



The AMBER Rocket – a Test Bed for Hypersonic Research

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Abstract

One of the key challenges associated with high-speed vehicle science and technology is availability, cost and performance of test vehicles. Especially in Europe, the number of demonstrated, ready-to-fly vehicles is very limited, hindering the European high-speed science and technology. This paper presents a new, flight-proven suborbital launch system that can provide Europe independent and sovereign access to low Hypersonic speeds and discusses its applicability to various types of hypersonic research. The ILR-33 AMBER 2K launch vehicle is a Polish suborbital rocket developed in-house along with its ground segment in Łukasiewicz Research Network – Institute of Aviation, Poland. The launch system has been flight-proven 5 times, with recent flight from Andøya Sub-orbital constituting a significant milestone by achieving the edge of space. Now, the launch system is ready to serve various end-users, including high-speed science and technology. Equipped with additional boosters, the rocket can provide short reentry Mach 6 in a high-altitude flight or prolonged periods well over Mach 5 when optimized for such flight. While achievable Mach numbers and payload masses are limited, this solution can offer short time-to-flight and a low unit cost of a rocket enabling numerous flight tests during a single campaign. System elements, such as the rocket's hybrid motor or multi-purpose launcher are ready to become elements of new, larger hypersonic vehicles. Due to the nature of hypersonic missions, flight over international waters are preferred in an European context, and AMBER is known to test ranges with such access. The paper discusses requirements of various high-speed science and technology missions and discusses AMBER systems applicability and readiness to perform such missions. Several mission concepts are shown. The AMBER launch system shows promise to serve as a sovereign provider of low hypersonic speeds for European high-speed science and technology missions. It is envisaged that the system can serve as a low-cost, first flight test for newly developed technologies before their used in less frequent missions in a more demanding environment.

Keywords: *suborbital flight, flight test, hypersonics, ILR-33 AMBER 2K*

1. Hypersonic flight testing merits and challenges

Hypersonic flight is at the forefront of cutting-edge research and development. Current developments, especially in military usage in USA, Russia and China show that this topic is important to the powers of the world and should not be ignored in Europe. High cost of entry, sensitive nature of obtained data, and numerous technical challenges leave this field underexplored relative to its importance.

Said hypersonic flight challenges include [1], but are not limited to:

- Very high heat flux impeding on flying object – Boundary layer may reach temperatures higher than 2000°C. High temperature gradients and heat flux over small areas demand advancements in material science,
- Unsteady and nonlinear aerodynamics complicate the guidance and control of the vehicle. The high Mach regime is still not understood in sufficient amount to be properly modelled in simulations, while exact data are proprietary or even classified,

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- Airbreathing propulsion at hypersonic speeds is challenge in itself, limiting options for sustainer engines.

Validation and verification of hypersonic performance is difficult. The number of wind tunnels that enables high speed tests is very limited. Its usage is expensive and, in case of European wind tunnels, focuses on fundamental fluid dynamic and flow research. Ground-test data also suffers from relevance with reference to real-world conditions. Issues are not limited to typical ones from supersonic and subsonic wind tunnels (scaling and blockage effects, wall interactions, etc.) but suffer also from lowered gas density, and low test times. Those influence heat transfer experienced by test specimen, which impacts boundary layer behaviour.

Flight tests, however, can be performed for longer durations and at conditions the same as target flight applications. The cheapest way to reach this conditions is to use sounding rockets. The trajectory used in many sounding rocket missions for hypersonic testing follow an “up-and-over” shape. Rocket is propelled at lower Mach numbers during ascending parts of flight, and reaches hypersonic velocities at downward part of trajectory, during re-entry [2]. This approach provides much closer testing conditions (in terms of density and Reynolds number, crucial for boundary – layer behaviour) than the ground testing.

Longer tests at conditions closer to operational enable:

- Studying of boundary layer transition – key aspect for modelling of aerodynamic coefficients and heating, impacting nearly all aspects key to hypersonic flight [3]
- Material study – Correct heat-flux, exposition time and chemical properties of impeding gas, when compared to ground tests where gas composition or heat flux will be different
- Control systems study – hypersonic flight is highly dynamic and may be nonlinear, which is certainly challenging from the point of view of trajectory control. Longer tests enable to observe and understand the trajectories changes better
- Propulsion systems – only in freeflight the inlet (and its interactions with the engine) can be properly studied.

