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## ALTAIR innovative air-launch system – consolidated design, lessons learned and perspective

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### Abstract

This paper presents the final design results of the H2020 ALTAIR project, focused on a cost-effective launch system for small satellites up to 150 kg in SSO, including the lessons learned from the flight experiment campaign using the small scale demonstrator EOLE.

The 4-year H2020 ALTAIR project, performed by a Consortium of 8 Partners from 6 countries and Coordinated by ONERA, aims at demonstrating the economic and technical viability of an innovative air launch system in order to pave the way for a future available, reliable and competitive European launch service for the access to space of small satellites. The ALTAIR concept (acronym for Air Launch space Transportation using an Automated aircraft and an Innovative Rocket) revolves arounds an innovative launch vehicle and an innovative ground segment, all of them designed towards the objective of cost-effectiveness. The vehicle part can be described as a semi-reusable air-launch system made of a reusable automated carrier designed specifically for the launch mission and an expendable launcher using hybrid propulsion for the two main stages and monopropellant H<sub>2</sub>O<sub>2</sub> liquid propulsion for the upper stages.

The first part of this paper presents the consolidated design of the ALTAIR system (carrier, launcher and ground segment), obtained during the 3-year design process made of 3 subsequent design loops, with a particular focus on the lessons learned.

The second part of the paper is devoted to the flight experiment program, which is the main focus of the 4<sup>th</sup> and last year of the ALTAIR project, and which should be completed by the time of the paper submission. Their goal is to validate in representative flight conditions several key technologies developed in the project, in particular the launcher avionics and the release system and procedure. ALTAIR flight experiments are performed using the existing small scale EOLE demonstrator (developed under ONERA's project management for the CNES PERSEUS project), equipped with a small-scale version of the release system and carrying an inert rocket mock-up with avionics and sensors. The ALTAIR flight experiment program, starting with captive flights (with the rocket mock-up attached) performed on the French St. Yan airfield, culminates with a flight test that is fully representative of the ALTAIR reusable carrier's mission, including the release of the rocket mock-up, performed at the Guyana Space Center (CSG) in French Guyana.

**Keywords:** air launch, small launcher, space transportation


### Acronyms/Abbreviations

ADS-B	Automatic Dependent Surveillance - Broadcast	ALTAIR	Air Launch space Transportation using an Automated aircraft and an Innovative Rocket
AGL	Above Ground Level	AMSL	Above Mean Sea Level
		BVLOS	Beyond Visual Line Of Sight
		DGAC	Direction Générale de l'Aviation Civile
		GNC	Guidance, Navigation and Control

GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSC	Guyana Space Center
HDRM	Hold-Down and Release Mechanism
IMU	Inertial Measurement Unit
NOTAM	Notice To AirMen
PERSEUS	Projet Etudiant de Recherche Spatiale Européen Universitaire et Scientifique
SME	Small and Medium Enterprise
VLOS	Visual Line Of Sight

## 1. Introduction

As an answer to the increasing market of small satellites (< 200 kg) and the need for Europe to dispose of a launch system fully adapted to this kind of payload, the 4-year ALTAIR project was started in December 2015 by a consortium of 8 Partners from 6 European countries (cf. Table 1).

Table 1 ALTAIR Consortium	
	ONERA – The French Aerospace Lab, France (Coordinator)
	Bertin Technologies, France
	GTD Sistemas de Información S.A., Spain
	NAMMO Raufoss SA, Norway
	Piaggio Aerospace, Italy
	CNES, France
	Swiss federal Institute of Technology Zurich (ETHZ), Switzerland
	SpaceTec Partners SPRL (STP), Belgium

ALTAIR is part of the European Horizon 2020 (H2020) research program. It is funded by the European Commission (3.5 M€) and Switzerland (0.5 M€).

The 4-year ALTAIR project aims at demonstrating the economic and technical viability of a future small satellite launch system for the access to space (Low-Earth Orbit) of small satellites in the range 50-150 kg.

The challenge is both technical and economic, as the system should be not only performant, available and reliable, but also economically competitive.

In order to address this challenge, the ALTAIR Consortium proposes an innovative launch system based on the concept of air-launch relying on an automated aircraft carrier designed specifically for the mission (cf. Fig. 1).



Fig. 1 Artist's view of the ALTAIR system after release of the rocket by the carrier

The main part of the ALTAIR project consists in a detailed design study of the whole system made of three parts – or sub-systems: the carrier vehicle (reusable), the launcher (expendable) and the ground segment.

The design tasks are coordinated and optimized with regards to economic efficiency, in accordance to input from market studies. In addition to the design tasks, an economic study and a development roadmap are performed.

