EASA
European Aviation Safety Agency

Final Report EASA_REP_RESEA_2008_3

Research Project:

Safety Aspects of Light Aircraft Spin Resistance Concept

An agency of the European Union

Safety Aspects of Light Aircraft Spin Resistance Concept

EASA.2008/03

Final Report

December 2009

Authors

Technical University Braunschweig
Institute of Flight Guidance
Dipl.-Ing. Rudolf Hankers
Dipl.-Ing. Falk Pätzold
Dipl.-Ing. Thomas Rausch
Hermann-Blenk-Str. 27
D-38108 Braunschweig

Leichtwerk Ingenieurbüro Dr. Kickert
Dr.-Ing. Reiner Kickert
Lilienthalplatz 5
D-38108 Braunschweig

messWERK GmbH
für Mess- und Anzeigetechnik
Dr.-Ing. Matthias Cremer
Dipl.-Ing. Jan Troelsen
Hermann-Blenk-Str. 27
D-38108 Braunschweig

i) Table of Contents

ii) List of Illustrations

iii) List of Tables

1 Acknowledgements

The study “Safety Aspects of Light Aircraft Spin Resistant Concept” was funded by the European Aviation Safety Authority (EASA).

The study was executed by the Institute of Flight Guidance at the Technical University Braunschweig (Germany) in cooperation with Leichtwerk Ingenieurbüro Dr. Kickert (Braunschweig) and messWERK GmbH für Mess- und Anzeigetechnik (Braunschweig).

The authors wish to thank Uli Schell, Heiner Neumann, Hans-Jürgen Berns, Gerhard Stich, Dietmar Schmerwitz, Hans-Ludwig Meyer and all participants of the questionnaire for their prolific contributions to the discussion.

2 Executive Summary

Since 1991, the U.S. Federal Aviation Regulation, part 23, permits an applicant to decide whether the aircraft concerned shall be certified as recoverable from spins or as spin resistant. The spin resistant option is not provided in the European regulation. This study investigates safety aspects of the concept of spin resistance and offers a proposal for a requirement code for implementation into the European regulation.

The study provides a review on the topic of spin resistance. It includes a literature research intended to collect information on NASA and other research results, an analysis of accident data intended to evaluate the experience of operation with current spin resistant aircraft, expert opinions gathered in interviews and during a workshop intended to collect a wider spread of views on the topic, and a survey among European manufacturers and authorities intended to integrate them into the discussion of the topic right from the beginning.

Additionally, flight trials were performed to investigate the effects of parameter variations of the control inputs on the behaviour of the aircraft during stall and the entry phase to spin.

Research showed that a drooped outboard wing section with a sharp discontinuity improves spin resistance characteristics, whereas applying maximum power setting and fast entry rates can still result in a spin entry.

As the situational awareness of the pilot is a very central aspect, the study revealed potential ways to prevent stall/spin-related accidents, of which spin resistance can only be one section within a range of possible measures. It should be combined with considerations on improved stall warning systems, envelope protection measures and concepts for pilot training. No further investigations into these were made as they were outside the scope of the study.

Investigations also showed that the level of safety of the U.S. spin resistance regulation is not sufficient because operational accident situations related to spin resistant aircraft are not covered completely by the representative manoeuvres which have to be performed for certification. The proposed code for implementation into the European regulation contains some additions compared to the U.S. requirement, including those that decisive manoeuvres must additionally be performed under maximum power setting and higher rates of speed reduction to be used in flight test of spin-resistant concept aircraft certification.

3 Background

The background is well formulated by the author of the tender specifications [1] of this project:

“Traditionally, non-aerobatic light aircraft have been designed so that recovery can be made from spins. Up until 1991, both the FAA and European codes placed restrictions on the number of turns or the time it should take to recover from a spin, and ensuring that even if an incorrect recovery procedure was used, straight and level flight could still be recovered.

Studies in the USA in the 1980s and 1990s showed that in the vast majority of accidents attributed to spinning, the initial altitude was insufficient for recovery. It was concluded by the FAA that it would be safer to try to prevent spins rather than ensure recovery can be made once a spin had been entered. The FAA introduced an amendment to FAR 23.221 in 1991, updated in 1996, which allowed aircraft to be certified with spin resistance as an alternative to meeting the spin recovery requirements. No similar amendment has been introduced to the European Codes.

Existing Designs

Two US aircraft are known to have been certified to this alternate FAA code. Both are four-seat single engine non-aerobatic aircraft. One of these also incorporates an aircraft parachute recovery system designed to improve the occupants’ chances of survival should control of the aircraft be lost.

Both of these aircraft have a wing leading edge discontinuity with a drooped outboard leading edge. The principal of this design is that at high angles of attack, the leading edge discontinuity introduces a vortex over the wing upper surface which acts as a wing fence, stopping the stalled flow from the inboard wing spreading to the outboard wing. The drooped outboard leading edge also delays the stall of the outboard wing which allows the ailerons to remain effective at high angles of attack. The elevator stop is set so that the stall angle of attack of the outboard wing is never reached.

It has been found that features in this design intended to make the aircraft spin resistant are detrimental to spin recovery, to the extent that aircraft do not meet the original requirements which only deal with spin recovery.

Based on limited evidence to date, the spin resistance and spin recovery itself appear to be mutually exclusive; good characteristics in one or the other can be achieved, but not both at the same time.

Situation in Europe

Results from a study of European spin accident statistics are very likely to reflect the US data as there are no fundamental difference in operations. It is considered that, if this is the case, EASA should also promote aircraft designs which minimise the risk of spinning, even if this is at the expense of degraded spin recovery. One of the two above mentioned US aircraft has been certified by EASA for use in Europe based on equivalent safety findings afforded by

(i) some spin recovery capability

(ii) a parachute recovery system

(iii) spin resistance with additional certification review (CRI) items which defined additional manoeuvres beyond those required by FARs.

The other type, however, has not been certified by EASA as the aircraft does not meet the CS-23 spin recovery requirements and there are no other features which could afford equivalent safety other than spin resistance itself.”

4 Aims and Objectives

The EASA certification specification CS23 does not currently provide requirements for aircraft that are certified as spin resistant as defined in the current FAR23.221(a)(2). According to the tender specification [1], the primary objective of the project is to investigate safety criteria and relevant test methods which will form the fundamental basis for proposing a change to CS-23.221. A secondary objective is to increase awareness of the design concept within European industry and to stimulate European designs.

1. Review of spin resistance

Any European and worldwide research into spin resistant designs shall be investigated and reported, in particular to determine what the target in-flight characteristics were. What kinds of implementations were chosen in former initiatives, what was the wording used to describe spin resistance, and what were the tests to prove aircraft meet the requirements?

Further, it is to be regarded how the results of the research stand in relation to the established FAR23.221(a)(2) requirements and, additionally, if findings can be derived from experience with aircraft certified as spin resistant in the USA.

It is recognised that, up to now, European manufacturers have not had the opportunity to certify spin resistant designs. Nevertheless, all significant European light aircraft manufacturers should be consulted. It is aimed to get the opinions of the European manufacturers on the topic of slow-speed flight accidents and possible approaches, as well as their affinity to an option on spin resistant certification.

2. Additional requirements for spin resistant aircraft in CS23.221

In co-operation with EASA and based on the research findings, the existing EASA Certification Review Items and the corresponding FAA code, a limited set of criteria shall be defined which, if demonstrated, would confirm that a design is adequately spin resistant. These should be in the form of additional requirements to the existing CS-23.221, and any additional explanations for inclusion as interpretative Advisory Material (AMJ) and Flight Test Guide material.

Within the scope of this project, an analysis of the requirements needing to be fulfilled for the substantiation of spin resistant aircraft is necessary. The study report shall contain an overall summary and discussion of results and recommendations regarding the final proposed requirements, a wording defining spin resistance, and a description of tests to prove aircraft meet the requirement.

3. Notes

The focus of this project is on light aircraft that comply with CS-23 [11]. The findings of this study might be applied to other categories of aircraft, e.g. ultra lights or gliders, later on.

This project shall not result in new measures of obtaining spin resistance. Common technical measures, solely flight mechanical measures at this time, shall be discussed in detail. Besides the existing measures and requirements for spin resistance, the topic of stall/spin-related accidents shall also be regarded from a more general or fundamental view. The discussion of the topic shall not be restricted to certain principles.

It was agreed to forgo testing an existing spin resistant aircraft because of the limited gain in knowledge for the topic and the limited funds of this project.

5 Methodology and Implementation

This Section describes the overall approach of this study. Detailed approaches are described in each Section if and as necessary.

Inadvertent entering of spins is one of the main reasons for aircraft accidents in General Aviation. The increase of flight safety by avoiding entering spin at low height has been a topic for many decades. A lot of research work has been done in the past, especially by NASA. The NASA investigations were the basis for the implementation of spin resistance requirements to FAR23 [2] in 1991 [6] and 1996 [5].

Thus we have the opportunity to question and evaluate the former aims, objectives, conclusions and implementations from today's point of view. Existing doubts and concerns were discussed with regard to the experiences made in the USA within the whole process of research, subsequently derived requirements, certification on the basis of these requirements, and experience in operation of these aircraft.

Achievement of the aims according to Section 4 was handled in three main work packages, which are described as sub packages, as follows.

<u>Work package 1: Literature reviews, interviews with experts and manufacturers</u>

1.a Provision of literature, analysis and structuring of literature

An extensive literature review was performed to gain detailed comprehension of research work carried out by NASA and others worldwide. Non-research sources were also considered. The literature was collected and structured to get an outline of the possible measures researched and realised in serial production. Furthermore, it is worth regarding how the results of the research stand in relation to the established FAR23.221(2) requirements.

1.b Interviews with manufacturers

Interviews with European manufacturers were performed. A questionnaire was developed with the findings gained from the literature reviews and the interviews with experts. It was sent to all the manufacturers we managed to contact.

1.c Consultation by manufacturer-independent experts

Some light aircraft experts were interviewed. These experts have comprehensive experience and knowledge in practical flight testing of light aircraft. They are not only committed to one individual manufacturer but have widespread experience. Interviews with manufacturer-independent experts provided a more critical view on the written knowledge of the study topic.

1.d Appraisement of accident data from study relevant aircraft

The available accident data was considered in order to derive appropriate requirements for spin resistant aircraft. In the process of the project, an appraisement was derived from an accident database on the effectiveness of the current spin resistant requirements according to FAR23.221(a)(2) [2].

1.e Conclusion and elaboration of flight test strategy

The investigation evaluated all aspects of the topic, and aspects that need to be investigated in detail during flight trials were identified. The flight test strategy worked out was designed to assess the derived requirements for the flight test evaluation of aircraft that aspire a spin resistant status.

Work package 2: Flight trials

The flight trials supported the identification and review of findings. The effects of the measures were recorded with onboard measurement equipment.

The Institute of Flight Guidance has access to several different aircraft:

- Cessna F 172N D-EMWF is owned and operated by the Institute of Flight Guidance.
- Laser D-EKKY is a privately owned and operated aircraft that has been used as a test bed for aerobatic investigations in the past.
- DR400 D-EEPQ is owned and operated by a local club and is an example of a gull wing aircraft.
- RV-4 D-EFFI is a privately owned and operated aircraft and is an example of a low wing aircraft.

Finally solely the Cessna F 172N was used for flight trials within this project.

Meaningful flight trials followed from the research work in work package 1. Flight trials with existing spin resistant aircraft were seen as not beneficial due to a limited gain in knowledge of the topic and the limited funds of this project.

Work package 3: Appraisements and conclusions

On the basis of the previous findings additional requirements to CS-23.221 were formulated in the final work package. This contains a draft of a Flight Test Guide (FTG) Section.

6 Review on spin resistance

This Section presents in detail the results of the literature review, the accident database research, the questionnaire and the interviews with experts.

6.1 Literature review

As stalling and spinning has been a subject of investigation since the early days of aviation, a lot of literature can be found on this topic. To get an outline of the conceptual considerations concerning spin resistance as well as of the technical measures researched and realised, and the experience gained with them, a literature review was carried out as a first stage of this project. The review mainly concentrated on the research activities on spin resistance done by NASA. Additionally, general literature on the topic, and information collected as preparation for flight testing has been reviewed.
The following Section describes the findings of this review in as far as they can be regarded as useful within the context of this project.

6.1.1 Historical background

Very early on, civil aeronautics regulations in different countries started to deal with the subject of spinning, and usually required that every aircraft must be recoverable from this situation (e.g.[10]), even if the acceptable behaviour of the aircraft was not described precisely in these regulations.

An outline of subsequent developments of the regulations will be given here, concentrating on the USA, as the concept of spin resistance was developed and implemented into the regulations there. Comparable regulatory activities from other countries are not known. Figure 1 gives a timeline showing the most important events related to spinning and spin resistance in US research and regulations.

