MarsHopper

SUMMARY

MarsHopper is a plane for investigation Mars poles and its surroundings. It uses CO_2, that in solid form covers surface to create jet thrust. At landing, plane harvests CO_2 for next flight and for deceleration. On the surface, plane accumulate radioisotopic energy in CO_2, by changing it phase from solid to liquid (or even to supercritical fluid). Liquid (or supercritical fluid) CO_2 at high pressure is used as a jet fuel for next jump, with possible short flight, hence the name of plane “hopper”.

To elaborate this idea we estimated viability of the mission in terms of energy consumption and flight condition. Our calculations showed that this project is possible with existing technologies. Also, to illustrate the idea we made computer modeling of flight process and made real life demonstration model of plane launched by jet force of CO_2.

Content

IDEA

The main idea is to use solid CO_2 on Mars poles as accumulator of energy with further use it for jet thrust.

Main power sources on existing Mars missions are radioisotope thermoelectric generator and solar panel. Both do not give sufficient power for fast transportation on Mars. One possibility to move fast is to use high-energy fuel from Earth, but it costs too much to deliver hence it is limited. Therefore, there is a necessity to accumulate energy and by rapid release create required force to move things.

We propose to use local resource, solid CO_2, to accumulate energy from RTG. The device that realize this idea we called MarsHopper. It is a plane. At landing, plane harvest CO_2 and thus slowing down. Than it accumulates radioisotope energy by heating CO_2. Rapid release of liquid (or supercritical) CO_2 to Mars low-pressure atmosphere will cause transition to gas and rapid expansion. High-pressure gas can be used as a jet thrust for next jump and create rotation of propellers to sustain flight. With multiple jumps, it can investigate large area of Mars poles and its surroundings.

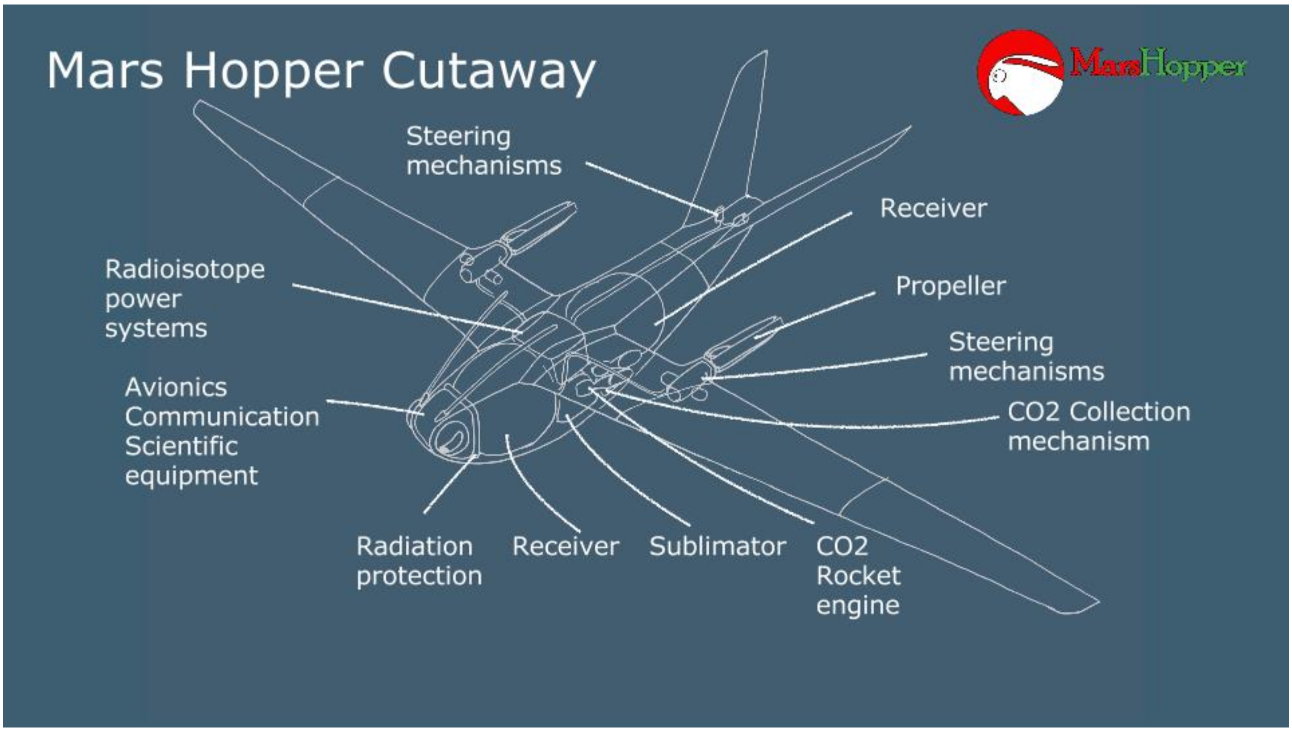
We believe that it can revolutionize the way Mars is explored.
It`s going to be the first martian insect.

