IMPLEMENTATION OF QUAD-M METHODOLOGY FOR HELICOPTER SYSTEM IDENTIFICATION –AN EXAMPLE WITH H-55 FLIGHT TEST

Sérgio Servilha de Oliveira, sergioservilhadeoliveira@hotmail.com
Luciano Luporini Menegaldo, lmeneg@ime.eb.br
Instituto Militar de Engenharia – Pós-Graduação em Engenharia de Defesa (PGED). Praça General Tibúrcio, nr 80, Praia Vermelha, CEP 22290-270 Rio de Janeiro – RJ, Brazil.

Abstract. *This work presents results obtained from a case study for H-55 Helicopter System Identification, which was carried out by an implementation of Quad-M Methodology purposed for Jategoankar. A comparison between Stability and Control Derivatives (SCD) tables from these results and those from literature is performed for some important flight conditions. This comparison allows us to conclude about the reliability of the method, to present preliminary SCD tables for the studied aircraft and point to possible future works.*

Keywords*: helicopter, Stability and Control Derivatives (SCD), flight test, Quad-M.*

1. INTRODUCTION

Simulations are important activities which can reduce work time and save money at different knowledge areas. Helicopter dynamic is not different. There, these activities are growing up quickly and a many rotorcraft industries are inverting appreciable human, material and financial resources. The recent technical literature in this field points mainly towards the development of new methods for estimating Stability and Control Derivatives (SCD), that are the basis of helicopter certification, development and design.

Some authors in Helicopter Dynamics Theory propose methodologies to perform system identification by determining SCDs using experimental data obtained from flight tests. Cookie (2002) presents and discusses Helicopter Test and Evaluation techniques and shows that they are fundamental for a successful aeronautical system identification. Tishler (2006) addresses System Identification and focuses in frequency domain methodology, presenting detailed techniques for this approach and exploiting their advantages. Padfield (2007) presents conceps regarding flying qualities and simulation modeling comparing Helicopter Flight Dynamics theory and application. Finally, Jategoankar (2006) presents a flight vehicle system identification method, based on a time domain approach, compares their advantages and problems face to frequency domain, and purposes some algorithms techniques for easy implementation using low cost computational resources.

Based on Quad-M methodology presented by Jategoankar (2006), Cruz et al. (2009a) and Cruz et al. (2009b) present a Dynamic Model for Flight Simulator. These works focuses on the lateral-directional helicopter system identification problem using Output-Error Method (OEM) and Genetic and Levenberg-Marquardt Optimization Algorithms. Hereinafter, Cruz et al. approach will be called Quad-M/CTA Methodology, since it intends to improve the Jategoankar Quad-M methodology with an specific approach developed at Centro Tecnico Aeroespacial (CTA), São José dos Campos-Brazil.

Departing from Quad-M/CTA results, (Oliveira and Menegaldo, 2010a) discusses about thresholds for Gauss-Newton Optimization for Output-Error Method, applied in system identification over helicopter flight test data and concludes about the conditions needed for OEM applicability.

After (Oliveira and Menegaldo, 2010b) concludes about important parameters to guarantee reliability at Quad-M/CTA researching about: the optimized maneuvers for exciting each natural dynamic mode, accuracy of SCD calculated by Cramer-Rao and Relative Correlation Coefficient (RCC) criteria, linear dependency of SCD-pairs and compliance with requirements for Flight Simultator Design, Overhauls and Supplemental Type Certification.

Results for system identification can be compared to literature results. In helicopter field of knowledge only few data is available regarding SCD. The main sources are Hefley (1979) and Padfield (2007), which are used in this work as comparison reference parameters.

This work was developed under research Project approved by Post-Graduated Program in Defense Engineering at "*Instituto Militar de Engenharia (IME)"*.and the mainly sponsor is Brazilian Army Aviation (BAAv), which is a huge helicopter operator, owning different models normally utilitarian which allow special configurations in order to perform great operative and ordinary mission range. BAAv has interest to implement and develop Flight Simulators.

2. METHODOLOGY

2.1 Stability and Control Derivatives (SCD)

Helicopter Dynamic studies are based on equilibrium equation for Momentum (L, M, N) and Forces (X, Y, Z) acting on helicopter during its flight. These equations are presented as a function of linear velocities (u, v and w) and angular rates (p, q and r), referred to the typical main rotorcraft axis (x, y and z). To calculate the path flight usually Euler angles (ϕ, θ, and ψ) are used. Figure 1 shows the helicopter main axis.

