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THE PEGASUS INCIDENT: THE LOSS OF THE FIRST ECUADORIAN SATELLITE AND ITS RECOVERY

Abstract

On April 25, 2013 after almost 4 years of development and testing the NEE-01 PEGASUS, the first Ecuadorian satellite took off to orbit on board an LM2D Chinese vector, launching from the Jiu Quan cosmodrome, it entered in its target orbit approximately 13 minutes later. At first the deployment presented some issues, like the satellite being too near to its travel companion, the Argentinean Cubebug-1, so we had to wait a few days until they become separated and the correct TLE and identifications being assigned, operations started nominally on May 5 and final NORAD IDs were assigned on May 13, on May 16 the first public operation and broadcast was made and the satellite operated correctly until May 23 when a close approach with the object SCC-15890 occurred.

After such event, the signal of the satellite was lost and even when we knew it was still transmitting we could not decode its signal, the Ecuadorian Civilian Space Agency tried to recover the contact for 3 months until the satellite was declared lost.

However being declared lost, we kept working in hopes of discerning the real cause of the problem, which we found out and could develop a solution by mounting a micro-repeater module code named PERSEUS in the twin of the satellite, the NEE-02 KRYSAOR, which at that time was being readied to be launched from the Yasny cosmodrome, The NEE-02 was injected into orbit on November 21, 2013 and it took some time until we found out the correct ID of the satellite which was the DNEPR-OBJECT-AB, we started the nominal testing procedures on December 5 and by December 20 we were testing the PERSEUS module.

On January 25 we could announce the recovery of the audio portion of the NEE-01 PEGASUS using the PERSEUS repeater onboard the NEE-02 KRYSAOR, at this time we continue working in this new field (for us) of inter-satellite communication in the hopes of being able to restore the full signal of our first satellite

Introduction: EXA is the Ecuadorian Civilian Space Agency, a civilian NGO created in 2007, in charge of the administration and execution of the Ecuadorian Civilian Space Program – ECSP.

As part of the ECSP[1], Project PEGASUS was developed to demonstrate indigenous satellite building, testing and operation capabilities and to this end, a ground station called HERMES-A[2][3][4][9][11] was built and tested successfully from 2009 to 2013 and 2 satellite flight models were also built and tested successfully, both in house and by a foreign third party.

NEE-01 is the Ecuadorian registry number meaning 'Ecuadorian Space Ship – 01' in Spanish, so the first spacecraft was christened **NEE-01 PEGASUS** and the second one was christened **NEE-02 KRYSAOR.**

The design and development team was led by Cmdr. Ronnie Nader and composed by Sidney Drouet, Manuel Uriguen, Hector Carrion, and Ricardo Allu[23]

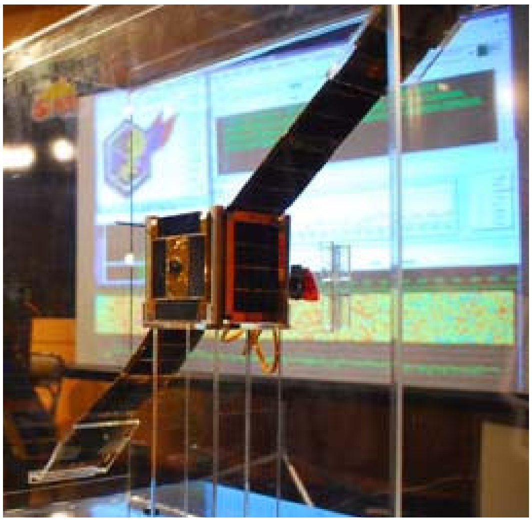


Fig-1 The NEE-01 PEGASUS in orbital flight configuration with its 2 DSA Multipanel solar wings deployed during its maiden presentation on April 4, 2011

Fig-2 The NEE-02 KRYSAOR in orbital flight configuration with its 2 DSA Multipanel solar wings deployed

Design: The NEE-01 PEGASUS was designed as a 1U cubesat form factor, however, as soon as the initial design was complete, a grave limitation was discovered in the power budget calculations: A lack of space for enough solar cells, so we decided to add a pair of multi-panel solar arrays[22] or 'wings' to address this deficiency.

Characteristics:

-Mass: 1266g

-Dimensions: 10x10x75 cm (wings deployed)

-MLI and titanium shielding.

-Command reception over FHSS 433 to 444 MHz over a 11 MHz bandwidth

-114dBm on-board reception sensitivity with diversity capability over 2 dipoles

-Capable of operation without batteries on solar power only.

-MCU-driven EPS with 8 input power channels each capable of supporting 6V@2A and 25ms switching capability.

Fig-4 Detail of the EPS-MCU daughterboard built by EXA personnel.

