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APPRAISAL OF HANDLING QUALITIES STANDARDS FOR ROTORCRAFT LATERAL-DIRECTIONAL DYNAMICS

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Abstract

The coupled vehicle roll-yaw-sway motion of Lateral-Directional Oscillations is often a contributor to rotorcraft Handling Qualities deficiencies. The extent of the deficiencies, and the required pilot control compensation to mitigate their effects, depend critically on the LDO damping and frequency and relative contributions from the roll, yaw and sway motions. Current rotorcraft performance/certification standards (e.g. ADS-33E-PRF/CS-29) for LDO stability have been developed from standards that date from the 1950s or from fixed-wing requirements; there has been limited flight test to support their validation. This paper builds on previous work examining the suitability of these LDO stability criteria to modern rotorcraft operations through ground-based simulation assessment covering a range of HQs, selected based on a frequency of 2.5 rad/s with varying damping and roll-yaw ratio. The underlying simulation model is a FLIGHTLAB Bell 412 model, augmented to ensure that the non-LDO HQs are Level 1. The LDO test configurations have been developed with delta-derivatives added to the nonlinear model to change the LDO frequency, damping and the magnitude ratio of the roll/yaw motion, whilst preserving yaw control sensitivity. The preliminary results demonstrate Handling Qualities generally degrade as the amount of roll in the LDO increased with a p/r = 1.5 giving a reasonable match with the military standards. If the ratio is reduced, Level 1 ratings were awarded with a lower damping. Conversely, no Level 1 ratings were returned for p/r = 2 when the LDO was triggered in the closed loop task.

1. INTRODUCTION

For both fixed and rotary wing aircraft, the lateral-directional oscillation (LDO) is considered a ‘nuisance’ mode, in that it contributes nothing useful to the aircraft performance and maneuverability [1]. Any excitation needs suppression by pilot control action, thus contributing to handling deficiencies. As with all oscillatory modes, the extent of the deficiencies depends on the modal damping, frequency and the amplitude ratios and phases of the coupled motions. Compared with fixed-wing aircraft, rotorcraft LDO damping is reduced by fin/tail rotor blockages effects and de-stabilizing dihedral [1]. The roll/yaw ratio can be unity or greater, and the phase between the motions can require complex pilot compensation.

Civil and military rotorcraft certification standards [2-4] define the acceptable amount of stability in terms of relative damping as a function of frequency for the LDO. Figure 1 shows the Handling Qualities (HQ) boundaries for the frequency (vertical axis) and damping (horizontal axis) from these standards. Flight test results for a range of current aircraft are shown on the chart illustrating typical levels of LDO mode characteristics. As can be seen, these unstabilised aircraft are, at best, Level 2 for the ‘all other Mission Task Elements (MTE)’ category in Aeronautical Design Standard-33 [4].

The civil standard, CS-29 [3], contains a list of requirements, and acceptable means of compliance, that must be satisfied for large rotorcraft to be certified for operations in a range of flight conditions e.g. Category A vertical operations, day/night. CS-29 states that the rotorcraft must be stable for flight in Visual Meteorological Conditions, represented by the vertical zero damping line in Figure 1, whilst in Instrument Meteorological Conditions, different damping levels are defined depending on the frequency of the LDO.

The military standard, ADS-33E-PRF [4], defines Handling Qualities (HQ) as Level 1, 2 or 3 with further differentiation relating to the mission of the aircraft. The regions for ‘*All Other MTEs*’ are aimed at cargo/utility aircraft while ‘*Target Acquisition and Tracking*’ (TA&T) boundaries are for scout/attack

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rotorcraft. As with CS-29, ADS-33E-PRF LDO damping requirements are dependent on the frequency of the oscillation. Ref. [7] notes that "*no supporting data for these boundaries relevant to helicopters have appeared in the open literature since publication of ADS-33*"; this is also true for the CS-29 standards.

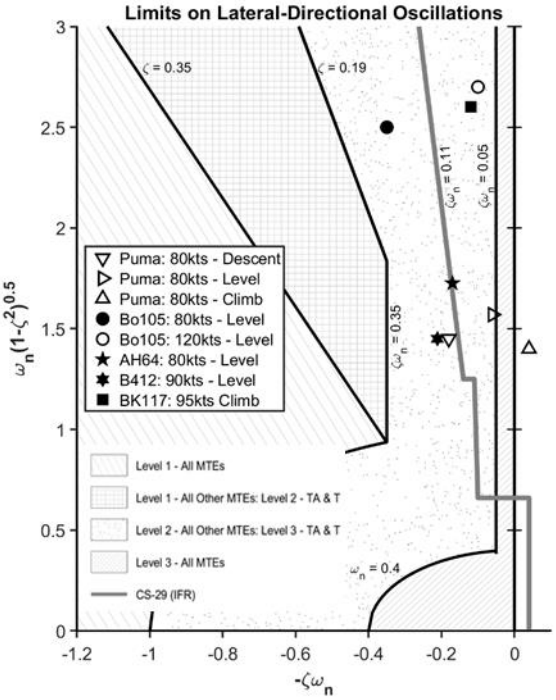

Figure 1. ADS-33E and CS-29 LDO boundaries, with flight test results for several types (Puma [5], Bo105 80 kts [5] , AH64 [5], Bo105 120kts, BK117 [6], B412 [1]).

