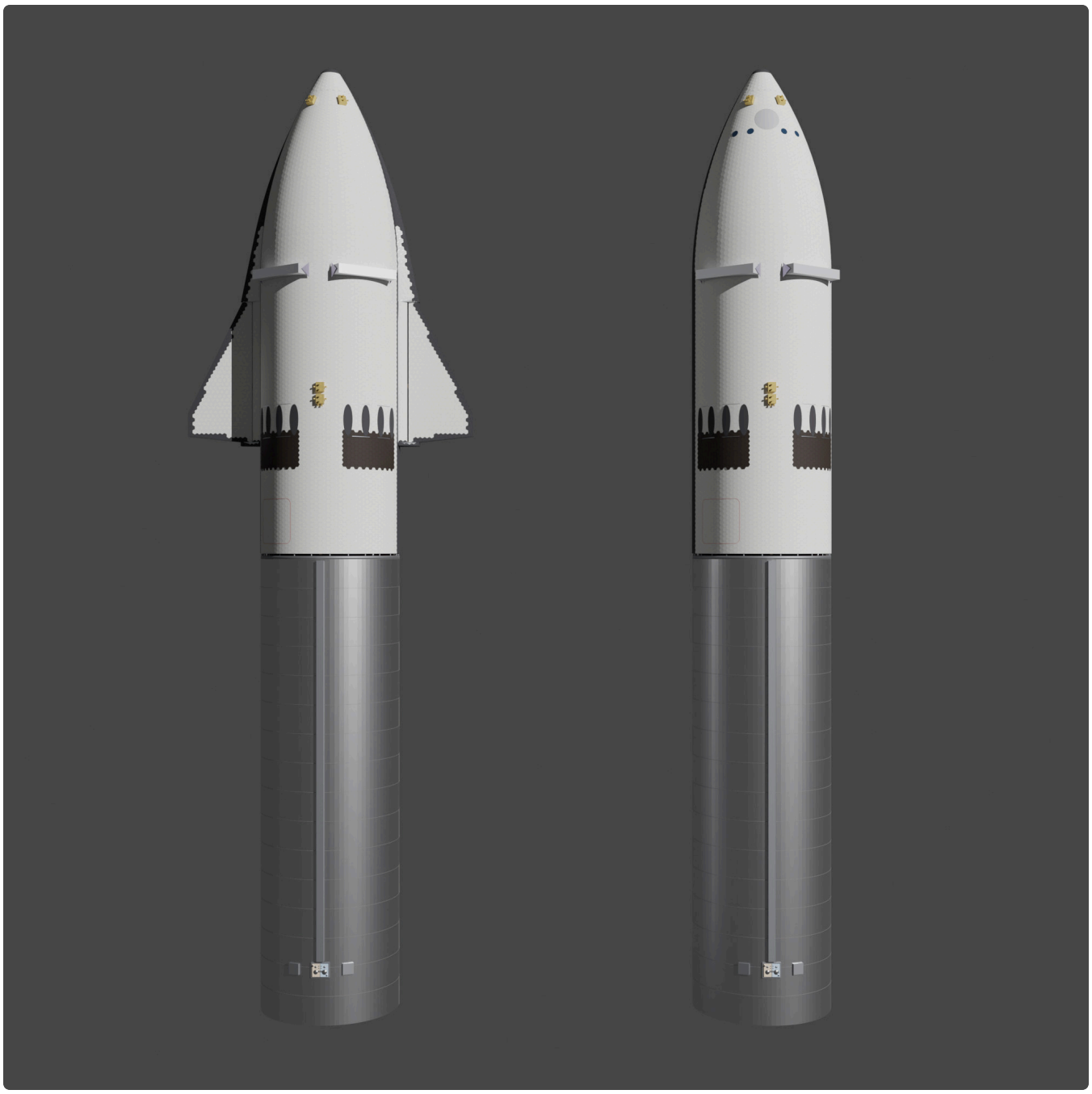


Figure 1 — MDV (left) and MDAV (right), each stacked on its expendable TMI stage. The MDV carries the trim flaps; the MDAV has the docking port and windows instead. The MDV flaps were added to gradually shift the CL aft as propellant is depleted and the CG shifts aft.

The Marship stack

The trick is to take Starship and split it into at least two stages. The lower half keeps its 6 (or 9) Raptors and methalox tanks, but those tanks are shrunk to make room for an upper stage which, in its MDV/MDAV incarnation, is stacked in such a way as to have a cargo basket base, *then* a ring of canted, pressure-fed thrusters with tanks of storable propellants, then a cabin/additional cargo area (see Figure 2). The overall height of an MDV/MDAV with TMI is ~60 m, a bit taller than a standard Starship. The MDV/MDAVs themselves are significantly shorter at ~30m.



Figure 2 — The same stacks cut away: the TMI stage's methane (tan) over its LOX (blue), with the six Raptors inside the aft skirt. The lander's base nests in the TMI stage's forward skirt.

Getting to Mars

The basic plan is to launch combined "Marships" into LEO, where *both* the methalox and storable propellants are (re)loaded by modified tanker Starships. The lower methalox TMI stage (Trans Mars Injection) then fires for Earth departure, after which it is expended. The upper MTV/MDV/MDAV stage continues on towards Mars.

At Mars, the MTVs both aerobrake into a 1-sol highly elliptical orbit, and after checkout, one of the two MTVs descends to a 300 km initial LMO (ultimately it will descend to 200 km). Any MDVs or MDAVs are also expected to aerocapture into a 1-sol orbit before descending to the surface. What makes 2035 so special is a v-inf below 3 km/s achieved simultaneously with a ~6-month crew transit time. Because all stages are to be expended, we don't care about TPS reuse, but there are still maximums to consider. Like Shuttle and probably Starship, the smaller-radius surfaces (nose, flap edges) are covered in a higher-temperature TPS material (TUFROC, SiC, RCC...).

Launch windows 2031–2050: Appendix F.

Landing

The descent engines are located above the lower cargo bay ("basket"). This was done to prevent the engines from scouring a deep hole in the landing site, but it has the side benefit of making the overall Marship MDV/MDAV more stable, due to a lowered center of gravity. The MDV flaps were added to gradually shift the CL aft as propellant is depleted and the CG shifts aft. It's also expected that the cargo will have to be carefully apportioned between top and lower cargo areas, and perhaps there will be a mechanism to pump water to adjust trim, since water is also a critical quantity for an early Mars base. The floor of the cargo bay may include a crush zone, to prevent penetration of the cargo area by flying debris or rocks on the ground, and as insurance against a faster than nominal descent.

Because the nozzles are above the cargo basket, they must be canted outwards and scarfed to fit the hull shape. Canting and scarfing the nozzles absolutely crushes the already mediocre performance of the landing engines, but fortunately, Mars' atmosphere does 98% of the work needed to decelerate the MDV or MDAV to the surface. Currently,

landing 43-44 t looks plausible for an MDV with a dry mass of 63 t or less. Landing a single MDV with "only" a 35 t science payload would be a worthwhile mission in itself, but it would have to be 100% robotic, of course. This is as good a point as any to concede that there is no hope of man-rating all these Marship derivatives by 2033, the point at which the first ships would have to set out for Mars before a human crew set out in 2035. So the 2033 "crew" will certainly be and the 2035 "crew" will almost as certainly be composed entirely of Optimus robots. Even within fan fiction we like to keep it somewhat real.

What one MDV lands, and the tanker fleet it requires: Appendix B. The MDV and MDAV mass budgets: Appendix A.

We expect Optimus robots will continue to make great strides leading up to 2033, in particular that they can be entrusted with not just loading and unloading cargo from the landed MDV, but metalworking: cutting and welding and drilling. Indeed, we expect the Optimuses will be sealed in the cargo hold before launch and without a door. There will be a support frame for a door, but they will have to cut themselves out of the cargo hold after landing.

The round trip

For a round-trip mission, complexity steps up an order of magnitude. The baseline is currently for 2 MTVs, 4 MDVs and 2 MDAVs to support a single round-trip to the surface. The MDVs are primarily refueling tankers, and all 5 landers set out for Mars 1 synodic period before the main crew (2033): the 4 MDVs and MDAV-1, an uncrewed MDAV that becomes the heated surface depot and the default ascent vehicle. If all the landings are successful, and the Optimuses are successful in setting up the base, then a human crew of 6 could set out for Mars in 2 MTVs plus MDAV-2 in 2035. The tankers' propellant is transferred into MDAV-1 well before the crew leaves, and kept above MON-25's −55 °C freezing point, so the crew's go/no-go can wait until their ride home is fueled and checked out. DRA 5.0 sets the same condition: its ascent vehicle lands early and makes its oxygen on Mars before the crew leaves Earth. The two MTVs provide an important degree of redundancy (and extra living space) in what is a completely new system. Both are fully stocked with supplies for at least 15 months (1 synodic period in the case of MTV-2). Arriving at Mars, there are a couple of options: all of the crew could transfer to MDAV-2 for a direct descent to the surface (any small braking on its thrusters; the main engines stay covered until landing), while the MTVs aerobrake into an initial 1-sol high elliptical orbit. Or they could all brake into parallel 1-sol orbits for checkout before transferring to MDAV-2 for descent. The MD/AVs have been spec'd with larger tanks to provide options.

The fleet for one crewed mission and its launch count: Appendix D. MTV and TMI stage specs: Appendix E.

The fuel economics of descent of MDAV-2, the crew's lander, are similar to its sister ship, except it is expected to carry only the most critical cargo plus up to 20 t more fuel than normal to give the captain and pilot options in the case of an engine failure or other anomaly. It is expected that the landings of each ship will be some distance apart, since a kicked-up pebble on Mars at 45° and 100 m/s will fly for 2+ km before landing. I'm favoring a line as shown in Figure 3, such that each successive MD/AV lands polewards of the one that landed before it, with the thicker black TPS facing in the direction of the next lander (as a minimal shield). The last in the chain will be MDAV-2, and I'd like to imagine that the astronauts will ride 3 Cyberquads (maybe a Cybertruck-derivative, if it can fit) to wherever the base has been set up (see Figure 3).



Figure 3 — MDAV-1 and four MDVs landed 1 km apart in a line on a crater floor (a synthetic Jezero stand-in), seen from a rim about 217 m up, with rover tracks between them. The MDAV is the farthest, 5.6 km out. Gemini picture as modified by Claude.

On the surface

The plan here is for a stay of 500+ days. This gives everyone, including the Optimuses, plenty of time to perform tasks that would be impossible even on a 1-month trip to the Moon. In particular, preparation of MDAV-1 for return to LMO is job one. Its tanks were

filled before the crew left Earth, but the 180 t or so of propellant they hold is enough only for a lightened MDAV. The MDAV is built with an ability to discard its lower cargo basket, much as the LM descent stage served as a platform to launch back into lunar orbit. That saves 10 t from the 63 t dry mass of the MDAV. Then, it is expected that 10,000+ TPS tiles will need to be removed, primarily by Optimus robots. How they will scale the side of a rocket on Mars is TBD, but tile removal is otherwise a straightforward procedure regularly performed by SpaceX. Personally, I favor burning them off with a CO2 laser since Mars' atmosphere comes almost CO2-laser-ready.



Figure 4 — On the surface: a landed MDV (left), MDAV-1 stripped for ascent with its tiles off and nozzle extensions fitted (center), and MDAV-2 as it lands (right). The ring seams on the stripped MDAV are 1.83 m apart, as on Starship. The heavier seam between the two nozzle groups is J4: everything above it flies to orbit, while the basket, legs and crushable floor below it stay on Mars.

What leaving the basket and tiles on Mars buys the ascent: Appendix C.

Refueling is a project in itself, and there are many challenges moving 160 t from the MDVs into MDAV-1, and holding it there until the crew launches, without at least the MON-25 freezing (we may leave some of its tiles on to assist with insulation), or some of the ethane leaking. The landing order is what makes it workable. MDAV-1 lands first, carrying a 10 kWe Kilopower-class reactor that keeps its propellant liquid. Next comes the MDV with the truck and its insulated tank trailers (Appendix H, 4a), which the reactor charges. The tankers wait in the 1-sol orbit and land one at a time starting in early summer (Ls 90–180, late October 2034 to late April 2035). Each is emptied into MDAV-1 before the next comes down, because keeping every lander's propellant liquid at once would take more power than the reactor has. Probably less difficult overall than managing a Sabatier plant plus cryogenic storage.

In addition, nozzle extensions will be manually fitted to all sixteen engines to boost effective Isp and axial thrust.

Ascent and the backstop

Before launch of the refueled and stripped MDAV-1 back to LMO, the MTV-2 will lower itself to a (higher-drag) 200km orbit in preparation to receive the MDAV for refueling. That is MTV-2's primary purpose: an LMO depot that can refill MDAVs to reach MTV-1. It contains enough fuel to rescue the crew and bring them to MTV-1 should the MDAV become dysfunctional on reaching orbit. However it also contains enough supplies to support the crew for a full synodic period should everything go south and strand the crew in LMO. In some sense it serves the function of Mars gateway, which it can perform in LMO rather then an NRHO because of its storable propellants.

Launch to LMO is backstopped by the sheer amount of fuel the MTV-2 will carry: enough so that if the MDAV underperforms and ends up in a low orbit, the MTV-2 can descend to get the MDAV, and then return the crew all the way to 1-sol elliptical to meet up with MTV-1 for the trip home. Otherwise it can stay in LMO to refuel future MDAVs. On the surface, the backstop is MDAV-2: if MDAV-1 can't fly, the crew's own lander can be stripped and filled from MDAV-1's tanks instead.