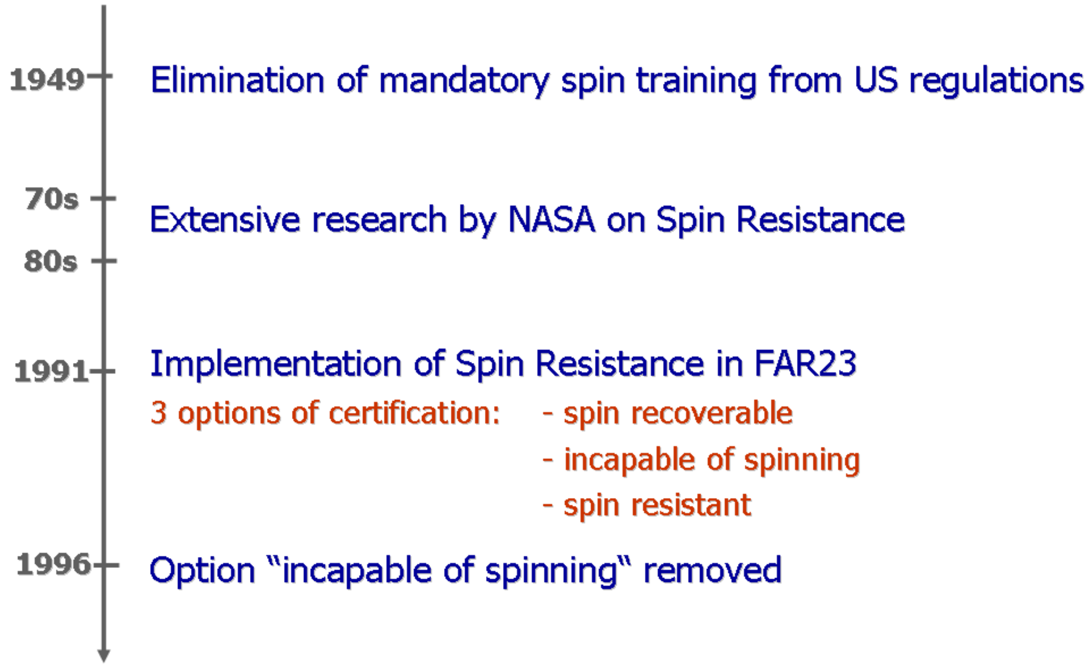


Figure 1: Timeline of events related to spin resistance

Before 1949, it was required for every pilot to demonstrate competency in spin recovery in the US Civil Aeronautics Regulation. This requirement was eliminated in 1949 [12] with the aim of preventing stall/spin-related accidents occurring during spin training. Since then, there have always been two ways of considering how to reduce the number of General Aviation (GA) stall/spin accidents: spinnable aircraft and spin training for every pilot, on the one hand, versus avoiding spins in all flight operations including education and more spin-resistant aircraft, on the other. It seems that these schools of thought have been regarded as principally incompatible in the common discussion among US experts since then, and that the aviation community really has been divided on this issue.

At that time, there were two options for certification of aircraft as regards spinning behaviour: spin recoverable and characteristically incapable of spinning. The concept of aircraft incapable of spinning was realised by the Ercoupe [21], designed by Fred Weick and originally manufactured by the Engineering and Research Corporation (ERCO) in Maryland, USA. Incapability to spin was mainly achieved via a two-control system, where rudder and aileron were linked, and a limited elevator deflection. It made its first flight in 1937 and became a rather successful project. Between 1945 and 1952, more than 5000 planes of this type were built, and production continued in smaller quantities until 1970 [22].

During the 70s and 80s, NASA dealt with the subject of spinning in general and spin resistance specifically, see 6.1.2. One result was the development of criteria to describe spin resistant aircraft. These criteria were then implemented into FAR23 in 1991 as a third option of certification. In 1996, the option “incapable of spinning” was removed as any aircraft that is “incapable of spinning” can be certified fairly easily with the spin resistance requirements.

6.1.2 NASA’s research activities on spin resistance

Studies on technical details to improve the stall behaviour, e.g. of an airfoil, can be found in large amounts, whereas NASA is the only institution having done any significant research on the concept of spin resistance in general. For this reason, the activities of NASA will be summarised in this Section.

During the years between around 1977 and 1989, NASA performed an extensive research programme on spinning GA aircraft. The issues discussed were behaviour of aircraft while spinning, recovery procedures, anti-spin parachutes, and the concept of spin resistance. While attempting to achieve higher resistance against spin entry, studies were made on configurations (e.g. canard), wing modifications and stall deterrent systems, using calculations, wind tunnel models, radio-controlled models and flight testing on research aircraft [27]-[40].

<u>Stall deterrent systems</u>

In the field of stall deterrent systems, different concepts have been analysed, including a stick-pusher, spoilers on the horizontal tail and an automatic trim concept, the latter especially developed for light twin-engine aircraft. As a result, artificial stall/spin prevention was judged feasible and even “extremely effective” [27] for GA aircraft, but the questions of cost, failure modes, weight, performance penalties and pilot acceptance remained to be addressed. It was stated that the rapid evolution of microprocessors and advanced electromagnetic control actuators may help to accelerate the implementation of such systems [35].

Wing modifications

Further research concentrated on wing modifications, particularly the modified outboard leading edge (MOLE), which means that the outer part of the wing is equipped with a drooped leading edge. The flow over the outer part of the wing stays attached to higher angles of attack and, if the transition between the two airfoil shapes is sharp, vortices are shed that preserve lift at stall. This leads to a positive effect on roll damping and aileron effectiveness.

Flight testing of these modifications was performed with aircraft based on the models Grumman American AA-1 Yankee, Beechcraft CS-23 Sundowner, Piper PA-28 Arrow, and Cessna C172 Skyhawk. Spin entry was attempted 1140 times, varying mass, centre of gravity position, flap deflection, bank angle, angle of sideslip, power setting, manoeuvre and rudder deflection. Spin entry was attempted from static flight as well as from dynamic manoeuvres.

The behaviour and abilities of these modified aircraft were used as a basis for the formulation of spin resistance criteria [34], see Section 6.1.3. The aim was for them to be *representative of operational situations*. By performing additional flight tests, these criteria were then reviewed [33].

The following Section provides a short description of the results of flight testing the MOLE-modifications on the different aircraft types. Figures showing the positions of the wing modifications on each aircraft can be found in the appendix.

Grumman American AA-1X: [27],[33],[35],[40]

The Grumman American Yankee was the first aircraft to be tested with a drooped leading edge. It was tested using four different wing configurations: unmodified wing, drooped leading edge on the whole wing span, and drooped leading edge on the outboard part of the wing (MOLE) either with a sharp transition between the two airfoil shapes (cf. pictures in Section 13.1) or with a tapered fairing to smooth the transition.

Prior to modification, the aircraft entered a spin in 96% of the attempts; after modification with the sharp-edged MOLE, in none of the attempts. Instead of spinning, the aircraft entered a steep, slow, spiral-type motion in which the outboard part of the wing remained unstalled and the aircraft responded immediately to flight controls. In the original report [40], this motion was still named ‘spin’, the wording was changed in later reports where NASA distinguished between spins, in a more narrow sense, and spirals. Stall behaviour was improved, the modified aircraft had a reduced roll-off tendency, but aerodynamic stall warning was judged inadequate.

Addition of the fairing caused the spin characteristics to be severely degraded, the aircraft entered spins and “locked in” to quite stable flat spins. Using the full-span drooped leading edge, the aircraft also had poor spin characteristics. It entered a fast flat spin from which no recovery was possible with normal controls.

<u>Piper PA-28X:</u> [31],[36]

NASA owned a PA-28 that featured a T-tail. According to the results of flight testing the AA-1, it was modified only with sharp-edged MOLEs. NASA performed 244 attempted spin entry manoeuvres with the modified PA-28; nine different loading conditions were used. Figure 2 shows how the matrix of manoeuvres must have looked, according to the NASA report [31]. Speed was reduced either by one knot per second or by manoeuvres described as “zoom manoeuvre” and “steep climb”. It is not reviewable whether every item in this matrix was tested, and not every item in the matrix was tested with every loading condition. Representative combinations were chosen which unfortunately have not been published thoroughly in the report. However, those manoeuvres in which spinning occurred were completely published. Spinning occurred after 13 entry attempts. The corresponding positions in the matrix of manoeuvres are marked in the Figure, partially representing several attempts with various loading conditions or with varied delays between rudder and aileron input.

Manoeuvre		**wings level zoom, steep climb** rudder prior to stall						**wings level zoom, steep climb** rudder at stall						**wings level 1 kn/s** rudder at stall						**30° banked turn 1 kn/s** rudder at stall	
aileron position		neutral		against		with		neutral		against		with		neutral		against		with		neutral	
rudder		left	right	left	right	left	right	left	right	left	right	left	right	left	right	left	right	left	right	**turn** left	right
power	**flaps**																				
idle	0°																				
	40°																				
for level flight	0°																				
	40°																				
maximum	0°			spin						spin				spin	spin						spin
	40°																				

244 manoeuvres
9 loading conditions:

CG (%)	23,97	25,94	27,78	27,9	27,87	28,23	28,42	29,98	32,07
mass (lb)	2678	2678	2656	2690	2829	2677	2670	2690	2690

colour scheme:
inside certified loading envelope
outside certified loading envelope

Figure 2: Flight test results, PA-28X with wing modifications

Spins were obtained with maximum power and flaps retracted. When reducing speed by only 1 knot per second in wings level flight, spins were only obtained if the aircraft was outside the approved loading envelope. From banked turn (speed reduction by one knot per second), spins were obtained at aft centre of gravity position and maximum approved mass. By using the zoom manoeuvres, spins were also obtained at middle centre of gravity position. In summary, the combination of maximum power setting and a zoom manoeuvre is clearly the most critical case.
Recovery from spins was possible, but it took up to three additional turns (after 1¾ turns of pro-spin input). In one case, the anti-spin chute had to be used, but in this case the aircraft was outside its approved loading envelope and the pro-spin input was held for six turns.

After those attempts not resulting in a spin, the aircraft either entered a spiral, or neither spin nor spiral was obtained. The report does not reveal how often and after which manoeuvres a spiral was obtained.

Beechcraft CS-23X Sundowner: [36]
A CS-23 was also tested with sharp-edged MOLEs; 7 of 134 entry attempts resulted in spins here. This time, all spins were obtained at loading conditions outside the approved loading envelope. Again, the amount of spirals obtained is not known.

Cessna C-172X: [30]
Flight tests with the Cessna 172 were performed after NASA had already developed a draft for spin resistance criteria together with FAA and the General Aviation Manufacturers Association GAMA. The aircraft was tested in six configurations: unmodified, with MOLE, with MOLE and another drooped leading edge on the inboard part of the wing, and each of these wing configurations either with or without a ventral fin to improve directional stability.
It was stated that the aircraft equipped with MOLEs only on the outboard wing and additional ventral fin was the only configuration to fulfil the criteria as regards the attempted spin entries, but it had problems with the stall requirements in this configuration. Like the other aircraft, the modified C172 in this configuration entered a spiral after some of the attempts. Without the ventral fin, it entered a spin in these cases.

6.1.3 Implementation of NASA research results

Based on the results of the NASA flight trials, criteria describing desirable characteristics of a spin resistant aircraft were developed. They were formulated in terms of explicit descriptions of representative manoeuvres, as it was needed for an implementation into the regulations. These criteria were then introduced to FAR 23.221 as an optional requirement, alternative to the spin recovery requirement.

The spin resistance criteria can be sub-divided into three parts:

1. Sufficient lateral controllability with the stick held aft must be demonstrated.
2. Manoeuvres for attempted spin entries must be performed.
3. The stall paragraphs (23.201 and 23.203) must be demonstrated with the aircraft in uncoordinated flight.

It was stated in [34] that the requirements should be representative of operational situations. Particularly the manoeuvres for attempted spin entries were formulated congruent with the abilities of the MOLEs as identified in the flight tests. When reducing speed by 1kn/s, full rudder must be applied the very moment the stall occurs and held for seven seconds. Afterwards, the aircraft must respond immediately and normally to primary flight controls. In fact, any aircraft entering a spiral after these manoeuvres thereby complies with the requirement. Figure 3 shows the matrix of manoeuvres needing to be performed.

		aileron position			
		neutral		against	
		turn direction			
power	**flaps**	left turn	right turn	left turn	right turn
idle	up				
	intermediate				
	down			**24 manoeuvres**	
for level flight	up				
	intermediate				
	down				

- corners of the approved loading envelope
- speed rate 1 kn/s
- power setting for level flight: 75% or less according to FAR23.201

Figure 3: Manoeuvres for attempted spin entry according to FAR23.221

In Figure 4, the requirements in FAR23.221 are compared to the flight tests with the PA-28. The area highlighted in orange contains all the manoeuvres in the requirement according to Figure 3. The most "spin-prone" cases, i.e. maximum power setting and zoom manoeuvres are not contained in the requirement.

Manoeuvre		wings level zoom, steep climb rudder prior to stall						wings level zoom, steep climb rudder at stall						wings level 1 kn/s rudder at stall						30° banked turn 1 kn/s rudder at stall	
aileron position		neutral		against		with		neutral		against		with		neutral		against		with		neutral	
rudder		left	right	left	right	left	right	left	right	left	right	left	right	left	right	left	right	left	right	turn left	right
power	flaps																				
idle	0°																				
	40°																				
for level flight	0°																				
	40°																				
maximum	0°			spin						spin				spin	spin						spin
	40°																				

244 manoeuvres
9 loading conditions:

CG (%)	23,97	25,94	27,78	27,9	27,87	28,23	28,42	29,98	32,07
mass (lb)	2678	2678	2656	2690	2829	2677	2670	2690	2690

colour scheme:
- inside certified loading envelope
- outside certified loading envelope
- covered by current FAR23.221(a)(2)

Figure 4: Comparison of flight test results and FAR-requirements

Retrospectively, it was stated that all four modified aircraft tested by NASA fulfilled these manoeuvres; only the modified C172 had some problems with the stall requirements.