2. ILR-33 AMBER 2K launch system performance

The ILR-33 AMBER 2K launch system is a flight-proven solution capable of performing suborbital flights utilizing a mobile ground infrastructure. The launch system has been flight-proven 5 times, with recent flight from Andøya Sub-orbital constituting a significant milestone by achieving the edge of space [4]. Now, the launch system is ready to serve various end-users, including high-speed science and technology. This chapter focuses on the performance of the AMBER launch vehicle and discusses its potential for hypersonic research.

2.1. ILR-33 AMBER 2K – As Is

In its base, unmodified state, the AMBER rocket has demonstrated the ability to reach a 100 km apogee. With a 30 kg payload, it is capable of reaching and sustaining flight at Mach 4 for up to 20 seconds, and Mach 3 for up to 2 minutes. While this launch vehicle does not reach hypersonic speeds, it is a platform ready to be used to demonstrate new technologies or components of a hypersonic flight systems in a flight environment.

The main advantage of current configuration is its high readiness of the system, its familiarity with numerous test ranges and the modular construction.

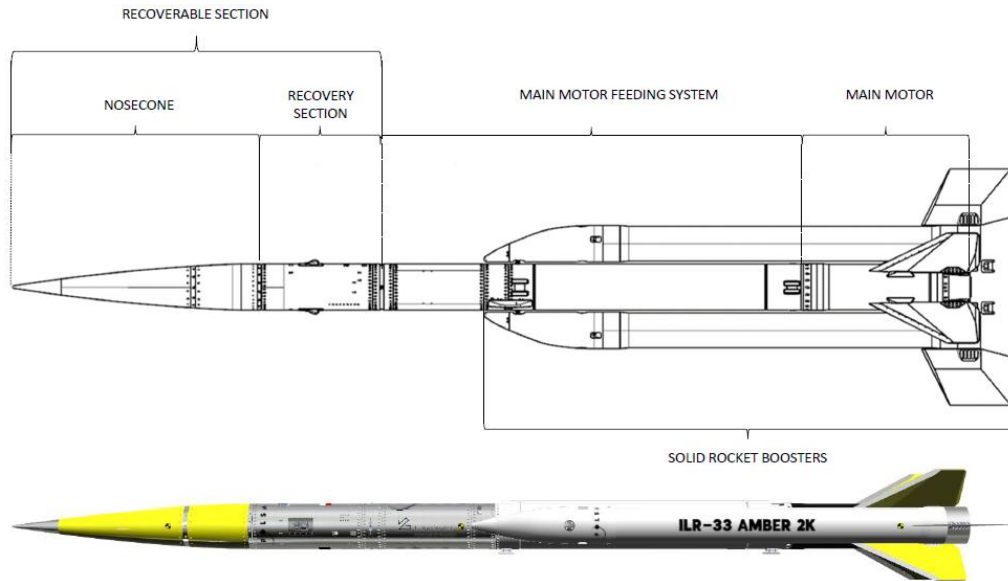


Figure 1 ILR-33 AMBER 2K outline.

