Replacement of Conventional Rocket Boosters and First Stage by Microwave Rockets

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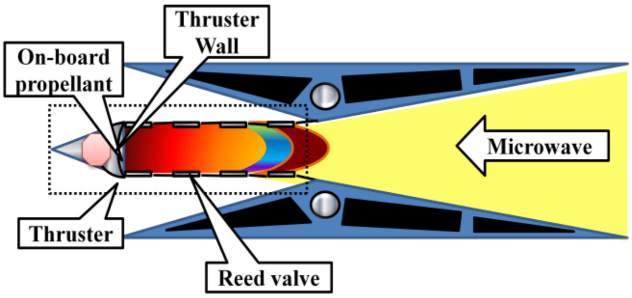

Fig. 1: Microwave rocket schematics

Introduction

The accessing cost to space remains one of the most important brakes against the development of human space activities. Many space projects remain at theoretical level because their realization costs are well far too important, mainly due to the launching part of the project. To reduce launching cost, alternative propulsion systems are studied such as the Microwave rocket. This latter is expected to have several advantages, it can work in air-breathing mode in dense atmosphere, it is a simple structure and the energy source is off-board and can be used many times.

Microwave rocket can be used as a complete launcher but it is possible to study its application as replacement for conventional booster or first stage.

Microwave Rocket Principles

Microwave rocket works like a pulsed detonation engine. First a microwave beam is focused at the closed side (thrust wall) and generates a plasma which then drives a detonation wave. Then, when the detonation wave reached the thruster open side, it leaves as an inert shock and an expansion wave is generated at the thruster open side and propagates toward the thrust wall. The pressure inside the thruster decreases through this expansion wave and when it reflects at the thrust wall, the pressure decreases even under the initial pressure. At last it is possible to take advantage of the pressure difference between the inside and the outside of the thruster to refill it through a reed-valves system for instance.

The thrust produced by the microwave rocket is estimated using a simple model developed at the University of Tokyo [1] [2][3]. This model is based on three steps of calculation corresponding to the three main steps of the pulsed detonation engine of the microwave rocket described earlier. The thrust is estimated using the pressure at the thrust wall evolution.

At last the microwave rocket can be used in air-breathing mode and rocket mode. In air-breathing mode the space around the thruster is assumed to be at the stagnation conditions at the beginning of the refilling. In rocket mode, the front of the microwave rocket is supposed to be closed, forming a closed space called the plenum, and maintained at constant conditions of temperature and pressure by on-board tank of some propellant (in this study, hydrogen).

Replacement of H2B rocket boosters or first stage

As a first approach of feasibility study of replacing H2B rocket boosters or first stage, a simple comparison between a vertical ascent in equatorial plan of a H2B rocket equipped with microwave rocket and conventional launch. Equations of such a launch can be found in[4]. The objective is to check if same altitude and velocity are reached at boosters burnout time or first stage main engine cut-off. In order to do trajectory simulations of H2B rocket equipped with microwave rocket as booster or first stage replacement, it is necessary to estimate the thrust produced by the microwave rocket during the flight. It is done using the analytical model recently developed at the University of Tokyo.

In H2B conventional launches, at boosters burnout time, 53 km of altitude is reached with a velocity of 1.9 km/s; at first stage main engines cut-off 184 km of altitude is reached with a velocity of 5.6 km/s [5].

