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Supporting Launchers with conventional Satellite Ground Stations: A New Functionality for the Antarctic station GARS O'Higgins

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Abstract

The German Aerospace Centre (DLR) operates the "German Antarctic Research Station (GARS) O'Higgins" since 1991. The station is located on the Antarctic Peninsula and used as a satellite ground station, as well as a radio telescope for providing VLBI (Very Long Baseline Interferometry) measurements. DLR provides the classical portfolio of satellite services to polar orbiting spacecrafts: Telemetry, Tracking, and Command (TTC) services, LEOP supports and payload data reception services.

Virgin Orbit develops the unique "Launcher One" small satellite launch vehicle. Launcher One is dropped from an aircraft flying at a high altitude. The concept aims to provide more flexibility to its customers. After a first launch attempt on May 20th 2020, it proved successful with the launch of January 17th 2021.

Virgin Orbit approached DLR in 2019 to evaluate the capabilities of O'Higgins to support their maiden flight. This paper describes the tasks undertaken for supporting Launcher One.

Tasks encompass verification of the antenna constraints, RF (Radio Frequency) compatibility tests, station and mission control configuration, strategy development for increasing station systems reactivity, and tailoring of telemetry recording for launcher events. A cost analysis of these new features will be presented. In addition, the station auto-tracking capability was upgraded. It adapts to high variations of signal strengths. Another key change was the introduction of CCSDS OEM (orbit ephemeris message) tracking capability. In contrast to conventional TLE (Two Line Element) based tracking the new data format allows to describe manoeuvres. An overview highlighting interests of OEM based and TLE based tracking for various scenarios is included.

Finally, we will present the results and insights gained as launcher support station during the two Virgin Orbit launch events.

Keywords: DLR, Virgin Orbit, LauncherOne, GARS, Antarctica

Acronyms/Abbreviations

Apparition Of Signal (AOS), Digital Elevation Model (DEM), Deutsches Fernerkundungsdatenzentrum (DFD – German Remote Sensing Data Center), Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR – German Aerospace Center), Electromagnetic (EM), European Space Agency (ESA), German Antarctic Receiving Station (GARS), Low Earth Orbit (LEO), Loss Of Signal (LOS), Radio Frequency (RF), station monitoring control system (SMCS), two-line elements (TLE), Telemetry (TM), Telecommand (TC), Telemetry Tracking & Command (TTC), Virgin Orbit (VO)

1. Introduction

This is no rocket science: satellites need to communicate with the ground, rockets too. Rocket world and satellites world could share resources. Surprisingly, when it comes to ground stations, both worlds, like two brothers, do not share. This is caused by opposed needs. On one side, antennas tracking lift-offs and the following minutes shall move fast, stay light, and not amplify much. On the other side, ground stations tracking more or less distant satellites shall move slowly, track with accuracy, and amplify as much as possible. Any resource sharing between the two becomes difficult if not impossible. But what happens to launchers when they reach higher altitudes? Can a conventional satellite ground station support launchers, when these become slower from the ground's perspective, when their signals become weaker, when their tracking require higher accuracy?

We consider a conventional satellite ground station: the DLR station GARS O'Higgins. Our goal is to support Virgin Orbit's rocket LauncherOne with this station. We present here the specificities of GARS and LauncherOne. We detail the tasks undertaken to enable the launcher support capability. We then discuss the results obtained during the launch attempts. At last we compare costs with those for the integration of a new satellite mission.

2. Background

2.1 DLR and GARS O'Higgins ground station [1] [2]

Since 1991, DLR is present in Antarctica through the existence of a remote station close to nothing but penguins. This is the German Antarctic Receiving Station GARS O'Higgins located 30km west from the tip of the Antarctic peninsula.

