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A CONCEPT OF SUBORBITAL SCIENTIFIC MISSION AND TECHNOLOGY VALIDATION

Andrzej Kotarski
Polish Astronautical Society, Warsaw Poland
Tripoli Rocket Association, Warsaw Poland
andrzej.kotarski@gmail.com

Abstract

Suborbital platforms are one of alternatives for satellites. They offer cheaper access to space to perform broad range of scientific and technology R&D. One of suborbital platforms are sounding rockets, which are suitable for these applications. A concept of scientific mission utilizing the sounding rocket is presented by author in this paper. The novelty of this mission is the operational responsive launch approach, which presents the example of the mission which responds for payload user needs, not payload contest approach, which is often in scientific community competing for payload space in space agency sounding rocket launch campaigns. The main mission goal is to perform astronomical observation of NEO using IR/VIS telescope. The secondary goal is to qualify the instrument for use on astronomical satellite observatory and raise its technology readiness level from TRL 6 to TRL 8. The expected mission output is to gain scientific data on NEO object and perform new IR/VIS optoelectronic instrument technology validation.

Keywords: Suborbital platforms, sounding rockets, space science, optoelectronic instrument, technology validation.

1. INTRODUCTION

Suborbital platforms are not new class of vehicles used for technology and science research and development. The first suborbital platforms were sounding rockets. Their application for this purpose began shortly in second half of 1940's, when V-2 rocket launched from White Sands on April 16th, 1946 started the application of sounding rocket for upper atmosphere research and solar radiation through early 1950's [1][2]. Sounding rockets today despite the satellites offer very broad range of applications like:

1. Solar system exploration,
2. Astrophysics,

3. Education,
4. Technology development,
5. Microgravity sciences,
6. Solar physics,
7. Earth-space science [3].

The most broad range applications is seen in NASA Sounding Rockets Program, which is cited above. The other notable examples of sounding rockets programmes are in Europe (ESA), India, Japan, China which are applied for one or more of above goals. In Poland sounding rockets were used mainly for meteorological research, but other applications were also considered and tested [4]. It is worth to mention about REXUS/BEXUS education program conducted by European Space Agency, in which students from Polish universities were participated. To date Polish 3 experiments were flown. In this program students are learning hands on experience of space projects and are testing novel scientific and technical experiments. The applying procedure is the payload contest, which is used by scientific community [5]. In recent years there was seen another shift in sounding rocket usage. There is emerging trend of missions which are performed operationally responding on demand of the customer. The customer oriented approach is the sign of New Space trend.

2. MICROGRAVITY ENVIRONMENT COMPARISON BETWEEN ORBITAL AND SUBORBITAL PLATFORMS

There are two main parameters which are significant in comparison of suborbital and orbital platforms microgravity environment:
1. The intensity microgravity in respect to Earth's gravity,
2. The duration of microgravity effect.

The examples of microgravity platforms used for comparison are:
1. Sounding rockets Maxus, Texus [6,7], Space Loft XL [8].
2. Microgravity satellite Photon (for comparison only) [6].
3. International Space Station [6,7].

In Table 1 microgravity environment present on board sounding rocket is compared to two orbital platforms: Photon satellite and International Space Station.

Table 1. Quality and duration of microgravity environment on board of microgravity platforms.

Microgravity platform	**Sounding rocket**	**Photon satellite**	**ISS**
Microgravity level [g]	10^{-4}-10^{-5}	10^{-5}-10^{-6}	10^{-4}-10^{-6}
Low gravity exposure duration time	1-10 min	10-15 days	10-180 days

Comparing the sounding rocket to other microgravity platforms like satellite and International Space Station its microgravity has the level in part of range of those available on last one but the duration time is very short. But another factor is important. The pre-launch and integration time. In space technologies there is visible trend of shortening of development time of new products and maturation time of space technologies. The timing to enter the market with new products and services ahead of competitors is crucial especially for commercial customers and public entities, where short decision times are crucial in fostering the innovation.

In Table 2 there are shown pre-launch and integration times of specified microgravity platforms above.

