# CONTROL SYSTEM PROJECT FOR UNMMANNED AIR VEHICLE’S LAUNCHING

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***Abstract.*** *This work presents the study of unmanned air vehicle lauch with the aid of ramp and booster. The objective is to optimize the initial self-controled launch parameters and the gains of the controller, minimizing the oscillations provoked by the configuration variation and propulsion, maximizing the airship's specific energy gain, carrying it to the beginning ascent speed, through a proportional-integral-derivative control. For the determination of ideal project's parameters, the methodology was to ponder, in a Performance Index, the energy maximization at the attended flight end and the minimization of the energy used moving the elevator and the attitude angle variation. In the index optimization process, the minimum limits of height and speed after the booster's burning end, the elevator's moving speed and its maximum deflection, the maximum airship rate of turn around the lateral axis, the minimum trajectory angle and the maximum lift coefficient were respected. It can be note that the most important factor in the launch is the booster’s allignment with the center of mass, because it can generate a moment that can not be controled at very low speeds, but a minimum ramp’s lenth can be calculated to avoid the fall down caused by low command’s efectiveness. Finally, it was show that the performance index’s optimization is the most adequated solution to time variant non-linear problems, but in this case the behavior of the sistem has to be carefully analized to achieve the function global minimum.*

***Keywords****: self-controlled launching , unmmanned air vehicle, optimization, performance index*

## 1. INTRODUCTION

Looking for simplicity and portability, it is common to launch high performance Unmanned Air Vehicles (UAV) with the aid of boosters (Jet Assisted Take Off - JATO) and recover them with parachutes. In this case, the most critical flight phase certainly is the launch. Besides the configuration and propulsion transition, the airship begins flight without enough speed to generate lift to balance the weight and assumes an ascending trajectory essentially due to thrust vertical component of the auxiliary rocket. Furthermore, the acceleration is elevated and the thrust moment can also be high, because it is directly proportional to the misalignment between thrust and UAV’s center of gravity (CG), that is variable with the mass. When that happens, generally the aircraft doesn't have aerodynamic command effectiveness to compensate it and the Automatic Pilot (PA) becomes unable to maintain the reference attitude ($\theta_{ref}$).

To avoid the UAV loose in the throw, a ramp can be used. Its main advantage is the fact that the aircraft has only one a degree of freedom in the initial instants of the launch and begins the flight with a relative controlability. As more significant disadvantage, it can be note the system decrease of portability by the size of the ramp. Under that point of view, it is interesting to concept the smallest ramp that guarantees the release with success.

The present study just consider the initial instants of the flight, since the beginning of the race in the ramp until the speed reaches approximately 1.2 Stall Speed (Vstall). That corresponds to the first five seconds of flight. Thus, the release can be divided in four different phases:

- Run in the ramp;
- Assisted Flight with booster;
- Self-propelling Flight with burned booster; and
- Self-propelling Flight (UAV alone).

The largest importance of that study is related with the need of having determined parameters and safe limits to the launch, because small variations in the parameters in this phase can cause catastrophic instabilities. Thus, the final objective consists of optimize UAV's launch with the aid of ramps and boosters, in way to minimize, in an performance index (*Id*), the oscillations provoked by the configuration and propulsion variation, without waste a lot of energy in the elevator movement and still maximize the specific energy gain for the UAV, taking it to the beginning climb speed using a proportional-integral-derivative control (*PID*), also obtaining the smallest ramp capable to assure the launch according to the imposed restrictions.

The software MATLAB® 6.5 R13 was used to simulate UAV movement, with a longitudinal movement model with 3DOF.

## 2. PROBLEM DEFINITION

The launch phase is very complex, because it involves UAV movement modeling, states' variation, forces and moments estimatives. It also have to be considered booster's caracteristics, as well as its assembly in the UAV and the requirements achieve.

### 2.1 Requirements

As defined by Costa (2004), some requirements were imposed to guarantee UAV safety flight in normal launch conditions, with safety margin:

- Auxiliary thrust chosen must be capable to take aircraft at least to a speed 10% larger than the UAV stall speed;
- Minimum height of non-attended flight was specified in 15 m, considered the height of the end of the take off (FAR23, 2000);
- Trajectory cannot be descending during this phase;
- Aircraft rate of turn around the lateral axis should be less than 45º/second, in module;
- Wind speed limits: 5.0 headwind and 1.0 tailwind;
- Other specified requirements are related to the booster assembly in the UAV. For assembly error in relation to the position and ideal angle, the following margins were specified:
    - ± 1.0 cm in longitudinal direction;
    - ± 0.5 cm in vertical direction; and
    - ± 1.0 º in the angle between the booster thrust vector and the longitudinal axis of the airship ($\alpha_b$).