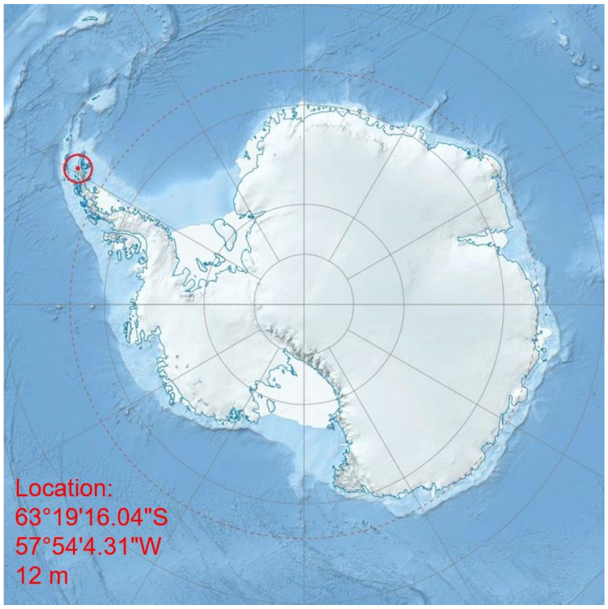

Fig. 1 GARS O'Higgins location

This emplacement is particularly interesting for communicating with polar orbiting spacecrafts (proximity to the South Pole increases contact time) while remaining decently accessible by air and sea. In fact, GARS is only 1360km away from Punta Arenas, Chile.

The station was originally built to retrieve remote sensing data from the ESA European Remote Sensing Satellites ERS-1 and ERS-2 (both polar orbiting). In the 2000s, the station was modernized with the addition of a TTC capability. As a result, GARS became one of the key ground stations for the TanDEM-X mission supporting both TTC and payload data reception. TanDEM-X is a mission consisting of two radar satellites flying in close formation to acquire a Digital Elevation Map (DEM) of the entire Earth with unprecedented accuracy. Due to this mission GARS had to be operated full-time year-round. Hence from 2008 on permanent human presence was needed at the station. This ensures not only correct operating of the station, but more importantly a running infrastructure (power generation, communications).

GARS main component is a Cassegrain type 9-meter antenna dish. The antenna construction is unique with its Marvin shape [8]. This allows the antenna to operate with winds reaching up to 150 km.h^{-1} and to withstand winds of at least 300km.h^{-1} in survival mode. Both situations have been regularly experienced during katabatic storms which are recurrent in this region.

Fig. 2 GARS main component

The antenna system is capable of TTC in S-band and payload data reception in X-band (it serves also radio telescope in S- and X-band for other purposes). All components beside the antenna itself are redundant, mainly due to criticality of satellite communication and common requirements on ground station availability, but also because of the absence of quick customer support in this region.

To summarize, GARS O'Higgins offers conventional satellite communication services in a location of particular interest for polar orbiting spacecrafts.

Table 1: General parameters of GARS

Parameter	Value	Unit
Antenna Position		
Latitude	-63.321125	deg
Longitude	-57.900822	deg
Altitude	12	m
Reflector System		
Type	Cassegrain	
Main Reflector Size	9.0	m
Environmental Constraints		
Max Wind Speed Average (operational)	150	km/h
Max Wind Speed in Gusts (operational)	180	km/h
Max Wind Speed Stow Position	300	km/h
General		
Missions	TSX-1, TDX-1, ERS-2, VLBI	
Visibility	~9 TSX-1 passes per day	

DLR is the German space agency leading research in aerospace, energy and transportation. The headquarters are located in Cologne. Beside Cologne, DLR is present in another 30 sites in Germany and it employs approx. 8.000 persons.

2.2 Virgin Orbit and LauncherOne [4] [6] [7]

Virgin Orbit wants to "open space to everyone". A bold statement, one could say, which led the company to look for a unique launching solution. To reach this objective, VO developed a cost-effective launch service for small spacecrafts with the need of reaching LEO from anywhere around the Earth.

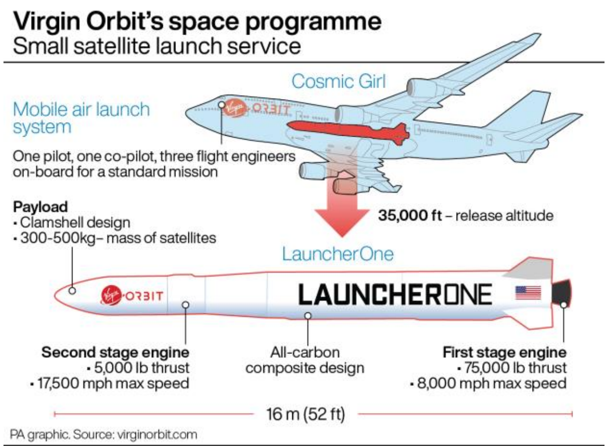

Fig. 3 Virgin Orbit's space programme [3] [5]

VO proposed the usage of a mobile launchpad combined with a rocket using readily available, conventional, easy-to-handle fuel. The result is the combination "LauncherOne & Cosmic Girl", a particularly interesting solution for commercial and national customers as well as for any country without launch capabilities.

