A Civilian Aircraft Landing Challenge*

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Abstract

From the early developments of the A320 program, thanks to Fly-By-Wire systems, Automatic Control techniques have significantly contributed to improve flight performance and safety of civilian aircraft. Today, most of the flight segments can be managed quite efficiently by the autopilot. However, the final approach and landing phases still remain critical in poor visibility and strong wind conditions. Based on a realistic nonlinear model of a civil transport aircraft in full configuration, the objective of the proposed challenge is to design an autopilot system to enable a correct landing despite parametric variations and **maximized cross wind** conditions.

1 Introduction

For all civil transport aircraft, final approach and flare segments still remain critical phases of the flight during which many variables have to be controlled imultaneously and high safety standards must be met. Fortunately, with the help of CAT III instrument landing systems (ILS) now commonly available in a rapidly growing list of airports, automatic landing control laws have recently contributed to secure these two phases notably in degraded weather conditions (fog, crosswinds). However, despite numerous methodological works [3, 1, 4, 5, 2] over the past two decades, the design, tuning and validation process of final approach and flare control systems remains a challenging and time-consuming task. As is observed in [4], where a complete design framework together with a dedicated software is proposed, the tuning phase requires rather tricky multi-objective optimization.

Automatic landing control has to prove robustness to a wide range of system and environmental phenomena dispersion like aircraft weight or wind disturbances. Indeed certification process requires the aircraft parameters to be within a range of a so-called mean and risk dispersion. Therefore the validation campaign, performed in a Monte Carlo framework, exposes the control law not only to scenarios where all the parameters are scattered following their own statistical distribution (mean dispersion) but also to operational situations where one parameter is fixed to its extreme value while dispersing the rest (risk dispersion). Consequently control design task becomes an iterative process where first the mean dispersion requirements are met and then all risk dispersion requirements are tested sequentially. The challenge appears when a risk is not satisfied, then two solutions are available:

- either adjust the control laws to improve the robustness versus a critical parameter which may result in robustness degradation versus others;
- limit the maximum dispersion that one seeks to cover which will then reduce the operational domain of the aircraft.

*download the software package and full documentation from the benchmark section of the SMAC project website at the following address **http://w3.onera.fr/smac/?q=aircraftModel**

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For example, control designer shall invest a great effort on satisfying a large domain of weight whereas he can accept a reduction of the crosswind capabilities. However, in order to improve aircraft operational reliability and reduce crew workload in difficult situations like crosswind landings the next generation of control architectures shall be able to cope with larger crosswinds domains. Nowadays A320 is certified to land with 20kts of crosswind while A380 is able to cope with 30kts and future aircrafts should target even a larger domain, eventually as large as the crosswind proven in manual flight (35kts for an A320).

This challenge goal is to inspire new control architectures which are able to cope with the largest possible crosswind while validating the certification requirements presented in Section 3. Proposed solutions shall minimize the use of actuators at high frequency ($bandpass < 2Hz$), avoid pitch and bank-bank oscillations that could induce the pilot to disconnect the autopilot (a damped second order response is required) and respect loads constraints (vertical load factor $\leq 2g$).

The quality of a design will be evaluated through its ability to fulfill the requirements detailed in Section 3. However, **methodological aspects** (simplicity, genericity,...) will also be considered.

2 Aircraft model

The aircraft model is representative of a large transport aircraft in full configuration from 1000 ft above runway until touch-down. It is fully implemented in open-access nested simulink blocks as illustrated by Figure.

The equations of the model and a complete description of the inputs and outputs are detailed in a specific note provided with the software package detailed in Section 4.