The ADS-33 boundaries are largely based on the fixed-wing military aircraft standards, MIL-F-8785C [8], for the 'Dutch roll' mode. One significant difference is the Level 1-2 boundary for TA&T tasks which is an extension of the 0.35 relative damping boundary line for yaw oscillations in low-speed tasks flown with divided attention. The ADS-33 user-guide [9] states that there are "*no quantitative data to support this limit in forward flight. The intent is the same, however, since excessive lateral-directional oscillations in a high workload environment, will result in degraded handling qualities at any speed*.". The 0.19 relative damping (ζ) and $\zeta\omega_n$ = 0.35 lines, correspond to the Level 1-2 boundary for fixed-wing aircraft in Category A flight phases. ADS-33 adopts this as the Level 1-2 boundary for 'A*ll other MTEs*', and Level 2-3 boundary for '*TA&T*' tasks, although Ref. [9] states that, "*the representation of this boundary as the Level 2 limit for slalom, ground-attack and air combat is less supportable, and is based on convenience of format*". The Level 2-3 boundary ($\omega_n > 0.4$, $\zeta\omega_n$ > 0.05) and (zero ζ) Level 3-4 boundary accord with the fixed-wing military aircraft standard. No further changes to these boundaries are recommended in the proposals for ADS-33F-PRF [10].

1.1. Research Questions

Particular questions stemming from this historical perspective are: (1) for the most demanding military helicopter tasks, is the minimum relative damping of 0.35 really required? (2) is a minimum relative damping of 0.19 sufficient for Level 1 HQs in general MTEs? (3) how close to zero damping is acceptable for Level 2 performance? Is a ζ of 0.2 sufficient? (4) is a ζ of 0.11 sufficient as a minimum standard for civil operations in IFR flight? And (5), how does the LDO *p/r* ratio impact the required compensation. Additional questions concern the impact of other LDO characteristics on the boundaries, e.g. roll-sideslip amplitude ratio and phase. ADS-33 separates these into independent criteria, again without supporting test evidence. Some of these questions are addressed in the research presented in this paper.

Clearly, the relevance of these aged standards to current rotorcraft operational needs is questionable, and further investigation is warranted. A key objective of this work is to examine the 'veracity' of the current military LDO HQ boundaries and civil standards. The first phase of the work was reported in [11] which assessed the composition of the LDO characteristics across the stability chart through flight testing and piloted simulation with a typical forward-flight, close to the surface, MTE. The Roll-Step [12], described in Appendix 1, was chosen as it provides moderate roll attitude changes and a flight-path/attitude tracking element. The paper reported that:

- Across the range investigated (LDO frequency of 1.5-2.5 rad/s,) changes to the LDO frequency has little impact on the HQs.
- Zero damping, neutrally stable, configurations were rated as Level 2 and would be unsuitable for flying tasks requiring additional attention demands.
- Aircraft with 'predicted' Level 1 HQs were generally not assigned Level 1 Handling Qualities Ratings (HQRs) by the pilots, due largely to deficiencies in simulation cueing; specifically, height keeping and loop-closure with cyclic and collective emerged as the dominant deficiency, particularly related to the quality of the surface visual motion cues.

The research reported in this paper continues to focus on research questions (1), (3) and (5) and addressing the latter point on the cueing environment. The paper continues by describing the methodology for establishing the test configurations, the test facilities, and followed by results from this phase of the research.

1.2. LDO Test Configurations

LDO test configurations were selected in [11] based on frequency and damping to cover a range of HQs on the ADS-33 and CS-29 stability chart illustrated as diamonds in Figure 2. The magnitude of the roll contribution to the LDO was relatively small compared to the dominant yaw oscillation (*p/r* ratio of 0.6). As discussed above, further investigation is needed for larger *p/r* ratios to determine if this increases the pilot compensation required for the task.

This paper explores the impact on LDO HQs of the third dimension of the LDO chart based on roll/yaw ratios as illustrated by the diamonds in Figure 3. The test configurations are focused around the ADS-33 / CS-29 boundaries to assess the sensitivity of assigned HQRs to LDO configurations that lie either side of the boundaries.

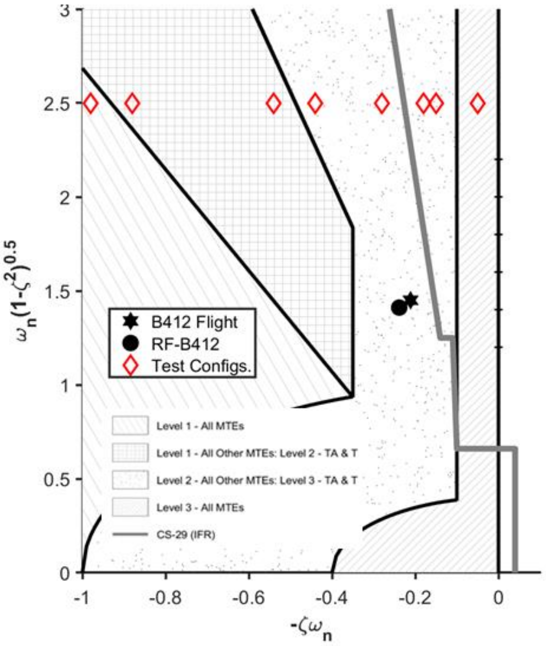

Figure 2. LDO test configurations on the frequency-damping chart.

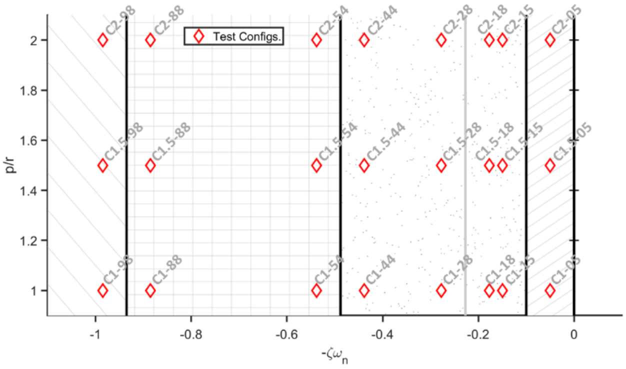

Figure 3. LDO test configurations varyinging with p/r ratio, on a slice through the frequency-damping chart.