### 2.2 Booster instalation

The most appropriate available booster consists of a motor rocket of 70 mm diameter, with constant thrust for 1.57 seconds (AVIBRÁS, 2004). It would be desirable that the insert of the booster didn't generate neither high thrust moment nor significant modification in the CG position to avoid abrupt variation of the moment on the UAV during the configuration change after the booster burn off. Unfortunately that is impossible just using a single booster, but that is possible to insert a balance mass in the most forward position in order to reduce the ammount of mass necessary to prevent high CG position variation with the installation of the booster. The determination of the maximum mass to be used is directly related to the minimum requirements of altitude and speed after the end of the it burns of the booster, according to item 2.1.

The option to use a single booster has the following advantages:

- The only consequence of a rocket malfunction is to abort the launch (the use of two boosters could provoke the UAV fall if only one doesn't work well);
- There is not possibility of a catastrophic lateral traction asymmetry;
- Longitudinal acceleration more adequated to control and equipment conservation ; and
- Smallest cost.

Even though, there also exist disadvantages:

- Final speed of attended flight close to the minimum requirement;
- Reduced margin for an eventual mass increment; and
- Flight in second regime.

Booster and balance mass positioning should be such that the thrust moment generated doesn't make the aircraft become uncontrollable at low speeds in the nominal condition. Thus, the booster assembly angle ($\alpha_b$) was defined as 14.6º.

### 2.3 Aircraft and Booster Mathematical Model

The aircraf used is basically a jet UAV, low mass and with ten minutes of autonomy. Its aerodynamic model used for the simulations was that obtained in Furtado (2003).

The stability derivatives calculation was based on the data supplied by DATCOM, taken the average of the angle of attack ($\alpha$) values between -9 and 9 º, in way to be inside of the strip considered in the simulations, that is, where Lift Coefficient ($C_L$) is less than 0.68, considered maximum $C_L$ of the aircraft. There were used the following stability derivatives:

$$C_{D0},\ k_1,\ k\ ,\ C_{D\delta e},\ C_{L0},\ C_{L\alpha},\ C_{L\delta e},\ C_{Lq},\ C_{L\dot{\alpha}},\ C_{m0},\ \mathrm{C}_{\mathrm{m}\alpha},\ \mathrm{C}_{\mathrm{m}\delta \mathrm{e}},\ C_{mq}\ e\ C_{m\dot{\alpha}}$$

Besides those ones, there were used others relative to the booster body: $C_{D0b}$ e $k_b$. All the another stability derivatives were considered small in relation to the aircraft equivalent values. Specifically with relationship to drag, the moment generated by the translation of the booster CG to (UAV + booster) CG is considered, according to the thrust moment, variable with the consumption of mass due to the variation of the CG.

Because drag generated by the aircraft and the booster separately is larger than the one of both simultaneously, in way to be conservative, that interference was despised.

UAV with booster can be visualized in the Fig. 1.