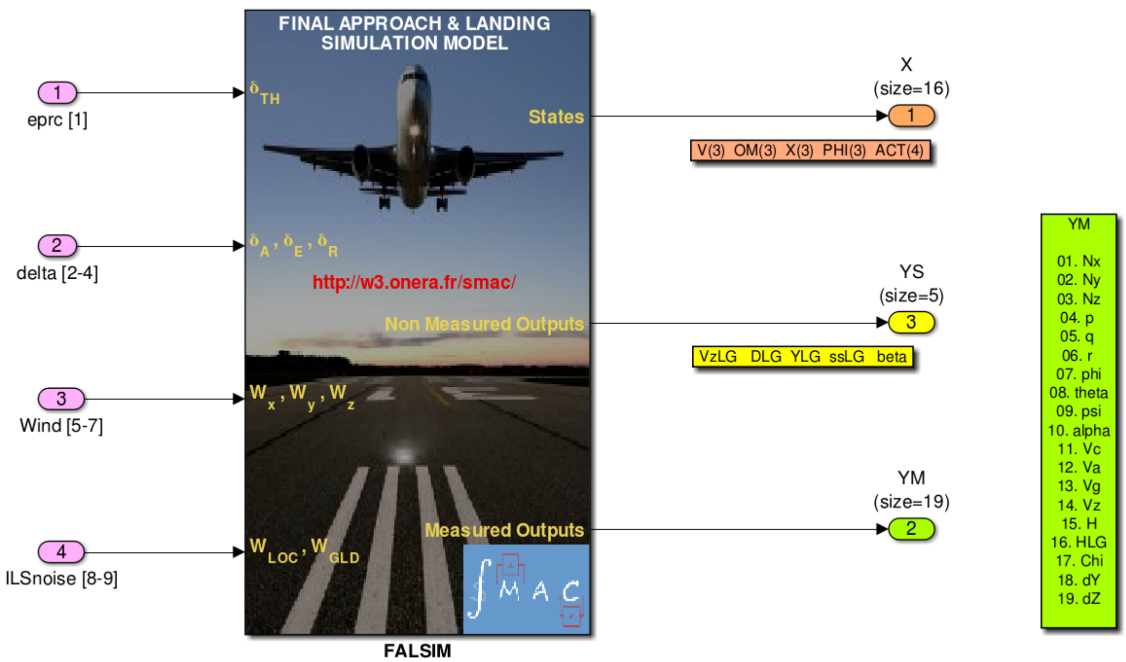

Figure 1: Open-Loop Aircraft Model

3 Control design objectives

Based on the above 3-axes nonlinear model, the main objective is to design an autoland control system to perform correct approach and landing tasks despite wind, turbulences, ground effects and variations of mass and center-of-gravity location.

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Ideally, the aircraft should hit the ground $400\,m$ after threshold, with a vertical speed around $2.5\,ft/s$ ($0.77m/s$). The lateral deviation at touchdown should be kept as small as possible, as well as the roll and main landing gear sideslip angles.

More precisely, the quality of the autoland control system is evaluated through a Monte-Carlo statistical analysis from a set of 2000 landings. These are performed with randomly distributed turbulences profiles, mass values, center-of-gravity locations, runway heights, runway slopes, temperatures, glide slopes and localizer displacements. The distribution characteristics are described in Table 1.

Remark 1 *Note that in this challenge, the crosswind (WY33) conditions are to be maximized, possibly beyond the standard values of Table 1. Control law validation shall be performed in two steps:*

- **Step1:** *First perform a Monte-Carlo analysis considering Table 1 distribution modifying the min and max value of the crosswind ?q=aircraftModel(WY33) dispersion to the sought level (i.e. $\pm 30kts$).*
- **Step2:** *Then fix the crosswind (WY33) to its maximum and perform a Monte-Carlo analysis dispersing the rest of the parameters following Table 1 distribution.*

Parameter	**distribution**	**mean**	σ	**min**	**max**
Long. Wind (WX33)	normal	$7.5\,kts$	$7.5\,kts$	$10\,T(+10)$	$30\,H(-30)$
Lat. Wind (WY33)	normal	$0\,kts$	$7\,kts$	$20L(-20)$	$20R(+20)$
Mass	uniform	NA	NA	$120\,t$	$180\,t$
CG	uniform	NA	NA	15%	41%
RWY alt	specific	NA	NA	$-1000\,ft$	$9200\,ft$
ISA	uniform	NA	NA	-69^oC	$+40^oC$
RWY slope	normal	0%	0.4%	−2%	2%
GLD slope	normal	-3^o	0.075^o	-2.85^o	-3.15^o
LOC displacement	normal	$0\,\mu A$	$2.5\,\mu A$	$-5\,\mu A$	$5\,\mu A$