A fourth dimension to explore is the phase between the roll and yaw motions. In addition to the LDO stability characteristics, ADS-33E-PRF characterises the bank angle changes in relation to the phase of the roll-sideslip oscillation. while the *x*-axis parameter, ψ_β, is the phase angle between roll rate and sideslip. The test configurations have been set such that ψ_β is -150 degrees for all cases. The *y*-axis parameter (ϕ_{osc}/ϕ_{av}) in Figure 4 is calculated from the ratio of peaks and troughs from the roll response. The oscillation ratios remain within Level 1 for all test configurations when *p/r* = 1. However, as *p/r* increases, the roll oscillation degrades to Level 2 for the low damping cases, an expected result that corresponds with the LDO characteristics.

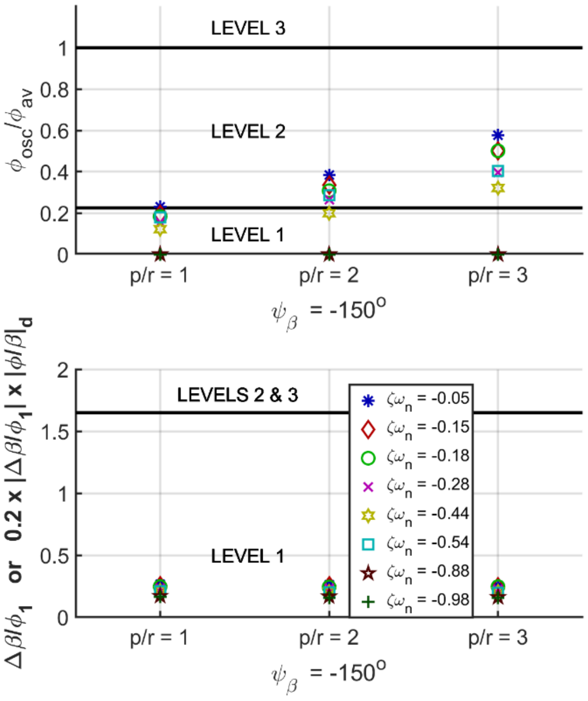

Figure 4. Roll from sideslip coupling.

2. TEST FACILITIES AND DEVELOPMENT OF A BASELINE SIMULATION MODEL

The reference aircraft is the National Research Council Canada's Bell 412 (B412) Advanced Systems Research Aircraft (ASRA) [13], Figure 5. Flight tests were conducted in support of the LDO research primarily to ensure that the baseline simulation model was representative of the aircraft. Figure 5 shows a view from the cockpit as the pilot commences the right to left runway crossing in the Roll-Step MTE (see Appendix 1).

Figure 6 shows the HELIFLIGHT-R flight simulator and a similar cockpit view. The multi-body-dynamic modelling and simulation environment FLIGHTLAB [14] was used to create the simulation model (RF-B412) of the B412 ASRA aircraft, using data measured on the aircraft from several flight test campaigns in support of control law design [15] and simulation fidelity research [16-25]. Two Further flight test campaigns have taken place during the current Rotorcraft Simulation Fidelity (RSF) project. The first flight trial provided data from clinical inputs to support further model development [25]; the second focused on measuring LDO characteristics.

Figure 5. NRC Bell 412 ASRA and view from the cockpit during the Roll-Step MTE

Figure 6. UoL Heliflight-R and view from the cockpit during the Roll-Step MTE.

2.1. Updates to the Legacy Simulation Environment

Height and speed cueing issues were a contributor in the HQR results presented in [11], where the pilot reported that vehicle dynamics that were predicted to be Level 1 did not result in Level 1 assigned handling qualities. The flight-simulator visual database lacked fine-grained surface texture and so central and peripheral 'visual flow cues were lacking. To remedy these visual cues deficiencies, the grass texture was increased and a pointer or 'bug' in the form of a yellow arrowhead was added at the 50ft marker in the radalt.

With the updates, the pilot was able to meet the desired performance standards, commenting that the grass surface texture provided good peripheral visual cues, resulting in less overcontrolling in the roll axis, more accurate height keeping and improved longitudinal speed cueing during the tracking phases. Consequently, less time was spent looking into the cockpit at the radalt display. When the pilot did look inside the cockpit for visual cues from the radalt, the new pointer or 'bug' allowed the aircraft height in relation to the 50ft datum to be scanned rapidly and excursions from 50ft immediately identified.

2.2. Simulation Model

To isolate the effects of LDO stability from other HQs, the test configurations should exhibit Level 1 for the non-LDO HQs. Typically, such HQ improvements are implemented through a stability augmentation system (SAS). However, in the present work, the HQs have been 'supplemented' using a delta-derivative technique [17] to, e.g. improve the pitch and roll bandwidth, reduce pitch-from-heave and roll-from-pitch cross couplings, which were not Level 1 in the baseline F-B412; The advantage of this approach is that it allows selected HQs to be improved instead of several derivatives being augmented by a single SAS channel. The handling qualities of the test configurations are summarized in Appendix 2.

The LDO test configurations illustrated in Figure 3 have been developed from the RF-B412 with supplemented HQs using the weathercock stability derivative N_v and the yaw damping derivative N_r. The magnitude ratio of the roll and yaw motion for the LDO test configurations was maintained constant to ensure that HQ effects due to roll/yaw/sideslip ratios and their phase did not impact the primary objective. This was achieved by modifying the dihedral effect, L_v, to maintain the defined ratio p/r ratio of 1, 1.5 or 2. N_p was supplemented to maintain ψ_β. In addition, N_{ped} was varied to give the same yaw control sensitivity as the B412 (16 deg/s.inch) across all configurations; this also ensures performance exceeds the minimum ADS-33E-PRF Level 1 yaw control power requirement [4]. The delta derivatives are recorded in Appendix 3.