Table 2. Pre-launch and integration time of microgravity platforms.

Microgravity platform	**Sounding rocket**	**Photon satellite**	**ISS**
Pre-launch and integration time	4-24 months	12-30 months	6-60 months

Table 2 shows that shortest pre-launch and integration times are available for sounding rockets operated by commercial entities. The difference is caused by customer oriented approach taken by commercial entities. Customer oriented approach gives the launch opportunity tailored to its needs and forces to maintain the quality of the service and competitive price. The main setback is the short microgravity duration offered by sounding rockets flight profile.

3. MISSION GOALS

The goals of proposed suborbital mission are following:

1. Perform the observation of NEO (PHA) using VIS/IR telescope.
2. Qualify the instrument for use on astronomical satellite observatory and raise its technology readiness level.

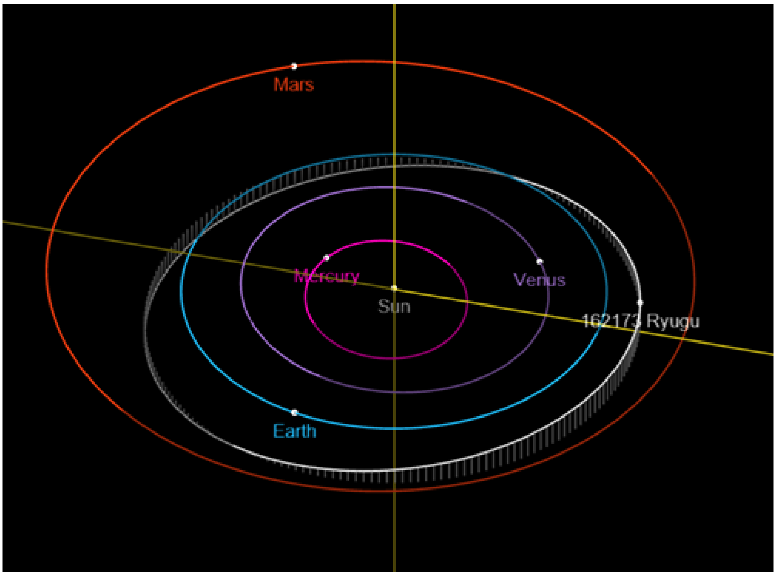
The expected output of this mission are hyperspectral characteristics of the NEO (PHA) asteroid in visual and infrared bands. The next output is the VIS/IR instrument validation for use on astronomical satellites and raise its technology readiness level.

4. MISSION TARGET

The target for suborbital mission 162173 Ryugu (1999 JU3) asteroid was selected. This asteroid belongs to rare spectral type Cg with both quantities of C-type and G-type asteroid [3]. This special characteristics caused that this minor planetary body was selected as the mission target. The orbit parameters of the Ryugu asteroid are presented below:

– Aphelion (AU): 1.41588260292345;
– Semi-major Axis (AU): 1.18954560042591;
– Rotation (hrs): 7.63;
– Inclination (deg): 5.88403511511904;
– Perihelion (AU): 0.963208597928362;
– Period (days): 473.881843720376;
– EMOID (AU): 0.000225189;
– e: 0.190284255403881;
– epoch: 2458000.5;

– dv (km/s): 4.663117;
– ma (deg @ epoch): 154.021706818727.



Pic. 1. Ryugu asteroid orbit *(CNEOS NASA)*.

Very interesting is the chemical composition of Ryugu. Basing on astronomical observations this asteroid contains following chemical elements:
– nickel,
– iron,
– cobalt,
– water,
– nitrogen,
– hydrogen,
– ammonia.

Its value according to Asterank database is estimated for 82.76 billion USD [9]. Because the mission target is moving with respect to Earth orbit, there are specified time periods where it is available for observers at launch site. The nearest close approach to Earth is expected on December 29th, 2020 year according to Asterank, but calculated for mission scenario described in this article basing on the data obtained from the NASA JPL closest approach observed from Łeba launch site is on March 12th 2022 at 06:06:34 GMT. The mission target will be moving with respect to Earth and sounding rocket payload and there are two challenges ahead:
1. Determination the launch window to perform the asteroid observation.
2. Payload attitude orientation and control during the observation.