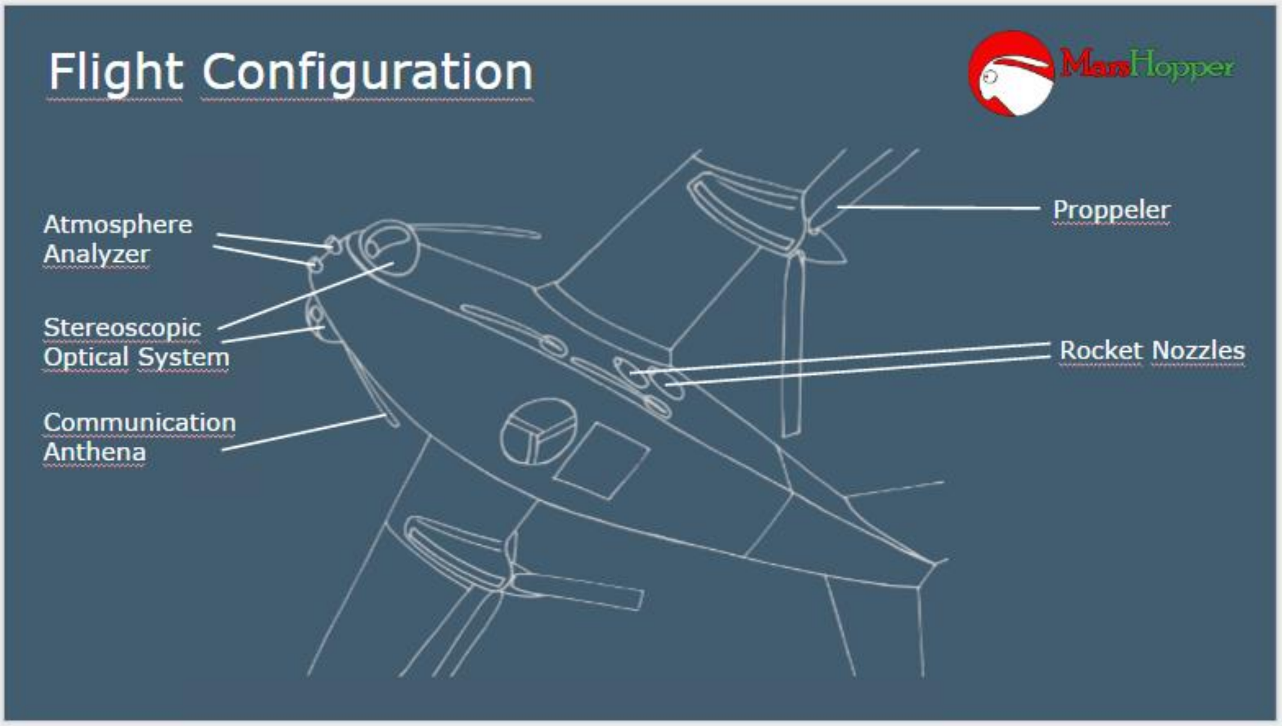
MARSHOPPER DESIGN

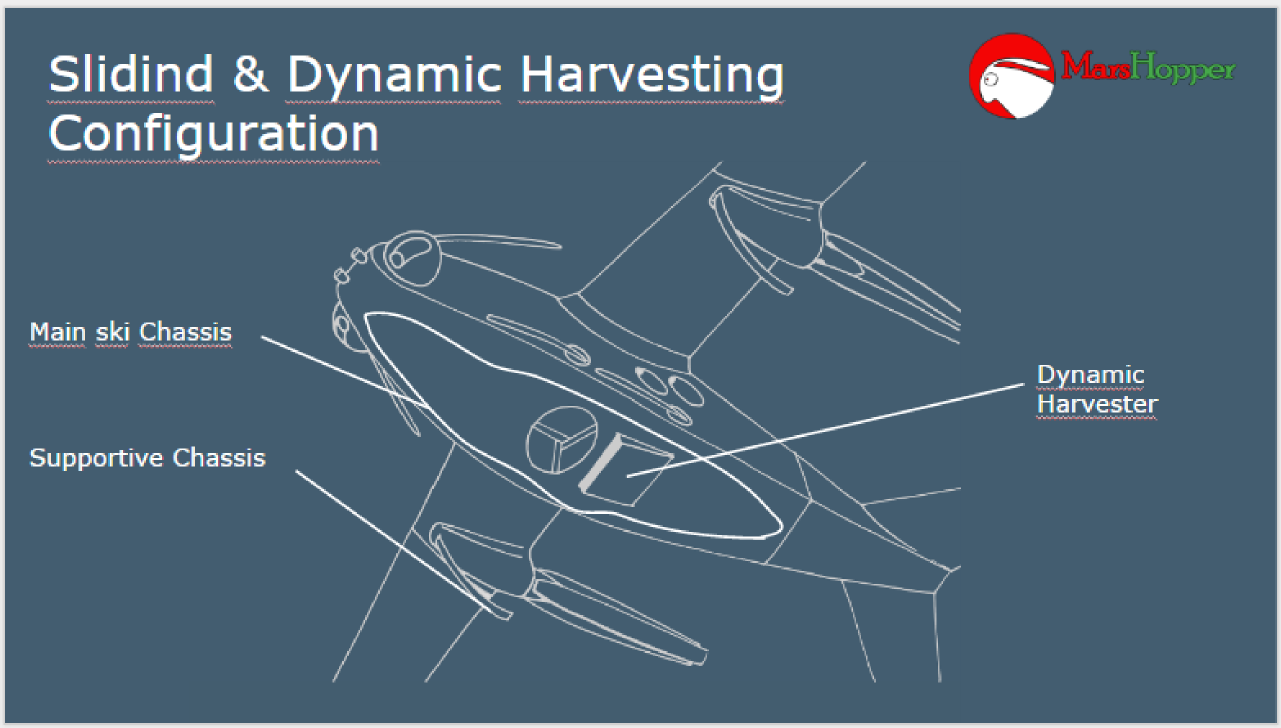
We were inspired by two biological examples albatross and grasshopper

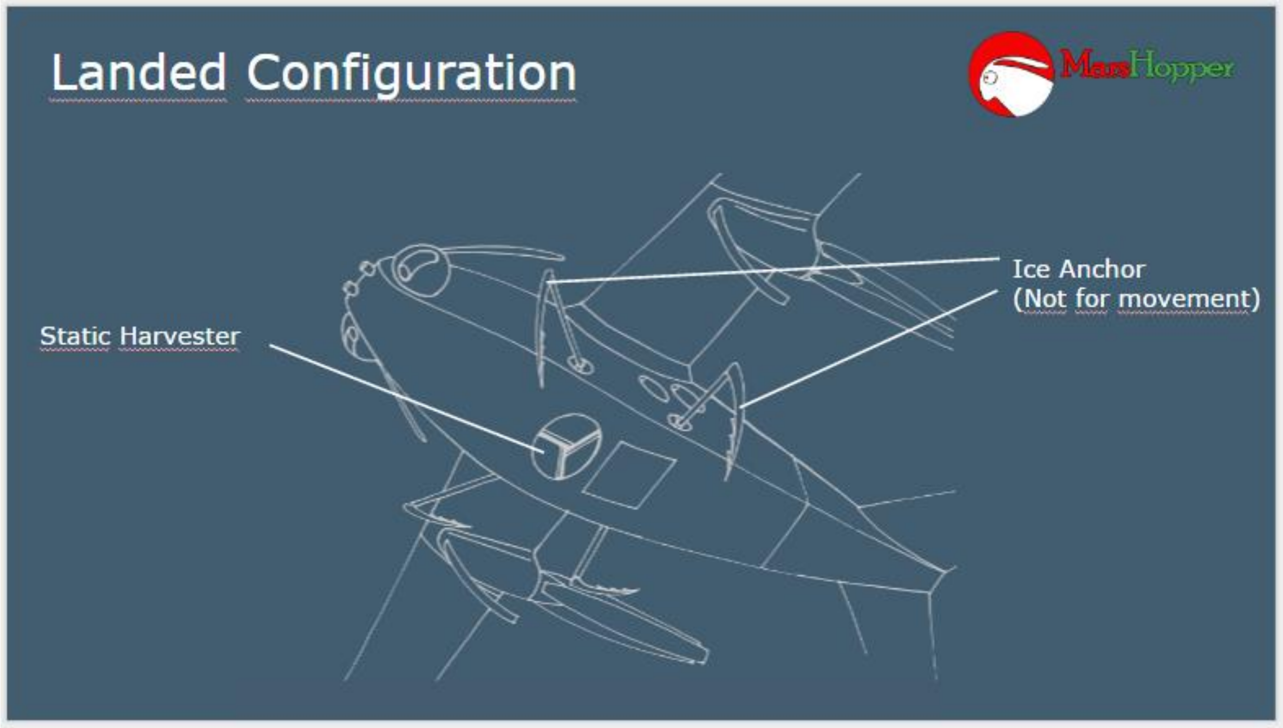
Albatross is an ideal example for gliders constructor. Its distinction is an ability to flight(glide) on winds to long. Also, albatross can live without food for a significant period of time. Grasshopper uses another strategy, it jumps from place to place multiple times and always has to live near his food location.