Since then, drooped leading edges have been used in several single aircraft to enhance stall characteristics, such as Norman Firecracker, Schweizer motor glider, VariEze or OMAC Laser [27], but all these aircraft have not been certified as spin resistant. The only aircraft developed and certified according to the concept of spin resistance and which have reached series production are Cirrus SR20/22 and Cessna 300/350. However, it must be mentioned that both aircraft were certified under special conditions.

6.1.4 Review of literature dealing with spin in general

The previous Sections focussed on technical measures to influence the behaviour of aircraft during the entry phase of a spin. More global approaches to the whole process of spinning can be found, beginning from different operational flight situations and configurations to the aircraft's stall behaviour and the pilot's awareness and behaviour in this situation. After that, the spin itself can be split into four phases: entry, incipient spin, developed spin and recovery. A description of this global approach is given by Stinton [79], [80].

This Section presents the main findings concerning the processes before a spin occurs, as a deeper analysis of the behaviour while spinning is not intended within the context of this project. The main findings on the topic of recoverability will be presented later on in Section 6.1.5.

Entry to a spin can occur from a wide range of in-flight situations. Ambros [19] regards the situation of a skidding turn (rudder deflected into the direction of turn, aileron against, low airspeed) as especially critical in this context, as it occurs in operational situations when a pilot does not dare to build up bank angle when close to the ground but nevertheless wants to enforce a heading change, and as this skidding flight supports the aircraft's rotation around its x-axis at stall. Consent to this appreciation can be found among experienced pilots, but an analysis of accident data (see Section 6.2) shows that a wide range of situations beyond this one additionally lead to fatal accidents.

Stinton [79], [80] provides a lot of information about the influence of several values on the behaviour of the aircraft at stall and during the entry to a spin, such as the rate of speed reduction, bank angle, slip angle, angle of climb or descent. A lot of additional information on the topic useful for the designer of an aircraft is given, such as a listing of the effects of changes of the basic configuration on stall and spin behaviour, and a description of the effects of tail location and wing shape.
He clearly defines three “rules for good stall quality”: there must be an identifiable warning, the aircraft must pitch down at the stall and it must be possible to control roll and yaw by normal use of the controls.

It is stated that it can be difficult to decide for any type of aircraft which configurations of in-flight parameters may be critical and which not, before having done the flight test programme. Even for aircraft certified as characteristically incapable of spinning, it can be possible to provoke a spin, and accidents may occur when a pilot intentionally spins an aircraft whose recoverability from spins has never been tested ([79] p. 516).

Stowell [12] describes in detail the importance of the pilot's awareness of the stall situation, and gives guidelines on how to improve this awareness by training.

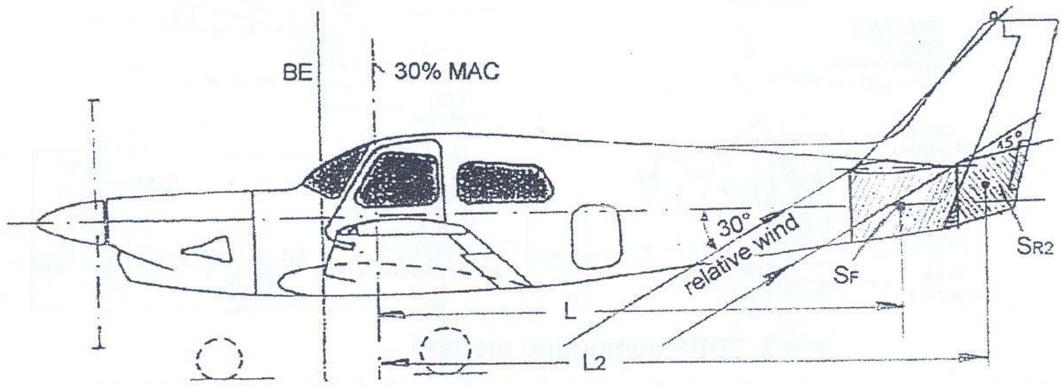
There are a lot of different stall warning systems available to help pilots recognise such situations. A cursory look at information on stall warning systems [64]-[69] shows that significantly improved systems are possible compared to the standard system with a simple acoustic signal as is the case in most aircraft today. The following represents some possibilities for improvements over the standard system (some have already been realised in certain systems):

1. As regards the quantities used: a selection of airspeed, accelerations, flap position, take off weight, angle of attack and / or pitch could be combined to decide in a more refined way whether a warning signal should be given.
2. The transmission of the warning to the pilot could be improved, with the warning signal getting louder rather than remaining constant; a stick shaker and / or a voice message could be used.

As these issues were outside the scope of this study, no further work on these aspects was conducted.

6.1.5 Flight mechanical aspects of spin recovery

A method to determine the spin recovery characteristics of an aircraft was developed by NASA [43]. The most important factor here is the tail configuration. Particularly interesting is the value of those surfaces on the vertical tail which are outside the dead-air region behind the stalled horizontal stabiliser at high angles of attack occurring during spins. Figure 5 illustrates how the so-called tail damping power factor (TDPF) is calculated.



$$TDR = \frac{S_F \bullet L^2}{S \bullet \left(\frac{b}{2}\right)^2}$$

$$URCV = \frac{SR_1 \bullet L_1 + SR_2 \bullet L_2}{S\left(\frac{b}{2}\right)}$$

$$TDPF = URVC \bullet TDR$$

Figure 5: Calculation of Tail Damping Power Factor [48]

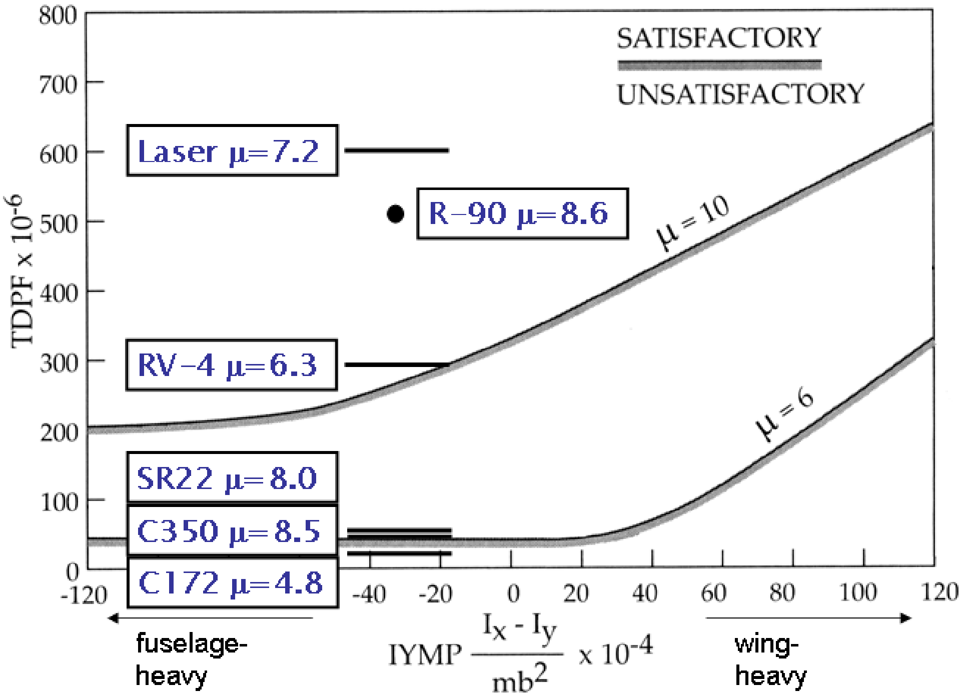
This factor is then combined with the relative density of the aircraft and the inertia yawing moment parameter to determine if the recovery behaviour will be satisfactory or not. The relative density is calculated by

$$\mu = \frac{m}{\rho S b}$$

where the aircraft mass is *m*, air density $= \rho$, wing area = *S* and wing span = *b*.

According to the NASA results, these factors are combined as shown in the diagram. For each aircraft, a position in the diagram can be marked according to its TDPF and inertia yawing moment parameter. This was done here for selected aircraft. The values were calculated based on drawings and published data about the aircraft. In most cases, the exact inertia yawing moment parameter is not known. For this reason, the corresponding position in the diagram is marked with a line. Additionally, relative densities are shown, each calculated using the air density at sea level.

This position and the relative density of the aircraft can then be compared to the lines contained in the diagram. Recovery behaviour is satisfactory if the position of the aircraft in the diagram is above its respective density line. Recovery behaviour is unsatisfactory if the position of the aircraft in the diagram is below its respective density line. The diagram presented here shows two lines (for densities of 6 and 10), the approximate position for any other density value can be interpolated. Please note that this diagram is only valid for aircraft with conventional wing design.



	TDPF	μ
Laser	596	7,2
R-90	512	8,6
RV-4	295	6,3
SR22	55	8,0
C350	45	8,5
C172	25	4,8

Figure 6: TDPF of several aircraft [12][13][43][49]

The diagram shows that some aircraft are expected to have excellent recovery characteristics (Laser, Ruschmeyer R-90 and RV-4) as their position in the diagram is clearly above the area which the density line values of 7.2, 8.6 and 6.3 belong to. The Cessna 172 has a low TDPF, but also a low relative density, so recovery behaviour is also acceptable as the position in the diagram is still above the area of the density line value of 4.8. The positions of Cessna 350 and SR 22 in the diagram show that these aircraft would have bad recovery characteristics due to their empennage design even if their wing design was conventional, as their position in the diagram is below the area which the density line values of 8.0 and 8.5 belong to.

Spin testing of a Ruschmeyer R-90 equipped with MOLEs [48][49] had shown that adding the MOLEs changes the recovery behaviour from excellent to clearly unsatisfactory. For aircraft equipped with MOLEs, a much higher TDPF would be required to ensure recoverability from a spin. As the flight testing of NASA shows, MOLEs and recoverability do not principally exclude each other (cf. recoverability of PA-28, Section 6.1.2)

The reader may find additional information not presented here in detail in the British Defence Standards [8],[9]: Another, more advanced method to calculate criteria for spin resistance and spin recovery of military aircraft is given there. The parameters ‘directional departure parameter’, ‘lateral control departure parameter’ and ‘unbalanced rolling moment coefficient’ are calculated there.

6.2 Accident situations and statistics

Accidents related to stall and spin can be seen as the motivation for any research activity on this topic. Additionally, as any air safety requirement needs to be oriented towards operational situations, the aim here was to use accidents as a source of information to identify critical situations and to investigate whether the concept of spin resistance creates any principle difference in the amount and in the sequence of events during accidents compared to conventional aircraft.

Accidents that occurred during a period of nearly ten years were reviewed in order to get most of the fatal accidents with aircraft certified according current FAR23.221(a)(2). As data storage at the European Coordination Centre for Accident and Incident Reporting Systems (ECCAIRS) is currently in the set-up process, it does not contain the data necessary for this analysis (see also [54] and [58]). Therefore, the review on statistics is based on the Aviation Accident Database published by the US National Transportation Safety Board (NTSB) [56],[60] and reports published by the AOPA Air Safety Foundation (ASF) [53],[55].

In this Section, information on the proportion of stall/spin-related accidents among GA aircraft that can be found in literature will be presented first. This will then be compared to one example of a spin resistant aircraft type, based on an analysis of accident data that can be found in the NTSB database. Finally, the position of all these occurrences within the traffic pattern will be reviewed.

6.2.1 Proportion of stall/spin-related accidents of light aircraft

AOPA Air Safety Foundation (ASF) states that only 7% of the aircraft involved in stall/spin-related accidents definitely started the stall/spin from a height of more than 1000 feet above ground level [53]. If an aircraft enters a spin at such low height, recovery from the spin will be impossible in most cases because the height loss during spin and recovery will be more than 1000 ft in most situations. In other words: In the majority of cases, the aircraft’s characteristics in spin recovery are not relevant; once a spin has been entered, the fatal accident is inevitable. On the other hand, many of these accidents occur without a spin being entered, the aircraft just enters a stall and the pilot does not recover from the stall until impacting the ground, as a review of accident reports shows (see Section 6.2.3). However, these types of accidents have always been the main argument for research and regulatory activities aimed at enhancing the stall characteristics of aircraft.

Among all fatal accidents in General Aviation, 14% were associated with stall/spin in the ASF study [53]. In past decades, this proportion has even been higher, 28% back in the 60s [35],[62]. It is interesting to note that student pilots are least likely to suffer stall/spin accidents compared to pilots with private and commercial licences. NASA's original intention was that implementing spin resistance technology would reduce total GA accidents by nearly 20% [61].

6.2.2 Proportion of stall/spin-related accidents of light aircraft certified as spin resistant

To evaluate the safety aspects of the spin resistance concept, accident reports of spin resistant aircraft have been analysed with the aim of identifying the proportion of stall/spin-related accidents among these aircraft. Among the two existing spin resistant designs Cirrus SR20/22 and Cessna 300/350, Cirrus SR-20 and SR-22 were chosen for this analysis, as the history of aircraft types in the Cessna / Columbia 300 / 350 family is rather complex, involving many home-built aircraft.
During the time period between January 1999 and July 2008, 39 fatal accidents occurred with the aircraft types Cirrus SR-20 and SR-22 [56]. In 7 cases, the course of events was too unclear for analysis, 10 of the remaining 32 accidents were related to stall/spin (i.e. 26% of the total sum, cf. 14% in General Aviation as stated in the ASF study), 8 of them started at a height of less than 1000 feet. Stall/spin after icing and stall/spin due to explicitly mentioned spatial disorientation under IFR conditions were not classified as stall/spin-related here.