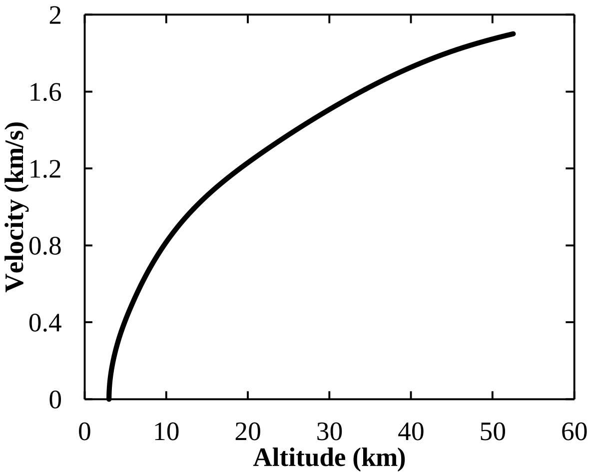

Fig. 8: H2B equipped with Microwave Rocket boosters flight

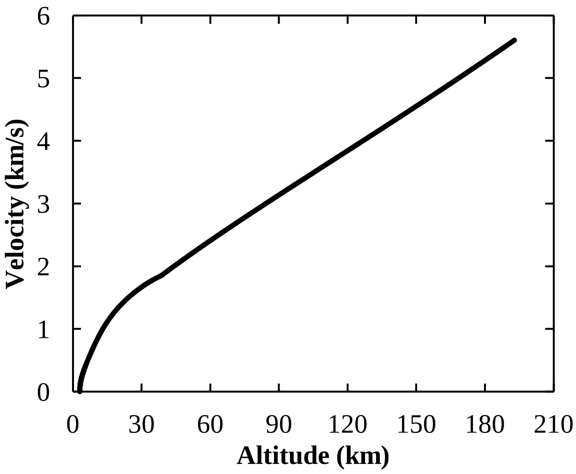

Fig. 3: Velocity as function of the altitude for a vertical ascent of H2B rocket equipped with Microwave Rocket first stage

Boosters Replacement

The figure 2 shows the H2B rocket (equipped with four microwave rockets as boosters) velocity as function of its altitude during a vertical ascent in the equatorial plan. The H2B rocket was equipped with four microwave rockets, instead of its usual four SRB-A boosters, with the following dimensions: L_R = 14 m, D_R = 5.2 m, L_{th} = 14 m, D_{th} = 3.6 m. First stage, second stage and payload fairing of H2B rocket was kept unchanged and the mass at lift-off was supposed to be 260 tons, leaving the place for 14.8 tons of payload if one microwave rocket mass is supposed to be 5 tons. In this configuration, the payload ratio of H2B rocket was more than doubled compared with conventional configuration, 6% instead of less than 3%.

The simulation shows that it was possible to reach similar conditions than conventional flight. 1.9 km/s was achieved at 52.5 km of altitude. However the microwave beam power required to complete the vertical ascent was about 143 GW (or 0.55 MW/kg of initial mass). Emitting such a power is not currently feasible technologically and economically as the cost of gyrotrons is now estimated at 0.1 M$/MW, this installations would cost at least 14.3 billions $.

Cost estimations, where ground base cost is not included, are nevertheless attractive. With an electricity price of 0.1 $/kWh and assuming that one microwave rocket booster costs less than 1 M$, then launch cost can be reduced at 5 k$/kg (of payload) instead of 7 k$/kg (of payload).

First Stage Replacement

The figure 3 shows the H2B rocket, equipped with microwave first stage, velocity as function of its altitude. In this configuration, the first stage of the H2B rocket was replaced by one microwave rocket with the following dimensions: L_R = 20 m, D_R = 5.7 m, L_{th} = 16 m, D_{th} = 4.2 m. The microwave rocket first stage was used in air-breathing mode up to 39 km of altitude (where 1.85 km/s was reached) and then in rocket mode. The rocket mode propellant was hydrogen at 2.4 bars and 280 K. Final characteristics of the vertical ascent were 192 km with a velocity of 5.6 km/s. Mass at lift-off was set to 90 tons, thus assuming that the microwave first stage mass is 6 tons, then 6.8 tons of payload can be onboard. With such hypothesis the payload ratio is 7.6 %, higher than when only the boosters are replaced.

In this situation 50 GW of total microwave beam power was necessary. Building the microwave beam emitter will thus costs about 5 billion $, which is much more reasonable than in boosters replacement case. Once more, without counting the ground base cost, high reduction of launch cost can be achieved, with an expected cost of 1 k$/kg of payload.

Conclusion

A preliminary study of boosters or first stage of H2B rocket replacement was conducted. Flight simulations show the possibility to achieve similar conditions of altitude and velocity by replacing boosters or first stage by microwave rocket. By doing so, the payload of H2B rocket can be greatly increased (by 150 % with first stage replacement) and the launch cost reduced (by 83 % with first stage replacement). However the ground base has to provide a huge amount of microwave beam power, which represents a very high cost and cause some technological problems.

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