AerospaceEurope Conference2021
WARSAW, POLAND | 23 -26 NOVEMBER 2021
CEAS Council of European Aerospace Societies

SOME RESULTS OF RESEARCH ON THE LATLAUNCH PROJECT FOR THE LAUNCHING SYSTEM OF PICO- AND NANOSATELLITES INTO LOW EARTH ORBIT

N.Kuleshov[1,2], V.Shestakov[1,2], S.Kravchenko[1,2], I.Blumbergs[1], D.Titov[1], N.Panova[1,2].

[1]Riga Technical University, 1 Kalku, street, Riga, LV-1658, Latvia, E-mail: kuleshov0552@gmail.com.
[2]Cryogenic and vacuum systems, 7/9 Andreja street, Ventspils, LV-3601, Latvia.

Abstract

Innovative technical solutions are considered for the delivery system of pico- and nanosatellites to low Earth orbits (LEO) from an aircraft platform. This launch system includes an A319 transport aircraft as an aircraft platform and a three-stage launch vehicle, code-named LatLaunch. After being dropped from the platform, the first stage, the aerodynamic prototype of which is one of the supersonic interceptor fighters, delivers the second stage to its optimum altitude at the optimum flight speed and dropping it. The article presents the results of a study of the technical characteristics of existing and prospective samples of aviation technology to obtain the necessary compromise between the altitude and flight speed of the first stage of LatLaunch in conjunction with the second stage before its dropping and an assessment of the characteristics of the second stage, which are necessary to carry out the withdrawal of the third stage of LatLaunch system to a given height at a given speed.

Keywords: aircraft platform, a satellite launch system, carrier stage, launch system characteristic

Acknowledgments

The authors are grateful for the support of the Latvian Council of Science, within the framework of which Project No. Lzp-2018/2-0344 “Design and modelling of Aerospace System for Launching pico- and nano-Satellites to Low Earth Orbit” the discussed research was performed.

1. Introduction

The Riga Technical University (Latvia) is developing a project of a launch system to carry up pico- and nanosatellites (PNS) into low Earth orbit (LEO) using an aerial platform called LatLaunch [1]. Launch systems, using a winged launch vehicle to launch PNS into LEO, have been developed since the middle of the 20th century in the USA [2], in the USSR (RF) [3], and other countries. Having analysed such options, an A319 type transport aircraft was chosen as the air platform and a three-stage launch system of PNS was specified as a launch carrier, the aerodynamic and specific characteristics of the first stage of which are the characteristics of one of the supersonic aircraft interceptors and a perspective winged vehicle waverider as a second stage of the launch carrier. The MiG-31 fighter-interceptor was chosen as an aerodynamic prototype of the first stage based on its technical characteristics (flight altitude record, flight speed record, and the availability of information on some aerodynamics characteristics) [4]. A mathematical model of the aerodynamic parameters of the first stage of Latlaunch was developed based on the aerodynamic characteristics of this aircraft. As the power plant of the LatLaunch first stage, the AL-55F jet engine was chosen. Modification of this engine can significantly increase its features.

The report presents the methods used by the authors to determine the flight parameters of the first and second stages of the LatLaunch, an assessment of the necessary characteristics for the implementation of the third stage to launch a satellite to a given altitude at a given speed, and an assessment of the results obtained, taking into account the problems of the aerodynamics of the carrier and the problems of increasing the power of engines for flight on high speeds and altitudes.

2. Winged systems for launching micro and nanosatellites into low Earth orbit

In the USA, some aircraft were studied as a possible first stage of a winged launch system (F-106, F-4, F-14, F-15), in the frame of the RASCAL project (Responsive Access, Small Cargo, Affordable Launch). In the course of research under the RASCAL program, the F-15 aircraft of various modifications were identified as the most suitable carrier aircraft with the F100 engine and a launch weight of up to 32 tons [2].