On Mars poles we have condition that similar to Grasshopper example, with a lot of necessary resources nearby. So, the idea of MarsHopper has born.




Flight Configuration
MarsHopper
Atmosphere Analyzer
Stereoscopic Optical System
Communication Anthena
Proppeler
Rocket Nozzles


Slidind & Dynamic Harvesting Configuration
MarsHopper
Main ski Chassis
Supportive Chassis
Dynamic Harvester


Landed Configuration
MarsHopper
Ice Anchor
(Not for movement)
Static Harvester

PHYSICAL CALCULATIONS

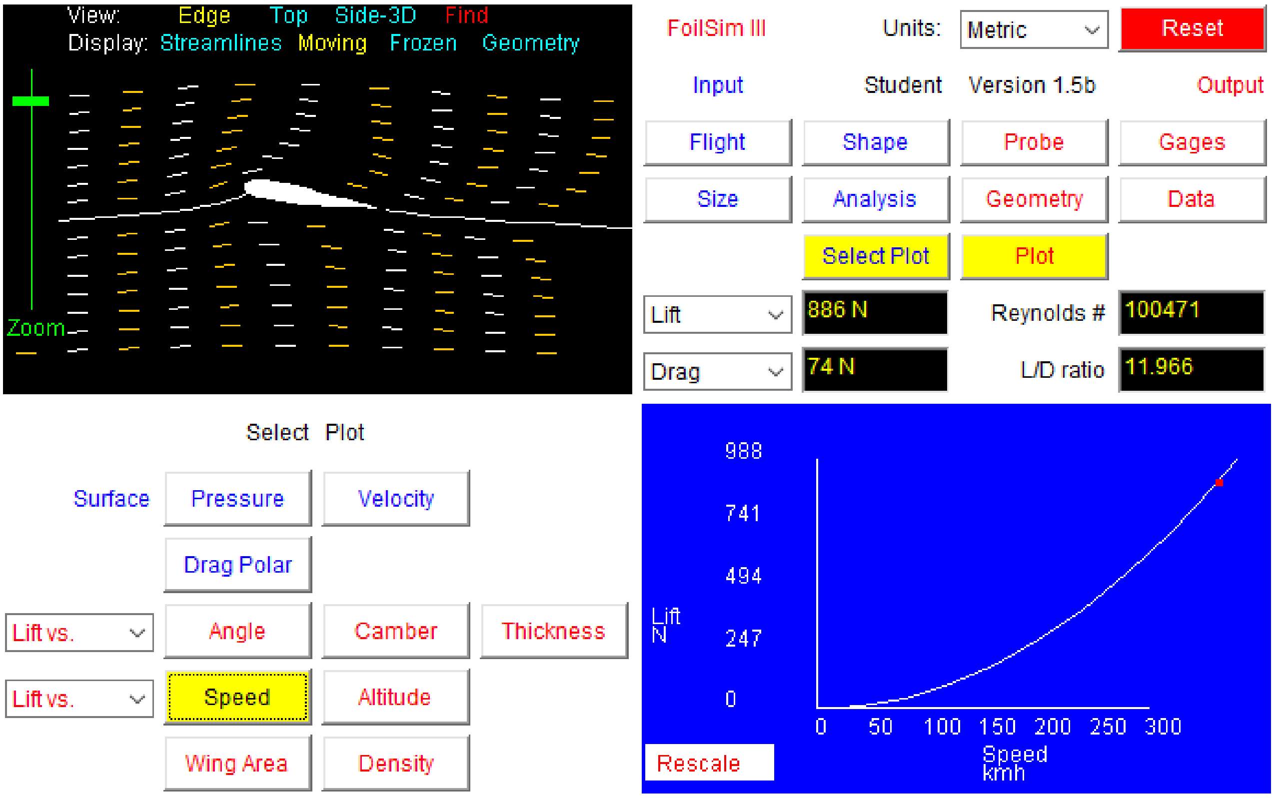
Generally, we need to estimate viability of the mission in terms of energy consumption and flight condition.