Cosmic Girl is a Boeing 747 modified to accommodate a rocket under its left wing. It also contains the necessary flying mission control for the rocket. In other words, Cosmic Girl is a small Kennedy Space Center on wings, which, instead of using a conventional and energy-consuming lift-off from the ground, carries a rocket to an altitude of approx. 35.000 feet above sea level and drops it at high speed.

LauncherOne is the two-stage 20-meter rocket fitting under the Boeing 747 wing. The two engines (one per stage) are fuelled by kerosene and liquid oxygen (LOX), both easily available at any airport big enough to receive a Boeing 747. When Launcher One is dropped from Cosmic Girl, it has already high altitude and velocity, two huge performance advantages compared to conventional ground-based lift-off solutions. These advantages allow LauncherOne to bring spacecrafts of 300kg to 500 kg to an orbit of 230 to 500km.

After a failed maiden flight on May 25th, 2020, VO second flight successfully deployed 10 cubesats on January 17th, 2021.

Fig. 4 LauncherOne mission profile [7]

In the end, Virgin Orbit has developed the world's first air-launched, liquid-fuelled launch system.

Further developments of VO are a capability to reach interplanetary destinations and the reusability of the first stage.

Virgin Orbit was created on March 2nd, 2017 as a spin-off from the company Virgin Galactic. Since then, VO undertook the development of the LauncherOne program. Virgin orbit is based in Long Beach, California, USA, carries current flights from the Mojave Air and Space Port and has currently about 400 employees.

3. Adapting the conventional ground station to launcher support

VO challenged the common activities at GARS. In fact, GARS had never before established communication with rockets. A detailed analysis was made by GARS engineers to understand the LauncherOne needs and to identify the necessary measures to be taken.

To ensure that GARS can support LauncherOne in all the situations we consider the best-case and worst-case scenarios. Thus, most of the figures below are not directly linked to real measurements, but are verifying GARS capability versus all LauncherOne configurations.

3.1 Antenna constraints

From the point of view of a ground station, the main difference between rockets and satellites with respect to antenna mechanical constraints is the velocity relative to the station. In other words, the rocket velocity shall not exceed the antenna angular speeds.

The calculation of the worst-case scenario calculation is based on the values from Fig. 4. This allows us to retrieve in a quick way the relative velocity of the rocket, when we:

- Use linear interpolations between the known points
- Assume that the difference between slant range and horizontal distance is negligible

- Use a value of 12.000 km for the distance between the LauncherOne drop zone and GARS

The worst case implies that the rocket flies at zenith (elevation = 90 deg) – this is the point where the rocket appears the "fastest" to the antenna.

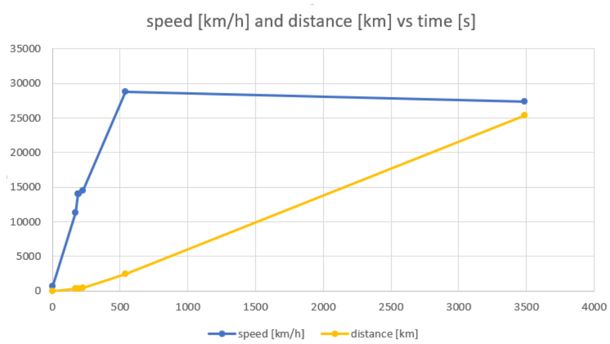

Fig. 5 Linear interpolations of speed and distance of LauncherOne vs time after drop (based on Fig. 4 values)

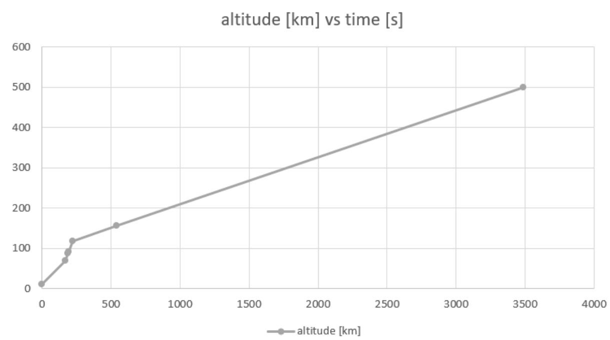

Fig. 6 Linear interpolation of altitude of LauncherOne vs time after drop (based on Fig. 4 values)

From the linear interpolations of Fig. 5 and Fig. 6, we deduct that the rocket would have the following values at the ground station zenith (90° elevation):

t = ~2000s after drop

v = ~7.780 m.s-1

h = ~335 km

The resulting angular velocity is:

$\omega = 7.780/335.000 = 0{,}023\ rad.s^{-1} = 1{,}33\ deg.\ s^{-1}$

This value applies when LauncherOne targets an orbit altitude of 500km.