Equipment and Modules: The following is a brief description of modules relevant to this paper, that composes the payload of the spacecraft:

CYCLOPS[24]: This module handles the radio transmission, the real-time video and the OSD telemetry. The camera has 720 lines of resolution and IR sensitivity of 0.0001 Lux and the video has no discernible delay. 1W TX power on beacon mode, 3W on area coverage mode, transmitting on 910MHz (PEGASUS) and 980MHz (KRYSAOR) transmission frequency with 25 MHz video bandwidth and 6 MHz audio

CDHM: Command Data handling Module, manages the command reception over FHSS 433 to 444 MHz over a 11 MHz bandwidth with -114dBm on-board reception sensitivity and diversity capability over 2 dipoles

PMSS: This is the spacecraft passive navigation system, which uses the Earth's Magnetic Field (EMF) to stabilize its position in 2 axes, using 4 linear arrays of magnets and 2 sets of HyMu-80 inertial-magnetic dampers

SEAM/NEMEA[13]: Its purpose is to moderate the S/C temperature, to block the Alpha, Beta, X, Gamma and GCR (Galactic Cosmic Rays) within the limits of the possible, without producing Bremsstrahlung radiation

EPS: It has 32 cells distributed in 2 arrays for a total of 28.8 amps or 107 watts, capable of operation without batteries on solar power only with MCU-driven core and 8 input power channels each capable of supporting 6V@2A and 25ms switching capability.

ADS[28]: The Antenna Deployment System is based on memory metals and is deployed using the heat of the sun in a gentle way to avoid any unwanted rotation.

Construction[44]: NEE-01 was built on the EXA facilities and as of the launch date had passed more than 1000 hours of tests Its hull is made of 50% aluminum and 50% titanium The design, test, assembly and integration was performed locally, down to the printed circuit level, a very detailed paper about this process can be found on Reference number 44

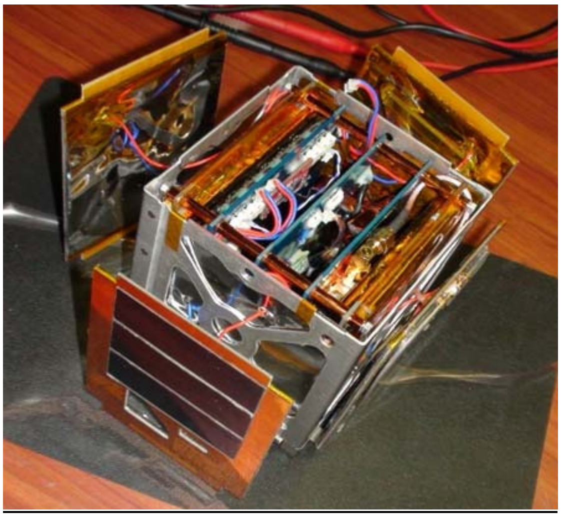


Fig-10 An exploded view of the NEE-01 PEGASUS payload integrated into its S/C hull with the SEAM/NEMEA shielding on the back of the solar panels.

Launch: NEE-01 was launched into orbit on 2013 April 25 23h00 local time [18][19][20] by a Chinese Long March 2D launch vehicle, from the Jiuquan Satellite Launch Center. It entered its target orbit approximately 13 minutes later. The launch was coordinated by ISISpace[14] on behalf of GWC, the owner of the launch vehicle. The orbital parameters were:

Regime Sun-synchronous
Semi-major axis 7,014.62 km
Eccentricity 0.0019229
Perigee 630 km
Apogee 657 km

Inclination 98.04 degrees
Period 97.45 minutes
Mean motion 14.78

NEE-02 was launched into orbit on 2013 November 21 02h10 local time[16][17][21] by a Russian Dneper launch vehicle, from the Yasny Cosmodrome. It entered its target orbit approximately 15 minutes later. The launch was coordinated by ISISpace[15] on behalf of IKSC Kosmotras, the owner of the launch vehicle. The orbital parameters were:

Regime Sun-synchronous
Semi-major axis 7,029.69 km
Eccentricity 0.0085226
Perigee 598 km
Apogee 718 km
Inclination 97.76 degrees
Period 97.76 minutes
Mean motion 14.73

Early Operations: First contact with NEE-01 was made on May 5, 2013, NORAD officially identified the satellite as NEE-01 PEGASUS on May 13, 2013.

In this case specifically, the LM2D ejected its secondary payloads on a vector perpendicular to the flight path and in the first days both NEE-01 and Cubebug-1 were very near each other, EXA worked with the Argentinean team who were having the same problems trying to identify their satellite.

However, in its first pass over Germany, a local radio amateur Mike Ruppretch[10] with whom we have been working for some time now and instructed him how to build an ARGOS[12] module for receiving the NEE-01 signal was able to detect the signal and relay it to us via HERMES Internet Relay gateway, so at about 4 AM in the morning we could hear the audio portion of the NEE-01 transmission[9], but could not see the video as Mike Rupprecth reported a problem that cause his computer to reboot every time he connected the video cable to the capture card. He was also able to decode the CW and SSTV[8] signals from the satellite in subsequent passes as it is detailed in his blog[10].

From May 16 up to May 21 all the satellite transmissions were successfully broadcasted via EarthCam and they reported that between 1 and 3 million people around the world were connecting to watch the passes.

Fig-12 A snapshot of the first public video transmitted by the NEE-01 during May 16 2013, 10h41m pass over South America

Thousands of Ecuadorians reported watching the broadcasts in their jobs and in the night at home and many schools started to work with the SSTV and CW audio signals and decoded them successfully.

