BRAZILIAN VLM – ATMOSPHERIC STAGE SEPARATION ANALYSIS

Conference Paper · October 2018

5 authors, including:

Carlos Henrique Melo Souza
Instituto de Aeronáutica e Espaço

Élcio Jeronimo de Oliveira
Luleå University of Technology

Paolo Gasbarri
Sapienza University of Rome

Ijar M. da Fonseca
Tecnological Institute of Aeronautics - ITA

IAC–18–44860

BRAZILIAN VLM - ATMOSPHERIC STAGE SEPARATION ANALYSIS

Mr. Carlos H. M. Souza[a] - Prof. Élcio J. de Oliveira[b] - Prof. Paolo Gasbarri[c] - Prof. Heidi Korzenowski[d] - Prof. Ijar M. Da Fonseca[e]

[a] *Institute of Aeronautics and Space (IAE), Brazil,* msouza.ch@gmail.com
[b] *National Institute for Space Research (INPE), Brazil,* elcioejo@fab.mil.br
[c] *Università di Roma "La Sapienza", Italy,* paolo.gasbarri@uniroma1.it
[d] *UNIVAP University, Brazil,* heidi.korzenowski@gmail.com
[e] *ITA-DCTA, Brazil,* ijar.fonseca@gmail.com

Abstract

The Brazilian Microsatellite Launch Vehicle (VLM) is a three-stage launcher, whose motor cases for first and second stages are manufactured by using filament-winding technique (carbon fiber). This vehicle is under development in the Institute of Aeronautics and Space - Brazil. In this project, the staging of the first stage during the atmospheric phase of fight (about 25km) is a critical issue that plays an important role of interest. At this altitude, the VLM is still under effect of non-negligible aerodynamic loads and, in the case of cold separation, the loss of control or re-contact between jettisoned part and the main body of the vehicle can occur. In the last years, methods based on CFD has been applied in the stage separation analyzes. However, these methods present high computational cost and consume a lot of time to process sensibility analyzes or Monte Carlo method due high number of cases to process. As a consequence of the problems addressed before, the main purpose of this paper is to discuss, model and analyze the atmospheric staging of the VLM considering hot separation and uncertainties and variations in the vehicle mass properties, inertia matrix, thrust rise time and TVC deviation. In order to achieve the purpose of this study, it is developed a 6-DoF mathematical model to simulate two body interactions during a hot separation process, by using a modified analytical technique for predicting the plume impingement force during tandem stage separation, including the reversed flow effects. Preliminary studies have shown good results in absence of uncertainties. By applying this new approach it is expected a fast and reliable methodology for hot separation analyzes.
Keywords: VLM, Staging, Monte Carlo, Flight Dynamics.

Nomenclature

CM_B	Center of mass of the body B
P_t	Thrust application point
τ_p	Tolerance on CM and P_t positions
τ_T	Percentile tolerance on thrust value
τ_I	Percentile tolerance on inertia moment values
ε	Exclusion angle
d_{min}	Minimal distance between the border and the nozzle axis
t	Time
$\mathbf{R}_{BT,T}$	Position vector of the body B
θ_B	Pitch angle
ψ_B	Yaw angle
ϕ_B	Roll angle
$\mathbf{V}_{BT,B}$	Velocity vector of B relatively to T frame
$\mathbf{w}_{BT,B}$	Angular velocity of B relatively to T frame
M	Mass
$\mathbf{I}$	Inertia matrix
$\mathbf{R}_{nB,B}$	Body B nose tip position
$\mathbf{C}_{BT}$	Rotation matrix from B to T
γ_t	Poisson ratio at the exit section
M_t	Mach number at the exit section
M_m	Jet momentum
R_d	Lower stage dome radius
F_{jet}	Jet force intensity
P_t	Central point of the exit section
P_c	Central point of the lower stage dome
P_d	Jet force application point
X_d	Distance between P_t and P_d
$\vec{R}_{dS}$	Vector from CM_S to P_d
$\mathbf{R}_{dS,S}$	Vector from CM_S to P_d @ S frame

69th International Astronautical Congress, Bremem, Germany, 1-5 October 2018.