3. PILOT-IN-THE-LOOP SIMULATION TRIALS

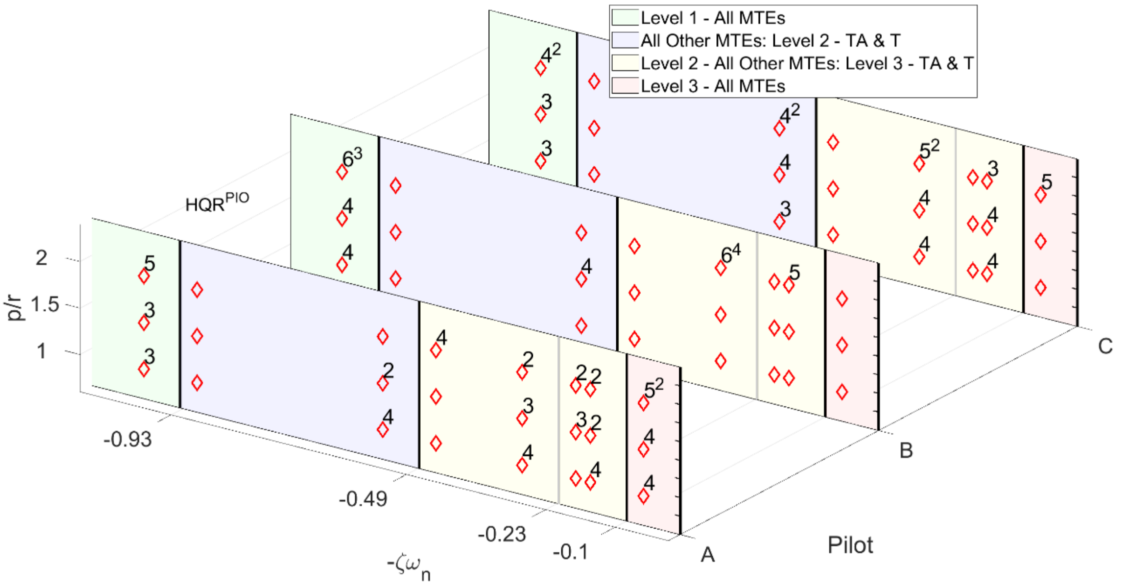

Figure 7. HQRs for the roll step MTE with varying LDO relative damping and frequency.

The HQRs, and where relevant, pilot-induced-oscillation (PIO) ratings returned by three pilots for the configurations tested to date are recorded in Figure 7. Each slice plot has the same format as Figure 3 and presents the ratings for a single pilot. Results from Pilot A are on the front slice plot, pilot B HQRs on the middle slide plot and finally pilot C HQRs on the slice plot at the rear. Some general observations on the HQRs are made before discussing the results in more detail:

1. The HQRs returned by the pilots generally improve as damping increases.
2. The HQRs returned by the pilots generally degrade as *p/r* increases.
3. *p/r* = 1.5 best correlates with the corresponding military-type task target acquisition and tracking boundary.
4. A lower *p/r* results in Level 1 configurations with $\zeta = 0.21$.
5. No Level 1 ratings returned when *p/r* is increased to 2.

These general trends are caveated by the following anomalies in the results:

1. Pilot B did not return a Level 1 HQR with a predicted Level 1 configuration.
2. Pilots A and C returned Level 1 HQRs for predicted Level 2 case C2-15.
3. Pilots A also returned Level 1 HQRs for predicted *p/r* = 1.5 Level 2 damping cases when $\zeta\omega_n \leq$-0.15.

Before focusing on the main questions of how the *p/r* ratio impacts HQs, and comparison with existing HQ boundaries, we need to better understand why the cases highlighted depart from 'theory'.

Consider LDO configuration C1-98. Figure 8 and Figure 9 show the performance and control inputs from the three pilots. Pilot A employed the most basic strategy, where the lateral translation and tracking was accomplished, primarily, using lateral stick. Very little pedal input was used to coordinate the turn. Instead, the pilot relied on the natural proverse yaw for turn coordination. Few small pulse inputs in longitudinal cyclic and collective were applied to maintain desired height and speed performance. Pilot C employed a similar strategy but used some pedal to coordinate the turn. Pilot C also flew the task more aggressively, completing the transition approximately 500ft before the tracking phase began to give additional time to stabilise the aircraft for the tracking phase. Both pilots A and C returned Level 1 HQRs. Pilot B however, initiated the turn in a similar manner to Pilot C (lateral cyclic and pedal to coordinate the turn), but reversed the pedal to align the heading with task heading, side-slipping the aircraft into position for the tracking phase. Another key difference between this strategy and others was that the collective was used sparingly, resulting in degraded height and consequently speed tracking performance.

The strategy discussion is re-enforced when considering the number of control attack points [27] in Table 1, a metric that captures the amplitude and rapidity of control movements. Few off-axis attack points were recorded for Pilot A; the total less than recorded for the primary lateral cyclic. The more aggressive strategy adopted by Pilot C is also evident, with more lateral stick and off-axis compensatory attack points. The main difference between these strategies and that adopted by Pilot B is in the pedal activity, reflected by the number of pedal attack points – more than double that of Pilot C who also uses the pedals to coordinate the turn and almost 5 times more than Pilot A.

Evidently, the strategy which involves side-slipping the aircraft into the tracking phase increases the workload and compensatory inputs beyond that acceptable for Level 1 HQs.

