A Nano-Satellite Launch Arrangement and Interface Control
11th Nano-Satellite Symposium

Koray Bayraktar[1], E. Nur Sayar Çınar[2], M. Cem Bahşi[3], M. Mehmet Nefes[4]
TURKSAT A.Ş, TÜRKİYE

kbayraktar@turksat.com.tr

Keywords: Launcher, CubeSat, Nanosat, Project Phases, Interface Verification

1. Overview

The global nanosatellite and microsatellite market are anticipated to witness growth due to advancements in microelectronics technology and rising satellite launch opportunities worldwide. Nanosatellites and microsatellites are low-cost satellites intended for commercial, communications, armed forces, and space research purposes. Recent technological advancements in the field of small satellites transformed the way of communication and area of research. It can be easily said that the demand for the nanosatellite and microsatellite industries will expand as private investment capital is going to spend further on space technology start-ups. In this study, the process has been described by addressing the launch service procurement, the calendar which has to be followed between the launcher and the nanosatellite contractor, the launcher and nanosatellite compatibility issues, and the important deliverables that have to be provided by the satellite manufacture.

2. Introduction to Nanosatellite

The “small satellite mission philosophy” represents a design-to-cost approach, with strict cost and schedule constraints, often combined with a single mission objective in order to reduce complexity. Figure 1 summarizes the standardized definition of satellites according to their weight: picosatellite (0.1-1kg), nanosatellites (1-10kg), microsatellite (10-100kg), and mini-satellites or small/medium satellites (100-1000kg).

As it can be easily seen from Figure 2, CubeSats come in several sizes, which are based on the standard CubeSat “unit”—referred to as a 1U. A 1U CubeSat is a 10 cm cube with a mass of approximately 1 to 1.33 kg.

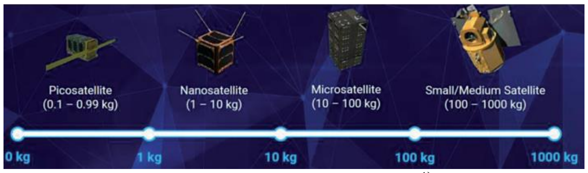

Fig. 1. Satellite Classification [1)]

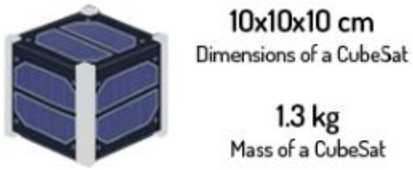

Fig. 2. 1U CubeSat [1)]

The intent of the CubeSat/Nanosat project is to reduce cost and development time, increase accessibility to space, and sustain frequent launches.

3. Launch Planning

One of the work packages to be done within the scope of the satellite project is to determine the launcher and book a place. The process begins by contacting the launch company to provide some initial information related to the desired orbit, launch timing, and expected satellite size such as volume, mass, and separation system interface type. Because it is a cost-effective solution, often large numbers of nano/cube satellites are launched into orbit in the same launcher. This situation causes a significant amount of workload for launch companies in terms of health management and coordination of projects. That's why companies like SpaceX, ArianeGroup, ILS, and ULA conduct launch set-up and interface verification through companies like SpaceFlight, ExoLaunch, Nanoracks, and ISILAUNCH, known as launch aggregators.

Considering that the services of the aggregators may differ, the general services are as follows:

- Requirements, verification and deliverables management to support integration & launch campaigns,
- Payload integration facilities and experienced integration technicians to support physical integration of spacecraft to separation system and subsequently to launch vehicle,
- Provision of flight hardware and support equipment including structures, avionics, separation systems, and signals.

When a NanoSat provider is ready to commit to a launch, the contracting process begins with a Letter of Agreement (LOA), which is a binding reservation for launch capacity that captures the high-level terms and conditions for the Launch Service Agreement (LSA). Upon signing the LOA, the launch aggregator assigns a mission manager who becomes the single point of contact for all spacecraft provider and launch vehicle interactions including mission planning, integration, and execution after the LSA is completed. The LSA follows soon after the LOA signing and commits the spacecraft to a specific launch opportunity. It also includes the required flow-down clauses from the associated launch vehicle provider and applicable governmental bodies followed by a detailed Statement of Work (SOW) with clear deliverables and mission timelines for submission.