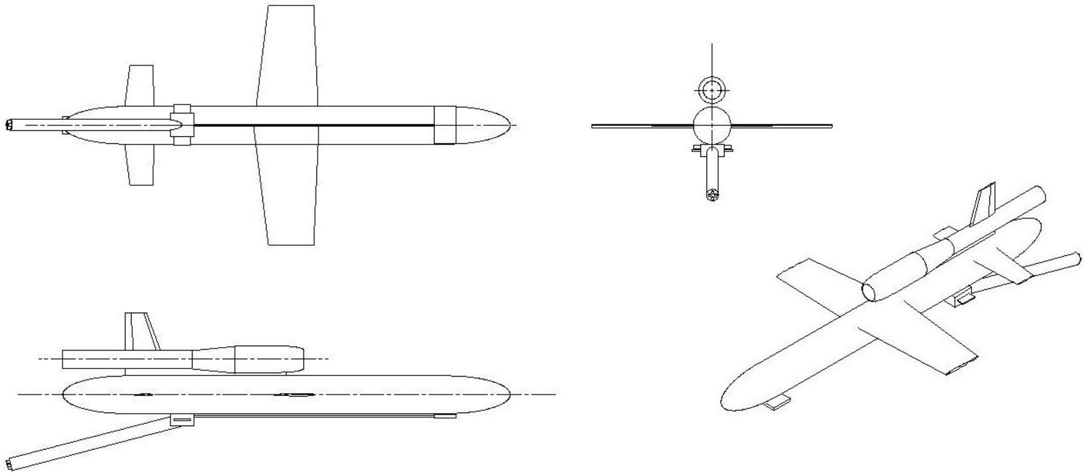

Figure 1 . UAV with Booster

The thrust model used for the UAV jet motor, according to Furtado (2003), is is based on the equation ( 1). For the booster, the model just consists of a constant traction for 1.57 seconds.

$$F = F_{\max}\left(1 + Mach\left(2.3202 - 2.0902\ Mach\right)\right)\left(\frac{\rho}{\rho_0}\right) \tag{1}$$

The thrust moment around the lateral axis is calculated in the equations ( 2), considering the variation of the position of CG of the group, presented in the equations ( 3) e ( 4):

$$M_F = F\left(z_F - dz_{CG}\right) + F_b\left(l_{F_b} + dl_{F_b}\right) \tag{2}$$

$$dz_{CG} = z_b\ t\ \frac{\dot{m}_b}{m_0} \tag{3}$$

$$dl_{F_b} = dz_{CG}\cos\left(\alpha_b\right) - x_b\ t\ \frac{\dot{m}_b}{m_0} sen\left(\alpha_b\right) \tag{4}$$

Once $\dot{m}_F \ll \dot{m}_b$, in that work the variation of the inertia moment ($I_{yy}$) in this phase only takes in consideration the relative portion to the variation of mass of the propelente of the booster:

$$I_{yy} = I_{yy0} + I_{yy_{b0}} + I_{yy_{pb}}\ t\ \dot{m}_b \tag{5}$$

Where $I_{yy0}$ is the UAV moment of inertia;

$I_{yy_{b0}}$ is relative to the booster assembly, translated to CG of the aircraft with booster;

$I_{yy_{pb}}$ is relative to the booster propelent.

### 2.4 Movement Model

We just considered the longitudinal movement of the airplane as rigid body, with 3 DOF, in which the airplane always stays in the same vertical plan. So it is not necessary to consider the direcional state variables and stability derivatives, just remaining the longitudinal movement states: $V$, $\alpha$, $q$, $H$ and $x$, that are governed by the equations according to Paglione (1985), with the terms relative to UAV and booster:

$$\begin{bmatrix} \dot{V} \\ \dot{\gamma} \\ \dot{q} \\ \dot{\alpha} \\ \dot{H} \\ \dot{x} \end{bmatrix} = \begin{bmatrix} \dfrac{F\cos(\alpha+\alpha_F) - \dot{m}\cdot V - mgsen(\gamma) - D - D_b}{m} \\ \dfrac{Fsen(\alpha+\alpha_F) + F_b sen(\alpha+\alpha_b) - mg\cos(\gamma) + L}{mV} \\ \dfrac{Ma + M_F}{I_{yy}} \\ q - \dot{\gamma} \\ Vsen\gamma \\ V\cos\gamma \end{bmatrix} \tag{6}$$

where:

$$\begin{bmatrix} L \\ D \\ D_b \\ Ma \end{bmatrix} = \frac{\rho V^2 S}{2} \begin{bmatrix} C_{L0} + C_{L\alpha}\alpha + C_{Lq}\left(\dfrac{l}{2V}\right)q + C_{L\dot{\alpha}}\left(\dfrac{l}{2V}\right)\dot{\alpha} + C_{L\delta e}\delta e \\ C_{D0} + k_1 C_L + k\ C_L^{\ 2} + C_{D\delta e}\delta e \\ C_{Db} + K_b\cdot(\alpha+\alpha_b)^2 \\ C_{m0} + C_{m\alpha}\alpha + C_{mq}\left(\dfrac{l}{2V}\right)q + C_{m\dot{\alpha}}\left(\dfrac{l}{2V}\right)\dot{\alpha} + C_{m\delta e}\delta e - \left(C_{Db} + K_b\cdot(\alpha+\alpha_b)^2\right)\left(z_b + dz_{CG}\right) \end{bmatrix} \tag{7}$$

Beyond those states, the mass variation is also considered in equation ( 8):

$$\dot{m} = \dot{m}_f + \dot{m}_b \tag{8}$$

And the actuator dynamic, defined as a first order system, with time constant of 0,05, can be saw in equation ( 9):

$$\dot{\delta e} = 20\delta e_c - 20\delta e \tag{9}$$

Where the commanded deflection of the elevator ( $\dot{\delta e}$ ), through a control *PID*, is given by the equation ( 10).
The elevator deflection rate was limited in the dynamic to 1.05 rad/sec (60º/s).

