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Preventing Loss of Control
Aiding pilot in recovery from roll-limited situations

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Roll control is particularly of interest in asymmetric power situations and for damaged aircraft. Reduction in lateral control due to asymmetric power is a problem, especially for propeller aircraft. If pilots adhere to all good practices and the V_{mca} speed, they might not experience roll control limited situations at all. However, if they exceed these limits or use ineffective controls, and data support that these situations do occur, they might enter a roll limited condition that requires special techniques to recover, for which pilots are neither trained nor have any instrumental guidance to aid the recovery. This paper discusses the research done to design instrumental guidance for pilots to recover from roll limited situations due to engine asymmetry as well as aircraft damage. This new instrumentation was tested in the TU Delft SIMONA research simulator with experienced pilots.

Contents

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Nomenclature

α = Angle of Attack [rad]
β = Aerodynamic side-slip angle (rad)
δ_a = Aileron deflection (rad)
δ_r = Rudder deflection (rad)
δ_{TR} = Right engine normalized thrust (-)
δ_{TL} = Left engine normalized thrust (-)
δ_c = Used to address all control input (-)
ϕ = Roll angle (rad)
ω = Roll rate (rad/s)
Ω = Skew symmetric roll rate matrix which transfers the vector product $\omega \times v$ in a matrix multiplication Ωv (rad/s)
AoA = Angel of Attack [rad]
b = Wingspan (m)
$c.g.$ = Centre of gravity (m)
I = Inertia tensor (kgm^2)
KTAS = Knots True Airspeed (knots)
l = Roll coefficient [-]
m = Pitch coefficient [-]
m = Aircraft mass (kg)
n = Yaw coefficient [-]
V = True Airspeed (m/s)
p = Roll rate (rad/s)
q = Pitch rate (rad/s)
r = Yaw rate (rad/sec)
u = Velocity in Body x -direction (m/sec)
v = Velocity in Body y -direction (m/sec)
w = Velocity in Body z -direction (m/sec)
V_c = Minimum Lateral Speed (m/sec)
V_{mca} = Minimum control speed air (knots)
x = Aircraft body axis in plane of symmetry pointing forward
y = Aircraft body axis perpendicular to plane of symmetry pointing right
z = Aircraft body axis in plane of symmetry pointing down

I. Introduction

The fact that the Wright Brothers were the first to fly was not only an achievement in aerodynamics and propulsion, but first and foremost in aircraft control [1]. They were the first who could effectively control a powered aircraft in flight and make turns without crashing. One hundred and fourteen years later, specific control areas are still cumbersome. Pilots still unintentionally stall and get into unusual attitudes. In this paper we focus on lateral-directional control problems, essentially the same problem that the Wright Brothers solved with ‘wing warping’. Roll control is normally not a problem for pilots, most aircraft stall before they run out of lateral-directional control. This situation changes dramatically when an aircraft experiences an engine failure. In this asymmetric power situation the aircraft will often depart in roll well before the stall. When a pilot has to recover from a roll limited situation he has to perform a manoeuvre for which he is not trained. Furthermore, this manoeuvre goes against the ‘natural and trained’ way he is used to flying his aircraft. In my research a system was developed to aid the pilot in recovery from roll limited situations. This system can also predict safe flying speeds for damaged aircraft. Tests revealed that this system is capable of aiding the pilot, but only when combined with rather extensive training.

II. The Theory

First we would like to differentiate between control and manoeuvring; in line with the definitions given in [2] we define control as a change of the state of the aircraft and manoeuvring in line with [3] as the change of flightpath. As shown in [4] this control definition can be modified into easily interpretable terms for pilots. For directional control this modifies to the ability to control side slip (β) and for roll control it modifies to the ability to change roll angle (ϕ). The lateral control limit can than be expressed as the capability to make a certain roll angle change within a specific time, and this is also in line with the roll requirements as expressed in the Mil. Specs. [5]. Lateral control should not be confused with the capability to change heading, because this capability depends on the available Angle of Attack and is therefore primarily dependent on the available longitudinal control.

II.A. The problem is roll control

When we look into the lateral-directional control of aircraft as done by [4], we notice that lateral control limits are normally reached prior to directional limits. The reason for this is simple: an aircraft can have a considerable side slip before the vertical tail stalls[a]. An example of this is shown in Fig. 1, which depicts the available aileron for a Piper Seneca (PA-34) with the left engine at maximum power and the right engine inoperative while the rudder is fully deflected to the left. This figure shows that roll control is lost at 71 KTAS when the required aileron exceeds the available aileron. At this point there is an excessive side slip, however, the fin stall angle is not yet reached. Because of this fact we can focus on the lateral control limit.