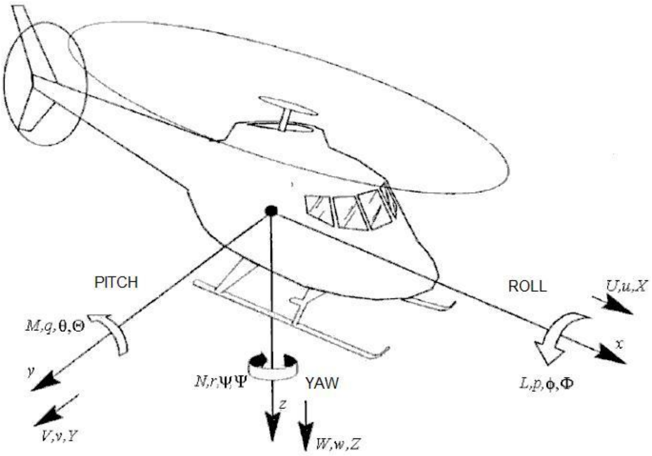

Fig. 1: Helicopter Main Axis

Dynamic equation are usually non-linear, nevertheless a linearization approach is useful to facilitate calculus. Using small disturbances in helicopter behavior from an equilibrium flight condition, it is possible to define the Stability and Control Derivatives (SCD) vector

$$\Theta = \begin{bmatrix} X_u, X_v, X_w, X_p, X_q, X_r, X_{d\delta c}, X_{d\delta m}, X_{d\delta l}, X_{d\delta n}, \\ Y_u, Y_v, Y_w, Y_p, Y_q, Y_r, Y_{d\delta c}, Y_{d\delta m}, Y_{d\delta l}, Y_{d\delta n}, \\ Z_u, Z_v, Z_w, Z_p, Z_q, Z_r, Z_{d\delta c}, Z_{d\delta m}, Z_{d\delta l}, Z_{d\delta n}, \\ L_u, L_v, L_w, L_p, L_q, L_r, L_{d\delta c}, L_{d\delta m}, L_{d\delta l}, L_{d\delta n}, \\ M_u, M_v, M_w, M_p, M_q, M_r, M_{d\delta c}, M_{d\delta m}, M_{d\delta l}, M_{d\delta n}, \\ N_u, N_v, N_w, N_p, N_q, N_r, N_{d\delta c}, N_{d\delta m}, N_{d\delta l}, N_{d\delta n} \end{bmatrix} \quad (1)$$

where each SCD represents a infinitesimal variation between a Force (X, Y, Z) or Moment (L, M, N) over a speed (u, v, w) or angular velocity (p, q, r), or yet a command displacement (ddc, ddb, dda, ddn). The ddc is collective command displacement; ddb or ddm is a cyclic longitudinal command displacement; dda or ddl is a cyclic lateral command displacement and ddn is a pedal command displacement.

The SCDs are represented respectively by the derivative expressions:

$$X_u = \partial X / \partial u \quad (2);$$

$$X_v = \partial X / \partial v \quad (3);$$

and so on.

2.2 Experimental tests

This work try to determine H-55 helicopter SCD, expressed in vector Θ. This vector represents all SCD of helicopter dynamic formulation. For each flight condition (altitude, speed, weight, CG-position) different vectors Θ of SCDs can be defined.

To carry out system identification in time dominium the ‘Helimat’ software was developed in Matlab R2007®. The computational mean employed was a Intel® Corel2™ CPU 6600 @ 2.4 GHz PC with 1.97 GB RAM. Helimat implements recursively the Output Error Method optimization method applying the Gauss-Newton algorithm. The criteria for accuracy validity of the SCD-Groups found are Cramer-Rao (CR) and Relative Correlation Coefficient (RCC). The initial guess used for the Helimat System Identification was found from Quad-M/CTA (Cruz et al, 2009a) results. Flight data was obtained from 16 flight test hours in a representative AS 355-F2 helicopter (also called H-55) with a measurement system that includes 35 flights parameters.

3. RESULTS

System identification carried out by Helimat program gave the following results, which were assembled in nine case studies. Table 1 presents flight condition at each case.

Table 1- Case Studies

Study of Case	Speed (kt)	Weight (kg)	Altitude (ft)
1	60	2,200	4,000
2	80	2,200	4,000
3	100	2,200	4,000
4	60	2,200	10,000
5	100	2,200	10,000
6	60	1,900	4,000
7	100	1,900	4,000
8	60	2,500	4,000
9	100	2,500	4,000

From case 1 to 3 speed was changed from 60 to 100 kt. Cases 4, 6 and 8, perfomed at 60 kt, allow comparison with Stability and Control Derivatives of case 1. For Case 4 altitude has been changed from 4,000 ft to 10,000 ft, at Case 6. It is possible to compare case 1 to a low-weight condition flight, varying from 2,200 to 1,900 kg. In case 8, there is also weight change, but now presenting a heavy condition of 2,500 kg. Similarly, Cases 5, 7, and 9 allow comparison with Case 3, at 100 kt. All flight data studied have been obtained from level flights performed under flight test rules. Stability and Control derivatives (SCD) identified for H-55 flight are presented in Tables 2 to 19, each pair presenting one case studied.