A compliance assessment is conducted during the contracting process to determine what export licenses are required if there are any International Traffic in Arms Regulations (ITAR) or Export Administration Regulations (EAR) restrictions or reporting requirements, and a compliance plan is outlined. This early assessment reduces program risk and gives the launch aggregator and spacecraft provider teams a roadmap for compliant mission execution.

The tasks of a mission manager include:

- Creation and management of schedule and Interface Control Documentation (ICD)
- Provision of templates for deliverables
- Completion and distribution of mission analyses
- Detailed review and feedback on deliverables
- Assessment of compliance with requirements
- Action tracking
- Guidance for range safety deliverables
- Export license arrangement
- Logistics coordination and support
- Provisions of standard Ground Support Equipment (GSE)
- Facilitation of spacecraft-specific engineering analyses (e.g. deployment, re-contact, environments derivation, and waiver assessments).

4. Schedule and Deliverables

The mission management process occurs over a period of time averaging 12 or more months before the scheduled launch date, with more complex missions requiring more time to execute. An example mission management timeline is summarized in Figure 3. The purpose of these schedules is to drive spacecraft provider deliverables to completion in support of the mission timeline and to inform planning schedules for mission support.

Milestone Date	Launch Aggregator Deliverables	Spacecraft Provider Deliverables
Contract Signing L-12 months	*Procure deployment system *Requirements for CAD & FEM models *ICD Template *Apply for export licensing (as required)	*Completed spacecraft questionnaire
Kickoff LSA signature+2 months	*Mission Schedule *Safety Submission template delivery	*S/C CAD Model *S/C FEM Model *S/C Test Plan *Initial Mass Reports
Mission CDR L-9 months	*Updated mission schedule *Current best estimate launch campaign schedule *Preliminary integration schedule *Preliminary launch operation plan	*Updated CAD Model *Updated FEM Model *Updated S/C Mass *Completed safety submission *S/C launch site operation plan *S/C licensing information sent to appropriate
System Readiness Review L-3 Months	*Updated mission analysis result *Final integration schedule *Final launch operation plan *A list of facilities and services available for S/C	*Verification compliance with ICD requirements *Updates to CAD, FEM, and Safety Package
Integration Process Start L-60 days	*Identify last access to the S/C *S/C provides the integration facility	*Final as-measured S/C mass and best estimated wet-mass *Delivery of S/C and associated electrical and mechanical GSE to integration facility for system level integration *Delivery of S/C mass simulator to integration facility for system level integration
Launch Readiness Review L-1 Day	*Approximate separation time	*Launch Readiness Review (LRR)
Launch Day	-	-
Spacecraft Separation L+4 months	*Separation confirmation and state vector	-
Notification Spacecraft Acquisition L+12 months	-	*Indication of S/C acquisition, state of health assessment

Fig. 3. Example of Mission Management Timeline and Deliverables [2)]

In addition to the information provided in Figure 3, the launch aggregator will also require additional analyses and supporting data prior to launch. This may include safety documentation, orbital debris information, materials and venting data, and spacecraft-specific models.

4.1. Spacecraft Provider Deliverables

As can be seen from Figure 4, there are some deliverables provided by satellite manufacturers. Firstly, the orbit requirements, interface details, mass properties, preliminary drawings, and unique spacecraft requirements are all included in the spacecraft questionnaire. Also, the satellite provider creates a CAD model of satellite indicating shape, dimensions, and outer mold line configuration of the satellite. Another important deliverable that must be sent by the satellite provider to launch aggregator is the initial mass report. Mission Readiness Review tracks the most recent best estimate mass properties from the spacecraft questionnaire. The values must include the nominal values as well as three sigma uncertainties. Drawings, schematics, RF Radiation, assembly instructions, and other technical information on all hazardous items are included in the Safety Package, which is a data package that it's format changes dependent upon Launch Range. In the scope of the Spacecraft Launch Operations Plan, each spacecraft supplier shall specify all handling limitations, environmental limitations, personnel requirements, equipment requirements, launch site verification procedures, integration procedures, and duration of such tasks for their satellite. Note that spacecraft Finite Element Model (FEM) and thermal model are not required for NanoSat class satellites, because Couple Load Analysis (CLA) does not make by launcher authority. Finally, it must be known whether a spacecraft provider chooses to use a launch aggregator or not, certification of flight is a key spacecraft responsibility. All spacecraft providers are required to independently determine and obtain the licenses necessary for the spacecraft. The launch aggregator will require proof of licensure before launching the satellite. Licensing processes are spread over time and managed in line with the needs over time. Copies of all licenses, permits, clearances, authorizations, and approvals necessary for the transportation of, communication with, operation, launch, and orbital deployment of the spacecraft including, but not limited to all licenses from the Federal Communications Commission (FCC) or spacecraft provider's applicable national administration/agency; and if applicable, the National Oceanic and Atmospheric Administration (NOAA).