It was determined that the first stage of the launch system will consist of a reusable aircraft similar to the Air Force's large-scale fighter F-22. The first stage will also use pre-compressor-cooled turbojets with fuel injection in accordance with the MIPCC concept (MIPCC - Mass Injection Pre-Compressor Cooling), which gives the possibility to raise the stage by about two hundred thousand feet before launching the second and third rocket stages. The first stage will be similar to a large fighter of the F-22 class, but a turbojet engine will be found in the more affordable F100 class. The flight profile is very similar to that which is flown by a typical aircraft. The launch vehicle segment of the flight profile is depicted in Fig. 1. The first stage attains only 12% of the altitude obtained in the overall mission [2].

In the USSR, in 1993, a project "Burlak" was presented on the basis of a modified Tu-160SK carrier aircraft [5]. The MiG-Cosmos JSC offered an aerospace complex based on the MiG-31 fighter-interceptor is designed to launch a satellite with a payload weight of up to 150 kg into LEO. The MiG-31 aircraft has unique characteristics that ensure its high efficiency as a carrier aircraft. The complex includes an aircraft as a carrier, designated MiG-31I, a three-stage carrier rocket suspended between the engine nacelles, and an air command and measurement complex based on the Il-76MD aircraft [3].

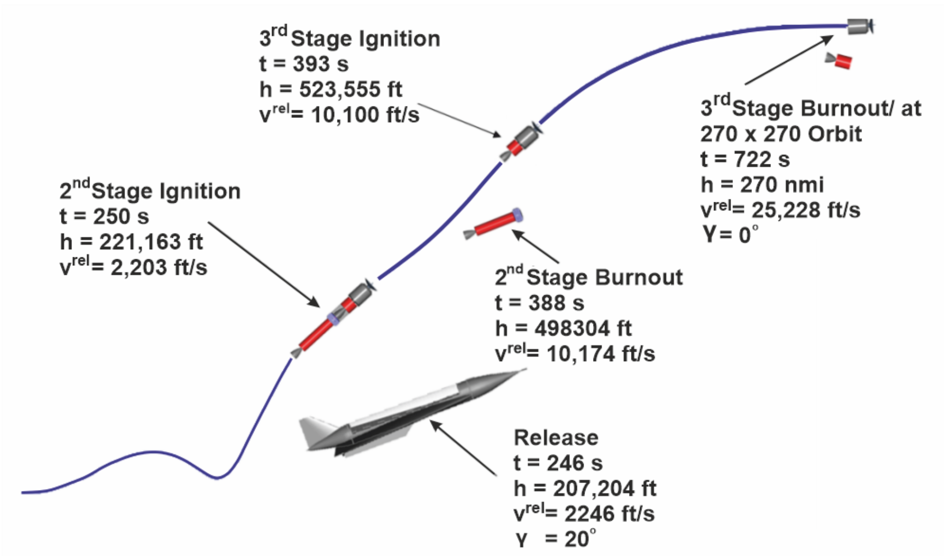

Fig.1 Launch component Breakdown according RASCAL [2]

3. External appearance and power plant of the Latlaunch first stage

The system for launching micro and nanosatellites into LEO, being developed at the Institute of Aeronautics of the RTU within the framework of a research project, has the code name LatLaunch [6]. This system includes platform aircraft and a three-stage launch system for the output of micro and nanosatellites, which, in turn, consists of two reusable stages in the form of winged carriers and one stage in the form of a non-reusable rocket. Such a scheme allows reusing of both the platform aircraft and the first two stages of LatLaunch, which presumably will reduce the cost of launching micro and nanosatellites into LEO and also reduce the pollution of outer space and the earth's surface [1]. As the prototype of the first stage of Latlaunch, the MiG-31 fighter-interceptor, holder of several records for speed and flight altitude, was chosen. The geometric and weight parameters of the first stage were determined based on the possibility of its location on the external sling of a specialized A319 transport aircraft [7].

