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

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Abstract

As an answer to Europe's need of an independent access to space for small satellites, for which the market is expected to grow, the ALTAIR project (Air Launch space Transportation using an Automated aircraft and an Innovative Rocket) has been launched in the frame of the European Union's Horizon 2020 research innovation program. The project, which is currently in its third and last year, aims at demonstrating the economic and technical viability of an innovative air-launch system whose carrier is a reusable automated aircraft designed specifically for the launch mission. The reference target mission is the launch of the 150 kg total payload weight into a Sun-Synchronous target orbit.

The paper presents the main projects results, lessons learned and perspective. In the first part of the paper, we remind the project's objectives, organization and methodology. The objective of cost reduction, which is of paramount importance in the project, is achieved through the use of Multidisciplinary Design Optimization (MDO) approach and appropriate system and technology choices. The second part of the paper is devoted to the technical results of the study. We present the consolidated design of the ALTAIR system, made of a reusable unmanned carrier, an expendable rocket using hybrid propulsion for the main stages and a ground system. We also present the preliminary results analysis of the flight experiments performed with the small scale EOLE demonstrator, which are focused of the carrier/launcher release and the innovative launcher avionics system. In the third part, we present the outline of ALTAIR's business plan and development roadmap.

Keywords: air launch, small launcher, space transportation

Acronyms/Abbreviations

ALTAIR	Air Launch space Transportation system using an Automated aircraft and an Innovative Rocket
UAS	Unmanned Aerial System

SpaceX, ...). Today, there exist launch options for small satellites but all of them have severe constraints:

- Piggy-back launch (launch as a secondary payload).
- Cluster launch (launch of a cluster of small satellites using a heavy launcher).

1. Introduction

Today, there exists an increasing demand for small satellite launch. Indeed, miniaturization and the availability of Commercial Off-the-Shelf (COTS) now enables with small platforms (< 200 kg) satellite applications that used to require larger platforms. Small satellites are considered for a large range of applications (telecommunications, science, etc.) and there exists many small satellites constellation projects (OneWeb,

Indeed, in the case piggy back launch, the target orbit as well as the launch date are fixed by the primary payload. In the case of cluster launch, a single small satellite cannot be launched "on demand" unless there is the correct number of small satellite payloads to launch at the same time.

For these reasons, there is a need for a dedicated small satellite launch system that would meet the market needs in terms of cost, reliability and availability without the constraints of existing launch options.

The ALTAIR project, launched in the frame of the European Union’s Horizon 2020 research and innovation programme , is intended to pave the way for a future launch system that could address this need.

ALTAIR is a 3-year project (December 2015 – November 2018). Its total budget is around 4 M€, including a 3.5 M€ from the European Commission and a 0.5 M€ from Switzerland

Its strategic objective is to demonstrate the economic and technical viability of a future available, reliable and competitive European launch service for the access to space (Low-Earth Orbit) of small satellites in the range 50-150 kg.

The ALTAIR Consortium is made of 8 Partners from 8 countries:

- 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

The roles and expertise of ALTAIR Partners is detailed in the following table:

Table 1. ALTAIR Consortium

Expertise	Partner name	Profile
Aerospace vehicle system study (aircraft, space transportation systems). Specific background in air launch systems, from early system design (Didolus/L3AR, Aldebaran) to small scale demonstration (EOLÉ demonstrator). Multidisciplinary Design Optimisation (MDO). Aerodynamics Guidance/control. Interdisciplinary project management. Launcher system study, including launch system for small satellites. Launcher technology Market studies, business analysis	Office National d’Etudes et Recherches Aérospatiales (ONERA) - France	RTD organisation
Launcher on-board software and avionics. Ground control segment systems for launchers	Bertin Technologies (Bertin) - France	Industry
Rocket stage design. Hybrid propulsion.	GTD Sistemas de Información S.A. (GTD) - Spain	Industry
Aircraft design, manufacturing, certification and development. Aircraft avionics including Unmanned Air Vehicles. Aircraft payload release system. Ground segment and ground operations. Support to concept development (viability, reorientation). Flight test center for Beyond Visual Line of Sight Flight (CSG) Light weight structures, characterisation Communication and user uptake / dissemination activities. Market studies	NAMMO Raufoss SA (NAMMO) - Norway	Industry
	Piaggio Aerospace (PAS) - Italy	Industry
	CNES - France	RTD organisation
	ETHZ - Switzerland	RTD organisation
	SpaceTec Partners	SME

2. Project’s objectives, organization and methodology

2.1 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.