TPS

All of the ships under discussion are expected to use the Starship TPS system on the windward side, modeled here as a roughly 35mm thick hollowed-out AETB/TUFI-derived tile, embedded in "crunch-wrap" over silica felt. We don't know the detailed

specifications, but at least one point SpaceX stated a 7.5kps entry speed at Mars, however we will target entry speeds below 6kps even if a higher tile limit is possible as there are structural limits in play. The nose, flaps and chines are expected to made of tougher tiles, possibly SiC, as small-radii structures see higher stagnation temperatures. Simple stagnation calculations are only good enough to suggest where the worst heating points will be, and SpaceX themselves didn't really seem to get it right until after several test launches of Starship.

The leeward side is expected to be covered by thin white tiles, as the CO2 in the plasma sheath on Mars radiates more strongly in the infrared than does Earth's atmosphere. How thin is TBD, but the leeward tiles are not so much about protecting the hull as insulating the tanks.

Structure

Choice of material is by reference to the TPS. The conventional choice would be (and could still be) a high-strength aluminum alloy, but the assumption is that Starship's TPS system is probably better suited to a more robust steel substrate.

Material. The welded hull is PH 13-8 Mo, one alloy and one temper, bought as solution-treated plate (Condition A) up to 23.75 mm thick depending on zone.

Barrel rings. Plate is rolled to roughly a 1.5 m radius so that it springs back to 4.5 m, then TIG-welded into a 9 m hoop with matching filler. The isogrid is machined from the inside of the closed hoop, referenced to the outer surface, leaving a 1.75 mm minimum skin with ribs about 2 mm wide and 16–36 mm deep.

Ogive rings. These are doubly curved, so they are formed as gores or short cone frusta, welded into rings, and machined the same way on a five-axis machine, with the grid stepping down ring by ring.

Segments. Rings are stacked and welded into five furnace segments, and the frames, bulkheads, flanges and tile studs are welded in. Each segment is aged whole to H1100 (593 °C for 4 hours), which is the only post-weld heat treatment. Flange faces are finish-machined after the age, and the segments are bolted together.

Furnace. Purpose-built, about 10 m inside diameter and 12 m working height, sized by the ogive.

Flaps

The idea of the flaps is, even if the ship comes in perfectly balanced, as the fuel depletes the CG will shift rearward and the flaps can be adjusted to maintain the optimal L/D. They are positioned where they are to avoid the exhaust of the descent engines, but one open design option is to jettison them before engine ignition, which would eliminate that requirement.

Radiation

I'd like to claim that if the MTVs were to store their ethane fuel in a 30 cm sheath around the cabin, long-term radiation exposure would be solved, but really it would only solve the solar proton and Van Allen belt problems. High-energy cosmic rays are unavoidable, and so in order for this mission to be permitted under NASA rules the radiation standards would have to be relaxed, because even with ethane shielding the stay on Mars pushes the astronauts over the limit. It could be that the inner sleeping quarters are also surrounded by mission water, but a real shelter would require multiples of the minimum for drinking and bathing.

Links

- SwRI: radiation exposure on a trip to Mars (RAD cruise data)
- SwRI: first radiation measurements from the surface of Mars
- NASA OCHMO radiation protection technical brief (NASA-STD-3001)

Appendix A — Release 0.1.1 numbers workbook

The MDV and MDAV as frozen in release 0.1.1 (*Stubby_Starship_numbers.xlsx*, design model at ICD 0.10.7.1, 26 Oct 2026). Masses are basic, with the systems allowance; the growth allowance is 10 % on sized items, 15 % on packages and 25 % on placeholders.

A.1 Headline numbers

Quantity	Value	Maturity
MDAV flies to orbit	49.9 t	Sized + placeholders
MDAV flies, with growth allowance	55.8 t	

Quantity	Value	Maturity
MDAV stays on Mars	15.6 t	
MDAV flying bill over the 44 t target	5.9 t	
MDV / tanker, empty	62.0 t	
Black tile areal mass	5.42 kg/m²	Estimate
Thermal protection, MDAV	4.97 t	Placeholder
Solar arrays (pair)	31.7 kW at 1 AU, 0.61 t	Estimate
Hull PH 13-8 Mo that flies, MDAV	28.2 t	Sized
Plate bought for it	164.1 t (buy-to-fly 5.8 : 1)	Estimate

A.2 Mass budget, kg

ID	Item	Maturity	MDAV	MDAV bill	MDV
A1	Landing legs	Placeholder	899	Stays	899
A2	Crushable floor	Sized	1,012	Stays	1,012
A3	Basket (lower cargo bay, landing stage)	Sized	8,939	Stays	8,838
A4	Engine bay and thrust structure	Sized	8,639	Flies	8,679
A5	Engines, 16 × 125 kN	Package	6,490	Flies	5,351
A6	Thermal protection (tiles, layers, covers)	Placeholder	4,771	Stays	5,619
A8	Upper hull (tank barrel, ogive, nose)	Sized	13,007	Flies	11,876
A9	Tanks and feed	Package	13,304	Flies	13,304
A10	Flaps and chines	Placeholder	none		1,822
A11	Cabin, docking port, windows, solar arrays	Placeholder	2,849	Flies	612
A6s	Tile studs	Placeholder	200	Flies	in A6
SA	Systems allowance (power, avionics, ECLSS…)	Allowance	5,450	Flies	3,950
	MDAV flies (with growth)		**49,939** (55,835)		
	MDAV stays on Mars (with growth)		**15,621** (18,033)		

ID	Item	Maturity	MDAV	MDAV bill	MDV
	Empty (with growth)		**65,560** (73,868)		**61,961** (70,037)

The MDAV's engines include the bolt-on ascent extensions; the MDV's flap carry-through is unresolved and not included. Each tonne that flies to orbit costs ~3.7 t of ascent propellant (Appendix C). The solar arrays are 2 × 4 × 11 m roll-downs (88 m²): 31.7 kW at 1 AU, 13.6 kW in Mars orbit, ~9.6 kW at a Mars noon, ~3.1 kW averaged over a sol. The unissued 0.11 draft takes the MDV to 63.0 t for the 5 g entry and the flaps note's heavier flaps.

A.3 Hull structure: MDAV isogrid shells (PH 13-8 Mo)

Zone	Area, m²	Skin, mm	Rib depth, mm	Flying, kg	Plate, mm	Buy-to-fly
Basket (landing stage)	207.0	1.75	22	4,294	23.75	8.9
Engine bay	103.5	1.75	20	2,245	21.75	7.8
Barrel R1	51.7	1.75	20	1,040	21.75	8.4
Barrel R2	32.3	1.75	22	669	23.75	8.9
Barrel R2, MON-25 tank wall	19.5	4.25	16	742	20.25	4.1
Barrel R3, MON-25 tank wall	17.1	4.25	16	653	20.25	4.1
Barrel R3	34.6	1.75	20	696	21.75	8.4
Barrel R4	51.7	1.75	18	1,007	19.75	7.9
Ogive R1	51.4	1.75	20	987	21.75	8.8
Ogive R2	50.0	1.75	16	941	17.75	7.3
Ogive R3	47.2	1.75	16	878	17.75	7.4
Cabin section	102.6	1.75	16	2,033	17.75	7.0
Nose tip, lower	14.3	1.75	16	277	17.75	7.1
Nose tip, upper	10.9	1.75	16	219	17.75	6.9
Isogrid total				**16,682**		**7.8**
Other parts (frames, fittings), 3 : 1 assumed				11,519		3.0
MDAV hull				**28,202**		**5.8**

Isogrid hull is 1.75mm skin with ribs that are 2–2.5 mm wide and 16–22 mm deep. The shells would be machined from curved plate, not chem-milled. The MDV's hull is 26,922 kg flying from 158,001 kg of plate (5.9 : 1). The periodicity of the isogrid is matched to the pitch of the TPS hex plates, with mounting studs welded to nodes of the isogrid. The rationale for steel as opposed to high-strength aluminum is the belief that the current Starship TPS (which this reuses) is better suited to steel than aluminum.

A.4 Thermal protection

Black tile: AETB-8 at 140 kg/m³, a 35 mm envelope averaging 20 mm solid with its hollow back (2.80 kg/m²), plus 2 mm of TUFI at 1,310 kg/m³ (2.62 kg/m²): 5.42 kg/m². Under it, a 10 mm backup layer at 200 kg/m³ (2.0 kg/m²) and crunch wrap in the 4 mm gaps. Plume-wash tiles below each engine bank add a 3 mm C/SiC face (5.7 kg/m²). White leeward tile: 10 (15?) mm at 200 kg/m³ (3.0 kg/m²).

Per vehicle	MDAV	MDV
Black tile area, m²	446.7	507.2
White tile area, m²	309.8	368.5
Plume-wash tile area (within the black), m²	37.4	37.4
Black tiles, kg	2,421	2,749
Backup layer, kg	919	1,044
Crunch wrap, kg	112	131
White tiles, kg	929	1,106
C/SiC face on the plume-wash tiles, kg	213	213
Port doors and covers, kg	376	376
Thermal protection, kg	**4,971**	**5,619**
Lost black tile: hottest bare skin the hull passes, °C	781	792

Appendix B — MDV landing: the landing calculator

Plan on 44 t of propellant per MDV tanker, the landing calculator's figure. The more detailed landing optimizer webapp is stuck at 33 t, and the mission model's ~62–65 t is out of reach. From the lead's *MDAV_Landing_Calculator_v10.2-PLAUSIBLE-r3* (attached 2 Nov 2026).

B.1 Four landing models, one MDV tanker

Model	Propellant landed per tanker	Tankers for the MDAV's ascent (~160 t)
Mission model (mission.py rev 4.1)	~62–65 t	3, not achievable
Java cargo optimizer, derived from the spreadsheet	55 t	3
Landing calculator v10.2, PLAUSIBLE r3	**44 t**	**4**
Landing optimizer webapp	33 t	5

The ~160 t is the ascent calculator's jettison column (Appendix C) with 2 t of crew and samples, less the 20 t the MDAV lands aboard. Much of the spread is the landing-attitude policy: the mission model lets the thrust point up to ~36° above the anti-velocity at ignition, the calculator 20°, and the control model budgets 3°. The webapp also finds that a tanker carrying only propellant can't trim at entry: it needs ~8 t of dense cargo low in the basket.

B.2 Engines: landing on the bare scarfed nozzle

Item	Value	Note
Engines	16	four banks of four, all canted 20°
Rating with the ascent extension	125 kN, 315.3 s	propulsion rev 4.1
Landing thrust per engine, bare nozzle	115.63 kN	extensions are fitted on the surface

Item	Value	Note
Landing Isp	291.7 s	CEA 309.6 s × 0.942 (injector, nozzle, film cooling, scarf)
Scarf thrust deflection	11.9°	on top of the 20° cant
Axial Isp / exhaust velocity	247.6 s / 2,428 m/s	Isp × cos(31.9°)
Installed axial thrust	1,570.6 kN	all engines at full thrust
Full mass flow	646.8 kg/s	
Burn throttle	0.30–0.92	92 % keeps differential-throttle steering
Thrust angle above the anti-velocity, max	20°	

B.3 Inputs

Input	Cargo (tanker)	Crewed (MDAV)
Vehicle dry mass	62.9 t	65.9 t
Delivered fuel cargo	44.0 t	20.0 t
Other cargo	0	10.0 t
Touchdown mass	106.9 t	95.9 t
Arrival v∞	3.0 km/s	4.0 km/s
Aero-phase start (after the hypersonic entry)	15 km, 950 m/s, −9.5°	15 km, 950 m/s, −9.0°
Flip and SRP ignition	Mach 4.29 (989.6 m/s)	Mach 4.29 (989.6 m/s)
Terminal hand-off	100 m, 10 m/s	100 m, 10 m/s
Final descent speed	1 m/s	0.5 m/s
Belly-first Cd / L/D	1.2 / 0.3	1.2 / 0.3

Geometry is still a placeholder (9 m × 35.46 m): drag area 383 m² belly-first, 63.6 m² tail-first.

B.4 Results: flip-and-burn with aerodynamic deceleration

Result	Cargo (tanker)	Crewed (MDAV)
Mass at flip, 1-D sizing	204.6 t	179.7 t
Belly-first ballistic coefficient	534 kg/m²	469 kg/m²
Belly-first terminal velocity at the flip altitude	917 m/s	860 m/s
Peak aero deceleration / dynamic pressure	0.41 g / 2.13 kPa	0.46 g / 2.13 kPa
Guided 2-D burn: time / thrust Δv	134 s / 1,166 m/s	183 s / 1,317 m/s
Propellant the 2-D burn needs	67.3 t	71.5 t
Mass at flip the burn needs	176.3 t	170.8 t
Peak throttle / T/W at flip	0.79 / 2.39	0.87 / 2.47
Terminal phase, 100 m to touchdown	2.2 t	3.4 t
Landing propellant, flip to touchdown	**69.4 t**	**74.9 t**
1-D sizing over the 2-D burn's need	28.3 t	8.9 t
Downrange, aero start to hand-off	68.9 km	67.5 km
Closure	OK	OK

Site: Jezero defaults (18.4° N, −2,600 m, Ls 50°, dust τ 0.5, 215 K), giving 754 Pa and 0.0183 kg/m³ at the surface, an 11.09 km scale height and 2.36 kPa at 15 km and 1,000 m/s. The retro plume is taken to displace the base drag entirely, so the atmosphere helps by bringing the ship down to the flip Mach, not during the burn. Without drag (the propulsion-only check) the burn would have to start 74 km (cargo) and 58 km (crewed) higher. The hypersonic entry above Mach 4 and the heating are not modelled; the start state is an assumption, and its flight-path angle matters more than its altitude.