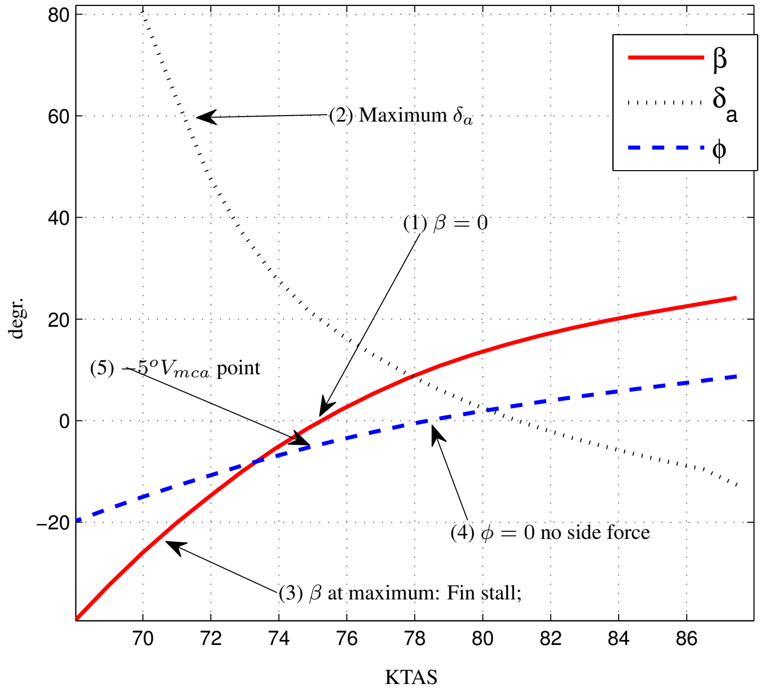

Figure 1: PA-34 Right Engine Inoperative, Left Engine Maximum Power and Rudder Full Left

II.B. Engine effects

As mentioned in the introduction, engine failures are the most common cause of limitations in roll control, but this effect is much stronger in propeller aircraft than in jet powered aircraft. This is the reason we will focus on propeller aircraft. There are several reasons why propeller aircraft pose a more severe control problem: propeller thrust increases with a decrease in airspeed [6], there is a large cross flow effect on the vertical tail [7], and there is a lift difference

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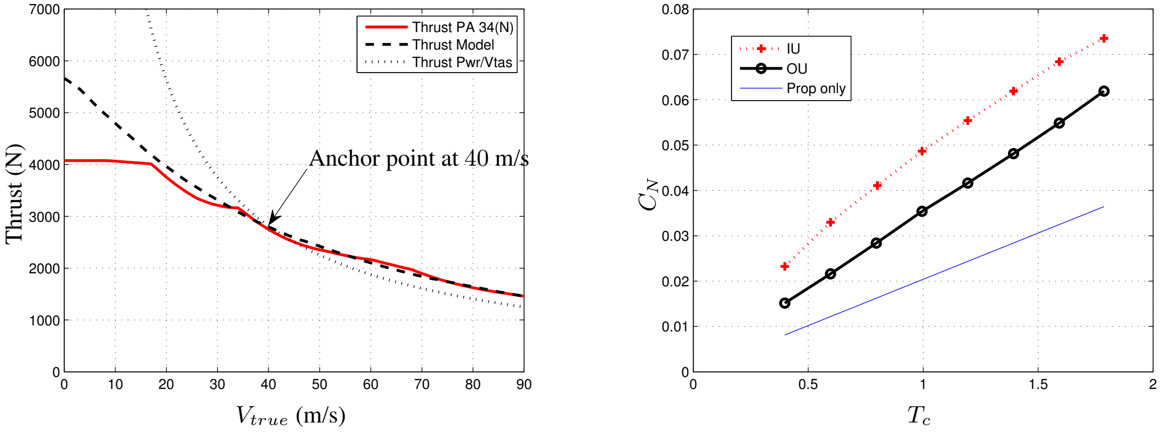
[a] The primary reason is the delta shape of the vertical tail and its lower aspect ratio compared to the wing.

cause by the propeller slipstream over the wings. To predict the roll control limits, it is essential to know how the airspeed will affect the roll performance and therefore we take a closer look into the velocity effect on lateral-directional control for propeller aircraft.



(a)

(b)

Figure 2: Propeller effects (a) Thrust of a PA-34; Comparing three models: the non-linear model, the blade model and the $\frac{P}{V_{true}}$ approximation (b) Mannee: Effect T_c on C_N for Inboard Up (IU) and Outboard UP (OU) turning propellers compared to the effect without vertical tail for a high wing configuration

The effect of thrust with airspeed is depicted in Fig. 2a. Three models are compared: the standard $\frac{1}{V}$ relationship, the non-linear model based on a software package for the PA-34, [8] and a blade model simulation made by the author. As can be seen the $\frac{1}{V}$ approximation works well for the PA-34. At very low speeds this approximation will of course fail[b]. For our determination of the roll control limits this relation works well, however for determining thrust at very low speed a different approach is needed.

The cross flow effect, as depicted in Fig. 2b, is normally considered to be linearly dependent on the thrust. However, when the wind-tunnel experiments of Mannee are compared with actual flight tests [9], this effect shows a slightly less linear relation with thrust. But from a practical perspective the $\frac{1}{V}$ relation for the directional moment caused by the asymmetric power is reasonably accurate. However, the roll moment caused by the slipstream behaves differently with airspeed. Simulation from [4] show, as depicted in Fig. 3, a much stronger relation with airspeed of approximate $\frac{1}{V^2}$.

II.C. Modelling V_c

The essence of the V_c prediction algorithm is that it presents the pilot with the minimum airspeed that guarantees sufficient roll control *based on the present control inputs and aircraft state and corrected for possible damage to the aircraft*. In this way the pilot receives feedback on his control actions and can judge if they contribute to a more favourable V_c or not.

After the initial test [4, Chapter 7] it became clear that presenting two V_c speeds was much better. The first value, V_{c1} presents the minimum airspeed to guarantee sufficient roll control based on the present engine settings and the present side slip. The second value, V_{c2} presents the airspeed that will give the required roll performance if maximum rudder is used. The spread between the two values is now an indication for the pilot how much can be gained with additional rudder.

