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# Evolutional Launch Concept for Pico/Nano Satellite

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**ABSTRACT**

As the capabilities (through standardization and modular design approaches) and users (from universities to research laboratories to private companies) of nanosatellites increase, there is a commensurate need for dedicated launch access to space. This paper reviews recent development efforts related to Nano-Launcher, an orbital payload launch service for nano and microsatellites (1-10 kg and 10-100 kg to orbit). The system uses mainly existing elements in combination, based upon existing solid stages (such as the SpaceSpike-1 and 2, stages evolved from the JAXA/ISAS S-520 solid rocket) along with existing air-launch aircraft (such as the F-104 and F-15). Nano-Launcher is deemed to have a lower development risk/cost and will be designed to be more responsive to nanosatellite customers than competing services. The program is being led by the authors with cooperation with Japan's Ministry of Economy, Industry and Trade and Institute of Space (METI) and Space and Astronautical Science (ISAS) of JAXA. Key technologies currently being developed for the system include boost motor propulsion, non-pyrotechnic stage separation system, and lightweight and low-cost avionics. There is envisioned to be a breadth of Nano-Launcher payload delivery services available for suborbital and orbital customers utilizing different combinations of rocket stages and carrier aircraft.

## INTRODUCTION

The global interest in nano-satellites (< 50kg) is increasing throughout the world. There is a large gap in affordable and dedicated launch options for such projects. Many nano-satellites (<50 kg) are used for educational purposes. Yet within the past few years nano-satellite applications have expanded to on-orbit technology demonstration and testing, telecommunications, and earth observation. Such a growing market is ever desperate for launch options. Such options currently include ride shares and piggybacking on medium to heavy expendable launch vehicles. Yet with such options nano-satellite customers have no control over launch schedule and desired orbit. New options would be a valuable service to the ever increasing global community of nano-satellite developers. Given constraints on launch sites for such micro-launchers, for instance limited orbits (no polar launch due to safety issues) and reduced launch windows (only about 180 days per year) at a typical launch site such as the Uchinoura Space Center in Japan, air-launch from a high speed aircraft can provide a better solution for more robust launch of nano-satellites.

This paper presents the results of a recent research and development effort of a "Nano-Launcher" nanosatellite launch vehicle with a Low Earth Orbit (LEO) payload capability of several to tens of kilograms, one that can be technically and economically competitive in the international launch market. Such a nanosatellite launch vehicle development project has just begun and a general outline will be provided of the program here. The program is being led by the authors with cooperation with Japan's Ministry of Economy, Industry and Trade and Institute of Space (METI) and Space and Astronautical Science (ISAS) of JAXA.

The specific concept being described here is an air-launch rocket architecture relying on a high-speed aircraft launching solid rocket stages. Air-launch allows more freedom relative to launch site and launch window constraints. Specific technology maturation activities and development are already underway for this project. This includes development of the booster motor and a lightweight/low-cost avionics package. A development plan is being finalized where such technologies will be used to upgrade solid rocket components of the system, namely the existing ISAS/JAXA S-520 solid rocket motor which will then be evolved into an air-launched (AL-520) variant.

This specific concept is not being developed exclusively for the Japanese market, one is that probably not sufficient to make such a launch service viable. This system is being examined for use internationally and specifically for potential operational availability in the United States. A more mature regularity regime for commercial launch and spaceport licensing makes the U.S. attractive as a home port for this system. Additionally, the use of licensed launch sites or spaceports in U.S. engenders a competitive advantage, enabling a potential early start to operational capability, minimizing opportunity loss.

Nano/pico-satellite launcher concepts are introduced here which use two different solid rocket stage combinations (based upon mostly existing stages) in combination with an existing aircraft. The solid rocket stage combinations, referred to as the SpaceSpike-1 and SpaceSpike-2 are derivatives of mostly existing solid motors.

The research and development phase of this Nano-Launcher project, including market/customer assessment and technical analysis of rockets and aircrafts, is a joint effort of international partners, led by IHI Aerospace Co., Ltd. (IA), CSP Japan, Inc. (CSP-J), the Institute for Unmanned Space Experiment Free Flyer (USEF), and SpaceWorks Commercial. The team has and is currently examining both technical and programmatic options for this program[2,3,4,5,6]. This specifically includes various candidate aircraft and motor combinations, as well a more detailed customer assessment (orbital and suborbital), and an overall strategic management plan. The actual Nano-Launcher architecture (carrier aircraft and rocket stages) presented within this paper is part of the overall development but continues to be refined and updated. No programmatic decisions on final launch vehicle stages or carrier aircraft have been made, but the concepts presented here represent concepts envisioned to be similar to any final launch vehicle architecture.

## LAUNCH MARKET FOR SMALL PAYLOADS

The Nano-Launcher service is envisioned to have both suborbital and orbital payload delivery capabilities. These capabilities will arise through various combinations of carrier aircraft and rocket stages. Prior to any actual discussion of the service, a quick review of the marketplace for such launch services can be helpful. This section will provide a quick synopsis of historical global demand for launch services for small payloads. The authors have developed databases for suborbital and orbital payloads. The authors have also developed future demand forecasts based upon actual and predicted demand (not included in this paper).