Table 2 - Stability Derivatives : Case Study Nr 1, H-55 helicopter; 60 kt Level Flight; 4.000 ft; 2200 kg

	u	**w**	**q**	**v**	**p**	**r**
X	-0,02494	0,02056	0,33652	0,00278	0,06924	-0,01219
Z	-0,06034	-0,77379	21,25270	0,00356	-0,02024	0,15582
M	0,02463	0,01364	-2,05335	-0,00092	-0,26629	0,00635
Y	-0,00039	-0,00626	0,07037	-0,10843	-0,45026	-21,32755
L`	-0,02991	0,03218	0,78405	-0,15219	-6,49507	0,18923
N`	-0,01004	0,00051	0,05867	0,06544	-0,66007	-0,78195

Table 3 - Control Derivatives : Case Study Nr 1, H-55 helicopter; 60 kt Level Flight; 4.000 ft; 2200 kg

	ddc	**ddb**	**dda**	**ddn**
X	0,48910	-6,13237	1,05309	-0,00315
Z	-71,58945	-14,93226	0,08410	0,00076
M	3,71686	14,10604	-4,21761	0,00454
Y	-0,72276	-0,82412	1,44827	3,38374
L`	4,48838	-15,18504	-38,99614	3,06690
N`	1,74749	-2,65286	-8,55004	-7,62205

Table 4 - Stability Derivatives: Case Study Nr 2, H-55 helicopter; 80 kt Level Flight; 4000 ft; 2200 kg

	u	**W**	**q**	**v**	**p**	**r**
X	-0,03118	0,01893	0,75314	0,00237	0,06987	-0,01405
Z	-0,02634	-0,84942	28,31778	0,00540	-0,05870	0,15454
M	0,02280	0,00745	-2,11812	-0,00103	-0,26629	0,00684
Y	0,00029	-0,00825	0,05466	-0,13163	-0,76420	-28,64937
L`	-0,02814	0,01804	0,79890	-0,15609	-6,42133	0,18598
N`	-0,00830	0,00063	0,09898	0,07277	-0,65911	-0,84480

Table 5 – Control Derivatives : Case Study Nr 2, H-55 helicopter; 80 kt Level Flight; 4000 ft; 2200 kg

	ddc	**ddb**	**dda**	**Ddn**
X	-0,13259	-6,08823	1,05328	-0,00344
Z	-78,56980	-22,11513	0,08411	-0,00008
M	5,69789	14,27670	-4,25491	0,00472
Y	-0,98364	-0,90009	1,30901	3,80328
L`	2,77426	-15,10829	-39,09486	3,37946
N`	1,77364	-2,42892	-8,37135	-8,53255

Table 6 - Stability Derivatives: Case Study Nr 3, H-55 helicopter; 100 kt Level Flight; 4000 ft; 2200 kg

	u	**w**	**Q**	**v**	**p**	**r**
X	-0,03771	0,01722	1,45377	0,00269	0,06277	-0,01573
Z	-0,00812	-0,90715	35,43191	0,00453	-0,06150	0,16902
M	0,02501	0,01250	-2,18671	-0,00100	-0,27743	0,00965
Y	0,00157	-0,01041	0,06188	-0,15513	-1,52085	-36,01247
L`	-0,02401	0,00498	0,81909	-0,15993	-6,35180	0,22345
N`	-0,00910	0,00485	0,06016	0,07551	-0,64914	-0,95196

Table 7 - Control Derivatives: Case Study Nr 3, H-55 helicopter; 100 kt Level Flight; 4000 ft; 2200 kg

	ddc	**Ddb**	**dda**	**Ddn**
X	-0,81433	-6,12640	1,06615	-0,00393
Z	-84,71469	-28,38774	0,01043	0,00122
M	7,35920	14,62176	-4,32446	0,00677
Y	-1,22871	-1,00480	1,28747	4,14470
L`	1,17878	-15,42161	-39,37695	3,71142
N`	2,02035	-2,18805	-8,27515	-9,24600