Taking into account the limitations imposed by the kinematics of various structural elements of the A319, the main geometrical dimensions of LatLaunch are: the permissible span, taking into account the gaps between the parts of the LatLaunch 1st stage and the aircraft-platform A319, is 8.5m; the first LatLaunch stage length is 12.9m; the first LatLaunch stage wing area is 26.6 m2; the LatLaunch total mass is no more than 10 tons (a limitation imposed by the A319 design); the wing loading, maximum, is 3687 N/m^2 (significantly lower than the maximum wing loading of the prototype which is 6327 N/m^2), Fig. 2.

a) b)

Fig. 2. General views of the considered LatLaunch system: a) - a combination of a platform aircraft and available space for accommodating LatLaunch; b) - available space for LatLaunch placement

Also, a mathematical model of the aerodynamic parameters of the first stage of Latlaunch was developed based on the aerodynamic characteristics of the prototype aircraft. As the power plant of the LatLaunch first stage, it is proposed to use an AL-55F jet engine, which has a maximum thrust of 29,420 N with a mass of 425 kg, specific fuel consumption of 1.65 kg/(kgf·h), and air consumption of 29.5 kg/sec [8]. MIPCC technology allows increasing the jet engine thrust up to 11%, its altitude performance up to 45000 meters, and its speed performance up to 6M [9].

During the modernization of such an engine, MIPCC technology proposes to use by injecting a large amount of water into the engine's air intake [10]. The afterburner can be dual-mode, that is, at low speeds and at low altitudes, hydrocarbon fuel is used in the afterburner, and hydrogen is used at high speeds and altitudes. The use of an additional substance, nitric oxide, to increase the thrust of the engines was also been used by the strategic reconnaissance aircraft SR-71 (USA) [11]. The RASCAL project investigated the possibility of using the F-15 with applied the MIPCC technology to the F-100 engine [1].

4. Determination of the speed and altitude flight of the LatLaunch first stage when dropping the second stage

When determining the launching trajectory, the data of the RASCAL project (see Fig. 1) and the MiG corporation Ishim project on the use of the MiG-31I aircraft were taken into account. According to the calculations of the developers of the Ishim project, the system is capable of launching a satellite weighing 150 kg into a circular polar orbit (700-1000 km). When the mass of the target load is doubled, the orbit altitude decreases to 200 km. At the same time, the MiG-31 takes off with a climb up to 16-17 km and subsequent acceleration in horizontal flight up to a speed of 750 m/s (M = 2.54). Then the MiG-31I performs a manoeuvre to increase the angle of trajectory so that the launch rocket was dropped when the trajectory is inclined 20 degrees to the horizon [12]. Using this information in relation to the first launch stage of LatLaunch allows determining the altitude for the acceleration before dropping the first stage of the winged air-launch vehicle LatLaunch. This height for the first stage of LatLaunch corresponds to 35-36 km. Then the first latLaunch stage climbs and at a maximum speed of 6M, pitch up its nose and dropping the second stage of LatLaunch.

5. Determination of the overall dimensions of the second stage LatLaunch

If the second launching stage has been dropped at a speed of 6M and at an altitude of 35 km then the lift force of the second LatLaunch stage $L_{2,35}$, at this altitude and corresponding to all these data the value of $(L/D)_{max}$, is $L_{2,35} \approx$ 11110 N with the mass of the second stage of G_2 = 39230 N. That is, the flight of the second LatLaunch stage at a speed of 6M at an altitude of 35 km possible only along an inclined trajectory with an angle $\alpha = arccos(L_{2,35}/G_2) \approx 74^o$, when a part of the aircraft weight is balanced by the engine thrust.

From the other side, the information about the optimal angle of inclination of trajectory is given in RASCAL report [1]. It is 20 degrees. This information allows to determine some geometric parameters of the second LatLaunch stage, based on the fact that the wing area, for flight along a trajectory with an inclination angle of 20 degrees, an altitude of 35 km, a speed of 1852 m/s, and a velocity head of 11499 kg/(m·sec^2), should be $G_2 \cdot cos(20^o)/(Cy_2 \cdot \rho_{35} \cdot (V_2^2/2)) \approx$ 96 m^2, which is unrealistic, where G_2 = 39 230 N is the weight of the second LatLaunch stage; Cy^2 = 0.0272 - second stage lift coefficient; $\rho_{35} \cdot (V_2^2/2)$ - high-speed head (ρ_{35} = 8.2139·10-3 - air density at 35 km altitude, V_2 = 1852 m/s - second LatLaunch stage speed during dropping). Therefore, an altitude of 35 km is not suitable for dropping the second LatLaunch stage.