### *Global Small Satellite Orbital Launches (2000-2009)*

One of the first steps prior to technical advancement is some notional understanding of the marketplace. In order to examine such demand, the authors have developed a Global Small Satellite Launch Database that contains almost all orbital small launches over the last decade. It currently contains 260+ data points of small satellites launches from 2000-2010. Satellites in the database range from 1-500 kg in mass. In addition to recording the satellite mass, the database includes, but is not limited to, the country of satellite manufacturer, contractor, project class, orbital location (apogee, perigee, and inclination), launch date, launch location, and launch vehicle used. The database contains all attempted launches. Unless otherwise indicated all data points mentioned below refer to attempted launches. It should also be noted that the number of satellites launched may not equal the number of launches in any given year since many satellites are multiple-manifested (i.e. more than one satellite on a particular launch). Many times in this paper, the term "launch" or "launches" may refer to the number of satellites launched (even though they may be multiple-manifested).

Over the past decade, there has been a general upward growth in the number of small satellites developed and launched. This has been even more prevalent over the past five years. As seen in Fig. 1 and 2, the number of launches at end of the first decade of the 21$^{st}$ century was more positive than at the beginning (in terms of overall launches for nanosatellites). As seen in Fig. 2 there has been an increase in the number of small satellites launched in the less than 10 kg mass range. One of the major factors contributing to this could be the standardization of satellite buses, specifically with the CubeSat phenomena which started at California Polytechnic State University in 1999. This growth is due to continuing improvements in CubeSat technology in recent years, encouraging a growth of projects in academia and radio amateur satellite communities to pursue.

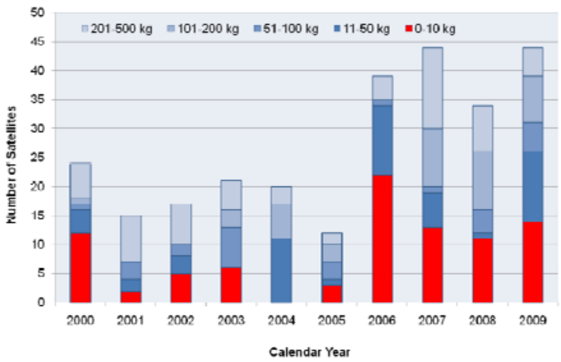



Figure 1. Number of Attempted Small Satellites Launches: 2000-2009 for 1-500 kg Satellite Class (Source: SpaceWorks Commercial Global Small Satellite Launch Database)

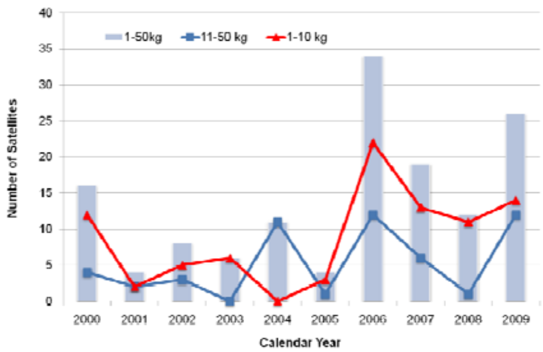



Figure 2. Yearly Launch History: 2000-2009 for 1-50 Kg Satellite Class (Source: SpaceWorks Commercial Global Small Satellite Launch Database)

From calendar years 2000-2009 there have been a mean of 14 satellites launched per year in the 1-50 kg payload class. There has been an average of 6.3 satellites launched in the 0-10 kg payload range respectively. Calendar year 2006 reflected a spike in attempted nanosatellite launches due to an unsuccessful Dnepr-1 launch of 16 satellites (15 of which were in the 1-50 kg range). Similarly in calendar year 2008, India's PSLV CA launch vehicle was successful in launching 10 satellites, of which 8 of the satellites were in the 1-50 kg mass class.

In terms of destinations, many of the satellites in the 1-50 kg mass range have tended to be located in polar Sun- and non-Sun synchronous orbits. For this mass range, orbital apogee in low earth orbit (LEO) ranges from around 600-850 km with many inclinations around 100 degrees. This may be due to less a desired for this particular orbital location versus the desire of the primary payload for such an orbit (desirable orbits for imaging and remote sensing).

Examining the historical data, one can notice many satellites launched in a multiple-manifest configuration for a launch vehicle. Many times, 10-15 satellites will be launched in such a fashion. Examination of this historical data also reveals that the most common nanosatellite mass is 1 kg. This is assumed to be due to the trend of CubeSat standardization, low financial costs at this payload class, and academic interest in CubeSat capabilities. Currently the Russian Dneper-1 and Indian PSLV launch vehicles are the main providers for nanosatellite secondary payload missions.

Oftentimes their position as the secondary payload prevents nanosatellites from reaching a preferred orbital location and thus they have to compromise by being placed next to the primary payload. The nanosatellite owner makes this compromise of orbital location in exchange for a launch opportunity. Therefore it is postulated that there may be a market for providing dedicated small (nano and pico-scale) satellite launches for those who are currently secondary payloads (offering a dedicated launch). Potential price points and specific elasticiticies of demand will have to be evaluated, but the first estimate indicates that there have been payloads, and potentially growing, in the nanosatellite mass category.