Table 8 - Stability Derivatives: Case Study Nr 4, H-55 helicopter; 60 kt Level Flight; 10000 ft; 2200 kg

	u	**w**	**Q**	**v**	**p**	**r**
X	-0,02351	0,01181	0,43597	-0,00025	0,06688	-0,01098
Z	0,04170	-0,54095	24,34855	0,00295	-0,01313	0,15771
M	0,02556	0,00434	-2,07377	-0,00129	-0,26538	0,00267
Y	-0,00004	-0,00268	0,06622	-0,08497	-0,53984	-14,96937
L`	-0,05650	0,01931	0,71046	-0,14580	-8,11797	0,10640
N`	-0,01123	0,00041	-0,24156	0,04900	-1,20176	-0,62302

Table 9 - Stability Derivatives: Case Study Nr 4, H-55 helicopter; 60 kt Level Flight; 10000 ft; 2200 kg

	ddc	**ddb**	**dda**	**ddn**
X	*0,27206*	-6,87217	1,05309	-0,00329
Z	*-50,93934*	-10,75547	-0,08410	0,00068
M	*9,48179*	14,55842	-642,28099	0,00462
Y	*-0,41408*	-0,76918	3,06741	2,50090
L`	*-3,43642*	-13,74342	-5,66990	2,26168
N`	*2,16426*	-2,31245	-0,96222	5,63151

Table 10 - Stability Derivatives: Case Study Nr 5 H-55 helicopter; 100 kt Level Flight; 10000 ft; 2200 kg

	u	**w**	**q**	**v**	**p**	**r**
X	-0,03119	0,00862	1,99917	0,00184	-0,07029	-0,01491
Z	-0,00500	-0,61305	40,96593	0,00319	-0,03700	0,16254
M	0,02230	0,00430	-2,12684	-0,00180	-0,27819	0,00987
Y	0,00124	-0,00689	0,05803	-0,11949	-1,80347	-25,85601
L`	-0,01384	0,00344	0,74116	-0,15255	-7,89119	0,13888
N`	-0,00029	0,00393	0,01255	0,05420	-1,21098	-0,75500

Table 11 - Stability Derivatives: Case Study Nr 5 H-55 helicopter; 100 kt Level Flight; 10000 ft; 2200 kg

	ddc	**ddb**	**dda**	**ddn**
X	-0,35478	-8,83193	1,06615	-0,00481
Z	-57,39188	-19,62293	0,00092	0,00042
M	-9,53351	15,97643	-5,04520	-0,12322
Y	-0,89434	-0,80384	1,29460	3,09740
L`	0,73108	-12,54973	-39,55142	2,79122
N`	2,32535	-2,01817	-8,27515	-6,89510

Table 12 - Stability Derivatives: Case Study Nr 6, H-55 helicopter; 60 kt Level Flight; 4000 ft; 1900 kg

	u	**w**	**q**	**v**	**p**	**r**
X	-0,02964	0,02922	0,33942	0,00519	0,07780	-0,01284
Z	-0,18740	-0,95979	28,35418	0,00411	-0,02446	0,15342
M	0,02161	0,01938	-1,89670	-0,00067	-0,24661	0,00650
Y	-0,00081	-0,01029	0,08214	-0,13058	-0,45401	-26,68132
L`	-0,00665	0,04070	0,81426	-0,10804	-5,60146	0,16995
N`	-0,00670	0,00045	0,34824	0,07371	-0,56882	-0,82492

Table 13 - Stability Derivatives: Case Study Nr 6, H-55 helicopter; 60 kt Level Flight; 4000 ft; 1900 kg

	ddc	**ddb**	**dda**	**ddn**
X	0,72652	-5,41703	0,46073	-0,00367
Z	-88,39322	-18,39379	-0,22426	0,00025
M	-2,19978	11,16557	-1,20503	0,00412
Y	-1,09167	-1,05762	1,45654	4,18119
L`	8,48584	-16,72277	-34,12607	2,80825
N`	1,47034	-2,40636	-8,22014	-8,14509

Table 14 - Stability Derivatives: Case Study Nr 7, H-55 helicopter; 100 kt Level Flight; 4000 ft; 1900 kg

	u	**w**	**q**	**v**	**p**	**r**
X	-0,04715	0,02538	1,41825	0,00385	0,06548	-0,01717
Z	-0,01167	-1,12440	44,44071	0,00594	-0,07587	0,17511
M	0,02395	0,01720	-2,05854	-0,00050	-0,24347	0,00881
Y	0,00248	-0,01511	0,07376	-0,18846	-1,47513	-45,05213
L`	-0,03581	0,00590	0,89722	-0,10307	-5,25865	0,19904
N`	-0,01203	0,00342	0,11917	0,08218	-0,65165	-1,00884