1. Introduction

The VLM project is a cooperation between Institute of Aeronautics and Space (IAE) and German Aerospace Center (DLR) to develop and construct launch vehicles envisioning the market of micro-satellites. This project has been developed since 2012 when its application in a re-entry experiment was proposed [1].

The VLM-1 is one of the vehicles to be developed in the VLM project. It is a controlled launch vehicle constituted of three stages in tandem configuration. The 1^{st} and 2^{nd} are planed to use the motor S50 under development and the 3^{rd} stage shall use the S44 motor, already developed. The vehicle attitude control during the flight of the first and second stages is based on Thrust Vectored Action (TVA).

Only the separation of the first stage is analyzed on this work, what means, three bodies are critical for the analysis. They are: the complete vehicle, the jettisoned stage and the vehicle that continues after the separation. The nomenclature and simbology proposed by [2] are adopted in this study as seen in the Fig. 1.

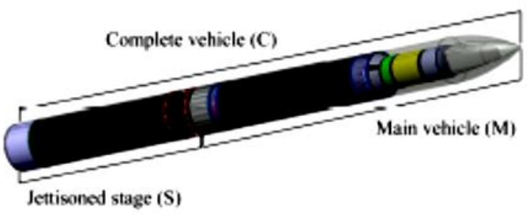

Fig. 1: VLM-1, its parts and nomenclature proposed. Figure adapted from [1].

After the launching, the VLM-1 will fly in atmosphere until the first stage burn-out, so then the staging starts. Thus, considering previous studies on staging, as [3] and [4], the analyzes presented here focuses on two main problems: The first one, a verify if the jet is able to push the jettisoned and, the second one, in which situations there is risk of collision.

The idea behind of these analyzes is to assess the reliability of the separation process considering several uncertainties inherent to the real vehicle. There are uncertainties on the position of the center of mass (CM) and thrust application point (P_t) of of all bodies which take part on the staging. There are, also, uncertainties on the thrust values and in the inertia moments.

These set of uncertainties were identified as critical for the relative rotation between the main vehicle and the jettisoned stage during the staging. The variation on CM and P_t positions result additional torques that are also influenced by the thrust variation. The inertia moment variation results in variation on angular velocity.

Taking into account only the translational effects, the thrust is the most intense force in separation and is also linked with the intensity of the jet force. When the trust varies, relative translation between both bodies varies intensively.

The first stage separation analysis shall consider the reference trajectory and vehicle configuration defined in [5]. The separation occurs around altitude of 25 km and Mach number of 2. Accordingly [4], VLM-1 separation process is classified as fire-in-the-role separation, also known as hot-separation. In this case, the jettisoned stage is pushed out by the jet ejected from the nozzle of the second stage.

To deal with this complex problem, a specific code was developed to process the equations of motion of the two bodies, considering a mathematical model for nozzle jet [5, 6]. The jet model is a modified version of the propose of [7] that includes the effect of relative lateral motion and rotation on the application of jet force.

The work will provide the dynamic analyzes of VLM hot separation, which allows a useful way for evaluating the effect of constructive uncertainties on the process and supports the vehicle design. This evaluation is made with the use of the Monte Carlo method. Several numerical results will complete the work.

This paper is organized as follow: 1. Introduction with a brief description of the work; 2. Presentation of the vehicle dynamic model; 3. Presentation of the jet force model; 4. Collision assessment; 5. Presentation of the Monte Carlo method; 6. Convergence analysis and simulation; 7. Discussion of results obtained; and 8. Conclusion.

2. Vehicle model

During the staging the main vehicle and the jettisoned stage are simulated, however the complete vehicle flight from lift-off until the separation is also simulated. The reason is that uncertainties affects its flight and influences the initial conditions on the separation process. Thus three bodies must be sim-