### *Global Suborbital Launches (2000-2009)*

The authors have also developed a Global Suborbital Launch Database to provide a comprehensive compilation of payloads launched suborbitally between 2000 and 2009. This database currently contains over 850 suborbital launches from 16 countries. Launch information was gathered from two online databases and research. Less emphasis was placed on developing this suborbital database versus the orbital database discussed in previous sections. Since the orbital mission will most likely be the defining mission for any system, the suborbital requirements were deemed to be important, but not the ultimate determinant of payload performance for the system. Thus a rough approximation of the suborbital market was developed. Similar to the orbital database though, information as gathered on specific payload parameters including date of launch, country of launch, launch vehicle, and payload (just to name some of the top level parameters). Since many suborbital launches are for military customers, it was decided to separate the suborbital launch data into two classes, military and non-military. Multiple suborbital launches in the database are for military targets. It was determined to spate these missions out. Thus the non-military category of launches may actually include non-target military payloads that were launched. It was deemed that these military target launches would be less open to potential commercial competitive solicitation.

As seen in Fig. 3 from 2000-2009, of an approximate 850+ globally, identified launches, more than 450 were "non-military" missions. Military launches constitute such a substantial share of total suborbital activity because of missile research and development. A spike in suborbital flights occurred throughout 2001 and 2002, attributable to scientific missions conducted in Norway (falling sphere measurements) and above average military/scientific activity in the U.S.

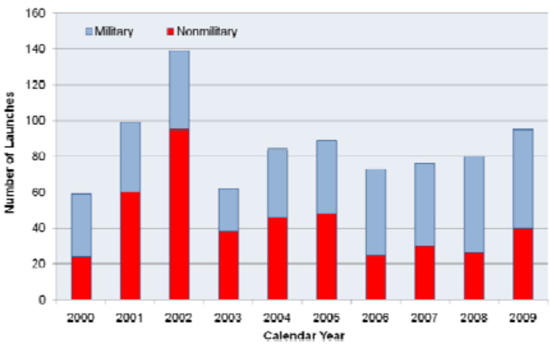



Figure 3. Number of Attempted Global Suborbital Launches: 2000-2009 - Preliminary (Source: SpaceWorks Commercial Global Suborbital Launch Database)

Roughly half of all suborbital missions between 2000 and 2009 were launched from the United States, approximately evenly split between military and non-military missions. The number of U.S. suborbital launches has fluctuated over the past ten years, but a relatively constant minimum level of activity is seen throughout. The pattern of U.S. launches follows very closely the global estimate given earlier, no doubt due to the large influence of the U.S. on global demand.

The services offered by suborbital launch providers vary, given different requirements on payload mass and orbit. This results in perhaps a less coherent set of standards, with more potential customization. Sometimes the maximum altitude is not the concern, the payload mass is. Sometimes a high velocity is required. Unlike orbital launches, where for instance, some requirements may be constant (low g-loads during entire ascent sequence, lower than perhaps some suborbital requirements), suborbital missions can include varying requirements from one customer to the next.

## SOUNDING ROCKET EVOLUTION

### *Solid Rocket System Roadmap*

The Nano-Launcher service is envisioned to be a nano and microsatellite (1-10 kg and 10-100 kg to orbit class) orbital payload delivery service using mostly existing elements in combination (mostly existing solid stages with existing air-launch aircraft). The resulting system is deemed to have a lower development risk with the ultimate service being more responsive to nanosatellite customers than competing services, potentially having a lower and more affordable development cost; one of the major problems that has affected all launch vehicle development projects. The major rocket hardware element of this system will be the solid rocket stages that will be utilized. Specifically the core of the system is based upon the ISAS/JAXA S-520 solid rocket. Fig. 4 is a notional roadmap of the development of the current variants of the S-520/SS-520 solid rocket motor to the NS-520, NL-520 (land launch variant), and eventually to the AL-520 (or "Air-Launch" 520 variant). Each subsequent progression in the roadmap will demonstrate key technologies for the next capability. For reference, the single-stage S-520 sounding rocket is solid rocket system that has 24 flights to date. The ultimate goal is to develop a commercially viable launch capability based upon an evolutionary use of existing solid rocket systems.

In terms of the development philosophy of the solid rocket system, high priority has been given to reliability in the development of the solid rocket launch stages. The evolution of the S-520/SS-520 will also entail reduction in weight and additional cost savings in multiple subsystems.