4.2. Launch Aggregator Deliverables

The launch authority performs some analysis using the deliverables sent from the spacecraft provider. As a result of these analyses; ICD (Interface Control Document) and MUDA (Mission Unique Design Analysis) are created and distributed to the satellite manufacturer. ICD outlines the mission, interface, and operational spacecraft requirements, along with acceptable verification techniques and verifications for each requirement, in order to successfully carry out the launch service. ICD is mutually generated in the process and frozen prior to the launch campaign. MUDA provides current best estimates through coordination with the launch vehicle team for launch environments, targeted orbital parameters, and deployment timing. Another deliverable from launch aggregator to spacecraft provider is schedule which provides current best estimates through coordination with the launch vehicle team for launch environments, targeted orbital parameters, and deployment timing. Finally, following the deployment confirmation, the flight report including the state vector and actual insertion parameters is distributed to the spacecraft provider.

5. Separation System Interface

One of the important responsibilities of the launch aggregator is to provide Picosatellite Orbital Deployers (POD) or dispensers for spacecraft providers. The primary responsibility of the POD is to ensure the safety of the CubeSat and protect the launch vehicle (LV), primary payload, and other payloads. PODs are designed to meet and exceed launch vehicle requirements. The satellites are deployed from the POD by means of a spring and glide along smooth flat rails as they exit the POD. After an actuation signal is sent from the LV to the P-POD door's release mechanism, a spring-loaded door opens and the CubeSats are deployed by the main deployment spring. In addition, with the evolution of form factors within the CubeSat standard, there are now different-sized PODs in use, such as 3U, 6U, 12U, and 16U launch separation systems. The separation systems essentially minimize the risks for the primary payload and for the launch vehicle. CubeSats / NanoSats are ejected from the PODs after reaching the relevant orbital altitude. The common form factor and standardized weight of the CubeSats are necessary to ensure that they are properly integrated into the CubeSat deployer without requiring customization or hindering its effective operation.

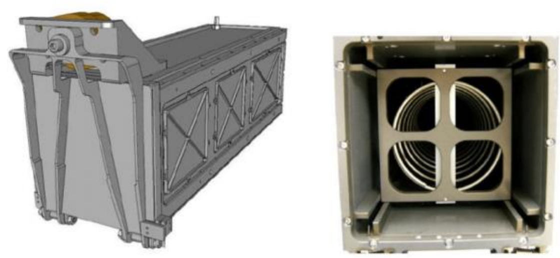

Fig. 4. POD Example [3)]

6. Launch Environment

It is ultimately the spacecraft provider's responsibility to ensure the spacecraft survives all environments encountered during the course of the mission; the launch aggregator makes it easy to access the environments, to understand how those environments are revised over time (including waiver requests), and to know what verifications are expected to demonstrate that a spacecraft is fit for flight. The mission environments are iteratively refined through coordination with the launch vehicle provider until final maximum predicted environments are provided as a part of the mission-specific launch vehicle critical design review.

6.1. Sinusoidal Vibration Environment

Some launch vehicle providers expect spacecraft to undergo sinusoidal (sine) vibration testing to demonstrate acceptability for flight. The sine vibration environment is defined as an input at the spacecraft interface and may be requested to be notched to avoid over-test at certain frequencies.[2)]