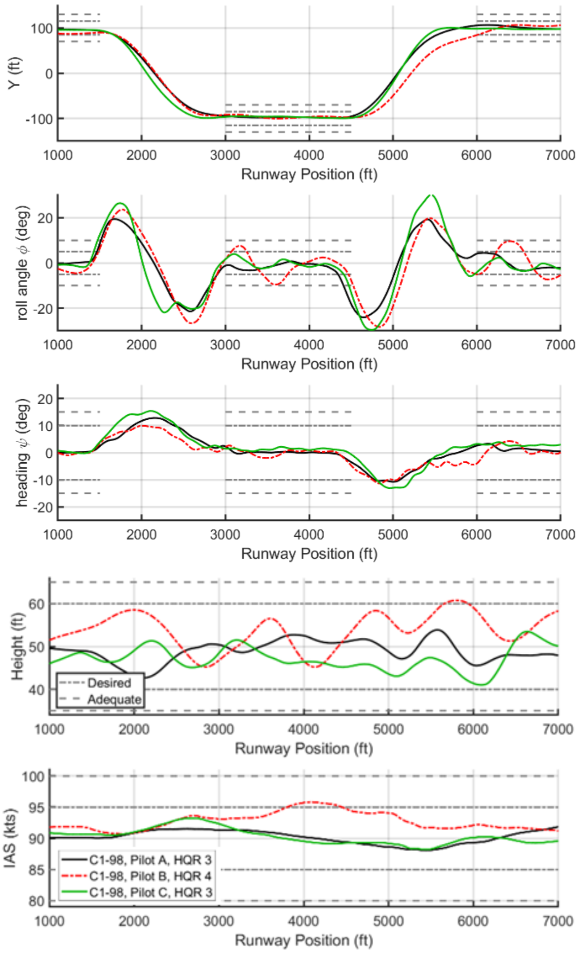

Figure 8. C1-98 performance by the 3 pilots for C1-98.

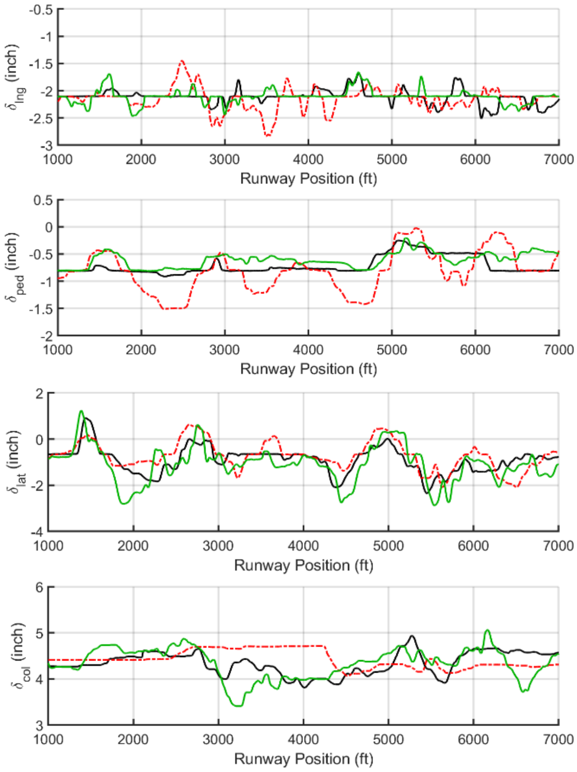

Figure 9. Control inputs by the three pilots for C1-98.

Table 1. C1-98. Number of Attack Points.

	δ_{lat}	δ_{lng}	δ_{col}	δ_{ped}
Pilot A	20	8	6	5
Pilot B	27	15	3	23
Pilot C	37	8	15	9

3.1. Configuration C2-15

Next consider the anomalous case (C2-15) where Level 2 HQs were predicted but Level 1 HQRs returned by both Pilots A and C. Anomalous because Level 2 HQRS were returned for configurations consisting of the same *p/r* = 2, with more or less damping. Consider first the performance (Figure 10) and control (Figure 11) traces for Pilot A (black lines). Desired performance is clearly met and off-axis inputs are restricted to minimal pulse-like corrective inputs. The strategy adopted by Pilot C was again similar to that in C1-98; more aggressive than Pilot A, to give greater time to stabilise the aircraft before reaching the gates. The lateral stick inputs were therefore larger in magnitude, as evident in the attack chart in Figure 12, and the number of compensatory off-axis inputs greater than those from Pilot A (Table 2). Pilot B continued to side-slip into position and then roll level for stabilisation. The side-slipping element involved applying doublet inputs which triggered the LDO, causing Pilot B to have to work much harder in roll and yaw to stabilise the oscillation and maintain track, only managing to bring the oscillation under control when well into the runway tracking phase of the task. Consequently, this higher workload coupled into height and speed further increasing workload.

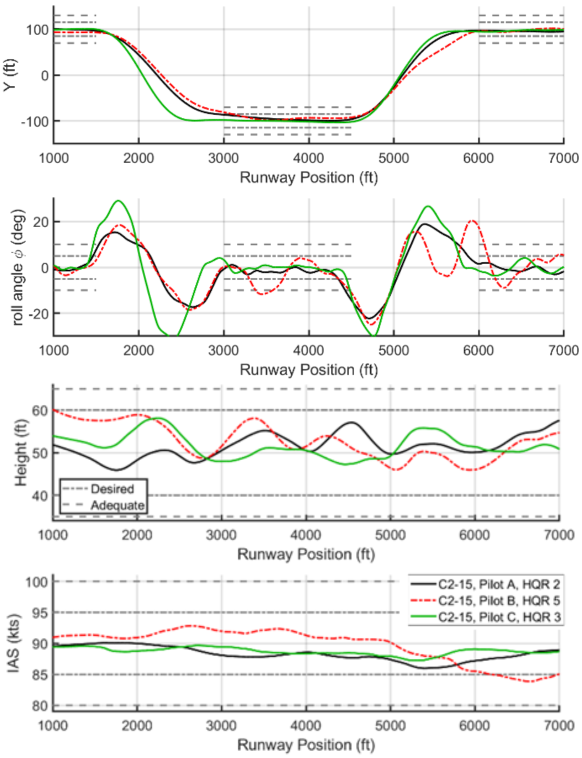

Figure 10. Performance for the three pilots for C2-15.

