New Methodology for Optimal Flight Control using Differential Evolution Algorithms applied on the Cessna Citation X Business Aircraft – Part 2. Validation on Aircraft Research Flight Level D Simulator

Yamina BOUGHARI[1], Georges GHAZI[1], Ruxandra Mihaela BOTEZ*,[1], Florian THEEL[1]

*Corresponding author
[1]ETS, Laboratory of Active Controls, Avionics and AeroServoElasticity LARCASE, 1100 Notre Dame West, Montreal, Que., Canada, H3C-1K3
yamina.boughari.1@ens.etsmtl.ca, georges.ghazi.1@ens.etsmtl.ca, Ruxandra.Botez@etsmtl.ca*, f.theel@gmail.com

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Abstract*: In this paper the Cessna Citation X clearance criteria were evaluated for a new Flight Controller. The Flight Control Law were optimized and designed for the Cessna Citation X flight envelope by combining the Deferential Evolution algorithm, the Linear Quadratic Regulator method, and the Proportional Integral controller during a previous research presented in part 1. The optimal controllers were used to reach satisfactory aircraft's dynamic and safe flight operations with respect to the augmentation systems' handling qualities, and design requirements. Furthermore the number of controllers used to control the aircraft in its flight envelope was optimized using the Linear Fractional Representations features. To validate the controller over the whole aircraft flight envelope, the linear stability, eigenvalue, and handling qualities criteria in addition of the nonlinear analysis criteria were investigated during this research to assess the business aircraft for flight control clearance and certification. The optimized gains provide a very good stability margins as the eigenvalue analysis shows that the aircraft has a high stability, and a very good flying qualities of the linear aircraft models are ensured in its entire flight envelope, its robustness is demonstrated with respect to uncertainties due to its mass and center of gravity variations.*

Key Words: *Flight Control; Linear Quadratic Regulator; Optimal Control; Heuristic Algorithm; Differential Evolution; Control Augmentation System; Stability Augmentation System; Proportional Integrator Derivative Tuning.*

1. INTRODUCTION

Recently many researches were curried on in the flight control domain, to optimize and automate the controller performances using modern control methods such as in [1], and [2] the weighting functions that described the H-infinity controller were optimized using GA and DE algorithms the resulting controllers were successfully cleared over the entire flight envelope, however the H-infinity controller is of high order, which made it difficult in real implementation. Hence the LQR method offered relatively simple controllers of law order, as the LQR controller performance rely on the weighting matrices selection, then it became interesting to automate the weighting searches processes, as shown in [3], where the LQR was genetically optimized for UAV control under wind disturbance, and gave good results in both performance and robustness, and [4] the authors optimized the performance of the controller using the LQR method, with the meta-heuristic Differential Evolution, the controllers were cleared for each flight condition in the Cessna Citation X aircraft flight envelope. In [5], and [6], LQR gains were optimized by using the Genetic Algorithm and were applied on Lynx helicopter, and lateral control on Cessna Citation X business aircraft, the robustness of the controllers was assisted by the guardian map theory, the optimized controllers show a very good results, in other hand, the application of the guardian map is a very long time computation, which made the guardian map method less desirable to clear the controller for the entire flight envelope.

The flight controller clearance of modern aircrafts that need to achieve high performance is a very complex process as shown in [7]. The required handling qualities, stability, and robustness criteria should be satisfied against any possible uncertainties. Many factors can led to the appearance of uncertainties such as control surfaces dynamics and delays, aerodynamics data values, Air Data measurements errors, and the mass and Xcg variations [8]. The clearance of controller has to be provided for the entire flight envelope because of the high number of data, and the effects of uncertainties. From the Airbus team point of view the clearance criteria are considered as robustness criteria, and were applied in linear and nonlinear analysis of the HIRM+ generic model and HWEM aircraft as shown in [7]. Five (5) new analysis techniques highlighted the importance of the clearance task presented in [9], and [10].

In this research the clearance analysis of Linear and nonlinear Cessna Citation X business aircraft is addressed. By using a Cessna Citation X Level D Research Aircraft Flight Simulator designed and manufactured by CAE Inc the benchmark was developed at Laboratory of Active Controls, Avionics and AeroServoElasticity LARCASE in [10]-[11]. This benchmark programmed in Matlab/Simulink was already used for new identification methods designed and developed in [12]-[13], for advanced flight control design and clearance [14]-[15], and for robust control analysis in [4]-[6].

This paper is organized as follows: First a description of the controller optimized using the differential evolution algorithm, the aircraft flight envelope is detailed, and then a brief description of the clearance criteria. Analysis of linear and nonlinear validation results and conclusions is further given.

2. TRACKING CONTROL WITH LQR-PI OPTIMIZATION

The aircraft dynamics' Stability Augmentation System (SAS) uses the LQR method to attenuate the undesired effects mainly on its longitudinal (phugoid) and lateral Dutch Roll modes in the presence of possible perturbations. Next, to follow the reference signals the PI gains are used in the control augmentation system (CAS). Where k_p indicates the proportional gain and k_i indicates the integral gain. The use of PI gains reduces the overshoot and eliminates the steady state error in order to improve the system response. Using the experimentation process to find the optimal values for these two gains can be quite time-consuming for a full flight envelope. Trial and error process and other types of methods for tuning PID gains using meta-heuristic algorithms are available, as the genetic algorithm GA [16], the swarm particle optimization PSO [17, 18], the Fruit Fly optimization algorithm [19]. Nonlinear methods such as fuzzy logic and neural network methods have also been applied to identification and control ([20],[21]), hybrid fuzzy logic ([22],[23]) real time optimization used on a morphing wing by[24]. Other parameter estimation and control methodologies were used and validated during flight tests ([25]-[42]).

All of these methods were developed with the aim of reducing the computation time while achieving satisfactory results. For this study, the DE algorithm was selected to tune the PI controller parameters, applied on a business aircraft as explained in the research presented in (Part 1), and the results of the optimized controller are validated in its entire aircraft flight envelope in this research (Part 2). In the next section the Cessna Citation X flight envelope is described.

3. CESSNA CITATION X AIRCRAFT FLIGHT ENVELOPE

Given the data extracted from the Research Aircraft Flight Simulator (RAFS) provided by CAE Inc., the aircraft dynamics are described for all of the flight envelope conditions.
Figure 1 shows the 36 points obtained for straight uniform flight level inside the flight envelope limits, which were selected to be trimmed. The aircraft models are obtained at each 5000 ft in the flight envelope and at 4 different speeds.