6.2. Random Vibration Environment

The random vibration environment is highly unique to each mission. Spaceflight provides generic mission acceptance-level enveloping environments to assist spacecraft developers with maximizing their flight opportunities. Mission-unique flight environments are communicated to the spacecraft provider via the ICD. Each spacecraft is expected to survive a 2-minute random vibration test in all three axes to ensure that it will both survive to accomplish its mission and not pose harm to other spacecraft during launch. If a spacecraft design is not compatible with high-frequency mission environments as stated in a mission-specific ICD, spacecraft designers may consider isolation systems that can effectively move more energy into lower frequency regimes experienced by the spacecraft. Given the need to address specific aspects of incompatibility, isolation systems are inherently associated with a specific mission and thereby reduce compatibility across launch opportunities.[2)]

6.3. Acoustic Environment

Acoustic qualification tests are expected to be 2 minutes in duration and typically 3 dB lower at all frequencies and the test duration is 1 minute. Spacecraft with large flat surfaces are typically susceptible to acoustic environments. Acoustic testing is recommended for any spacecraft with structural components susceptible to excitation by acoustic environments, though many micro-sats of smaller form factors may find that random vibration environments envelop acoustic environments for a particular mission. CubeSats do not typically undergo acoustic testing due to their small size, protection from direct acoustic excitement inside a dispenser, and the random vibration environment enveloping the acoustic environment.[2)]

6.4. Shock Environment

In many rideshare situations, the shock environment induced by a spacecraft separation system envelops the shock environment induced by launch vehicle events (e.g. fairing separation, stage separation, etc.). The launch vehicle-induced shock environment is highly mission-specific so launch aggregators usually recommend all spacecraft (including CubeSats) be tested in either the following environment given in Figure 5. Since it can be highly possible to over-test the satellite by conducting shock tests, Spaceflight regularly assists rideshare spacecraft in completing shock tests successfully by the way of a clear definition of test levels based on mission-specific requirements.[2)]

Frequency (Hz)	Amplitude (g)
100	40
1,000	1,000
10,000	1,000

Fig. 5. Shock Environment [2)]

6.5. Depressurization Environment

During spacecraft launch, the satellite systems undergo a rapid depressurization before reaching a steady state condition. Venting analysis identifies ventable and non-ventable volumes and venting area locations, and verifies the NanoSat has adequate venting to prevent explosive decompression of containers on the NanoSat as it transitions from the standard atmosphere to vacuum. Generally, sustained depressurization rate is taken as 2.4 kPa/sec while transient is 4.8 kPa/sec for as much as 5 seconds.[7)] Due to the specialized test facilities that are required to perform depressurization testing, launch aggregators usually accept verification by both analysis and/or test. Note that for CubeSats, this is often as simple as looking at the ratio of volume to be vented to the vent area. A minimum ratio is 2000 $inch^3/inch^2$, referenced in the CubeSat Design Specification, is often used.[2)]

6.6. Electromagnetic Environment

Figure 6 shows the enveloping electromagnetic interference (EMI) environment across all launch opportunities for both LEO and GTO missions. Launch aggregators recommend all spacecraft be tested to either the LEO or GTO environment, as appropriate, to ensure the spacecraft will survive (and not change power state during exposure to) EMI caused by the range, the launch vehicle, and other sources.[2)]

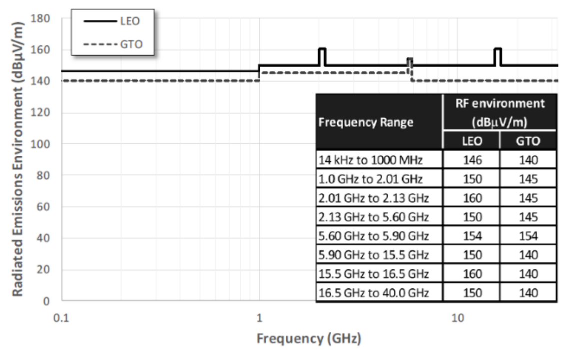

Fig. 6. Enveloping Electromagnetic Environment [2)]

6.7. Limits to Spacecraft Radiated Emissions

Spacecrafts are expected to be tested in an anechoic chamber in the launch configuration (including power state). Rideshare spacecraft are also expected to inhibit intended RF emissions until after deployment in orbit. Launch aggregators can make arrangements for spacecraft RF testing at specific times during the integration process with appropriate prior planning. The limits given in Figure 7 envelop all missions and launch opportunities. Spacecraft providers can expect less restrictive limits to be defined in the mission-specific ICD.[2)]