In order to advance the Technology Readiness Level (TRL) of some key technologies, ALTAIR also includes flight experiments using the existing small-scale demonstrator EOLE (cf. Fig. 2). These flight experiments are focused on the launcher avionics system and the carrier/launcher release.



Fig. 2 Artist's view of the small scale demonstrator EOLE releasing a rocket mock-up

The first part of this paper provides the final results of the ALTAIR design tasks (section 2). The second part details the flight experiments task, which have been achieved with a successful final campaign at the Guyana Space Center (CSG) in French Guyana (section 3).

## 2. ALTAIR system final design and results

### 2.1 Advantages of the ALTAIR concept

The ALTAIR system is based on the concept of air launch. The vehicle part of the system is made from two vehicles:

- A reusable unmanned aircraft carrier.
- An expendable 3-stage rocket.

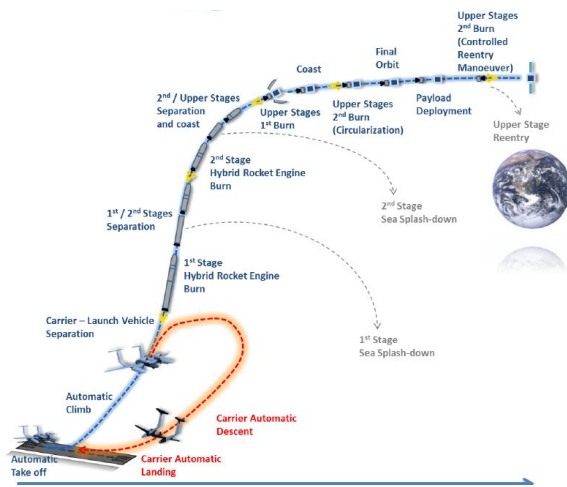


Fig. 3 ALTAIR mission profile

The carrier brings and release the rocket at a given altitude. The starting of the rocket at a high altitude instead of the ground level has two benefits on the rocket performance:

- Reduction of drag losses.
- Reduction of the nozzle losses.

Due to this gain of performance, the air-launched rocket is smaller than the equivalent ground-launch rocket with the same performance

### 2.2 Target mission and release conditions

The following reference target mission has been defined according to a market analysis (which has been updated throughout the project):

Mission		
Performance	[kg]	150.0
Payload envelop diameter	[m]	1.2
Payload envelop length	[m]	1.5
Type of orbit	-	SSO
Apogee Altitude	[km]	600.0
Perigee Altitude	[km]	600.0
Inclination	[deg]	97.8

Fig. 4 ALTAIR target mission

The cost target is 5 M\$/launch, considering a launch rate of 30 launches / year.

A thorough multidisciplinary study and sensitivity analysis has led to the following release conditions:

Initial conditions (at separation) of the launcher		
Launch base name	-	CSG
Altitude	km	12.0
Mach	-	0.65
Relative velocity	[m/s]	179.7
Flight Path Angle	[deg]	20.0
Flight azimuth	[deg]	-11.5
Latitude	[deg]	5.2
Longitude	[deg]	-55.0

Fig. 5 Initial release conditions

### 2.3 Carrier

The following figure illustrate the carrier CONOPS.

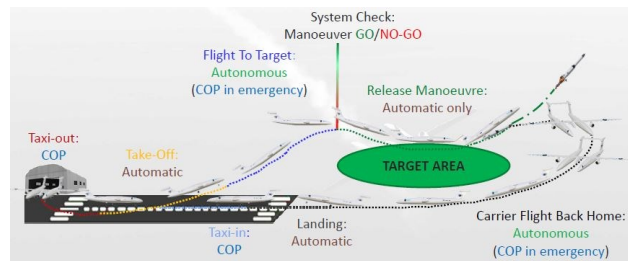


Fig. 6 ALTAIR CONOPS: COP (Carrier Operator) vs. Autonomous Operation

The mass break down of the carrier is the following:

Table 2 Carrier mass break-down

	Weight(t)
Structures	21.05
Powerplan	6.30
Systems	4.43
<b>Operative Empty Weight (OEW)</b>	<b>31.78</b>
<b>Fuel (2 h mission+reserve)</b>	<b>6.09</b>
<b>Launcher weight</b>	<b>26.63</b>
<b>Maximum Take-Off Weight (MTOW)</b>	<b>64.50</b>



Fig. 7 View of the carrier with the launcher attached

### 2.4 Launcher

The launch vehicle has a 3-stage architecture:

- 2 main stages: NAMMO hybrid propulsion (same chambers: 7 for 1st stage , 1 for 2nd stage).
- Orbital Module (H2O2 monopropellant).