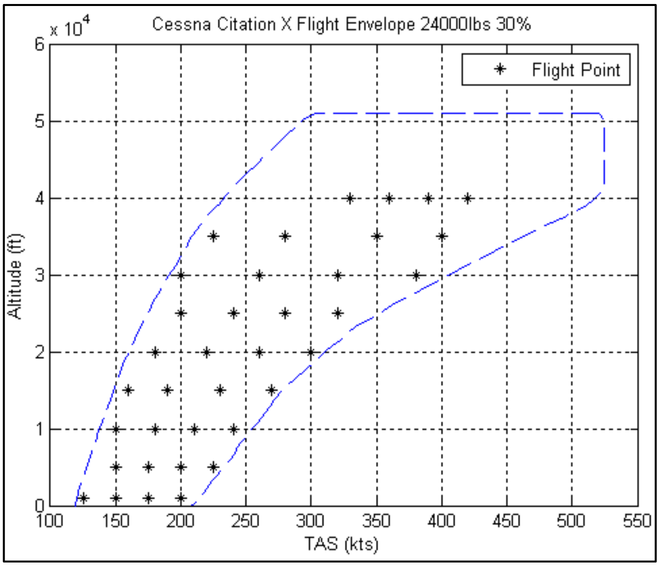

Figure 1. Cessna Citation X Aircraft Flight Envelope

Before carrying out the interpolation, two steps must be performed. The first step defines the region for an altitude and a range of True Air Speed (TAS) where the interpolation will be performed; the four corners of the region form the vertices. Each of these ranges has a lower and upper value, which are the bounds. The second step is the normalization of these bounds in order to attribute each coordinate of the vertices to a value equal to 1 or -1.

To optimize the accuracy, the smallest possible regions have been defined, containing only 3 or 4 flight points to use as reference points for the interpolation. This definition only allows a bilinear interpolation, for which 4 coefficients must be found, using equations (1), (2) and (3), where equation (3) was used for both longitudinal and lateral matrices A.

$$\mathrm{A}_{long/lat}(h, TAS) = \mathrm{A}_{0_{4,4}} + \mathrm{A}_{1_{4,4}} h + \mathrm{A}_{2_{4,4}} TAS + \mathrm{A}_{3_{4,4}} TAS \times h \tag{1}$$

$$\mathrm{B_{long}}(h, TAS) = \mathrm{B}_{0_{4,1}} + \mathrm{B}_{1_{4,1}}h + \mathrm{B}_{2_{4,1}}TAS + \mathrm{B}_{3_{4,1}}TAS \times h \quad (2)$$

$$\mathrm{B_{lat}}(h, TAS) = \mathrm{B}_{0_{4,2}} + \mathrm{B}_{1_{4,2}}h + \mathrm{B}_{2_{4,2}}TAS + \mathrm{B}_{3_{4,2}}TAS \times h \quad (3)$$

The Least Square (LS) method is employed to minimize the relative error in these reference points. The maximum errors found for the state space matrices A and B are negligible, and has a value of 3.97 $e^{-11}\%$, therefore the results are good.

From these results, 26 regions are obtained, which covers a large part of the flight envelope. The mesh is valid for all of the weight and balance conditions presented in Figure 3. It can be observed from Figure 2 that some of the regions superimpose others (darker zones) due to the common reference points, and in many cases there is not only interpolation but also extrapolation.

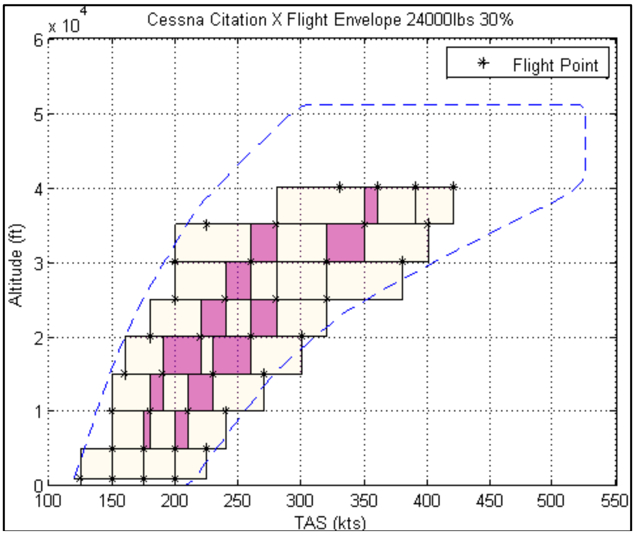

Figure 2. Region definition

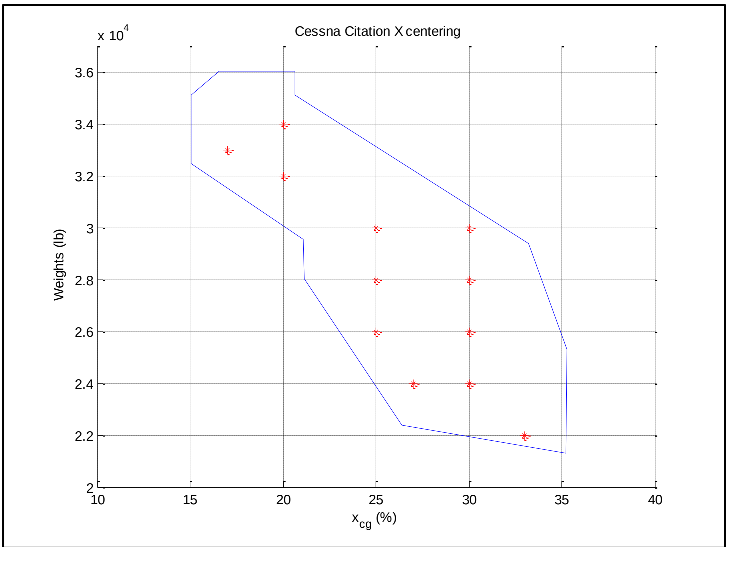

Figure 3. Cessna Citation X Weight/Xcg conditions

These regions are presented by LFR models, where the center of each region is used to calculate a controller that can be applied on the 4 vertices of the region, which lead to an optimization of the number of controller used to control the aircraft in its flight envelope, and to ensure a relatively certain robustness against the altitude (*h*) and the True Air Speed (*TAS*) variations.

All vertices of these 26 regions lead to 72 different flight points to be analyzed shown by Figure 4, which make it possible to more closely approximate the flight envelope limits.

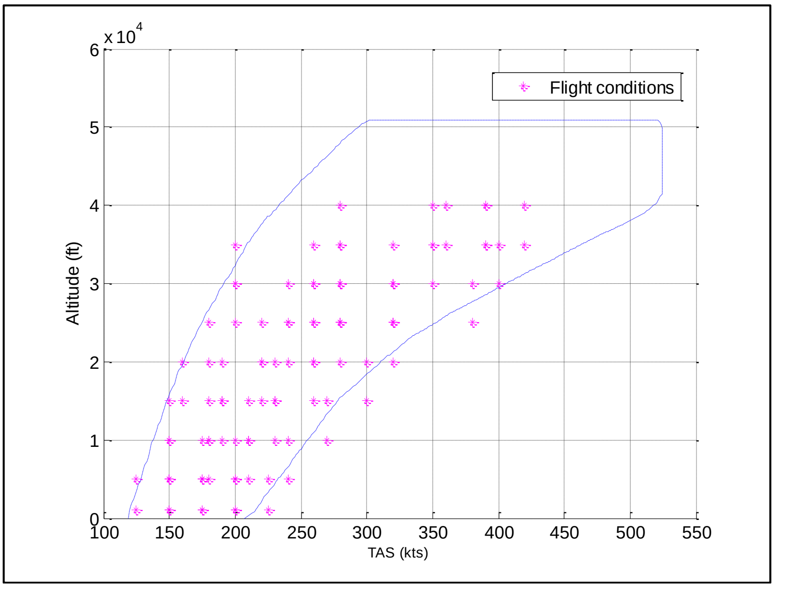

Figure 4. Flight points obtained by LFR models

4. CLEARANCE CRITERIA

A civil aircraft should have good handling qualities requirements in addition of the stability ones. To prove that the aircraft is stable with sufficient margin stabilities over its entire flight envelope is crucial for the aircraft clearance and certification as shown in [43] and [44], where the weight functions method was applied to assess the HIRM, and the business Hawker 800 XP aircrafts stability.