Appendix C — MDAV ascent: the ascent calculator

Leaving the basket and tiles on Mars cuts the propellant loaded for the climb to the 200 km LMO from 229.6 t to 173.3 t. From the lead's *MDAV_Ascent_Calculator_v10-mod* (attached 2 Nov 2026): a backward mass budget from orbit, using the flown 2-D trajectory at each column's own liftoff T/W plus the 0.25 km/s ICD margin. The jettison column still carries 0 t of payload as a placeholder; with the crewed column's 2 t it would load ~180 t.

C.1 Engines: ascent on the extended nozzle

Item	Value	Note
Engines	16 × 125 kN, 315.3 s	one engine set, liftoff to orbit
Cant	20°	all engines
Axial Isp / exhaust velocity	296.3 s / 2,905.6 m/s	used for every mass ratio
Installed axial thrust	1,879.4 kN	all engines at full thrust
Thrust held on ascent	95 %, 1,785.4 kN	keeps differential-throttle authority
Full mass flow	646.8 kg/s	
Nozzle extensions	71 kg each, 1.14 t for 16	Nb C-103; the bare nozzle gives 0.93 of the thrust

C.2 Inputs and results

	Basket and TPS jettisoned	No jettison
Empty mass	49.6 t	63.0 t
Payload to orbit (crew, consumables, samples)	0 (placeholder)	2.0 t
Unusable residuals	5.0 t	5.0 t
Flown ascent Δv	3.837 km/s	3.926 km/s
ICD margin	0.25 km/s	0.25 km/s

	Basket and TPS jettisoned	No jettison
Burnout, with residuals	54.6 t	70.0 t
Mass at orbital insertion	59.5 t	76.3 t
Margin propellant still aboard at insertion	4.9 t	6.3 t
Ascent mass ratio	3.745	3.862
Liftoff mass	222.9 t	294.6 t
Ascent propellant burned	163.4 t	218.4 t
Total propellant loaded	**173.3 t**	**229.6 t**
Δv capability, flown ascent + margin	4.087 km/s	4.176 km/s
Liftoff T/W, thrust held	2.15	1.62
Liftoff T/W, one / two engines out	2.01 / 1.88	1.52 / 1.42
Gravity / steering / drag loss	184 / 150 / 69 m/s	189 / 245 / 66 m/s
Burn time at thrust held	266 s	355 s
Propellant fraction	77.7 %	77.9 %

Site basis: a generic conservative site at 41° latitude (180 m/s of rotation), −3 km, 0.020 kg/m³ at the surface. Jezero would give ~228 m/s of rotation and ~48 m/s less Δv. DRA 5.0′s high-orbit ascent allowance, 6.50 km/s, is shown for comparison only.

C.3 Addendum: from the LMO to the DRA 5.0 1-sol orbit (crewed column)

Item	Value
Burn 1: 200 km LMO to a 33,793 km apoapsis	1,210.8 m/s
Burn 2: periapsis 200 to 250 km	+2.8 m/s
Total transfer Δv, impulsive	1.214 km/s
Mass needed in the LMO before the transfer	115.8 t
Transfer propellant, after reaching the LMO	39.6 t

Item	Value
Coast to apoapsis / 1-sol orbit period	12.3 h / 24.6 h
Flown ascent + transfer + margin	5.39 km/s

Two-body, coplanar and impulsive, with the 0.25 km/s margin kept intact; no finite-burn, plane-change or rendezvous losses. The refill in the LMO is budgeted elsewhere.

C.4 TPS that may have to fly

The jettison column assumes all 4.56 t of TPS comes off. The hull note (31 Oct) lists what might stay on the MDAV:

TPS left on the MDAV	Flies	Extra ascent propellant
Tile studs, welded at the isogrid nodes	~0.25 t	~0.9 t
Bonded backup layer, until a strip method is shown	0.64 t	~2.4 t
Tiles over the MON-25 tank band, as freeze insurance	~0.8 t	~3 t
All three	**~1.7 t**	**~6 t**

The default answer to the oxidizer freezing (MON-25 at −55 °C; Mars nights reach −80 to −100 °C) is to make MDAV-1 a heated depot: its reactor keeps it warm, while the tankers land one at a time in summer and are emptied into it by the insulated tank trailers.

Appendix D — One crewed mission of six

Eight vehicles, 2,161 t sent to Mars and about 65 Starship-boosted launches. From *MDAV_crewed_mission_6_masses_v3*: dry masses and cargo; the rest rebuilt on the aerocapture basis of the TPS-limits review. Every lander leaves LEO at 253 t after TMI (a propulsive capture needed 361.5 t), each vehicle on its own expended v13 TMI stage, entering at the working 6 km/s. The cargo flies the ~210-day 2033 Type I (C3 9.7), the crew the 2035 Type I (C3 10.7); landing engines 125 kN. A first-order rebuild from the review's stage loads, not yet re-run in the workbook.

D.1 The fleet, tonnes

Vehicle, window	Qty	Dry + dry cargo	Storables	After TMI	TMI stage load	Stack in LEO	Refuelling flights, methalox + storable
MDAV-1, 2033 (surface depot, default ascent vehicle)	1	65.6 + 12	175	253	582	907	5 + 2
MDV tanker, 2033	3	63.0 + ~8 (trim)	~182 each	253	582	907 each	5 + 2 each
MDV with truck and tank trailers, 2033	1	63.0 + ~30	~160	253	582	907	5 + 2
MTV-1, 2035 (crew of 6)	1	107 + ~13	133	253	593	918	5 + 1
MTV-2, 2035 (depot)	1	107 + ~21	262 (80 of it MDAV top-offs)	390	843	1,305	7 + 2
MDAV-2, 2035 (crew lander, backup ascent vehicle)	1	65.6 + 12	175	253	593	918	5 + 2
Mission	8		~1,450	2,161	4,939	7,676	42 + 15

The LEO campaign: 8 booster launches, 42 methalox refuelling flights (36 if loads can be split between stages) and 15 storable deliveries (11 if split; ~1,450 t of MON-25/ethane), 65 launches in all, against 72 on the propulsive-capture basis. Stack in LEO is the stage's 71.5 t inert mass plus its load plus the vehicle. A lander's storables are its 253 t less dry mass and dry cargo; every MDV carries some basket cargo to trim at entry, ~8 t on a tanker. Still to re-run: whether the four MDVs and MDAV-1's own landed load cover the ~180 t ascent (B.1's ~160 t from the tankers assumed the crew's MDAV landed 20 t of it), and, if the 2033 Type I is flown, the tanker ascents to a 55–64° LEO (Appendix F), which cut each delivery by very roughly 5–10 %.

D.2 Landing engine thrust: 100, 125 or 150 kN per engine

	100 kN	125 kN	150 kN
Tanker after TMI / at entry / landed	159 / 154 / 103 t	177 / 170 / 109 t	186 / 179 / 123 t
Tanker delivery: tankage + trim cargo	30.0 + 10.4 t	36.9 + 9.5 t	49.8 + 9.0 t
MDAV at entry / its own ascent propellant landed	147 / 21 t	175 / 28 t	183 / 40 t
MDAV ascent T/W	1.66	2.07	2.45
Fuel to deliver for the ascent	160 t	152 t	142 t
Tankers needed (besides the truck MDV)	5	4	3
Sent to Mars (after TMI)	1,906 t	1,892 t	1,766 t
Mission mass in LEO	7,355 t	7,117 t	6,567 t
Refuelling flights, methalox + storable	36 + 11	40 + 10	36 + 9
All launches (if loads split)	57 (52)	59 (50)	53 (47)

D.2 brackets the landing-engine thrust with landers from the belly-flip guidance optimizer, entering from the 1-sol orbit at 4.715 km/s and −9.5°. The 5.97 MN entry-force limit binds in every case. Each tanker carries 9–10 t of trim cargo low in the basket, and the cost rows are rolled up as in D.1. Fuel to deliver is the ~180 t ascent less what MDAV-1 lands in its own tanks. The landers enter at 147–183 t, not D.1's 243.5 t. The table counts the tankers' trim mass as cargo; carried instead as propellant in a basket container, it brings the tankers needed down to 4 / 3 / 2. D.1's three tankers and the truck MDV then close the 125 kN ascent by ~4 t, before the containers' own mass. With the trim mass as cargo, it can be closed with fuel landed on MDAV-2 or another tanker.

From 100 to 150 kN a tanker's propellant goes from 30 to 50 t. Launches don't fall steadily with thrust: the 100 kN landers just fit three methalox refuelling flights each, the 125 kN ones need four. At 100 kN the ascent closes by only 0.3 t, inside the search's scatter. At 150 kN there are 36 t to spare, but the legs, basket (+14 %) and J4 frame (+29 %) grow, and that mass is not in these numbers. Also not included are the hull's 7.80 MN MDV force limit (worth ~4 t per tanker on an earlier run) and the 2033 tankers' ascent to a 55–64° LEO (−5–10 % per delivery). A direct entry (v_∞ 2.7 km/s, −11°) would need 7 / 5 / 3 tankers. Source: project note *landing-note-d2-thrust-bracket-belly-flip* (12 Nov 2026).

Appendix E — MTV and TMI stage summary specs

The MTVs are sized only as mass and propellant envelopes; their habitat, consumables and structure are not designed. From *mars_mtv_sizing_v13* (26 Oct 2026) and the parametric Blender model of the TMI stage (27 Oct 2026).

E.1 MTVs

	MTV-1 (crew)	MTV-2 (depot)
Dry mass	107 t	107 t
Storable propellant tank	368 t	368 t
Storables needed	133–162 t	262 t (own 66 + MDAV top-offs 80 + rescue 117)
After TMI	253 t	390 t
Stack in LEO, with its TMI stage	936 t	1,332 t

The MTV is a Starship-derived hull with the methalox tankage, Raptors and thrust puck removed (−44 t): storables only. Crew transits are presumed 180+ days out and 270+ days back; cargo can take a longer path. Both MTVs initially aerocapture into a 1-sol orbit; MTV-2 then aerobrakes to the 200 km LMO in the landing plane. MTV-2's rescue reserve lets it fetch an MDAV stranded in a low orbit and lift it to MTV-1's 1-sol orbit.

E.2 TMI stage

	Ring model (MTV sizing v13)	Blender build
Diameter / length	9 m / 32.9 m (18 rings)	9 m / 29.5 m (16 rings + 0.2 m interface)
Methalox capacity	1,163 t (1,152 t usable)	1,136 t at warm densities (1,125 t usable)
Dry mass	60 t (inert 71.5 t)	71.8 t
Engines	3 RVac + 3 sea-level Raptor 3	same

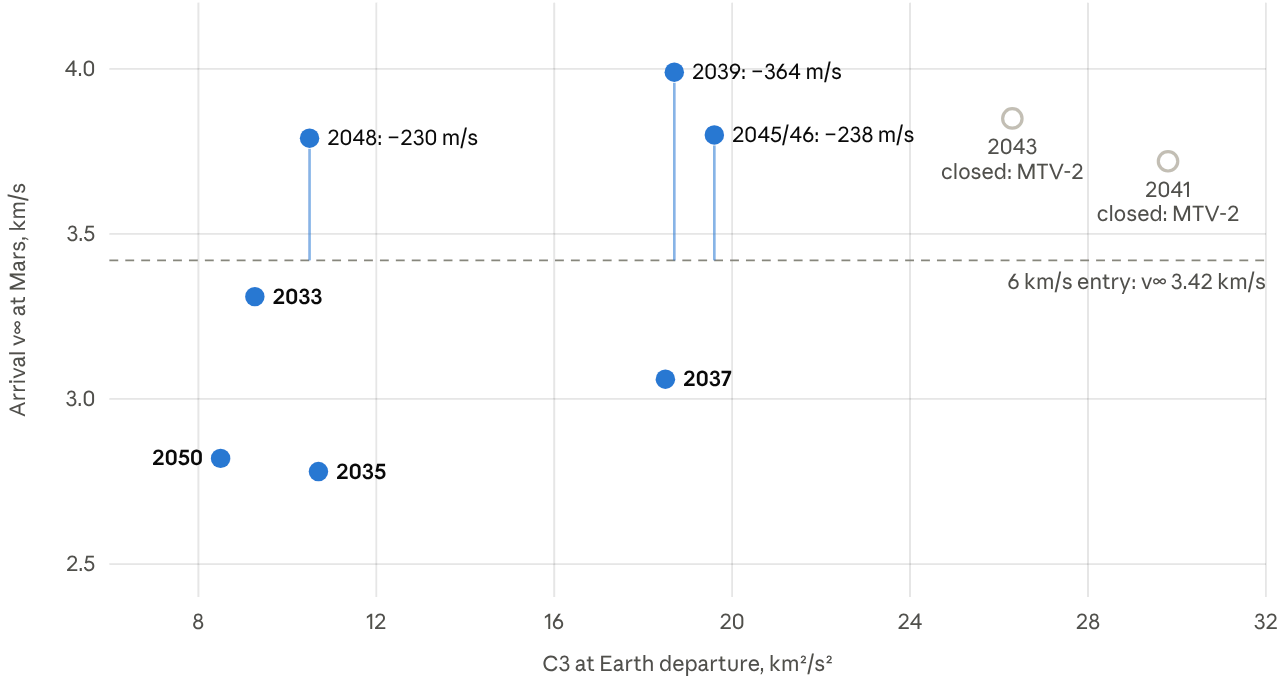
The stage is the tank-and-engine half of a Starship V3, refilled in LEO and expended after the departure burn: no tiles, no RCS. Its size is set by MTV-2 in the 2037 window (989 t to load); 6–7 tanker flights of 150 t fill it for the big stacks, at an effective 370.9 s. On a full-load lander it cuts off at 2.72 g unthrottled, against the hull's 1.5 g placeholder. Arrivals above v∞ 4 km/s (the fast 2041/2043 transfers) would need a stage ~16 % bigger than a V3. Sources: project notes *mtv-sizing-v13-tmi-stage*, *tmi-stage-blender-model*.