Launch window is dependent on visibility of mission target from the launch site and minimised light pollution from Earth. Boundary conditions were as follow:

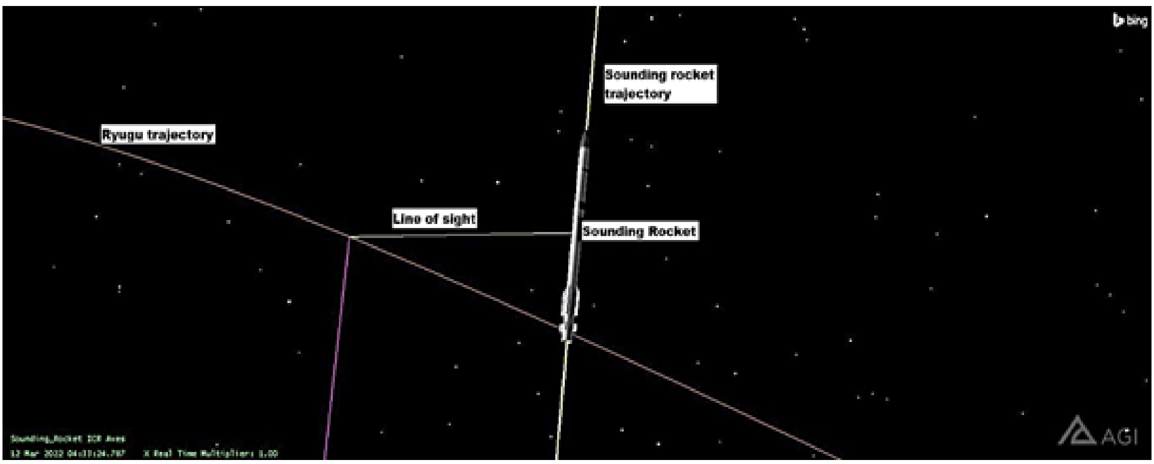
1. Elevation angle above the horizon 15 degrees.
2. Umbra time to penumbra start time.
3. Observation window near maximum angle of elevation from launch site.

Basing on data used to calculate closest approach seen from launch site on date specified above launch window was determined. Table 3. Shows launch window times and mission target position with respect to the launch site.

Table 3. Launch window times and mission target observation parameters from launch site.

Date [UTCG]	**Time [UTCG]**	**Azimuth [deg.]**	**Elevation [deg.]**	**Range [km.]**	**Launch window time**
12.03.2022	02:05	142.8	15.1	20 442 830	Launch window opens
12.03.2022	04:34-04:37	180.2	22.1	20 440 540 to 20 440 516	Mission target maximum elevation window
12.03.2022	05:15	190.9	21.6	20 440 270	Launch window closes

Crucial issue to perform the observation of the mission target is to ensure the payload stability. To maintain required payload attitude accuracy 3-axis attitude and orientation control system is necessary. The AOCS system will contain chemical propulsion system or cold gas system, gyros and star trackers. Prior payload deployment fixed orientation of the rocket during the flight will be necessary. And mission target trajectory have to be loaded into AOCS system memory.