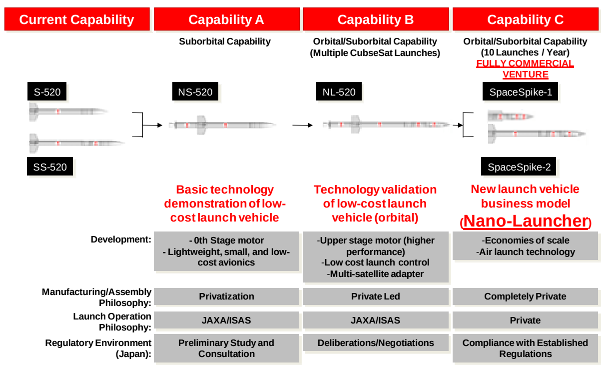
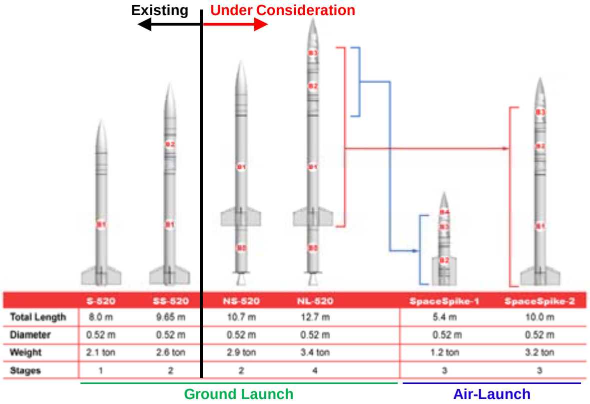



Figure 4. Sounding Rocket to Nano-Launcher Roadmap

### *NS-520 and NL-520 Solid Rocket Systems*

The single stage S-520 is the basic building block of the rocket elements of the Nano-Launcher service. The S-520 is a single stage solid rocket (stage referred to B1). The SS-520 is a two-stage version of the S-520 (second stage referred to as B2). As seen in Fig. 5 the NS-520 is two-stage solid rocket combining the S-520 solid rocket with a boost motor referred to as the B0 motor stage (B0 + B1 stages). The B0 booster stage is a ground launch stage that can be viewed as a proxy for air-launch.

As part of the overall roadmap, the NS-520 is an advance technology demonstrator for the land-launch NL-520. The NS-520 will demonstrate reduced development time processes, simplified stage separation systems, and miniaturized avionics. The NS-520 doubles the payload capability of the S-520 and is anticipated to cut the unit cost of the system in half versus the S-520. The NS-520 is also anticipated to be used as a flight test bed of other technologies (such as advanced air breathing engines).




| | S-520 | SS-520 | NS-520 | NL-520 | SpaceSpike-1 | SpaceSpike-2 |
|---|---|---|---|---|---|---|
| Total Length | 8.0 m | 9.65 m | 10.7 m | 12.7 m | 5.4 m | 10.0 m |
| Diameter | 0.52 m | 0.52 m | 0.52 m | 0.52 m | 0.52 m | 0.52 m |
| Weight | 2.1 ton | 2.6 ton | 2.9 ton | 3.4 ton | 1.2 ton | 3.2 ton |
| Stages | 1 | 2 | 2 | 4 | 3 | 3 |

Figure 5. SpaceSpike Heritage from S-520/NL-520 Configurations

The roadmap progresses past the NS-520 to the NL-520, which is a four-stage Nano-Launcher demonstrator (adding another stage, B3). The NL-520 adds the B2 and B3 solid rocket motors to the NS-520. The ground launch NL-520 is anticipated to be able to launch several kilograms of payload to LEO. The B2 and B3 stages (along with a smaller stage, B4) can also be used as the foundation of a smaller Nano-Launcher, namely the use of the B2 and B3 motors as the first and second stage of a three stage vehicle (to be used in an air-launch configuration), referred to as the SpaceSpike-1. Eventually the AL-520 (the rocket stages of the large "Nano-Launcher", referred to as the SpaceSpike-2) will consist of the NL-520 without the B0 booster stage (the smaller "Nano-Launcher" being the second and third stages of the large "Nano-Launcher" and referred to as the SpaceSpike-1). Generally, the SpaceSpike-1 and 2 have stage commonality with the NL-520. This modular roadmap allows off-ramps on the eventual development path and offers flexibility in the development of either a SpaceSpike-1 or larger SpaceSpike-2. The B1 and B2 stages will use existing motors, whereas the B3 and B4 stages are potential designs optimized for propellant weight. Thus most, but not all, of the stages for the SpaceSpike-1 and SpaceSpike-2 are based upon existing designs.

***B0 Motor Development***

The B0 motor will be used to accelerate a ground-launch vehicle to subsonic velocity. The B0 motor is designed with efficiency, relative to previous generations of motors. The 2,580 mm-long B0 motor has a propellant mass of 445 kg. The size of the motor is determined assuming use of the conventional S-520 rail launcher. Specification and design of B0 motor are shown in Table 1 and Fig. 6, respectively. The initial thrust for the B0 motor is designed to provide initial acceleration of more than 6Gs to minimize attitude disturbance generated at a launch away from a rail launcher.

Table 1. B0 Motor Specification

| Item | Design | Test Result |
|---|---|---|
| Diameter | φ524 mm | ← |
| Length | 2,580 mm | ← |
| Propellant | 445 kg | 444 kg |
| Maximum Thrust (Sea Level) | 288 kN | 330 kN |

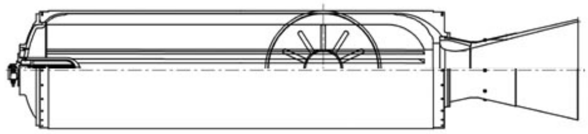


Figure 6. Design of B0 motor

Static firing test of B0 motor was performed at the JAXA Noshiro Testing Center on March 17, 2010. The test was successfully conducted and data was collected without any major issues. Static firing test and B0 motor after testing are shown in Fig. 7 and 8, respectively.