Appendix F — Earth–Mars launch windows, 2031–2050

Only 2035 and 2050 give optimal six-month transfers with an arrival v∞ under 3 km/s together, but other windows are open, some without propulsive braking. Ballistic Lambert transfers on JPL approximate elements, no deep-space manoeuvres, good to ~0.1–0.2 km/s; C3 in km²/s², v∞ in km/s.

At 6 km/s max entry speed, several Mars windows permit capture with <7 month transit time

Departure C3 and arrival v∞ of each window's ~7-month Type I; above the line, the ships brake down to it



Filled: open · ring: closed by MTV-2's TMI stage · −m/s: the MDAV's braking down to the line before aerocapture

Each window's ~7-month Type I at the working rating, worst day of a 20-day launch period: project note entry-note-tps-limits-review (11 Nov 2026) · 2033: NASA TM-2010-216764, Type I least v∞ (20 Apr → 6 Nov 2033)

The run agrees with NASA's *Interplanetary Mission Design Handbook: Earth-to-Mars Mission Opportunities 2026 to 2045* (TM-2010-216764) to within ~0.1 km²/s² and ~0.1 km/s wherever the handbook's Type I minimum-C3 transfer falls inside 210 days (2033, 2035,

2037, 2045/46), and with the table below. 2050 is beyond the handbook's range (project windows note, JPL approximate elements). It repeats 2035's geometry fifteen years on, with its 180-day transfer arriving at v∞ 3.05 km/s.

Lowest transfer in each window at the working rating: TMI stage load + on-board storables, t (arrival v∞, km/s), on the worst day of a 20-day launch period.

Window	Transfer (the MDAV's worst day)	MTV-1	MTV-2	MDAV	MDV
2033	7 Apr 2033 · 210 d Type I · C3 9.7	581 + 133 (3.39)	826 + 262 (3.39)	582 + 0 (3.39)	582 + 0 (3.39)
2035	13 Jun 2035 · 198 d Type I · C3 10.7	593 + 133 (2.78)	843 + 262 (2.78)	593 + 0 (2.78)	593 + 0 (2.78)
2037	26 Aug 2037 · 390 d Type II · C3 15.5	646 + 133 (3.41)	918 + 262 (3.41)	646 + 0 (3.39)	646 + 0 (3.39)
2039	19 Sep 2039 · 386 d Type II · C3 12.7	614 + 133 (3.25)	874 + 262 (3.25)	614 + 0 (3.25)	614 + 0 (3.25)
2041	11 Oct 2041 · 346 d Type II · C3 10.5	590 + 133 (2.84)	840 + 262 (2.84)	590 + 0 (2.84)	590 + 0 (2.84)
2043	8 Nov 2043 · 298 d Type II · C3 9.3	577 + 133 (2.86)	820 + 262 (2.86)	577 + 0 (2.86)	577 + 0 (2.86)
2045/46	6 Dec 2045 · 294 d Type II · C3 10.4	589 + 133 (3.26)	838 + 262 (3.26)	589 + 0 (3.26)	589 + 0 (3.26)
2048	14 Mar 2048 · 202 d Type I · C3 10.5	625 + 152 (3.79)	908 + 275 (3.59)	628 + 19 (3.79)	628 + 19 (3.79)
2050	17 May 2050 · 204 d Type I · C3 8.5	568 + 133 (2.82)	808 + 262 (2.82)	568 + 0 (2.82)	568 + 0 (2.82)

The v13 TMI stage holds 1,152 t usable; the MTVs' storable tank is 368 t. From 2037 to 2046 the lowest transfers are Type II, 294–390 days. A Type I of about seven months costs ~165–290 t more per vehicle in 2039–2046 (MTV-2 ~250 t, over its stage's 10 % margin in 2039), and MTV-2 can't fly it in 2041 or 2043. 2031 (C3 ⩾ 20) is not re-run.

Seasons at Jezero (18.4° N) on arrival: the 2033 cargo on the ~210-day Type I arrives in early November 2033 at Ls ~270° (the northern winter solstice, in the dust-storm season), and the 2035 crew in late December 2035 to early January 2036 at Ls ~326–333° (late northern winter). The northern summer between them, Ls 90–180, runs 25 Oct 2034 to 27 Apr 2035 and ends two months before the crew leaves Earth. Ls from the Mars24 algorithm (Allison & McEwen 2000).

The working rating is a 6 km/s entry at 125 km: v_∞ 3.42, since entry speed is $\sqrt{(v_\infty^2 + 24.33)}$ km/s, with no credit for Mars's rotation. There the barrel runs 1,600–1,740 K at p99, against TUFI's 1,870 K single-use limit, at 1.6–1.9 g, so nothing binds. At TUFI single-use the structure binds first: the landers at v_∞ 4.05–4.12 (6.4 km/s) on their 5.97 MN, MTV-1 at 4.32 and MTV-2 at 4.25 on the 2.5 g placeholder. The nose cap (SiC or TUFROC) will be sized from a physical design with CFD; CO_2 shock-layer radiation above ~6.5 km/s is not modelled. Sources: project notes *arrival-note-windows-2031-2050* (22 Oct 2026) and entry-note-tps-limits-review (11 Nov 2026).

2033's Type I transfers leave Earth far south: over 7–26 April the departure asymptote's declination runs −51° to −64°, out of a coplanar burn's reach from a 28.5° parking orbit. The options are a LEO campaign at 55–64° (about +150–200 m/s on every tanker ascent), a three-burn departure (~0.1 km/s more and a week or more in a high orbit), leaving late in the window (−42° to −47° at C3 10–12), or the near-equatorial Type II, which arrives at v_∞ 4.3–4.4 and needs 51–59 t of braking per lander. Which of these is TBD.

Appendix G — Optional missions

The same hardware can fly two side missions that are not part of the baseline: lunar polar landings by an MDV or MDAV, and a Mars sample return. Both are first-order studies.

G.1 Lunar polar landings

On the Moon the limit flips. The 16 engines are thrust-rich there (T/W 2–3 at ignition, 5–8 at liftoff) and the whole arrival is propulsive, so the hull binds first: the leg posts' 133.5 t touchdown rating caps the cargo at ~65 t. From the lead's lunar landing and ascent calculators v1.0, built from the two Mars calculators.

	Cargo: 80 t, direct from TLI	Crewed: 10 t + 73 t return propellant, via LLO
Touchdown mass	147.9 t	153.9 t
Braking start	120 km, −10°, 2,468 m/s, 800 s	15 km periapsis, 1,692 m/s, 450 s
Braking Δv (losses)	2,620 m/s (162)	1,783 m/s (101)
Mass at ignition / peak throttle	440 t / 0.87	326 t / 0.79
LOI + DOI		863 + 20 m/s

	Cargo: 80 t, direct from TLI	Crewed: 10 t + 73 t return propellant, via LLO
Mass at TLI / propellant loaded	446 t / 303 t	475 t / 399 t
Landing propellant, ignition to touchdown	292 t	172 t
Binding limit	leg posts: ~65.6 t of cargo	leg posts: even the return ship is 20 t over

- **Direct from TLI is not cheaper for a heavy ship.** The braking has to kill ~2.5 km/s at the throttle cap, so an 80 t cargo lander leaves TLI at 446 t direct against 454 t via LLO, and the LLO stop keeps the abort.
- **Landing costs ~1.1 t of propellant per tonne landed** from ignition via LLO, against 0.65–0.8 t on Mars.
- **Without the legs' limit,** the tanks and engines would land 72 t of cargo direct or ~94 t via LLO on the 63 t dry mass. Next in line: the basket deck (33 t of cargo), the J0 pin fittings at Earth launch (~54 t), and TLI with full tanks (~615 t above J4 against the bay frame's 337 t at 1.5 g, so the stage throttles).
- **Ascent** from the pole to a 100 km polar LLO (crewed, 63 + 2 t): 1.82 km/s flown at liftoff T/W 7.7, 142.8 t at liftoff, 77.8 t of propellant. LLO to TEI is another 0.83 km/s (25 t).
- **The nozzle extensions** are worth ~70 t of propellant on a direct landing and ~20 t on the ascent, for 1.1 t of hardware, if they can be landed with (fairing and leg clearance are open). An Earth round trip needs them: 15 t of cargo down with 2 t back to a high Earth orbit on the 63 t ship, 49 t on a ~54 t untiled lunar variant.
- **Battery:** the direct braking takes ~640 kWh against 410 usable; split the LOI and add ~0.6 t of pack.
- **Thermal:** storables need far less insulation than cryogens at the poles. The ethane in sunlight governs, which favours a white outer cover.

Sources: project notes *lunar-calculators-v1* (2 Nov 2026) and *performance-note-moon-ceres-sep-return* (30 Oct 2026).

G.2 Mars sample return

An MTV can do the ESA Earth Return Orbiter's job on the storables it already carries, with no second MTV. The cheapest way to fly it is as MTV-2, the depot, sent two years early in 2033 with a 2 t capture kit (option B0). The ship aerobrakes into the sample container's

343 km orbit, captures it, and leaves from there with all the Oberth help the low orbit gives: TEI is 2.0–2.6 km/s.

Option	Storables	Stage methalox	Launches (stack + methalox + storable)	Cost*	Home
ERO-class MTV, out 2035, back 2037, ship captured into cislunar orbit	238 t	755 t	1 + 6 + 2	$1.27B	Mar 2038
The same, releasing an Earth-entry capsule and flying by	177 t	646 t	1 + 5 + 2	$1.2B	Mar 2038 (capsule)
B0: MTV-2 flown in 2033 with the ERO kit	~275 t	~900 t	1 + 6 + 2	$1.3B	depot stays; samples ride home with the crew
B: B0 plus the propellant to bring the depot home	358 t	955 t	1 + 7 + 3	$1.43B	Mar 2038
A: in and out in 2033–35, before the crew leaves	208 t	689 t	1 + 5 + 2	$1.20B	Nov 2035

*Stack launch, methalox tankers and storable flights at the lead's placeholder prices (craft $500M, stage $100M, launches $75M).

B0 is the one to look at. MTV-2 flies anyway; sending it in 2033 puts the relay, the MDAV's 80 t of top-offs and the rescue reserve in place before the crew arrives, and gives the crew's go/no-go 18 months of flight data on the MTV hull.

Someone still has to put the samples in orbit. The cheapest way is a cargo MDV carrying a NASA-class Mars Ascent Vehicle (~0.5 t) in the same 2033 window: a 198.6 t stack, 552 t of stage propellant and ~$1.05B, using ~1 t of its 30 t of capacity. The 2033 pair, depot plus MDV, costs ~$2.35B. It flies every element of the crewed mission except the MDAV's ascent: entry and landing at the real site, surface operations, a launch from Mars, orbit capture, the depot's loiter, and the relay throughout.

Two alternatives:

- **The Jezero pathfinder.** MTV-2, the MDAV and 3–4 tankers fly; the MDAV lifts the samples to the depot, refuels, does TEI on ~72 t and releases a capsule. It costs $6.7–8.1B, against the MSR replan's $5.8–7.7B.
- **An MDAV-launched ion probe.** A ~500 kg xenon-ion probe released in the LMO needs 9–10 km/s, 133–216 kg of xenon and 2.5–3.5 years to reach cislunar space.

Open items:

- **Capturing the container:** a small free-flying container caught by a 9 m ship needs a free-flyer or a deployable capture module.
- **Planetary protection** follows the ERO's containment chain.
- **The Mars Ascent Vehicle** is assumed to exist.
- **The 2033 arrival** is at v∞ 3.3 km/s.

Sources: project notes *performance-note-ero-on-an-mtv* (2 Nov 2026), *performance-note-mdav-full-tanks* §C (29 Oct 2026) and *performance-note-moon-ceres-sep-return* (30 Oct 2026).

From a purely economic perspective, however, simply landing 35t of state-of-the art laboratory at Jezero to examine samples in nearly the same detail as what can be done on Earth is by far the cheaper option. Conceivably COTS equipment operated in a pressurized cabin.

G.3 Spin-off: Boosting Orion+ESM to LEO and the Moon

Seems plausible that a TLI stage similar to the TMI stage proposed here could be useful for using SH to boost Orion+ESM into orbit and on to the moon. Although currently prohibited by legislation, seems unlikely that hasn't been at least a tacit design study at SpaceX.

Appendix H — Prerequisites by 2033

The 2033 cargo flights only go if seven things exist by then. None is part of this design; each is assumed.

