# Narrative Statement – LEMUR-2 Fleet Application

## A. Introduction and Background

NanoSatisfi Inc. (NanoSatisfi), a Delaware corporation based in San Francisco, California, requests a conventional experimental radio license to conduct a market trial pursuant to 47 C.F.R. §§ 5.3(k), 5.54(a)(1), and 5.602. With this experimental license, NanoSatisfi seeks to research and evaluate the demand in the maritime, meteorological and education markets for nanosatellite technology as part of its ongoing market trial.[1]

NanoSatisfi creates tools that make it simple for anyone to interact with space by offering convenient, affordable, and on-demand access to satellites.[2] The enterprise grew out of a volunteer effort by four graduate students at the International Space University who began building a prototype nanosatellite as a platform for making space accessible and affordable to students. Early funding for the concept came from the crowd-funding website Kickstarter, where the original ArduSat (short for Arduino-based satellite) concept raised more than $100,000 from nearly 700 private space enthusiasts.[3]

*Kickstarter Launch – ArduSat-1 and ArduSat-X.* Based on the success of this Kickstarter campaign, and pursuant to a grant of special temporary authority awarded earlier this year,[4] two

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[1] *See* NanoSatisfi Inc., File No. 0532-EX-PL-2013, Call Sign: WG2XXW (Dec. 7, 2013) (awarding NanoSatisfi an experimental license to conduct a market trial using its ArduSat-2 satellite).

[2] NanoSatisfi, *Homepage* (last accessed July 10, 2013), http://www.nanosatisfi.com/.

[3] *ArduSat – Your Arduino Experiment in Space*, Kickstarter (last accessed July 9, 2013), http://www.kickstarter.com/projects/575960623/ardusat-your-arduino-experiment-in-space.

[4] The Commission granted Special Temporary Authority to ArduSat Inc. for operating these satellites on April 26, 2013 (Call Sign: WG9XFC; File No. 0917-EX-ST-2012). ArduSat Inc. has since applied for a full experimental authorization through the end of 2014. *See* File No: 0787-EX-PL-2013 (filed Dec. 24, 2013). Note that ArduSat Inc. is a non-profit corporation founded solely to launch these two satellites. While the applicant here, NanoSatisfi, was founded by many of the same members of the ArduSat Inc. team, NanoSatisfi is a separate, for-profit entity.

ArduSats (the ArduSat-1 and the ArduSat-X) were launched on August 3, 2013[5] and, after a brief stay in the International Space Station, released into orbit on November 19, 2013.[6] Since these satellites have been launched, Kickstarter funders and others are using these satellites to test experiments, play games, take pictures, and run applications. For this pioneering work related to the ArduSat-1 and ArduSat-X, the Obama Administration has recognized NanoSatisfi Co-founder and CEO Peter Platzer as a Champion of Change.[7] While these first two satellites are not a part of the ongoing market trial that is the subject of this application, they provide useful background of the company and suggest the power of ArduSat technology.

*ArduSat-2 and Initial LEMUR-1 Satellite.* Based on the experience with ArduSat technology and the great deal of interest surrounding it, NanoSatisfi sought and received authority to conduct a market trial to determine if somewhat more advanced ArduSats – the ArduSat-2 and the initial LEMUR-1 satellite – had consumer and commercial applications in the maritime, meteorological, and educational markets.[8] The ArduSat-2 was launched into space on January 9, 2014 as part of the Cygnus Orb-1 resupply mission to the International Space Station (ISS),[9] and it was released from the ISS on February 28, commencing transmissions shortly

[5] Japan Aerospace Exploration Agency, *Launch Result of H-II Transfer Vehicle "KOUNOTORI4" (HTV4) by H-IIB Launch Vehicle No. 4* (Aug. 4, 2013), *available at* http://bit.ly/1ewSHIE.

[6] NASA, *Crew Deploys Tiny Satellites and Tests Spacesuit Repairs* (Nov. 19, 2013), *available at* http://1.usa.gov/1hJEJSm.

[7] *Creating Next Generation Innovators Through Space Education*, The White House (June 6, 2013), http://www.whitehouse.gov/blog/2013/06/06/creating-next-generation-innovators-through-space-education.

[8] *See* Call Sign: WG2XXW, File No.: 0532-EX-PL-2013 (granted Dec. 7, 2014).