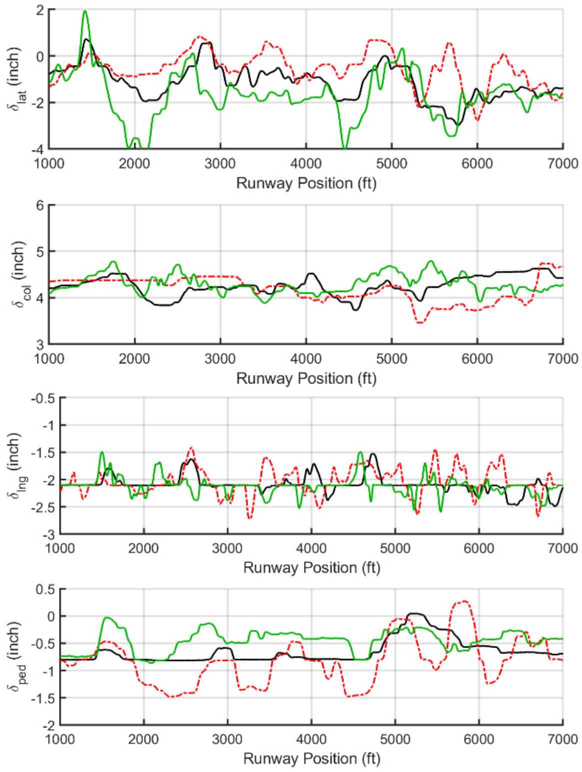

Figure 11. Control activity for the three pilots for C2-15.

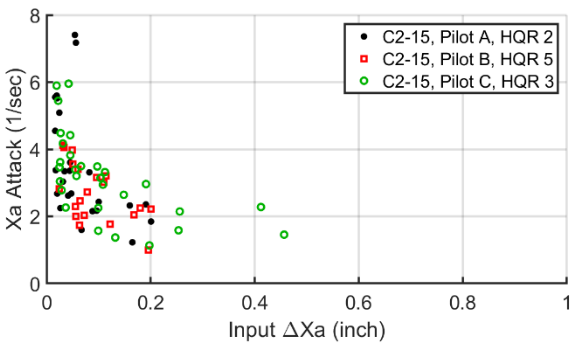

Figure 12. Lateral stick attack for each pilot flying configuration C2-15.

Table 2. C2-15. Number of Attack Points.

	δ_{lat}	δ_{lng}	δ_{col}	δ_{ped}
Pilot A	26	10	6	8
Pilot B	38	27	3	24
Pilot C	45	20	11	12

3.2. Impact of *p/r* on HQs

So, what of the impact of *p/r* on the assigned HQs within the existing boundaries. The general trend in Figure 7 of increasing *p/r* is to degrade the handling qualities.

Figure 13 illustrates time histories from Pilot A for the Level 1 cases with increasing *p/r* ratio. Performance remains within Level 1 as *p/r* increases to 2. However, workload in the roll axis increased during the bank angle capture phase when entering the gates and stabilising through the gates. The pilot commented that desired performance was only marginally achieved with moderate compensation.

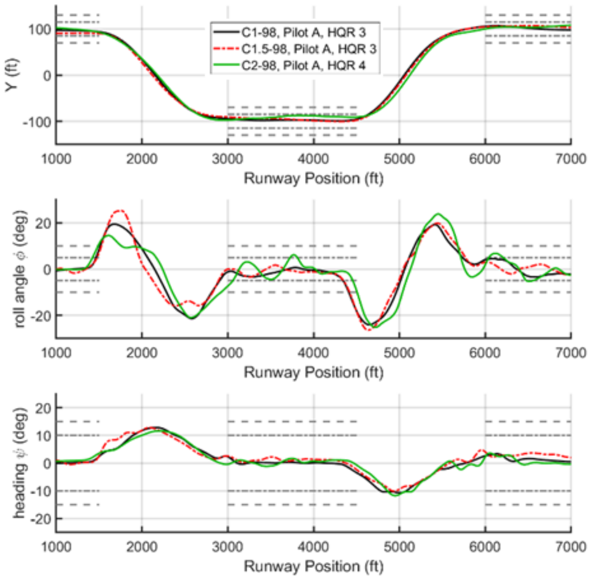

Figure 13. Directional/Lateral control and task performance in the MTE, Pilot A flying configurations with predicted Level 1 HQs.

This is confirmed when considering the number of attack points in the MTE shown in Table 3. As the amount of roll in the oscillation increases, Pilot A applies additional compensatory inputs in all axes.

Table 3. Pilot A. Number of Attack Points.

	δ_{lat}	δ_{lng}	δ_{col}	δ_{ped}
C1-98	20	8	6	5
C1.5-98	34	15	19	13
C2-98	45	25	11	10

Returning to the research questions relating the amount of damping to HQ Level boundaries, and the impact of *p/r* ratio, the research to date has exposed some anomalous results, explained through variations in pilot strategy. However, regardless of the strategy, the expected result that handling qualities improve as damping increases holds for each pilot, particularly with low *p/r* ratio.

Comparing results with existing boundaries however becomes somewhat more complex. For example, Pilot B's results do not conform with the existing Level 1 HQ boundary, as the strategy he adopted required moderate levels of compensation.

Turning to Pilot A and C, ratings in the same HQ Levels for configurations with *p/r* = 1 were returned, suggesting that the Level 1 Target Acquisition and Tracking boundary of $\zeta = 0.35$ can be relaxed to $\zeta = 0.19$, i.e. the same as that defined for the All Other MTEs category.