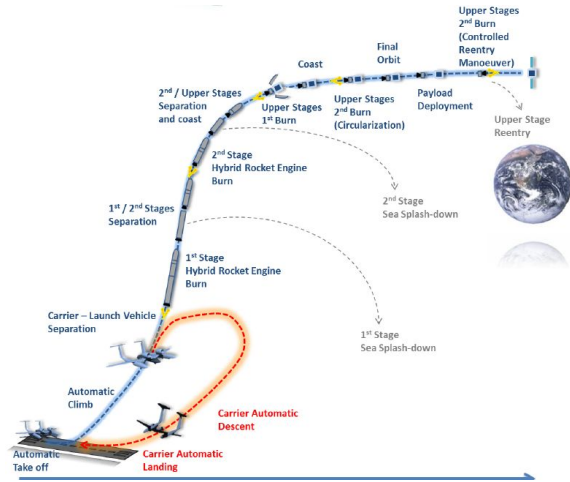


Fig. 1 ALTAIR mission profile

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-launched rocket with the same performance



Fig. 2 Artist’s view of the ALTAIR system after release of the rocket by the carrier

2.2 Methodology

In a first stage, the ALTAIR work has consisted in defining a preliminary mission definition and high level requirements.

These elements has been continuously evolving throughout the project according to the advances of the design tasks and the updates if the market analysis.

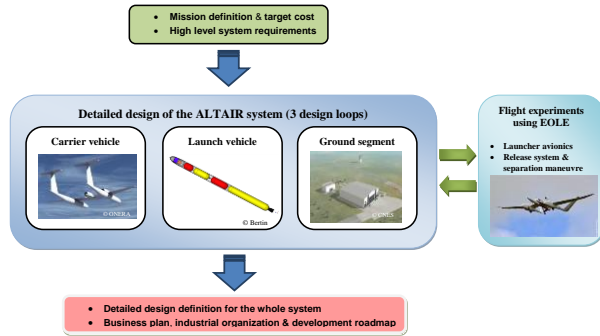


Fig. 3 ALTAIR overall approach & methodology

Then, the bulk of the ALTAIR work has consisted in design task (each one being the subject of a given work package):

- The carrier vehicle (WP3)
- The launcher vehicle (WP4)
- The ground segment vehicle (WP5)

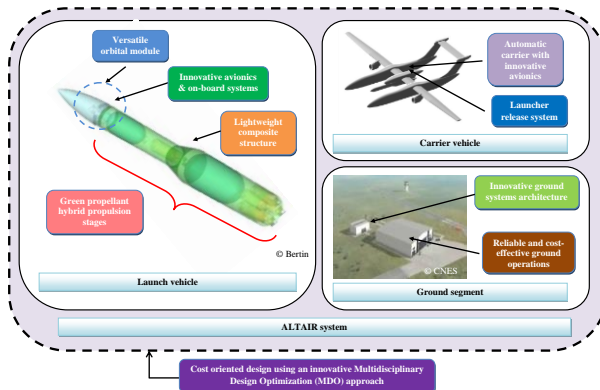


Fig. 4 Global view of ALTAIR design work

3. Results

3.1 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. 5 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. 6 Initial release conditions

3.2 Carrier

The following figure illustrate the carrier CONOPS.