Firstly, we need to estimate plane size, mass, flight velocity. Secondly, to estimate how much we need jet fuel in form of liquid (or gas) CO_2 to achieve flight conditions. Thirdly, to estimate whether we can obtain enough amount of energy to transform initial state of CO_2 (P_1,T_1) to final(P_2,T_2).

Following calculations are only estimation to get order of magnitude of desired values to estimate viability of the project.

1. Flight conditions

To estimate flight condition we used FoilSim, software developed at NASA Glenn Research Center.



In Mars atmosphere with following parameters:

wing size(chord = 1m, span = 10m),

airfoil angle = 10 deg,

flight speed 360 km/h,

we have lift force 886N and drag 74N. It is enough to carry estimated mass of plane 200 kg with weight 742N (Mars gravity $g = 3.711\frac{m}{s^2}$). Here we do not take in account the drag force of a fuselage.

2. Jet thrust

Here we need to estimate amount of fuel needed to achieve flight speed 360 km/h. To make rough approximation we can use model of variable-mass system (Meschersky equation)

$$M\frac{dV}{dt} = v_e\frac{dm}{dt}$$

v and m are velocity and mas of CO2 respectively. To estimate v we can use equation of velocity for de Laval nozzle.

$$v_e = \sqrt{\frac{TR}{M}\cdot\frac{2\gamma}{\gamma-1}\cdot\left[1-\left(\frac{p_e}{p}\right)^{\frac{\gamma-1}{\gamma}}\right]},$$

T	$370K$
R	$8.314\, J/mol\cdot K$
M	$0.044\, kg/mol$
γ	$1,35$
p_e/p	$0,000125$

$$v_e = 700\, m/s$$

Let suppose that plane have acceleration 50 m/s2 and in 2 sec it achievei velocity 100m/s that equals 360 km/h. Than, according to Meschersky equation we need to consume 15 kg/s of CO2. In 2 seconds we will consume 30 kg and achieve 360 km/h.

We will also use two propellers powered by CO2, and we need to consume 10 kg CO2 on each.

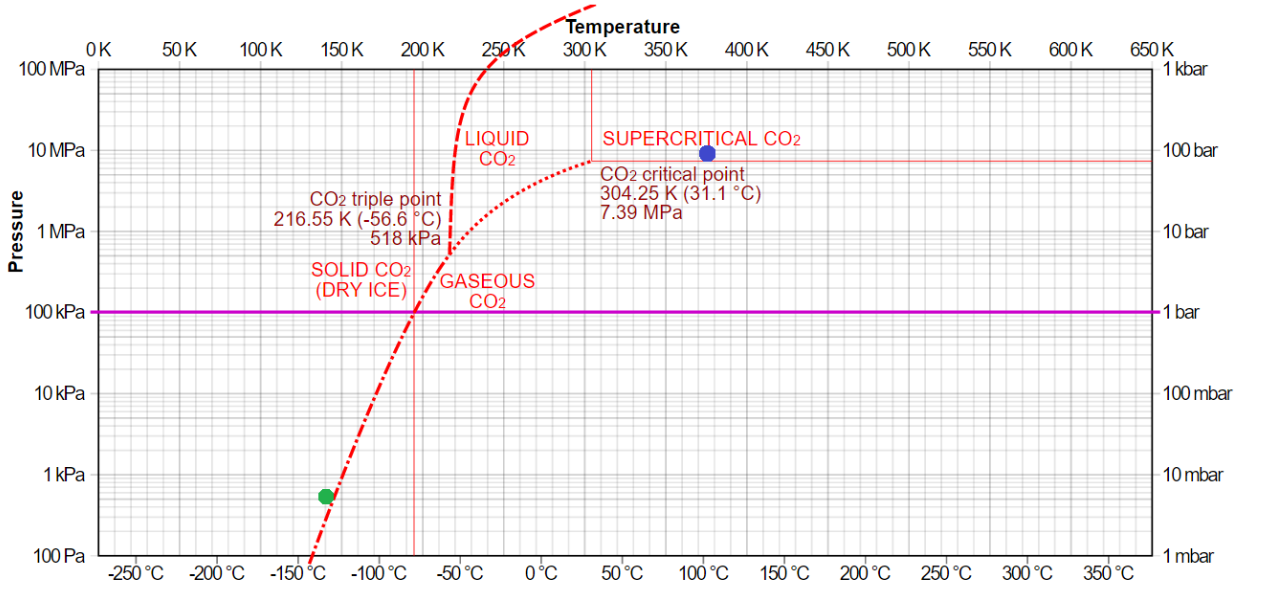
We can change acceleration and accordingly CO2 consumption, but totally, we need very roughly 50 kg of CO2.