Increasing *p/r* to 1.5 yielded results that are in line with current ADS-33 Target Acquisition and Tracking requirements for Pilot C. Pilot A did not trigger the LDO when $-\zeta\omega_n \leq -0.15$, returning Level 1 ratings for these configurations. Finally, increasing *p/r* to 2 yielded no Level 1 ratings. All pilots had to adapt their task strategies, reducing their cyclic gain and pedal usage to achieve adequate performance. With this higher *p/r* ratio, pilots were more likely to experience a roll PIO when entering and during the stabilization phase of the task. However, the occurrence of PIOs, as reflected by PIO ratings, did not follow an obvious pattern. The 'worst' case was pilot B flying C15-28, linked with an HQR 6; adequate task performance was barely achieved, as a consequence of the pilot struggling to control the LDO with pedals. Pilot interaction with a weakly damped LDO varied from this case to pilot C flying C2-15, already discussed, where the LDO was not triggered and an HQR 3 returned. Of course, the task was flown in still air. Gusts and turbulence are likely to impact the results, perhaps significantly, if the pilot is forced to engage with the 'nuisance' to maintain performance; a question worthy of further investigation.

Regarding the Level 3 boundary, no Level 3 ratings were returned, even for the low damping configurations. This is unsurprising in that Ref. [9] does highlight that the boundary is located as a matter of convenience of format. Furthermore, Ref. [9] indicates that tasks were able to be completed even with unstable configurations, but the boundary was set to disallow unstable modes.

4. FUTURE WORK

There are several aspects of the appraisal of LDO HQs that need attention to complete the study. The paper has focused on exploring *p/r* ratios between 1 and 2, building on previous work with lower ratios and a wider range of frequencies. But further testing and analysis are needed to complete the matrix and also better understand the impact of pilot strategy on the task, the strength of which was an unexpected result from the study.

The HQ characteristics and potential deficiencies when the roll contributions to the LDO increase has been shown to require more complex compensation strategies for MTEs like the roll-step. It seems clear that MTEs more representative of civil operations, for example, cruise and approach tasks in IMC need to be explored to address the questions related, for example, to the CS-29 dynamic stability requirements. The inclusion of atmospheric disturbances and their impact on the levels of compensation required to suppress a weakly damped LDO in both military and civil MTEs is an important area for exploration.

5. CONCLUDING REMARKS

An investigation into the suitability of current Lateral-Directional-Oscillation handling qualities, military and civil, standards has been conducted using a Bell 412 FLIGHTLAB simulation model, supplemented with stability derivatives to create a range of test configurations. For this preliminary study, the selected Mission Task Element was the Roll-Step, a visual, near-Earth military-style task.

The legacy task visual cueing environment was updated to improve the micro-texture, macro-texture and instruments, allowing the pilots to better perceive translational cues and return Level 1 ratings for the predicted Level 1 handling qualities baseline configuration.

Handling qualities generally degraded as the amount of roll in the LDO increased. With a *p/r* ratio of 1, the HQ Levels corresponded with those for the ADS-33 'All Other MTEs' category. When *p/r* was increased to 1.5, the HQ Levels corresponded with the ADS33 'Target Acquisition and Tracking' performance requirements. Finally, when *p/r* was increased to 2, the pilots generally required greater compensation than acceptable to achieve desired performance and, in most cases, also experienced a PIO with *p/r* = 2, albeit not a threat to task performance (PIO 2).

An unexpected result was that the flying strategy adopted by Pilot B did not result in any Level 1 HQRs, even for predicted Level 1 HQs; the compensation required to stabilise after side-slipping the aircraft into the turn was perceived as moderate. Furthermore, Pilot B did not attempt to adapt his strategy to reduce workload even though he triggered an LDO-based PIO (PIO 4).

The continuing research will focus on completing the configuration test matrix and expand to include civil-style IMC tasks and explore the impact of atmospheric disturbances on the HQs.

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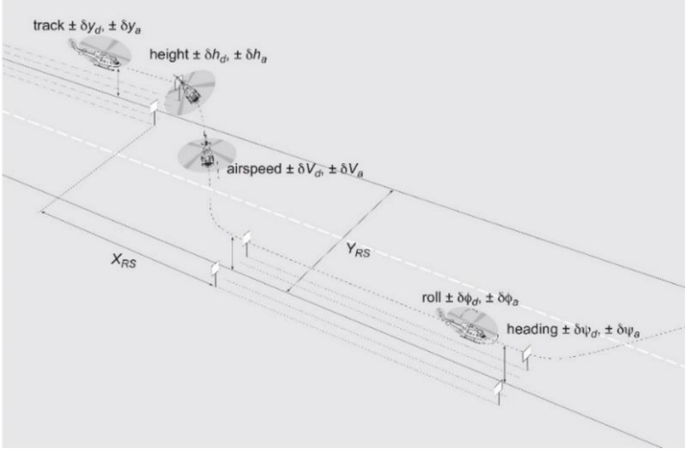
Appendix 1: Roll-Step MTE