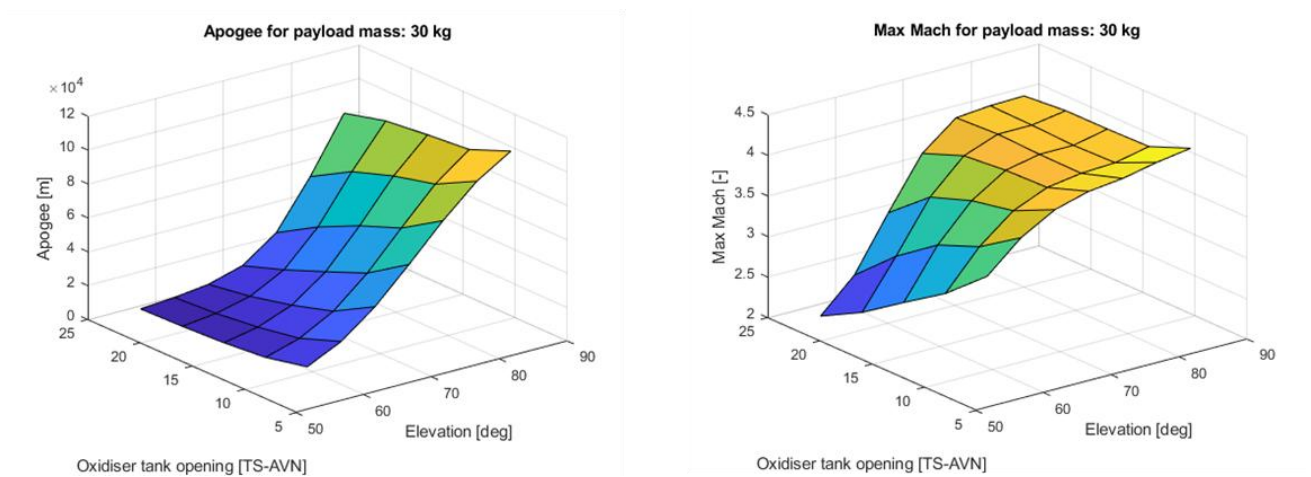


Figure 2 ILR-33 AMBER Apogee and Max Mach for 30kg payload as a function of Oxidizer tank opening and elevation

2.2. Upgraded ILR-33 AMBER rocket

A more performant version of the AMBER rocket can be implemented relatively easily using existing components. Either by replacing currently used boosters by a more powerful motor in a tandem configuration or by using four solid rocket motors instead of two, the rocket's performance can be increased significantly.

Depending on desired test conditions, "AMBER plus four boosters" would be able to allow for hypersonic conditions during ascent and descent part of the flight, as well as around the apogee depending on launcher elevations. This configuration would be able to reach Mach 6 and exceed Mach 5 for around 2 minutes (spread throughout the flight, the longest single segment Mach 5 regime lasts for around 90 seconds).



Figure 3 ILR-33 AMBER 2K with 4 solid rocket motors - outline.

Launcher elevation and hybrid motor start time can be adjusted to allow for hypersonic Mach research during different periods of flight, as seen on Figure 4. Max achievable Mach for 60 kg and 30 kg payload can be seen on **Erreur ! Source du renvoi introuvable..**

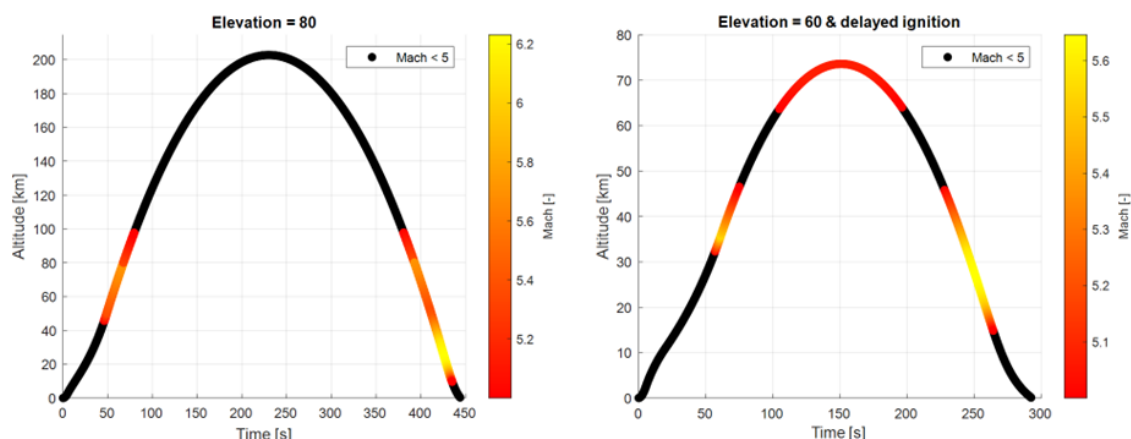


Figure 4 AMBER + 4 boosters Mach range depending on launcher elevation and hybrid motor ignition (30kg payload)

