

Summary of simulation results for two-stage solid propellant MAV, April 2022.

Hold initial launch angle for 0.1 seconds, then gravity turn trajectory with aero drag and planet rotation.

Yellow highlight indicates numbers published by NASA MSFC, March 2022.

Blue highlight indicates numbers calculated separately from the trajectory simulation.

Disclaimer: Intended to shed light on design tradeoffs and challenges, not to suggest specific engineering answers.

MAV launch mass at Mars departure (approximate limits of possibilities)	400 kg	425 kg	450 kg
MAV target mass allocation	400 kg	400 kg	400 kg
Mars orbit desired altitude (from Yaghoubi 2022 IEEE Aerospace Conference)	380 km	380 km	380 km
Payload mass (from Yaghoubi 2022 IEEE Aerospace Conference)	16 kg	16 kg	16 kg
Stage 1 propellant mass (from Yaghoubi 2022 IEEE Aerospace Conference)	213 kg	213 kg	213 kg
Stage 1 burn time (from Yaghoubi 2022 IEEE Aerospace Conference)	70 s	70 s	70 s
Stage 1 burn rate (propellant mass divided by burn time)	3.04 kg/s	3.04 kg/s	3.04 kg/s
Solid propellant Isp (catalog value for STAR 20 solid rocket motor)	288 s	288 s	288 s
Stage 1 thrust (calculated from burn rate and Isp)	8588 N	8588 N	8588 N
Stage 1 delta V (rocket equation, launch mass, Stage 1 propellant mass, Isp)	2146 m/s	1963 m/s	1810 m/s
Launch angle from vertical (adjusted for gravity turn to 380 km apoapsis)	11.8 deg	7.94 deg	3.89 deg
Stage 1 burnout altitude (from simulation)	41.7 km	43.6 km	45.0 km
Speed at Stage 1 burnout (from simulation)	2114 m/s	1880 m/s	1651 m/s
Published coast time (from Yaghoubi 2022 IEEE Aerospace Conference)	400 s	400 s	400 s
Coast time from Stage 1 burnout to 380 km (from simulation)	519.6 s	493.5 s	473.8 s
Time from launch to 380 km (Stage 1 burn time plus coast time)	589.6 s	563.5 s	543.8 s
Apoapsis angle around planet from launch site (from simulation)	13.5 deg	9.9 deg	6.0 deg
Speed of MAV (in direction of orbit) at 380 km apoapsis	1489 m/s	1138 m/s	705 m/s
Mars orbit speed for 380 km circular orbit (calc. from planet mass, altitude)	3375 m/s	3375 m/s	3375 m/s
Stage 2 delta V for circular orbit (orbit speed minus MAV apoapsis speed)	1886 m/s	2237 m/s	2670 m/s
Stage 2 propellant mass (from Yaghoubi 2022 IEEE Aerospace Conference)	47 kg	47 kg	47 kg
Stage 2 burn time (from Yaghoubi 2022, for reference only here)	18 s	18 s	18 s
Stage 2 burn rate (prop mass divided by burn time, for reference only here)	2.61 kg/s	2.61 kg/s	2.61 kg/s
Stage 2 thrust (calculated from burn rate and Isp, for reference only here)	7370 N	7370 N	7370 N
Stage 2 spent mass (rocket equation, Stage 2 delta V, Isp, and prop. mass)	49.4 kg	38.9 kg	29.8 kg
Stage 2 total mass including payload (spent mass plus propellant)	96.4 kg	85.9 kg	76.8 kg
Summary for overall comparison	(400 kg)	(425 kg)	(450 kg)
Total rocket delta V to reach 380 km circular orbit (Stage 1 plus Stage 2)	4032 m/s	4200 m/s	4480 m/s
Share of total delta V on Stage 2	0.47	0.53	0.60
Stage 1 total mass (launch mass minus Stage 2 total mass with payload)	303.6 kg	339.1 kg	373.2 kg
Stage 1 propellant mass fraction (propellant mass divided by total)	0.70	0.63	0.57
Stage 1 hardware mass (Stage 1 total mass minus solid propellant mass)	90.6 kg	126.1 kg	160.2 kg
Stage 2 initial mass without payload (Stage 2 initial mass minus payload)	80.4 kg	69.9 kg	60.8 kg
Stage 2 propellant mass fraction (without payload)	0.58	0.67	0.77
Stage 2 hardware mass (Stage 2 without propellant or payload)	33.4 kg	22.9 kg	13.8 kg

In the stage summary numbers, **red** indicates a greater challenge, and **green** indicates less difficulty (not "easy").

Note that Stage 1 "hardware mass" includes RCS propellant carried to Stage 1 burnout.

As the MAV gets heavier for the fixed amounts of solid propellant, the Stage 1 speed decreases while its trajectory becomes steeper in order to coast up to 380 km altitude. The steeper initial ascent reduces trajectory efficiency, so total delta V increases and significantly more delta V is needed from Stage 2.