Table 15 - Stability Derivatives: Case Study Nr 7, H-55 helicopter; 100 kt Level Flight; 4000 ft; 1900 kg

	ddc	**ddb**	**dda**	**ddn**
X	-1,26138	-3,43005	1,11461	-0,00455
Z	-104,70699	-34,98466	0,01626	0,00137
M	20,73957	10,90181	-3,60372	0,01354
Y	-1,83702	-1,37126	1,28984	5,10994
L`	1,52408	-17,58536	-34,26510	3,39496
N`	2,11063	-1,52212	-7,67475	-9,86473

Table 16 - Stability Derivatives: Case Study Nr 8, H-55 helicopter; 60 kt Level Flight; 4000 ft; 2500 kg

	u	**w**	**q**	**v**	**p**	**r**
X	-0,02341	0,01824	0,33726	0,00139	0,06231	-0,01301
Z	-0,02894	-0,63798	16,67792	0,00329	-0,01747	0,15470
M	0,02788	0,00744	-2,18762	-0,00123	-0,28897	0,00616
Y	-0,00019	-0,00391	0,06165	-0,09348	-0,44713	-17,56793
L`	-0,04542	0,02526	0,77412	-0,19605	-7,31546	0,20403
N`	-0,01285	0,00055	0,12694	0,06167	-0,73265	-0,73745

Table 17 - Stability Derivatives: Case Study Nr 8, H-55 helicopter; 60 kt Level Flight; 4000 ft; 2500 kg

	ddc	**ddb**	**dda**	**ddn**
X	0,44019	-6,34636	1,11891	-0,00315
Z	-59,47065	-12,54363	-0,04205	0,00040
M	8,79910	17,10820	-4,82012	0,00462
Y	-0,45925	-0,81038	1,45929	2,83956
L`	0,98183	-15,95390	-44,16837	3,26243
N`	2,06271	-2,89937	-9,64973	-7,12882

Table 18 - Stability Derivatives: Case Study Nr 9, H-55 helicopter; 100 kt Level Flight; 4000 ft; 2500 kg

	u	**w**	**q**	**v**	**p**	**r**
X	-0,03361	0,01372	1,49574	0,00222	0,05728	-0,01607
Z	-0,00673	-0,74053	30,95279	0,00372	-0,05019	0,16298
M	0,02576	0,00711	-2,27746	-0,00140	-0,30611	0,01021
Y	0,00124	-0,00795	0,05399	-0,13256	-1,54224	-29,73850
L`	-0,01872	0,00438	0,79280	-0,21543	-7,33120	0,24305
N`	-0,00440	0,00567	0,04609	0,06810	-0,68674	-0,89557

Table 19 - Stability Derivatives: Case Study Nr 9, H-55 helicopter; 100 kt Level Flight; 4000 ft; 2500 kg

	ddc	**ddb**	**dda**	**ddn**
X	-0,62801	-7,17193	0,77538	-0,00370
Z	-69,32814	-23,52980	-0,00982	0,00049
M	-5,93754	18,47073	-5,76595	-0,00271
Y	-1,11591	-0,85704	1,24701	3,48683
L`	0,98589	-14,87084	-44,45391	3,96079
N`	2,13747	-2,60935	-9,34544	-8,66732

4. COMPARATIVE ANALYSIS

At Section 2, reliability of the methodology has been discussed. Unfortunately, no H-55 helicopter Stability and Control Derivative are available in literature, for comparison proposes. However, it is possible to to compare SCD H-55 behavior with those of a similar aircraft. The UH-1D (Hefley,1979) and BO-105 (Padfield, 2007) results has been selected for this propose, due to similarity of profile and weight of that rotorcraft.

Firstly, Figure 2 shows Helimat SCD results and Figure 3 show UH-1D results (Hefley,1979). By simplicity, these results in Figures 2 and 3 show 9 graphics among all 60 possible SCD presented at Tables 2 to 19. They are the derivatives of Forces (X, Y and Z) over linear velocities (u, v and w). Also, Figures 2 and 3, present all 9 study case listed at Table 1 which represents different flight conditions varying velocities (60, 80 and 100 kt), low-weight (1900 kg) versus nominal condition (2,200 kg), heavy weight (2,500 kg) versus nominal condition (2,200 kg),