In addition to the two main hybrid propulsion stages, the launch vehicles includes an Orbital Module (or “upper stage”) using monopropellant H2O2.



Fig. 8 ALTAIR rocket

General Parameters		
Performance	[kg]	148
Fairing Mass	[kg]	70
Reference orbit	-	SSO, 600 km
Total Length	[m]	18.40
GLOM	[t]	26.6
Intermediate Orbit (Stage 2 burnout)	-	-50x600 km
Launch Base	-	CSG (Air Launch)

Table 3 ALTAIR LV mission general parameters

Main flight parameters		
T/W @ Lift-off	-	2.1
Longitudinal maximum acceleration - Stage 1	[g]	8.8
Longitudinal maximum acceleration - Stage 2	[g]	10.1
Transversal maximum acceleration (longitudinal acceleration)	[g] ([g])	0.75 (2.6)
Max Q (kPa)	[kPa]	36.3
Pdyn @ separation 1-2	[kPa]	3.3
Altitude @ separation 1-2	[km]	53.5

Table 4 ALTAIR LV main flight parameters



Fig. 9 ALTAIR LV trajectory

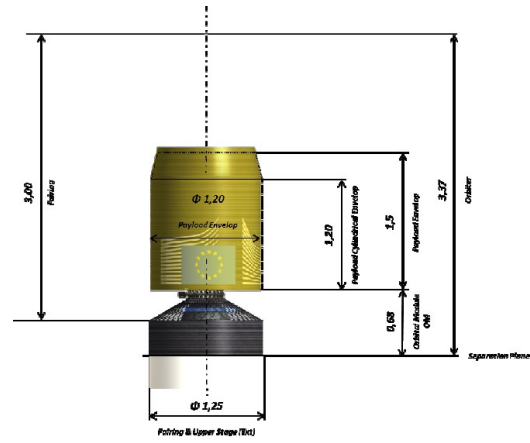


Fig. 10 Orbital module

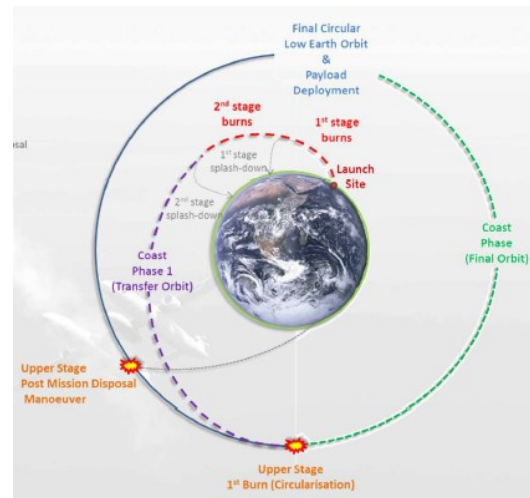


Fig. 11: Orbital module mission profile

## 2.5 Ground segment

The Ground Segment work has included the following tasks:

- Functional analysis of the ground segment
- Detailed specification of the systems.
- Preliminary architecture design.
- Preliminary CONOPS (work in progress).
- Preliminary cost estimation based on parametric and statistical approaches.

Several possible sites have been studied. In the end, 2 “best candidates” have been identified:

- Guyana Space Center (CSG)
- Andoya Space Center (ASC).

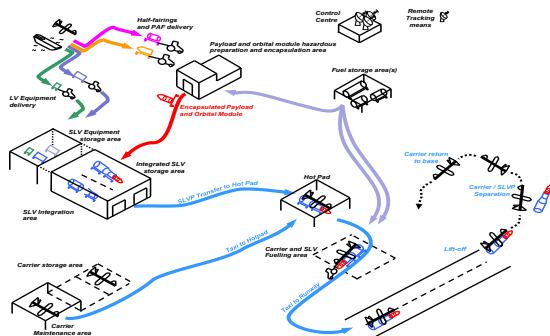


Fig. 12 Schematics of the operations



Fig. 13 One of the two best candidate sites identified: the Guyana Space Center

### 3. Flight experiments with the EOLE demonstrator

#### 3.1 Flight experiments objectives

The flight experiment activities of ALTAIR are dedicated on the one hand to the ALTAIR launcher on-board system and on the other hand to the ALTAIR system separation phase, including the separation manoeuvre achievement and the release system activation.

For the launcher on-board system, the objectives are to assess its strength toward disturbances caused by the carrier (multipath effects and dynamic flight conditions perturbations), validate the launcher navigation instruments initialization strategies and algorithms, validate the launcher navigation system performance and validate the launcher safety automatic procedures and algorithms.