Fig. 7 ALTAIR CONOPS: COP (Carrier Operator) vs. Autonomous Operation

The mass break down of the carrier is the following:

Table 2. Carrier mass beak-down

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



Fig. 8 View of the carrier with the launcher attached

3.3 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. 9 ALTAIR rocket

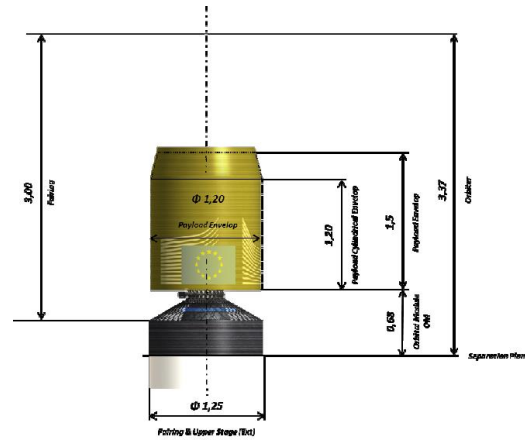


Fig. 13. Orbital module

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)

Fig. 10 ALTAIR LV mission general parameters



Fig. 14. Orbital module mission profile

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

Fig. 11 ALTAIR LV main flight parameters

3.4 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 ALTAIR LV trajectory

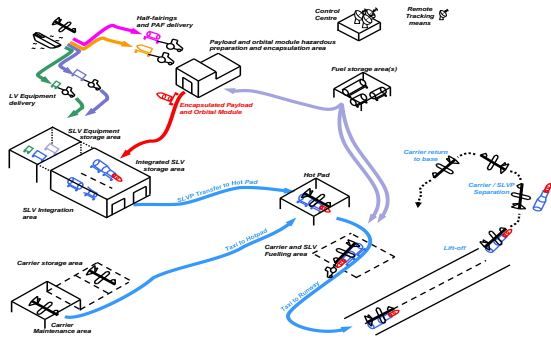


Fig. 15 Schematics of the operations



Fig. 16. One of the two best candidate sites identified: the Guyana Space Center.

4. First flight experiments with EOLE

In addition to the design tasks and the “exploitation” tasks (market study, development roadmap), the ALTAIR project includes a flight experiment work package, aimed at increasing the TRL for different technologies relevant to the ALTAIR concept.

For these flight experiments, we use the existing small scale flight demonstrator EOLE, which has been previously designed developed by ONERA and built by Aviation Design in the frame of the CNES PERSEUS project.

This small-scale demonstrator has a 150 kg Gross Take-Off Weight mass and is able to carry a 43 kg payload to an altitude of a few kilometres.

EOLE main characteristics	
Weights	
Max. Take-Off Weight	150 kg
Operating Empty Weight	107 kg
Max. Payload Weight	43 kg
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	2.57m ²
Aspect ratio	17

Fig. 17 EOLE Main characteristics

The objective of the flight experiments is to assess and validate:

- The launcher on-board system (for safer and more reliable launch operations):
 - Assessment of the disturbances caused by the carrier.
 - Validation of the initialization strategies and algorithms before the separation phase
 - Validation of the automatic safety procedures and algorithms implemented for the launcher flight.
- The release system and the separation maneuver.
 - Validate the release system physical principle.
 - Validate the separation chronology and the separation maneuver achievement.

EOLE main characteristics	
Weights	
Max. Take-Off Weight	150 kg
Operating Empty Weight	107 kg
Max. Payload Weight	43 kg
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	2.57m ²
Aspect ratio	17

Fig. 18 EOLE Main characteristics



Fig. 19 EOLE flying scale demonstrator

A first flight experiment campaign has taken place at the St. Yan airfield (France). This first flight campaign was limited to Visual Line of Sight flight (VLOS), with no release of the rocket.

Unfortunately, due to a technical issue, the flight experiment activity is currently on hold and will not be achieved as planned by the end of 2018. An extension of this activity in 2019 is currently under study.

6. Conclusions

The ALTAIR project has pushed further the study of the air-launch concept in Europe.

The main outcome of the project is:

- A first deep analysis of a European air-launch system for small satellites
- The demonstration of concept feasibility, with sufficient operation flexibility and low recurring cost (supported by an economic study and a market analysis)

The main identified drawback of the ALTAIR concept is the carrier development cost and the low number of carriers to be built (only 2 for an operational Altair system).

Although the current version of the Altair system is credible, some variants/adaptations of the current concept are considered in order to study how these issues could be addressed.

The end of 2018 ALTAIR work will be devoted to the consolidation of the business plan and development roadmap.



Fig. 20 ALTAIR mission patch

Acknowledgements

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