Development and Design of the Landing Guidance and Control System for the S20 UAV

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Abstract – The work developed in this thesis focuses on the design and validation of an autoland guidance and control system capable of landing the S20 UAV. To accomplish the task in hand, the six degree of freedom nonlinear model of the vehicle provided by Spin.Works was studied, and the actuators and sensors of the platform were modeled. The landing guidance strategy defines the three dimensional landing path using wind speed and direction information and the desired landing site given by the operator. The wind information is obtained from an Extended Kalman Filter EKF, that estimates wind speed and direction using air speed and ground speed information provided by the pitot tube and the GPS respectively. Based on the assessment of the S20 UAV dynamics, the longitudinal control structure using a Linear Quadratic Regulator LQR and Proportional-Integral controller, was developed centered on controlling vertical speed, air speed and height. In order to implement the LQR, the model was linearized and simplified to describe only the phugoid mode of the vehicle longitudinal motion. The lateral control structure was provided by Spin.Works and is based on path following algorithms. The final part of the thesis consists of performance and sensitivity analyses of the landing procedure using Monte Carlo simulation techniques, where the variables used were the wind speed and wind direction deviation, and the initial position and heading of the aircraft.

Keywords – Fixed wing UAV, Autoland, LQR, EKF, Monte Carlo simulations.

1 Introduction

An Unmanned Aerial Vehicle (UAV) is an aircraft capable of flying without an on-board human pilot. It may be remotely operated from a ground station, or by means of modern control systems, it may be autonomous in the sense that it is capable of fulfilling different tasks without direct human interaction. The development of UAV technologies has been recently centered on developing solutions for civil markets such as agriculture, terrain mapping or fire surveillance. To fulfill these requirements, landing the UAV is one of the key operations in flight which define the overall success of the mission.

Landing of UAVs has been a problem since the early stages of their development. All weather and night operation of UAVs by manual controllers is extremely difficult unless the reliance and load on the external pilot is kept at a minimum. In order to overcome these difficulties and expand the operational envelope of the UAVs there has been a lot of research and development in the autolanding area.

Following more traditional approaches, several control techniques have been studied to land an UAV in predetermined locations. Using robust control techniques in [1], the authors explored the possibility of implementing a control system where the $H_2$ performance variables are responsible for controlling the aircraft states, such as speed and height, and the $H_{\infty}$ technique is implemented to minimize the atmospheric disturbances to the output. One other approach was taken in [2] using dynamic inversion techniques. The underlying assumption of this study, considering an accurate knowledge of the dynamic model of the UAV, combined with the fact that the system was not tested for real wind conditions, leads one to
conclude that this method is still to be proved. In [3] a different technique was adopted. This method only presents the control of the UAV in the longitudinal plane, based on independent control techniques for the elevator deflection command and thrust command. Adaptive backstepping control techniques were used for the elevator controller and the thrust controller is a PI structure. Finally in [4], a combination of classical control techniques and first and second order pre-shape filters for input demands was used, with results showing effective control of the trajectory and touchdown point in the presence of wind.

2 Modeling the UAV motion and its components

In order to fully understand the S20 UAV characteristics and behavior, this section presents the S20 model, a small UAV developed in house by Spin.Works. It is a flying wing UAV and the philosophy behind the design is to improve the ratio of maximum lift coefficient to minimum drag coefficient, thus improving energy consumption and flight time. Table 1 summarizes the S20 specifications.

<table>
<thead>
<tr>
<th>State</th>
<th>Variation</th>
<th>State</th>
<th>Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>µk</td>
<td>0</td>
<td>xg</td>
<td>Na</td>
</tr>
<tr>
<td>γk</td>
<td>*</td>
<td>yg</td>
<td>Na</td>
</tr>
<tr>
<td>χk</td>
<td>0</td>
<td>zg</td>
<td>Na</td>
</tr>
<tr>
<td>V</td>
<td>Vt</td>
<td>p</td>
<td>0</td>
</tr>
<tr>
<td>βk</td>
<td>0</td>
<td>q</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2: Trim glide flight. No wind.

![Image of lift over drag and γt over trim velocity](image)

Figure 1: Lift over drag and γt over trim velocity.

where * indicates states that can freely vary until stabilization, Na stands for not applicable and applies to the position states that vary without stabilizing. The results of the mentioned test were used to determine the favorable conditions for the landing of the S20 UAV, and are presented in figures 1 and 2.

