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Effect of different flight conditions at the release of a small spacecraft from a high performance aircraft

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ABSTRACT

In recent years, mainly due to miniaturization of electronics as well as to the improvement of computer performance, small spacecraft have increased their capabilities. More and more frequently specific mission objectives can be achieved with cheap satellites of reduced size. The growing use of small satellites stimulates the development of systems specifically dedicated to orbit injection of small payloads. In this context, one option is represented by air-launched rockets. The use of an air-launched rocket for delivering a small payload into the desired orbit has several advantages. First of all, payload release is much more flexible, because the delivery conditions are directly related to the dynamics of the aircraft and can be viewed as independent of ground facilities. In addition, reduced costs are associated with higher efficiency of an aircraft in the lower layers of the atmosphere with respect to traditional ground-launched rockets. To date, air-launched rockets separate from the aircraft in a horizontal flight condition. Then they maneuver in order to achieve the correct flight path angle for injecting into a gravity-turn arc of trajectory. Relevant losses are associated to this pitch maneuver; in addition, in this phase the rocket usually needs an aerodynamic control. Hence, the release of a rocket departing with a high flight path angle from the aircraft would avoid these losses and would simplify the control system, because in such a situation the pitch maneuver becomes unnecessary. This paper is aimed at investigating the dynamic behavior and performance of a payload delivered from a high performance aircraft, which flies with a high flight path angle. In particular, this work is concerned with showing the differences and tradeoffs among different starting conditions of a multistage air-launched rocket related to several flight path angles of the aircraft at release. An optimal system configuration, which allows placing a micro-satellite into a specified low Earth orbit, is proposed. This configuration is selected by optimizing the release condition, the mass distribution among the stages, and the trajectory (through the determination of the optimal control law).

1. Introduction

Air launch systems exhibit some advantages with respect to conventional ground-launched systems. First of all, a mobile platform allows the selection of the optimal launch conditions for any mission, by avoiding expensive out-of-plane maneuvers and reaching free drop zones. Moreover, the carrier aircraft can provide autonomous range support activities (such as telemetry, tracking and flight safety). Air-launched rockets are dropped at high altitudes, associated to a lower dynamic pressure and lower structural and thermal stresses, and this allows the use of advanced, lighter materials. The engine pressure

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losses are also reduced and the expansion ratio of the engine nozzle can be closer to the value optimized for operating in a vacuum. Another important point is the readiness to launch on demand. This is due to the fact that an air-launched system needs a reduced amount of operations and ground support, and, as a consequence, the time needed to launch is limited. In addition, such a system is more reliable under unfavorable weather conditions. Fast response and reliability are crucial issues when space support is required in case of humanitarian emergencies, conflicts, natural disasters, etc. In 1994 the Orbital Science Corporation operated Pegasus, the first commercial air-launched rocket [1]. Pegasus is a three-stage rocket dropped from horizontal flight of a cargo aircraft at altitude of 12 km (at Mach 0.8). Other similar projects, involving heavy carrier aircraft, are currently under development. A different strategy can be implemented by supersonic carrier aircraft. This idea was introduced in 1956 in [2], where the F-404 was proposed as carrier aircraft of an orbital winged launcher. In 2005 the use of the European fighter EFA was proposed to carry a three-stage rocket able to inject micro-satellites in circular orbits at several altitudes (up to 700 km) [3]. In 2006 the use of the F-15 was proposed as carrier aircraft for a bigger rocket, released from the upper part of the fuselage [4]. The use of the MiG 25 was proposed in [5] to inject satellites with a mass up to 200 kg. Lastly, in 2007 the use of the Douglas F-4D Skyray was proposed for the orbital injection of nanosatellites [6]. The present paper is aimed at investigating the dynamic behavior and the performance of a payload delivered from a supersonic aircraft which drops the launcher with a high flight path angle. In particular, this work is concerned with showing the differences and trade offs among different starting conditions of a multistage EFA-launched rocket related to several flight angles of the aircraft at release.

The paper is organized as follows: in Section 2 the three-stage EFA-launched rocket is described and its performance is determined by using the analysis included in [3]. In Section 3 the rocket nominal initial conditions are changed and a comparison among the different solutions is performed. In Section 4 two different carrier aircraft are used: the performance of the three-stage rocket is evaluated using the MiG 25 aircraft (as also proposed by [5]) and the Tornado aircraft instead of the EFA carrier aircraft.

2. EFA launched system: nominal trajectory

2.1. The EFA launched system

With reference to a launch system installed on a fighter aircraft, the main constraint is the dimension of the system. More specifically, two constraints must be considered: the first is related to the length of the missile and is due to the limited space between the engine of the aircraft and the landing gear. In addition, the diameter is constrained to a maximum value due to the low height of the aircraft and to the clearance space for the take-off maneuver. These constraints represent the central problem while trying to employ the stages of existing rockets, because the use of available stages with admissible diameters yields an overall rocket configuration that generally violates the length constraint.

The designed system is a three-stage rocket composed of two initial stages equipped with a solid propellant and a third stage with a liquid propellant motor. The first stage is assumed to be 3 m long, each of the remaining stages is about 1 m long, whereas the fairing (containing the payload) is assumed to be a tangent ogive one and half meter long. For all the stages the diameter is set to approximatively 1 m. The control system for all stages will be based on the thrust vector control (TVC) strategy. However, the first stage is also equipped with four fins in order to assure a small static stability margin needed for a safe separation between the aircraft and the rocket when the rocket motor is off (i.e. unable to provide any control). As also stated in [7], the static stability reduces the performance of the TVC system, so the fin set is selected in order to achieve a minimum stability margin, strictly sufficient to stabilize the rocket for the time interval between separation and the ignition of the first stage. Subsequently, the engine ignition stabilizes the rocket through the action of the TVC system, so the fin set can be released. The selected fins are trapezoidal with a chord of 50 cm at root and 30 cm at tip, with a span of 60 cm from the root. The positioning of the fins around the rocket is studied both to optimize the aerodynamic characteristics and to take up less space under the EFA.

In fact calculations made with USAF Missile DATCOM Software [8] show that the positioning of four fins equally spaced around the rocket is associated with the same aerodynamic characteristics as if the fins were positioned in the horizontal and vertical planes or rotated by 45°. However, this latter option would take up less space under the carrier aircraft. See Fig. 1 for the positioning and the

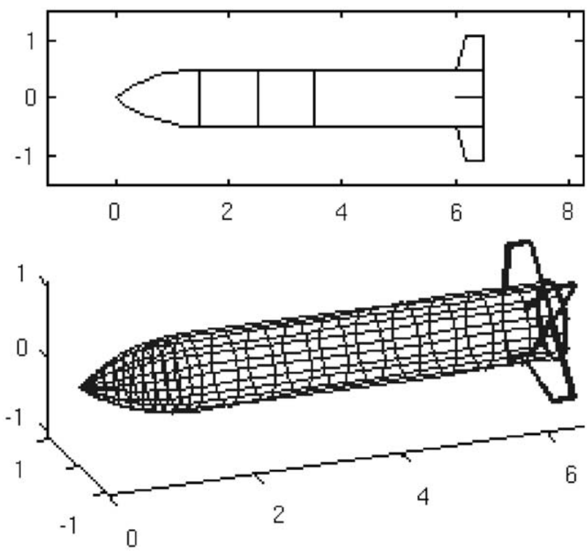

Fig. 1. Simple drawing of the rocket showing the relative dimensions of fairing, stages and fins (above) and 3D wireframe drawing showing the positioning of fins (below). Dimensions are in meters.