In this research, Roll and Pitch linear stability margins were investigated using Bode plots of open-loop frequency responses for the Cessna Citation X business aircraft. However the closed loop eigenvalues were investigated by using zero poles maps. In addition these graphs were used to verify the resulting handling qualities in the frequency domain according to those given in the design requirements. Also the time domain criteria given by: Pitch acceleration peak time, pitch rate overshoot/drop back, pitch rate peak time, roll mode time constant, and time to bank [45]. Furthermore, the aircraft nonlinear simulations have to investigate problems encountered in the linear simulation, and to evaluate the aircraft stability, handling and control in the presence of nonlinearities.

By using different inputs types (pull/push, step, and ramp), the aircraft maneuvers are usually evaluated in modern flight control, which means that the load factor and angle of attack are proportional to the pitch command (stick deflection), as well as the rapid roll control mode, which is a very important criterion to be checked, where the required aircraft responses trajectory should not exceed the safety limits including added uncertainties.

5. RESULTS VALIDATION

The validation of results was performed using the nonlinear aircraft model. The nonlinear model, of the Cessna Citation X was formed by the aircraft's, actuators', and sensors' dynamics. The dynamics of the aircraft, was given in Part 1. To control the augmented system, two internal loops were added: the first internal loop represented by the SAS, and the CAS formed the second internal loop; the autopilot dynamics was modeled in the external loop. First, the LQR weighting matrices were optimized for 36 flight conditions extracted from the Cessna Citation X Flight Simulator as given in [4] and then further generalized for 72 flight conditions obtained using the interpolation method, than a second optimization is performed for tuning the PI controller. Both the PI and the LQR parameters were optimized by using the differential evolution as described in Part 1.

5.1 Linear validation

Simulations of both aircraft motions were performed for all CG locations and flight conditions given above in Figures 2 and 3. The controlled system was then simulated in the time domain to reach the satisfactory dynamic characteristics of the aircraft. The results were given for each region, delimited by four vertices which lead to 72 fight conditions as explained in Section 3, and for each centering, as shown in Figures 5, 8, 11, and 14.

Pole-zero map responses were obtained for pitch angle, pitch rate, roll rate and roll angle as shown in Figures 6, 9, 12, and 15, where handling quality requirements parameters were superimposed over results.

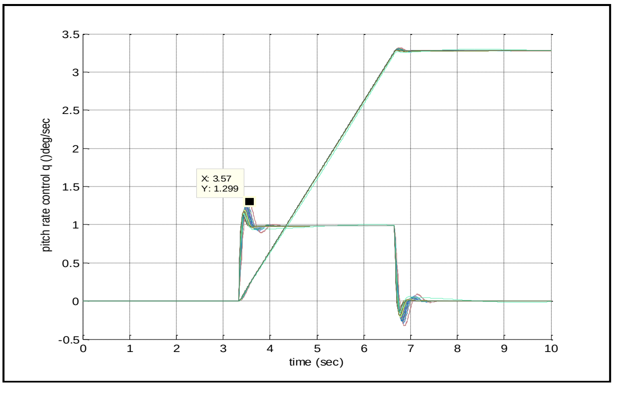

Figure 5. Pitch rate q (deg/sec) control and the resulting pitch angle θ (deg)

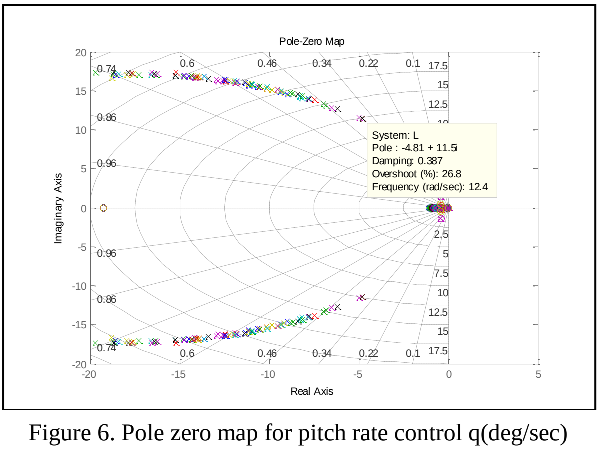

Figure 6. Pole zero map for pitch rate control q(deg/sec)

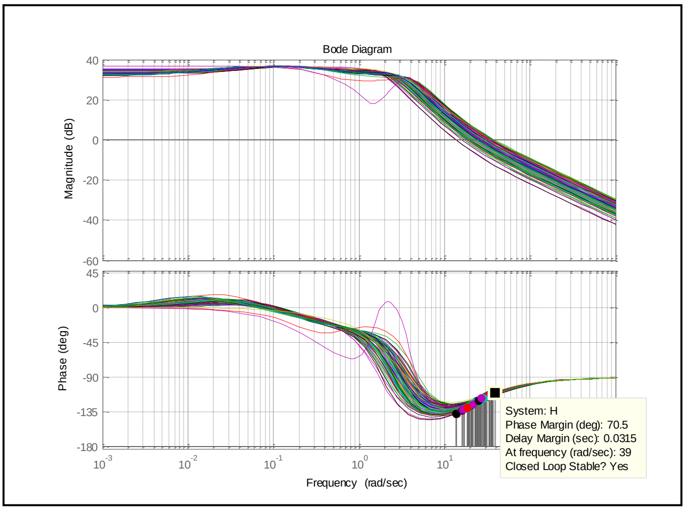

Figure 7. Bode diagram for pitch rate q (deg/sec) control

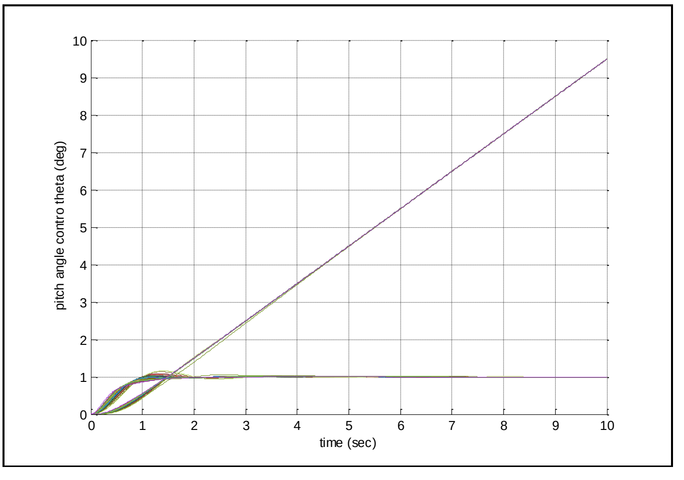

Figure 8. PI Tracking reference for pitch angle θ(deg)