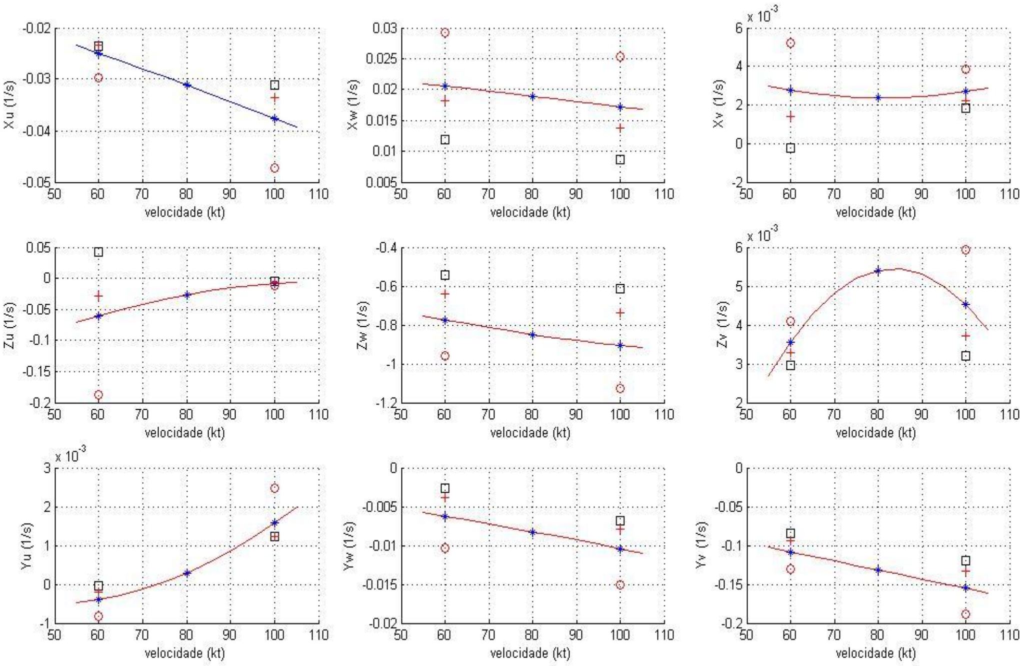

Figure 2 : Stability and Control Derivatives - Force and speed components - of H-55 Helicopter (Helimat Results)
“o” high alttitude; “+” low-weigth; □ heavy

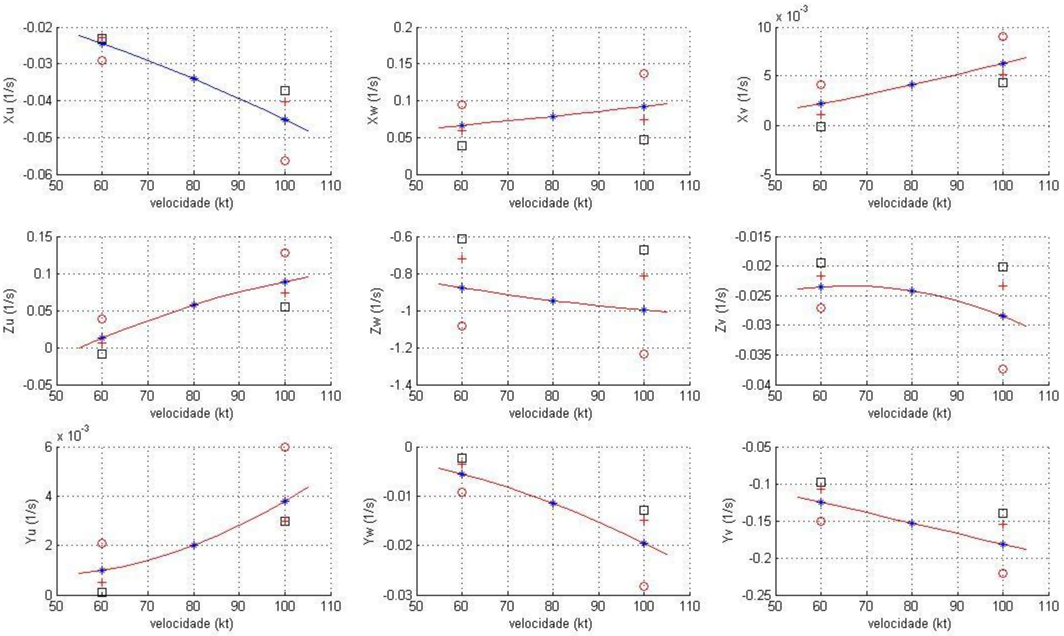

Figure 3 : Stability and Control Derivatives - Force and speed components - of UH-1D Helicopter (Hefley, 1979)
“o” high alttitude; “+” low-weigth; □ heavy

Observing these graphics allow one to conclude that for all of them SCD for both helicopters (H-55 and UH-1D) has the same tendency: slope down for Xu, Xv, Yv, Yw, Zu, and Zw; crescent for Yu; almost stable for Xw; almost parabolic for Zv. The magnitude for all 9 SCD are almost in the same range. Also, for both rotorcrafts, the comparative magnitude are similar: Xu, Xw, Zu, Zw and Yv are significant greater than Xv, Zv, Yu and Yw. The effect of altitude and low and heavy weight are similar for both aircraft for all SCD over all flight conditions.