Ground Station: ARGOS hyper amplification manifold: Due the high bandwidth usage involved in transmitting video (25Mhz) even at 3W of EIRP, the signal coming down to earth would be to faint to be detected with any standard amateur equipment, which is why EXA developed the ARGOS hyper amplification manifold[12] back in 2010, this allowed us to receive a clear video transmission from orbit. In the first days of operations it became clear that no standard radio amateur equipment would be able to even detect the carrier signal of the NEE-01 which was reaching earth at -132dBm, however EXA did receive some emails from Japanese and Australian radio operators claiming to have detected the carrier wave and even decoding the CW audio messages[31]

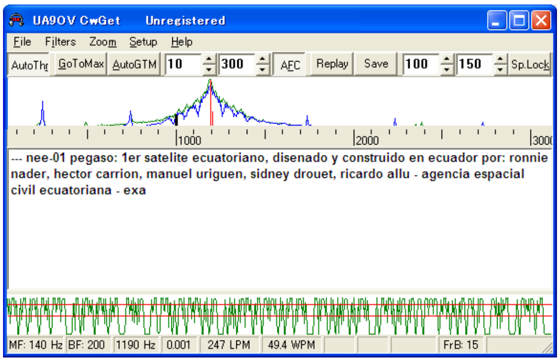
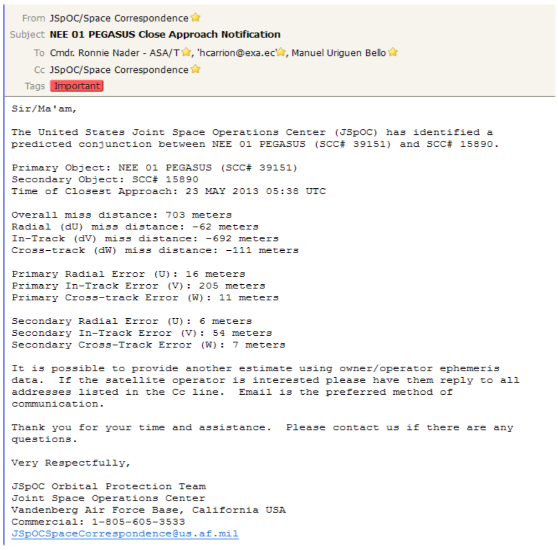


Fig-13 Screen capture showing the decoding of the CW signal of the NEE-01 from the Japanese amateur operator JE9PEL © Mineo Wakita JE9PEL

<u>The Incident</u>[(45)]<u>:</u> On May 21 at 20h10 local time, we received a Close Approach Notification (CAN) from JSpOC/NORAD informing EXA as the satellite operator, that a probable conjunction would occur between NEE-01 and NORAD Catalog Number 15890 on May 23 at 0538 UTC, this was our first CAN and after analyzing the data EXA came to the conclusion that the conjunction was risky as the Radial Miss Distance was only 62 meters. EXA notified high ranking government officers and after consultations this officials decided to make it public. A press conference was called for May 22 at 10h30 local time[(29)],to brief the public on the situation.


From JSpOC/Space Correspondence
Subject **NEE 01 PEGASUS Close Approach Notification**
To Cmdr. Ronnie Nader - ASA/T, 'hcarrion@exa.ec', Manuel Uriguen Bello
Cc JSpOC/Space Correspondence
Tags Important

Sir/Ma'am,

The United States Joint Space Operations Center (JSpOC) has identified a predicted conjunction between NEE 01 PEGASUS (SCC# 39151) and SCC# 15890.

Primary Object: NEE 01 PEGASUS (SCC# 39151)
Secondary Object: SCC# 15890
Time of Closest Approach: 23 MAY 2013 05:38 UTC

Overall miss distance: 703 meters
Radial (dU) miss distance: -62 meters
In-Track (dV) miss distance: -692 meters
Cross-track (dW) miss distance: -111 meters

Primary Radial Error (U): 16 meters
Primary In-Track Error (V): 205 meters
Primary Cross-track Error (W): 11 meters

Secondary Radial Error (U): 6 meters
Secondary In-Track Error (V): 54 meters
Secondary Cross-Track Error (W): 7 meters

It is possible to provide another estimate using owner/operator ephemeris data. If the satellite operator is interested please have them reply to all addresses listed in the Cc line. Email is the preferred method of communication.

Thank you for your time and assistance. Please contact us if there are any questions.

Very Respectfully,

JSpOC Orbital Protection Team
Joint Space Operations Center
Vandenberg Air Force Base, California USA
Commercial: 1-805-605-3533
JSpOCSpaceCorrespondence@us.af.mil

Fig-13 The original notice from JsPOC on May 21, 2103 received by the EXA's Space Operations team

By that time EXA managed to make new CAC (conjunction assessment calculations) with information obtained from sources in Russia about the nature of the object and particularly about the known fact (for this sources) that the object still shed debris and particles, and that this particles were continuously produced, believed to be composed mostly by particles left due VUV paint decomposition and debris from the separation mechanism so a close approach to it will probably mean contact with this particles. We were left with the impression that they knew about this because an earlier experience with this object.