Table 1: Distributions for parameters affecting the landing performances

For each landing, the following six parameters:

- **HTP60** : height of the main landing gear above runway, $60\,m$ after threshold
- **XTP** : touch-down point distance from the runway threshold
- **VZTP** : vertical speed at touch-down
- **YTP** : touch-down lateral deviation from the runway axis
- **PHI** : roll angle at touch-down
- **SSTP** : touch-down lateral deviation from the runway axis

are evaluated, plotted in bar-diagrams and interpolated by gaussian functions. From such interpolations, probability levels that the above variables exceed critical values can be computed.
The certification requirements are presented in the last two columns of Table 2:

- ***Average Risks Level*** is the highest probability allowed to a given evaluated risk in Table 2 when dispersing all the parameters ?q=aircraftModelfollowing Table 1 distribution (i.e. **step 1** described in Remark 1).
- ***Limit Risks Level*** is the highest probability allowed to a given evaluated risk in Table 2 when a parameter in Table 1 is fixed at its maximum level (i.e. crosswind $WY33 = 30kts$) while ?q=aircraftModeldispersing the rest of the parameters following Table 1 distribution (i.e. **step 2** described in Remark 1).

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Evaluated risk	Probability	Avr. Risks Level	Lim. Risks Level
Short landing	$\mathcal{P}(HTP60 < 0)$	10^{-6}	10^{-5}
Long landing	$\mathcal{P}(XTP > 915\,m)$	10^{-6}	10^{-5}
Hard landing	$\mathcal{P}(VZTP > 10\,ft/s)$	10^{-6}	10^{-5}
Decentered landing	$\mathcal{P}(YTP > 15\,m)$	10^{-6}	10^{-5}
Steep bank angle	$\mathcal{P}(PHI > 12^o)$	10^{-8}	10^{-7}
Steep sideslip angle	$\mathcal{P}(SSTP > 14^o)$	10^{-6}	10^{-5}

Table 2: Risks evaluation

Designers are advised to follow an iterative process: ?q=aircraftModel

1. design & and perform an initial tuning of the control law to cope with the average risks requirements,
2. verify and adjust the control law if needed, to satisfy the limit risks ?q=aircraftModelrequirements.

In this challenge, the objective is to design an autoland control system that meets both average and limit risks requirements with **maximized crosswind** conditions.

The design presenting the highest crosswind will be declared as challenge best design. In case of two design present the same level of maximum crosswind, the design presenting higher margins with respect to Table 2 limits will be considered as the best.

For a **quick start** with the control design problem, a **baseline controller** is proposed and implemented in a closed-loop SIMULINK model (ALS.slx) as shown on Figure 2. This autoland system implements a basic flare & decrab mode enabling to perform correct landings on a reduced parametric domain with low wind conditions.

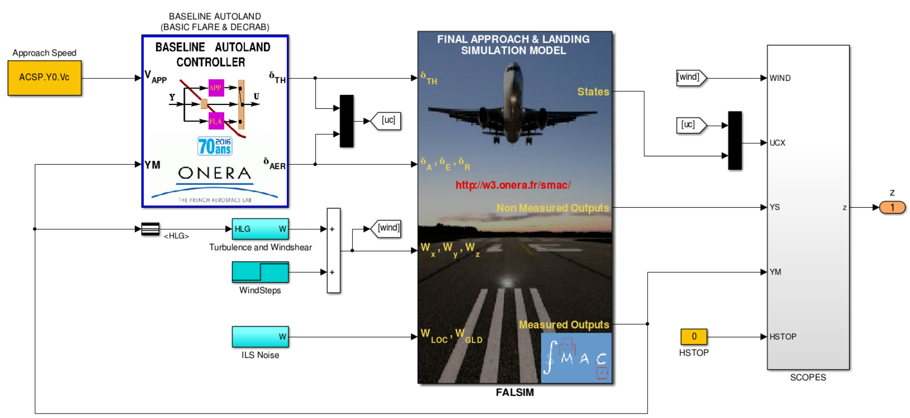

Figure 2: Closed-Loop Model with a Baseline Autoland Control System

4 Description of the software package

The software package *CALC.zip* related to the proposed challenge can be downloaded from the SMAC project website **http://w3.onera.fr/smac/** in the aerospace benchmark section. This package contains 2 SIMULINK files (ACS.slx and ALS.slx), 6 MATLAB functions and a MATLAB script file ALSeval.m to perform evaluations of the designed control system. For a good and fast understanding of the models and routines, a good strategy is to start by opening the script file and running it line-by-line with the baseline controller. Both deterministic and statistic evaluations will