When we want to model the roll control of a damaged aircraft we can not assume that mass, c.g. location and inertia tensor are known. This uncertainty leads to a model with an increased number of parameters. In [4, Chapter 4] the following relations are derived for $\dot{\beta}$, $\dot{p}$ and $\dot{r}$.

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[b] This relation would work much better if it was not related to the true airspeed but to the velocity of the air in the propeller slipstream.

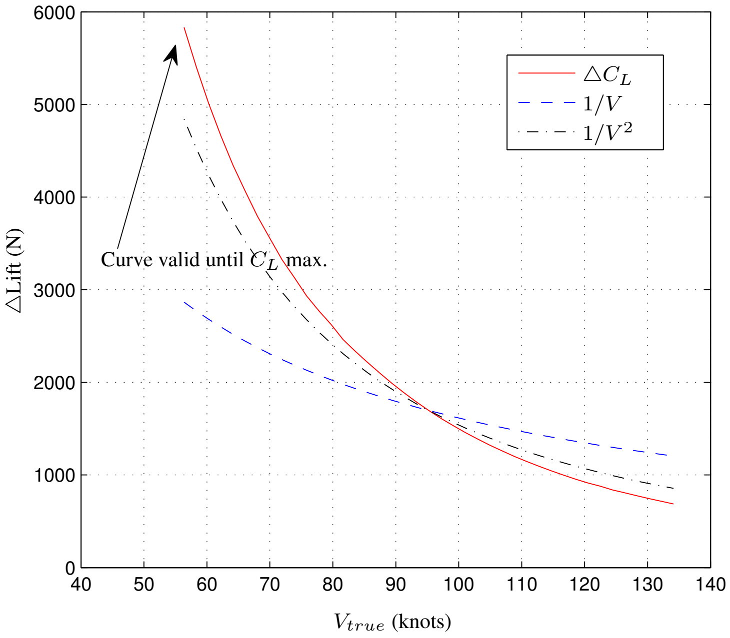


Figure 3: Additional lift caused by propeller slipstream for the PA-34 using maximum power. Graph only valid until maximum C_L is reached. The $1/V$ and $1/V^2$ curves are 'anchored' to the $\triangle L$ at 97.2 knots.

$$\begin{aligned}\frac{b\dot{\beta}}{V} = \quad & y_\beta\beta + y_\phi\phi + y_p(\tfrac{pb}{2V}) + y_r\left(\tfrac{rb}{2V}\right) + y_{\delta c}\delta c + \\ & + y_x\left(\tfrac{pb}{2V}\tfrac{qb}{2V} + 0.5\tfrac{\dot{r}b^2}{2V^2}\right) + y_y\left(\left(\tfrac{pb}{2V}\right)^2 + \left(\tfrac{rb}{2V}\right)^2\right) + y_z\left(\tfrac{qb}{2V}\tfrac{rb}{2V} - 0.5\tfrac{\dot{p}b^2}{2V^2}\right)\end{aligned} \tag{1}$$

and

$$\begin{aligned}\frac{\dot{p}b^2}{2V^2} = & \, l_\beta.\beta + l_p.\left(\frac{pb}{2V}\right) + l_r.\left(\frac{rb}{2V}\right) + l_{\delta_a}.\delta_a + l_{\delta_r}.\delta_r + l_{TL}.\delta_{TL} + l_{TR}.\delta_{TR} + \\ & + l_{\dot{q}}.\left(\frac{\dot{q}b^2}{2V^2}\right) + l_{q^2}.\left(\frac{qb}{2V}\right)^2 + l_{p^2}.\left(\frac{pb}{2V}\right)^2 + l_{r^2}.\left(\frac{rb}{2V}\right)^2 + l_{qp}.\left(\frac{qb}{2V}\frac{pb}{2V}\right) + \\ & + l_{qr}.\left(\frac{qb}{2V}\frac{rb}{2V}\right) + l_{pr}.\left(\frac{pb}{2V}\frac{rb}{2V}\right) + l_{ax}.\left(\frac{a_x b}{2V^2}\right) + l_{ay}.\left(\frac{a_y b}{2V^2}\right) + l_{az}.\left(\frac{a_z b}{2V^2}\right) + dF_l\end{aligned} \tag{2}$$

and

$$\begin{aligned}\frac{\dot{r}b^2}{2V^2} = & \, n_\beta.\beta + n_p.\left(\frac{pb}{2V}\right) + n_r.\left(\frac{rb}{2V}\right) + n_{\delta_a}.\delta_a + n_{\delta_r}.\delta_r + n_{TL}.\delta_{TL} + n_{TR}.\delta_{TR} + \\ & + n_{\dot{q}}.\left(\frac{\dot{q}b^2}{2V^2}\right) + n_{q^2}.\left(\frac{qb}{2V}\right)^2 + n_{p^2}.\left(\frac{pb}{2V}\right)^2 + n_{r^2}.\left(\frac{rb}{2V}\right)^2 + n_{qp}.\left(\frac{qb}{2V}\frac{pb}{2V}\right) + \\ & + n_{qr}.\left(\frac{qb}{2V}\frac{rb}{2V}\right) + n_{pr}.\left(\frac{pb}{2V}\frac{rb}{2V}\right) + n_{ax}.\left(\frac{a_x b}{2V^2}\right) + n_{ay}.\left(\frac{a_y b}{2V^2}\right) + n_{az}.\left(\frac{a_z b}{2V^2}\right) + dF_n\end{aligned} \tag{3}$$

This approach led to a considerable increase in the number of parameters compared to modelling based on known mass, c.g. and inertia tensor. We will come back to the model size issue later.