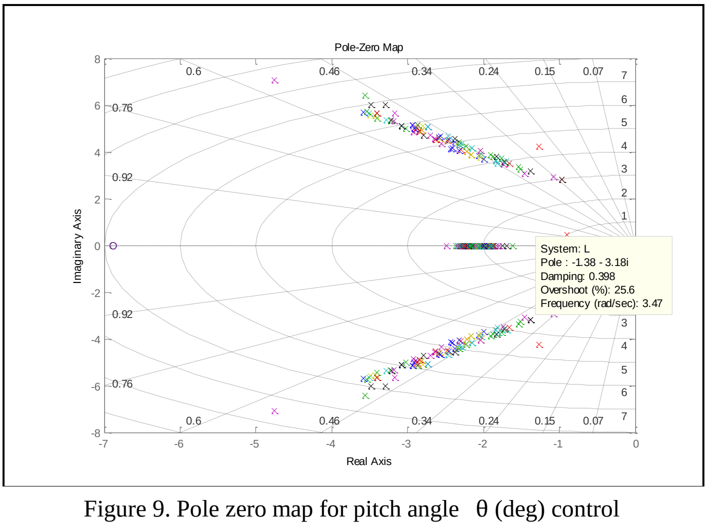

Figure 9. Pole zero map for pitch angle θ (deg) control

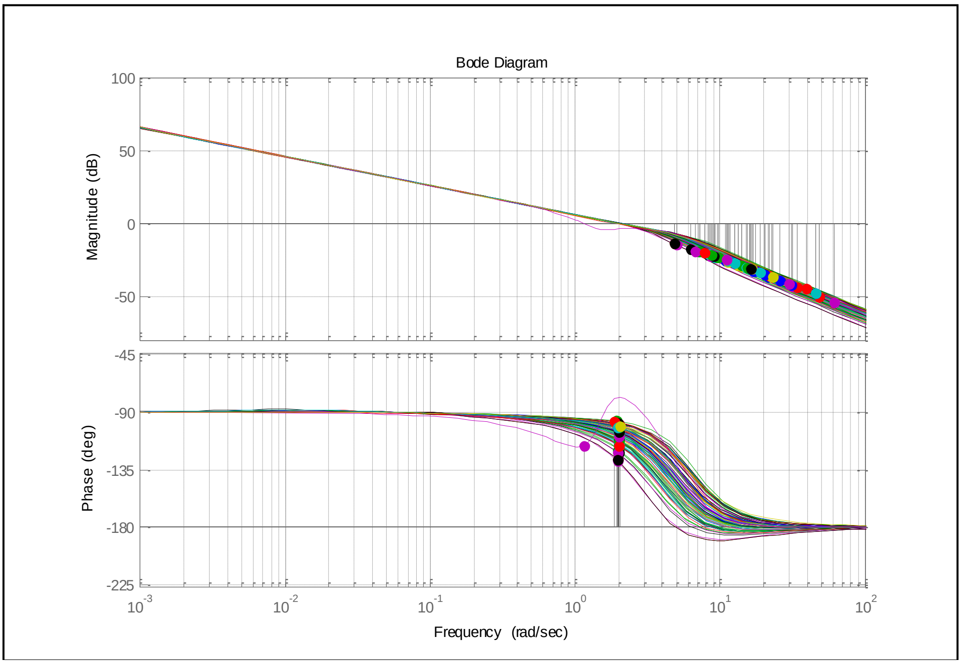

Figure 10. Bode diagram for pitch angle θ (deg) control

Previous research was done in [4], where the LQR and PI control were achieved for 36 flight conditions and 12 centre of gravity locations and showing good stability and command tracking of the aircraft.

Also the system successfully tracks the reference signals when the control is generalized for 72 flight conditions for all aircraft motions (Figure 5, Figure 6, Figure 11 and Figure 15). Bode diagram is plotted for each control to assess its stability margins in Figures 7, 10, 13, and 16, which confirms what was said previously in Section 4.3 that the resulting controller gives an infinite gain margin and secure phase margin.

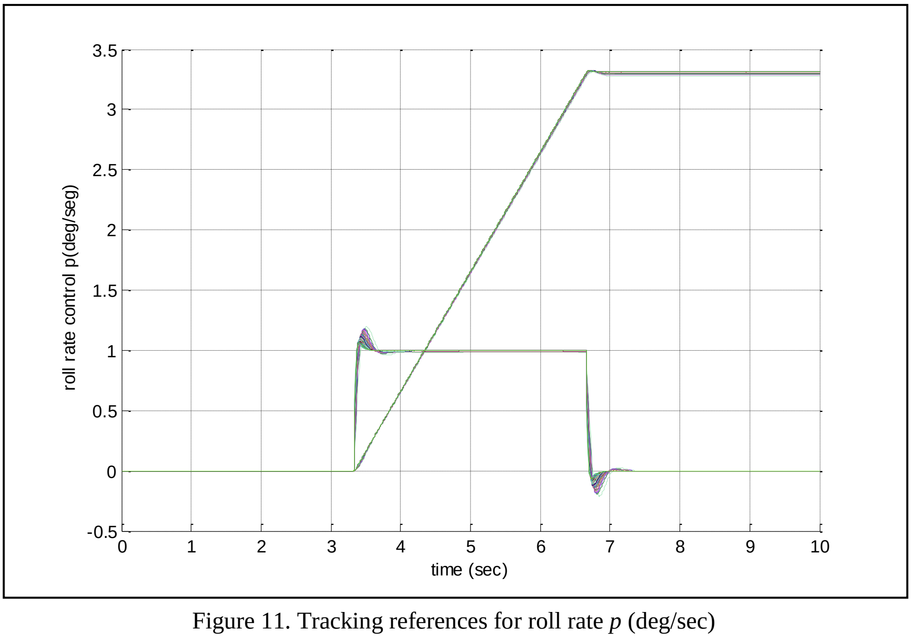

Figure 11. Tracking references for roll rate *p* (deg/sec)