<table>
<thead>
<tr>
<th>State</th>
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</tr>
</thead>
<tbody>
<tr>
<td>µk</td>
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</tr>
<tr>
<td>γk</td>
<td>*</td>
<td>yg</td>
<td>Na</td>
</tr>
<tr>
<td>χk</td>
<td>0</td>
<td>zg</td>
<td>Na</td>
</tr>
<tr>
<td>V</td>
<td>Vt</td>
<td>p</td>
<td>0</td>
</tr>
<tr>
<td>βk</td>
<td>0</td>
<td>q</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2: Trim glide flight. No wind.
3 Landing guidance

The landing guidance strategy is responsible for guiding the vehicle from the time where the landing procedures are activated until touchdown. Its core function is to receive data from the GPS and wind estimator, and the desired landing site DLS input from the operator and through imposed constraints, convert them into control references. By design, the landing procedures always occur against the wind. To provide for an efficient landing, the strategy was divided into two: one responsible for guiding the vehicle in the vertical plane, and the other responsible for guiding the vehicle in the horizontal plane. In order to evaluate the method proposed, and its limitations, Spin.Works defined the landing requirements summarized in table 3.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landing area</td>
<td>100 m × 30 m</td>
</tr>
<tr>
<td>Operational wind speed</td>
<td>≤ 10 m/s</td>
</tr>
<tr>
<td>Wind direction</td>
<td>360 deg</td>
</tr>
<tr>
<td>Touchdown vertical speed</td>
<td>≤ 0.6 m/s</td>
</tr>
<tr>
<td>Touchdown speed over ground</td>
<td>≤ 14.5 m/s</td>
</tr>
</tbody>
</table>

Table 3: Landing requirements.

3.1 Longitudinal guidance

The longitudinal guidance was designed to bring the S20 UAV from a determined altitude to the ground within pre-determined conditions. The procedure implemented considers three sequential flight phases: approach, descent and flare, as described in figure 3.

The approach phase is used to bring the vehicle near to the descent path. In this phase the air speed reference is maintained at close to mission levels and the altitude reference is maintained at values within the range of the laser altimeter:

\[ V_{a_{ref}} \approx V_{a_{cruise}} \]  

\[ z_{ref} < z_{alt_{limit}} \]  

During the descent, the air speed reference is imposed as a constant and the height reference is determined using a function of position \( p = (N, E, D) \) and descent flight path angle \( \gamma_d \):

\[ V_{a_{ref}} = V_{a_d} \]  

\[ z_{ref} = \tan \gamma_d \times d_c + z_{fl} \]

where \( z_{fl} \) is the flare height and \( d_c \) is the distance between the position of the vehicle at any given time and the flare point, and is determined using:

\[ d_c = \sqrt{(N_{ft} - N_c)^2 + (E_{ft} - E_c)^2} \]

where \( (N, E)_c \) are the coordinates of the vehicle at any given time and \( (N, E)_{ft} \) are the coordinates of the flare point, both expressed in the ground frame. Due to the fact that the landing procedures will always occur against the wind, the force that the wind...
applies in the vehicle varies with the wind speed, and with it the speed over ground of the aircraft. With more intense forces acting on the frame, the descent flight path angle can be increased without increasing the speed over ground of the vehicle, hence reducing the distance traveled over ground. The method implemented uses a descent angle increment related with wind speed:

\[ \gamma_d = \gamma_0 + V_w \gamma_{inc} \]  

(6)

Finally, the descent flight path angle when there is no wind is set to \( \gamma_0 = -4 \) (deg) as proposed in section 2, and \( \gamma_{inc} \) is defined in section 5.

The flare phase uses exponential equations dependent on time to shape the air speed reference:

\[ V_{a,ref} = (V_{a0} - V_{aid})e^{-\frac{t}{\tau_2}} + V_{aid} \]  

(7)

where \( V_{a0} \) is the air speed at the start of the flare, \( V_{aid} = 11 \) m/s is the targeted touchdown air speed and \( \tau_2 = 10s \) is the time constant at which the reference air speed is decreased. And the vertical speed reference:

\[ \dot{z}_{ref} = (\dot{z}_0 - \dot{z}_{td})e^{-\frac{t}{\tau_1}} + \dot{z}_{td} \]  

(8)

where \( \dot{z}_0 \) is the vertical speed at the beginning of the flare, \( \dot{z}_{td} = 0.3 \) m/s is the targeted vertical speed on touchdown and \( \tau_1 = 3.2s \) is the time constant at which the vertical speed is decreased.