## 3. CONTROLLER'S PROJECT

The basic simulation tool used in the controller's project was the Software Matlab6 Release13.

Taking the simplest control mesh that make possibel a safe launch, we just choose a pitch control that try to keep the attitude in a predetermined reference value (attitude hold), considering the motor at full power and the elevator as control variable.

To obtain an adequate transitory and null permanent error, it was choose a Proportional-integral-derivative type controller (*PID*), where the feedback to generate the elevator deflection uses the signs of $\theta$, integral of $\theta$ and $q$, properly pondered for an attitude hold, according to the equation ( 10).

$$\delta e_c = \delta e_0 - K_t\left(\theta - \theta_{ref}\right) - K_q q - K_i \int \left(\theta - \theta_{ref}\right) dt \tag{10}$$

To obtain the best set of close loop mesh gains, several methods exist, most of them for use in time invariant linear systems. But booster-assisted UAV during the lauch are neither linear nor time invariant, then the traditional methods failed to not considering the configuration's variations of the aircraft linearized model.

In orther to verify the points in which there happen abrupt elevator deflection rate variations, it was made a simulation considering the inverse problem, that is, given a fixed $\theta_{ref}$, at each integration step the elevator deflection is calculated to maintain the balance of the aircraft in rotation, maintaining null q and its derived. The result of that simulation is explicit in Fig. 2.

The value of $\theta_{ref}$ was obtained as the one that maximize the specific energy gain.

In Fig. 2, it can be seen the first derivative discontinuities of $\alpha$, $\gamma$ and $\delta e$ in two instants: in the end of the ramp and in the end of booster's burn. It is important to note that it's still the ideal case. The lauch with acceptable margins in its extreme values take to very larger variations and flight instants where the aerodynamic moment generated is unable to compensate the thrust moment.