Should we consider a target orbit altitude of 300km, then the angular velocity would be in the range between 2 and 4 $deg.s^{-1}$

In GARS the maximum velocities are 11 $deg.s^{-1}$ in azimuth and 5 $deg.s^{-1}$ in elevation (see Table 2).

Consequently, GARS can support LauncherOne from a mechanical point of view.

A comparison of the worst-case scenario with the OEM and TLE files provided later on by VO validated our results.

Table 2: Mechanical parameters of GARS

Parameter	**Value**	**Unit**
Tracking & Pointing		
Pointing Accuracy	0.01	deg rms
Tracking Modes	program-track, auto-track: S, X or S/X auto-diversity	
Max Speed Azimuth	11	deg/s
Max Speed Bent Axis	7	deg/s
Max resulting Speed Elevation	5	deg/s²

3.2 RF compatibility

To ensure RF compatibility, we must verify the link budget and the compatibility of signal specifications (modulation, coding, etc) with the equipment available at the ground station. In this subchapter, we will focus on the link budget.

The link budget analysis shall consider the extreme cases, typically 5° elevation and 90° elevation for a satellite already flying. While a satellite has a rather constant altitude, LauncherOne altitude changes, not only during the flight, but also due to the target altitude. We will consider that the drop zone stays at a distance of approx. 12.000 km. As a consequence, the rocket altitude should not be below 200km over our station and cannot exceed 500km. The latest is comparable to the average situation for GARS: a satellite flying at an altitude of 500km (LEO). We will also consider the case of chapter 3.1 with an altitude of 335 km.

Due to their altitudes, all cases described above are consequently subject to identical atmospheric losses. Only the slant range and resulting free space loss are driving factors of the variations in the attenuation.

Let us have a detailed look at their values inTable 3.

As a reminder, we consider the following cases for the calculation:

Case 1: Altitude = 500km, assumed furthest and our reference @ 5° elevation (weakest signal)

Case 2: Altitude = 500km, our delta reference @ 90° elevation (maximum delta for a reference satellite)

Case 3: Altitude = 200km, assumed closest @ 90° elevation (strongest signal)

Case 4: Altitude = 335km, from chapter 3.1 @ 5° elevation

Case 5: Altitude = 335km, from chapter 3.1 @ 90° elevation

Table 3: Link budget comparison based on ITU recommendations [9]

Link Budget	Case 1 (ref)	Case 2	Case 3	Case 4	Case 5
Frequency [GHz]	2.3	2,3	2,2	2,2	2,2
Elevation [deg]	5	90	90	5	90
Altitude [km]	500	500	200	335	335
Slant range [km]	2081	500	200	1613	335
Free Space Loss [dB]	166	154	145	163	150
Delta [dB]	**0**	**12**	**21**	**3**	**14**

At the furthest (cases 1 and 2), LauncherOne is equivalent to a common satellite. At the closest (case 3), the same transmitter will transmit with 21dB more power.

A 21 dB stronger signal is critical for ground stations communicating only with satellites as this is the case in GARS. Equipment on site is tuned for weaker signals. Thus, to be clear, the main risk is to "fry something on the way".

Consequently, we verified the maximum input specifications of each devices on the downlink path. Then, for each launch attempt, we adjusted when necessary the maximum inputs through the use of attenuators.

3.3 Auto-tracking

Auto-tracking is an important necessity when tracking bodies, especially when such bodies accelerate or modify their course, as rockets can do. The GARS antenna uses single channel monopulse tracking technique [10], [11]. The deviations are modulated on the satellite signal and conveyed to the antenna control unit. There, the signal is interpreted if above a minimum threshold which shall prevent the system to track side lobes instead of on the main lobe [12].

The 21 dB issue mentioned in chapter 3.2 can cause damage also to tracking equipment. The same technique as in chapter 3.2 was used for protecting the tracking equipment.