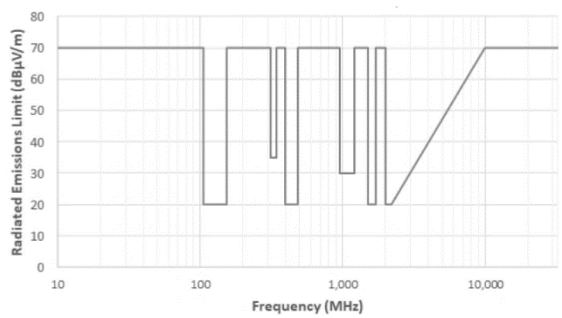

Fig. 7. Radiated Emissions Limits for Rideshare Spacecraft (LEO missions) [2)]

6.8. Thermal Environment

The unpacking and integration processes within the integration processing facility, transportation to the launch site, and mission and launch vehicle-specific encapsulated pre-flight phases are all included in the pre-flight thermal environment. It is advised that all spacecraft suppliers design their spacecraft to withstand the pre-flight environmental conditions listed in Table 1. Note that the values given in Table 1 are an example and may change depending upon a certain mission. Also, many launch vehicle providers have facilities and equipment to allow the prime spacecraft to specify the desired humidity limits.

It is known that CubeSats are typically shielded by their dispenser from the ascent thermal environment and are therefore not significantly affected by the ascent radiated thermal environment. Aerothermal heat flux typically drops quickly from this value while the solar flux remains constant. Similar to the ascent radiated thermal environment, MicroSats are more exposed to this environment than CubeSats. Unique thermal sensitivities should be provided in the spacecraft questionnaire.

Table 1. Enveloping Thermal Environments [2)]

Integration & Launch Site Ground Transportation	Encapsulated prior to Launch
• Temperature: 13˚C to 30˚C	• Temperature: 13˚C to 30˚C
• Relative Humidity: 30% to 65%	• Relative Humidity: 0% to 65%
• Cleanliness Class 8 (ISO 8 or 100k)	• Cleanliness Class 8 (ISO 8 or 100k)

Nearby rideshare spacecraft and flight support equipment also have an impact on the thermal environment for rideshare spacecraft, which is primarily controlled by solar flux and Earth albedo. The duration of exposure and the position of the Sun in relation to any particular spacecraft are very mission-specific. Launch aggregators typically advise that all rideshare spacecraft be capable of withstanding continuous direct solar exposure for 65 minutes on any spacecraft face. Also, they suggest that all rideshare spacecraft should be able to survive multiple no Sun exposure orbits if the spacecraft is shadowed before deployment. It can be said that the thermal analysis conducted for previous rideshare missions showed that rideshare spacecraft temperatures prior to deployment often range from -15 ° C to + 40 ° C, with some missions experiencing more extreme temperatures depending on the type and timing of the orbital maneuvers involved.

Finally, pre-flight environmental conditions are further refined throughout the mission planning process and are officially communicated via the ICD.

7. Shipping & Transportation

After assembly and testing, CubeSat must be properly packaged and shipped to the launch service provider. In general, satellite AIT centers are not always near the launch site facility. CubeSat is usually first transported to an intermediate location for final integration into the launch vehicle interface before entering the launch facility. Launch aggregators take the responsibility for the satellite from the moment it enters their facilities to the orbit insertion, and they sometimes even offer support to developers during the delivery process.

The CubeSat must be moved from a clean area of the laboratory to another clean area of the launch service provider's location without exposure to dust. A resealable antistatic bag is usually sufficient to cover the entire satellite. A small amount of air inside the bag can act as a cushion and protect the CubeSat from heavy impact, but it is best to vacuum the bag. In general, solar panels are very sensitive to scratches, so ideally, they should not be touched during their entire lifespan. A common measure to prevent accidental contact with solar panels during ground operations is methacrylate coating. Although they are very effective in protecting solar panels, in general, an anchor point is required on the structure to secure it with suitable fasteners.[8)]


Fig. 8. CubeSat Transport Case [4)]

Safe transport of the satellite requires an impact-resistant suitcase, which is used to transport delicate equipment such as optics and imaging equipment. These bags usually come with cushion foam inside that protects the product from any impact. However, foam materials can easily become electrically charged and leave a residue after being discharged, which can be detrimental to cleanroom operations. In addition, tamper-evident seals, such as a simple zipper, must be used to prevent the transport case from opening during transit.