As an alternative for the dropping of the second LatLaunch stage at an altitude of 35 km, a calculation was carried out to determine the favourable altitude for the dropping of the second stage and the mode of its passive flight until its own engines starting and entering into the full mode. The favourable dropping altitude was 26900 m, the speed was 1798 m/sec, the flight in the corridor 26900 - 27000 meters for 5 seconds is maintained by changing the inclination of the trajectory from horizontal to inclined, with the decrease of the weight projection of the second launching stage to the normal axis of the flight trajectory. The decrease in flight speed due to this manoeuvre is about 7 m/s. In the project it is proposed to perform the Latlaunch second stage according to the waverider scheme, then its aerodynamic characteristics can be estimated according to the data presented in [13], see Fig. 3 and Fig. 4.

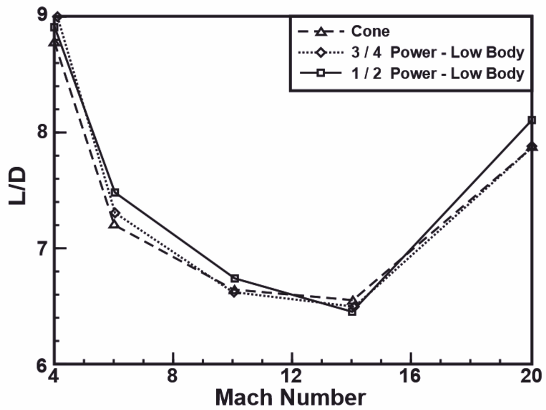

Fig. 3. Lift-to-drag ratio vs Mach numbers for the optimum waveriders [13]

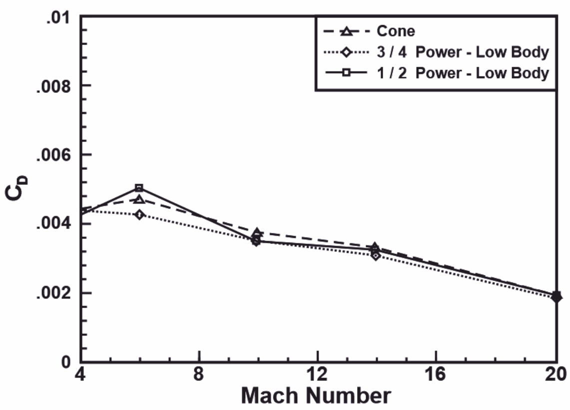

Fig. 4. Drag coefficient vs Mach numbers for the optimum waerieders [13]

LatLaunch, as a peaceful object, does not need the high manoeuvrability of its prototype - aircraft-interceptor, which simplifies its aerodynamic layout and provides a decrease in drag, the weight of its structure, and an increase in $(L/D)_{max}$, that means a decrease in the required thrust, respectively. The second direction of improving the aerodynamic qualities of LatLaunch at high speeds is the transition to the aerodynamic design of the waverider, which shows significant advantages in hypersonic flight modes. The ideas inherent in the concept of a waverider are illustrated in Fig. 5 [14].

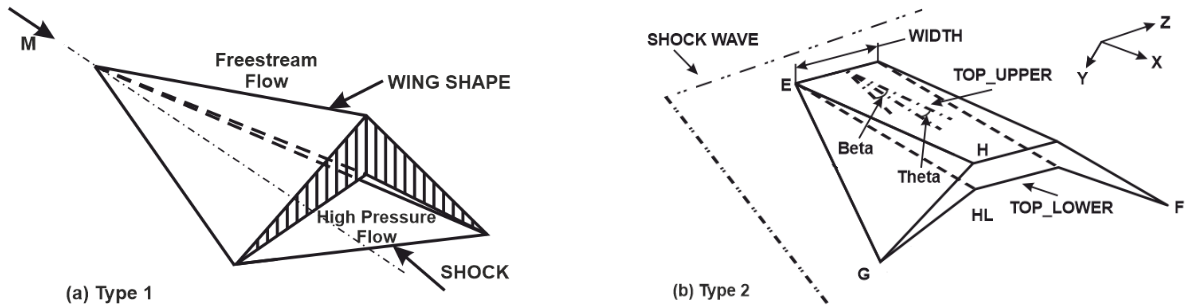

Fig. 5. The idea behind the waverider flight design [14]