#	Prerequisite	What the plan needs it for
1	**Starship refuelling works as advertised:** refuelling in LEO is proven and economical.	Every Marship leaves LEO refilled. One crewed mission takes 46 methalox refuelling flights and 18 storable deliveries, 72 launches in all (Appendix D). The storable deliveries also need a MON-25/ethane tanker.

#	Prerequisite	What the plan needs it for
2	**Mars communications and navigation:** a minimal constellation with GPS- and Starlink-like service, plus a large relay dish to Earth (the Mars Telecommunications Orbiter, with Blue Origin letting SpaceX use it).	Precise landings in a line 1–2+ km apart; two years of robot work before the crew arrives; navigation for aerocapture and entry.
3	**Optimus robots** that can weld, cut and bolt large steel sections while working from a scaffold or hanging from a crane.	Cutting out of the sealed hold (11.1 m of 1.75 mm skin round the 3.0 × 2.8 m door); stripping 10,000+ tiles up to ~30 m above the ground; fitting the nozzle extensions; setting up the base and the propellant lines.
4	**Autonomous Mars trucks at TRL 9** that move 5+ t at a time (a Cybertruck plus trailer, ~3 t together) and fit through a 3 m rounded-rectangle door.	Cargo to the base, and the crew from the MDAV. The basket door is 3.0 × 2.8 m with its sill 2.8 m above the ground, so the trucks need a ramp or a hoist.
4a	**Two tank-trailer versions with pumps,** one for fuel and one for oxidizer.	Moving ~160 t of propellant from the MDVs to the MDAV: ~32 loaded trips at 5 t, each 1–2+ km between ships in the line. MON-25 freezes at −55 °C, so the oxidizer trailer must be heated and insulated.
5	**A new storable engine, designed and qualified** (the UltraDraco). Whether it can be derived from SuperDraco is TBD.	All 16 engines on every MDV and MDAV: 125 kN with the ascent extension, 315 s, throttled 30–92 %, landing burns of 134–183 s and a 266 s ascent after months on the surface (Appendices B and C).
6	A 10 kWe-class fission surface power unit (Kilopower-class), qualified to land on an MDAV and run unattended for years.	Keeping MDAV-1′s propellant liquid from its landing until the crew launches in 2037, and charging the trucks. MDAV-1′s solar arrays average only ~3.1 kW over a sol (Appendix A).

Where the first two stand (November 2026):

- **Refuelling:** no Starship-to-Starship propellant transfer has been flown, and neither SpaceX nor NASA had set a public date for the demonstration as of October 2026. Flight 14 (28 September 2026) was the first Starship to reach orbit. (KeepTrack)
- **Mars relay:** on 1 September 2026 NASA awarded Blue Origin a contract worth up to ~$700M for its Mars Telecommunications Network: one orbiter, built on Blue Origin's Blue Ring platform and due by 31 December 2028, with the network working at Mars by 2030. It carries relay and navigation data for NASA's missions; nothing has been said about commercial users, and no navigation constellation is funded. (NASA contract release)

On item 4: a stock Cybertruck is 5.68 m long, 2.03 m wide and 1.80 m tall, weighs ~3.0–3.1 t at curb and can tow ~5 t on Earth (specs). It fits the door's cross-section, but the truck alone is already ~3 t, so "3 t including the trailer" means a lighter Mars build, in cryogenic-rated CFRP or lightweight aluminium.

On item 5: SuperDraco, the obvious parent, burns MMH/NTO at ~71 kN (16,000 lbf), 6.9 MPa chamber pressure and 235 s at sea level. It throttles 20–100 % and was qualified in 2014 with a regeneratively cooled, 3D-printed Inconel chamber (SpaceX release, Wikipedia). The UltraDraco needs ~1.8× its thrust, a 40 bar chamber fed at 50 bar by the electric pumps, MON-25 in place of NTO, and burns of minutes rather than SuperDraco's 25 s abort profile. With ethane as the fuel it is no longer hypergolic, so it would also need an igniter.

MDAV Mars Ascent Calculator v10 (flown-trajectory budget, 16 x 125 kN, equipment jettison comparison)

Backward mass budget from a 200 km LMO to the Mars surface: the flown 2-D trajectory (Trajectory table) at each column's own liftoff T/W, plus the 0.25 km/s ICD margin. Column *J* = crewed, column B = cargo (placeholder inputs). One engine set: 16 x 125 kN at 20 deg cant. The addendum below takes the crewed ship from LMO to the DRA 5.0 1-sol ellipse with the margin intact.

SHARED CONSTANTS / MAIN ENGINES	VALUE	UNIT	NOTE (column B links to column J)
Earth standard gravity g_0		9.80665 m/s²	
Mars gravity		3.72076 m/s²	
Main-engine Isp, vacuum with extension		315.3 s	Rev-4 engine table (rows 21-25) at 125 kN per engine
Main engines (canted)		16 engines	4 pods x 4 engines, all canted; one engine set from liftoff to orbit
Thrust per engine, vacuum with extension		125.0 kN	Input. Propulsion rev 4.1 rating; must be a row of the rev-4 engine table (rows 21-25)
Engine cant (all engines)		20.0 deg	Thrust and Isp along the axis = x cos(cant)
Installed axial thrust		1879.4 kN	N x F x cos(cant), all engines at full thrust
Isp along the axis		296.29 s	Isp x cos(cant): what the rocket equation sees along the axis
Exhaust velocity along the axis		2905.6 m/s	Used for every mass ratio in this sheet
Full-thrust mass flow		646.8 kg/s	N x F / (Isp x g0): every engine's full thrust, not only the axial part
Ascent thrust held (steering reserve)		0.95 x	Propulsion rev 4: the engines run at 95% on ascent to keep differential-throttle authority
Axial thrust held		1785.4 kN	Installed axial thrust x thrust held: the liftoff T/W basis
Bare scarfed / extended thrust and Isp		0.93 x	Propulsion rev 4: 295.3 / 317.4 s at the same mass flow (scarf effective area ratio ~21, extension ~106)
Extension mass per engine		0.071 t	Propulsion rev 4: Nb C-103, 71 kg each, 1.14 t for 16 engines

Rev-4 engine table: columns I-L (named ranges Eng_kN, Eng_Isp), one table for both columns

SHARED CONSTANTS / MAIN ENGINES	VALUE	UNIT	NOTE
Earth standard gravity g_0	9.80665	m/s²	
Mars gravity	3.72076	m/s²	
Main-engine Isp, vacuum with extension	315.3	s	Rev-4 engine table (rows 21-25) at 125 kN per engine
Main engines (canted)	16	engines	4 pods x 4 engines, all canted; one engine set from liftoff to orbit
Thrust per engine, vacuum with extension	125.0	kN	Input. Propulsion rev 4.1 rating; must be a row of the rev-4 engine table (rows 21-25)
Engine cant (all engines)	20.0	deg	Thrust and Isp along the axis = x cos(cant)
Installed axial thrust	1879.4	kN	N x F x cos(cant), all engines at full thrust
Isp along the axis	296.29	s	Isp x cos(cant): what the rocket equation sees along the axis
Exhaust velocity along the axis	2905.6	m/s	Used for every mass ratio in this sheet
Full-thrust mass flow	646.8	kg/s	N x F / (Isp x g0): every engine's full thrust, not only the axial part
Ascent thrust held (steering reserve)	0.95	x	Propulsion rev 4: the engines run at 95% on ascent to keep differential-throttle authority
Axial thrust held	1785.4	kN	Installed axial thrust x thrust held: the liftoff T/W basis
Bare scarfed / extended thrust and Isp	0.93	x	Propulsion rev 4: 295.3 / 317.4 s at the same mass flow (scarf effective area ratio ~21, extension ~106)
Extension mass per engine	0.071	t	Propulsion rev 4: Nb C-103, 71 kg each, 1.14 t for 16 engines

REV-4 ENGINE TABLE	kN / engine	Isp ext. (s)	SOURCE
Rating, rev 4	100	317.4	propulsion rev 4
Rating, rev 4	115	316.1	propulsion rev 4
Rating, rev 4	125	315.3	propulsion rev 4
Rating, rev 4	150	313.3	propulsion rev 4
Rating, extrapolated	175	311.3	extrapolated -0.08 s/kN; replace if rev 4 has it

JETTISON BASKET AND TPS

INPUTS	TPS/BASKET DELETED	UNIT	NOTE
Empty mass	49.60	t	Placeholder: the owner fills the cargo variant
Payload : crew, consumables, samples	0.00	t	Placeholder: cargo payload to orbit
Burnout (empty + payload)	49.60	t	Empty 49.6 t + payload 0.0 t; residuals (row 31) sit on top
Unusable residuals carried to orbit	5.00	t	Placeholder: the owner fills the cargo variant
Required main ascent Δv (flown)	3.837	km/s	Flown 2-D trajectory at this column's liftoff T/W of 2.15, from the Trajectory table (200 km)
ICD margin: dispersions, rendezvous, manoeuvres	0.250	km/s	Linked to J33

RESULTS — WORKING BACKWARDS FROM ORBIT	TPS/BASKET DELETED	UNIT	NOTE
1. Burnout incl. residuals	54.60	t	Burnout 49.6 t + residuals 5.0 t
2. Margin mass ratio	1.0899	×	ICD margin 0.25 km/s at the axial Isp (296.3 s)
3. Mass at orbital insertion	59.51	t	Burnout incl. residuals + margin propellant
4. Margin propellant	4.91	t	Still aboard at insertion: the ICD margin
5. Ascent mass ratio	3.745	×	For the flown ascent Δv (row 32)
6. Liftoff mass	**222.86**	t	Mass at orbital insertion x ascent mass ratio
7. Ascent propellant	163.36	t	Burned from liftoff to orbital insertion
8. Total propellant loaded	173.26	t	Liftoff mass - burnout: ascent + margin propellant + residuals
9. Δv capability	4.087	km/s	Flown ascent + ICD margin
10. Liftoff T/W (site gravity, thrust held)	2.15	× Mars weight	Must sit inside the Trajectory table's 1.25-4.00 range: outside it the helper shows an error
11. Gravity loss	184	m/s	Helper pass 4, Trajectory table
12. Steering loss	150	m/s	Helper pass 4, Trajectory table
13. Drag loss incl. coast	69	m/s	Helper pass 4, Trajectory table
14. Liftoff T/W, 1 engine out	2.01	× Mars weight	15 of 16 engines operating
15. Liftoff T/W, 2 engines out	1.88	× Mars weight	14 of 16 engines operating
16. Full-thrust mass flow	646.8	kg/s	N x F / (Isp x g0), all engines at full thrust
17. Burn time at thrust held	265.8	s	Ascent propellant / (full mass flow x thrust held)
18. Propellant fraction *iteration helper (rows 55-75, grouped: click + to open)*	77.7%		Total propellant loaded / liftoff mass Four passes of T/W, table row, fraction, flown Δv and liftoff mass against the Trajectory table, as section 1

BASIS / NOTES	VALUE	UNIT	NOTE
NASA DRA 5.0 published high-orbit ascent allowance		6.50 km/s	DRA 5.0 high-Mars-orbit ascent: comparison only; not used
Site basis			Generic conservative site: 41 deg latitude (180 m/s rotation), -3 km, rho0 0.020 kg/m3. Jezero (18.4 deg, -2.6 km) would give ~228 m/s of reSite basis

NO JETTISON

INPUTS	NO DELETIONS	UNIT	NOTE
Empty mass	63.00	t	MDAV ascent stage empty mass (owner's input, 2026-10-20)
Payload : crew, consumables, samples	2.00	t	Carried to orbit
Burnout (empty + payload)	65.00	t	Empty 63.0 t + payload 2.0 t; residuals (row 31) sit on top
Unusable residuals carried to orbit	5.00	t	Tanks rev 1.2: 4.57 t + 0.2 % of the load (~5 t)
Required main ascent Δv (flown)	3.926	km/s	Flown 2-D trajectory at this column's liftoff T/W of 1.62, from the Trajectory table (200 km)
ICD margin: dispersions, rendezvous, manoeuvres	0.250	km/s	Propellant still aboard at orbital insertion

RESULTS — WORKING BACKWARDS FROM ORBIT	NO DELETIONS	UNIT	NOTE
1. Burnout incl. residuals	70.00	t	Burnout 65.0 t + residuals 5.0 t
2. Margin mass ratio	1.0899	×	ICD margin 0.25 km/s at the axial Isp (296.3 s)
3. Mass at orbital insertion	76.29	t	Burnout incl. residuals + margin propellant
4. Margin propellant	6.29	t	Still aboard at insertion: the ICD margin
5. Ascent mass ratio	3.862	×	For the flown ascent Δv (row 32)
6. Liftoff mass	**294.64**	t	Mass at orbital insertion x ascent mass ratio
7. Ascent propellant	218.36	t	Burned from liftoff to orbital insertion
8. Total propellant loaded	229.64	t	Liftoff mass - burnout: ascent + margin propellant + residuals
9. Δv capability	4.176	km/s	Flown ascent + ICD margin
10. Liftoff T/W (site gravity, thrust held)	1.62	× Mars weight	Must sit inside the Trajectory table's 1.25-4.00 range: outside it the helper shows an error
11. Gravity loss	189	m/s	Helper pass 4, Trajectory table
12. Steering loss	245	m/s	Helper pass 4, Trajectory table
13. Drag loss incl. coast	66	m/s	Helper pass 4, Trajectory table
14. Liftoff T/W, 1 engine out	1.52	× Mars weight	15 of 16 engines operating
15. Liftoff T/W, 2 engines out	1.42	× Mars weight	14 of 16 engines operating
16. Full-thrust mass flow	646.8	kg/s	N x F / (Isp x g0), all engines at full thrust
17. Burn time at thrust held	355.3	s	Ascent propellant / (full mass flow x thrust held)
18. Propellant fraction *iteration helper (rows 55-75, grouped: click + to open)*	77.9%		Total propellant loaded / liftoff mass Four passes of T/W, table row, fraction, flown Δv and liftoff mass against the Trajectory table, as section 1

BASIS / NOTES	VALUE	UNIT	NOTE
NASA DRA 5.0 published high-orbit ascent allowance		6.50 km/s	DRA 5.0 high-Mars-orbit ascent: comparison only; not used
			Generic conservative site: 41 deg latitude (180 m/s rotation), -3 km, rho0 0.020 kg/m3. Jezero (18.4 deg, -2.6 km) would give ~228 m/s of rotation and ~48 m/s less Δv; kept conservative on purpose.