[9] Orbital Sciences, *ISS Commercial Resupply Services Mission (ORB-1)* (last accessed Mar. 4, 2014), https://www.orbital.com/NewsInfo/MissionUpdates/Orb-1/MissionUpdate/.

thereafter.[10] A few months later, on June 19, 2014, the initial LEMUR-1 satellite was launched as part of the UniSat-6 mission and commenced transmissions that same day.[11]

*Extension of the Ongoing Market Trial – LEMUR-2 Fleet.* While the original three ArduSats and the initial LEMUR-1 satellite have provided useful market data, NanoSatisfi requires shorter revisit times to test the market demand for these applications. For example, NanoSatisfi cannot test the market demand for a maritime tracking service if it is only able to revisit the location once every 24 hours. NanoSatisfi thus seeks approval to operate up to twenty-four technically identical satellites (the "LEMUR-2 Fleet") that are very technically similar to the initial LEMUR-1 satellite as part of its ongoing market trial in order to continue testing the educational, meteorological, and maritime markets.

**B. Description of Equipment and Theory of Operation**

NanoSatisfi seeks to continue its market trial of the educational, meteorological, and maritime markets from the initial ArduSat-2 with the addition of a fleet of up to twenty-four satellites.

*1. The ArduSat Concept.*

An ArduSat is a nanosatellite built in the CubeSat form factor,[12] a standard that helps reduce the cost of launching small satellites into space by allowing for a common deployment system. The basic unit for the CubeSat form factor is a single 10-centimeter cube, weighing no more than 1.33 kilograms. The CubeSat standard, however, is scalable along one axis, allowing up to three of these 10-centimeter cubes to be joined together (so-called "1U," "2U," and "3U"

[10] *See, e.g.*, NASA, *It's a March of the CubeSats as Space Station Deployment Continues* (Mar. 3, 2014), http://1.usa.gov/1jOJJal. The ArduSat-2 de-orbited and ceased transmissions on November 7, 2014.

[11] *See* Call Sign: WH2XCV, File No. 0213-EX-PL-2014 (granted Apr. 25, 2014).

[12] *See* California Polytechnic State University, *CubeSat Design Specification* (last visited July 10, 2013), http://www.cubesat.org/images/developers/cds_rev12.pdf.

CubeSats). The original ArduSats are constructed according to the 1U form factor, while the AruSat-2 and LEMUR-1/LEMUR-2 models are designed to the 2U and 3U specifications, respectively.

ArduSats carry a suite of sensors and a payload computer that can be reprogrammed while in space. The user-programmable payload computer is comprised of an array of Arduino processors (AVR processors) and can run code developed on the ubiquitous, open-source Arduino software development platform. ArduSats were invented with the purpose of creating an inexpensive, accessible development platform in space on which students, teachers, hobbyists, and researchers could affordably create and run their own custom-built experiments and applications.

Under this original educational focus – the primary purpose of the ArduSat-1 and the ArduSat-X – users can design their own space-based applications, experiments, and even space games using the Arduino open-source prototyping platform. Once a user-designed application has passed testing on an ArduSat clone located on Earth, users can upload their applications to the payload computer of an ArduSat that is orbiting in space, where it is monitored and maintained by the satellite's main computer. From there, the applications are free to sample data from the payload sensors and bus, take pictures, and return data to the user's web browser whenever the satellite is in range of a participating ground station. At the end of the user's experiment period, which can be up to a week in length, any remaining data is downlinked and returned to the user.

An ArduSat's payload consists of a suite of sensors, including an optical spectrometer, a Geiger counter, an atmospheric sensor, an infrared sensor, an accelerometer, a gyroscope, a magnetometer, a sun sensor, an electromagnetic wave sensor, a dual-frequency GPS receiver (for

ionospheric studies), a megapixel camera, and more. The sensors (and other telemetry values) are sampled by the user-generated programs running on the payload computer. The first two ArduSats began transmissions on November 19, 2013 under Call Sign WG9XFC.[13]

*2. ArduSat-2.*

The ArduSat-2 fits the 2U CubeSat form factor, with a total mass of 2.66 kg and an outer envelope of 10x10x20 centimeters (excluding the deployable dipole antenna). With this additional capacity, the ArduSat-2 follows the same basic ArduSat concept but has increased room onboard for hosting experiments, improved data downlink capability, and new payload sensors. The ArduSat-2 commenced transmissions on February 28 under Call Sign WG2XX and is being used to test the maritime, meteorological, and educational markets.[14]

*3. Initial LEMUR-1 Satellite.*

The initial LEMUR-1 satellite is a 3U CubeSat, adding an additional 10-centimeter cube to the ArduSat-2, for a total mass of approximately 4 kilograms and an outer envelope of 10x10x34.5 centimeters (excluding the deployable antenna). This additional capacity primarily houses another receiver allowing for supplemental gyroscopic equipment for steering the satellite more precisely. The initial LEMUR-1 satellite launched and commenced transmissions on June 19, 2014.