For the separation phase, the objectives are to validate the release system physical principle and validate the separation manoeuvre and chronology.

The objectives of the flight experiments are fully described in the reference [4]. Those experiments are made with the contribution of four partners of the

ALTAIR Consortium: ONERA (flight experiments work package leader), CNES, GTD Sistemas de Información S.A. and Piaggio Aero Industries S.p.A.

#### 3.2 Experimental system description

The ALTAIR flight experiments use the already existing flying demonstrator EOLE which has been designed and developed by ONERA, under CNES support within the PERSEUS project [5][6].



Fig. 14 : EOLE demonstrator equipped with a launcher mock-up at CSG airfield

EOLE is an experimental flying platform dedicated to study air-launch systems: investigating in realistic conditions the separation phase between the carrier and the launcher, testing various separation procedures and technologies [6].

EOLE has been designed jointly by ONERA and the French SME Aviation Design and its on-board system has been developed by the Luxembourg SME LM Design.

EOLE is a 6.7 m wingspan two fuselages V-tails vehicle with a take-off weight of 150 kg. It offers a central free space, between the two fuselages, able to accommodate, under a central pod, a launcher mock-up attached through a release system. Table 5 gathers the main characteristics of EOLE.

Dimensions	
Wingspan	6.7 m
Length	3.3 m
Height	1.4 m
V-tails (in 2 parts)	55.5° dihedral
Wing characteristics	
Reference area	2.57 m <sup>2</sup>
Aspect ratio	17

Table 5 : EOLE main characteristics

For the ALTAIR project, EOLE is used as a test bench to immerse sub-systems, representative of the

full-scale ALTAIR system, in the realistic conditions of the free flight [4].

For that purpose, a 1:13 sub-scale mock-up of the ALTAIR launcher has been manufactured and equipped with a dedicated version of the ALTAIR launcher on-board system. Fig. 15 illustrates a CAD view of the launcher mock-up, with its internal layout, and Fig. 16 illustrates the launcher mock-up manufactured.

For the experiments purpose, two computers have been developed. A first computer (Downstream Computer) is installed inside the launcher mock-up for running the several launcher on-board system algorithms and a second computer (Upstream Computer) is installed in EOLE central pod for duplicating the collected data. In the launcher mock-up, the Downstream Computer is fed by an Inertial Measurement Unit (IMU) using Global Positioning System (GPS) hybridization. The Downstream Computer sends the collected data to the Upstream Computer located in EOLE through a dedicated Wi-Fi datalink. This datalink is implemented in order to record the flight data collected by the launcher mock-up during the whole flight, including the captive flight and the ballistic flight after its release.

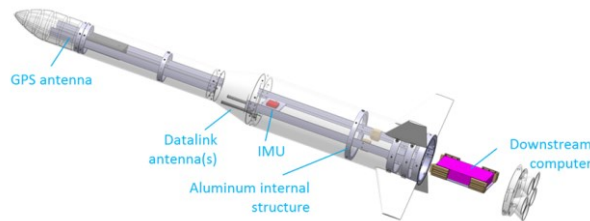


Fig. 15 : CAD view of the launcher mock-up internal layout



Fig. 16 : Launcher mock-up

An adaptation of the full-scale ALTAIR release system is also manufactured and mounted under EOLE central pod. In particular, this release system mock-up represents the same separation concept through the use of the same physical principle based on Hold-Down Release Mechanism (HDRM). Fig. 17 illustrates the launcher mock-up attached to the release system structure.

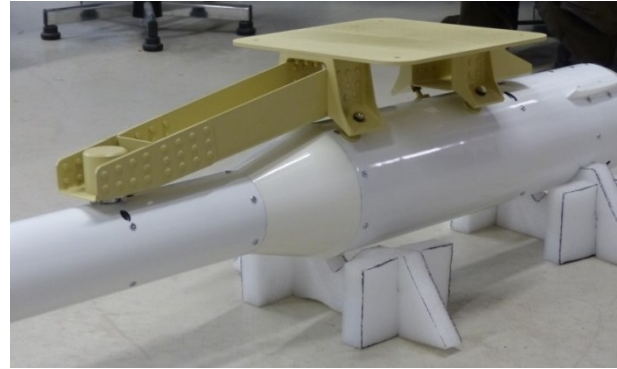


Fig. 17: Launcher mock-up attached to the release system mock-up

Finally, an adaptation of the ALTAIR separation manoeuvre Guidance, Navigation and Control (GNC) laws is implemented in EOLE automatic pilot. Fig. 18 illustrates the separation manoeuvre defined for the ALTAIR system and Table 6 indicates the release flight conditions for both the ALTAIR system and the experiments expected with EOLE.