The last meaningful transmission of NEE-01 was on May 21 2013 starting at 23h12, on May 22 2013 there were no scheduled transmissions as the passes were too low, however after a long analysis EXA decided to put the satellite in survival (safe) mode, which meant that it would broadcast continuously along its orbit with nominal power, as opposed to operating in the Overlord mode in which it transmits only when activated by HERMES-A ground station and with high power.

This command was sent to the satellite during low passes on May 22 at 21h00 and 23h00 local time approximately, and we did it because if we left it in Overlord mode, any loss of attitude control will never allowed us to ascertain the real situation of the satellite if we were not able to activate it, also, in safe mode, we should prevent freezing of the batteries as NEE-01 uses a thermal routing system based in carbon nano-tubes (NTDS) that uses the battery arrays as a heat sink due its mass which is about 33% of the satellite mass.

<u>Decision Rationale:</u> This command decision had its downside: In the possible scenario that the satellite will pass to a safe distance of the object but face some of the suggested particles shed by the object, maybe the NEMEA shield could protect the spacecraft hull from a low velocity particle impact, as the collision was to be lateral the terminal velocity of the particles would not exceed 8200 km/h and any particles will probably disintegrate on contact due its suggested composition, but the momentum of force will be enough to induce an tumble on the spacecraft only if this particles were to be under 0.5 millimeter in diameter. Otherwise, the spacecraft will be destroyed.

Fig-14.1 Example of damage caused by a 1 mm size particle on a satellite electrical cable. See reference #47

Fig-14.2 Impact crater. Scanning Electron Micrograph (SEM) of a tiny crater in the surface of a window of Space Shuttle Challenger, following mission STS-7 of 18-24 June 1983. The crater is about 640 microns in diameter and 630 microns in depth, surrounded by a spall zone of 2.4 millimeters diameter. The pit contains some titanium oxide, which possibly originated from a flake of paint. Credit NASA/SCIENCE PHOTO LIBRARY

By May 22 at 23h18 local time we received an update of the CAN indicating that the radial miss had reduced even further and was 58 meters then.

By May 23 at 01h42 local time we received and update of the CAN indicating that a full collision have not happened

By May 23 10h42 local time, the very first pass after the conjunction, we were not able to detect any meaningful signal from NEE-01, nor in subsequent passes up until a week later when we were able to detect the vertical sync TV signal appearing and disappearing at a high pass in the sky, not enough to form an image, but enough to be sure that the satellite was in tumbling. NEE-01 carries 2 TX antennae and 4 RX antennae.

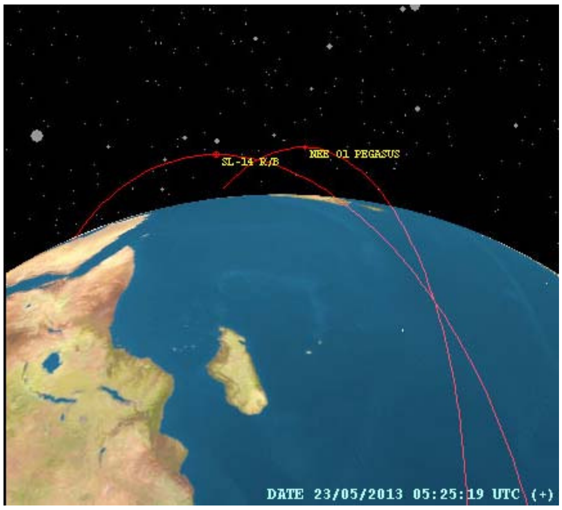


Fig-14 3D Stereo simulation of the close approach simulation between NEE-01 and SCC-15890 © Satflare.com

At this point we were sure that the safe mode command was received by NEE-01 and executed correctly because the spacecraft was transmitting during illumination without the need of the activation code from the EXA's ground station.

On May 23 2013 we called a press conference at 15h30 local time[30] and announced what had happened and what we knew at that time, also announced that we had started a rescue operation that we nicknamed PERSEO and that we will implement our OMEGA communication protocol which means we will not talk to the press until the operation is finished within 90 days, that will be over at August 28 2013[33], if after that date we are not able to recover the use of the satellite, we will activate the insurance policy.

Signals received after the incident: At that time we were able to detect a vertical TV sync high in the sky were NEE-01 position should be in that particular moment, but that signal came and went, like on and off, that for us indicated a tumbling due the geometry and position of the RX antennae on the spacecraft, the power rate or received signal strength varied chaotically, without a discernible pattern, TV signals are not easy to debug due its composite nature and their power distribution along its various carriers.