The next step was the design of the V_c algorithm. If the available aileron deflection ($\delta_{a,av}$) and all the aircraft control an stability parameters are known it can be proven [4] that for a certain roll angle change ($\delta\varphi_{req}$) in a fixed time period (T) the V_c can be approximated by solving for V in Equation 4.

$$\varphi_{req} = \left(\tau e^{-\frac{T}{\tau}} + T - \tau\right) p_{max} \tag{4}$$

where

$$\tau = \frac{-b}{V\, l_p} \tag{5}$$

and

$$p_{max} = -\frac{2V}{b}\frac{l_{\delta_a}}{l_p}\delta_{a,av} \tag{6}$$

This simple equation would work if there was no thrust asymmetry nor any asymmetric mass distribution. In that case the available aileron would not change with airspeed. However, because the V_c calculation is specifically needed for these conditions, the available aileron deflection is not necessarily constant and velocity dependent corrections are required. Furthermore, if during a deceleration the rudder will reach its maximum deflection (in order to maintain present β), the β will increase and additional aileron is needed to counter the roll due to the increased β. Another effect that has to be accounted for is Dutch Roll. If rudder is at maximum deflection at the V_c the adverse yaw will excite the Dutch Roll and this will also affect the roll angle change. All these required corrections are described in detail in [4, Chapter 4].

II.D. Challenges

Having a correct model and a V_c algorithm is a necessary, but not sufficient condition to make a V_c indication that is usable for a pilot. It was found [4] that three specific adaptations were required.

Firstly, the model size needed to be tuned to make accurate and fast V_c prediction possible. It was shown in [4, Chapter 5] that the higher order aircraft parameters, that were determined after aircraft damage was detected, lack the needed accuracy to predict correctly for the maximum roll condition at a lower airspeed, and would even degrade and delay the solution. Therefore some higher order parameters had to be omitted.

Secondly, it was found that error detection based on the change in the model residue, was not usable to detect failures in smooth and turbulent conditions without false alarms or missed detections. A new detection method was developed based on the Sequential Probability Ratio Test (SPRT) [10] in which the residue was projected on the aircraft parameters and the SPRT was applied to this projected error [4, Appendix D].

Thirdly, it was necessary to optimize the normalisation and the reset of the covariance matrix after failure detection [4, Chapter 6]. Furthermore, it was proven that it was more accurate to predict the roll angle change for a short time interval due to inaccuracies in the parameters that determine the adverse yaw effect.

II.E. Off-line results

After all these optimization efforts it was found that an accurate prediction of the V_c was achievable. This was tested in scenarios with and without turbulence for an array of failures including engine failures, control failures, lateral asymmetries and rudder hard-overs. One example is shown in Fig. 4, this figure shows how the V_c value converged to the correct value after the aircraft had experienced a sudden lateral asymmetry at 30 seconds into the simulation. Two V_c values are calculated, one for a right roll and the other for a left roll. The V_c value presented to the pilot is the higher of these two values.

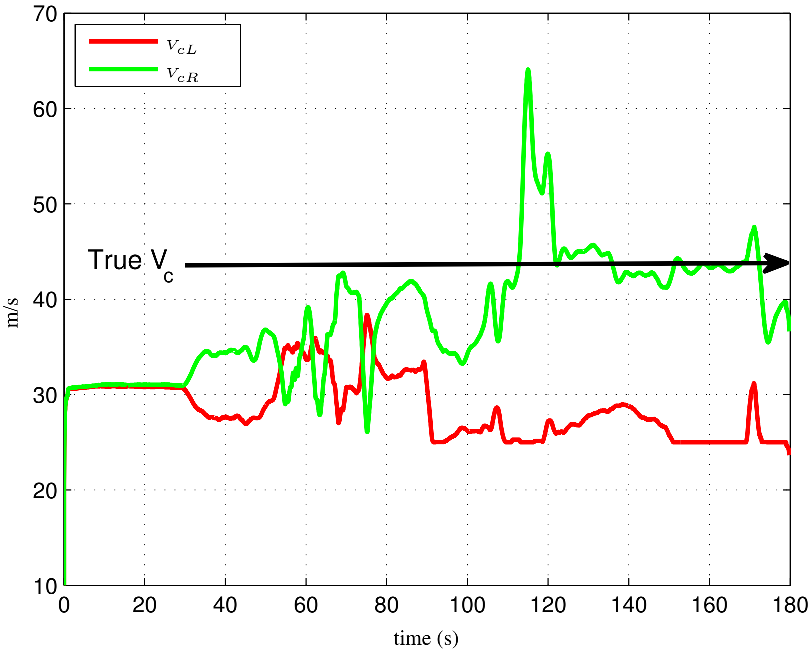


Figure 4: Simulation of an asymmetry in turbulent conditions

II.F. V_{mca} or V_c

Presently the only lateral-directional limit that might be known to a pilot is the V_{mca}. That the V_{mca} is not always known to the pilot is the result of the fact that the V_{mca} limit is often incorporated into other limits, for example the rotation speed or the minimum single engine approach speed. Primarily, V_{mca} is a certification criterion. This certification criterion [11, & 149] has two aspects: firstly it is the speed that will make it possible to maintain a fixed heading with maximum asymmetric power and less than 5 degrees of bank in the most unfavourable configuration without exceeding the maximum rudder force limits. Secondly, it must be possible at this speed to maintain control of the aircraft when a sudden engine loss occurs. In the acceptable means of compliance, this second requirement transforms to having a limited heading change. In its pure form the V_{mca} neither guarantees that $\beta = 0$ can be reached, which is favourable to minimize drag, nor that a certain roll performance is still available. In additional requirements in [11, & 149] it is stated that a 20 degree heading change in 5 seconds away from the inoperative engine is required. But this heading change requirement is not a pure roll requirement but depends also on the airspeed and the achievable load factor.