In addition to the overdrive problem, the rocket rolling impacts the signal significantly for the tracking system. Despite rockets rotate around their roll axis, communication shall be maintained. This is secured by installing several antennas on their rocket. Nevertheless, all antennas have their antenna patterns and offer "black spots" with almost no signals and the potential consequence to lose autotracking if signals drop below the threshold.

The setting of the threshold in accordance with the precise link budget secured the auto-tracking function, back-up by the readiness to manually adjust the threshold value in real-time.

3.4 OEM vs TLE

Even though every measure was taken to avoid loss of autotracking, a fall-back solution in form of a precise prediction of the trajectory shall exist for the antenna. With satellites, such predictions are typically propagated based on two-line elements (TLE). [13]

```
ISS (ZARYA)
1 25544U 98067A   21273.16080250  .00001082  00000-0  27919-4 0  9990
2 25544  51.6455 183.6851 0003947  43.3963 105.3346 15.48870253304867
```

Fig. 7 Example of TLE for ISS

In fact, TLEs are perfect for predicting the position of an orbiting body like a satellite. They use a specific algorithm with the parameters contained in the TLE data to retrieve the satellite position.

Unfortunately, TLEs have several limitations. The most notable is that the algorithm used with TLE data cannot handle manoeuvres. TLE predictions can only represent an orbit before, during or after a manoeuvre event. This is a major issue for rockets trajectories which are anything but constant. It is worth mentioning that this is also a known issue during satellite manoeuvres. CCSDS developed the new format OEM [15] which improves both static and dynamic accuracies, thus solving the issue of dynamic orbit changes. It can also carry more information than the 162 characters of the TLE file and consider additional effects, e.g. solar radiation.

A summary of the main differences between TLE and OEM is in Table 4.

Table 4: Main differences between OEM and TLE formats [13], [14], [15]

Parameter	TLE	OEM
Origin	NORAD	CCSDS
Last year of use	2056	9999
Maximum number of characters	162	Unlimited
Maximum NORAD ID	99999	Unlimited
Data	Keplerian elements	Vectors
Propagation	Algorithm	Interpolation
Dynamic accuracy	Not supported	Supported
Static accuracy	1km on first day, deviation of ~ 1-2km per day	*Higher*

After the GARS engineering team was approached by VO, the team implemented an OEM propagator and interfaced it to the station monitoring control system (SMCS). GARS is now capable to support the OEM format, an important improvement not only for future rocket supports but also for satellites manoeuvres as mentioned before, as seen below in Fig. 8.

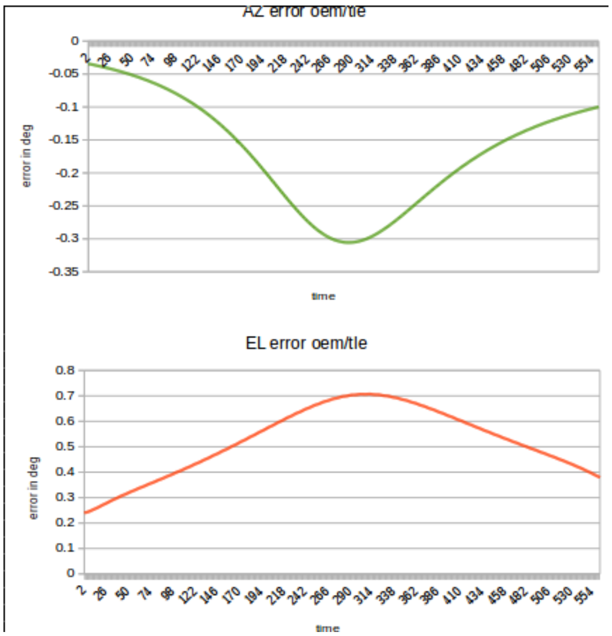

Fig. 8 OEM vs TLE during simulated LauncherOne support

3.5 Tailoring of telemetry recording for launcher events

The nominal scenario of telemetry recording at a satellite ground station is to simply record satellite TM from AOS to LOS. This way, we are secured to record any important information which might be dumped during this period. And events happening in this period, while particularly rare during satellite nominal activities, will also be recorded.

On the other side, the life of a rocket is much shorter than the life of a satellite. And it is way more eventful! Engines start, shut down, restart. Trajectories change. All these events happen in real time and require specific care and quick reaction from the Launcher team.