Model note: budget = the flown 2-D trajectory from the Trajectory table at each column's own liftoff T/W (gravity, steering, drag and back-pressure losses included) + the 0.25 km/s ICD margin. Target 200 km LMO; the tanker refill in LMO is budgeted elsewhere.

Source for DRA 5.0 high-orbit ascent figure: https://ntrs.nasa.gov/api/citations/20090010571/downloads/20090010571.pdf?attachment=true

LMO → DRA 5.0 1-SOL ORBIT ADDENDUM	VALUE	UNIT	NOTE
Transfer is treated as two impulsive burns: raise apoapsis from the 200 km circular LMO, then a small burn at apoapsis to set periapsis to the DRA 5.0 value. Crewed column, margin intact.			

TRANSFER CONSTANTS / INPUTS	VALUE	UNIT	NOTE
Mars mean radius	3389.50	km	JPL mean radius
Mars GM (μ)	42828.375816	km³/s²	JPL DE440 Mars-system GM
LMO circular altitude	200.0	km	Linked to section 1's target LMO (B118)
DRA 5.0 target periapsis altitude	250.0	km	DRA 5.0 1-sol parking orbit
DRA 5.0 target apoapsis altitude	33793.0	km	DRA 5.0 1-sol parking orbit

TRANSFER RESULTS	VALUE	UNIT	NOTE
1. Final mass after transfer	76.29	t	Crewed mass at orbital insertion (J38): burnout incl. residuals + the 0.25 km/s ICD margin, untouched
2. Burn 1: 200 km LMO → high-apoapsis ellipse	1210.8	m/s	Prograde burn at 200 km altitude
3. Burn 2: periapsis 200 → 250 km (positive = prograde)	+2.8	m/s	Signed: target-orbit apoapsis speed minus transfer apoapsis speed
4. Total LMO → DRA 1-sol transfer Δv	**1.2136**	km/s	[burn 1] + [burn 2], ideal impulsive
5. Mass required in 200 km LMO before transfer	**115.84**	t	Transfer propellant + the untouched 0.25 km/s margin; burns at the axial Isp (296.3 s), same ve as the main block
6. Propellant consumed by LMO → 1-sol transfer	**39.55**	t	Incremental propellant required after reaching LMO
7. Coast time from LMO burn to apoapsis	12.27	h	Half-period of the 200 km x 33,793 km transfer ellipse
8. Target DRA-orbit period	24.59	h	Keplerian period for 250 km x 33,793 km using the constants above
9. Flown ascent + transfer + margin Δv	**5.390**	km/s	Flown ascent 3.926 + transfer 1.214 + ICD margin 0.25 km/s (crewed column)

NOTES / SOURCES	VALUE	UNIT	NOTE
Transfer method			Two-body, coplanar, impulsive. Burns at the axial Isp of 296.3 s; LMO 200 km. No finite-burn, plane-change or rendezvous losses.
DRA 5.0 1-sol orbit source			https://www.nasa.gov/wp-content/uploads/2015/09/373667main_NASA-SP-2009-566-ADD.pdf
Mars GM source			https://ssd.jpl.nasa.gov/astro_par.html
Mars mean-radius source			https://ssd.jpl.nasa.gov/planets/phys_par.html

ENHANCEMENTS (v9.3, updated in v10, 2026-10-20) - purple = new. Yellow = inputs. Change log in section 5. The main block above now uses the same flown-trajectory budget and the same engine block as these sections.

1. ASCENT DELTA-V AND LOSSES AGAINST THRUST PER ENGINE, CREWED VEHICLE (2-D optimised trajectory, 'Trajectory table' sheet)

The ascent delta-v here is the flown 2-D trajectory at each case's own liftoff T/W, interpolated from the 'Trajectory table' sheet, plus the margin: the same budget as the main block. The liftoff mass is iterated, because the T/W depends on it. Gravity, steering and drag losses are broken out. Edit the yellow cells.

MDAV Mars Landing Calculator v10.2

Two use cases: a CARGO (uncrewed) column and a CREWED column (arrival v∞ 3.0 / 5.0 km/s, Section 2). One engine set: 16 main engines, landing on the bare scarfed nozzle (115.63 kN, 291.7 s each, 20 deg cant + 11.9 deg scarf deflection). Supersonic retropropulsion (SRP) starts at an editable speed and altitude while atmospheric drag continues. Section 3 adds a time-stepped flip-and-burn model with belly-first aerodynamic deceleration (see Trajectory sheet). v8.1: ρ_0, scale height and speed of sound come from a GRAM-lite / Withers (2012) surface state. Trajectory altitude remains AGL.

SHARED CONSTANTS / MAIN ENGINES	VALUE	UNIT	NOTE (one engine set; landing on the bare 20:1 nozzle)
Earth standard gravity g_0	9.80665	m/s²	
Mars gravity	3.72076	m/s²	
Engines	16	engines	One engine set: the terminal phase is a throttle regime of the same engines, not separate hardware
Extended rating per engine	125.0	kN	Matches Ascent v10 J9 (rev 4.1 rating, with extension). Must be a row of the rev-4 table (rows 20-24)
Isp with extension	315.3	s	another value (v10-myfix had 320 s).
Bare / extended ratio	0.93	×	(rev 4 at 100 kN: 0.930). v10-myfix had 0.92.
Landing thrust per engine	115.63	kN	Bare scarfed nozzle (effective area ratio ~17); the extensions are fitted on the surface
Landing Isp	291.7	s	Bare nozzle. Back-pressure at 20:1 is small (exit pressure well above the ~750 Pa ambient): not modelled
Cant	20	deg	All engines
Isp axial	247.60	s	Landing Isp x cos(cant + scarf deflection): what the rocket equation sees along the axis
Exhaust velocity axial	2428.2	m/s	Used by Section 1, the Solver and the Trajectory sheet
Installed axial thrust	1570.6	kN	full thrust
Full mass flow	646.8	kg/s	N x F / (Isp x g0): same as the extended engine, by construction
Scarf thrust deflection	11.9	deg	assumption.

REV-4 ENGINE TABLE	kN / engine	Isp ext. (s)	SOURCE (copied from the ascent workbook; no cross-workbook link)
Rating, rev 4	100	317.4	propulsion rev 4
Rating, rev 4	115	316.1	propulsion rev 4
Rating, rev 4	125	315.3	propulsion rev 4
Rating, rev 4	150	313.3	propulsion rev 4
Rating, extrapolated	175	311.3	extrapolated -0.08 s/kN; replace if rev 4 has it

CEA run: frozen at throat, O/F 4.1, 50 bar		311.9
Propulsion's solver, same O/F and Pc	~306.4	
At its design point, O/F 4.5 and 40 bar: frozen / equilil	305.3 / 316.0	
Ideal = frozen + 40 % of (equilibrium − frozen), a parti		309.6
× η_c* 0.975 (pintle injector at 40 bar)		
× η_cf 0.986 (11° cone divergence 0.991 × 0.995 for other nozzle losses)		
× 0.990 (~1.5 % fuel film cooling)		
× 0.990 (scarf)		
Delivered: 309.6 × 0.942		291.7

CARGO (uncrewed)

INPUTS	VALUE	UNIT	NOTE
Vehicle dry mass	62.90	t	Ascent v10 carries 60 t empty; reconcile or document the difference
Delivered fuel cargo	44.00	t	Payload; not consumed during landing. Cargo column: enter the tanker delivery (45-64 t per ascent Section 4) when the cargo variant is updated
Other cargo	0.00	t	
Touchdown mass	106.90	t	Dry mass + delivered cargo
SRP start speed	1000.000	m/s	User input; thrust begins while drag continues
SRP start altitude	15.000	km	User input; default 15 km
Terminal hand-off speed	10.000	m/s	At 100 m altitude
Terminal hand-off altitude	100.000	m	Throttle-regime change on the same engines
Final controlled descent speed	10.000	m/s	
Mars entry-interface altitude	125.000	km	
Prograde atmosphere reduction	0.240	km/s	Best-case aligned prograde component
Starship comparison entry speed	7.500	km/s	Simple TPS speed screening only
1. TERMINAL LANDING — hand-off (100 m / 10 m/s) → touchdown			
Mass at terminal hand-off	109.08	t	Includes brake + 10 m/s controlled-descent propellant
Terminal T/W at hand-off	3.87	Mars weight	Installed axial 1571 kN / Mars weight at hand-off
Full-thrust deceleration burn time	0.93	s	Full 1571 kN axial until vertical speed reaches zero
Full-thrust stopping distance	4.67	m	
Can stop within 100 m?	OK		Check against the 100 m hand-off altitude
Altitude after reaching 0 m/s	95.33	m	Remaining altitude for controlled descent
Controlled descent speed	10.00	m/s	Constant 10 m/s to touchdown
Controlled descent time	9.53	s	
Propellant for 10 → 0 m/s brake	0.60	t	Full-thrust brake: brake time x full mass flow
Propellant for 10 m/s controlled descent	1.57	t	Hover needs 25% of installed axial thrust (4.1 engines' worth at full thrust): flown on 4-5 engines, not 16 throttled. Note only, not modelled
Total terminal-phase landing propellant	2.18	t	Brake + controlled descent

CREWED

INPUTS	VALUE	UNIT	NOTE
Vehicle dry mass	65.90	t	Ascent v10 carries 60 t empty; reconcile or document the difference
Delivered fuel cargo	20.00	t	Payload; not consumed during landing
Other cargo	10.00	t	
Touchdown mass	95.90	t	Dry mass + delivered cargo
SRP start speed	1000.000	m/s	User input; thrust begins while drag continues
SRP start altitude	15.000	km	User input; default 15 km
Terminal hand-off speed	10.000	m/s	At 100 m altitude
Terminal hand-off altitude	100.000	m	Throttle-regime change on the same engines
Final controlled descent speed	5.000	m/s	
Mars entry-interface altitude	125.000	km	
Prograde atmosphere reduction	0.240	km/s	Best-case aligned prograde component
Starship comparison entry speed	7.500	km/s	Simple TPS speed screening only
1. TERMINAL LANDING — hand-off (100 m / 10 m/s) → touchdown			
Mass at terminal hand-off	99.29	t	Includes brake + 5 m/s controlled-descent propellant
Terminal T/W at hand-off	4.25	Mars weight	Installed axial 1571 kN / Mars weight at hand-off
Full-thrust deceleration burn time	0.82	s	Full 1571 kN axial until vertical speed reaches zero
Full-thrust stopping distance	4.12	m	
Can stop within 100 m?	OK		Check against the 100 m hand-off altitude
Altitude after reaching 0 m/s	95.88	m	Remaining altitude for controlled descent
Controlled descent speed	5.00	m/s	Constant 5 m/s to touchdown
Controlled descent time	19.18	s	
Propellant for 10 → 0 m/s brake	0.53	t	Full-thrust brake: brake time x full mass flow
Propellant for 5 m/s controlled descent	2.86	t	Hover needs 23% of installed axial thrust (3.6 engines' worth at full thrust): flown on 4-5 engines, not 16 throttled. Note only, not modelled
Total terminal-phase landing propellant	3.39	t	Brake + controlled descent

Touchdown mass	106.90 t	Dry mass + delivered cargo	

2. ENTRY + SUPERSONIC RETROPROPULSION			
Mars arrival v∞	3.000 km/s	Cargo / ~9-month planning case	
Mars escape speed at entry interface	4.937 km/s	At entry-interface altitude	
Inertial atmospheric-entry speed	5.777 km/s	sqrt(v∞² + vesc²)	
Inertial entry speed < 8 km/s?	OK	Compared with 8 km/s reference	
Prograde atmosphere reduction	0.240 km/s	Optional best-case prograde component	
Atmosphere-relative entry speed	5.537 km/s	Scalar subtraction for aligned prograde entry	
Atmosphere-relative entry speed < 8 km/s?	OK	Compared with 8 km/s reference	
SRP start speed	1000.000 m/s	Propulsion begins while aerodynamic drag continues	
SRP start altitude	15.000 km	Editable start altitude	
Powered descent: start → 10 m/s	990.000 m/s	Net speed reduction	
No-drag rocket ΔV including gravity loss	1551.021 m/s	Conservative: credits no aerodynamic drag	
No-drag gravity loss	561.021 m/s	Mars gravity during powered phase	
No-drag main-descent propellant	97.53 t		
Mass at SRP start	206.61 t		
Installed main-engine thrust	1570.60 kN	deflection	
Initial main-descent T/W	2.04 Mars weight		
Main burn time, no drag	150.78 s		
No-drag required burn-start altitude	88.61 km	Distance needed by propulsion-only model + 100 m	
Available descent distance to 100 m	14.90 km	Start altitude minus the 100 m hand-off	
Additional altitude required without aero drag	73.61 km	Distance SRP aerodynamics must effectively save	
No-drag altitude feasibility	NEEDS AERO DRAG	NEEDS AERO DRAG is expected for combined SRP	
Mass at terminal hand-off	109.076 t	Equals the Section 1 hand-off mass (row 42); feeds the Trajectory sheet	