Estimating such data and comparing them with other types of aircraft is limited; results must be regarded with caution for the following reasons:

1. The amount and distribution of flight hours and the differences in the type of operation are not known. By choosing the proportion of stall/spin-related accidents among all fatal accidents as the number to be regarded, the consideration is independent of the total amount of flight hours.

2. Different types of aircraft are designed to appeal to different target groups of pilots; it seems probable that certain types of aircraft appeal more to inexperienced pilots.
3. The total number of accidents as regards a single type of aircraft is very low (statistically seen).

Please note that successful deployments of the Cirrus Airframe Parachute System (CAPS) are not contained in these accident data. As a result, there may be an additional unknown amount of stall/spin-related incidents.

Conclusion

The aim of NASA of largely eliminating stall/spin accidents seems not to have been achieved with the existing spin resistant designs. The proportion of stall/spin accidents among all fatal accidents is of the same order, or higher, as among spinnable aircraft, most of these accidents still starting from low height. Single stall/spin accidents starting at higher height may occur where the poor characteristics in spin recovery lead to a fatal accident.

6.2.3 Position of occurrences within the traffic pattern

In addition to the above mentioned accident reports, fatal GA accidents in 2006 with all aircraft were also analysed. The aim was to find out:

1. Which sections of the traffic pattern are most critical?
2. Are there any differences between spin resistant and conventional aircraft?
3. Can any indications for manoeuvres and control inputs leading to the accidents be found?

Including the 10 above-mentioned stall/spin-related accidents with SR-20/22, 57 stall/spin-related accidents were analysed, this time including some “mixed” causes like stall/spin in combination with engine problems or pilots impairment due to drugs. A list showing the dates of the accidents reviewed here and the registration numbers of the involved aircraft is contained in the appendix.

38 of these 57 accidents occurred in the traffic pattern of an airfield,

7 elsewhere starting at below 1000 ft height,

8 elsewhere starting at over 1000 ft height,

3 not classified due to lack of information,

1 accident occurred after attempting to pick up a banner.

The aircraft sometimes impacted the ground in a spin movement. In many cases, no spin was entered; the aircraft impacted the ground just in a stalled flight condition.
The position of the 38 accidents within the traffic pattern can be seen in Figure 7. Most accidents occurred in the standard sections of the traffic pattern. Some accidents occurred during a teardrop manoeuvre (position in the Figure marked *1) after real or simulated engine failure. Some accidents occurred away from the usual flight path, mostly after an aborted approach (marked *2). The positions of the accidents with SR-20/22 (1999-2008) are marked in black, those of the accidents with other aircraft types (2006) are marked in red.

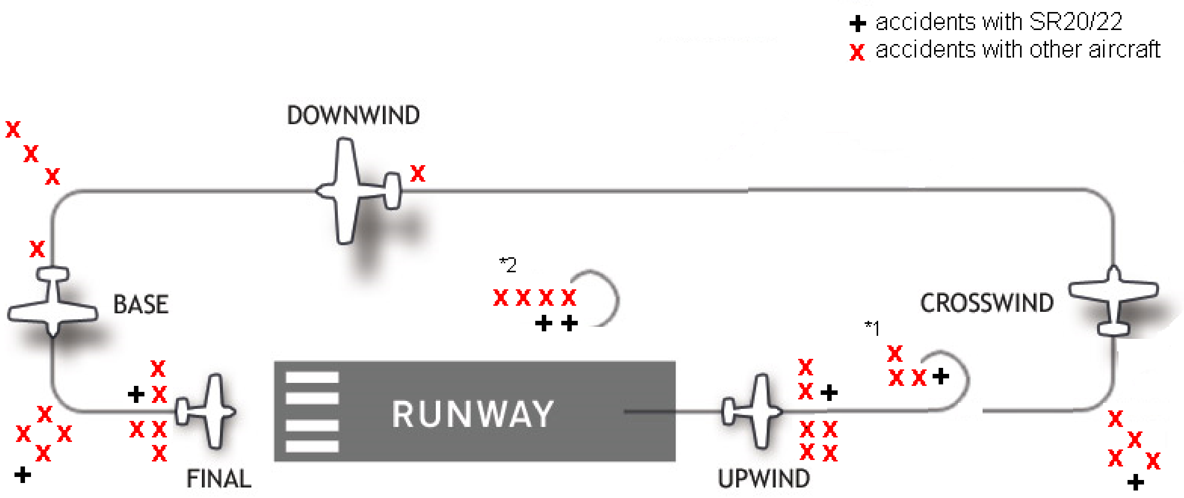


Figure 7: Positions of stall/spin-related accidents within the traffic pattern (image based on [17])

The distribution shows that accidents occur in the descending phase of the traffic pattern as well as during ascent, starting from "straight" sections as well as from "turning" sections. No obvious differences between spin resistant and other aircraft can be found. Likewise, the accident reports reveal no principle differences in the sequence of events between accidents with spin resistant aircraft and others.

Conclusion

A precise reconstruction of the manoeuvres and control inputs leading to the accident was not possible in any of the cases. However, the following aspects could be found in several cases (mostly derived from the observation of witnesses during the accident or shortly before the accident):

- Turning flight with high bank angles (up to 70-80°) and / or suddenly induced bank angle
- Unusually steep pull up
- Wrong flap setting

These findings were taken into consideration when defining manoeuvres for flight trials within this project (see Section 7.3).

As regards the distribution of the accidents within the traffic pattern, no obvious differences between the accidents with SR-20/22 and those with other aircraft types could be found.

6.2.4 Statistical occurrence of accidents with different types of aircraft

The same conclusions as in the previous Section can be drawn from NTSB statistics published by Cirrusaircraft [63], see next page.

As regards statistical variations, the rate of “fatal mishaps per year” is broadly independent of aircraft type. The Cessna 172 is particularly low. The medium rate of “mishaps per year” of the Cessna 172 is probably due to usage of this type for training, etc. Both the spin resistant candidates SR20/22 and Cessna 350 do not stand out in any way (considering the small statistical sample).

2007/2008 US General Aviation Mishaps (NTSB)			
	US Registered Aircraft (approx.)	Mishaps/yr. (Fatal) (per 1,000 ac)	Mishaps/yr. (per 1,000 ac)
Mooney M20	7,800	0.9	3.7
Cessna 182*	16,100	0.7	4.1
Cirrus SR20/SR22	3,700	1.4	4.3
Cessna 350/400	660	2.3	5.3
Cessna 172*	26,700	0.5	5.5
Beech 36	2,850	2.3	6.4
All US-registered SE Aircraft	146,000	1.3	7.5
Piper PA-46 Malibu/Matrix	850	1.8	7.6
Diamond (Single Engine)	1,080	0.9	7.9

* Recent model C-172 have a somewhat worse record; C-182 a slightly better record

Table 1: NTSB statistics 2007/2008 for some light aircraft [63]

To link the rate of "fatal mishaps per year", the NTSB database was used to find out, how many fatal accidents are stall/spin-related. For the period from 1999 – July 2008 the following numbers were determined for some types of aircraft.

Cessna C172	19%
Piper PA28	8%
Mooney M-20	16%
Cirrus SR20/22	26%

Table 2: Percentage of stall/spin-related fatal accidents for some aircraft types

Combining the content of Table 1 and Table 2 it is evident that the amount of stall/spin related fatal accidents of the SR20/22 is considerably higher-than-average.

6.3 Questionnaire

To take account of the experience and needs of the European GA manufacturers right from the beginning, a questionnaire was sent to them containing technical questions on general considerations on stall and spin, on the concept of spin resistance, and on future concepts. The questionnaire can be found in Section13.3.

The questionnaire was sent to 146 recipients. These included 22 manufacturers of part23 aircraft, 11 manufacturers of VLA or aerobatic aircraft, 27 European national civil aviation authorities, 12 bureaux for aircraft accidents investigation, and other members of the European General Aviation Safety Team (EGAST).

17 answers were received, 14 of them were completed questionnaires, the others single comments submitted per e-mail. 7 completed questionnaires were received from manufacturers of part23 aircraft, the other answers came from: 1 manufacturer of VLA, 1 national bureau of aircraft accidents investigation, 1 national affiliate of a pilots' association and 7 national civil aviation authorities.

The following Sections contain summaries of the answers. The original anonymised answers can be found in Section 13.4. Some comments have been rearranged from their initial position as they fitted better to a different question.

A. General considerations on stall and spin

Question 1: *How do you rate a pilot of average ability to manage spin recovery of non-aerobatic (normal and utility category) aircraft complying with CS 23.221(a) requirement?*

The chance of the pilot was clearly rated to be poorer at lower height. The following comments were given:

- The reflex of many pilots to pull when the aircraft directs towards the ground.
- If the situation is recognised properly, the pilot can perform recovery from the entry to the spin. In this context, height loss from the beginning of spin to level flight is a very important factor.
- There might be national differences: It was stated, that accidents due to inadvertent spin are practically unknown in this country.
- It was stated several times that more properly regulated mandatory spin and spin-awareness trainings and trainings in unusual attitude recovery are necessary.

Question 2: *In your opinion, would you rate the parameters applied in CS23.221(a) suitable to describe spin recovery behaviour or would you prefer to apply others?*

Of the manufacturers, 4 participants of the survey rated the parameters suitable, 3 would prefer others. Of the other participants, only 1 would prefer others. Comments were given on:

- 1 turn for recovery: It was stated that this is too strict, compared to twin-engine aircraft, but it was also stated that it is too long, as inexperienced pilots may give up the attempt to recover earlier.
- Duration of pro-spin control inputs: It was suggested to expand CS23.221(a) with "...or from the motion caused by 3 seconds of full pro spin control".
- Released rudder: One participant proposed that it should be not required to use opposite rudder, the aircraft should stop the spinning motion when the rudder is released.

B. Concept of spin resistance

Question 3: *Are you aware of the concept of spin resistant aircraft?*

All manufacturers were aware of the concept. Of the others, two were not or at least not acutely aware.

Question 4: *Are aircraft designs of your company already influenced by this principle? If yes, what different flight characteristics were the designs intended to have relative to a standard design?*

Three manufacturers partly used the principles to improve the stall characteristics (CS 23.201 – CS 23.207), one combined the concept with a stick pusher. The following opinions were stated:

- Spin resistance characteristics of the commonly used GA aircraft today are more than adequate.
- It is very difficult to design a really good plane with spin resistant characteristics.
- Quick recoverability is more desirable than spin resistance.

Question 5: *How would you improve the requirements provided by FAR-23.221(a)(2)?*

Some participants regarded the requirement as reasonable. Others criticised the following aspects:

- Dynamic spin entries and uncontrolled situations are disregarded.
- Limitations of control effectiveness do not solve the problem.
- Solution lies in correct stall characteristics, i.e. in CS23.201, CS23.203 and CS23.207.
- “One ball width displacement” is not standardized. It was proposed to use lateral acceleration, angle of sideslip or the temporary control forces specified by §23.143(c).
- Harmonisation is a priority for manufacturers. The requirements should make reference to the possibility of an artificial stall barrier system (Ref. FAR 23.691).
- Aircraft speed should also be reduced at a rate of approximately five knot per second.
- Ailerons should also be deflected into the direction of turn, in the most adverse manner.

Question 6: *Would you consider certifying an aircraft as spin resistant (in a broader sense) if the CS-23 would provide the possibility?*

Four manufacturers answered yes.

C. Future Concepts

Question 7: *Would you like to make any suggestions for technical means to achieve spin resistance to be investigated in this project?*

Besides the aerodynamic means leading edge droop, outboard wing design and airfoil selection, artificial stall barrier systems were mentioned again here. One participant answered: “No, because many other problems would occur.”

Question 8: *Do you see alternative concepts to flight mechanics measures for the increase of level of safety compared with CS-23.221 (a) and spin resistance concept (FAR-23.221(a)(2))?*

Stall warnings and envelope protection were mentioned here.
Additionally, the need for better trainings was stated again.

Questions 9 and 10: *Would you be prepared to take part in an interview on this matter? Are you interested in commenting the preliminary outcomes of this study?*

Most participants were interested / prepared.

Question 11: *Please feel free provide any further comments.*

Some general comments against spin resistance were stated here, also some general comments pro spin resistance, even in CS-22 and CS-VLA. Some specific comments were given:

- Specific information is required to prevent pilots from intentionally spinning spin-resistant aircraft.
- The criticality of artificial systems must be considered.
- There is a need for explicit requirements for aircraft parachute recovery systems.
- Spin resistance has a negative effect on pilots’ awareness and abilities.

Conclusion

Summarising all the answers, some general conclusions can be drawn from the survey, as well as many interesting aspects in detail:

1. The participants of the survey were widely aware of the concept of spin resistance.
2. Considerations with the aim of reducing accidents related to stall and spin were generally appreciated.
3. Not only improved flight mechanics should be taken into consideration, but also means like artificial stall barrier systems and stall warnings.
4. Both sympathy towards and rejection of the (current) concept of spin resistance in general could be detected.
5. The main aspect of criticism on FAR-23.221(a)(2) was the lack of dynamic spin entries.
6. According to the content, “spin resistance” is more related to stall characteristics than to spinning itself.
7. As the pilot’s situational awareness and behaviour is a very central aspect, training of and warnings for critical situations should be addressed.
8. Some European manufacturers would consider certifying an aircraft as spin resistant if CS-23 allowed this.