<table>
<tr><td>Title</td><td colspan="2">Roll-step</td></tr>
<tr><td>Mission</td><td colspan="2">Scout-Attack</td></tr>
<tr><td>Critical HQ</td><td colspan="2">HQs associated with lateral-directional stability</td></tr>
<tr><td>Objectives</td><td colspan="2">• Check ability to manoeuvre in forward flight with respect to the ground.
• Check roll and heave co-ordination.
• Check turn co-ordination for moderately aggressive forward-flight manoeuvring.
• Check for objectionable inter-axis coupling during moderately aggressive forward-flight manoeuvring.</td></tr>
<tr><td>Manoeuvre Description</td><td colspan="2">The pilot is required to fly through an ordered series of these gates which form the roll-step task. The manoeuvre starts with the aircraft displaced aft of the runway threshold, lined up with the left-hand edge of the runway at an altitude of $h$ft trimmed at Vknots. The manoeuvre requires the pilot to traverse the runway, Y_{RS}ft, over a distance of X_{RS}ft and then capture and track the right-hand edge of the runway, before traversing back across the runway and completing the manoeuvre by capturing and tracking the left hand runway edge. Speed and altitude requirements must be maintained throughout the MTE. Roll attitude, $\delta\phi$°, heading $\delta\psi$°, and lateral ground track requirements, within the δyft, are applied between the gates on the runway edges (see figure below).</td></tr>
<tr><td>Test Course Description</td><td colspan="2">200ft wide airport runway which is flanked by a series of numbered gates 500ft apart (see figure below). The lateral separation of the gates indicates the adequate performance requirements; half of this distance is the desired performance requirement.</td></tr>
<tr><td>Performance Standards</td><td>Desired (<i>d</i>)
• Maintain lateral ground track, δy along runway edge: ±15ft
• Maintain altitude, h: ±10ft
• Maintain speed V: ±5kts
• Maintain heading through gates $\delta\psi$: ± 10deg
• Maintain bank angle through gates $\delta\phi$: ± 5deg</td><td>Adequate (<i>a</i>)
• ±30ft
• ±15ft
• ±10kts
• ± 15deg
• ±10deg</td></tr>
<tr><td colspan="3">

Roll-step performance standards</td></tr>
</table>

Appendix 2: Summary of Predicted HQs of SRF-B412

Criteria	Axis	Direction	Boundaries	90 Knots	
				Baseline	HQ_{sup}
Stability	LDO		TA&T	3	3
			All Other MTEs	2	2
	Spiral Mode			1	1
	Phugoid Mode		Fully Attended	1	1
			Divided Attention	2	2
	Short Period Mode		Fully Attended	1	1
			Divided Attention	1	1
Bandwidth	Roll		TA&T	1	1
			All Other MTEs - VMC and Fully Attended Operations	1	1
	Pitch		TA&T	2	2
			All Other MTEs - VMC and Fully Attended Operations	2	1
	Yaw		TA&T	2	1*
Quickness	3.4.6.2 Roll	Left	TA&T	2	1
			All other MTEs	1	1
		Right	TA&T	2	1
			All other MTEs	1	1
Control Power	3.4.6.3 Roll	Left	Limited/ Moderate/ Aggressive/ TA&T	1	1
		Right	Limited/ Moderate/ Aggressive/ TA&T	1	1
	Pitch		requires multi-axis inputs		
	Yaw	Left	Aggressive	1	1
		Right	Aggressive	1	1
Cross Coupling	3.4.3 Flight Path	Front	requires multi-axis inputs		
	3.4.5.1 Pitch from coll.		small	Pass	Pass
	3.4.5.1 Pitch from coll.		large	Pass	Pass
	3.4.5.2 Roll from pitch		Aggressive	1	1
	3.4.5.3 Pitch from roll		Aggressive	1*	1*
	Roll-Sideslip (3.4.7.1)		Bank angle oscillation limitations	1	1
	Roll-Sideslip (3.4.7.2)		Sideslip excursion limitations	1	1

*Based on ADS-33F-PRF

Appendix 3 LDO Supplemented Derivatives (includes renovation to RF-B412)

config	$\triangle N_v$	$\triangle N_r$	$\triangle L_v$	$\triangle N_{ped}$	$\triangle N_p$
RF-B412	0.024	-1.029	-0.037	-0.671	0
1-05	0.0029	0.5451	-0.0308	-0.17	-0.377
1-15	0.0029	0.2976	-0.0294	-0.036	-0.346
1-18	0.0034	0.2458	-0.0292	0.01	-0.344
1-28	0.0051	0.109	-0.0295	0.12	-0.311
1-44	0.0072	-0.3602	-0.0287	0.23	-0.218
1-54	0.0088	-0.5528	-0.0285	0.29	-0.187
1-88	0.0182	-1.1489	-0.0283	0.53	0.065
1-98	0.0215	-1.2234	-0.0269	0.59	0.313
1.5-05	0.0011	0.2654	-0.0514	-0.207	-0.348
1.5-15	0.0023	0.0146	-0.0495	-0.081	-0.286

1.5-18	0.0023	-0.0189	-0.0495	-0.063	-0.286
1.5-28	0.000	-0.2734	-0.0488	0.08	-0.255
1.5-44	0.0074	-0.6418	-0.0484	0.28	-0.193
1.5-54	0.01	-0.8359	-0.0492	0.35	-0.16
1.5-88	0.0196	-1.4669	-0.0476	0.60	0.088
1.5-98	0.023	-1.5973	-0.0473	0.67	0.181
2-05	-0.0003	-0.0073	-0.0712	-0.225	-0.319
2-15	0.0014	-0.2515	-0.0682	-0.108	-0.257
2-18	0.0014	-0.2856	-0.0682	-0.099	-0.257
2-28	0.0044	-0.5362	-0.0676	0.04	-0.195
2-44	0.0082	-0.8906	-0.0671	0.24	-0.133
2-54	0.0105	-1.1061	-0.0665	0.37	-0.102
2-88	0.0239	-1.6409	-0.0675	0.65	0.177
2-98	0.0255	-1.8432	-0.0671	0.72	0.177

2021-01-04

Appraisal of handling qualities standards for rotorcraft lateral-directional dynamics

Cameron, Neil

European Rotocraft Forum

Cameron N, White MD, Padfield GD, Lu L. (2021) Appraisal of handling qualities standards for rotorcraft lateral-directional dynamics. In: 47th European Rotorcraft Forum: ERF21, 7-9 September 2021, Virtual Event

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