[13] *See* File No. 0917-EX-ST-2012; *see also* NASA, *Crew Deploys Tiny Satellites and Tests Spacesuit Repairs* (Nov. 19, 2013), *available at* http://1.usa.gov/1hJEJSm.

[14] *See* File No. 0532-EX-PL-2013.

*4. LEMUR-2 Fleet.*

The LEMUR-2 Fleet of twenty-four satellites will be, like the initial LEMUR-1 satellite, 3U CubeSats, each with a total mass of approximately 4 kilograms and an outer envelope of 10x10x34.5 centimeters (excluding the deployable antenna) and will be largely similar to the initial LEMUR-1 satellite currently operating.

As with the updates between previous generations of ArduSats, the key updates to the LEMUR-2 Fleet from the LEMUR-1 are to improve components. For example, the LEMUR-2 Fleet satellites will contain a redundant UHF transceiver (with the exact same RF properties) that is only turned on if there is a failure in the primary UHF transceiver. Similarly, these satellites will contain a new experimental S-band transmitter, an improved bus, improved battery capacity, improved solar panels, and an improved camera.

For purposes of the operating frequency of the LEMUR-2 Fleet, NanoSatisfi is applying for the 2.020 to 2.025 GHz frequency range in addition to the 2.40 to 2.48 GHz and 400.00 to 403.00 MHz [15] frequency ranges for which the initial LEMUR-1 satellite was approved. Although NanoSatisfi is applying for both the 2.020 to 2.025 GHz and the 2.40 to 2.48 GHz frequency ranges, it would greatly prefer to operate using the 2.020 to 2.025 GHz range due to the challenging noise environment at 2.40 to 2.48 GHz. NanoSatisfi has only added 2.40 to 2.48 GHz to its application as a backup in the event it is unable to receive authorization for the 2.020 to 2.025 GHz range, and it does not plan to use both the 2.020 to 2.025 GHz and the 2.40-2.48 GHz ranges.

[15] Note that NanoSatisfi's current operational plan focuses on a much narrower frequency range (402.425-402.625 MHz) than the full 400.00-403.00 MHz range.

## C. Construction, Launch, and Orbit Details

| LEMUR-2 FLEET: Summary of Construction, Launch, and Orbit[16] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Number to be Deployed** | **Altitude** | **Inclination** | **Schedule of Construction** | **Proposed Launch Date** | **Launch Service Provider Point of Contact** | **Launch Vehicle Operator** | **Launch Site** | **Vehicle** | **Mission** |
| 4 | 650 km | 6 degrees | In Development | Q3 2015 | Spaceflight, Inc. | Antrix / ISRO | Sriharikota, India | PSLV | Secondary payload on ASTROSAT satellite launch |
| 2 | 600 km | 98 degrees | In Development | Q4 2015 | Spaceflight, Inc. | Roscosmos | Baikonur, Kazakhstan | Soyuz | Secondary payload on METEOR satellite launch |
| 7 | 575 km | 31 degrees | In Development | January 2016 | Spaceflight, Inc. | JAMSS / JAXA | Tanegashima, Japan | HII-A | Secondary payload on a satellite launch |
| Up to 8 | 450 x 750 km | 98 degrees | In Development | Q1 2016 | Spaceflight, Inc. | SpaceX | Vandenberg, CA, US | Falcon-9 | Secondary payload on a FORMOSAT-5 satellite launch |
| Up to 8 | ~500 km | TBD | In Development | Q3-Q4 2015 | Working with several brokers to negotiate launches | TBD | TBD | TBD | TBD |

[16] Each satellite in the LEMUR-2 Fleet will be serialized as LEMUR-2-XXXX.