### 3.2 Lateral guidance

The lateral guidance is responsible for guiding the vehicle in the horizontal plane defined by \((N, E)_G\). Given wind direction, initial position and the DLS, the lateral guidance determines a set of waypoints that define the horizontal path to be followed.

After the landing direction is defined the waypoints are calculated sequentially:

\[ N_{i+1} = N_i + \sin \chi_L d_{i+1} \]  

(10)

\[ E_{i+1} = E_i + \cos \chi_L d_{i+1} \]  

(11)

where the first waypoint to be defined is the flare point and the following are calculated in the order described in figure 4. \( d_i \) is the distance between the two waypoints. The flare distance, \( d_{fl} \) along with the buffer distance, \( d_{bf} \) are determined in section 5. As for the descent distance, it is defined using the descent height \( z_d \), the flare height \( z_{fl} \) and the descent flight angle:

\[ d_d = (z_d - z_{fl}) \tan(\gamma_d) \]  

(12)

The output of the lateral guidance is the waypoints matrix:

\[ WP = \begin{bmatrix} N_{fl} & E_{fl} \\ N_d & E_d \\ N_{bf} & E_{bf} \end{bmatrix} \]  

(13)

### 4 Wind estimation and control

The wind estimation tool is responsible for providing the landing guidance with wind speed and direction information and the control platform is responsible for providing the system with control commands in the form of elevator, aileron and thrust inputs. Figure 5 is the sketch of their integration.

![Lateral guidance strategy](image)

Figure 4: Lateral guidance strategy.

First the landing direction \( \chi_L \) is defined using the wind direction \( \chi_w \):

\[ \chi_L = \chi_w - 180 \]  

(9)

4.1 Wind estimation

The estimation of wind speed and direction uses an Extended Kalman Filter EKF based on GPS and
Pitot tube measurements. The algorithm implemented follows [6], with the difference that the wind is estimated in Cartesian coordinates, instead of Polar coordinates. The method used is based on finding the wind vector \( \vec{V}_w \) using the measured values of speed over ground \( \vec{V} \) and air velocity \( \vec{V}_a \):

\[
\vec{V} = \vec{V}_a - \vec{V}_w
\]  

(14)

The speed over ground is given directly by the GPS and the air speed can be determined using the measured pitot air speed \( V_p \). Due to the fact that the pitot tube is mounted along the longitudinal axis of the vehicle, the measurement has to be corrected for installation errors as well as attitude variations. The two are related using:

\[
V_a^2 = \frac{V_p^2}{\cos\alpha \sin\beta} = \frac{q_\infty}{sf}
\]  

(15)

where, \( \alpha \) is the angle of attack, \( \beta \) is the side slip angle, \( q_\infty \) is the dynamic pressure measured by the pitot tube and \( sf \) is the scaling factor. With the ground speed and air velocity defined, the equation combining all three can be written:

\[
(V^N - V_w^N)^2 + (V^E - V_w^E)^2 = \frac{q_\infty}{sf}
\]  

(16)

The implementation of the EKF assumes that the wind is constant and horizontal. Additionally the pitot tube scaling factor \( sf \) is also estimated, completing the state vector, \( x = [V_w^N \ V_w^E \ sf]^T \). The system dynamics are described as follows:

\[
x(k+1) = Fx(k) + \omega_k
\]  

(17)

where

\[
F = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}, \quad \omega_k \sim N(0,Q)
\]  

(18)

and the measurement equation \( h(x) \) is obtained from (16), and setting the measurement \( z_k \) to be the dynamic pressure \( q_\infty \), the nonlinear observation system is obtained:

\[
z_k = h(x) + v_k = sf((V^N - V_w^N)^2 + (V^E - V_w^E)^2) + v_k
\]  

(19)

By linearizing (19) and using the algorithm establish in [6] the EKF was obtained. The extended Kalman filter was tuned for the center of the wind speed landing envelop interval, \( V_w = 5 \text{ m/s} \), and table 5 summarizes the filters parameters.