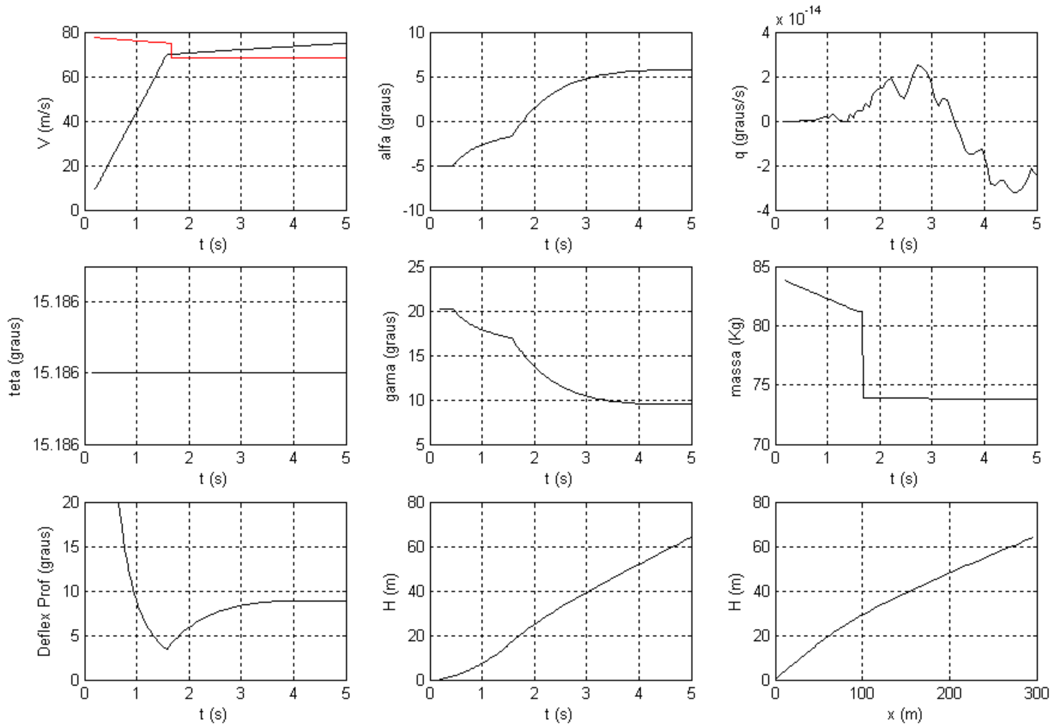


Figure 2. Inverse Control – Ideal case without wind

### 3.1 Performance Index Minimization

Given the peculiar characteristics to the launch, as the aircraft in those conditions is not a time invariant linear system, it was necessary to define a performance Index (*Id*) that represents the conditions established as desirable. That sends to the problem definition and the real physic characteristics of the aircraft, of the controls and of the sensors (Lewis, 1986).

Because its an attitude hold, it is natural that one of its components is its own attitude variation.

Besides, considering the sensor quality, for being UAV a low cost conception aircraft, naturally its inercial sensors will tend to insert mesure errors very larger if the aircraft attitude varies excessively.

The Specific Final Energy ($E_f$) also becomes very important because the booster can only take the aircraft to a condition of non-attended flight very close to the minimum required conditions of speed and height.

Finally, as the elevator command should be electric and the energy to this movement is provided by a battery, it is undesirable that the elevator oscillates a lot, wasting energy, that is limited. Once that energy is directly linked to the kinetic energy transferred to the elevator, the third factor of *Id* considers the square of the angular deflection speed supplied by the actuator.

In that way, to obtain optimum gains, the used method consist of maximize an *Id* that consider the aircraft specific final energy and the reduction of the attitude angle variation ($\theta$) and energy consumption to moove the elevator, properly pondered, as show in equation ( 11):

$$\mathrm{Id} = s_1 \cdot (E_f - E_{f0}) + s_2 \cdot J \qquad (11)$$

where:
$$\begin{cases} E_f = \dfrac{V_f^{\,2}}{2} + H_f \cdot g \\ E_{f0} = 3433 \dfrac{m^2}{s^2} \\ J = \displaystyle\int_0^{tf} \left[ (1-s_3)\left|\theta - \theta_e\right| + s_3 (\dot{\delta} p)^2 \right] dt \\ s_1 = -0.0001 \\ s_2 = -10 \\ s_3 = 0.5 \end{cases}$$

The final time for the simulation was defined as 5 seconds, enough time to burn and separate the booster and to begin the ascent attitude stabilization with constant θ.

The value taken as Specific Final Energy of Reference ($E_{f0}$) was obtained by the simulation of the ideal assembly case for inverse control, as shown in the Fig. 2.

It can be note that the *Id* is composed by dimmensionally incompatible values. Then, the values for the factors *s1, s2* and *s3* were arbitrated to make *Id* results prioritize the stability of the state θ and inhibits excessive and unnecessary elevator movements, without however forget the aircraft energy gain at the end of the simulation.

The great advantage of the *Id* is the possibility to model, without larger complications, a control that allows the otiptimization considering the variations in the model along the launch and the saturated actuator answer in terms of maximum elevator deflection speed inserting that limit in the aircraft dynamic.

To obtain final *Id* considered in the minimization routine, an average was taken among calculated *Ids* from nine different cases. Considering the ideal configuration and the critics combinations of the booster assembly margins, there were three configurations showed in the Table 1. To those configurations there were applied three wind conditions: head, null and tail wind from the requirements.

Table 1 – Critic Booster Assembly Configurations

| Configuration | Longitudinal Error (x) [cm] | Vertical Error (z) [cm] | Angle assembly error [º] |
|---|---|---|---|
| 1 | 0.0 | 0.0 | 0.0 |
| 2 | 1.0 | -0.5 | 1.0 |
| 3 | -1.0 | 0.5 | -1.0 |

It is know that it’s a very critical problem in terms of the imposed restrictions and nonlinearities. Due to this, the minimization method “Nelder-Mead Simplex" implemented in MATLAB doesn't supply satisfactory results. When it converges, it is just for local minimum. In that way, a *exhaustive search* had to be implemented to provide best initial estimate value for the minimization. With this initial values, MATLAB’s search method supplied best results. In spite of that, there is not guarantee that the obtained values correspond to the function global minimum.