A more detailed interview of certain participants, as it had originally been intended, was not considered necessary.

6.4 Interviews with experts

The six invited experts had very different experiences with small aircraft, from a perspective of research, type certification and sale. The aim of the interviews was to get detailed information about the handling of Certification Standard requirements and the interviewees' attitude beyond these requirements. The intention was to provide a more distinctive view on the written knowledge of the study topic.

Three interviews were organised. With the exception of the second interview, we tried to initiate a discussion between the experts to appraise similarities and differences in their opinions. The interviews were discussions on the topic of slow-speed flight accidents with emphasis on spin resistant concept.

<u>November 6, 2008</u>

- Hans-Ludwig Meyer (former DLR[1] test pilot,
  former head of DLR flight test department)
- Gerhard Stich (former DLR test pilot)

<u>November 13, 2008</u>

- Dietmar Schmerwitz (former DLR scientist for parachutes and light aircraft)
  Mr. Schmerwitz is an expert for anti-spin chutes. We interviewed him in view of the planned flight trials, and also talked about his experience in assisting spin trials.

<u>November 27, 2008</u>

- Uli Schell (Test pilot)
- Heiner Neumann (Test pilot)
- Hans-Jürgen Berns (DLR test pilot)

[1] *DLR – German Aerospace Center*

6.4.1 Results of interviews

The message of the three interviews was almost identical, so that the statements can be merged without hesitation. The statements can be subdivided into five groups:

A. General statements

- Experience has shown that if an aeroplane is averse to entering spins, then it is typically averse to recovery. However, is the end of flight mechanical development reached at this point or may new approaches solve this dilemma?
- “Spinning is no people’s sport,” meaning that spinning – and flying near stall – is always at the lower speed border of dynamic flight and connected with hazards.
- “There are no certainties in spinning.” Small changes in basic conditions can change the resulting reaction of the aircraft rapidly.
- The Certification Standard is the sum of the experiences. This must be kept in mind if existing requirements are to be substituted (e.g. spin recovery).

B. Statements on operation

- “Technology and training come together in operation.” Technical improvements of any kind also require adequate pilot training.
- Pilots’ situational awareness for high angles of attack and the consequences is essential.
- If the pilot does not know how to recover, the aircraft need not be recoverable because a pilot that does not have the ability to recover from spin will not apply the correct inputs even if the aircraft would be recoverable with these inputs.
- Improvement of stall/spin awareness trainings is strongly recommended.
- “Not so much a part23 problem.” I.e.: better pilot trainings would improve the situation more than concentrated technical improvements.

C. Statements on spin resistance concept

- Spin resistance is out of place in "23.221" as spin resistance describes stall characteristics.
- In the concept of spin resistance, the classic phases of stall warning, behaviour and recovery are replaced by additional time. However, that time cannot substitute pilot skills if they are not aware of the situation.
- Known flight mechanical spin resistance measures contradict good-natured spin recovery.
- Current "representatives of operational situations" do not cover reality completely:
  - Speed rate of 1 kn/s does not cover all operational situations
  - Different findings at 1 kn/s and 5 kn/s stall trials
  - Height loss for recovery is not considered in current FAR23.221(a)(2)
  - Spins of modified PA-28 during NASA flight trials, see [31], are not considered in current FAR23.221(a)(2).
- "A bit of spin resistance is unsatisfactory." In operation, the full spectrum of entry manoeuvres will be flown.
- Spin resistance is currently handled as spin proofness. This safety suggestion may result from the marketing conflict to propagate an aircraft as safer than it is.
- Characteristics of customers of spin resistant aircraft?
- No financial pay-off from avoiding spin recovery flight tests: The verification of compliance with spin recovery requirements undoubtedly requires an extensive flight program. As known, the amount of flight tests to demonstrate compliance with current spin resistant requirements is not smaller, because the tuning of the flight mechanics measures is based on trial and error.
- A proper definition of the term *spin resistance* is not available. Today's definition of spin resistance is a set of manoeuvres in FAR23.221(a)(2).

  The term *spin resistance* could, considering only the term itself, also be understood as the behaviour of an A/C to recover itself from spinning. This would mean that the aircraft would stop any spinning motion when the pilot just releases the control, without the necessity for any consciously induced recovery action.

D. Miscellaneous statements on spin

- Wing level stall at 1 kn/s is not representative of operational situations.
- Higher speed rates and gusts must be considered.
- Design of appropriate empennages to recover from spin is well known today.
- No renouncement of spin recoverability without need
- Exceeding compliance of elevator trim requirements can be problematic for recovery: Because of high elevator forces, the pilot may apply an insufficiently low elevator control input during the attempt to recover.

E. Statements on possible technical measures

Three groups of possible measures were emerged:

- Flight mechanical measures
  - Unambiguous control forces and control movements
  - The experts see limited potential for droop leading edges or similar devices
    because of degraded spin recovery
  - Other configurations do not improve the situation (canard, T-tail)
  - Excessive limitations of controls contradict good spin recoverability
  - Knowledge about the design of appropriate empennages for spin recoverability is available

- Stall warning systems
  - The situation today is that audio warnings are used for different purposes, but are not standardised. As such, the audio warning schemes between different aircraft may differ entirely. In critical situations, pilots using different types of aircraft may be engaged in interpreting the warning signals instead of immediate reaction.
  - No consideration of angle of sideslip
  - Progressive warning can be advantageous

- Envelope protection

  True envelope protection may be technically possible. But this would change the character of light aircraft operation and would require adapted training concepts.

Concluding statements

- The experts see limited potential for flight mechanical measures to improve the level of safety.
- Experts recommend improved stall warning systems and envelope protection systems.
- Experts recommend substantial stall and spin training.

6.4.2 Appraisement of interviews

The conformity of the statements may lead to this conclusion: All interviewed experts come from Germany, so they may be influenced by the similar environment.

We expected that comparable experts from other European countries would principally express similar statements, see e.g. [79] p.503. After consultation with EASA, efforts to access additional interview partners from other European countries were discontinued.
Stall/spin behaviour must be seen as partly a safety aspect and partly an economic aspect. Following the experts' opinion, today's approaches to spin resistant aircraft design using flight mechanical measures do not yield the intended results. The term "spin resistant" is not necessarily connected to passive flight mechanical measures.

Advanced stall warnings, envelope protection and concepts for stall/spin trainings as discussed by the experts are not intended to be investigated in this study.

7 Discussion of review on spin resistance and progressing considerations

7.1 Experiences with the current FAR spin resistance requirements

Based on the findings described in the previous Sections, this Section presents an evaluation of the existing spin resistance criteria after some years of operational experience.

As shown in Section 6.1.3, the FAR requirements define a set of manoeuvres to be performed for certification as a spin resistant aircraft. Figure 8 visualises the relationship between this regulation and the two main kinds of stall/spin-related accidents, i.e. those starting at low height and those starting at high height. As a kind of “exchange deal”, the applicant does not need to prove that the aircraft is recoverable from spins. The reason being that the higher statistical amount of accidents start from low height (see Section 6.2.1).

<table>
<tr><td></td><td colspan="2">I</td><td>II</td></tr>
<tr><td>Accident situation</td><td colspan="2">Stall/spin starting at low height above ground</td><td>Stall/spin starting at large height</td></tr>
<tr><td>Ratio of stall/spin-related accidents</td><td colspan="2">80%</td><td>7%
unknown: 13%</td></tr>
<tr><td>Constraint</td><td colspan="2">Recovery from spin (as the case may be even from stall) not possible, due to limited height above ground</td><td></td></tr>
<tr><td>Consequential requirement</td><td colspan="2">Prevent stall and spin entry</td><td>Ensure recoverability within a certain height</td></tr>
<tr><td></td><td colspan="3">**Spin resistance:
“exchange deal”**</td></tr>
<tr><td></td><td>“resistance” against spin entry</td><td>←
→</td><td>no proof of recoverability</td></tr>
</table>

Figure 8: Spin resistance in relation to stall/spin-related accidents starting at low and at high height

To prove that this regulation leads to the same level of safety as the conventional way of certifying spin recoverable aircraft, it would be necessary to prove that the amount of stall/spin-related accidents starting at low height can be reduced so that loss of safety due to missing proof of recoverability would thereby be justified.

The regulation defines a rather limited set of manoeuvres to be tested for certification as a spin-resistant aircraft. Flight testing performed by NASA already indicated that additional manoeuvres leading to a spin for some aircraft are not contained within this requirement.

The analysis of accident data in Section 6.2 shows that the current spin resistant aircraft does not provide a significant improvement (considering the limited data available) as regards stall/spin-related accidents compared to conventional GA aircraft.

It is assumed that the execution of a manoeuvre contained in the requirements does not lead to fatal accidents because the requirements ensure that an average pilot can recover from the flight state obtained. Thus, it can be concluded that, prior to the accidents analysed above, manoeuvres not covered by the current requirement have been performed by the pilots. In consequence, it can be concluded that the requirement, which was originally intended to be *representative for operational situations*, does not cover these operational situations completely, or indeed, obviously does not cover those manoeuvres decisive for stall/spin-related accidents.

These considerations regarding decisive manoeuvres will be combined with the results from the flight trials in Section 9.3.

<u>Remark</u>

In this context, it is interesting to note a difference in the distribution of responsibilities between the rulemaking authorities and test pilots doing the flight testing for certification of the aircraft. During spin testing of conventional aircraft, the test pilot, “guided” by the requirement, is essentially the deciding party as to whether the spinning behaviour of the aircraft is good-natured enough for any pilot to be able to deal with it or not. As regards spin resistant aircraft (FAR23.221(a)(2)), the rulemaking authority in some way takes on more responsibility by precisely defining all manoeuvres and control inputs which are then executed by the test pilot.

7.2 Considerations on the spin resistance concept

The whole topic of stall/spin-related accidents (14% among all fatal accidents) has to be discussed in order to redefine the spin resistant option from today's point of view.

In the following, the considerations are numbered to simplify cross references. The following aspects will be discussed:

a) Statements
b) Aims of spin resistance
c) Implications
d) Possible measures to reduce the number of stall/spin-related accidents
e) Principal approach for flight trials

a) Statements

I. As only 7% of the aircraft involved in stall/spin-related accidents definitely started the stall/spin from a height of over 1000 feet above ground level, recoverability from spins is applicable in only a smaller part of the stall/spin-related occurrences. Without doubt, the approach to prevent stalls and spins is the appropriate measure to avert the larger part of the accidents.

   The height of 1000 ft corresponds approximately to the usual airfield traffic pattern height.

II. The mode of action of spin resistance (why and how it is aimed to reduce accidents by spin resistance measures) has not yet been completely determined.

   a. One possible way spin resistance helps is to give the pilot more time to react and to recover from a stall. This method of describing the mode of action of spin resistance is problematic because we cannot assume that a pilot in a stressed situation is aware of the stall.

      Improved stall warnings and envelope protection measures should manage to effectively help reduce this problem. As it was mentioned in Section 6.1.4, vital improvements compared to the standard system installed in most aircraft are possible. This corresponds with the results of research done by NASA on the topic of *stall deterrent systems* (see Section 6.1.2), the outcomes of the expert interviews and various answers on the questionnaire.

b. In the current FAR23.221(a)(2), spin resistance is defined using manoeuvres. These manoeuvres are intended to represent accident relevant operational situations. This evokes the problem that it is difficult to appoint the ratio of accident relevant operational situations that are covered by the defined manoeuvres.

III. Compared to the existing FAR spin resistance requirements, higher rates of speed reduction (5 kn/s) must be included. The review of NASA research flights has shown that the behaviour of the aircraft can change from satisfactory to critical with higher rates, and in the review of accident reports, hints on pull-up manoeuvres prior to the accidents have been found. These assessments have been confirmed in the answers to the questionnaire and in the interviews with experts.

IV. Compared to the existing FAR spin resistance requirements, maximum power setting must be included. The reasons are:

a. The occurrence of stall/spin-related accidents within the traffic pattern is similar in amount in the descending and ascending parts of the traffic pattern; the latter mostly with the pilot having full power applied.

b. Flight tests for certification are usually performed at a much increased density altitude for safety reasons. The actual power at which the behaviour of the aircraft is investigated is thereby much lower compared to the power in operational situations within the traffic pattern.

c. Flight testing of the PA-28 at NASA (see Figure 2 and [31]) has shown that spins were obtained at maximum power setting, whereas no spins were obtained at the power setting for level flight.

V. Compared with the existing FAR spin resistance requirements, banked turns with pro-spin control inputs must be included. Many of the stall/spin-related accidents within the traffic pattern occurred during turns. Flight tests of the PA-28 at NASA have shown that stalls starting from banked turns are more critical than stalls from level flight for this type of aircraft.

VI. It is insufficient to merely prevent aircraft from the motion of spinning, as impact on the ground in a non-spin but stalled flight state also often ends up fatally. Therefore, a maximum allowable height loss must be defined for any entry into a stalled flight state and subsequent recovery.

VII. For certification of spin resistant aircraft (acc. current FAR23.221(a)(2)), no proof of recoverability from spins needs to be demonstrated. This renouncement of the proof of spin recoverability results (if regarded as a separate aspect) in a decrease of the level of safety. The need for the proof of spin recoverability should therefore not be released just to facilitate the certification process without further urgent reasons, unless the aircraft is not capable of entering a spin under any circumstances.