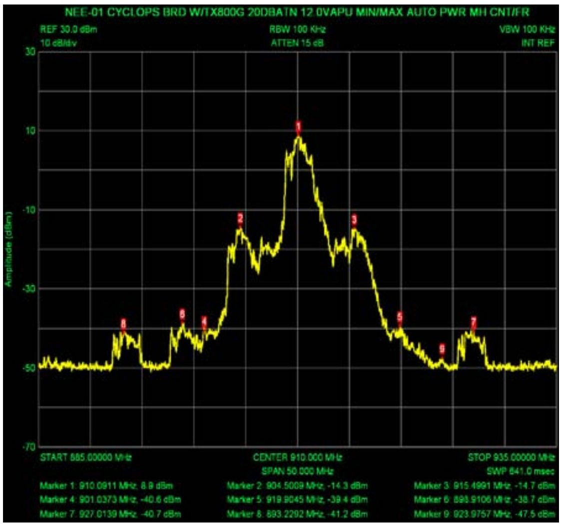


Fig-15 The original received signal for NEE-01 around May 2013 ***before*** *the anomaly, compare this signal with the signal depicted in Fig-16 for September 2013, nicknamed "The Ghost of Pegasus"*

The main problem in this situation was not the pointing error, or even a signal polarity error, because in time the tumbling could stop due the geometry of the spacecraft, the solar arrays could act as radial breaks as the B* term analysis of the TLEs was suggesting, and also the PMSS system included magneto dynamical breaks.

The NEE class satellites have no means of altering its attitude by command or change its orbit, they have no reaction wheels, magnetorquers or thrusters of any kind, the only system that stabilizes the spacecraft attitude in 2 axes is the PMSS subsystem working with the DSA solar panel deployment system, which had worked flawlessly, but can be easily disturbed by external factors and also takes some time to stabilize the spacecraft properly.

So any loss of attitude has to be the result of external forces acting over the spacecraft.

The main problem was that such movement could not allow the solar panels to charge the batteries as they should, and transmitting a TV signal from space consumes a lot of power and the survival mode in which we put the satellite makes it transmit all the time whenever is in daylight, then if the spacecraft was in tumbling it cannot collect the heat of the sun in the way we have planned for the NTDS system to work properly and the batteries could freeze.

<u>Ascertaining the situation:</u> In June 13 2013 we were able to gain command of the activation and deactivation during the night passes, and this indicated a lot of things for us:

-The batteries were holding, they were charging, we still don't know how. Otherwise NEE-01 could not be commanded to start in eclipse.

-We could not ascertain the tumbling rate due the complexity of the TV signal, however such tumbling should have been diminishing if we were able to command the spacecraft to start; however, the RX system has 4 antennae, the double of the TX system and we were transmitting from the ground station with a EIRP of 51.5dBm

-We are able to confirm that the TX system was working as we could detect the vertical TV sync signal which has the strongest signature of all

-In the specific case of the NEE-class of satellites, in order for the TX to work, the whole system must work.

-We did not know how many solar cells were broken or offline in the spacecraft.

There were some few options at our hand to do every time we had a high pass to make NEE-01 stop rotating until the PMSS navigation system can take over, if we achieved that threshold, it was only a matter of days that the spacecraft should stabilize and it signal could de received properly again. Or so we thought.

<u>Proof of life and communications opportunities:</u> From this point forward, we attempted to receive the signal from NEE-01 almost every day, its orbit brings one communication opportunity in daylight between 10h00 and 11h30 each day and one in the night, between 22h00 and 23h30. Soon became clear to us that in this conditions it would be futile to attempt contact in days where the passes where not over 30 degrees, which were about 2 or sometimes 3 days in the week.

To add to that, in safe mode the NEE-01 switches itself off in eclipse, however we can wake it up and command it to work by sending the activation code sequence from the HERMES-A ground station, this activation code is unique and it resides in the firmware of the command reception and handling module of the NEE-01.

When NEE-01 receives the activation sequences it executes a series of commands to bring the main payload online, booting up the transmitter and the camera, all of this resulting in a very specific EM signature which power surges in the first 1250ms of the transmission and almost in every case it responds within the first 1500ms from the sending of the activation code.

In the best days we could detect a faint EM signature, this means that we could see a very small 'walking' carrier signal growing in intensity just over the -89 dBm threshold traveling from +910.xxx MHz to -909.xxx MHz with a 20 to 25 Mhz bandwidth which was coincident with the orbit of the NEE-01's Doppler change expected and with the time and day of the pass, in the night passes we sent out the activation sequences and saw a surge in the center frequency appear and then the signal would show in the oscilloscope, which corresponds to the boot up EM signature, we made many tests to rule out background noise:

-We ran the sweep just before and after the pass looking for the same signal, the result was always negative.

-For this test we ran the clock on the computers forward or backwards to match the orbital pass of the day, so the antennae will point to same coordinate path in the sky for the whole sweep

-During a night sweep we intentionally sent the on-off command and the reading from the oscilloscope matched the boot-up and shutdown times of the NEE-01, which we could detect by registering the same fain EM signature we were seeing on every sweep.

To our best knowledge, no other source in the sky could produce the same results than NEE-01, We were sure that NEE-01 had survived, however for some reason, the transmission was not reaching earth strong enough for our ground station to decode it. We nicknamed this faint EM signature as "*The Ghost of PEGASUS*" or TGP.

