A Model of a 2-Stage Safir Launch Vehicle

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There has been some question among analysts what technical characteristics Iran's Safir 2 launcher would require to have placed a 27-kg satellite in orbit with only two stages, and whether that level of technology would be available to Iran. Modeling has shown that the level of technology assumed for the North Korean Nodong and Taepodong-1 missiles, which is essentially improved Scud technology, is not sufficient.

For this model, I assume the Safir has capabilities comparable to the Chinese Long March launch vehicles since that is relatively advanced technology that has been used in China's space launch vehicles since the mid-1970s, and therefore is likely to be achievable by other countries. Those missiles, however, are considerably larger than the Safir, and typically use a third stage, since they are designed to launch much larger payloads into orbit. So China's experience is not directly applicable to understanding the Safir.

My calculations show that assuming this level of technology, a two-stage launcher the size of the Safir could place a small satellite with a mass of a few tens of kilograms into orbit. Moreover, something close to this level of technology is needed to do this. This implies that Iran's launch technology is more advanced than North Korea's.

This analysis is not intended to suggest that China has assisted Iran with its development program or transferred technology to Iran, since this kind of technology has been around for decades. The analysis uses Chinese launchers as a concrete example of what booster parameters have been achieved.

Assumptions and Analysis

The Omid satellite was tracked in an orbit with a perigee of about 240 km and an apogee over 300 km. To reach this orbit, the launcher would have to deliver the satellite to an altitude of 240 km with a speed of 7.79 km/s. The launch appears to have been in a direction 162 degrees from north,[1] over the Arabian Sea. The component of the earth's speed in that direction is about 0.21 km/s, so the launch vehicle would have had to be able to increase the satellite's speed by 7.58 km/s while lifting it to 240 km.

Following the launch, the head of the Iranian Space Agency reportedly stated that the Safir 2 has a mass of 26 tons, a length of 22 m length, and a diameter of 1.25 m.[2]

Using a diameter of 1.25 m, measurements of photos of the launcher show that the first-stage propellant tanks have an overall length of about 15 m, and the second stage tanks have an overall

[1] Geoff Forden, private communication, 11 February 2009.
[2] http://www.armscontrolwonk.com/2174/congratulations-iran#comment

length of about 3 m. The payload section is about 2 m long, and the overall length of the launcher is roughly 22 m.

Assuming an average propellant density of 1.2 to 1.3 g/cc, which is appropriate for IRFNA/UDMH, N2O4/MMH, etc,[3] the tank volumes give approximate propellant masses for the two stages of 20 t for the first stage and 4 t for the second stage. This is roughly consistent with a total launcher mass of 26 t.

For this analysis, I estimate values of the specific impulse (Isp) and fuel mass fraction of the Safir from the Chinese Long March space-launch vehicles.

A paper presented in 1987 by two engineers who were part of China's missile and space-launch programs gives technical parameters for the LM-2 and LM-3 launchers.[4] The LM-2 began launching payloads in the mid-1970s, and LM-3 in 1984. Both launchers usd clusters of YF-20 engines for the first stage, with N2O4/UDMH as the propellant, and had a sea-level Isp of 260 s. The burntime was 132 s.

These launchers used YF-22 engines for the second stage, with the same propellant, and had a vacuum Isp of 295 s. The burntime for this stage was 132s.

Later versions of the LM-3 and 4-series launchers also use clusters of YF-20 engines for the first stage, with N2O4/UDMH as the propellant.[5] The LM-3A and 3B began launching payloads in the mid-1990s, and the LM-4B in 1999. Published parameters for these launchers give a sea-level Isp of 260.7s with a burntime of 132 to 145 s.

These launchers also use the YF-22 engine for the second stage, with the same propellant. Published parameters are a vacuum Isp of 298 s with burntimes ranging from about 120 for the LM-3A to 195 s for the stretched versions.

Since the Safir appears to use jet vanes on the first stage for guidance rather than a gimbaled engine, I assume the Isp for the first stage is somewhat lower than the Chinese values.

The LM-3 and 4 launchers have diameters of 3.35 m and lengths of 23 m for the first stage and 10 m for the second. They are made of aluminum and have fuel mass fractions of about 0.95 for the first stage and 0.90 for the second stage. The LM-1M launcher is smaller, with diameter of 2.25 m. It had fuel mass fractions of 0.94 for the first stage and 0.83 for the second stage.[6] Because the Safir first stage has a much larger length to diameter ratio and therefore a higher surface to volume ratio, I assume the fuel fraction of the first stage will be somewhat less than these values. I assume the second stage fuel fraction of the Safir lies between the second-stage values for the LM-1M and LM-3.

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[3] Liquid Rocket Propellants, http://en.wikipedia.org/wiki/Liquid_rocket_propellants

[4] H. Zuwei and R. Xinmin, "Long March Launch Vehicle Family: Current Status and Future Developments," *Space Technology*, Vol. 8, No. 4, pp. 371-375, 1988.

[5] S. J. Isakowitz, J. B. Hopkins, J. P. Hopkins, *International Reference Guide to Space Launch Systems, Fourth Edition* (AIAA, 2004), p. 247-9.

[6] Zuwei and Xinmin, "Long March Launch Vehicle Family."

It is interesting to note that unlike the Chinese launch vehicles, the Safir does not have an open interstage between the first and second stages. In China's launch vehicles (as well as the Taepodong), this allows the second stage to be ignited while the first stage is still being accelerated by the first stage, which can be useful in starting liquid engines. The Safir second stage engine must use a different mechanism.

Based on these numbers, I consider the following model:

Stage 1:

Propellant mass: 20 t
Fuel mass fraction: 0.91
Isp(SL) = 258 s
Isp(vac) = 280 s
Burntime = 140 s
Thrust = 361.2 kN

Stage 2:

Propellant mass: 4 t
Fuel mass fraction: 0.85
Isp(vac) = 298 s
Burntime = 140 s
Thrust = 83.4 kN

Satellite mass = 27 kg
Payload shroud = 50 kg, released at 150s when the second stage is above 100 km.

I assume a round earth, and use a model atmosphere to calculate drag during launch.

Using the parameters given above, I calculate a burnout speed of 7.6 km/s at an altitude of about 240 km, which is consistent with the Omid launch.

Moreover, this trajectory gives a first-stage burnout at 66 km altitude, which appears to be consistent with a report from Iranian radio about the launch.[7]

I should caution that I do not have enough information about the Safir launcher to suggest that these represent the actual values for the booster, or that it uses N2O4/UDMH propellant. My goal in presenting this calculation is to show that booster parameters consistent with those that were developed several decades ago would allow a two-stage launcher of the size of the Safir to place a small satellite in orbit, without the need of an additional kick stage.

[7] http://www.armscontrolwonk.com/2174/congratulations-iran#comment