A limitation of the minimization methods commonly used is that the reached minimum is just local and can be very different to the Global Minimum of the function. Besides, the function in this case is very sensitive to variations in the gains and its form is such that several local minimum can exist in disconected areas due to the restrictions. Thus, depending on the initials gains, the function will converge for different points.

In this work the *exhaustive search* was done through a Performance Index Map (*MID*), that indicates which initial point should be taking in way to lead the convergence for a best minimum.

An important usefulness of *MID* is to supply an initial estimate that satisfies all the restrictions, guaranteeing the convergence of the MATLAB’s minimization.

Thus, it was implemented a sub-routine that, starting with a mesh of values supplied by the user, plot a 3D graphic relative to the mesh *Ids, s*howing the gains *Kq* and *Ki*. As it would be difficult the visualization of a graph that incorporated the three entrance variables and *Id* simultaneously, it was used for the graph the value of *Kt* that results in the smallest *Id* at each orderly pair (*Kq, Ki*).

About the restrictions, in this analysis, in order to make easy the visualization of the points where some restriction is hurt, when that happens *Id* assumes the value -10 automatically. This value is very lower than the optimized index values.

With the gains that satisfy all the restrictions, MATLAB build in function can start its *Id* minimization. That considers the nine cases showed in Table 1, the restrictions proposed in 2.1 and the acceptable strip of gain values between 0 and 100.

The ramp angle should be sufficiently big to guarantee an initial non-attended flight height of 15 meters, but small enough to reach the minimum speed of flight of 1,1 $V_{stall}$. In that solution, seaching for the minimum *Id*, the program search the best project parameters.

Other important dimmension to determine is the ramp lenth. The shorter the ramp, more difficult it is to obtain a combination of the gains and initial parameters that correspond to a simulation that doesn't hurt any restriction. The solution adopted starts with a larger ramp length and later on it is made the ramp size minimization using as initial guess the values obtained for a larger ramp size.

To do the *Id* minimization, it was taken as entrance parameters, $\alpha_0$, $\delta_0$, $\theta e$ and $\delta r$ besides the gains *Kq*, *Kt* and *Ki*.

Following a method denominated *Continuance Method*, starting with the entrance parameters optimized values for a initial ramp length, the ramp size is reduced and the parameters are recalculated through a sub-routine similar to that used in the *Id* minimization. If the minimization fails, the program reduces the step for the half and it continues repeating that process until that the step becames less than 0,1 meters or that the wanted ramp length is reached.

Specifically, in this project, the initial ramp length is 10 meters and the desired lenth is 5 meters. The initial step used is 1 meter.

## 4. RESULTS

In Fig. 3 it can be seen *MID*, considering the ideal assembly, windless condition. it can be noticed that *Id* has a relatively smooth behavior for the ideal assembly. On the other hand, when considering the 9 wind-assembly combinations, saw in Fig. 4 , the situation modifies and, in several gain arrangement, there are simulations that disagree with the restrictions. That forms several areas that can be unconnected, where the minimization will converge to different values.