Calculations. For the considered speed of the second stage after its dropping, which is 6M, and the range of speeds, which is up to 12M, the coefficient $(L/D)_{max}$ of the waverider is estimated as $(L/D)_{max}$ ≈ 7.2 – 6.6, where *L* is lift force and *D* - drag force. The values of the drag and lift coefficients are *Cx* ≈ 0.004 - 0.0035 and *Cy* ≈ 0.0288 - 0.0231, respectively. For a ¾ Power-Low Body waverider, the calculations give the following data: with $(L/D)_{max}$ ≈ 6.8, the flight speed *M* = 6, and the wing area S_2 in the extended position is $S_2 \approx 25$ m^2.

In this case, the aerodynamic and weight parameters of the second stage of LatLaunch allow the delivery of the third, rocket stage of LatLaunch, to an altitude of 70 km at a speed of 3547 m/s, weighing up to 960 kg. This makes it possible to equip the third stage of LatLaunch with a solid fuel engine with specific characteristics of the Orion-38. Such an engine with an estimated mass of 893 kg and a trust of 34310 N accelerates the third stage to a horizontal speed of 8030 m/s, without taking into account the speed of the earth rotation, to an altitude of more than 300 km, with the mass of last equipment up to 65 kg.

Propose to use a special rocket engine with specific characteristics of rocket engines of the Orion series, such as Orion-38 or Orion-50, designate it as “Orion-42”, that is, an engine with a mass of 1120 kg, with a thrust of 39500 N, and an operating time of 70.1 sec (similar to Orion-50). The third stage of LatLaunch, a rocket launch vehicle with a mass of 1295 kg, equipped with such booster, launching into Earth orbit 300 km equipment weighing 175 kg at an orbital speed of 8003 m/s.

6. Choice of the power plant of the second stage Latlaunch

NASA's Next Generation Launch Technology (NGLT) program is investing in hypersonic air-jet engines that can significantly improve the safety and efficiency of space launch systems. Their advantage over rocket engines for access to space is associated with an increase in the efficiency of the power plant (see Fig. 7), determined by its specific impulse (Isp) [15].

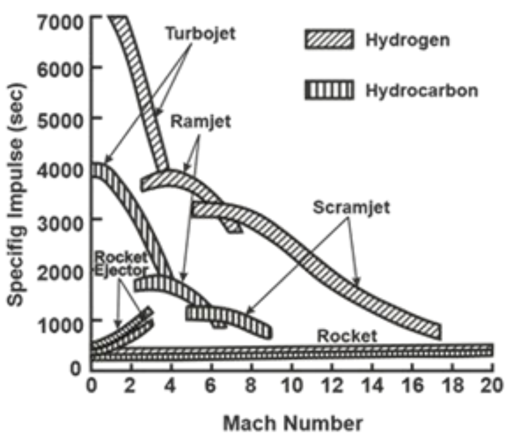

Fig. 7. Approximate specific impulse performance of different propulsion cycles [15]

Various options for NGLT engine technologies are considered: dual-mode ramjet jet engines (ramjet/scramjet engines), rocket-based combined cycle (RBCC) concepts, and turbine-based combined cycle (TBCC) concepts.

As the power plant of the second stage of Latlaunch, it is considered the use of a dual-mode rocket-ramjet engine modified in accordance with MIPCC concept technologies using a two-mode afterburner operating, that is, with a transition from hydrocarbon fuel to hydrogen and vice versa.

MIPCC technology involves cooling the airflow in the engine air intake, including by using liquid hydrogen which is as fuel in the afterburner operating in the ramjet engine mode.

Fig. 8. The appearance of the RCC BrahMos, http://newsby.org/

As a prototype of such an engine, we can consider the ramjet engine ZD55 of the BrahMos anti-carriage missile, Fig. 8 [16]. **Engine data.** The nozzle is regulated by the rotary flaps depending on the design speed for a given section of the flight path. The engine thrust is 4000 kg, the combustion chamber diameter is 640 mm, and the dry weight is 200 kg. The flight speed of the rocket without the use of MIPCC technology methods reaches 3500 km /h.