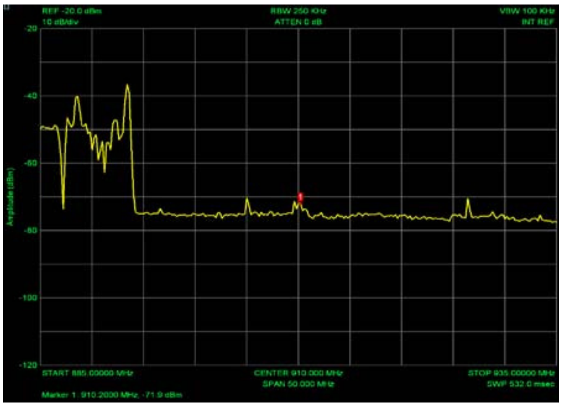


Fig-16 Screen capture of the EM signature for NEE-01 around September 2013, nicknamed "The Ghost of Pegasus". ARGOS hyper-amplification manifold was operating at full capacity providing +120dBm filtered, narrow band amplification.

By the first days of August we could notice that TGP was getting more and more stable, this is, the vertical sync TV portion, located near the center of the bandwidth varied in intensity less and less and it was more stable with each passing, for us this was a cyclic polarity change consisting with tumbling decreasing, and the peak of this signal channel was more noticeable and pronounced with each pass.

By the end of August this signal channel was stable, but however being the most powerful in the whole signal, it will not raise over -83 dBm and the whole signal will not raise over -85 dBm in the best case.

Reaching the end of August also meant that we were near the deadline of the insurance policy coverage, and not being able to re gain the signal of the NEE-01 we notified the proper authorities which in turn notified the insurance company, which with due diligence executed the policy. And we had to declare the NEE-01 lost.

<u>The PERSEUS device:</u> Declaring our first satellite lost was a blow to us and to the country, however we knew that the spacecraft had survived and it was working properly, if not, no signal would have been received and no response to our commands would have been recorded.

But something beyond tumbling prevented the signal from reaching our ground station with the calculated power, ARGOS was very sensitive, but also a very complicated machine and we practically rebuilt it from scratch looking for something we could exploit to boost the signal gain over the noise floor. However time was running out as we have to prepare for the next launch of NEE-02

But even when the task ahead was clear: To forget about NEE-01 and focus our efforts in the getting NEE-02 ready to launch, the whole team could just not let NEE-01 go, we have invested too much on it, the country really cared about it, it was our first satellite and it was something very personal to all of us, it would have been easier if we have never received any signs of life from it after the incident, but we knew it was up there, alive and working, even after such event, it was a testimony of our engineering and ingenuity, we could just not abandon him.

So we kept tracking NEE-01 as usual and a few days later we came to the conclusion that the most probable cause for the phenomena we were observing was that the incident somehow have displaced the antenna in a way that could no longer point in the proper direction, we arrived to this conclusion by analyzing and simulating what would have been the attitude of NEE-01 during the incident and we found out that the side facing the supposed particles was exactly the side were the main TX antenna was mounted over.

However, the NEE-01 antennae were made of NiTinol, a memory shape alloy that we had customize to have a transition temperature of 535 degrees Celsius, it was very improbable that a high speed, sub-millimeter particle would just have been that lucky to hit any of the 2.0mm diameter dipoles or the 3mm diameter 18k Au fasteners but the panel they were mounted over presented a bigger target.

The side panels were reinforced with the SEAM-NEMEA shielding, which included 2 sheets of 0.25mm CP-2 titanium alloy, 99.98% pure and behind that there was a 9 mm gap between the panel and the battery array which was also heavily shielded, so assuming that something very small had hit the spacecraft, whatever thing it was, did it over the most shielded part of the spacecraft.

But this also meant that there was no possible way, that there was nothing we could do here on earth to receive the signal properly if the panel was out of alignment and the antenna had lost its zero, we will have to just let it go.

Unless we do something in orbit: Maybe we could do nothing here on earth, but we surely could do something in space.

<u>Using NEE-02 KRYSAOR as a lifeline:</u> We were just preparing another spacecraft to be sent to an orbit that, for pure luck, intercepted the orbital path upper projection of the NEE-01 every two weeks at a minimum distance of 100km in the poles and 300km over the Ecuador, the very right place where we just happen to be.

The NEE-02 mission was the same as the NEE-01 and they are identical in every aspect, their masses only differ by 0.09 grams.

Then we came up with the idea of installing a simple repeater inside the NEE-02 as a secondary payload, a small reception device tuned in the same frequency of the transmission frequency of the NEE-01 and directly connected to the input of the main transmitter of the NEE-02, we still had 9 command channels available in the main MCU port and we will only need 2 command channels to operate it.

Fortunately, we had all the materials at hand and all the expertise to build it, and in fact we already have been working in such a device for a different project some 2 years ago, we already had a chipset that allowed us to have a -121dBm sensitivity over the target frequency with 2 diversity channels, and we had to mount 2 dipoles more over the NEE-02 hull and make this dipoles deployable using the same techniques we used to build the DSA arrays, this 2 dipoles were made from a NiTinol 0.25mm diameter core and shrouded by a 0.12mm Pt-Ir alloy sheet bind to a 18K Au fastener. So from mid August to mid September the PERSEUS device was ready, tested and installed on the NEE-02, which was ready to be shipped to the ISISpace installations on the Netherlands, to be integrated into the ISIPod alongside the Argentinean Cubebug-2.