**D. Purpose, Scope, and Objective of Market Trial**

NanoSatisfi Inc. seeks authority to operate the LEMUR-2 Fleet – a fleet of up to 24 satellites – to continue its market trial, which was initially approved as a basis for its authority to operate the ArduSat-2 and later, the initial LEMUR-1 satellite. To adequately test the demand for the meteorological, maritime, and educational markets, NanoSatisfi must provide a service with high revisit times. For purposes of the experimental period, NanoSatisfi is targeting revisit times of 30 minutes for monitoring ships and approximately one week for imaging, which will require a small constellation of up to twenty-four satellites. NanoSatisfi requests a two-year experimental authorization to continue this market trial.

1. *Maritime Monitoring*.

NanoSatisfi requests authority to test the market for using its nanosatellite technology to monitor maritime activity. Current maritime monitoring systems are generally land-based and do not offer the ability to track ships when they are outside of a 50-mile zone. NanoSatisfi plans to test a satellite-based system relying on a small constellation of up to twenty-four satellites, so that satellites will provide reasonable revisit times of approximately 30 minutes for purposes of monitoring ships. The satellites will passively monitor Automatic Identification System ("AIS") signals at 161.975 MHz and 162.025 MHz for purposes of tracking nautical activity (note that they will not emit any signals at these frequencies). For purposes of this trial, no equipment will be required onboard subject vessels as vessels with gross tonnage of 300 tons or greater are already required by international law to carry a functional Automatic Identification System (AIS) beacon transmitter on-board.[17]

[17] *See* The International Convention for the Safety of Life at Sea, Dec. 2002 Amendments (Dec. 2002), *available at* http://bit.ly/15vyqx5.

NanoSatisfi believes that such data is of interest to shipping companies, harbor operators, governments, Vessel Traffic Service (VTS) data providers, and financial services companies. Additionally, NanoSatisfi hopes to fuse optical data with communication data to help detect pirate ship activity. However, these uses have to be verified, which is the purpose of this experimental period.

During this experimental period, NanoSatisfi expects to have a small number of pilot customers (less than 100) to help refine the service and quantify the market need for this data, which it predicts could be tens of thousands of customers across the globe.

*2. Meteorological Monitoring*.

NanoSatisfi requests authority to test the market for using its nanosatellite technology to conduct atmospheric studies. Current satellite-based systems rely on large, expensive satellites and suffer from extensive delays and long revisit times. NanoSatisfi plans to test a satellite-based system relying on a small constellation of up to twenty-four satellites. These satellites will provide reasonable re-visit times.

To conduct this meteorological monitoring, satellites in the constellation will passively monitor GPS signals at L1 (1575.42 MHz) and L2 (1227.60 MHz) frequencies (no transmissions are required). Based on these GPS signals, the satellites will employ a relatively new technique – GPS-Radio Occultation.[18] Because GPS signals refract differently as they pass through the atmosphere depending on temperature and the concentration of water vapor, it is possible to measure weather patterns using this technology, and there is a great deal of interest both commercially and in government to explore this technology further. For example, the Weather

[18] *See, e.g.*, NASA, *Generating Climate Benchmark Atmospheric Surroundings Using GPS Radio Occultations* (July 2007), 1.usa.gov/1bOUxEI.

Forecasting Improvement Act of 2013 (H.R. 2413) specifically includes provisions for the National Oceanic and Atmospheric Administration to examine this technology.[19] Weather monitoring technologies such as GPS-Radio Occultation and others are currently receiving particularly extensive attention because of a looming gap in the US government's ability to monitor the weather with one of its satellites scheduled to reach the end of its useful life in the near future and without a replacement scheduled for some time.[20]

NanoSatisfi believes that such data is of interest to governments, consumers and the financial services community. Additionally, NanoSatisfi hopes to fuse optical data with atmospheric properties to provide an enhanced value-added product. However, these uses have to be verified, which is the purpose of this experimental period.

During this experimental period, NanoSatisfi expects to have a small number of pilot customers (less than 100) to help refine the service and quantify the market need for this data, which it predicts could be tens of thousands of customers across the globe.

[19] *See, e.g.,* Dan Leone, *Commercial Weather Provisions in NOAA Bill Survive First Vote in House*, SpaceNews (Jul. 9, 2013), http://bit.ly/16bpmwo.

[20] *See* U.S. Government Accountability Office, *Polar-Orbiting Environmental Satellites* 25 (June 2012), *available at* http://www.gao.gov/assets/600/591643.pdf.