As a consequence, our nominal TM recording scenario needed to offer more flexibility. The code of the TM recording was updated and integrates now the setting of recording duration. This allows recordings of specific shorter periods of TM (i.e. when important events happen). The resulting "TM snippets" are then transferred in an expedited manner to VO. The nominal dump telemetry scenario was active at the same time and a complete recording of the telemetry was uploaded to VO after the end of the contact.

Note: Satellite missions typically employ Space Link Extension (SLE) services to transfer relevant time critical data online. However, SLE does not work with IRIG formatted telemetry.

4. Results and analysis

4.1 First launch attempt

On 25 May 2020, Virgin Orbit attempted their first maiden flight. LauncherOne was released and the first stage was ignited as expected. Unfortunately, a component failed and forced the termination of the mission.

4.2 Second launch attempt

On 17 January 2021, Virgin Orbit reattempted a launch. It was a full success when the rocket reached the target orbit and delivered 10 NASA cubesats into space.

Fig. 9 Launching the VO rocket LauncherOne from CosmicGirl [3]

On its way, LauncherOne flew over GARS. During the passage:

- The angular velocities did not exceed the antenna maximums
- OEM data provided by VO was extremely precise, no time offset was observed., which allowed tracking from 1° elevation (typically stable lock only above 3° elevation when using TLE)
- Autotracking engaged stably on LauncherOne signal after initial acquisition with OEM programmed tracking
- Signal strength stayed below the maximum allowed (No equipment fried!)
- Snippets caught the events and were provided immediately to VO.

4.3 Issues encountered in GARS

During the LauncherOne passage, two autotrack drops were observed. The first one occurred at 2° elevation and the second one at 10° elevation. Even if those did not impact the operations, it is worth discussing here.

The first drop at 2° elevation is a result of the Earth's noise, a well-known issue by all satellite ground stations. At extremely low elevations, parabolic antennas pick up a major amount of the Earth's EM

radiations. Radiation strength sometimes overtakes the spacecraft signals. This is identified quickly in logs because the autotracking system keeps a "lock" but the antenna starts to look away from the spacecraft.
There was no impact on operations as preventive measures were already taken in the form of scheduling TM transfers at higher elevation.

The second drop at 10° elevation can have several root causes, but none could be identified with certainty (interferences, phase-shifter setting, signal gap from antenna pattern, …). Thus no preventive or corrective measure could be taken.

5. Cost comparison

From the perspective of a satellite ground station, the reference in terms of preparation costs is for a new satellite mission. Table 5 summarizes the main differences between the support of a launcher like VO's LauncherOne and a satellite mission like TanDEM-X.

Table 5: Necessary tasks for satellite mission and launcher support

Task	Satellite mission	Launcher support
Verification of antenna constraints	Rough	Precise
Link budget analysis	Yes (for each channel!)	Yes
Fine tuning of autotracking	Yes	Yes
OEM	No	Yes
Tailoring of TM recording	No	Yes
Channels implemented	TM, TC, and possibly payload data	TM

The main cost-driving factor for LauncherOne support was the integration of an OEM propagator. But this is a single-time effort which will not be repeated as the capability now exists for GARS.

The tailoring of TM recording is also a single-time effort and part of the new portfolio of functions offered by the station.

Other differences are compensating each other. The verification of the antenna constraints is more time-consuming for a launcher. On the other hand, the link budget analysis is also a time-consumer and it is simpler for a launcher as we only consider the TM channel.

6. Conclusions

Because Virgin Orbit contacted DLR about 2 years ago, and DLR accepted the challenge, GARS is now officially capable of supporting a launcher. This new feature came through accurate work from both teams and because we accepted to challenge our habits and vision of spacecraft support.
Today, GARS can track more precisely with the OEM format support. This helps not only launchers but also satellites, particularly during their manoeuvres.
Other necessary measures to consider for a launcher support are known from the GARS team.
And costs for a launcher support are expected to remain lower than for the preparation of a TTC support if reusing the technology developed for LauncherOne.
The only major drawback generated by the support of launchers is delay. This can have a disastrous impact on the pass schedule which is typically decided days if not weeks in advance.
In the end, a better tracking combined with GARS unique location, the know-how won by the team and cost-efficient solutions ensure that from now on GARS shall be considered for any rocket launching satellites to polar orbits. This, yet, is only possible if both rocket world and satellite world converge towards the same technology used.

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