After, Figure 4 presents in the same graphics results which allow comparison among Stability Derivatives – Forces X, Y and Z over Linear Velocities u, v and w - among 3 aircrafts: H-55 (Helimat results), UH-1D (Hefley, 1979) and BO-105 (Padfield, 2007). Figure 5 presents in the same graphics results which allow comparison among Control Derivatives – Forces X, Y and Z over longitudinal command displacements ddb and ddc, for the same 3helicopters.

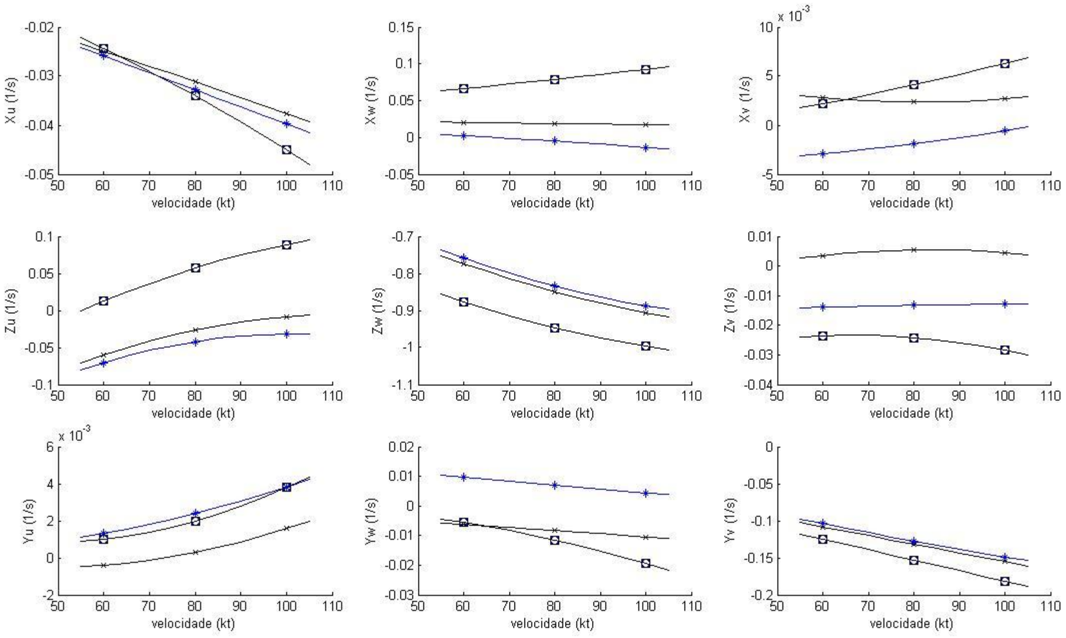

Figure 4 : Comparison for Stability Derivatives - Force and velocity components - of 3 different aircrafts
“”BO-105 (Padfield, 2007); “x” UH-1D (Hefley, 1979); ◘H-55(Helimat)*