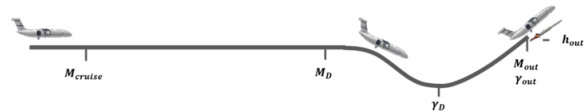


Fig. 18: ALTAIR separation manoeuvre

Release flight conditions	ALTAIR	EOLE
Release altitude: $h_{out}$	12000 m	1000 m
Release Mach: $M_{out}$	0.65	0.2
Release flight path angle: $\gamma_{out}$	20°	20°
Normal load factor: $n_z$	1.5 g	1.5 g

Table 6 : Release flight conditions for the ALTAIR system vs. experiments with EOLE

The equipment and software specifically developed for the ALTAIR experimental system are fully described in the reference [4].

### 3.3 Flight tests campaigns program

Two main flight tests campaigns are planned for the ALTAIR project.

The first campaign deals with safety procedure validation (launcher impact point and impact area assessment) and navigation alignment procedure validation with soft trajectories. On account of the small flight area required, those tests take place in the French civilian airfield of Saint-Yan and are performed through Visual Line Of Sight (VLOS) flight conditions at low altitude. The separation manoeuvre is tested in several initial conditions but the launcher mock-up is not released.

The second campaign aims to submit the launcher on-board system to more dynamic trajectories for the navigation alignment procedure validation and, at the end, release the launcher mock-up. Higher altitudes and higher speeds are planned, requiring Beyond Visual Line Of Sight (BVLOS) flight conditions. At the end, the full separation manoeuvre is planned including the release system activation and the launcher ballistic flight. This second campaign is planned at the French Guyana Space Center (GSC) of Kourou.

Both flight tests campaigns are performed with dedicated permit to fly delivered by the French Aviation authority Directorate-General for Civil Aviation (DGAC), specifically delivered for each flight tests centre.

The flight tests program is composed of manoeuvres defined for the launcher on-board system alignment in order to validate the initialization strategies and algorithms defined for the full-scale ALTAIR launcher before the separation. The manoeuvres are defined as Straight Flight, Coordinated Turn, Thach Weave and Wing Rock.

The Straight Flight manoeuvre is defined by a zero net acceleration. The thrust compensates drag and lift compensates gravity. It is used as the no-manoevrue test-case and has no added alignment value, as both acceleration and angular velocity remain constant.

In the Coordinated Turn manoeuvre, the aircraft changes its heading in such a way that net acceleration in the non-inertial aircraft frame stays inside the aircraft vertical plane. Fig. 19 describes a typical Coordinated Turn manoeuvre.

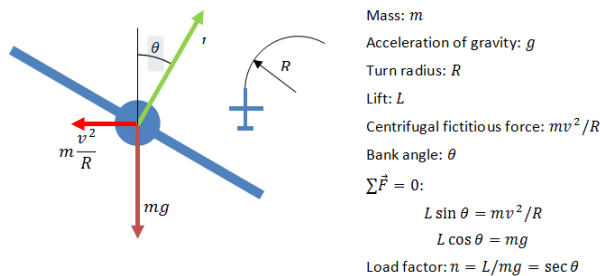


Fig. 19: Coordinated Turn manoeuvre

Then, the Thach Weave manoeuvre is based on the eponymous defence manoeuvre and consists of a series of coordinated turns to either side, creating an S-like trajectory path. Fig. 20 illustrates a typical Thach Weave manoeuvre with one S-like trajectory path. Several manoeuvres have been defined with different speeds (from 42 m/s to 75 m/s) and different number of S-like trajectory path (from one S to three S).

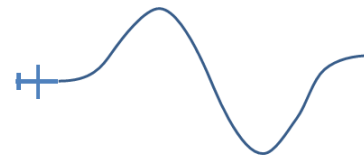


Fig. 20: Thach Weave manoeuvre (one S-like trajectory path)

Finally, the Wing Rock manoeuvre represents a variation of the Straight Flight manoeuvre, in which the aircraft dips its wings from side to side without any change of heading. Fig. 21 illustrates a typical Wing Rock manoeuvre. Several manoeuvres have been defined with different speeds (from 42 m/s to 65 m/s) and different bank angle (from 20° to 45°).