VIII. As regards the sequence of events during a stall/spin-related occurrence (see Figure), the elements ‘situational awareness of the pilot’ and ‘situation after recovery’ could be heeded more thoroughly when trying to find concepts to avoid accidents.

Phases of flight / configuration
Ascending flight
Descending flight
Wings level
Turning
…
↓
Manoeuvres (’control abuse’)
↓
Behaviour of plane
Tendency to spin
Rotations or accelerations leading to disorientation of pilot
Stall warning behaviour
↓
Situational awareness of the pilot
↓
Return to level flight / Situation after recovery
Height loss
…

Figure 9: Sequence of events that has to be considered when analysing stall/spin-related occurrences

This corresponds to the global approaches to the process of spinning presented in Section 6.1.4, whereas the existing spin resistance concept presently concentrates on technical measures to influence the behaviour of the plane.

IX. Generally, pilot education and training are surely decisive aspects for safety in aviation. In the following are some thoughts on this in relation to spin resistance:

a. Any deficiency in pilots' awareness, education and training cannot be solved solely by partial technical measures. It is most certain that best results in accident reduction can be achieved if technical and educational measures are not regarded independent of each other. Educational measures, in this context, address the issue of spinning as well as awareness for stalled flight states.
Remark: *To prevent accidents occurring during stall and spin training, it might be useful to concentrate this training on specific courses and / or facilities, performed by personnel who are more aware and better in training than the average flight instructor.*

b. Usually, behaviour during stall and the entry phase to a spin and recovery from unusual flight attitudes can be trained in principle with every aircraft. It is not possible to safely educate and train the behaviour during stall and the entry phase to a spin with spin resistant aircraft, as the aircraft may enter a non-recoverable flight state. Because of this, pilots used to spin resistant aircraft may lose awareness and knowledge of post-stall processes. Lack of pilot training and warning behaviour of the aircraft can result in pilots going closer and closer to the borders of the flight envelope during everyday operation.

c. Although there is no evidence that accidents have occurred where pilots deliberately spin aircraft not cleared for deliberate spinning, it can be assumed that a large number of pilots of spin resistant aircraft are not aware of the principally different safety philosophy as regards stalls, nor of the fact that the aircraft can enter a non-recoverable flight state.

X. Following today's state of knowledge, good characteristics in recovery from spins according to Section 6.1.5 (effectiveness of rudder) are opposed to spin resistance.

Active devices (e.g. rudder limiter) may partially solve this contradiction, but this will only result in a safety benefit if its functionality respects a wider range of operational situations. A border area between spin resistance in a more narrow sense and full envelope protection arises when discussing this subject.

b) Aims of spin resistance

XI. The aim of spin resistance measures is to prevent the pilot substantively from entering a stalled flight state that cannot be recovered within certain limits (height, time).

XII. The term 'spin resistance' can generally be described as the ability of an aircraft, due to design, to counter entry into the flight state of spinning or other stall-related flight states resulting in unfavourable height loss and long recovery time.

c) Implications

XIII. The description in XII portrays a tendency in the first instance towards 'spin resistant' as opposed to 'spin prone'. Technical measures to achieve spin resistance in today's FAR23.221(a)(2) interpretation are also used to enhance the stall characteristics of conventional aircraft.

XIV. The demarcation between spin resistant aircraft and other aircraft is presently done using the manoeuvres defined in FAR23.221(a)(2). A new formulation of spin resistance requirements allows the consideration of other methods, see 7.1, "Remark".

a. One option is to require that no undesirable flight state can be reached by *any input.* The test pilot would be responsible for confirming that. It would be necessary to define acceptable limits for the behaviour of the aircraft, as for example:
   i. Wings level flight (representing initial climb and final)
      1. No uncontrollability
      2. Positive climb at 75% PWR always possible while stalling with speed reduction rate < 1 kn/s (no loss of height)
      3. After stalls with speed reduction rate > 1 kn/s: recoverable within the height that was present at $1.5v_S$ (no height loss during manoeuvre)

   ii. Banked turns with 45° bank (minimum height of turns within the traffic pattern estimated to 300 ft)
      1. Stalls with speed reduction rate < 1 kn/s: Recoverable within 300 ft from the beginning of the stall. (max. 300 ft height loss for recovery)
      2. After stalls with speed reduction rate > 1 kn/s stalls: recoverable within the height that was present at $1.5v_S$ minus 300 ft (max. 300 ft height loss during manoeuvre)

   The extent of flight tests for such certification is without doubt comparable to the extent necessary to prove recoverability from spins.

b. The other option is to define manoeuvres. It would be necessary to give reasons for the choice of the *representatives of operational situations* from today's point of view. Here again, it would be necessary to define acceptable limits for the behaviour of the aircraft. A limited set of manoeuvres can simplify flight testing for final certification, but modifying the aircraft until it complies is, as far as we are informed, a very extensive task.

XV. In principal, there are three possible ways of approaching manoeuvres for flight trials within this project and as a basis for a requirement:

1. Single manoeuvres are defined based on ‘intuition’ or experience.
2. Accident data are analysed, and manoeuvres subsequently derived from the analysis.
3. Starting from a wide matrix of manoeuvres and parameters attempting to cover any possible pilot input, a selection of representative manoeuvres can be made.

It would be most preferable for the selection of manoeuvres to be based on statistical data of the detailed course of events leading to accidents and on control inputs used by pilots during education and normal operation. Analysis of accident data within this project showed that only rather vague information on the course of events leading to accidents can be derived; reconstruction of the detailed control inputs is not possible. It can be concluded that no justification can be given for any selection of manoeuvres for implementation into a regulation which is completely derived from firm facts. Any selection can only be based on indications, assisted by the advice of experienced experts.

XVI. Choosing representative manoeuvres and control inputs will always imply that it is at least partially known which controls are decisive for the aircraft’s stall behaviour, based on the experience made with existing aircraft designs. It evokes the problem that conceptually different future aircraft are not covered by this approach.

XVII. As manoeuvres for implementation into the regulation, in this context, shall be a kind of standardised simulation of manoeuvres during operation, it is not sufficient to define only manoeuvres and control inputs. It is also necessary to define a point in time at which the operational pilot is assumed to have realised the situation and starts recovery. The behaviour of the aircraft during the whole process and the situation after recovery has to be considered and must be kept within defined borders.

d) Possible measures to reduce the number of stall/spin-related accidents

XVIII. Summarising findings and thoughts of literature reviews, questionnaires and interviews with experts, the following four bullet points present possible measures that could help to reduce the amount of stall/spin-related accidents.

1) Spin resistance by passive flight mechanical measures

→ "Spin resistance" as defined by the current FAR23.221(a)(2)

- o Manoeuvres / configurations decisive for accidents are not included (dynamic speed reduction, maximum power setting, turning flight with pro-spin rudder input)
- o Completely omitting the proof of recoverability is a decrease of safety

→ New requirements for "spin resistance"

- o Inclusion of dynamic speed reduction, maximum power setting, turning flight with pro-spin rudder input
- o Partial proof of recoverability proposed
- o Maximum allowable height loss
- o Clearer information / warning to the pilot to prevent intentional spinning

2) Improved stall warning

- Method of indication must consider the psychological aspects of a pilot under stress
- Different measured quantities to be combined in a sophisticated way

→ Obligatory for every aircraft

→ Or, as an alternative option, as an "exchange deal" with partial instead of full proof of recoverability

3) Envelope protection

→ Stick force input, pilot can oversteer

→ True envelope protection, pilot cannot oversteer

- o Border area to aircraft "incapable of spinning"
- o See ONBASS study for feasibility [70]-[73]

4) **Training**

Properly regulated mandatory spin and stall/spin awareness trainings and trainings in unusual attitude recovery

The best results in accident reduction will be achieved if several aspects of these possible measures are combined, see IX.

XIX. As the topic of this project is specified as safety aspects of light aircraft spin resistance concept, the following considerations will concentrate on the first point, enhanced stall qualities, manoeuvres for flight trials and implementation into a regulation.

e) Principal approach for flight trials

XX. There are two conceivable central ideas when developing a schedule for flight trials in preparation for a requirement:

1. The aim of the flight trials is to identify the capabilities of state-of-the-art measures.

2. The flight trials investigate the question of what is necessary to ensure safety.

The advantage of the first approach is that the resulting code will contain requirements which can be realised in the nearer future. The advantage of the second approach is that the resulting code will merely target safety aims and be open to future developments. In the best case, there is an intersection between these two approaches. After all, it is a question of ethics, responsibilities of certification requirements and project funds.

XXI. Flight trials using existing aircraft certified as spin resistant according to the current FAR23.221 are not helpful. These aircraft are well fitted to the existing requirements and can be assumed as state-of-the-art. As this project aims for a generic view on the topic, a common aircraft is much more appropriate for the flight trials.

7.3 Conclusions drawn from the review on spin resistance for preparation of flight trials

The conclusions for the flight trials within this project have been compiled in this Subsection, based on the statements presented in the previous Section.

The considerations showed that the variety of manoeuvres for a regulation must be expanded. In particular, manoeuvres with maximum power setting, higher rates of speed reduction and banked turns with pro-spin control inputs must be added. Most manoeuvres should contain a defined range of time during which defined control inputs must be held.

The flight trials were designed to get a better understanding of the changes in the behaviour of an aircraft caused by variations in the in-flight parameters such as power setting, rate of speed reduction, flap setting, bank angle or aileron deflection. Furthermore, the usability of the developed manoeuvres shall be determined with regard to later utilisation in a requirement.

According to the findings of the previous Section, it was decided that the flight trials should at least contain:

- Stalls with
  - Engine idle (representing descending flight)
  - Engine setting for level flight
  - Engine at maximum power (representing climbing flight)
  - Engine power raise from idle to 100% in less than 3 s (representing go around or the pilot's attempt to recover from stall)
- Stalls with 1kn/s and 5kn/s deceleration
- Bank angle up to 45°, left and right
- Stick at rear stop up to 7s
- Stalls with slip and skid
- Rudder at stall (dynamic rudder)
- Various aileron deflections

The following states will also influence stall behaviour, but are deemed to be discussed separately:

- T/O mass
- Mass distribution
- Density effects
- Effects of variable-pitch propeller

The realisation in the flight test program is presented in the next Section in more detail.

8 Flight trials

The flight trials were designed to implement the considerations and conclusions of Section 7.3. They were performed with a Cessna F 172N that was equipped with a comprehensive measurement system, see Section 8.3.

8.1 Design of manoeuvres

The schedule of manoeuvres of the flight trials is based on “CS23.221 proposed amendment to incorporate spin resistance concept, Version 5” (see Section 13.5, abbreviated as “EASA-V5”) submitted by EASA, which is a modification / further development of current FAR23.221. Implementing this text into a flight test schedule results in eight types of manoeuvres which will subsequently be referred to as “manoeuvre type A” to “manoeuvre type H”. According to the outcomes of Section 6 and 7, as shown in Sections 7.3, these manoeuvres have been extended by additional variations of parameters.

The eight types of manoeuvres and the additional variations are presented below. A more detailed listing containing each manoeuvre with its dedicated configuration and parameters can be found in Section 13.6.

Manoeuvre Type A

Source:	EASA-V5 23.221(b)(1)+(2)
Content:	1 kn/s, wings level → *Uncontrollable nose pitch down?* If no: roll 30° to 30° bank without rudder, stick aft → *Abnormal characteristics?* If yes (pitch down): stick aft 2s, no rudder, then standard stall recovery → *Max bank more than 15°?* → *Return to unstalled immediate?* → *Any tendency to spin?*
Parameters to be varied acc. V5	o power setting o wing flaps
Parameters to be varied additionally	none

This manoeuvre type was adopted from the EASA-proposal without amendments.

Manoeuvre Type B

Source:	EASA-V5 23.221(b)(3)
Content:	45° banked turn until pitch down or stick aft, then immediate recover to level flight, no power change → *Height loss more than 300ft?* → *Undue pitch up?* → *Any tendency to spin?* → *Max bank more than 60°/15°?* → *Exceeding max speed or load?*
Parameters to be varied acc. V5	o speed rate: 1 kn/s and 3-5 kn/s o power setting o wing flaps
Parameters to be varied additionally	o additional power settings o duration stick held aft o dynamic control inputs

Some manoeuvres with pro-spin control inputs (dynamic rudder at the moment the stall is reached) were added here, corresponding to the results of flight testing the PA-28 by NASA, where banked turns have been a more critical case than stalls from wings level flight. As a significant part of the accidents occurs in connection with turning flights, the behaviour of the aircraft during such a manoeuvre should be determined. To observe the stall behaviour, the stick shall be held aft for seven seconds, identical to the NASA/FAA manoeuvres with pro-spin control inputs.

Here, as well as at manoeuvre types C and H, maximum available power was scheduled as the configuration for many of the additional manoeuvres as it may be a critical case for many aircraft, and because many of the stall/spin-related accidents occur in ascending phases of the traffic pattern.