Figure 7. Static Firing Test (B0 motor)

Figure 8. B0 motor after static firing test

Fig. 9 shows thrust-time profiles of predicted and measured values for Seal-Level Thrust through the test. Some representative data from the test is also presented in Table 1.

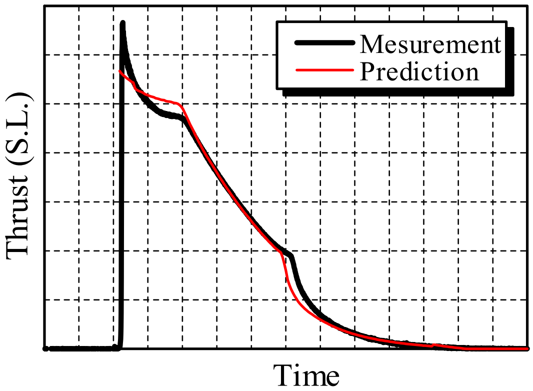



Figure 9. Thrust-time Profile of B0 Motor

## NANO-LAUNCHER CONFIGURATIONS

Using the above described solid rocket development roadmap a Nano-Launcher payload delivery system is envisioned that utilizes an existing aircraft to boost the SpaceSpike-1 or SpaceSpike-2 multi-stage solid rockets to a specific release condition.

### *Air-Launch Element of Nano-Launcher*

The Nano-Launcher Earth-To-Orbit (ETO) launch system includes the above mentioned SpaceSpike-1 and SpaceSpike-2 coupled with existing aircraft. Various combinations of SpaceSpike variants could be utilized with potential high speed aircraft in various air-launch architectures. There is currently envisioned to be both a suborbital and orbital product line for the Nano-Launcher system.

For example, potential high-speed aircraft that could be employed in such air-launch architectures include the F-104 (for suborbital missions using the SpikeSpike-1) and the F-15D (for orbital missions using the SpaceSpike-1 or SpaceSpike-2). Notional upper limits of external payload weight, operational altitude, and speed for some of these selected aircraft are being determined. Although it is no longer used as a mainline fighter aircraft, the F-104 is potentially available by private companies. The F-15D is still used by selected militaries around the world.

A suborbital Nano-Launcher (F-104 + two-stage SpaceSpike-1, see Fig. 8) and an orbital Nano-Launcher configuration (F-15D + three stage Spacespike-2) are the two initial configurations chosen for examination. These configurations do not represent the final optimum aircraft + solid stage combination for the Nano-Launcher but are examined here as potential candidates. No final decision on launch aircraft has been made at this time. These aircraft will be discussed in this paper as representative examples of potential air-launch aircraft for the Nano-Launcher concept.

Figure 10. Notional Nano-Launcher Illustration (Suborbital Configuration: F-104 + SpaceSpike-1)

In order to determine the optimal separation conditions for each candidate airplane, the flight envelopes of the airplanes were analyzed. Comparisons of the velocity vs. maximum altitude capabilities of the aircraft to the payload contour plots demonstrated that performing a zoom-climb maneuver, where the airplane's kinetic energy is exchanged for increased altitudes, would not increase the payload capabilities. The highest payload capabilities were discovered to occur at the maximum altitude within the flight envelope at the airplane's maximum Mach number (see tables 2 and 3). This statistic was researched for the candidate airplanes. The performance impact of additional centerline weight was determined from reference material for the F-104 and similar impacts were applied to the F-15D, producing a trace of optimal release conditions vs. centerline weight addition for both vehicles. It is currently assumed that the solid rocket stages will be carried along the centerline geometric space for these aircraft.

### *Suborbital Nano-Launcher*

The "SpaceSpike-1" is three-stage solid rocket that employs the B2 and B3 motors from the NL-520 as 1st and 2nd stages and uses a B4 motor for 3rd stage. The SpaceSpike-1 gross weight is 1.2 MT being 5 m long and 520 mm in diameter. The SpaceSpike-1 can be configured to be launched in a captive-carry configuration underneath an aircraft (see the flight sequence in Fig. 11). After separation from a high-speed aircraft, the B1 motor and its thrust-vector control (TVC) system inserts the rocket on a trajectory to orbital altitude. After launch vehicle spin–up, the B1 stage is separated and B2 is ignited, and then the B2/B3 stage vehicle goes into a passively stabilized mode, eventually leading to B2 stage separation and B3 stage ignition resulting in final orbit insertion.

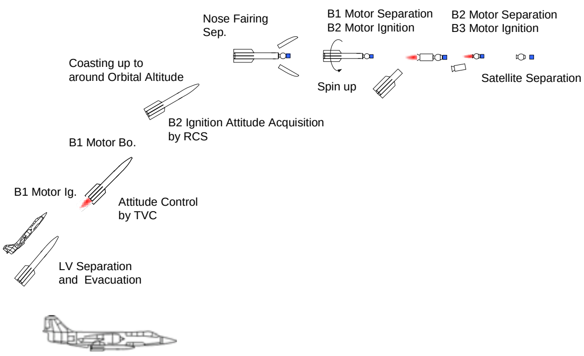



Figure 11. Three-Stage SpaceSpike-1 Flight Sequence

For the suborbital variant of the Nano-Launcher only a two stage SpaceSpike-1 is examined (B2 + B3 motors). Fig. 12 shows the resultant capability of the Suborbital Nano-Launcher system for two specific release conditions (at M=0.75 and M=1.5). The metric used to differentiate capability was time above 100 km. This is determined to be an important parameter (altitude) for the suborbital research marketplace. Generally the suborbital Nano-Launcher system can achieve tens of kilograms of suborbital payload.