Touchdown mass	95.90 t	Dry mass + delivered cargo	

2. ENTRY + SUPERSONIC RETROPROPULSION			
Mars arrival v∞	5.000 km/s	Manned / fast-cargo ~6-month planning case	
Mars escape speed at entry interface	4.937 km/s	At entry-interface altitude	
Inertial atmospheric-entry speed	7.027 km/s	sqrt(v∞² + vesc²)	
Inertial entry speed < 8 km/s?	OK	Compared with 8 km/s reference	
Prograde atmosphere reduction	0.240 km/s	Optional best-case prograde component	
Atmosphere-relative entry speed	6.787 km/s	Scalar subtraction for aligned prograde entry	
Atmosphere-relative entry speed < 8 km/s?	OK	Compared with 8 km/s reference	
SRP start speed	1000.000 m/s	Propulsion begins while aerodynamic drag continues	
SRP start altitude	15.000 km	Editable start altitude	
Powered descent: start → 10 m/s	990.000 m/s	Net speed reduction	
No-drag rocket ΔV including gravity loss	1461.567 m/s	Conservative: credits no aerodynamic drag	
No-drag gravity loss	471.567 m/s	Mars gravity during powered phase	
No-drag main-descent propellant	81.98 t		
Mass at SRP start	181.27 t		
Installed main-engine thrust	1570.60 kN	deflection	
Initial main-descent T/W	2.33 Mars weight		
Main burn time, no drag	126.74 s		
No-drag required burn-start altitude	73.34 km	Distance needed by propulsion-only model + 100 m	
Available descent distance to 100 m	14.90 km	Start altitude minus the 100 m hand-off	
Additional altitude required without aero drag	58.34 km	Distance SRP aerodynamics must effectively save	
No-drag altitude feasibility	NEEDS AERO DRAG	NEEDS AERO DRAG is expected for combined SRP	
Mass at terminal hand-off	99.292 t	Equals the Section 1 hand-off mass (row 42); feeds the Trajectory sheet	

MODEL NOTES

The SRP calculation intentionally separates the trajectory assumption from the conservative propulsion-only check. SRP starts at the user-selected altitude and speed while drag continues; the solver itself credits zero drag. v8.1 atmosphere: surface density, scale height and speed of sound come from GRAM-lite's Withers surface pressure and the editable Ts. The Trajectory sheet is still an isothermal exponential in AGL — not a full hydrostatic T(z) integration, winds, or dust-heated 15–50 km layer.

Therefore a 'NEEDS AERO DRAG' result is not a failure of SRP. It quantifies how strongly the 15 km trajectory depends on continuing aerodynamic deceleration while the engines are firing.

Final landing below 100 m is the terminal phase of the same 16 main engines (bare nozzle, 115.63 kN each): full thrust from 10 m/s to zero, then a throttled 10 m/s descent, flown on 4-5 engines.

No Mars heating model is included. Entry speeds are shown only as an 8 km/s screening comparison, with and without the optional 0.240 km/s prograde atmosphere reduction. GRAM-lite is an engineering climatology (not NASA Mars-GRAM) and is used here only to set the exponential column's surface state.

ATMOSPHERE / AERO CONSTANTS (shared by Sectio	VALUE	UNIT	NOTE
Surface atmospheric density ρ_0	0.0183	kg/m³	GRAM-lite / Withers: ρs = Ps/(R Ts). Was a fixed 0.02 kg/m³. Edit site cells
Density scale height	11.09	km	Isothermal H = R Ts / g_Mars. Was 11.1 km. Good to a few percent over 0-
Speed of sound	230.7	m/s	a = √(γ R Ts). Was a fixed 230 m/s. Flip speed = flip Mach × this, so Ts now
Mars mean radius	3389.5	km	Curvature term in the flight-path-angle equation
SRP plume drag retention	0.00	fraction	0 = base drag fully displaced by the retro plume (high thrust coefficient); 1
Integration time step	0.50	s	Trajectory tables: 600 / 800 / 600 rows → 300 s / 400 s / 300 s coverage at 0.5 s
Burn throttle, maximum	0.92	×	Steering reserve: propulsion rev 4.1 holds the landing burn at 92 % so diffe
Burn throttle, minimum	0.30	×	Pintle injectors throttle 30-100 % on all 16 engines; shutting engines down
Thrust angle allowed, α max	20.0	deg	0 = thrust strictly retrograde (v10). Propulsion's mission.py lets the guidan
Hand-off altitude tolerance	10	m	Closure accepts a hand-off this far below the hand-off altitude (the guidan

Jezero defaults

GRAM-LITE SITE STATE	VALUE	UNIT	NOTE
Latitude (planetocentric)	18.4	deg	*Jezero default. Mid-lat landing sites only weakly change T; elevation dominates ρ.*
MOLA / areoid elevation	-2600	m	*GRAM-lite height_m = this + AGL. Gale ≈ −4500, VL1 ≈ −3630, Tharsis plateau ≈ +3000.*
Ls (aerocentric solar long.)	50.0	deg	*0 = NH spring equinox, 90 NH summer, 180 autumn, 251 perihelion, 270 NH winter.*
Dust visible optical depth τ	0.50	–	*Climatology ~0.3–0.7; regional storm ~1–2; global storm 3–5. Affects T suggestion only here.*
Surface air temperature Ts	215.0	K	*Editable daily-mean air T. Yellow = input. 210–220 K typical mid-lat; dusty perihelion ~240 K.*
Withers season factor	1.039	–	*Withers 2012 Viking-1 harmonic; mean ≈ 1, amplitude ~±15% from the CO_2 cap cycle.*
Solar declination	19.03	deg	*Mars obliquity 25.19°.*
Polar-winter P sink	1.000	–	*GRAM-lite extra cap sink; ~1 at mid-latitudes.*
Surface pressure Ps	754.0	Pa	*Withers VL1 anchor 797.2 Pa at −3.63 km, H0 = 11 km, times season and polar sink.*
R specific (CO2 mix)	191.84	J/(kg·K)	*M = 43.34 g/mol as in GRAM-lite.*
γ (cp/cv)	1.29	–	*CO_2-rich mix; used only for speed of sound.*
Ts suggestion (not used)	209.3	K	*Rough GRAM-lite-like hint only. Copy into K92 if you want it. Does not feed ρ.*
ρ at 15 km AGL (this column)	0.0047	kg/m³	*Same exponential the Trajectory sheet uses. Compare to GRAM-lite query at height_m = elevation + 15000.*
q-bar at 15 km, 1000 m/s	2362	Pa	*Dynamic pressure at the Section 3 aero-phase start state.*
Flip speed from a(Ts)	989.6	m/s	*Equals B120 (flip speed). Changes automatically when Ts changes.*

3. FLIP-AND-BURN WITH AERODYNAMIC DECELERATION (time-stepped)			
Aero-phase start altitude	15.000	km	Post-hypersonic state from which the belly-first phase is integrated
Aero-phase start speed	950.000	m/s	≈ Mach 4.3; the guidance-dominated hypersonic entry above this is not m
Aero-phase start flight-path angle	-9.500	deg	Negative = descending; lifting entries pass Mach 4 at roughly −5° to −13°
Vehicle diameter	9.000	m	Placeholder geometry — replace with MDAV values
Ring count	12.000		
Ogive	13.500	m	
Vehicle length	35.460	m	Placeholder geometry — replace with MDAV values
Belly-first drag coefficient	1.200	–	Broadside cylinder at supersonic speed, on D × L planform area
Belly-first lift-to-drag ratio	0.300	–	Positive = lift up (lofting); 0 = ballistic

3. FLIP-AND-BURN WITH AERODYNAMIC DECELERATION (time-stepped)			
Aero-phase start altitude	15.000	km	Post-hypersonic state from which the belly-first phase is inte
Aero-phase start speed	950.000	m/s	≈ Mach 4.3; the guidance-dominated hypersonic entry above
Aero-phase start flight-path angle	-9.000	deg	Negative = descending; lifting entries pass Mach 4 at roughly
Vehicle diameter	9.000	m	Placeholder geometry — replace with MDAV values
	12.000		
	13.500		
Vehicle length	35.460	m	Placeholder geometry — replace with MDAV values
Belly-first drag coefficient	1.200	–	Broadside cylinder at supersonic speed, on D × L planform ar
Belly-first lift-to-drag ratio	0.300	–	Positive = lift up (lofting); 0 = ballistic

Tail-first drag coefficient		1.000 –	Blunt base-first body on base area; multiplied by plume retention	Tail-first drag coefficient		1.000 –	Blunt base-first body on base area; multiplied by plume rete
Flip / SRP ignition Mach number		4.290 –	Belly-to-tail flip and main-engine ignition trigger. v10.1 default 2.25: the lo	Flip / SRP ignition Mach number		4.290 –	Belly-to-tail flip and main-engine ignition trigger. v10.1 defa
Belly-first drag area Cd·A		383.0 m²		Belly-first drag area Cd·A		383.0 m²	
Tail-first drag area Cd·A		63.6 m²		Tail-first drag area Cd·A		63.6 m²	
Flip speed		989.6 m/s	Flip Mach × speed of sound	Flip speed		989.6 m/s	Flip Mach × speed of sound
Mass at flip / SRP ignition		204.60 t	Sized by a backward 1-D vertical burn from 100 m / 10 m/s (conservative, r	Mass at flip / SRP ignition		179.69 t	Sized by a backward 1-D vertical burn from 100 m / 10 m/s (
Belly-first ballistic coefficient		534.3 kg/m²	m/(Cd·A); sets the lowest Mach the aero phase can reach	Belly-first ballistic coefficient		469.2 kg/m²	m/(Cd·A); sets the lowest Mach the aero phase can reach
Main-descent T/W at ignition		2.06 Mars weight		Main-descent T/W at ignition		2.35 Mars weight	
SRP propellant (1-D sizing)		95.53 t	Flip → 100 m / 10 m/s	SRP propellant (1-D sizing)		80.39 t	Flip → 100 m / 10 m/s
Rocket ΔV of burn, 1-D sizing		1527.4 m/s	Axial exhaust velocity x ln(mass ratio)	Rocket ΔV of burn, 1-D sizing		1440.2 m/s	Axial exhaust velocity x ln(mass ratio)
Propellant saved vs Section 2 no-drag case		2.00 t	Aero phase does the work down to the flip Mach	Propellant saved vs Section 2 no-drag case		1.58 t	Aero phase does the work down to the flip Mach
Required flip altitude, vertical burn		85.69 km	1-D reference only; the real flip is on a shallow path	Required flip altitude, vertical burn		71.04 km	1-D reference only; the real flip is on a shallow path
Time from aero-phase start to flip		0.0 s		Time from aero-phase start to flip		0.0 s	
Altitude at flip		15.00 km	Where the belly-first phase reaches the flip Mach	Altitude at flip		15.00 km	Where the belly-first phase reaches the flip Mach
Flight-path angle at flip		-9.5 deg		Flight-path angle at flip		-9.0 deg	
Belly-first terminal velocity at flip altitude		917.3 m/s	Vertical-fall equilibrium speed; the flip Mach cannot go much below this	Belly-first terminal velocity at flip altitude		859.7 m/s	Vertical-fall equilibrium speed; the flip Mach cannot go much
Peak aero deceleration		0.41 Earth g	Belly-first phase	Peak aero deceleration		0.46 Earth g	Belly-first phase
Peak dynamic pressure		2.13 kPa	Belly-first phase	Peak dynamic pressure		2.13 kPa	Belly-first phase
Aero-phase status	FLIP		FLIP = reached flip Mach; GROUND = hit the surface first	Aero-phase status	FLIP		FLIP = reached flip Mach; GROUND = hit the surface first
2-D burn time		134.0 s	Flip → 10 m/s, thrust retrograde, gravity turn	2-D burn time		182.7 s	Flip → 10 m/s, thrust retrograde, gravity turn
Altitude when 10 m/s is reached		0.10 km	Must be ≥ the 100 m hand-off altitude	Altitude when 10 m/s is reached		0.10 km	Must be ≥ the 100 m hand-off altitude
Flight-path angle at handoff		-76.0 deg		Flight-path angle at handoff		-89.2 deg	
Altitude margin at handoff		0.00 km	Positive = the burn ends above the hand-off; the crewed closure pays to fly	Altitude margin at handoff		0.00 km	Positive = the burn ends above the hand-off; the crewed clos
1-D sizing less the 2-D burn's need		28.26 t	Positive = the backward 1-D sizing (row 124) carries more than the guided	1-D sizing less the 2-D burn's need		8.86 t	Positive = the backward 1-D sizing (row 124) carries more tha
Hover-out time to hand-off altitude		0.0 s	Descends the altitude margin at the 10 m/s hand-off speed	Hover-out time to hand-off altitude		0.1 s	Descends the altitude margin at the 10 m/s hand-off speed
Hover-out propellant		0.00 t	Hover thrust ≈ weight, at the axial exhaust velocity	Hover-out propellant		0.01 t	Hover thrust ≈ weight, at the axial exhaust velocity
Same, after paying the hover-out		**28.26** t	Information only: the closure uses the guided burn (rows 145-151)	Same, after paying the hover-out		**8.85** t	Information only: the closure uses the guided burn (rows 14
Total downrange, aero start → handoff		68.9 km		Total downrange, aero start → handoff		67.5 km	
Flip-and-burn closure, cargo	OK		Lowest flip Mach that reads OK = least propellant (row 150); raise it for ma	Flip-and-burn closure, crewed	OK		Lowest flip Mach that reads OK = least propellant (row 150);
Burn thrust ΔV, guided 2-D		1166 m/s	∫ thrust / mass dt, flip to hand-off (Trajectory row 31)	Burn thrust ΔV, guided 2-D		1317 m/s	∫ thrust / mass dt, flip to hand-off (Trajectory row 31)
Propellant the 2-D burn needs		67.27 t	Hand-off mass (+ hover-out) x (exp(ΔV / axial exhaust velocity) - 1): the bur	Propellant the 2-D burn needs		71.53 t	Hand-off mass (+ hover-out) x (exp(ΔV / axial exhaust velocit
Mass at flip the burn needs		176.34 t	Compare row 121 (1-D sizing, which the trajectory used for the drag phase	Mass at flip the burn needs		170.84 t	Compare row 121 (1-D sizing, which the trajectory used for t
Peak throttle at the needed mass		0.79 ×	Must stay ≤ 1 (full thrust); above the maximum in row 94 the steering rese	Peak throttle at the needed mass		0.87 ×	Must stay ≤ 1 (full thrust); above the maximum in row 94 the
Thrust angle above the anti-velocity, max		20.0 deg	Limited by α max (row 96)	Thrust angle above the anti-velocity, max		20.0 deg	Limited by α max (row 96)
Landing propellant, flip → touchdown		**69.44** t	2-D burn + hover-out + terminal phase (the hypersonic entry is not modell	**Landing propellant, flip → touchdown**		**74.94** t	2-D burn + hover-out + terminal phase (the hypersonic entry
T/W at flip (needed mass)		2.39 Mars weight	Installed axial thrust / Mars weight	T/W at flip (needed mass)		2.47 Mars weight	Installed axial thrust / Mars weight