Manoeuvre Type C

Source:	EASA-V5 23.221(b)(4)
Content:	reduce speed until stick aft, 7s full rudder, ailerons deflected opposite “attempting to maintain heading” → *Immediate respond to flight controls?* → *Reversal of control effect?* → *Temporary control forces above limit?* → *State of flight achieved before recovery?*
Parameters to be varied acc. V5	o power setting o wing flaps
Parameters to be varied additionally	o speed rate o aileron deflection o additional power settings

This manoeuvre type has already been the most significant manoeuvre in the NASA flight tests. Higher rates of speed reduction (as it can be assumed that the rate of speed reduction in critical operational situations is much higher than 1 kn/s), additional aileron positions (at least the neutral position), maximum available power and a rapid change in the power setting at stall are to be determined here, as all these configurations can be typical operational stall situations in the traffic pattern.

Manoeuvre Type D

Source:	EASA-V5 23.221(b)(5)
Content:	1.1Vs1, sudden rudder deflection (in less than 2s) for heading change of the lessor of 1100/Vs1 or 20°, if not possible full rudder → *controllable by conventional use?*
Parameters to be varied acc. V5	o power setting o wing flaps
Parameters to be varied additionally	o $d\zeta/dt$, ζ = rudder deflection

One manoeuvre with application of rudder “as sudden as possible” instead of “in less than two seconds” has been added to types D and E.

In the EASA proposal, it was intended to use the rudder deflection determined for this manoeuvre type again to define the uncoordinated flight condition in manoeuvre types F to H.

Manoeuvre Type E

Source:	EASA-V5 23.221(b)(6)
Content:	1.1Vs1, sudden aileron deflection (in less than 2s) for bank of 30°, if not possible full aileron → *controllable by conventional use?*
Parameters to be varied acc. V5	o power setting o wing flaps
Parameters to be varied additionally	o $d\eta/dt$, η = aileron deflection

Manoeuvre Type F

Source:	EASA-V5 23.221(b)(7) in connection with CS 23.201(a)
Content:	In uncoordinated flight (rudder deflection like type D) roll and yaw before stall → *Possible?* → *Control reversal?*
Parameters to be varied acc. V5	o power setting o wing flaps
Parameters to be varied additionally	None

Manoeuvre types F to H result from the demand that the stall paragraphs 23.201 and 23.203 are to be fulfilled with the aircraft in uncoordinated flight. This type of manoeuvre was adopted from the proposal without amendments.

Manoeuvre Type G

Source:	EASA-V5 23.221(b)(7) in connection with CS 23.201(b), (c), (d)
Content:	In uncoordinated flight (rudder deflection like type D) 1 kn/s until pitch down or hold stick aft the longer of 2s or time in Sec. 23.49 → *Max. roll + yaw more than 15°?*
Parameters to be varied acc. V5	o power setting o wing flaps
Parameters to be varied additionally	None

This type of manoeuvre was adopted from the proposal without amendments.

Manoeuvre Type H

Source:	EASA-V5 23.221(b)(7) in connection with CS 23.203
Content:	In uncoordinated flight (rudder deflection like type D) 30° banked turn until pitch down or stick aft, then immediate recover to wings level flight, no power change → *Excessive height loss?* → *Undue pitch up?* → *Uncontrollable tendency to spin?* → *Max bank more than 60°/30° resp. 90°/60°?* → *Exceeding max speed or load?*
Parameters to be varied acc. V5	o speed rate o power setting o wing flaps
Parameters to be varied additionally	o bank angle o additional power settings o duration stick held aft

As for type B, items were added here where the stick shall be held aft for seven seconds. Additional power settings and a bank angle of 45° were added.

8.2 Flight test strategy and flight test charts

The manoeuvres according to Section 13.6 were flown in the order according Table 8 in Section 13.6. All manoeuvres of one type were flown at a stretch to get a broad impression of that manoeuvre.

Although the aircraft was equipped with a comprehensive measurement system, as described in the following Section, the crew made notes of several states and perceptions. This procedure was chosen to record any perception beyond the capability of the measurement system and to train the crew for possible flight trials with aircraft that cannot be equipped with a measurement system.

A documentation scheme was compiled for every flight. The cover page contains all general information and is followed by an overview of the manoeuvre scheduled for the flight. Every single manoeuvre was then assigned a separate page. It contains all relevant information for the crew to fly the manoeuvre and – if completed correctly – all relevant information for the team to assess the trails. Section 13.7 shows the blank documentation with a small selection of manoeuvre sheets.

The flight trials were performed with two crew members to free the pilot from writing records.

8.3 Description of the measurement system for flight trials

8.3.1 General overview

For the flight trials with the Cessna F 172N of the IFF a measurement system was installed by messWERK using sensors for the following quantities:

- Position and ground speed with GPS
- Pitot and static pressure
- Air temperature
- Angle of attack and side slip
- Control inputs of elevator, aileron and rudder
- Power lever and flap position
- Stick forces
- Acceleration (3 axes, part of the inertial sensor pack)
- Angular rates (3 axes, part of the inertial sensor pack)

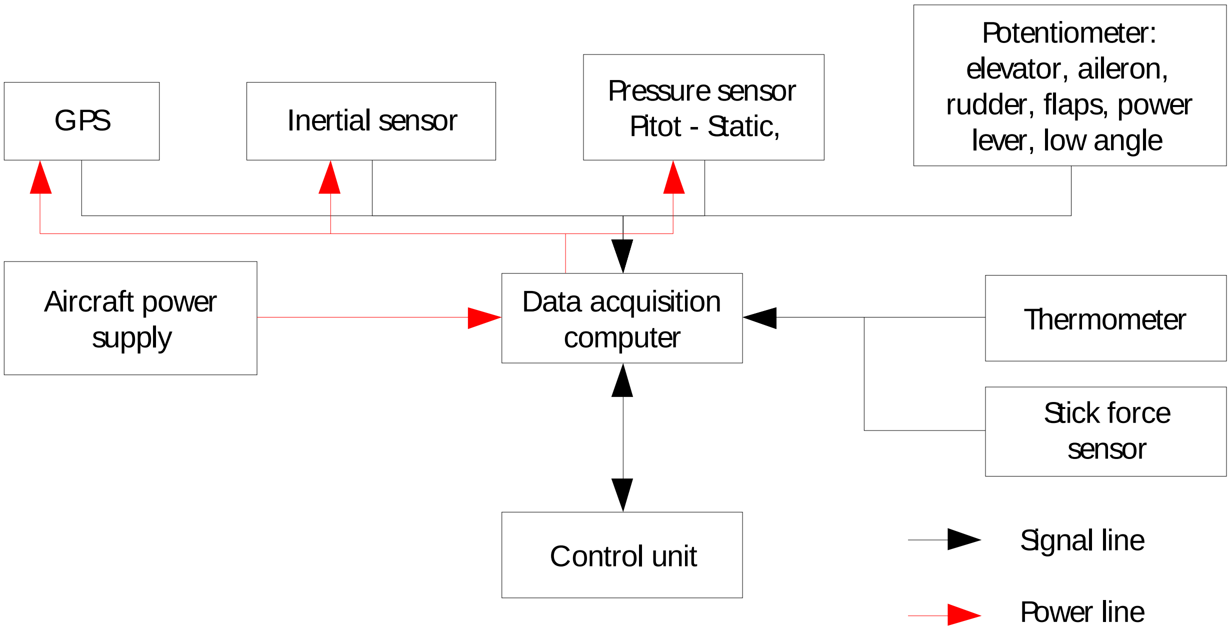


Figure 10: Block diagram of sensor system

The complete system consists of the following components:

Sensor	Type	Range	Remarks
static pressure	Setra 270	400 – 1050 hPa	pitot-static system of wind boom
dynamic pressure	Setra 239	0 - 350 hPa	pitot-static system of wind boom
flow angle (attack and side slip)	mW MK1 vanes	±160°	on wing boom
temperature	PT100	-50 to +50 °C	wing boom
inertial measurement unit (IMU)	iMAR VRU-FC	±10 g, ±300 °/s	
GPS	Novatel OEM V		sampling rate 1 Hz
control surface deflection	angle sensors	0-340 °	attached directly to control surface
stick force	mW DMS-stick	± 500 N	attached to stick
power lever	wire potentiometer	250 mm	installed on power lever inside the cockpit
data acquisition	messWERK mR-14		analogue sensor sampling rate 100 Hz

Table 3: Overview of sensors

Remarks:

- All sensors (besides angle and force sensors) and the data acquisition system were installed on a tray in the baggage compartment of the Cessna F 172N (E-EMWF)
- Power supply: 28 V by aircraft system
- Angle sensors were installed on the control surfaces
- The pressure sensors for the Pitot-static were connected to the Pitot-static probe of the sensor head on the tip of the wing boom
- The pressure sensors were calibrated prior to installation with an RVSM Pitot-static reference system by DMA Marchiori, type MPS 31 B
- All data were recorded with 100 Hz on Compact Flash cards
- The attitude of the aircraft was computed by using GPS and inertial data of the IMU.

8.3.2 Photo documentation of the sensor installation

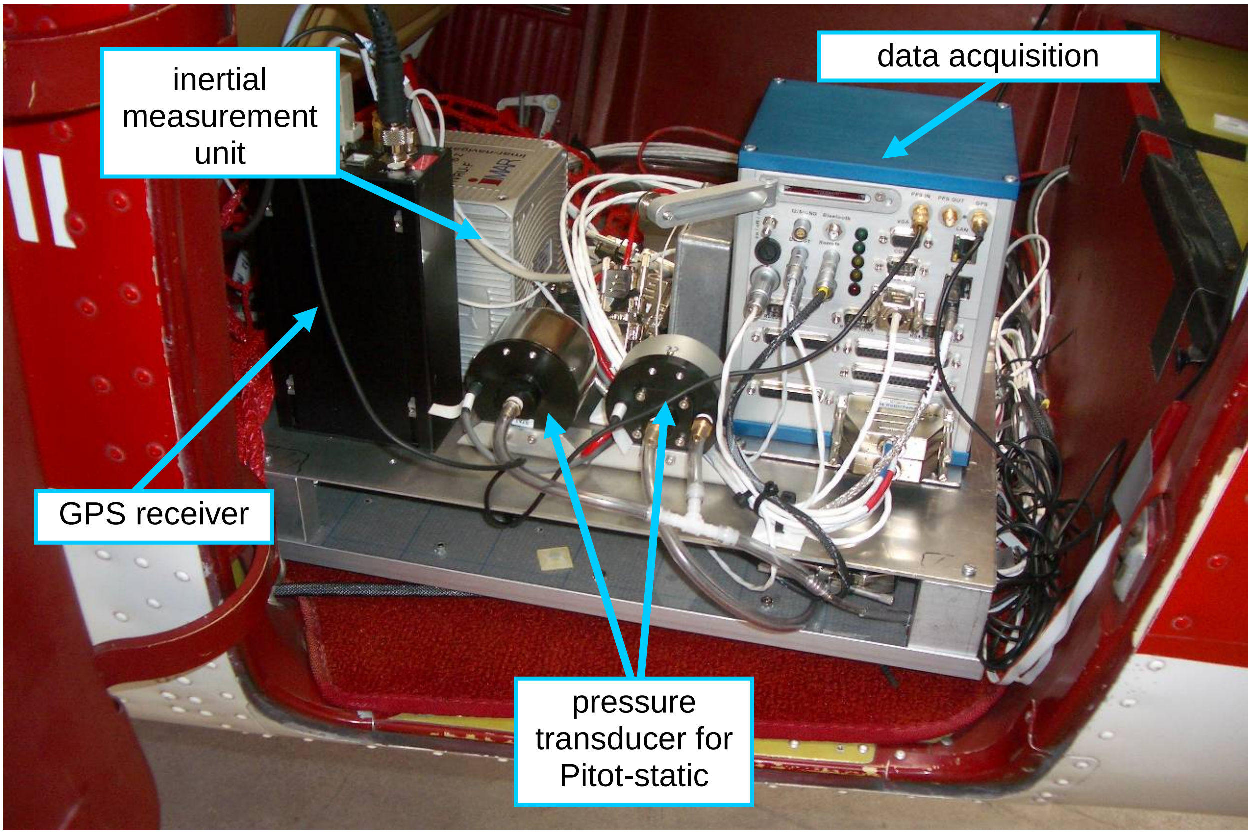


Figure 11: System on tray in baggage compartment

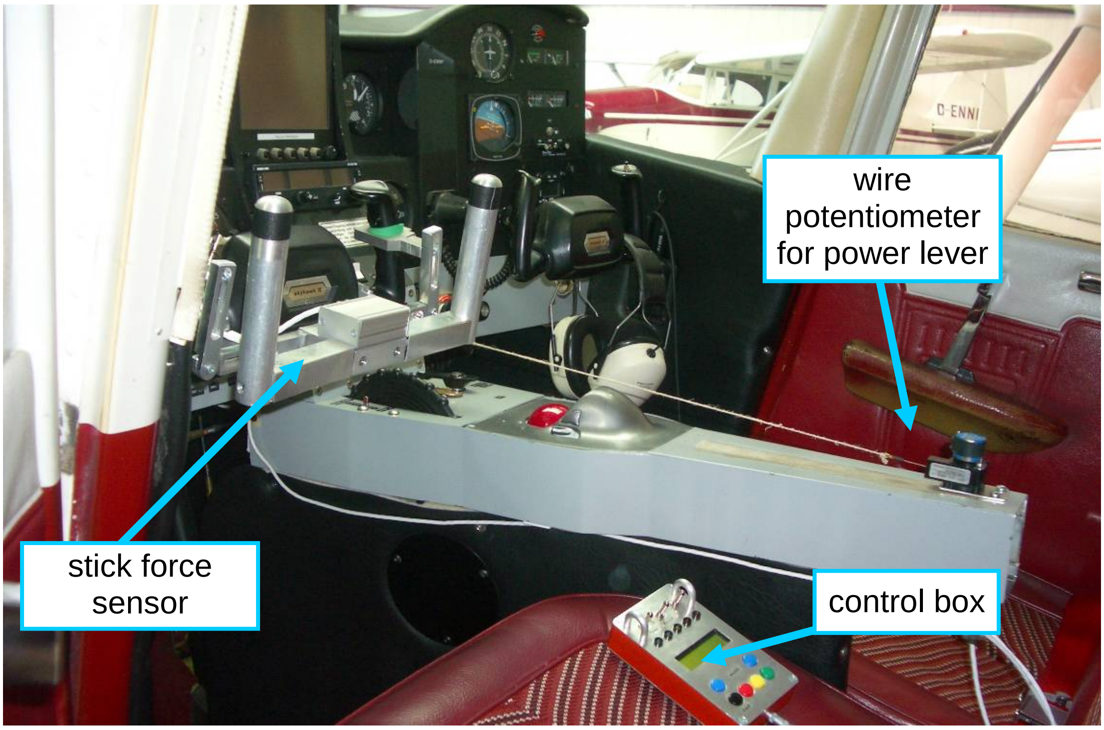


Figure 12: Sensors in the cockpit

Figure 13: Angle sensor on left wing (flaps on the right and aileron on the left side of the picture)