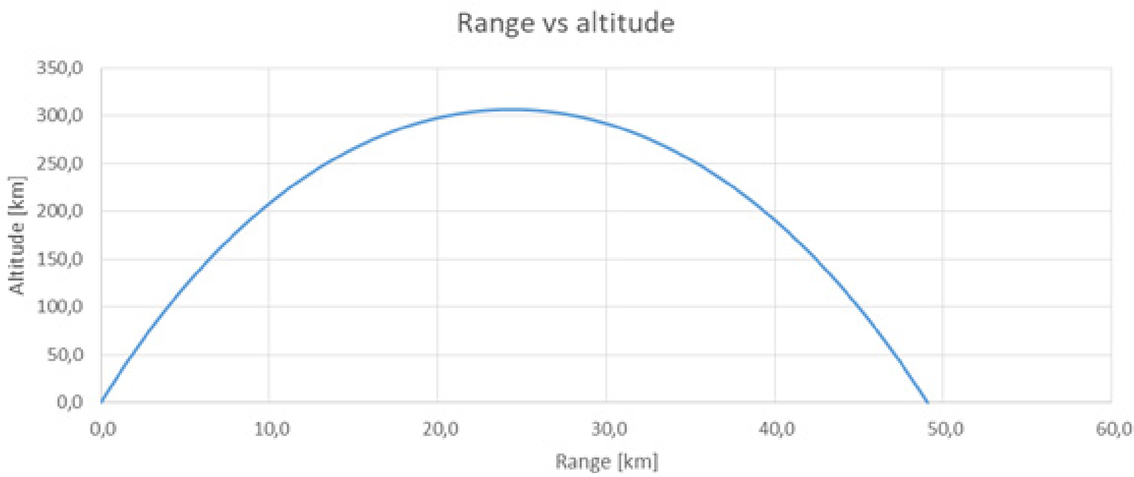
Pic. 2. View from sounding rocket to mission target.

5. MISSION PAYLOAD

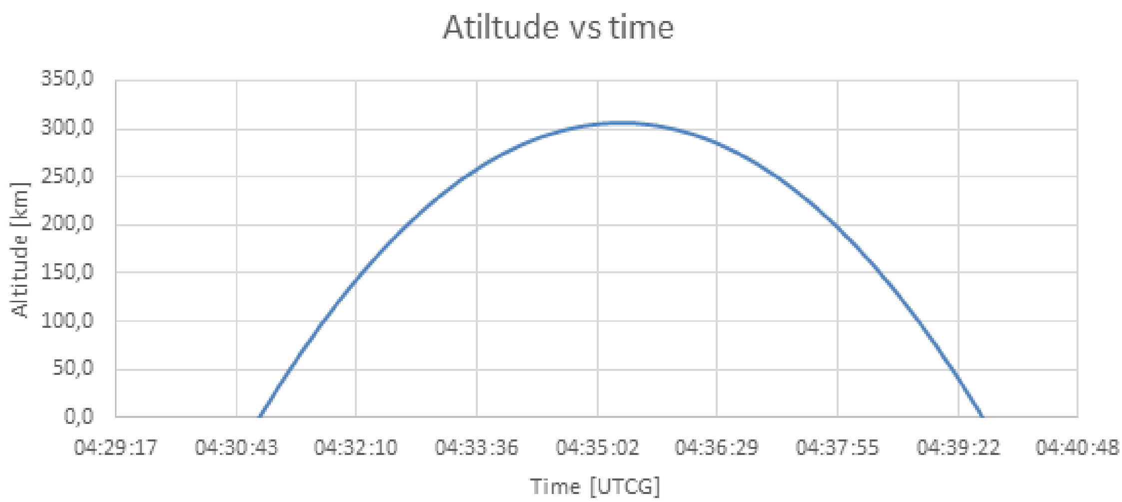
The mission payload will be hyperspectral telescope with synthetic aperture covering the spectral range 350-12000 nm to be used on astronomical microsatellite observatory. The estimated weight of the instrument is about 3 kg. Apart of instrument alone ACS module and recovery system will be added. The overall payload mass is estimated for 10 kg. The instrument is the proprietary technology of one the space company developing high quality optoelectronics. Communication with the payload will be maintained on S and X-bands. Payload telemetry will be sent on S-band. Payload scientific images will be sent on X-band.

6. MISSION TRAJECTORY

The trajectory profile of the sounding rocket carrying the mission payload is depicted on Pic. 3. and 4. Picture 3 shows the trajectory profile vs ground range. Picture 4 shows the mission altitude vs time.



Pic. 3. Suborbital mission general trajectory profile. Payload recovery phase not included.



Pic. 4. Suborbital general mission profile altitude vs. time. Payload recovery phase not included.