3. Energy consumption

Here we need to estimate how many energy we need to accumulate in 50 kg CO2 and to evaluate whether we can get this energy with existing technologies.

Dry ice harvested with surface condition T = -130 C, P = 600 Pa (green dot on plot below, near the phase transition). Our goal is to accumulate energy (reach blue dot). While heating dry ice we sublimate it to gas phase. We have an advantage that dry ice is near phase transition. Pressure of gas rises and we achive triple point of CO2. After that, we begin to obtain liquid phase.

What energy we need to apply to transit from green dot to blue dot?



Suppose dry ice is crumbly, with density

$$\rho_{crumbly} = 1000 \,{}^{kg}\!/\!_{m^3}$$

$$\rho_{solid} = 1562 \,{}^{kg}\!/\!_{m^3} \; solid\ CO_2, 1atm - 78,5C$$

$$\rho_{liquid} = 1101\ kg/m^3 \left(liquid\ \ at\ \ saturation\ \ -37°C\right)$$

Thus, reservoir with volume 50 l has 50 kg of CO2/

<u>Heat capacity of solid</u> $C_{co2} = 1047 \,{}^{J}\!/\!_{\kappa g \cdot K}\ with T = -130C$ (To heat 1 g of CO2 for an 1K we need to apply 1J)

<u>Enthalpy change of sublimation</u> $q^s{}_{co2} = 590 \,{}^{\kappa J}\!/\!_{\kappa g}$ (To transit 1g solid CO2 to gas we need 590J)

<u>Enthalpy change of fusion</u> $q^f{}_{co2} = 184 \,{}^{\kappa J}\!/\!_{\kappa g}$

How much mass of CO2 we need to sublimate to reach triple point and how much energy we need for this?

We can use Van der Waals equation.

$(p+\frac{a\nu^2}{V^2})(V+b\nu) = \nu RT$, where a=0.36088 N•м4/mol^2, b=42.840 sм3/mol

$$V = V_0 - \frac{m_{solid}}{\rho_{solid}} = 50 - 32 = 18l$$

$$p = 518\kappa Pa$$

$$T = 216.55K$$

$$m = 240g$$

$$Q = q^s m = 141356J$$

Thus, we need to sublimate approximately 240g of CO2 and 142 кJ. To reach triple point we need also to heat dry ice

$$Q = C_{solid} m_{solid} \Delta T = 1.16 \cdot 50 \cdot 80 \approx 4.7MJ$$

How much energy we need to melt all ice?

$$Q = q_n m_{solid} = 9.2MJ$$

To heat liquid to 100C we need:

$$Q = C_{liq} m \triangle T = 2.46 \cdot 50 \cdot 150 = 18.45MJ$$

Totally, to transit from green to blue dot we need approximately 23MJ.

$$Q_{total} = 4.7 + 18.45 + 0.141 + 9.2 = 32.2MJ$$

We decided to heat to 100C because it accumulates sufficient amount of energy to prevent phase transition after injection to de Laval nozzle (phase transition will lower pressure in the nozzle, thus lower thrust).

Energy source.

We suggest using radioisotopes as a main energy source. Approximately 1 kg gives 0.5 kJ/s. Suppose we use 10 kg of radioisotopes, and we have ideal case when all energy goes to dry ice. Than we need

$t = \frac{32.2}{0.005} = 6440s = 1.8h$ to wait on surface for energy recharge.