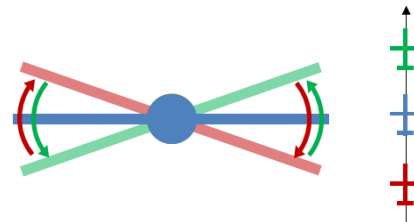


Fig. 21: Wing Rock manoeuvre

The alignment manoeuvres are tested through several scenarios in order to cover nominal and non-nominal system functioning (malfunctioning GNSS, malfunctioning IMU or degraded navigation data). The several scenarios are activated regularly all along the flights.

Beside the alignment manoeuvres, the flight tests program is also composed of tests of the launcher on-board flight safety system strategies and algorithms defined for the full-scale ALTAIR launcher. Those strategies and algorithms concern the evaluation of two safety criteria, ground and flight safety. The launcher ground impact point and impact area, the detection of sensible ground areas to be protected from launcher ground impact and the detection of target areas for secure/controlled launcher release. The flight safety criterion corresponds to the acceptance/inhibition of the launcher ignition considering the launcher dynamic state with respect to the nominal ignition point after the release and ballistic fall.

Then, the flight tests program is composed of several trials of the separation manoeuvre, without release of the launcher but getting through each sequences of the separation manoeuvre including the internal tests for the release order sending to validate the overall separation phase sequence and chronology. For those experiments

the release system is disarmed to avoid any risk of release of the launcher mock-up.

Finally, the flight tests program ends with the effective release of the launcher mock-up during the separation manoeuvre achievement, followed by a launcher mock-up ballistic flight. Only for this flight, the release system is armed in order to be activated and thus release the launcher mock-up.

### 3.4 First campaigns at Saint-Yan airfield

The Saint-Yan flight area is defined around the Saint-Yan airport. The Saint-Yan airport only allows performing VLOS flights. The flight area limit is 1 km around the pilot and 500 m Above Ground Level (AGL) (750 m above mean sea level). For the flight tests, a specific non-permanent restricted flight area is set at Saint-Yan airport and activated at the request of the flight tests team through NOTAM broadcasting. Fig. 22 shows the flight area defined at Saint-Yan.



Fig. 22: Saint-Yan flight area

The flight tests campaigns at Saint-Yan began in July 2018 but were interrupted after two flights facing some technical issues of the experimental system. A one-year extension of the ALTAIR project allowed to solve the technical issues and go back to flight with two new flight tests campaigns performed at Saint-Yan respectively in May 2019 and July 2019.

The May flight tests campaign was composed of three flights dedicated on the one hand to perform the program required for the launcher mock-up on-board system (alignment manoeuvres and safety system tests) and on the other hand to perform attempts of the separation manoeuvre without releasing the launcher mock-up.

As a synthesis, the tests performed across the three flights of this campaign are:

- 6 Straight Flight manoeuvres performed from 42 m/s to 65 m/s.
- 15 Coordinated Turn performed from 42 m/s to 65 m/s.
- 9 Wing Rock manoeuvres performed from 42 m/s to 65 m/s at a bank angle from  $\pm 20^\circ$  to  $\pm 45^\circ$ .
- 7 Thach Weave manoeuvres of one S performed at 42 m/s.
- 6 safety tests performed from 42 m/s to 65 m/s.
- 3 separation manoeuvres without release of the launcher mock-up.

Each hippodrome was composed of several types of tests, as illustrated in Fig. 23. In particular, Fig. 23 left illustrates a combination of a Thach Weave manoeuvre (TW1), a safety test (SAF1) and a Coordinated Turn (CT1) made at 150 km/h (42 m/s). Fig. 23 right illustrates a combination of a Wing Rock manoeuvre (WR4), a safety test (SAF2) and a Coordinated Turn (CT2) made at 200 km/h (55 m/s). The blue stars visible on both circuits indicate the scenarios changes for activating nominal and non-nominal system functioning. The scenarios changes are made just before the alignment manoeuvre (Thach Weave, Coordinated Turn or Wing Rock).

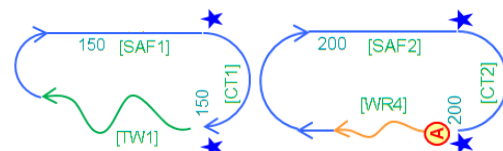


Fig. 23: Illustration of tests combination during Saint-Yan flight hippodromes

For the safety tests, the hippodrome ground flow over area is divided in several categories with regard to safety concerns (prohibited area, target area, etc.). Fig. 24 indicates the definition of prohibited areas through the circuit ground flow over area and Fig. 25 illustrates the launcher on-board system associated response while running the hippodrome.