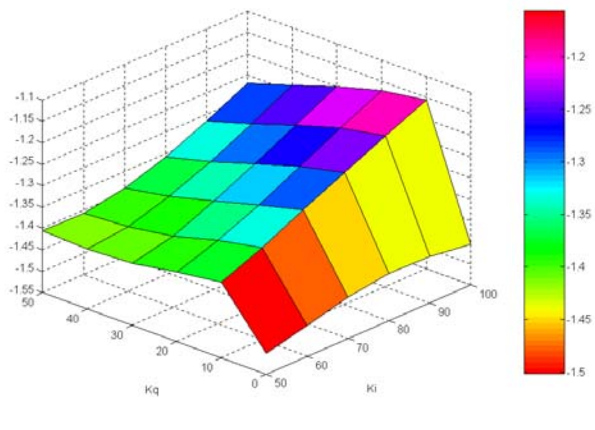


Figure 3 – MID for ideal condition, without wind

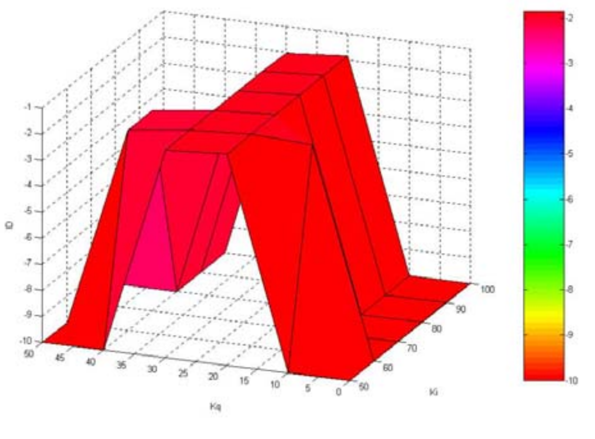

Figure 4 – MID considering 9 different conditions of configuration and wind

In the Table 2, it can be seen the comparison among the optimized parameters for 10 meters ramp, starting from two different initial guess values: null gain and those obtained from *MID*. The results ratify the use of *MID*, once *Id* obtained without using the initial *MID* gains corresponds to a local minimum 15% larger than the minimum obtained starting with MID guess.

Table 2. Comparison among the minimização results

| **Initial Condition** | **Without MID null initial gain** | **With MID to obtain initial gain** |
|---|---|---|
| **Parameter** | **Optimized Value** | **Optimized Value** |
| **Id** | 1,87 | 1,53 |
| $\mathbf{K_q}$ | 12,29 | 15,47 |
| $\mathbf{K_t}$ | 33,38 | 70,81 |
| $\mathbf{K_i}$ | 100,00 | 40,13 |
| $\boldsymbol{\alpha_0}$ | -4,2 | -3,9 |
| $\boldsymbol{\delta e_0}$ | 10,5 | 6,6 |
| $\boldsymbol{\theta_e}$ | 19,3 | 12,7 |
| $\boldsymbol{\Delta r}$ | 22,9 | 17,2 |

Tabela 3. Optimized Gain before ramp reduction to 5 meters, considering 9 cases

| **Parameter** | **Value** |
|---|---|
| ***Id*** | 3,16 |
| ***Kq*** | 34,86 |
| ***Kt*** | 32,35 |
| ***Ki*** | 100,00 |
| $\boldsymbol{\alpha_0}$ | -5.00 |
| ***DE0*** | 3.03 |
| $\boldsymbol{\Theta e}$ | 13.18 |
| $\boldsymbol{\Delta r}$ | 20.19 |

From the theoretical analysis of aerodynamic moment, it was observed that, in the nominal condition, defined in configuration 1, for speeds smaller than 20 m/sec, there is no elevator deflection capable to maintain moment balance. For the configuration 2, that speed is 26 m/sec and, for the configuration 3, it is 46 m/s.

It means that a temporary instability exists if the aircraft is out of ramp before reaching those speeds. In that way, an inverse control using a ramp lenth less 9.6 meters would not result in a constant $\theta$ for the most critical configuration, that is for 3. However, it is acceptable a temporary UAV instability, since it doesn't hurt the imposed restrictions with or without wind.

For the launchs with the 5 meters ramp, instability happened for a maximum of 0,57 seconds in the configuration 3, but, in Fig. 5, it can be seen that there is no catastrophic instability risk. The situation is quickly normalized and the flight normally continues.

It can be note that mainly caused by the condition of tail wind, although it is a weak wind, the attitude reference angle $\theta_{ref}$ should be reduced to satisfy to the requirements of final speed.

Table 4. *Ids* for each analised configuration

| Configuration | Head Wind (m/s) | Id |
|---|---|---|
| 1 | 0,0 | 1.14 |
| | 5,0 | 0.98 |
| | -1,0 | 1.18 |
| 2 | 0,0 | 4.12 |
| | 5,0 | 3.79 |
| | -1,0 | 4.18 |
| 3 | 0,0 | 4.31 |
| | 5,0 | 4.51 |
| | -1,0 | 4.20 |
| Average | - | 3.16 |