If take into account roughness of estimations we may rely on 2-4 h of energy recharge.

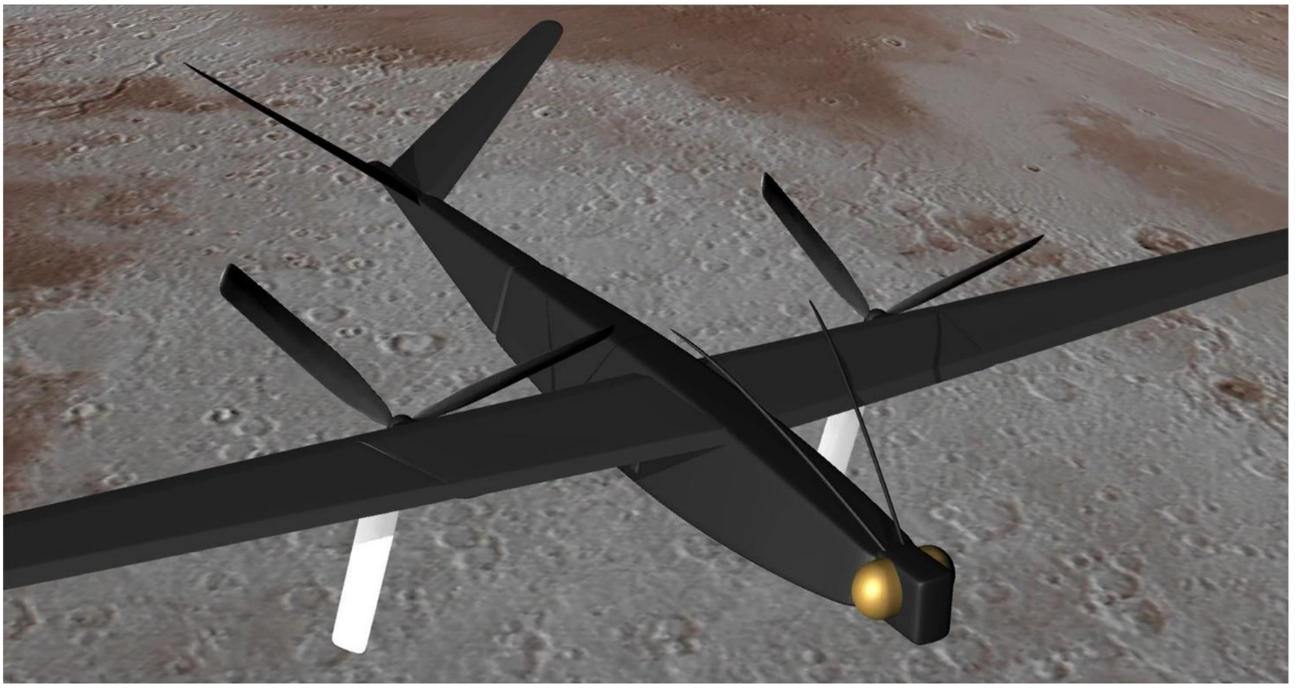
Thus, we confirm energy viability of MarsHopper project.

MODELING

1. Virtual model

We created virtual model of MarsHopper. This model we put in the virtual environment that resembles surface of Mars. Video on link below demonstrates the process of unpacking, initial landing and further start with jet thrust.

https://www.youtube.com/watch?v=-1Za_VylHnQ



2. Real life demonstration model

We created demonstration model of plane powered by CO_2 pressure.

We reached 4atm pressure in the 0.5l bottle.To do this we need only 3g of solid CO_2. Video of flight process with these parameters is available on the link below.

https://www.youtube.com/watch?v=W8fOkVJrmQw

FUTURE OF MARSHOPPER

We are starting Earth Hopper project. Its aim is to test different technical aspect of future MarsHopper mission. First subproject is to create prototype on earth to test heat transfer system and propulsion system. Second subproject is to test plane by releasing it from aerostat at 35км, to test transformation process and flight process at this altitude that resembles Mars atmosphere. National Space Agency of Ukraine showed interest in our project and we expect on cooperation.

OPEN QUESTIONS

Jet engine design at low temperatures.

Heat system design (energy transition from radioisotopes to CO_2)

Precise calculation of wings lift force

Heat preservation

Autonomous flight control

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