In the framework of the MIPCC program, studies were carried out to assess the possible results of such modernization of air-jet and rocket-ramjet engines [1] and [9]. Fig. 9 and Fig. 10 presents the results of studies devoted to increasing the altitude of engines and improving their speed characteristics.

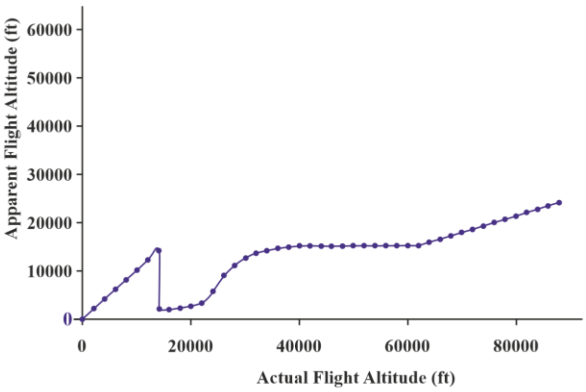

Fig. 9. Apparent Flight Altitude Experienced by the Turbo Machinery as a Function of Actual Flight Altitude [1]

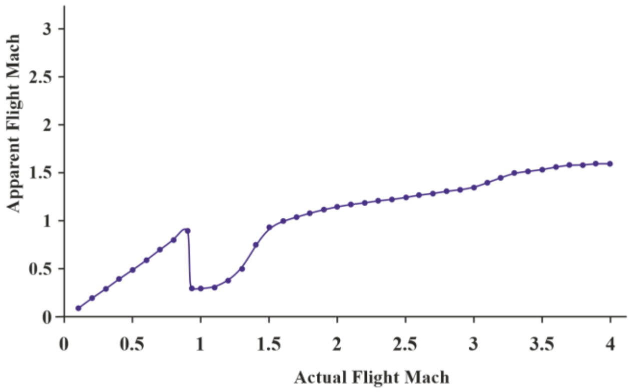

Fig. 10. Apparent Mach Number Experienced by Turbo Machinery as a Function of Actual Flight Mach Number [1]

The modernization of the engine involves equipping it with all the necessary systems provided for by the MIPCC program, in particular, systems for supplying water/water-alcohol mixture to the engine air intake and the hydrogen system that supply hydrogen to the afterburner operating as a ramjet engine, in some scheme after passing liquid hydrogen through the radiator of air intake heat exchanger.

7. Conclusions

Modeling and research within the LatLaunch project show that:

The A319 transport aircraft has overall dimensions that allow placing a three-stage system on the external sling, two stages of which are winged air vehicles for launching micro and nanosatellites into low Earth orbit. The aerodynamic scheme of the LatLaunch first stage prototype, equipped with a low bypass turbojet engine with afterburning, is capable of performing all the tasks of bringing the second stage to a given height at a given speed. At the same time, the first stage jet engine needs to be modificative in order to increase altitude and power features, which is possible with the use of MIPCC technology. The second winged stage of LatLaunch, equipped with a rocket-ramjet engine capable of performing its functions in all flight modes of the second stage at a given altitude with a given speed and trajectory angle.

References:

[1] S. Kravchenko, N. Kuleshov, V. Shestakov, N. Panova, I. Blumbergs. Advantage of Using Aircraft-Type Stages for Creating “LatLaunch” Launch Vehicle. [online cit.: 2021-06-20]. Available from: http://www.tf.llu.lv/conference/proceedings2021/Papers/TF202.pdf

[2] D. A. Young, J. R. Olds. Responsive Access Small Cargo Affordable Launch (RASCAL) Independent Performance Evaluation. [online cit.: 2021-04-06]. Available from: https://www.semanticscholar.org/paper/Responsive-Access-Small-Cargo-Affordable-Launch-Yo

[3] A.Fomin, I.Afanasjev “Migom” – to stars”. “Isim” project. [online cit.: 2021-04-06] Available from: http://www.airwar.ru/enc/other/mig31i.html (in Russian)