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be performed. An example of the obtained results is visualized in Figure 3 which corresponds to a Monte-Carlo analysis on a reduced parametric domain with low wind conditions.

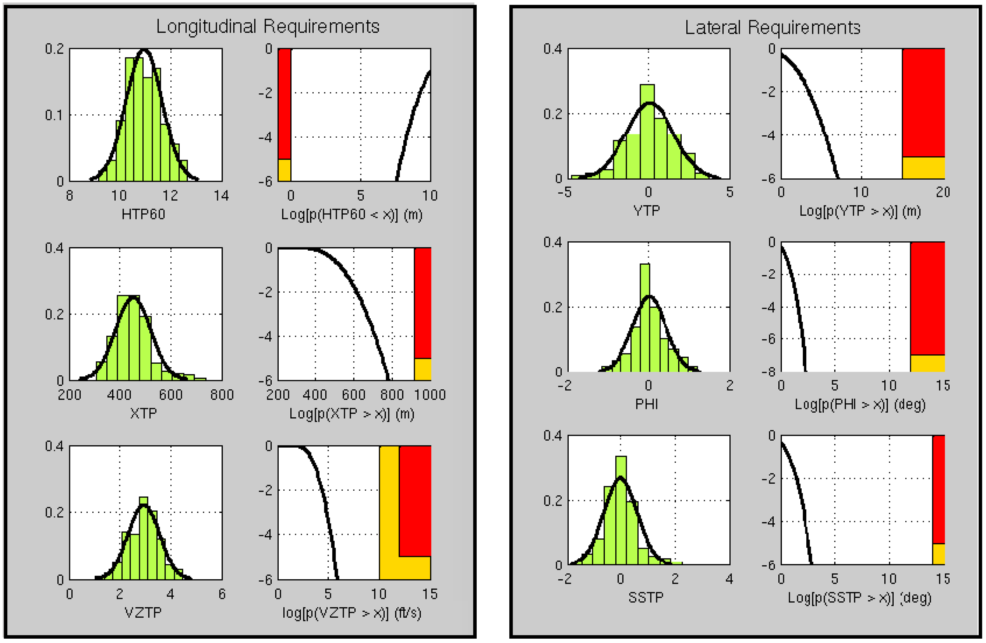

Figure 3: Results of Monte-Carlo analysis on a reduced operating domain

For further details on the models and routines, see the documentation provided with the package.

5 Conclusion

Good luck and enjoy with the model!

References

[1] J-M. Biannic and P. Apkarian. A new approach to fixed-order H_∞ synthesis : Application to autoland design. In *Proceedings of the AIAA GNC*, Montreal, Canada, August 2001.

[2] J-M. Biannic and C. Roos. Flare control law design via multi-channel H_∞ synthesis: Illustration on a nonlinear aircraft benchmark. In *Proceedings of the American Control Conference (ACC)*, Chicago, IL. USA., July 2015.

[3] I. Kaminer and P. Khargonekar. Design of the Flare Control Law for Longitudinal Autopilot using H_∞ synthesis. In *Proceedings of the* 29^{th} *IEEE Conference on Decision and Control*, Honolulu, Hawaii, December 1990.

[4] G. Looye and H.D. Joos. Design of Autoland Controller Functions with Multiobjective Optimization. *Journal of Guidance, Control and Dynamics*, 29(2):475–484, March-April 2006.

[5] H. Sadat-Hoseini, A. Fazelzadeh, A. Rasti, and P. Marzocca. Final Approach and Flare Control of a Flexible Aircraft in Crosswind Landings. *Journal of Guidance, Control and Dynamics*, 36(4):946–957, August 2013.

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