The V_c developed in [4] is not intended as a certification limit, but as an additional warning for the pilot. However, I believe that if the same criteria are used for V_{mca} as for V_c, we can achieve a better control limit that guarantees sufficient control. The proposed form for this new V_{mca} would be that at this speed, with maximum asymmetric thrust in the most unfavourable configuration, it must be possible to maintain $\beta = 0$ and still have the minimum required roll performance into the operating engine. This minimum roll control will be type dependent and can for example be based on the Military Specifications [5]. Of course, it is paramount that also in a dynamic engine failure condition, especially at a steep climb angle, this speed must guarantee that bank angles and side slip angles will not exceed certain pre-set limits. However, I consider it better to set roll and side slip angle limits than limits on heading change to avoid mixing of later-directional and longitudinal control limits.

III. Pilot-in-the loop results

Two Pilot-in-the-loop experiments were conducted in the SIMONA research simulator at TU Delft to investigate the usability of V_c indication. The aircraft simulated was the Piper Seneca (PA-34).

III.A. Initial tests

The first test were conducted in October 2014 and 10 pilots participated who were all familiar with twin propeller aircraft. These initial tests were exploratory in nature and were intended to investigate if pilots could work with the new V_c indication to prevent and recover from situations with reduced lateral control. The scenarios used were a One Engine Inoperative (OEI) traffic pattern, a OEI go-around and a rudder hard-over. In the first two scenarios, the initial velocity was 10 knots below the standard OEI approach velocity, but above V_{mca}, to invoke situations with limited lateral control. The third scenario was used to evaluate if the pilot could work with an advisory system that calculated a new safe lateral control velocity. During these scenarios many roll limited situations did occur and from these events and the pilot comments the following (not anticipated) effects were discovered.

1. Pilots were often using less than maximum rudder in situations that required a full deflection; furthermore, they were often not aware of doing this.
2. After initiating a go-around or a recovery from a roll limited situation, pilots found it hard to establish a correct climb angle and consequently regularly entered a second roll limited situation caused by a too steep climb angle.
3. Pilots were not all aware that the gear must be raised in order to get a climb rate and not after a climb rate is established.

Based on these results several modifications to the original display were made. Firstly, instead of just showing the V_c for the present β, an additional V_c was added that was based on the use of full rudder. The spread between the two values is an indication for the pilots that additional lateral control is possible with more rudder. Secondly, a ‘climb bar’ was added to the PFD. When the pitch angle is equal to the ‘climb bar’ the airspeed will remain constant, so by pitching less than the ‘climb bar’ the pilot ensures that the airspeed will increase.