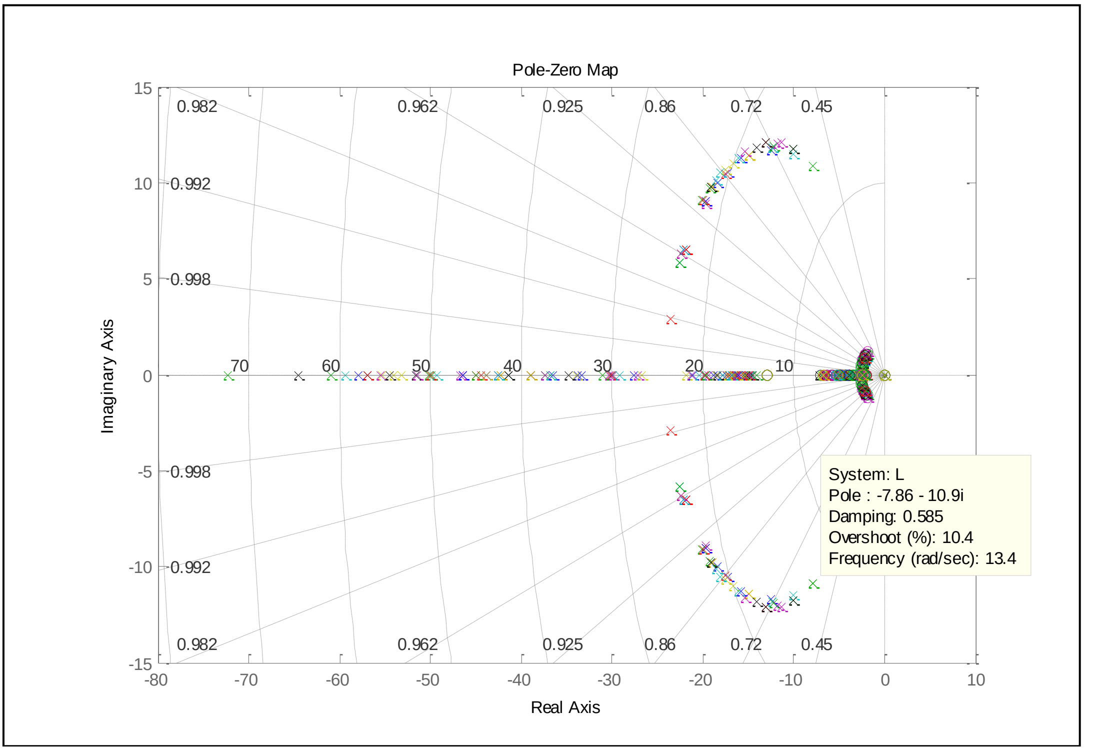

Figure 12. Pole zero map for roll rate *p* (deg/sec)

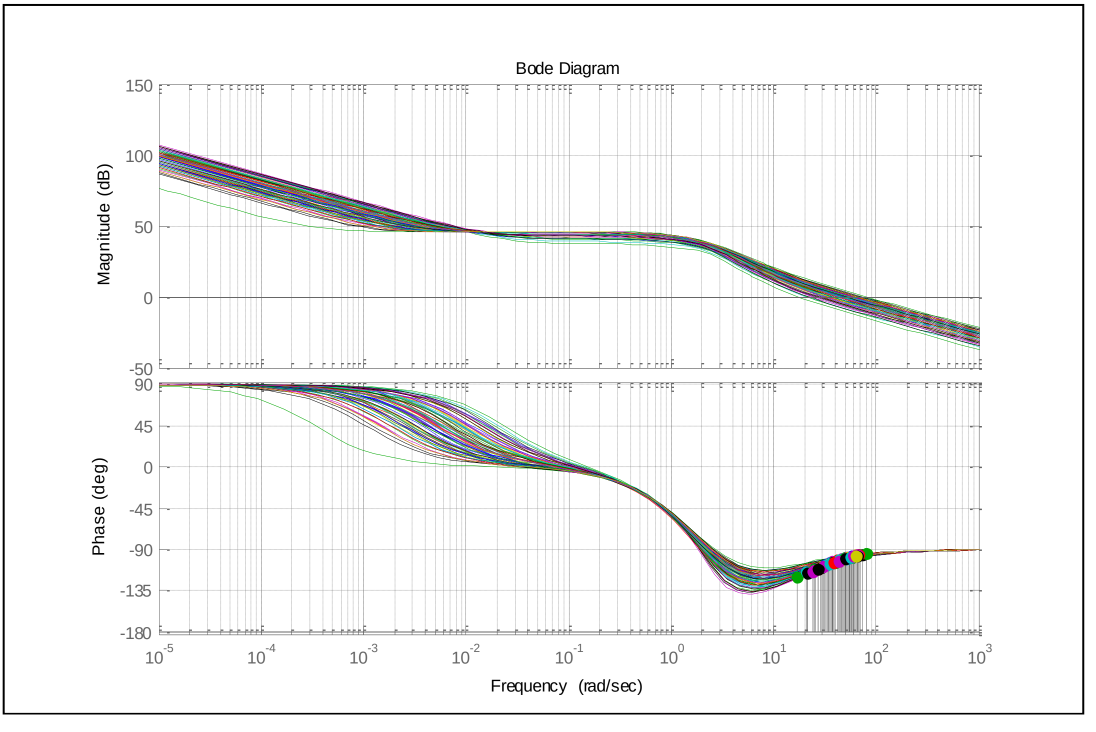

Figure 13. Bode diagram for roll rate *p* (deg/sec)

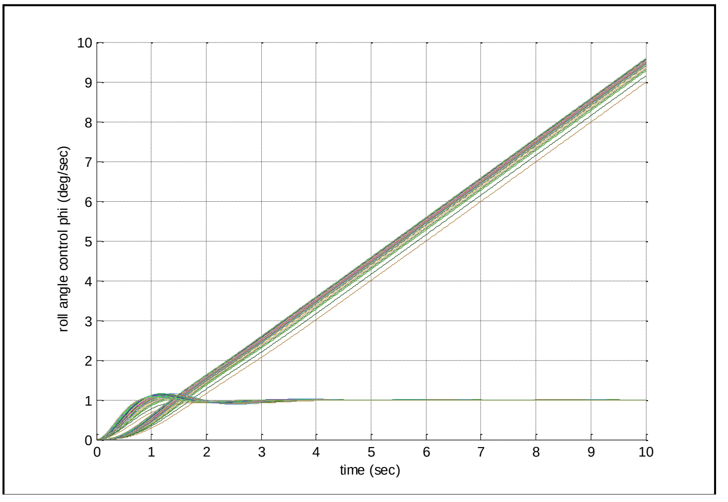

Figure 14. Roll angle ϕ (deg) control and the resulting roll rate p (deg/sec)

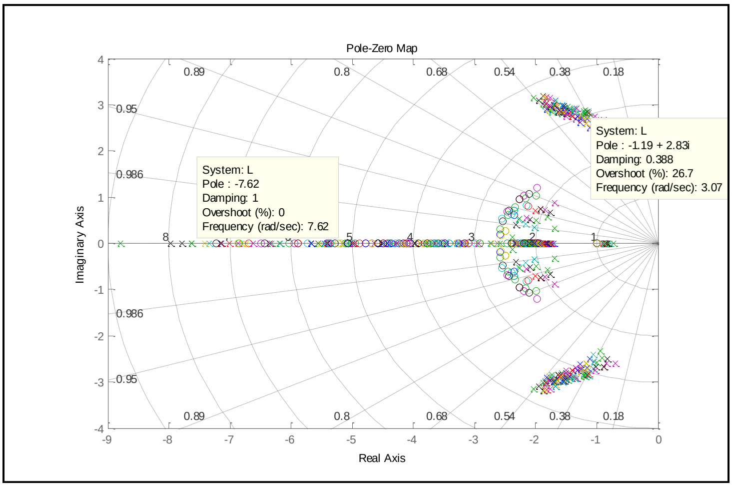

Figure 15. Pole Zero map of roll angle ϕ (deg)