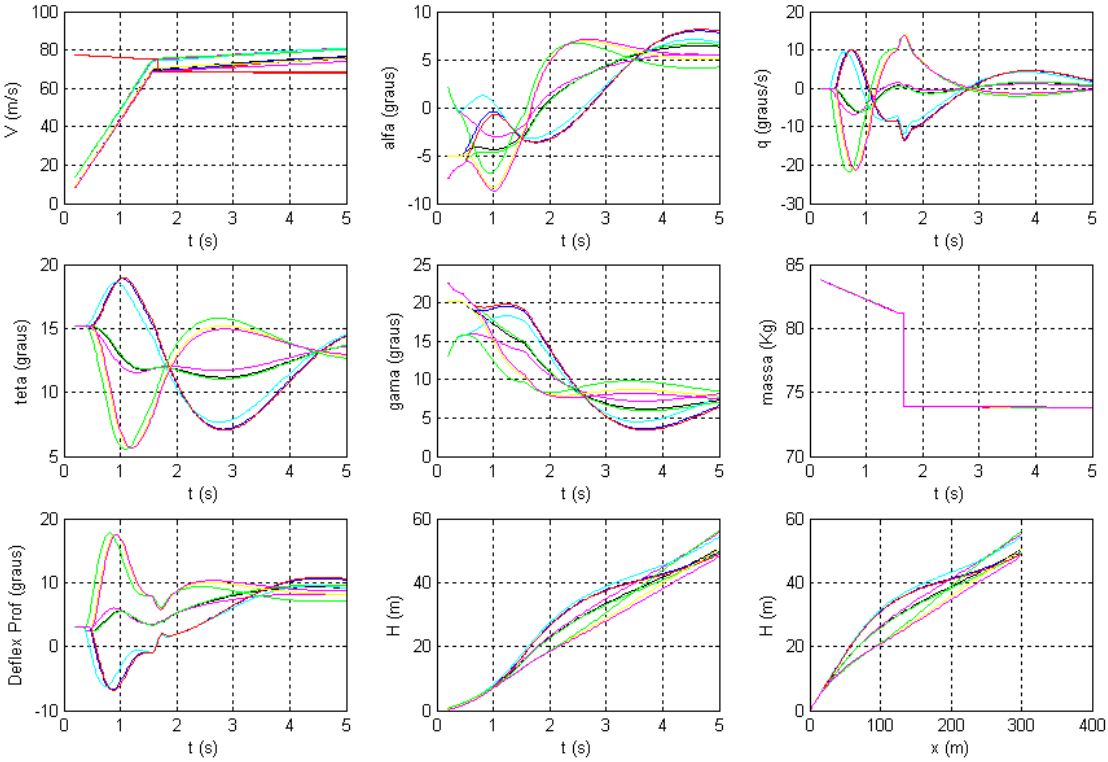


Figure 5. Simulated states for 5 m Ramp with optimized launch parameters in all the proposed conditions

## 5. CONCLUSION

The launch of unmanned air vehicles is consider in most cases, the criticest phase of the mission. For that reason, it was accomplished a deep study of that phase. Due to the UAV's State Matrix, that is time variant non-linear during the launch, linear optimization methods are not effective for the proposed objective. Thus, it was opted to minimize a performance index that considers the attitude variation, the elevator deflection rate and the final energy reached by the aircraft. The time considered in this simulation is 5 seconds.

Through the balance calculations in rotation, it was possible to determine that the aircraft, if was thrown staticaly it would fly for about one second unable to balance thrust moment because of the lack of aerodynamic effectiveness in the control surfaces. This only stops when speed reaches 46 m/sec in the configuration 3. For that reason, a ramp was inserted and maintains the aircraft attitude under imposed limits in the initial instants of assisted acceleration.

Even though, the ramp size is not free and, once it is desirable to have a compact and simple support apparatus to the launch, it was necessary to limit the maximum ramp length in 5 meters. That limit generated up to 0,57 seconds of flight without control, but that time is insufficient to cause a fall down, since the conditions and initial parameters are appropriately determined.

To guarantee a safe launch, once they are critical instants, it is necessary to simulate all the combinations of assembly configurations and wind conditions in the launch, that were identified as decisive. Besides, it is important to consider since the beginning all the requirements, to obtain initial guess for the optimization.

When considering all the factors mentioned above, the Performance Index Map is capable to supply an initial guess that certainly will converge for a local minimum before optimization and, if the mesh refinement is correctly adjusted, that minimum is quite close of the Global Minimum of the function.

Of ownership of the result obtained for a length of larger ramp, it can be reduced gradativamente that length until reaching a more appropriate ramp size, through a Method of Continuation.

As minimization results, the following parameters are supplied: feedback gain for PID controller; position and assembly angle of the booster in the UAV; attack angle during the race in the ramp; elevator initial deflection and minimum ramp length that optimize the launch, respecting its respective acceptable variation margins foreseen in the problem formulation

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## 5. RESPONSIBILITY NOTICE