3. *STEM Education*

Especially in the United States, but also in Europe and elsewhere throughout the world, economies are suffering from a lack of graduates in the crucial fields of science, technology, engineering, and math (STEM). While these fields are generally accepted to be at the very core of our ability to innovate, generate jobs and stimulate economic growth, budget cuts in our education system have increasingly endangered these fields and created a problematic dearth of graduates.

NanoSatisfi is testing a novel approach to inspire students to pursue careers in these fields by giving them access to control the sensors and cameras of a nanosatellite. Students will engage in an online curriculum similar in format to those offered by Udacity or Coursera. At the end of this online curriculum, students will have access to the satellite's microprocessor to upload their own experiment and control the sensors and cameras. Using a simple online satellite control interface, users can program and control the satellite, provide instructions on sensor activation, track the satellite's orbit, implement experiments and download data and pictures from space. Users already have access to the initial LEMUR-1 satellite and will have access to up to twenty-four additional satellites for purposes of testing their experiments and running their applications. Hiding the complexities of space, this simple, integrated environment democratizes space for schoolchildren everywhere so that it is no longer only the province of rocket-scientists.

During this experimental period, NanoSatisfi plans to work with a select number of pilot organizations (less than 200) to help refine the service and curriculum and qualify the market for this kind of educational tool. Nanosatisfi estimates that the total market for this tool could be in the hundreds of thousands of customers across the globe.

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Including authority to operate a fleet of up to twenty-four satellites under this proposed market trial will help NanoSatisfi better evaluate the demand for its technology in each of these various sectors. Consistent with 47 C.F.R. § 5.602, NanoSatisfi will own all transmitting and receiving equipment in the study, and it will ensure that all trial devices are rendered inoperable at the conclusion of the trial.

**E. Contribution of the Proposed Market Trial to the Radio Art**

Testing these satellites as part of this proposed market trial promises to significantly contribute to the development, extension, expansion and utilization of the radio art. As described above, NanoSatisfi's proposed market trial will explore three areas to determine the market demand for innovative nanosatellite technologies. These CubeSats will be among the first nanosatellites employed for monitoring meteorological and maritime activities and for allowing the general public to access space in a meaningful way. If these market trials are successful, NanoSatisfi plans to widely deploy its technology, promising to offer extensive consumer and educational benefits.

**F. Orbital Debris Mitigation Statement**

Consistent with 47 C.F.R. § 5.64, NanoSatisfi has included an Orbital Debris Assessment Report (ODAR) as an exhibit to this application. As discussed therein, except for the PSLV launch vehicle, the longest expected nominal orbital life for any of the orbits is approximately eight years. For all of the launches except for the PSLV launch vehicle, the outer limit of the orbital life of a satellite in the constellation is approximately twenty years, assuming a very unlikely worst-case scenario in which the satellite is non-functional and both the solar arrays and the antennas fail to deploy. For the PSLV launch vehicle, the nominal expected orbital life is 17.3 years, and in the very unlikely event of complete failure (which would, among other things,

require the failure of an antenna that has already successfully deployed during the LEMUR-1 mission), the worst-case orbital life is approximately forty years.

At the end of each satellite's orbital life, the nanosatellite will re-enter the atmosphere and completely burn up before reaching the ground. None of the satellites contain or will contain any hard metals or other hazardous materials that could survive reentry.

**G. Onboard Cameras**

NanoSatisfi is in the process of submitting an application to the National Oceanic and Atmospheric Administration ("NOAA") to operate each satellite's two onboard cameras (one is for visible light and one is for infrared light). NanoSatisfi has previously obtained licenses for the cameras onboard the ArduSat-1, ArduSat-X, ArduSat-2, and initial LEMUR-1 satellite.[21]

**H. Conclusion**

By granting this application, the Commission can help NanoSatisfi make space accessible to anyone and to unleash the valuable commercial applications made possible with innovative nanosatellite technology.

The "stop buzzer" point of contact for the market trial is Joel Spark, Lead Engineer Satellite Bus (415-356-3400 x201; joel@nanosatisfi.com).

[21] *See* NOAA, *About the Licensing of Private Remote Sensing Space Systems* (last accessed Jan. 21, 2015), http://www.nesdis.noaa.gov/CRSRA/licenseHome.html (click on "NOAA Licensees").