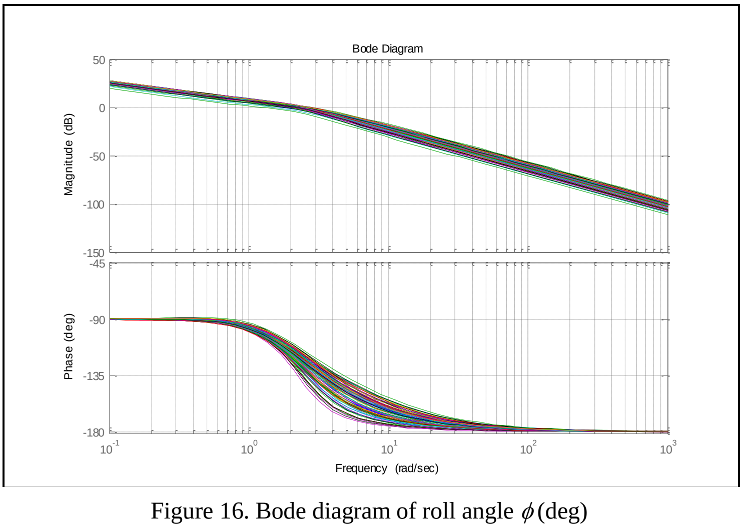

Figure 16. Bode diagram of roll angle ϕ (deg)

These results have been validated using a linear model for all of the flight conditions. The steady state error is less than 2% for pitch rate q, pitch angle θ, and both roll rate p and roll angle φ, while the overshoot is less than 30% for all responses, and the settling time Ts is less than 2 sec; therefore, the system is stable and behaves as desired, and all the performance criteria are reached.

Generally, the optimal controllers with LQR-PI gains are more suitable for their stability performance and simplicity of integration in the FCL design.

5.2 Nonlinear validation

Simulations were performed for more than 500 flight points at different mass and centering conditions on the nonlinear model of the Cessna citation X aircraft. The results are shown in Figures 17, 18, 19, and 20 for pitch angle, pitch rate, roll angle and roll rate controls; all of these responses track the command given as input. The nonlinear simulations demonstrate the efficiency and the reliability of the optimal controllers.

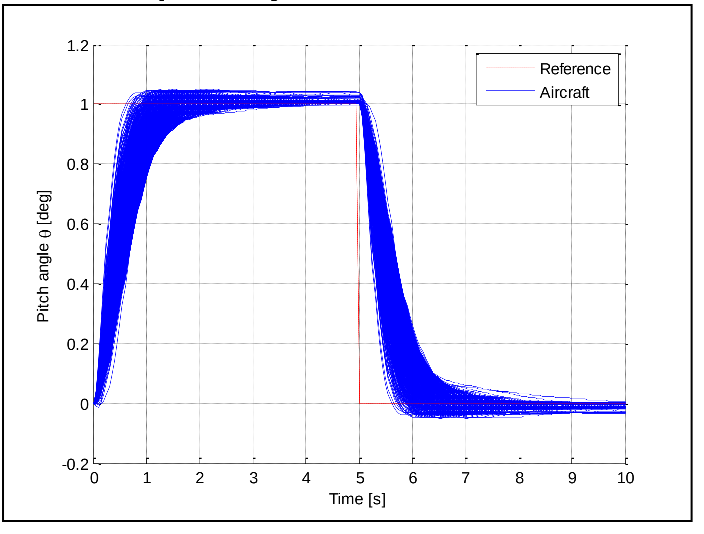

Figure 17. Pitch angle θ (deg) control of the nonlinear aircraft model

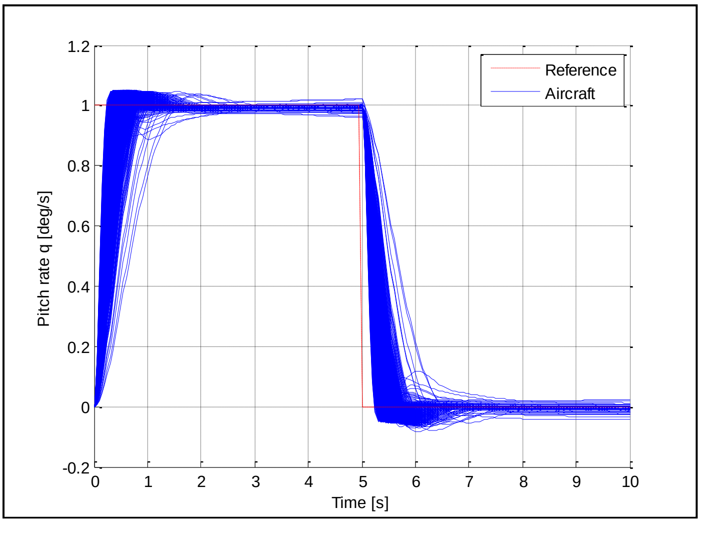

Figure 18. Pitch rate q(deg/sec) control of the nonlinear aircraft model

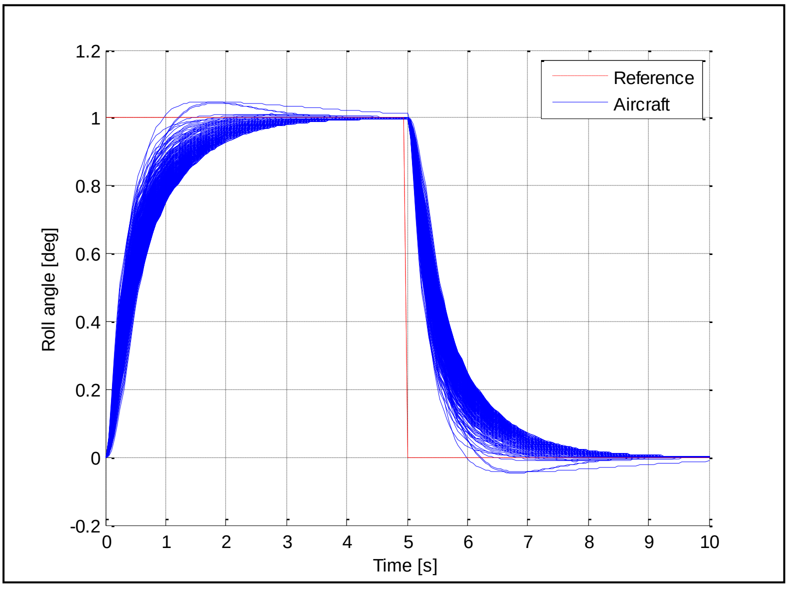

Figure 19. Roll angle φ(deg) control of the nonlinear aircraft model

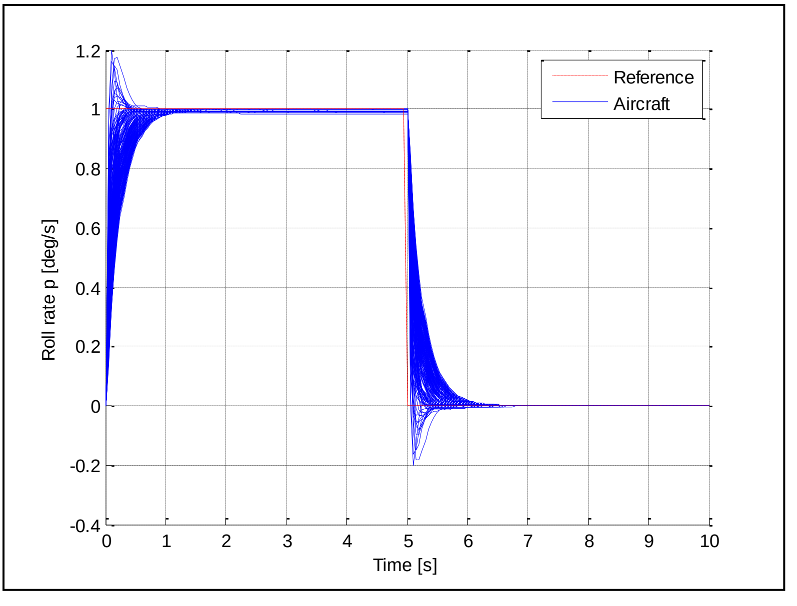

Figure 20. Roll rate p (deg/sec) control of the nonlinear aircraft model

6. CONCLUSIONS

Before the first flight and the aircraft certification, an airplane must pass a multitude of tests. Some of these tests involve the aircraft control laws, which assess whether an aircraft is able to fly safely in a variety of conditions.