[4] Kulikov A.A. 1978. Practical aircraft aerodynamics MiG-25RB. / Ed. Silin A. N., Moscow: Military publishing house of the USSR Ministry of Defense, 320 p. (tutorial, in Russian)

[5] Balashov V.V., Buzulukov V.M., Davidson B.Kh., Smirnov A.V. VOZMOZHNOSTI ISPOLZOVANIYA SERHZVUKOVIH SAMOLETOV-NOSITELEY DLYA ZAPUSKA MALIH, MINI- I MIKROSPUTNIKOV. [online cit.: 2021-04-06]. Available from: https://readings.gmik.ru/lecture/2003-VOZMOZHNOSTI-ISPOLZOVANIYA-SVERHZVUKOVIH-SAMOLETOV-NOSITELEY-DLYA-ZAPUSKA-MALIH-MINI--I-MIKROSPUTNIKOV (in Russian)

[6] A. Urbahs, S. Kravchenko, M. Urbaha, K. Carjova, N. Panova, R. Chatys. LatLaunch Air-Launch System for Low-Cost Launching of Small Satellites into Low Earth Orbit. [online cit.: 2021-06-20]. Available from: https://journals.vgtu.lt/index.php/Aviation/article/view/12382

[7] Airbus A319. Aircraft Characteristics Airport and Maintenance Planning. 2005. Airbus S.A.S., 367 p.

[8] A. Lulka-Saturn, joint stock company. [online cit.: 2021-04-06]. Available from: https://docplayer.ru/58840415-Tel-095-faks-095.html (in Russian)

[9] YU.A. Ulitenko, A.V. Yelansky, I.F. Kravchenko. Upgrading of bypass turbofan engine

[10]with afterburner by water injection in air intake air-gas channel. Vesnik Dvigatelestroenija, 2/2014. [online cit.: 2021-04-06]. Available from: https://cyberleninka.ru/article/n/modernizatsiya-turboreaktivnogo-dvuhkonturnogo-dvigatelya-c-forsazhnoy-kameroy-sgoraniya-putem-vpryska-vody-v-protochnuyu-chast/viewer (in Russian)

[11] V.Zrelov. Otechestvennie GTD. Osnovnie Parametri i Konstruksionnie Shemi. Part 1. 2002. Samara: Samara State Airspace University. 210 p. (in Russian)

[12] Timothy R. Conners. Predicted Performance of a Thrust-Enhanced SR-71 Aircraft with an External Payload. 1997. NASA Technical Memorandum 104330. [online cit.: 2021-04-06]. Available from: https://www.semanticscholar.org/paper/Predicted-Performance-of-a-Thrust-Enhanced-SR-71-an-Conners/191eb3df2bcaa9f6145849245378a88c1a1d7992

[13] MiG-31. [online cit.: 2021-04-06]. Available from: http://skyships.ru/?page_id=894 (in Russian)

[14] S. Corda, J.d. Anderson. Viscous Optimized Hypersonic Waveriders Designed from Axisymmetric Flow Fields. [online cit.: 2021-04-06]. Available from: https://www.researchgate.net/publication/269215543_Viscous_optimized_hypersonic_waveriders_designed_from_axisymmetric_flow_fields

[15] Feng Ding, Jun Liu, Chi-bing Shen, Wei Huang, Zhen Liu, Shao-hua Chen. An overview of waverider design concept in airframe/inlet integration methodology for air-breathing hypersonic vehicles. [online cit.: 2021-04-06]. Available from: https://www.researchgate.net/publication/327428996_An_overview_of_waverider_design_concept_in_airframeinlet_integration_methodology_for_air-breathing_hypersonic_vehicles

[16] Jr. C.E. Cockrell, A. H. Auslender, R.W. Wayne Guy, Ch. R. McClinton, Sh. S. Welch. Technology Roadmap for Dual-Mode Scramjet Propulsion to Support Space-Axcess Vision Vehicle Development. AIAA 2002-5188. [online cit.: 2021-04-06]. Available from: https://ntrs.nasa.gov/api/citations/20030000444/downloads/20030000444.pdf

[17] BrahMos, rocket PJ-10. [online cit.: 2021-04-06]. Available from: http://militaryrussia.ru/blog/topic-92.html