However this was a long shot, all theory in principle, sound theory and no unproven or fancy technology, but the shaky part of the undertaking was that the unproven hypothesis that the panel was hit and the antennae displaced and that we could pick up the signals with only 4 antennae and using the wings of the DSA as reflectors at 300km in space just using casual pointing. Obviously this project was not announced or notified to anyone except the very few people involved in it. If it worked, we could get the NEE-01 back, if not, business as usual.

We had nothing to lose and everything to gain.

NEE-02 Launch and Operations: On November 21, 2013 the NEE-02 was launch as planned and reached its target orbit, due the PERSEUS operation we said to the press that we needed about 40 days to start operating the satellite, however we had the first beacon contact on the day after the launch indicating that the satellite was responding to commands and that the DSA were deployed and operating properly.

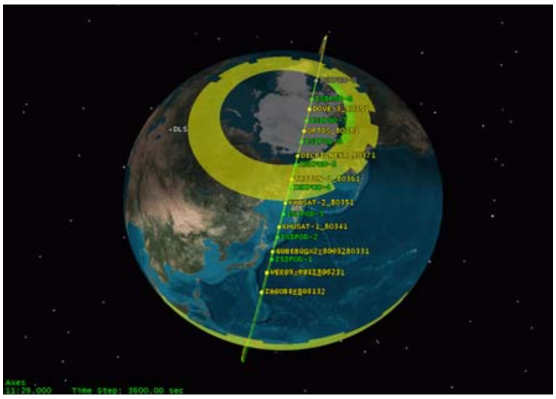


Fig-17 3D simulation of the Dnepr launch #14 showing the 33 objects deployed, © T.S. Kelso.

NEE-02 was part of a record launch of 33 objects[32], with the help of Dr. T.S. Kelso from CelesTrak, we were able to locate it as DNEPR-OBJECT AB and start operating it again like 2 weeks after launch.

The NEE-class satellites are unlike any other cubesat projects, they need very accurate pointing due the strict link budget that comes associated with the problem of getting a 25Mhz bandwidth TV signal at 3000 kms away that has a maximum EIRP of 3W, that is why we developed the ARGOS technology that works in conjunction with very large ground antennae with pointing accuracies below 0.2 degrees and narrow beams of less than 3 degrees and very precise rotators and controllers too. Then a TLE lottery supposes a very tedious and sometimes frustrating work in this case.

Getting results from PERSEUS: By mid December 2013 we were able to make the first successful in-orbit tests of the PERSEUS device at a maximum range of 2000 km of separation between the spacecrafts and minimum range of 800km of separation, we could heard the audio portion of the whole signal coming from NEE-01.

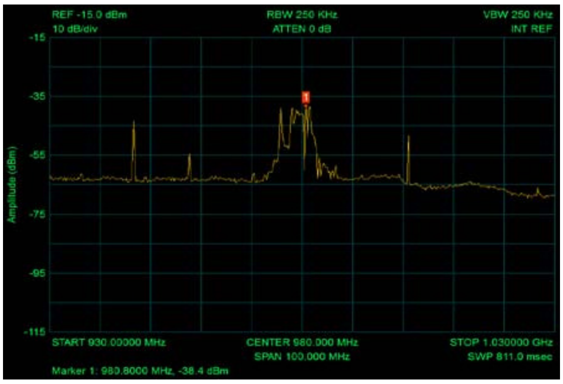


Fig-18 Signal spectrum of the NEE-01 signal re-transmitted by the NEE-02 in its center frequency carrier of 980MHz during one of the first PERSUS operations on mid December 2013. Note the audio signal horn at 976 to 974 MHz, which corresponds to the original 906MHz on the NEE-01 center frequency, while the rest of the signal indicates that video signals are also being received and retransmitted.

NEE-01 has a very different audio beacon than NEE-02: PEGASUS transmits its name and callsign in CW, 600Hz, 50ppm, with a very specifical pattern switching every 50 CW segments from 300, 600 and 1200Hz and transmitting its beacon every 10 CW segments and sending an SSTV image every 20 CW segments. While KRYSAOR transmits its data in high speed modes like QPSK and BPSK among other modes in just one data block each, and sending a SSTV signal every block and then its beacon in 600Hz CW, all this using the 6KHz audio channel of the video link.

Both spacecrafts fly near each other enough for us to activate the PERSEUS device only every 2 weeks approximately, so our windows of communication opportunity with NEE-01 are reduced to 3 or 4 days per month. We have also tried to receive NEE-01 transmission directly from earth, to negative results up to completion of this paper, however, all attempts to receive its transmission via PERSEUS have been successful.