In this research, the optimized controller parameters were used in the validation of the linear aircraft models in its entire envelope. Furthermore, the controller number was also optimized by using the LFR features, were the controller is calculated for the center of each region represented by LFR model and applied on the 4 vertices of the region, which means that the

72 flight points are controlled by 26 controllers which correspond to the number of flight envelope regions.

The resulting controllers were then used for the aircraft nonlinear model validation, where its data is extracted from the Aircraft Research Flight Simulator of Level D (highest level of certification for the aircraft flight dynamics).

The flight control laws design optimization provided gains that have ensured very good stability margins in terms of phases and gains, these gains also provided to the aircraft very good flying qualities of Level 1. Regarding the manoeuvres such as the pitch and roll hold, their stability and robustness in presence of uncertainties dues to the mass and center of gravity variations was tested on the nonlinear aircraft model, and the obtained results were found to be very good.

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REFERENCES

[1] Y. Boughari, R. M. Botez, G. Ghazi, F. Theel, *Evolutionary Algorithms for Robust Cessna Citation X Flight Control*, Paper No. 2014-01-2166. SAE 2014 Aerospace Systems and Technology Conference, Cincinnati, Ohio, USA, 2014, September 23-25, doi:10.4271/2014-01-2166.

[2] Y. Boughari, R.M. Botez, G. Ghazi, F. Theel, Flight Control Clearance of the Cessna Citation X using Evolutionary Algorithms, *Proceedings of the Institution of Mechanical Engineers* (*IMechE*), *Part G: Aerospace Engineering*, 2016 Apr. 11, doi: 10.1177/0954410016640821.

[3] Kukreti, S., Kumar, M., K. Cohen, Genetically tuned LQR based path following for UAVs under wind disturbance, *In Unmanned Aircraft Systems (ICUAS)*, 2016 *International Conference* on 2016 Jun. pp. 267-274 . IEEE.

[4] Y. Boughari, R. M. Ruxandra, F. Theel et G. Ghazi. 2014a. *Optimal Flight Control on Cessna Citation X Aircraft Using Differential Evolution*, In IASTED International Conference on Modelling, Identification and Control, MIC. (Innsbruck, Austria, Feb.17-19, 2014), p. 189-198. Coll. Proceedings of the IASTED International Conference on Modelling, Identification and Control: Acta Press. < http://dx.doi.org/10.2316/P.2014.809-052 >.

[5] G. Ghazi, R. M. Botez, *New Robust Control Analysis Methodology for Lynx Helicopter and Cessna Citation X Aircraft Using Guardian Maps, Genetic Algorithms and LQR Theories Combinations*, AHS 70th Annual Forum & Technology Display Proceedings, Montreal, Quebec, Canada, 2014, May 20-22.

[6] G. Ghazi, R. M. Botez, *Lateral Controller Design for the Cessna Citation X with Handling Qualities and Robustness Requirements*, 62nd Canadian Aeronautical Society Institute CASI Aeronautics Conference and AGM & 3rd GARDN Conference Proceeding, Montreal, Que., Canada, 2015, May 19-21.

[7] C. Fielding et al., *Advanced techniques for clearance of flight control laws*, Springer Science & Business Media; Berlin Heidelberg, Germany, 2002.

[8] Y. Boughari, M. R. Botez, *Optimal Flight Control on the Hawker 800 XP Business Aircraft*, In IECON 2012-38th Annual Conference on IEEE Industrial Electronics Society Montreal, Canada, 2012, Oct 25, pp. 5471-5476.

[9] M. Slier et al., New Analysis Techniques for Clearance of Flight Control Laws, *AIAA Guidance, Navigation, and Control Conference and Exhibits*,11-14 August, Austin, Texas, Usa, 2003, pp.5476.

[10] A. Varga et al., *Optimization Based Clearance of Flight Control Laws*, Lecture Notes in Control and Information Science. Springer-Verlag Berlin Heidelberg, Germany, 2012.

[11] G.Ghazi, *Développement d'une Plateforme de Simulation et d'un Pilote Automatique-Application aux Cessna Citation X et Hawker 800XP*, Doctoral dissertation, Master's thesis, University of Quebec-École Polytechnique de Montréal, Canada, 2014.

[12] G. Ghazi, M. R. Botez, *Development of a High-Fidelity Simulation Model for a Research Environment*, SAE AeroTech Congress and Exhibition,Seattle, WA, Usa; 2015, Sep 9 pp. 2569

[13] C. Hamel, A. Sassi, R. Botez, C. Dartigues, Cessna Citation X Aircraft Global Model Identification from Flight Tests, *SAE International Journal of Aerospace*, vol. **6**, 2013, no 1, pp. 106-114.

[14] C. Hamel, R. Botez, M. Ruby, *Cessna Citation X Airplane Grey-Box Model Identification without Preliminary Data*, In SAE 2014 Aerospace Systems and Technology Conference, ASTC 2014,. Cincinnati, OH, United states, Sept. 23- 25, 2014, Vol. 2014-September.

[15] G. Ghazi, R. Botez, J. M. Achigui, Cessna Citation X Engine Model Identification from Flight Tests, *SAE International Journal of Aerospace*, Vol **8**, 2015 Sep 15; pp. 2015-01-2390.

[16] M. J. Neath, A. Swain, U. Madawala, and D. Thrimawithana, An Optimal PID Controller for a Bidirectional Inductive Power Transfer System Using Multi-objective Genetic Algorithm, *Power Electronics, IEEE Transactions on*, vol. PP, pp. 1-1, 2013.

[17] M. K. Tan, Y. K. Chin, H. J. Tham, and K. T. K. Teo, Genetic algorithm based PID optimization in batch process control, in *IEEE International Conference on Computer Applications and Industrial Electronics (ICCAIE)*, 2011, pp. 162-167.

[18] M. S. Rahimian and K. Raahemifar, Optimal PID controller design for AVR system using particle swarm optimization algorithm, in *E24th Canadian Conference on Electrical and Computer Engineering (CCECE)*, 2011, pp. 000337-000340.

[19] R. G. Kanojiya and P. M. Meshram, Optimal tuning of PI controller for speed control of DC motor drive using particle swarm optimization, in *2012 International Conference on Advances in Power Conversion and Energy Technologies (APCET)*, 2012, pp. 1-6.

[20] H. Jiuqi, W. Peng, and Y. Xin, Tuning of PID controller based on Fruit Fly Optimization Algorithm," in *2012 International Conference on Mechatronics and Automation (ICMA)*, 2012, pp. 409-413.