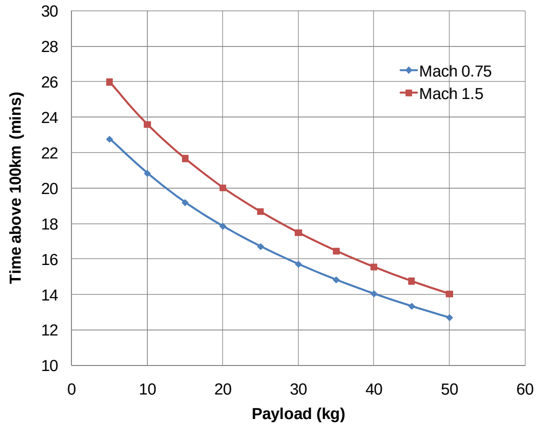



Figure 12. Suborbital Nano-Launcher Preliminary Payload Capability: F-104 + two stage SpaceSpike-1, Two Release Conditions: M=0.75 (at 9.144 km/30 kft) and M=1.50 (at 14.427 km/47.33 kft)

### *Orbital Nano-Launcher*

The orbital variant of the Nano-Launcher would consist of a better performing aircraft and potentially larger solid rocket such as the larger SpaceSpike-2. The "SpaceSpike-2" is a three stage solid rocket that essentially consists of the NL-520 without the B0 booster stage. The SpaceSpike-2 gross weight is 3.0 MT being 10 m long and 520 mm in diameter. Its anticipated launch capability to LEO is a few tens of kilograms. Its 1st stage (B1 stage) is aerodynamically stabilized, the 2nd stage (B2) is TVC controlled, and the 3rd stage (B3) is spin stabilized.

From these analyses, the target orbit was determined to be a 250 km circular Low Earth Orbit (LEO) at a 28.5 degree inclination. The assumption was that this system would be launched from the United States so such an inclination was chosen (representative of launch from a near shore location near Kennedy Space Center). Table 2 and Fig. 13 show the outcome payload capability (payload to LEO and trajectory visualization) for the F-15D + SpaceSpike-2 configuration. A second third configuration, an F-15D + SpaceSpike-1 was also examined and preliminary results are shown in Table 3. This second, orbital configuration was chosen as a more achievable aircraft + rocket stage combination (in terms of payload capability and geometric fit). These analyses were performed for different release conditions (different Mach number release conditions for the rocket), ranging from Mach 1.5 to 2. Separate analyses were also performed for release conditions with a zoom climb (zoom climb starts at Mach 2 so any increase in altitude results in decrease of speed. For this analysis, the Mach 1.5 release condition is determined to be the nominal case.

This initial analysis indicates that the F-15D + SpaceSpike-2 configuration is estimated to deliver

33.71 kg of payload to the same orbit. The F-15D + SpaceSpike-1 can deliver 6.19 kg to the same orbit.

Table 2: Orbital Nano-Launcher Preliminary Payload Capability Estimate: F-15D + SpaceSpike-2 Configuration (to 250 km Circular LEO, 28.5 degree inclination launch site)

| Aircraft Stage Mach Number Release Condition | Maximum Nominal Altitude (m) | Payload (kg) | % Gain from M=1.5 Point (F-15D + SS-2) |
|---|---|---|---|
| 1.50 | 14,839 | 33.71 | ----- |
| 1.75 | 15,542 | 38.11 | 13.1% |
| 2.00 | 14,972 | 41.49 | 23.1% |
| w/Zoom Climb | | | |
| 1.50 | 17,896 | 35.32 | 4.8% |
| 1.75 | 16,406 | 38.46 | 14.1% |

Notes:
Subtracted 2% from Max Altitude for given Mach number for Margin
Zoom climb starts at Mach 2 so any increase in altitude results in decrease of speed

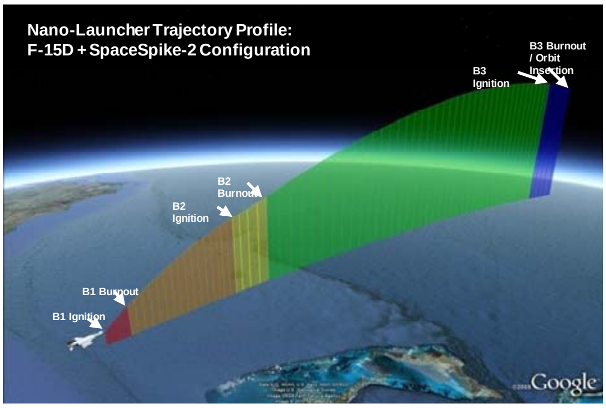



Figure 13. Orbital Nano-Launcher Preliminary Trajectory Profile: F-15D + SpaceSpike-2 Configuration (to 250 km Circular LEO, 28.5 degree inclination launch site, release point off the coast of Florida)