The suborbital mission trajectory is a ballistic one. The peak of the trajectory will be achieved after 4 minutes and 20 seconds. To reach 306 km altitude 2.4 km/s delta vee is required at least [5]. Drag and gravity losses are to be added for velocity budget and are depending on sounding rocket drag characteristics. Two stage sounding rocket is considered to lift the mission payload.

7. SUBORBITAL MISSION LAUNCH SITE

The launch site of the NEO suborbital mission for conceptual study near Łeba in Poland was selected, where Meteor sounding rockets were launched. The launch range and launch corridor are depicted on Pic. 5.

Pic. 5. Launch range zone and launch corridor of NEO Suborbital Mission. Green – impact zone. Red – launch range zone. Purple – launch site.

Temporary launch range zone was determined to provide the allowable launch azimuth and launch elevation angle to perform the mission. It provides the dedicated airspace and sea surface where other air and sea vehicles than those used in mission are not allowed to enter the launch range. In case of veering off the sounding rocket from the nominal flight profile flight termination system will separate the mission payload and destroy the sounding rocket to prevent the damage on the ground.

8. MISSION SCENARIO

After defining all elements mission scenario presents as follow. Two stage sounding rocket lifts off from the launch site in Łeba at 4:31 UTCG. Onboard computer has mission target data and maintains pre-programmed trajectory and rocket attitude in respect to it. 20 seconds later at height about 46 km after first stage engine burn-out, depleted stage is jettisoned and second stage engine starts burn and continues flight along programmed trajectory and attitude. At height of 57 km and in 25 second of flight second stage ends its burn and rocket coasts to higher altitude. At 100 km height and in 46 second of flight fairing is jettisoned and payload separates from second stage with active attitude control. Having the attitude and flight trajectory inherited from second stage of sounding rocket payload using own AOCS begins fine target acquisition phase and begins target scanning transmitting data to ground station. At 306 km and in 4 minutes 20 seconds of flight payload reaches peak of trajectory and descends toward surface of Earth. At 150 km height and in 7 minute 25 second of flight mission target scanning ends and payload begins recovery phase using two stage recovery device. After successful deployment of recovery device payload lands in sea and is recovered by recovery crews.

9. CONCLUSIONS

A suborbital mission concept for NEO hyperspectral observations and VIS/IR instrument technology validation was presented. The output from the mission will be hyperspectral data of Ryugu asteroid and new broadband hyperspectral instrument technology validation to raise its TRL level from 6 to 8 for use on microsatellite astronomical observatories. The mission will be performed on two stage sounding rocket, which will carry the 6-10 kg payload on 306 km altitude. The studied launch site was Łeba in Poland. To prevent the damage on the ground launch range zone and impact zone were established.

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KONCEPCJA NAUKOWEJ MISJI SUBORBITALNEJ I WALIDACJI TECHNOLOGII

Streszczenie

Platformy suborbitalne są jedną z alternatyw dla satelitów. Oferują one tańszy dostęp do przestrzeni kosmicznej na cele badań naukowych i rozwoju technologii. Jedną z suborbitalnych platform są rakiety badawcze, które są odpowiednie do tych zastosowań. W niniejszym artykule autor prezentuje koncepcję naukowej misji suborbitalnej z użyciem rakiety badawczej. Głównym celem misji jest przeprowadzenie astronomicznych obserwacji obiektu NEO z użyciem teleskopu pasma widzialnego i podczerwieni. Dodatkowym celem jest kwalifikacja instrumentu do zastosowań na astronomicznych obserwatoriach satelitarnych oraz podniesienie jego dojrzałości technologicznej z TRL 6 do TRL 8. Oczekiwanym rezultatem misji jest zebranie naukowych danych nt. obiektu NEO i przeprowadzenie walidacji nowego instrumentu optoelektronicznego pasma widzialnego i podczerwieni.

Słowa kluczowe: platformy suborbitalne, rakiety badawcze, nauki o przestrzeni kosmicznej, instrument optoelektroniczny, walidacja technologii.