[21] R. M. Botez, G. Kouba, N. Boëly, Identification of F/A-18 model from flight tests using the fuzzy logic method, in *Proceedings of the 47th AIAA Aerospace Sciences Meeting Including The New Horizons Forum and Aerospace Exposition*, Orlando, FL, USA., 2009.

[22] R. M. Botez, N. Boëly, G. Kouba, Identification of F/A-18 nonlinear model between control and structural deflections, in *Proceedings of the 47th AIAA Aerospace Sciences Meeting Including The New Horizons Forum and Aerospace Exposition*, Orlando, FL, USA, 2009.

[23] T. L. Grigorie, R. M. Botez, A. V. Popov, M. Mamou, and Y. Mebarki, A hybrid fuzzy logic proportionalintegral-derivative and conventional on-off controller for morphing wing actuation using shape memory alloy Part 1: Morphing system mechanisms and controller architecture design, *Aeronautical Journal*, vol. **116**, pp. 433-449, 2012.

[24] T. L. Grigorie, R. M. Botez, A. V. Popov, M. Mamou, and Y. Mébarki, A hybrid fuzzy logic proportional-integral-derivative and conventional on-off controller for morphing wing actuation using shape memory alloy, Part 2: Controller implementation and validation, *The Aeronautical Journal*, vol. **116**, pp. 451-465, 2012.

[25] A. V. Popov, L. T. Grigorie, R. M. Botez, M. Mamou, and Y. Mébarki, Real time morphing wing optimization validation using wind-tunnel tests, *Journal of Aircraft*, vol. **47**, pp. 1346-1355, 2010.

[26] M. G. Perhinschi, Parameter optimization via genetic algorithm of fuzzy controller for autonomous air vehicle, in *AIAA Guidance, Navigation, and Control Conference and Exhibit, Portland, OR*, USA, 1999.

[27] S. A. Frost, B. R. Taylor, and M. Bodson, Investigation of Optimal Control Allocation for Gust Load Alleviation in Flight Control, in *AIAA Atmospheric Flight Mechanics Conference*, 2012, p. 4858.

[28] M. G. Perhinschi, M. R. Napolitano, G. Campa, B. Seanor, S. Gururajan, and G. Yu, Design and flight testing of intelligent flight control laws for the WVU YF-22 model aircraft, in *AIAA Guidance, Navigation, and Control Conference*, 2005.

[29] M. G. Perhinschi, M. Lando, L. Massotti, G. Campa, M. R. Napolitano, M. L. Fravolini, 2002, Online parameter estimation issues for the NASA IFCS F-15 fault tolerant systems, *IEEE Proceedings of the 2002 American Control Conference*, pp. 191-196.

[30] S. A. Frost, M. Bodson, J. Burken, V. Jutte, B. R. Taylor, K. V. Trinh, 2015, Flight Control with Optimal Control Allocation Incorporating Structural Load Feedback, *Journal of Aerospace Information Systems*, pp. 1-10, doi: 10.2514/1.I010278, doi: 10.2514/1.I010278.

[31] M. J. Balas, S. A. Frost, 2014, Direct Adaptive Control for Infinite-dimensional Symmetric Hyperbolic Systems, *Procedia Computer Science*, vol. **36**, pp. 549-555.

[32] M. J. Balas, S. A. Frost, 2014, Robust adaptive model tracking for distributed parameter control of linear infinite-dimensional systems in Hilbert space, *IEEE/CAA Journal of Automatica Sinica*, Vol. **1** (3), pp. 294-301.

[33] M. J. Balas, S. A. Frost, 2013, Discrete-time infinite-dimensional adaptive control and rejection of persistent disturbances: To D or not to D?, *IEEE* 2013 *21st Mediterranean Conference on Control & Automation* (MED), pp. 1042-1049.

[34] S. A Frost, M. J. Balas, 2012, Evolving Systems: An Outcome of Fondest Hopes and Wildest Dreams, *AIAA Guidance, Navigation, and Control Conference*.

[35] B. Tang, Z. Wu, C. Yang, Aeroelastic scaling laws for gust load alleviation control system, *Chinese Journal of Aeronautics*, Vol. **29**(1), pp. 76-90, 2016.

[36] Z. Wang, Q. Wang, C. Dong, L. Gong, Closed-loop fault detection for full-envelope flight vehicle with measurement delays, *Chinese Journal of Aeronautics*, Vol. **28**(3), pp. 832-844, 2016.

[37] H. Songshan, J. Zongxia, W. Chengwen, S. Yaoxing, Fuzzy robust nonlinear control approach for electro-hydraulic flight motion simulator, *Chinese Journal of Aeronautics*, Vol. **28**(3), pp. 832-844, 2016.

[38] W. Zhigang, Y. Chao, A New Approach for Aeroelastic Robust Stability Analysis, *Chinese Journal of Aeronautics*, Vol. **21**, No. 5, pp. 417-422, doi:10.1016/S1000-9361(08)60054-0, 2008.

[39] X. Zhou, L. Liu, Z.-j. Chen, H.-b., Duan, "Validation of Flight Control Law Based on LFT and Structured Singular Value, *Chinese Journal of Aeronautics*, Vol. **20**, No. 1, pp. 60-65. doi:10.1016/S1000-9361(07)60008-9, 2007.

[40] M. Pavel, J. Malecki, B. DangVu, P. Masarati, M. Genaretti, M. Jump, M. Jones, H. Smaili, A. Ionita, L. Zaicek, *Present and Future Trends in Aircraft and Rotorcraft Pilot Couplings - a Retrospective Survey of Recent Research Activities within the European project ARISTOTEL*, The ERF Forum (Ed.), Proceedings of the 37th European Rotorcraft Forum 2011, Gallarate, Italy: Agusta Westland, 2011.

[41] M. Pavel, J. Malecki, B. DangVu, P. Masarati, M. Gennaretti, M. Jump, H. Smaili, A. Ionita, L. Zaicek, *Aircraft and rotorcraft pilot coupling: a survey of recent research activities within the European project ARISTOTEL*, 3rd CEAS Air & Space Conference-XXI AIDAA Congress, 2011.

[42] M. D. Pavel, M. Jump, P. Masarati, L. Zaichik, B. Dang-Vu, H. Smaili, G. Quaranta, O. Stroosma, D. Yilmaz, M. Johnes, M. Gennaretti, A. Ionita, Practises to identify and prevent adverse aircraft-and-rotorcraft-pilot couplings—A ground simulator perspective, *Progress in Aerospace Sciences*, Vol. **77**, pp. 54-87, 2015.

[43] N. Anton, R. M. Botez, Weight Functions Method for Stability Analysis applied as Design Tool for Hawker 800XP Aircraft, *The Aeronautical Journal*, Vol. **119**, no 1218, pp. 981-999, 2015.

[44] N. Anton et al., Application of the Weight Function Method on a High Incidence Research Aircraft Model, *The Aeronautical Journal*, Vol. **117**, 2013, no 1195, pp. 897-912.

[45] Y. Boughari et al. Optimal Control New Methodologies Validation On the Research Aircraft Flight Simulator of the Cessna Citation X Business Aircaft, Internationa Journal of Contemporary Energy, Vol **3**, No. 1, 2017. DOI: 10.14621/ce.20170102.