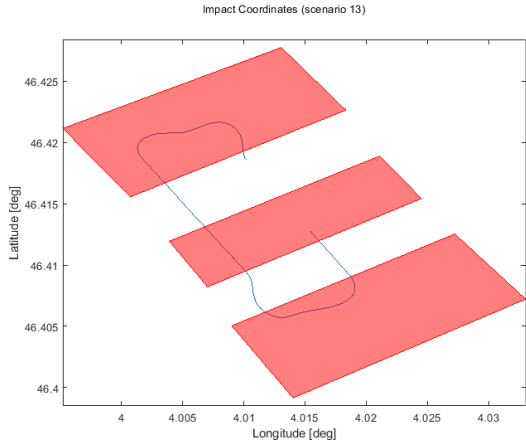


Fig. 24: Definition of prohibited areas through of the circuit ground flew over area

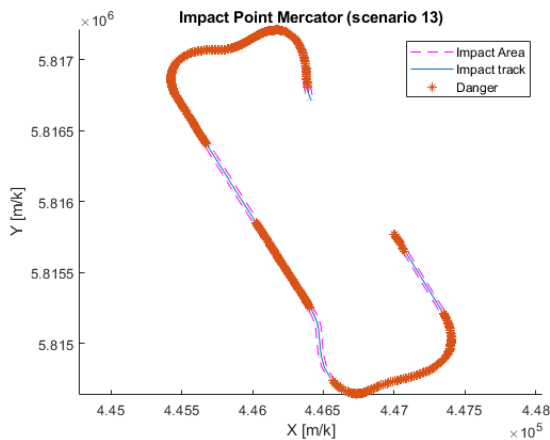


Fig. 25: Illustration of the launcher on-board system response while running a safety tests

The July flight tests campaign was composed of two new flights. As a synthesis, the tests performed across the two flights of this campaign are:

- 2 Wing Rock manoeuvres performed at 42 m/s and a bank angle of  $\pm 45^\circ$ .
- 4 Thach Weave manoeuvres of one to three S performed from 42 m/s to 45 m/s.
- 1 separation manoeuvre without release of the launcher mock-up.

This campaign was also used to test the overall system functioning before the final campaign at Guyana Space Center and especially in the configuration required for the BVLOS flight conditions with full telemetry (downlink) and remote controller (uplink) power emission developed for covering the 20 km BVLOS maximal range.

Finally, during this campaign, a release of the launcher mock-up was made on ground in order to check the release system working order.

### 3.5 Final campaign at Guyana Space Center

The Guyana Space Center (GSC) flight area is defined within a permanent prohibited area. The ground limit of the permanent prohibited area is represented in Fig. 26 and goes from 0 to 24500 ft AMSL (7468 m AMSL).



Fig. 26: Guyana Space Center permanent prohibited area

The ground and low altitude operations (experimental system preparation, take-off, landing, VLOS flights, etc.) take place at the Kourou airfield, which is inside the permanent prohibited flight area. The Kourou airfield is specifically equipped in order to welcome the flight tests campaign, as illustrated in Fig. 27.



- |   |  |
|---|--|
| <p><b>Operational area:</b></p> <ul style="list-style-type: none"> <li>- Take-off position (turn-around area)</li> <li>- Ground Control Station (1 shelter)</li> <li>- Office (1 shelter)</li> <li>- Cherry picker for datalink antennas</li> </ul> | <p><b>Preparation and storage area:</b></p> <ul style="list-style-type: none"> <li>- Hangar</li> <li>- Office (airfield club house)</li> </ul> |
|---|--|

Fig. 27: Kourou airfield ground installation

According to the available flight area, the possible manoeuvres for the launcher on-board systems can be made at higher altitude and higher speed than the ones tested at Saint-Yan. Those manoeuvres are planned above the sea in Beyond Visual Line Of Sight (BVLOS) flight conditions.

In addition to the wide available flight area, the Guyana Space Center offers the possibility to activate the release system during the separation manoeuvre and perform the launcher mock-up ballistic flight. This operation is planned for the final flight at around 1000

m AMSL. The launcher mock-up has no propulsion on-board. It is naturally stable on every axis and is not controlled after its release. Its ballistic flight ends with the launcher mock-up loss in the sea.

The flight tests campaign safety management relies on the typical rules applied by CNES for launcher operations, but nevertheless with taking into consideration the specificity of the air-launch operations. About this topic, a deep safety management analysis has been performed by CNES [7]. This analysis leads to a tri-dimensional flight area, as represented in Fig. 28.