Table 3: Orbital Nano-Launcher Preliminary Payload Capability Estimate: F-15D + SpaceSpike-1 Configuration (to 250 km Circular LEO, 28.5 degree inclination launch site)

| Aircraft Stage Mach Number Release Condition | Maximum Nominal Altitude (m) | Payload (kg) | % Loss from M=1.5 Point (F-15D + SS-2) |
|---|---|---|---|
| 1.50 | 16,040 | 6.19 | 82% |

Notes:
Subtracted 2% from Max Altitude for given Mach number for Margin

### *Upperstage Options*

As more detailed analysis is performed of the suborbital and orbital Nano-Launcher system, additional trade studies will be performed. Table 4 lists potential motor candidate for the B2, B3, and B4 stages for the SpaceSpike-1 and SpaceSpike-2. Future potential trade studies include substituting some of these stages for alternate stages, specifically the B3 and B4 stages.

Table 4. Stage Motor Candidates

| Motor Candidates | In-House R&D | SS-520B2 | RBM |
|---|---|---|---|
| Stage | B2 | B3 | B4 |
| Supplier | IA | IA | IA |
| Country | Japan | Japan | Japan |
| Propellant Weight [kg] | 670 | 325 | 55 |

## MINIATURIZED AVIONICS DEVELOPMENT

One of the key technology development efforts to achieve affordability for the Nano-Launcher is focused on small and lightweight avionics systems. The specific avionics systems envisioned are currently under development and supported by subsidies by NEDO/METI in Japan. Internal studies by the authors have demonstrated that placing avionics currently used for Japanese launch vehicles on notional non-Japanese operational launch vehicles results in a payload loss of 100 kg. Currently used avionics within Japanese launch vehicles may be insufficient to provide mass and cost savings required for new systems such as the envisioned in the Nano-Launcher.

Existing avionics design philosophy with Japanese launch vehicles were developed with a priority towards high functionality, performance, and reliability. Accordingly, the result was large, heavy and costly avionics. As an example, it is well recognized that avionics mass reduction can be achieved using semiconductor relays for power control. However, in reality using flight proven components has been given a higher priority than incorporating more advanced technologies. As another example, the launch vehicle’s Data Handling System has been centralized rather than distributed with the result that total mass and labor cost of the vehicle’s wire harnesses have been increased.

### *Miniaturized and Low Cost Avionics*

Thus there is need for smaller and lower cost avionics for such systems such as the Nano-Launcher. As part of the Nano-Launcher project, specific technology development projects such as the development of a miniaturized avionics suite are being carried out.

Specifically, such development of lightweight and low-cost avionics should emphasize the following, main basic points:

- Proactive use of COTS components/parts including semiconductor relay and MEMS
- Reinforcement of system integration technology
- New functional and environmental testing method for lightweight avionics
- Simplified vehicle health check using self-diagnosis systems

Fig. 14 illustrates the system block diagram of a potential miniaturized and low cost avionics architecture. Major avionics systems are centralized in the upper stage and rest of avionics are distributed to avoid excessive weight increase in the wire harness. Telemetry/tele-command and power supply systems are the specific systems subject for distribution because these are individually optimized for different launch vehicle configurations.

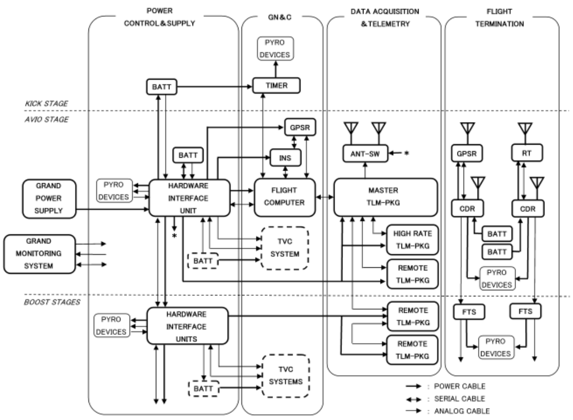


Figure 14. System Block Diagram of Miniaturized and Low-cost Avionics

Table 5 is a mass breakdown of such a miniaturized avionics system. The listed total mass of 52 kg is a target weight for the avionics systems, potentially representative of the most feasible miniaturization possibility.

Table 5. Miniaturized Avionics Target Mass

| Item | | Mass (kg) |
|---|---|---|
| GN & C | | 8 |
| Data Acquisition and Telemetry | | 11 |
| Power Control and Supply | | 8 |
| Flight Termination | RT & Command | 19 |
| | Power Supply | 6 |
| TOTAL | | 52 |

It is envisioned that the miniaturized avionics will be attached to either the outer or inner surface of the cylindrical structure of the launch vehicle. These include areas such as the inter-stage structure, payload adapter, and motor attachment in the fairing. Some preliminary design studies indicate that such miniaturized avionics for the Nano-Launcher are possible even given the small diameter of the stages.