The performance of the wind estimation tool is documented in section 5.

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**Table 4: Wind estimation. Kalman filter parameters.**

<table>
<thead>
<tr>
<th>Initial states</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X_0 = \begin{bmatrix} 3.85 \text{ m/s} \ 3.21 \text{ m/s} \ 0.6125 \text{ kg/m}^3 \end{bmatrix} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Initial covariance</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_0 = \begin{bmatrix} 0.28^2 &amp; 0 &amp; 0 \ 0 &amp; 0.28^2 &amp; 0 \ 0 &amp; 0 &amp; 0.001^2 \end{bmatrix} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measurement noise</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R = 44(\text{Pa}^2) )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process noise covariance</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Q = \begin{bmatrix} 5e - 8 &amp; 0 &amp; 0 \ 0 &amp; 5e - 8 &amp; 0 \ 0 &amp; 0 &amp; 1e - 10 \end{bmatrix} )</td>
</tr>
</tbody>
</table>

---

### 4.2 Longitudinal controller

The longitudinal controller is responsible for the control of the longitudinal motion of the aircraft. In [7] are described the two main modes of the longitudinal motion of an aircraft, the phugoid and the short period. The S20 UAV is no exception and can be described in the same way. From the analyses executed to the linearized longitudinal motion of the vehicle it was determined that the phugoid motion is the mode to be controlled because of the fact that it is slower and less damped than the short period mode, hence it is the one determining the dynamic behavior of the vehicle. The approach taken to control the longitudinal motion of the vehicle consisted in implementing an integrative Linear Quadratic Regulator \( \text{iLQR} \) using the states \( x_{ilqr} = [v \ \dot{z} \ x_1 \ x_2]^T \), where \( v \) is the speed over ground, \( \dot{z} \) is the vertical speed and \( (x_1, x_2) \) are the integrative states of the first two. The linearization of the longitudinal motion of the vehicle leads to a state space representation of the system using the states, \( x = [v \ \alpha \ \theta \ q]^T \), where \( \theta \) is the pitch angle and \( q \) is the pitch rate. The next step consisted in trimming the system for \( V = 12 \text{ m/s} \), and perform a set of state substitutions and approximations to transform the original system, \( x \) into the desired \( x_{ilqr} \). Figure 6 documents the evolution of the system through the process.

The transformations documented in figure 6 correspond to, first a substitution where \( \theta \) is replaced for \( \gamma \), using the relation:

\[
\gamma = \theta - \alpha
\]  

(20)
Figure 6: Phugoid mode variation through the simplification process.

The second transformation is the longitudinal motion of the vehicle approximation using the phugoid motion documented in [7], and the third step consisted of replacing $\gamma$ with $\dot{z}$ using the trim speed:

$$\dot{z} = \gamma v_t$$  \hspace{1cm} (21)

Finally, using Matlabs algorithm ”lqr2” the gain matrix $K$ was obtained and by closing the control loop, the following eigenvalues were determined:

<table>
<thead>
<tr>
<th>Eigenvalues</th>
</tr>
</thead>
<tbody>
<tr>
<td>-23.4</td>
</tr>
<tr>
<td>-0.12</td>
</tr>
<tr>
<td>-0.0046</td>
</tr>
<tr>
<td>-0.013</td>
</tr>
</tbody>
</table>

Table 5: Closed loop eigenvalues. ($\dot{x}_{ilqr} = (A - BK)x_{ilqr}$)

4.3 Approach and Descent controller

The approach and descent controller is responsible for the height control during the respective phases. The method used to implement this entity consists in a Proportional-Integral $PI$ controller that actuates the system to neutralize the height error $e_z$:

$$\dot{e}_z = e_z[K_{PA}D + \frac{K_{IAD}}{s}]$$  \hspace{1cm} (22)

where $K_{PA}$ and $K_{IAD}$ were found to be 0.4 and 0.5 respectively.

5 Simulation setup and Results

5.1 Simulations description

The approach taken to assemble the simulation tool consisted in merging the aircraft models, the landing guidance and the control structure described in the previous sections into the same computational environment, which for the present case was Matlabs Simulink platform. Figure 7 is the sketch of the simulation tool. The following sections present simulation results, for which the descent height and flare height are fixed parameters: $z_d = 40$ m and $z_{fl} = 6$ m.