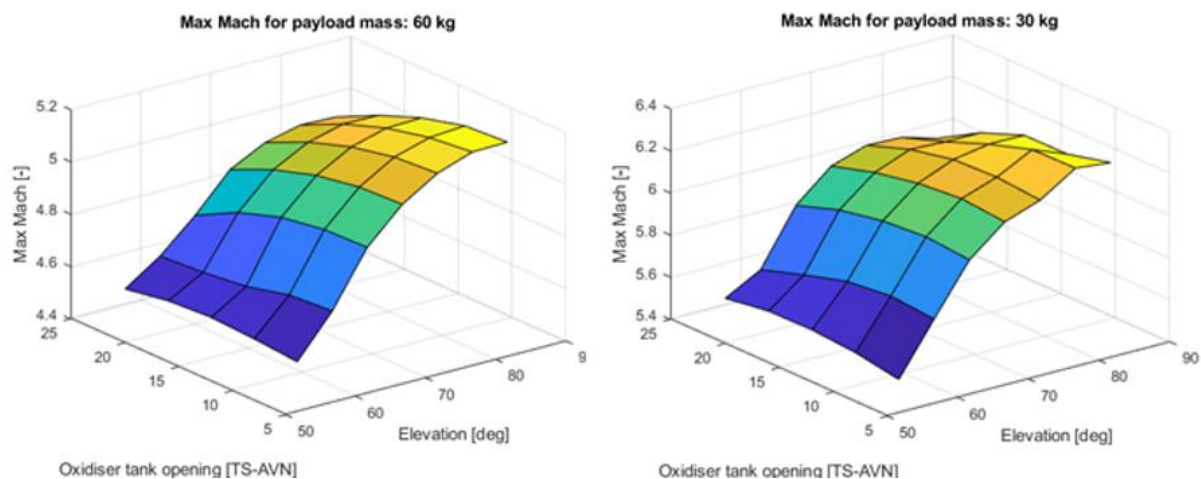


Figure 5 Maximum Mach numbers as a function of hybrid motor start time and launcher's elevation

3. AMBER elements in other hypersonic systems

In this chapter a number of elements of the AMBER system that can be re-used in other vehicles, especially hypersonic ones, are described.

3.1. Hybrid Motor

This flight proven hybrid propulsion system is ready to be utilized in other experimental vehicles. In the context of hypersonic research it could serve as a sustainer motor, allowing to fly a hypersonic vehicle at high Mach number for a prolonged time. A model of a drag coefficient has been prepared, spanning up to Mach 10 (see **Erreur ! Source du renvoi introuvable.**). A simplifying assumption has been made that this coefficient will be the same regardless of vehicle's size.

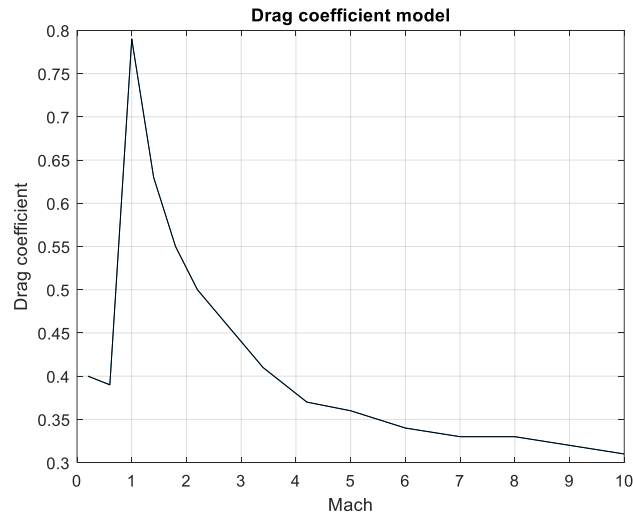


Figure 6 Drag coefficient of a rocket vehicle as a function of the Mach number.

An analysis was performed, where the motor's thrust (approximately 4.5 kN in vacuum) was to even out the drag. Assuming the mentioned drag model, the maximum reference area of rockets for a range of Mach numbers and altitudes were found.