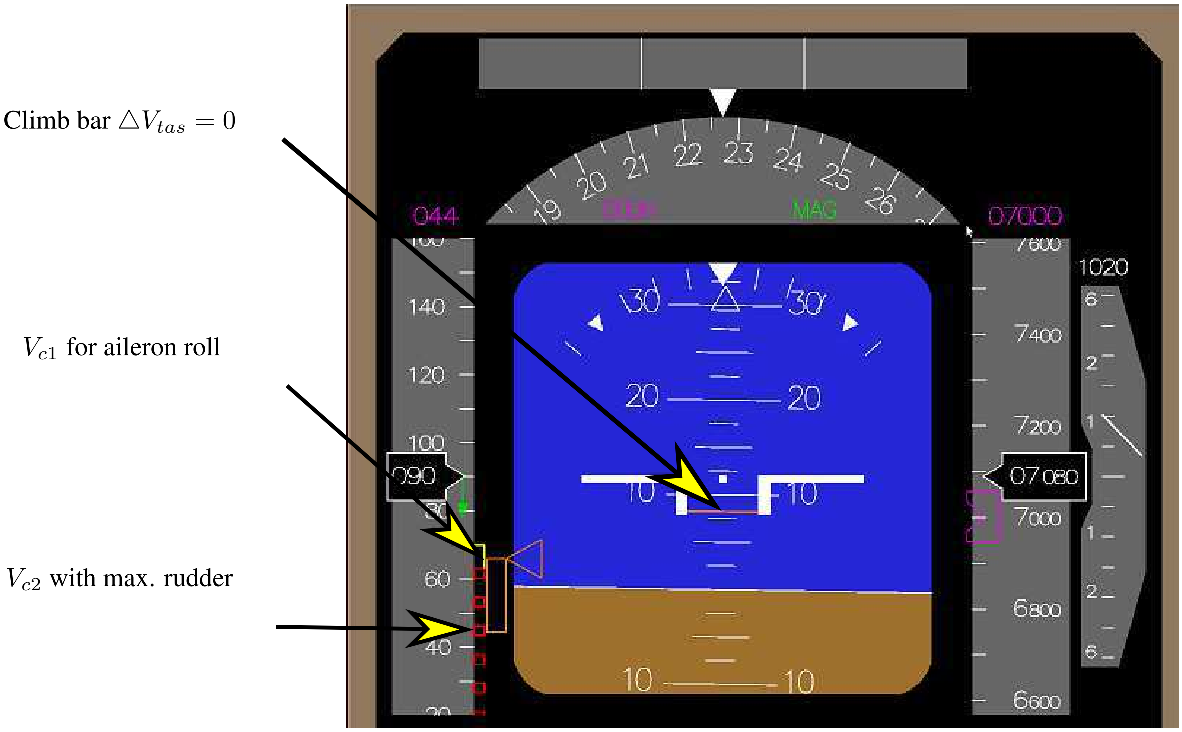
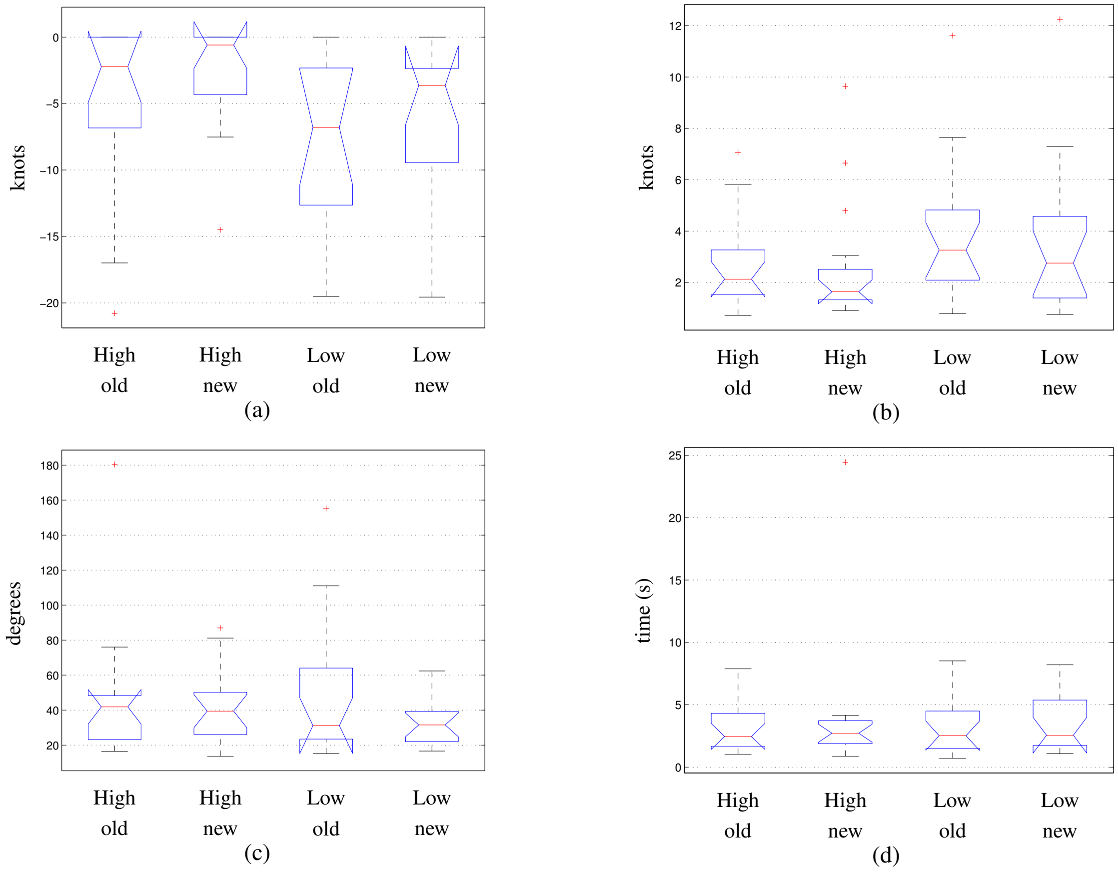


Figure 5: The PFD used in the experiments, augmented with the new V_c indications for aileron roll (V_{c1}) and roll with maximum rudder (V_{c2}). The climb bar in the centre is added to show the climb angle required to maintain the present speed.

III.B. Final tests

In August 2015 the final test were conducted in the TU Delft SIMONA research simulator in which 19 pilots participated. The first objective was to see if the new display as presented in Fig. 5 would improve the recovery from a roll limited situation.

To this end every pilot performed four different go-arounds with and without the V_c and 'climb bar' indications at low and at medium altitude. A Latin square was used for the order of the runs to mitigate the learning effect. The medium altitude scenario was added to investigate if this would allow the pilots to spend more time looking at the PFD instead of focussing mostly outside.