SECTION 3 NOTES

The atmosphere does not materially help the burn itself: at these thrust coefficients the retro plume displaces the base drag (retention 0.0 here), so the real aerodynamic contribution is the belly-first phase that brings the vehicle down to the flip Mach. The flip trades a ~383 m² drag body for a ~64 m² one, so flip as late as
Mass closure uses a backward 1-D vertical burn from the 100 m / 10 m/s hand-off (no iteration needed). The trajectory uses forward 2-D planar integration — drag, lift, gravity turn, Mars curvature — of the belly-first phase, then of the burn from the actual flip state with thrust retrograde. Euler on speed and angle, trapezo
Belly-first terminal velocity bounds the flip Mach from below (row 131: cargo 917 m/s, crewed 860 m/s ≈ Mach 3.7). A higher ballistic coefficient (row 122: cargo 534, crewed 469 kg/m²) reaches a given Mach lower down, so it needs more thrust or a higher-Mach flip.
The hypersonic entry (5–7 km/s down to ~Mach 4) is guidance-dominated and not modeled; the aero-phase start state is an assumption, as the 15 km / 1000 m/s ignition point was in Section 2. The flight-path angle at that state matters far more than the altitude.
Section 2 is retained as the propulsion-only reference. Section 3 supersedes its 'NEEDS AERO DRAG' verdict.

ENHANCEMENTS (v9.1) — purple = new

AERO / SRP SENSITIVITY NOTES

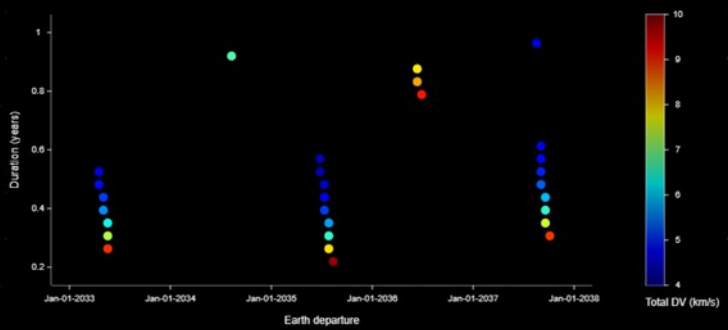
Belly-first Cd and L/D are key drivers of the altitude at which flip/SRP can begin. Current model credits aero drag during SRP; validate Cd against CFD or wind-

Simple Cd sensitivity (cargo case, approximate)

Baseline belly Cd	1.200	*Linked from main inputs*
Cd multiplier for sensitivity	1 ×	*Editable; 0.8–1.2 typical uncertainty*
Effective Cd	1.2	

RECOMMENDATION

Landing margins look healthy with aero assistance. Primary risks are: (1) tile blow-off reliability and residual heating after exposure of thrusters, (2) plume int



Tabulated Results Export to CSV

► **Column heading descriptions**

	SPK ID	Name	Abs Mag	Size	Orbit condition code	Earth Departure	Destination Arrival	Duration	Injection C3 (km^2/s^2)	Abs DLA	Injection ΔV (km/s)	Post-Injection ΔV (km/s)	Total ΔV (km/s)	Route
View	499	Mars		6779 km	0	Jun-26-2035	Jan-20-2036	208 days	9.6	14°	3.65	0.66	4.31	EM
View	499	Mars		6779 km	0	Jun-26-2035	Jan-04-2036	192 days	9.3	18°	3.64	0.69	4.33	EM
View	499	Mars		6779 km	0	Jul-12-2035	Jan-04-2036	176 days	12.2	20°	3.77	0.72	4.48	EM
View	499	Mars		6779 km	0	Apr-17-2033	Oct-26-2033	192 days	8.1	21°	3.59	1.03	4.62	EM
View	499	Mars		6779 km	0	Aug-18-2037	Aug-05-2038	352 days	15.6	6°	3.91	0.74	4.65	EM
View	499	Mars		6779 km	0	Sep-03-2037	Apr-15-2038	224 days	19	11°	4.06	0.62	4.67	EM
View	499	Mars		6779 km	0	Jul-12-2035	Dec-19-2035	160 days	13	22°	3.8	0.9	4.7	EM
View	499	Mars		6779 km	0	Sep-03-2037	Mar-30-2038	208 days	18.3	8°	4.03	0.72	4.75	EM
View	499	Mars		6779 km	0	Apr-17-2033	Oct-10-2033	176 days	8.3	19°	3.6	1.21	4.8	EM
View	499	Mars		6779 km	0	Sep-03-2037	Mar-14-2038	192 days	18.3	7°	4.03	0.93	4.95	EM
View	499	Mars		6779 km	0	May-03-2033	Oct-10-2033	160 days	13.5	17°	3.82	1.28	5.1	EM
View	499	Mars		6779 km	0	Jul-12-2035	Dec-03-2035	144 days	14.2	23°	3.85	1.26	5.11	EM
View	499	Mars		6779 km	0	Sep-03-2037	Feb-26-2038	176 days	18.8	7°	4.05	1.27	5.32	EM
View	499	Mars		6779 km	0	May-03-2033	Sep-24-2033	144 days	15	17°	3.89	1.7	5.59	EM
View	499	Mars		6779 km	0	Jul-28-2035	Dec-03-2035	128 days	24.6	22°	4.29	1.42	5.71	EM
View	499	Mars		6779 km	0	Sep-19-2037	Feb-26-2038	160 days	30.3	5°	4.52	1.35	5.87	EM
View	499	Mars		6779 km	0	May-19-2033	Sep-24-2033	128 days	28	19°	4.43	1.89	6.33	EM
View	499	Mars		6779 km	0	Sep-19-2037	Feb-10-2038	144 days	31.9	5°	4.59	1.93	6.52	EM
View	499	Mars		6779 km	0	Jul-28-2035	Nov-17-2035	112 days	27.9	23°	4.43	2.11	6.54	EM
View	499	Mars		6779 km	0	Aug-10-2034	Jul-12-2035	336 days	17	40°	3.97	2.77	6.75	EVM
View	499	Mars		6779 km	0	May-19-2033	Sep-08-2033	112 days	32.3	21°	4.6	2.71	7.32	EM
View	499	Mars		6779 km	0	Sep-19-2037	Jan-25-2038	128 days	34.8	7°	4.71	2.78	7.49	EM
View	499	Mars		6779 km	0	Jun-12-2036	Apr-28-2037	320 days	23.5	10°	4.25	3.59	7.83	EVM
View	499	Mars		6779 km	0	Jul-28-2035	Nov-01-2035	96 days	33.8	23°	4.67	3.24	7.9	EM
View	499	Mars		6779 km	0	Jun-12-2036	Apr-12-2037	304 days	23.5	10°	4.25	4.02	8.26	EVM
View	499	Mars		6779 km	0	Oct-05-2037	Jan-25-2038	112 days	63.8	8°	5.82	3.11	8.92	EM
View	499	Mars		6779 km	0	May-19-2033	Aug-23-2033	96 days	39	23°	4.88	4.08	8.96	EM
View	499	Mars		6779 km	0	Jun-28-2036	Apr-12-2037	288 days	35.5	11°	4.74	4.38	9.12	EVM
View	499	Mars		6779 km	0	Aug-13-2035	Nov-01-2035	80 days	66.9	20°	5.93	3.93	9.86	EM

MARS · MDV CARGO LANDER · ENTRY / DESCENT / LANDING

v1.21 · offline · no dependencies

Cargo landing guidance optimizer

Standalone 2-D Mars descent simulator derived from Landing Calculator v10.2 · rigid-body pitch from the flip to touchdown, driven only by the engine ring and the bare-body aerodynamics · search over entry mass, propellant, trim schedule and guidance.

Flight inputs & controls

Simulate current | Find max cargo

Revert inputs | Reset inputs

Trajectory CSV | Scenario JSON

Save settings | Load settings

Current trajectory simulated. upright soft landing.

Mass & constraints

Dry mass (B28)	Delivered cargo (B29)
62.9 t	47.7 t
Landing fuel loaded	**Fuel reserve at touchdown**
73.34 t	1.5 t
Fuel tank capacity limit	**Max vehicle entry mass**
120 t	240 t

Mass stations (CG & pitch inertia)

Cargo layout: Tanker: 55 % of the cargo in the tanks

A starting point: each layout comes with the guidance and cargo a search found for it. Rerun the search after changing anything that matters.

Propulsion mass with the engines: Follows the engine rating and count (propulsion rev …

Dry-mass CG	Dry pitch radius of gyration
14.6 m	9.5 m
Cargo station (basket bay)	**Cargo share in the nose bay**
6 m	0 fraction
Nose-bay station	**Cargo share carried in the tanks**
29 m	0.55 fraction
Propellant CG, belly-first	**Propellant CG, settled**
19.5 m	15 m

Propulsion mass (v1.17): the dry mass describes the 16 × 125 kN

Best verified-in-model payload	Landing propellant consumed	Entry / start mass	Touchdown / end speed
47.70 t	**71.57 t**	**183.9 t**	**0.4 m/s**
Current cargo passes all contact screens	Loaded 73.3 t; left 1.8 t	Dry + delivered cargo + landing fuel	Upright soft contact · upright soft landing

Current trajectory — Entry interface 125 km, v∞ 2.7 km/s, -11.0° +

g-force & flight-load limits — g-force (Earth g) +

Centre of gravity, propellant & trim — Incidence: flown vs bare-body trim, with the flap + RCS band +

Attitude & thrust geometry · synchronized replay

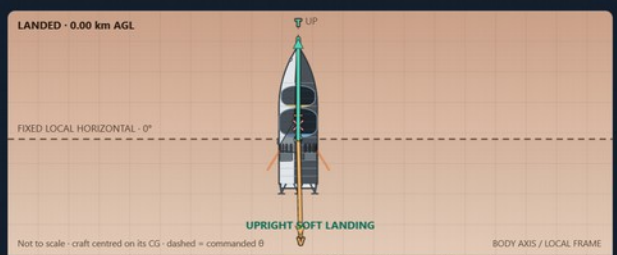
Vertical-plane projection · fixed local horizon

Play | ↔ Start | −5 s | +5 s | Speed 50× | Roll by bank

t = 504.0 / 504.0 s

• Record video | MP4 (H.264) | 1280 × 720 | 30 fps | Frame by frame at the replay speed above; nothing is dropped.

Simulation time — 504.0 s



θ · Pitch vs horizon	90.0°
α · AoA vs air velocity	178.7°
δ · Net thrust vs body	-0.1°
ψ · Thrust vs velocity	178.6°
λ · Thrust vs horizon	90.0°
Upright tilt at contact (0° target)	0.0°
g-force (sensed)	0.39 g

Altitude 0.00 km · Mach 0.00 · Speed 0.4 m/s · body tilt 0.0° · γ -88.6° · pitch rate 0.03°/s · done · throttle 27% · ring side force -1 kN · CG z 13.15 m, x -0.00 m · g-force 0.39 g

θ, δ and λ are signed; α and ψ are unsigned [0°, 180°]. No thrust angles are plotted with engines off.

Angle history (degrees)

Click or drag chart to seek · dashed line = current time