5.2 Landing guidance setup

In section 3 the landing guidance was presented, however not all tuning parameters were determined. In this section the descent flight path angle increment $\gamma_{inc}$, the flare distance $d_{fl}$ and the buffer distance $d_{bf}$ are defined using the simulation tool without any input uncertainties or perturbations.

The first parameters to be defined are $\gamma_{inc}$ and $d_{bf}$. Simulations performed for the wind speed interval of $V_w = [0 - 10]$ m/s showed that the relation between the wind speed and the flare distance appears to be quadratic. Due to the fact that incrementing the descent flight path angle increases the air speed at which the vehicle is traveling, which in turn has an impact in the distance between the flare point and the touchdown, there is a specific $\gamma_{inc}$ that linearizes the flare distance over wind speed relation. The need to have a linear relation to the expression mentioned, comes from the fact that for safety reasons is desired to have a simple expression for the flare distance, so that the operator can easily determine the safe area around the DLS. Through simulations it was found that $\gamma_{inc} = 0.15$ (deg m/s) linearizes the flare distance over wind speed relation, and at the same time reduces in 20 m the descent distance for a wind speed of $V_w = 10$ m. As for the flare distance, performing a linear regression to the variation of the flare distance over the wind speed the following expression was found:

$$d_{fl} = 151.6 - 5.9281V_w$$  \hspace{1cm} (23)
With (23) is finally possible to impose the DLS for which the landing guidance designs the trajectory accordingly. Figure 8 shows the error imposed by the simplifications imposed in terms of distance to the DLS.

To determine the buffer distance, several simulations were performed under the worst possible conditions in terms of flight trajectory convergence. It was imposed a wind speed \( V_w = 0 \text{ m/s} \) and a wind direction \( \chi_w = 225 \text{ (deg)} \), and an initial position and heading of \( p = (−50, −50) \text{ m/s} \) and \( \chi = 225 \text{ (deg)} \) respectively. For the DSL = (0, 0) m/s the vehicle flies with the initial heading until the buffer point is reached and then performs a 180 deg turn to align with the landing path. The exercise consisted in varying the buffer distance until a satisfactory convergence between the landing trajectory and the actual trajectory flown by the vehicle was achieved. This principle guarantees the convergence under every wind conditions. From the simulations it was determined that a satisfactory convergence occurs for \( d_{bf} = 500 \text{ m} \).

5.3 Landing Simulation

This section presents a full simulation of the system implemented subjected to the initial parameters summarized in table 6.

The simulation process follows the same sequence as the real mission. First, the wind is estimated, and once this process is complete the landing process starts. Figure 9 shows the estimated variables for the present simulation. Although the variables are estimated in Cartesian coordinates, as explained in section 4, they are presented here in polar coordinates for simplicity reasons.

The estimation results are presented in comparison to the mean wind characteristics, and the errors in the process are small, \( \epsilon_{V_w} = 0.04 \text{ m/s} \) and \( \epsilon_{\chi_w} = 0.7^\circ \) which are encouraging results. Figure 10 represents the desired landing trajectory and the actual trajectory flown by the vehicle.

Table 6: Initial simulation parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position ( p_0 )</td>
<td>(100, −500) ( G ) \text{ m}</td>
</tr>
<tr>
<td>Heading ( \chi_0 )</td>
<td>180°</td>
</tr>
<tr>
<td>Speed ( V )</td>
<td>16 \text{ m/s}</td>
</tr>
<tr>
<td>Wind Speed ( V_w )</td>
<td>4 \text{ m/s}</td>
</tr>
<tr>
<td>Wind Azimuth ( \chi_w )</td>
<td>225^°</td>
</tr>
<tr>
<td>DLS ( DSL )</td>
<td>(0, 0) ( G ) \text{ m}</td>
</tr>
</tbody>
</table>

Figure 9: Landing simulation: wind estimation results.