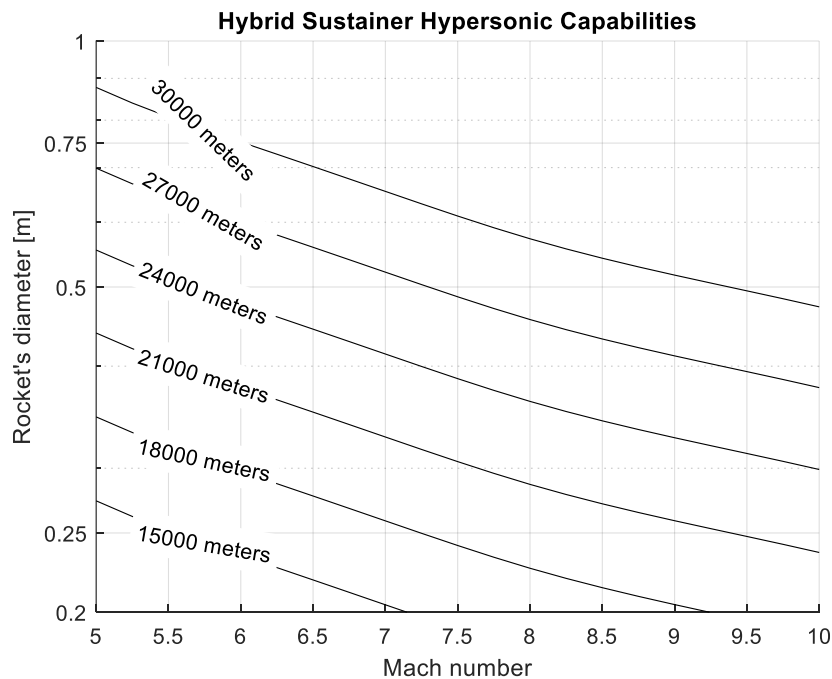


Figure 7 Maximum diameters of rockets as a function of Mach number the hybrid motor can sustain, shown for altitudes ranging from 0 up to 30 000 meters.

3.2. WR-2 launcher

Within the framework of the AMBER program, Łukasiewicz - ILOT has developed a mobile, autonomous launch pad for rockets up to 3 tonnes of mass. Launch pad is designed to launch single-stage and multi-stage suborbital rockets with parallel and stacked stages. The product was developed by the Łukasiewicz - Institute of Aviation to launch the ILR-33 AMBER 2K rocket, but the technical capabilities have been extended to rockets of significantly larger scale. The launcher will find application in areas where the construction of permanent launch facilities are not possible. It can also be used as an additional launcher, for example, in case of simultaneous launch of several rockets. Key features:

- Possibility to remotely adjust the launch azimuth and elevation angles
- Maximum mass of the launched vehicle: 3 000 kg
- Maximum thrust at launch: 80 kN
- Designed to work in a wide range of weather condition
- Equipped with hydraulic moving support system, allowing autonomous loading and unloading to/from a transport trailer
- Fully autonomous operation (built-in power sources and control systems)
- Precise lifting of the launcher arm complemented by the unique feature of precise azimuth angle setting
- Remote communication and adjustments performed from the rocket launcher command center
- Convenient long-distance land and sea transport, and the possibility of storage in a standard-size container



Figure 8 WR-2 rocket launcher with a suborbital rocket, getting ready to launch.

3.3. Avionics

Numerous avionic systems developed for the AMBER rocket can be re-used in new hypersonic vehicles. For instance, the OBC-K1 is a modular on-board computer. It has been designed to perform in-flight data acquisition, guidance, navigation and control. Thanks to its use of standardized modules, the device can be easily tailored to a specific mission. Small module form factor allows for use in space-restricted applications. The OBC-K1 is a flight-proven, reliable solution for rockets. With a dedicated enclosure it is capable of withstanding even the harshest environmental conditions. Key features:

- Dimensions: 110 x 120 x 160 mm enclosure / 55 x 55 mm single module
- Digital interfaces: CAN, RS-232, RS-422, RS-485
- Analog interfaces: 0-5V/16 bit/ 10 kHz; 0-12V/16 bit / 1 kHz
- Standby operation time: 30 days
- Mass: 1.7 kg with enclosure



Figure 9 OBC-K1 flight computer.

3.4. Other

Numerous other systems developed and flight-proven within the AMBER program can be reused in new, hypersonic systems. These include, but are not limited to:

- Igniters
Łukasiewicz - ILOT has developed new, reliable 1A/1W pyro-cartridges with numerous use-cases.
- Recovery systems
AMBER rocket has employed a 3-stage parachute recovery system that can be re-used in other vehicles.
- Separation systems (incl. low-shock)
Several separation systems, including low-shock systems have been developed and flight-proven. This includes a system separating rocket's recoverable section as well as systems to separate solid rocket motors from the main rocket's body [5].
- Flight simulations
Łukasiewicz - ILOT has developed advanced algorithms regarding flight simulation, flight optimization, safety analyses and flight-data postprocessing.

4. Conclusions

The paper discusses requirements of various high-speed science and technology missions and discusses AMBER systems applicability and readiness to perform such missions. Several mission concepts are shown. The AMBER launch system shows promise to serve as a sovereign provider of low hypersonic speeds for European high-speed science and technology missions. It is envisaged that the system can serve as a cost-effective, first flight test bed for newly developed technologies before their use in more frequent missions in a more demanding environment.

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