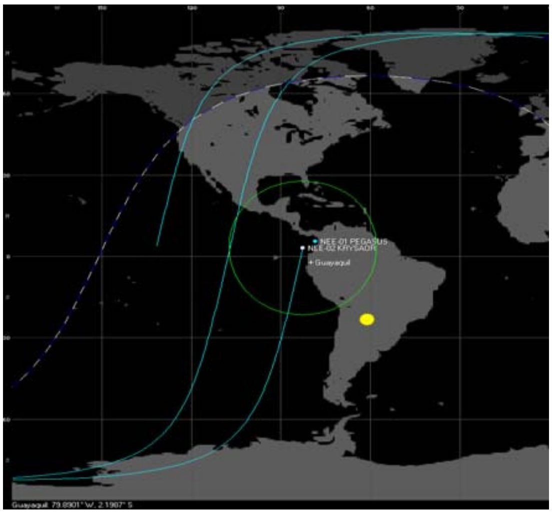


Fig-19 Screen capture of the first PERSUS operation on mid December 2013

Although the repeater was designed to re-transmit the full video and audio signal, we were only able to receive the audio portion of the signal, however, this was enough for us at that time to know that many of our assumptions were correct in the matter of the functionally of both the PERSEUS device and the NEE-01.

Even when we can clearly see in the oscilloscope readings that the video portion of the signal is being received by PERSEUS onboard NEE-02 and being re-transmitted, we still cannot decode it properly as it looks like some portions of the horizontal sync and vertical sync signal are not being processed as they should.

Fig-20 Screen capture of one of the NEE-02 transmissions received in January 2014.

In January 25 2014, the first public transmission of NEE-02 was aired in a national TV broadcast, at the middle of the transmission we were able to successfully operate the PERSEUS device and link with the NEE-01 via NEE-02, the audio portion was clearly heard, although no video signal was received in the ground station. And on the emotional side, the Ecuadorian people could clearly heard the NEE-01 voice beacon indentifying itself as the first Ecuadorian satellite and reproducing the national anthem, once again.

We had recovered PEGASUS.[36] [37] [38] [39] [40] [41] [42]

Fig-21 Krysaor re-transmits Pegasus audio signal, 10h05m January 25, 2014.

Findings: Even when the data and experience in this project supports the notion than an anomaly occurred to NEE-01 and that such anomaly resulted in physical damage to the spacecraft, as supported by the results of the successful operation of the PERSEUS device, we cannot precisely point out the cause of the anomaly, however we can summarize the facts surrounding this project:

-A close approach with object SCC-15890 was coincident with the anomaly. However a detailed analysis of the conjunction shows that NEE-01 passed at a safe distance from SCC-15890 and also shows that the supposed particles from this object should have spread in a geometry that should not have threatened NEE-01.

-Russian sources did clearly pointed out that they believed that SCC-15890 continuously producing particles. The most probable cause for this, they believed, was VUV decomposition due the chemical structure of the rocket body paint used in the Tsyklon-3 vehicles of the Soviet era.

-It is not impossible that any particles being shed by SCC-15890 could have impacted NEE-01, however, after a detailed dynamics analysis, the probability of occurrence of this scenario is low.

-At that time frame, the Eta Aquariids meteor shower was happening over the southern hemisphere and by the time of the anomaly detection, it had decreased greatly, where we suppose the close approach with SCC-15890 occurred, however this meteor shower has high speed meteoroids about 66km/s.

-Eta Aquariids meteor showers are mostly visible from 0 to 30 degrees south, and the close approach with SCC-15890 was supposed to happen between 18 and 20 degrees south.

-There is a report of another satellite suffering an anomaly[(34)] very much like the one that affected NEE-01, the NOAA GOES-13 satellite reported a loss of attitude control 22 hours before the NEE-01 reported anomaly.

-According to NASA[(35)] sources: "the anomaly occurred on 22 May when NOAA's GOES 13 spacecraft International Designator 2006-018A, U.S. Satellite Number 29155) suffered an attitude disturbance of unknown origin, causing an attitude drift of at least 2 degrees per hour off nadir pointing.". This anomaly left it unable to return weather data for about 4 weeks[(46)]

-GOES-13 mass is 3133kg. NEE-01 mass is 1.26Kg.

-NEE-01 did suffered physical damage, to the best of our abilities we could ascertain that the B panel (+Y axis) is inoperative and the battery array on that side is operating at less than half its capacity, this panel is the one were the main transmission antennae array was mounted.

-The main supporting evidence for physical damage comes from the successful operation of the PERSEUS repeater on board the NEE-02 which was designed under the assumption that the main transmission array on NEE-01 was out of alignment, no longer pointing its lobes to earth and now pointing its nulls to the nadir instead.

-The PERSEUS repeater design would prevent it to work properly if the main transmission antennae on NEE-01 were pointed correctly.

-NEE-01 and NEE-02 are practically identical in every detail, except for the additional mass of the PERSEUS device on board NEE-02, and the component and materials used in both came from the same lots of inventory and manufactured using the same techniques by the same persons in every case.

-NEE-02 has never had any anomalies in its service life in space, to us this minimizes the chances that the anomaly would have been caused by a design or manufacturing error.

-Up to the completion of this paper, NEE-01 has had 9 CAN messages from JsPOC and NEE-02 only 2.

-To this date, both GOES-13 and NEE-01 anomalies remain unsolved.

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