Specific technology advancement related to Guidance, Navigation & Control (GN&C) includes development of a MEMS IMU coupled with GPS (to compensate for the deterioration of signal accuracy from Navstar satellites). Commercial off-the-shelf (COTS) CPU and high package density technology were applied to fabricate a prototype of such a flight computer (as seen in Fig. 15). A prototype of a lightweight Hardware Interface Unit was built for the Power Control & Supply subsystem, utilizing solid-state relay and surface-mount technology.

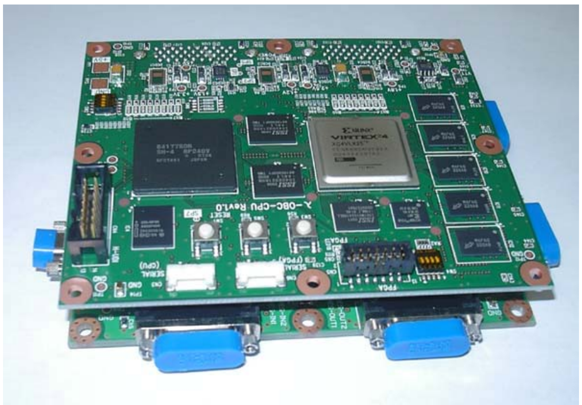


Figure 15. Flight Computer (prototype)

The mass of a launch vehicle's wire harness is quite large in conventional vehicle because electrical components are dispersed and each component is connected with parallel cables. Alternative technical approaches are being examined with Nano-Launcher. A Master Telemetry Package will be mounted in the upper stage while a Remote Telemetry Package will be placed in each stage. High-speed serial communication between these packages will simplify inter-stage interface and should reduce harness mass. Miniaturization of packages could be achieved through the use of industrial COTS products. Figure 16 is a prototype of such a Master Telemetry Package. Functional testing, vibration, and shock environment testing of prototypes are planned to verify applicability of miniaturized avionics to the Nano-Launcher.

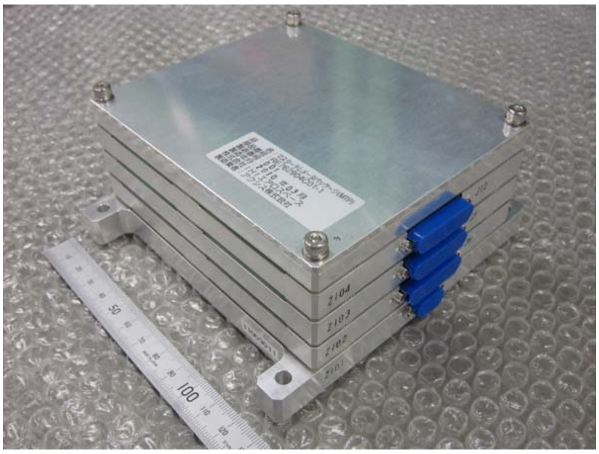


Figure 16. Master Telemeter Package (prototype)

Another issue with launch vehicle avionics is that because high-speed serial communication enables FPGA logic circuits to be distributively mounted on various components including a flight computer, a problem occurs in properly demonstrating the logic in each component. One solution to this is to use an Integrated Simulation Platform (ISP) that enables a demonstration of all functions in a monolithic simulation by linking related components. Functions are verified by simulation using various conditions in line with a Highly Accelerated Life Testing (HALT) method. The ISP essentially works as flight and I/O simulator. It also can be used to detect design failure in the development phase and to support product assurance in the production phase. Short development cycles and frequent rollouts of new products are major issues associated with the use of COTS products for space applications. Solutions such as an ISP could verify functions responsively when next generation avionics products are introduced.

## SUMMARY

Even though the global interest in nano-satellites (<50kg) is increasing there is a large gap in affordable and dedicated launch options for such projects. Yet within the past few years nano-satellite applications have expanded to on-orbit technology demonstration/experimentation, telecommunications, and earth observation. Such a growing market is ever desperate for launch options. Such options currently include ride shares and piggybacking on medium to heavy expendable launch vehicles. Yet with such options, nano-satellite customers have no control over launch schedule and desired orbit. New options would be a valuable service to the ever increasing global community of nano-satellite developers. A dedicated nano-launcher for such satellites is currently being designed based upon multi-stage derivatives (SpaceSpike-1 and SpaceSpike-2) of mostly existing suborbital expendable launch stages (namely the ISAS/JAXA S-520 solid rocket stages) upgraded with small and lightweight avionics systems (currently under development).

Given constraints on launch sites for such micro-launchers, for instance limited orbits (no polar launch due to safety issues) and reduced launch windows (only about 180 days per year) at a typical launch site such as the Uchinoura Space Center in Japan, air-launch from a high speed aircraft can provide a better solution for more robust launch of nano-satellites.

This paper has discussed the market demand for such a launch service and the potential Nano-Launcher solution for both suborbital and orbital customers. The Nano-Launcher is an air-launch nano-satellite orbital payload delivery system currently under study by the authors. The system uses an existing high-speed aircraft utilizing mostly existing solid rockets (either the SpaceSpike-1 or SpaceSpike-2) with the potential for foreign partnership for some aspects of the system. Such international partnership with private companies and institutional bodies is deemed to be a key strategy for global operability and marketing.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