Standard shipping companies may not be reliable enough to ship CubeSat (from Europe), as they do not appear to offer special services tailored to CubeSat packages and do not offer reasonable insurance for such packages. One of the most popular options for CubeSat transport is to personally deliver it to its destination. Travelers should always take precautions and be prepared during the trip with sufficient documentation such as manuals, plans, export licenses, and any other proof of shipment to minimize difficulties during customs and security checks.

8. Integration to Separation System and LVA

During the integration campaign, spacecraft providers are expected to communicate the upcoming plans for any standalone operation requiring launch aggregator or launch provider support on a daily basis. Those standalone material handling equipment operations and facility clears for safety are expected to be conducted by the launch aggregator or the launch provider with the coordination of the spacecraft provider.

The launch aggregator and the spacecraft provider team typically perform joint operations for the following types of activities:

- The mate of spacecraft to the separation system
- The installation of spacecraft to rideshare adapter, including mating of separation connector and setting of separation switches (as applicable)

Spacecraft provider involvement in the integration activity is generally a function of the spacecraft's complexity. Launch aggregator conducts the integration activity with spacecraft provider observation, tests the separation circuit continuity, and involves the relevant spacecraft provider team when manipulating spacecraft.

Once a spacecraft is mated to its separation system, the separation system interface is used to manipulate the integrated spacecraft for attachment to the rideshare adapter, thereby avoiding any need for the launch aggregator to directly interface with the spacecraft after separation system integration. Spacecraft providers are expected to be present any time a spacecraft is to be handled prior to and during joint operations.

Fig. 9. Integration to LV [5)]

All preliminary integration activities must be complete to permit shipment to the launch site, typically occurring no later than L-45 days. The final integration process takes place in a controlled facility on or near the launch site. Prior to handoff to the launch vehicle provider, the launch aggregator conducts a series of continuity checks to ensure the proper functioning of their systems. The integrated rideshare payloads are then mated with the prime satellite and/or launch vehicle's upper stage. Finally, the payload assembly is encapsulated within a payload fairing. Upon completion of the integration process, the launch vehicle provider team prepares the Launch Vehicle (LV) for launch (attachment of fairing to LV, fueling, transit to launch pad, etc.).

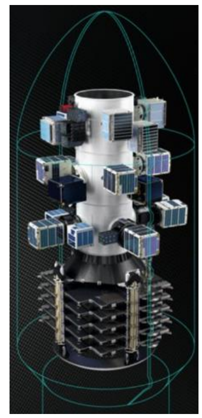

Fig. 10. CubeSats Accommodation Configuration in Fairing [6)]

9. Conclusion

Recently, there has been an increase in the use of nano-satellites and micro-satellites. Nanosatellites and microsatellites are low-cost satellites intended for commercial, communications, armed forces, and space research purposes. In this study is aimed the process has been described by addressing the launch planning, launch service procurement, the calendar which has to be followed between the launcher aggregator and the nanosatellite contractor, and the important deliverables that have to be provided by the satellite manufacturer. This procedure which is described in Project Milestones is given below in Figure 11.

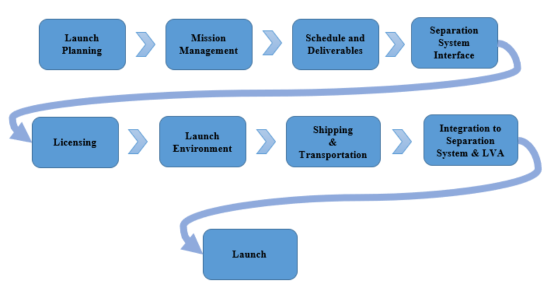

Fig. 11. Project Milestones

The end of the mission and re-entry of the atmosphere process are also important in addition to describing project milestones and launching the nanosatellites. Currently, it is recommended that operators with satellites in low-Earth orbit ensure that their spacecraft will re-enter Earth's atmosphere within 25 years following the completion of their mission. As the number of objects in space increases, it leads to the probability of collision. Therefore, Space Innovation; Mitigation of Orbital Debris in the New Space Age's revision report is aimed to shorten the timeframe required for satellite post-mission disposal to five years.

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