Figure 10: Landing simulation: horizontal trajectory. 1 - Initial position, 2- buffer point, 3 - descent point, 4 - flare point and 5 - DLS

Figure 11 documents the evolution of the control references and commands as well as the inputs of the the
The initial position could be any inside an area defined by:

\[
\left[-1725 \leq (N_0, E_0) < 50\right] \cap \left[-725 \leq (N_0, E_0) < 50\right]
\]

\[(m)\] (24)

- The initial position could be any inside an area defined by:
- \(0 \leq \chi_0 \leq 360\) (deg)
- \(0 \leq V_{w,\text{mean}} \leq 10\) (m/s)
- \(-25 \leq \Delta\chi_{w,\text{mean}} \leq 25\) (deg)

5.4 Monte-Carlo simulation results

In order to validate and assess the performance of the developed algorithms, 1400 Monte-Carlo simulation runs were performed. With the purpose of comparing results, the desired landing site and wind direction were fixed throughout the simulations, \(DLS = (0, 0)\) and \(\chi_w = 225^\circ\). For each simulation the following parameters were varied, randomly,
where \((N_0, E_0, \chi_0)\) is the vehicles set of initial position and heading which are uniformly distributed, \(V_w\) is the wind speed normally distributed, and \(\Delta \chi_w\), also normally distributed, is the imposed wind deviation and accounts for the variation of wind direction after the wind is estimated onboard, hence the wind direction after estimation at every simulation is defined as the sum of the constant direction plus the variation after estimation: \(\chi_w + \Delta \chi_w\). Figures 13 and 14 are the representation of the 1400 simulation trajectories in the horizontal and vertical planes respectively.

Figures 13 and 14 show that in spite of the significant dispersion of the initial position and heading, the profiles converge to the landing approach profile, hence the mentioned have no influence in performance of the landing procedures. Figure 15 presents the wind estimation errors.

In terms of speed estimation, the results are encouraging due to the fact that the maximum error observed is 0.5 m/s, and more than 50% of the estimations are under the 0.1 m/s of error. On the other hand, the wind direction estimation presents very concentrated error values in the interval \([0^\circ - 10^\circ]\) where 99.5% of the results are, however, the other 0.5% are dispersed, being the worst case 42\(^\circ\) of error in wind direction estimation. These results are the reason for the seven landing trajectories outside of the main trajectory cone observed in figure 13. Finally, figure 16 presents the touchdown coordinates for the set of simulation runs.

Figure 16 shows that a single landing procedure failed due to the fact it is outside the designated area. It was also determined that 96.1% of the landings are within 30 m of the the DLS. As for the the other landing requirements summarized in table 3, the speed over ground presents few landings in the imposed limit of \(V = 14\) m/s, the pitch is always inside the safe limits and the vertical speed presents a distribution centered on 0.38 m/s with a maximum of 0.48 m/s which is well inside the landing envelope. The landings with touchdown distances superior than 30 m were studied in detail, as they are considered poor performance procedures. From that exercise it was concluded that the performance of the system is enhanced for medium to high wind speeds, and that errors in wind estimation and variations in the wind direction are an influence on the performance of the
landing procedures for the entire spectrum of wind conditions.

6 Conclusions

The feasibility of using a guidance and control system based on position and speed commands for the S20 UAV landing was verified using 6-DOF nonlinear simulations. Acceptable performance and robustness was demonstrated. The landing trajectory is defined based on the wind direction and the DLS, because by design the trajectory is always against the wind. Simultaneously, the wind speed is used to improve the descent angle and flare distance, determined by the landing guidance system. It was proved that these characteristics generate more efficient landing results. The wind characteristics used in the landing guidance system are obtained using an Extended Kalman Filter EKF, that estimates wind speed and direction. Simulation results showed that the EKF performed well, although, it was also noted that the incorrect estimation of the variables can lead to poor landing performances. The LQR was implemented using the approximation of the aircrafts phugoid motion. From the simulation results it was concluded that, because of the dependency between the two states, it was impossible to accurately control one state without influencing the other. It is then proposed to introduce some spoiler actuator to add drag into the system, or conventional flaps. The independent control of these surfaces will benefit the accuracy of the system implemented, by providing shorter landing trajectories and smaller touchdown speeds. Performance studies prove that the designed guidance and control system is flexible enough to cope with the complete S20 UAV landing envelope, and at the same time achieve satisfactory performance. These are important factors that lead one to conclude that system is ready to be implemented and tested in the S20 UAV.

References