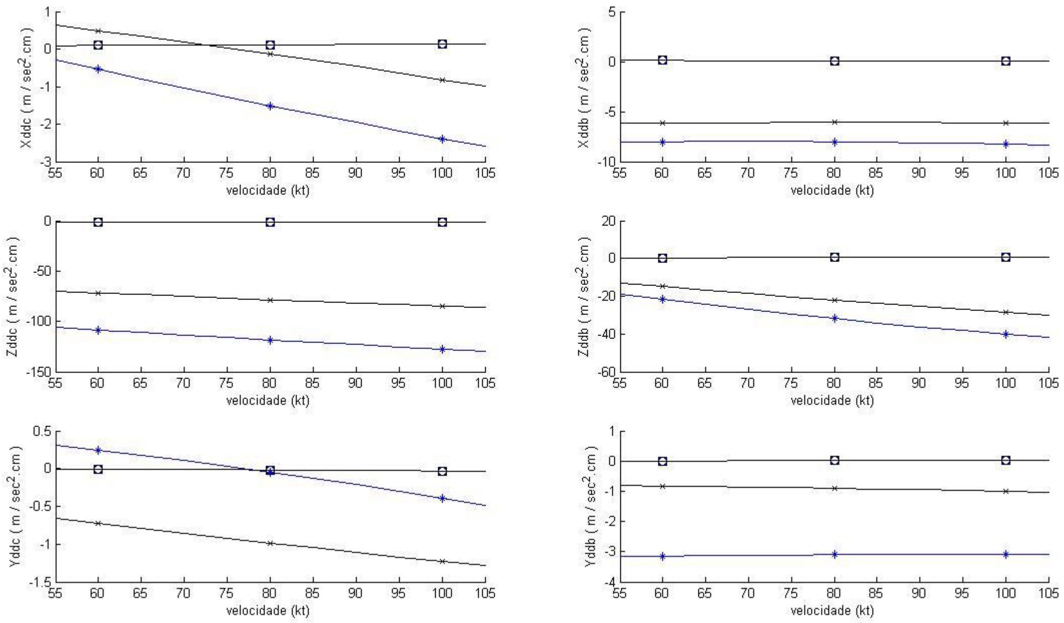

Figure 5 : Comparison for Control Derivatives - Force and command displacement components - of 3 different aircrafts *"*"BO-105 (Padfield, 2007); "x" UH-1D (Hefley, 1979);* ◘*H-55(Helimat)*

Again, observing these graphics from Figures 4 and 5, one can conclude that for the 3 helicopters (H-55, UH-1D and B)-105) all SCD for have the same tendency: slope variation, magnitude and comparative magnitude.

4.1 Conclusion

This work extends Cruz et al. (2009a) results, with Quad-M/CTA methodology. Cruz *et al.* has performed system identification for flight test data successfully just for one flight condition, while this work presents nine conditions. The nine flight conditions studied allow comparison with literature results. First, it has been compared with UH-1D identified SCD by Hefley (1979) in all nine different conditions. The results shown similar tendencies for SCD evaluation among speed, altitude and weight variation. Also the magnitude of each SCD are very similar for helicopter models analyzed:.BO-105 (Padfield, 2007); UH-1D (Hefley, 1979) and H-55 (Helimat identification).

The similar tendencies and the compliance with Cramer-Rao and Relative Correlation Coefficient criteria for acceptability in all system identification performed allow one to conclude over the reliability of the methodology Quad-M/CTA applied and acceptability of reached results.

5. ACKNOWLEDGEMENTS

Thank you for "Grupo Especial de Ensaios em Voo" (GEEv) from "Centro Técnico Aeroespacial" (CTA), São José dos Campos, Brazil, for share important flight data and means to perform flight test which became this work possible

6. REFERENCES

Cooke, A,K. e Fitzpatrick, E. W. H., 2002, "Helicopter Test and Evaluation". American Institute of Aeronautics and Astronautics Inc., pp 330-340. Reston VA, E.U.A.

Cruz, R. V., Góes, L. C. S., and de Andrade, 2009a, "Desenvolvimento de um Modelo Dinâmico para Simuladores de Helicópteros", Doctoral Thesis, pp 90-166, Instituto Tecnológico de Aeronáutica, São José dos Campos, SP, Brazil.

Cruz, R. V., Góes, L. C. S., and de Andrade, D.,2009b,"Results of Lateral-Directional Helicopter System Identification using Output-Error and Both Genetic and Levenberg-Marquardt Optimization Algorithms", proceedings of Brazilian Symposium on Aerospace Eng. & Applications, by Agência Aeroespacial Brasileira –AAB, São José dos Campos, Brazil.

Hefley, R. K. et al, 1979, "A Compilation and Analysis of Helicopter Handling Qualities Data Volume One", National Aeronautic and Space Administration, NASA Contractor Report 3144, Houston, TX, E.U.A.

Jategaonkar, R. V.,2006, "Flight Vehicle System Identification: A Time Domain Methodology", American Institute of Aeronautics and Astronautics Inc., Progress in Astronautics and Aeronautics, pp 59-129. Reston VA, USA.

Oliveira, S.S. e Menegaldo, L. L., 2010a, "Thresholds for Gauss-Newton Optimization at Output-Error Method Applied at System Identification over Helicopter Flight Test Data", proceedings of DINCON 9th `10, Brazilian conference on Dynamic, control and their Applications", Brasil,

Oliveira, S.S. e Menegaldo, L. L., 2010b, "Applications Limits between Global and Local Search Algorithms for Helicopter Stability and Control Derivatives Identification", proceedings of Heli Japan 2010, 4th advanced otorcraft Rechnology and Safety Operations. American Helicopter Society (AHS)–International, Saitama, Japan.

Padfield, G. D. "Helicopter Flight Dynamics, 2007, The Theory and Application of Flying Qualities and Simulation Modelling", 2nd. Ed., pp 185-281, AIAA, Blackwell Science. Oxford, OX, UK.

Tishler, M. and Remple, R., 2006, "Aircraft and Rotorcraft System Identification: Engineering Methods - with Flight Test Examples", American Institute of Aeronautics and Astronautics Inc., pp 330-340. Reston VA, USA.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.