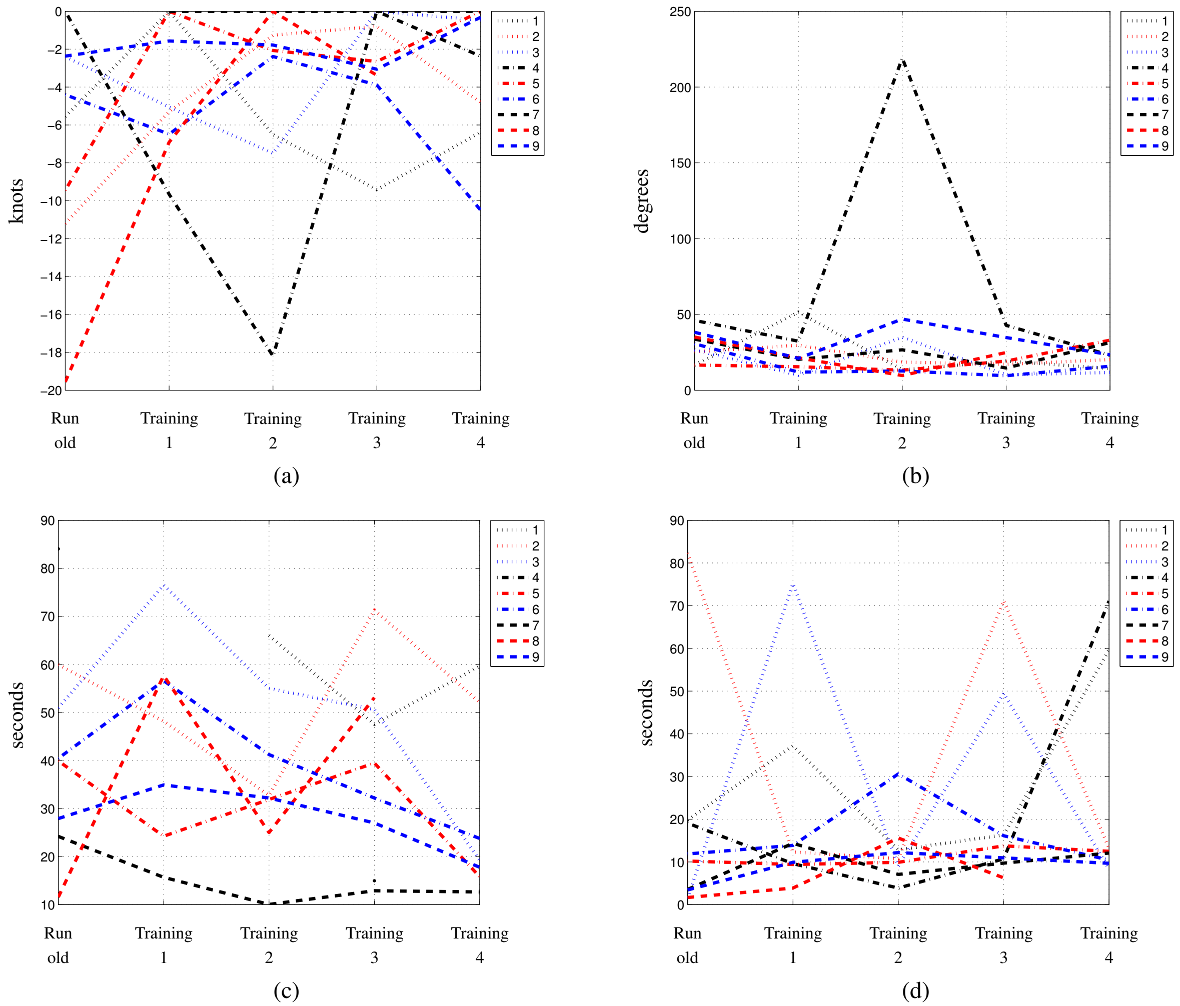


(a) (b) (c) (d)

Figure 6: Safety related parameters in OEI go-around. (a) The V_c exceedance, (b) the maximum velocity decrease after the engine failure (c) the maximum bank angle and (d) the time required to get maximum rudder deflection.

For the analysis of the data, box plots were used, the notches represent the 95% confidence interval of the median. As can be noted by the overlapping notches in Fig. 6, there was no statistically significant difference in pilot performance with and without the V_c display. In their verbal comments pilot did appreciate the V_c indication and the climb bar but normally started using these features by the time the recovery was almost completed and just as a confirmation that the pitch angle and speed were now on the safe side. Further analysis revealed that I had underestimated how extremely difficult and unnatural this scenario is for pilots and that consequently the training time needed is much more than initially anticipated. An indication of the difficulty of the scenario was the number of crashes in this scenario. Six crashes occurred at low altitude, only one crash was in a run where the new display was used, all others were with the traditional display. One or less out of six has a binomial chance of 11.9% given that both results have the same probability. Consequently, the reduction in crashes is not significant at the $p \leq 0.05$ level.

Fortunately, the fact that this scenario was actual too difficult became already apparent half way during the experiments. Therefore an additional test was added at the end of the regular test in which 9 pilots participated. The results of these tests are depicted in Fig. 7. The data show that dedicated training with deliberate use of the V_c indication and



(a) (b) (c) (d)

Figure 7: Subjects learning curves in OEI go-around training. (a) maximum $\triangle V_c$, (b) Maximum bank angle excursion in degrees (c) the recovery time and (d) time minimum energy is reached after the engine failure.

the climb bar, enabled 7 out of the 9 participating pilots to show a good ‘learning curve’ and a much quicker and safer recovery.

III.C. Results damaged aircraft simulation

An important question was if the V_c indication would enable pilots to improve the safety during approach and landing when the aircraft experienced an unknown type of damage. In this experiment each pilot made two runs. In the first run the pilot was asked to ‘act as he would do in real life‘ with the standard PFD. In the second run the V_c was displayed on the PFD and pilots were instructed to act in accordance with the ‘controllability check’ as described in [12]. There was a significant difference between three pilots with a military flying background[c] and the others. The first group carried out the standard controllability check on the first run and configured at altitude, allowing for a safe approach without configuration changes. The second group showed a large variety in procedures, generally configuring the aircraft was done late and approach speeds varied widely from excessively fast to dangerously slow, as can be seen in Table 1. It should be noted that the NATOPS prescribes to configure and decelerate to approach speed at altitude and to perform the deceleration in small speed increments while performing controllability checks at each speed interval.

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[c] Two were active military pilots and one was an ex-military pilot.

Table 1: Pilot assessment and actions during combined asymmetry and partial aileron failure. Pilots with a military training background are marked with an (m) behind their number. For the configuration changes the acronym ‘dwnd’ means downwind and ‘C Ch’ means that the configuration change was done as part of the controllability check.