Fig. 28: Guyana Space Center flight area

The flight tests campaign at Guyana Space Center lasted two weeks, from August 26<sup>th</sup> to September 07<sup>th</sup> 2019. The first week was mainly dedicated to ground operations with no flights:

- Preparation of the experimental system at the Kourou airfield (assembly of the demonstrator EOLE and attachment of the ALTAIR launcher mock-up through the ALTAIR release system mock-up, coupling of the datalink antennas with the cherry picker, installation of the EOLE ground control station at the dedicated shelter and full pre-flight checklist completion).
- Interfacing of the experimental system with the GSC means involved in the operations (safety desk using telemetry data and ADS-B information for redundancy, and tracking system which receives EOLE downlink and transfers it to the Kourou airfield through a 10 km optic fiber cable).
- Finalization of operational documents (detailed operations chronology, pre-flight check-list adjustments according to local procedures & organization, etc.).

The second week was then dedicated to the flights, with the completion of three flights.

The first flight occurred on 04<sup>th</sup> September 2019 and only covered VLOS flight conditions. Its aim was to test

the overall system in flight after the experimental system reconditioning and ground means implementation, in Saint-Yan like flight conditions, and to train the pilot to handle the flight paths to follow for the take-off and landing phases.

The second flight occurred on 05<sup>th</sup> September 2019 and represented the first BVLOS flight. During this flight, a first phase consisted of hippodromes around the Kourou airfield, in VLOS conditions, in order to check the tracking system. Once the telemetry reception confirmed, the second phase of the flight is started by activating the BVLOS trajectory. This trajectory is composed of three loops performed at increasing range and altitude. After those three loops, a last circuit is made at 1000 m AMSL in order to perform a trial of the separation manoeuvre, without releasing the launcher mock-up. The ground track recorded from EOLE ADS-B during this flight is illustrated in Fig. 29. Fig. 30 shows a picture taken above the sea from an embedded video located at the internal face of the right fuselage.

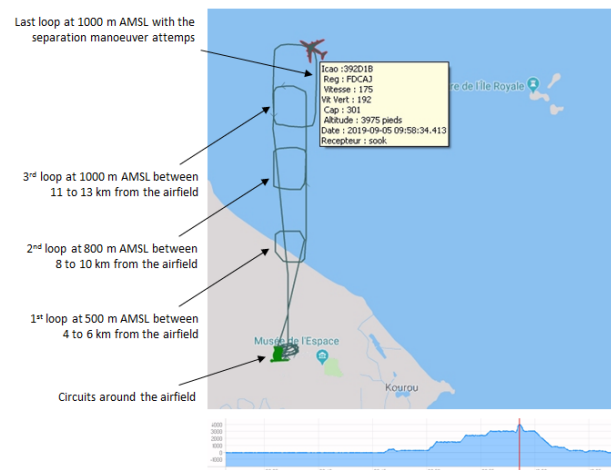


Fig. 29: Ground track and altitude profile of the first GSC BVLOS flight



Fig. 30: Picture during the first GSC BVLOS flight

Because of the delay in the overall campaign operations, the initial flight tests program has been modified and shortened in order to be sure to have the launcher release before the end of the campaign two weeks slot.

The third and final flight occurred on 07<sup>th</sup> September 2019. During this flight a Thach Weave manoeuvre of three S was performed at 45 m/s during a hippodrome made at 1000 m AMSL in BVLOS flight conditions, as represented in Fig. 31. This manoeuvre is then followed by the activation of the separation manoeuvre at the beginning of the next BVLOS hippodrome. For this final flight, the release system was armed during the pre-flight check-list in order to be activated and thus release the launcher mock-up. The separation manoeuvre execution ended with the effective release of the launcher mock-up followed by a launcher mock-up ballistic flight. Fig. 32 illustrates three pictures of the launcher evolution away from EOLE after the release system activation.

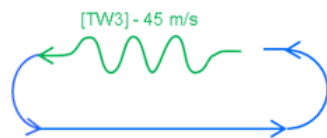


Fig. 31: Three S Thach Weave manoeuvre at 45 m/



Fig. 32: Launcher evolution after separation

All the data collected during the Saint-Yan and the Guyana Space Center flight tests campaigns are being studied by ONERA, CNES, GTD and Piaggio Aero

Industries S.p.A. and will provide very fruitful feedbacks in order to confirm or improve the ALTAIR system definition.

#### 4. Conclusions

With the output 4-year ALTAIR project, the ALTAIR Consortium proposes a feasible innovative solution to address the challenge of the dedicated access to space of small satellites.

Provided a sufficient level of funding, the development of the ALTAIR system shall be started on the basis of the output of the projects, which include a detailed design, a development roadmap and flight experiment results.

The end of the H2020 ALTAIR (till November 2019) will be devoted to the exploitation of the flight experiment results.



Fig. 33 ALTAIR mission patch

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