P	Assumed Cause	Gear Selection feet	Flap Selection feet	Final Speed KIAS	Rudder at final degr.	Asym Pwr
1	Aileron damage	800	550	90	10	yes
2	Roll/yaw problem	400	400	100	10	no
3	Heavy aileron	600	500	100	10	no
4	Jammed aileron	300	dwnd	95	5	no
5	Aileron or flaps	700	up	110	0	no
6	Jammed control	1050	300	90	4	no
7	Asymmetric drag	1000	1000	92	5	no
8	Some disturbance	dwnd	700	80	30	no
9	Limited aileron	500	dwnd	90	8	no
10	Aileron problem	1000	not	110	15	no
11	Control cables	dwnd	dwnd	83	10	no
12	Asymmetric Flap	dwnd	up	105	5	no
13(m)	Aileron problem	C Ch	C Ch	90	10	no
14	Aileron heavy	1000	up	110	6	no
15	Heavy aileron+β	900	up	90	9	no
16(m)	Aileron problem	C Ch	C Ch	78	-5	yes
17(m)	Adverse yaw	C Ch	C Ch	90	20	no

Table 2: Improvement in safety per pilot when using the new display in final approach from 300 to 50 feet; Columns two and three shows the speed margin $V_{tas} - V_c$, a negative value indicates lack of sufficient roll capability. Columns 4 and 5 give the maximum aileron in the final approach phase, and columns 6 and 7 show the fraction of time the V_{tas} was below the V_c.

	$V_{tas} - V_c$	$V_{tas} - V_c$	Max δ_a	Max δ_a	$V_{tas} < V_c$	$V_{tas} < V_c$
pilot	old	new	old	new	old	new
1	**-10.0**	**-3.8**	38.2	46.4	0.8	0.6
2	22.7	0.2	41.8	43.0	0.3	0.7
3	17.5	0.0	27.1	0.0	0.0	0.0
4	23.5	26.5	27.3	34.2	0.0	0.1
5	43.1	**-15.6**	30.1	45.5	0.0	0.8
6	**-10.2**	27.9	52.8	42.5	0.6	0.0
7	**-7.7**	18.2	39.8	44.7	0.7	0.1
8	**24.8**	40.3	19.2	27.9	0.0	0.0
9	**-24.6**	9.6	34.5	24.9	1.0	0.0
10	44.8	24.5	10.2	41.2	0.0	0.1
11	**-28.2**	28.1	55.0	45.2	1.0	0.0
12	**-13.2**	12.4	33.1	11.9	1.0	0.0
13(m)	**-19.1**	15.9	35.1	31.8	1.0	0.0
14	**-29.2**	**-1.2**	18.0	32.9	1.0	0.5
15	**-9.8**	3.8	27.4	25.5	1.0	0.3
16(m)	18.0	19.0	24.6	35.7	0.0	0.0
17(m)	18.0	4.4	19.7	26.9	0.0	0.2
Mean	3.6	12.4	31.4	33.0	0.5	0.2

In this second run there was of course no surprise effect what would happen to the aircraft. However, all pilots were still unaware of the exact cause. Also, except for the three pilots that performed controllability check in the first run, they were unaware about the safety margins. For these pilots the second run was their first option to set a safety margin for their approach, so it is interesting to note how these margins changed. These results are presented in Table 2. A considerably increased safety margin was achieved, which proves the validity of using the controllability check combined with a V_c display. Another noteworthy fact was that by doing the controllability check some pilots discovered that they could use asymmetric thrust to reduce the effect of the lateral weight asymmetry.

IV. Discussion and Conclusion

IV.A. Discussion

Pilots do of course train OEI go-arounds, but these are performed at a much higher airspeed where the roll limited situation is not encountered. Furthermore, the roll-limited situation is not applicable to all aircraft but predominantly a propeller aircraft phenomenon. It is especially this fast decrease in roll control of propeller aircraft that surprised the pilots. Some pilots were so surprised by the controllability that they questioned the validity of the model. On these occasions pilots were given an additional demo after the formal test in which they could perform the same go-around with the standard airspeed of 90 KIAS instead of 80 KIAS, to their surprise the aircraft reacted exactly as expected. This surprise effect, combined with the unfamiliarity of the pilots with this scenario revealed that it was impossible to purely test the effect of the V_c display but that only the result of the combined learning effect could be tested.

The available data indicate that training does improve pilot performance in the recovery from roll limited situations. It was also clear from the comments that pilots were using the climb bar and the V_c indication according to the instructions given. However, we also have to realize that a (very) large part of the pilot attention is devoted to maintaining the aircraft level and countering the yaw, leaving little time to accurately position the climb angle, correctly position the throttles and raising the gear. Still, six out of the nine pilots showed a good progression while three clearly required more time than could be given in this experiment.

It is obvious that the pilot's capability to handle complex emergencies, caused by damage to the aircraft, is in the interest of flight safety. The military practice of using the controllability check is a good starting point for handling these type of emergencies, because it is not based on solving the emergency at hand, but it establishes the remaining controllability, regardless of the type of emergency. The V_c indication can help to find a safe approach speed. In future test one might also do 'in between group test' where one group does the controllability check with, and the other without the V_c indication while handling an unknown damage situation. This way one can quantify the effect of the V_c presentation.

IV.B. Conclusion

Presently most pilots are neither trained in recovering from a roll limited situation nor in the correct handling of a damaged aircraft with reduced lateral-directional control. The combination of a V_c and 'climb bar' indications combined with adequate training can improve flight safety in these situations.

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