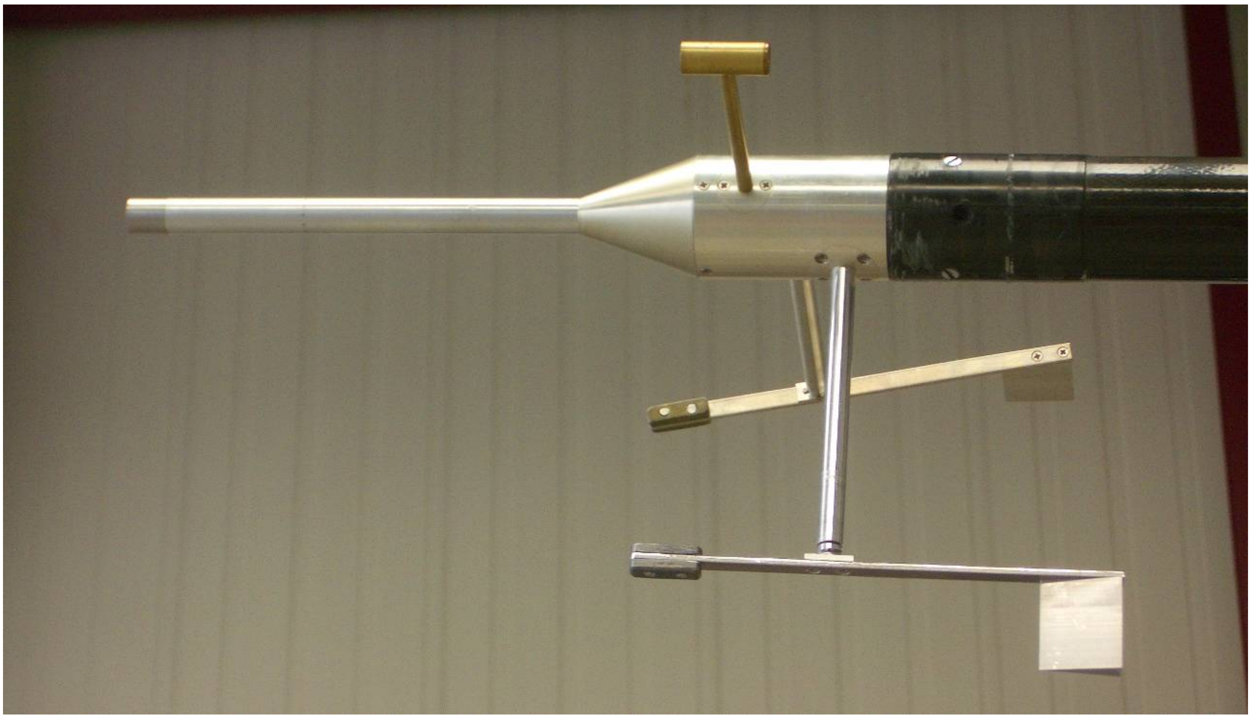


Figure 14: Air data probe on wing boom on the right side

8.3.3 List of acronyms

acronym name	formula symbol	unit	remark
BAS		m/s	basic airspeed
TAS		m/s	true airspeed
Hbaro		m	barometric altitude
Hdens		m	density altitude
density		kg/m³	local density
Pstat_r		hPa	static pressure
Pstau_r		hPa	dynamic pressure
F_eta	F_{eta}	N	elevator force on stick (push positive)
F_ksi	F_{ksi}	N	aileron force on stick (left positive)
eta_r		°	elevator deflection (positive push)
eta_p		%	relative elevator deflection
ksi_r		°	aileron deflection (positive left)
ksi_p		%	relative aileron deflection
zeta_r		°	rudder deflection (positive left)
zeta_p		%	relative rudder deflection
alpha_r		°	angle of attack
beta_r		°	angle of side slip
power_r		%	relative position of power lever
Ttotal_r		°C	total air temperature
Tstat		°C	static air temperature
T_ISA		°C	corresponding temperature of standard atmosphere
Hpunkt	H_{pkt}	m/s	vertical speed (up positive)
GPSLat, GPSLon		°	GPS position
GPSAlt		m	GPS altitude
GPSStdLat		°	standard deviation of GPS
GPSStdLon		°	standard deviation of GPS
GPSStdAlt		m	standard deviation of GPS
GPSVHor		m/s	horizontal speed
GPSVDir	χ	°	direction of horizontal speed
Theta	Θ	°	pitch angle (nose up positive)
Phi	Φ	°	bank angle (left wing up positive)
Psi	Ψ	°	heading
VRU_accx, y, z		m/s²	acceleration (3 axes) of INS
VRU_omgx, y, z	p, q, r	°/s	angular rate of INS
sys_time		s	system time, synchronised to GPS time
Event		-	event marker

Table 4: List of acronyms

8.3.4 Calibration and accuracy

8.3.4.1 Pressure sensor

All pressure transducers were calibrated against an Air Data Test Set MPS 31 B by Marchiori (accuracy 0.5 kn at 50 kn and 3 ft at sea level).

This system generates static and dynamic pressures which were applied to the sensors used for the Cessna F 172N. For each sensor, the coefficients for a linear regression were computed and updated in the data acquisition system. This procedure calibrates the entire measurement chain and includes the correction of any errors caused by the data acquisition system.

As such, the remaining errors should not exceed the specific accuracy stated by the manufacturer of the Air Data Test Set plus the maximum of the residual error of the calibration:

dynamic pressure: 0.5 kn + 0.2 kn (0.04 hPa)= 0.7 kn

static pressure: 3 ft + 6 ft (0.18 hPa)= 9 ft

8.3.4.2 Stick force

The force sensors are calibrated by applying a weight to the sensor. The output signal of the force sensor is the sum of each side. As such, both hands, or one on the left or one on the right can be used.

The remaining error after calibration is stated with 3 N for aileron and elevator force.

8.3.4.3 Potentiometer

All control inputs are detected with angle sensors attached to the control surfaces. The output of these sensors is linear to the control surface deflection angle. A calibration with an additional angle sensor (installed on the control surface only for the calibration) was performed. The same applies for the angle sensors of angle of attack and side slip. The remaining error is stated with 1°.

The wire potentiometer on the power lever is installed almost in line with the lever, so the output signal is fairly linear to the position. It is calibrated so that idle is 0% and full power is 100 %.

8.3.4.4 GPS position, velocities, attitude

The accuracy of the GPS receiver is stated in the technical data sheet as follows:

- Position: 1.5 m CEP[2] with use of L1/L2 antenna (*OEMV Family Installation and Operation User Manual Rev 1*)
- Velocity: 0.03 m/s RMS (Root Mean Square)

Attitude: The attitude was determined by integrating the angular rates measured by the inertial measurement unit. This signal was lowpass filtered with an apparent gravity method based on lateral and longitudinal accelerations, TAS and GPS ground speed vector. The fibre optic gyros have a drift of 0.03 °/s according to the technical data sheet (*iMAR iVRU-FQ: Vertical Reference Unit (Accel. /Rate/ Attitude/ rel. Heading) Quotation N°: 06.080301H*). Following this, the maximum error for the relative attitude is 1.8° after 60 seconds (duration of longest manoeuvre analysed) for each attitude angle.

8.4 Execution of flight trials

The centre of gravity of the Cessna F 172N was located at the most rearward certified position for the utility category, but significantly further forward than the certified aft position for the normal category:

CG-range Utility:	0.89-1.03m
CG-range Normal:	0.89-1.20m
CG flown:	approx. 1.03m
CMTOW Utility:	907kg
CMTOW Normal:	1043kg
T/W flown:	approx. 905kg

Table 5: Weight and balance of test aircraft

Flights were completed in April 2009. One and the same pilot completed all the flights.

---

[2] CEP: Circular Error Probable

8.5 Outputs and results of flight trials

8.5.1 Time plots of manoeuvres

The measurement system described in Section 8.3 provides a lot of information. Exemplary diagrams for each manoeuvre type are pictured in annex 13.8. Each diagram contains 5 plots of different states vs. time:

- Plot 1: Indicated airspeed and barometric altitude
- Plot 2: Attitude: Heading, roll (Phi) and pitch (Theta)
- Plot 3: Deflection of control surfaces
- Plot 4: Pilot's input forces and normal load factor
- Plot 5: Angle of attack and side slip

Each manoeuvre flown in this campaign can be reconstructed this way.

8.5.2 Tabulated overview of the flight trial results

A presentation of time plots is less useful for an appraisement of the flight trials. Instead, a clear combination of measuring and crews' perceptions in view of compliance with the interim requirements is needed. This overview is given tabulated for each manoeuvre type in annex 13.9.

The first group of columns characterises the flown manoeuvre. The background colour of the manoeuvre number indicates whether the manoeuvre can be used to demonstrate compliance with EASA-V5 and FAR23.221(a)(2) or not. The second group pictures the interim requirements according to Section 8.1 and the result of the compliance check. The third group of columns displays some additional information.

In case of non-compliance, the respective cell is coloured red; otherwise it is green. In case of an undetermined result, the colour orange and the letter b for *borderline* is used. This scheme provides a comprehensive overview of the results.

8.6 Outcomes and conclusions of flight trials

Based on the overview of the results presented in the previous Section, some more in-depth analysis was done.

8.6.1 Relative number of non-compliances

Table 6 shows the total number of manoeuvres flown per manoeuvre type, the number and percentage of manoeuvres that ended with a *tendency to spin* and the number and percentage of manoeuvres that did not comply with the interim requirement. The bottom line of this analysis shows the sum of all manoeuvre types. The cells with relevant entries are highlighted with bold numbers and grey shading.

Manoeuvre type	FAR23.221(a)(2) conform					EASA-V5 conform					All manoeuvres flown				
	total number	Tendency to spin?		Non-compliance?		total number	Tendency to spin?		Non-compliance?		Total number	Tendency to spin?		Non-compliance?	
A	8	0	0%	0	0%	8	0	0%	0	0%	8	0	0%	0	0%
B	-	-	-	-	-	**32**	0	0%	**4**	**13%**	**62**	0	0%	**17**	**27%**
C	**16**	**4**	**25%**	**8**	**50%**	**16**	**4**	**25%**	**8**	**50%**	**33**	**21**	**64%**	**25**	**76%**
D	-	-	-	-	-	16	0	0%	0	0%	18	0	0%	0	0%
E	-	-	-	-	-	16	0	0%	0	0%	18	0	0%	0	0%
F	8	0	0%	0	0%	8	0	0%	0	0%	8	0	0%	0	0%
G	**8**	0	0%	**2**	**25%**	**8**	0	0%	**2**	**25%**	**8**	0	0%	**2**	**25%**
H	**32**	**3**	**9%**	**9**	**28%**	**32**	**3**	**9%**	**9**	**28%**	**44**	**4**	**9%**	**13**	**30%**
All	**72**	**7**	**10%**	**19**	**26%**	**136**	**7**	**5%**	**23**	**17%**	**199**	**25**	**13%**	**57**	**29%**

Table 6: Numbers and relative numbers of non-compliant occurrences

It can be seen that:

- o The number of detected "tendencies to spin" does not change from FAR23.221(a)(2) to EASA-V5 requirements
- o The number of detected "non-compliances" rises slightly from FAR23.221(a)(2) to EASA-V5 requirements
- o The number of detected "tendencies to spin" changes rapidly with the additional manoeuvres
- o The number of detected "non-compliances" is doubled with the manoeuvres not covered by EASA-V5 and FAR23.221(a)(2)
- o Particularly manoeuvre type C with the additional manoeuvres produces remarkably more "tendencies to spin" and "non-compliances".

It must be kept in mind that all these outcomes are only valid for the Cessna F 172N.

Conclusions

The Cessna F 172N in the flown configuration complies with a majority, but at least not all the requirements of EASA-V5 and the current FAR23.221(a)(2). The coherence of these outcomes with the results of the accident data analysis is discussed in Section 9.3.

8.6.2 Relative number of non-compliances vs. power setting

The following table lists the number of manoeuvres flown with a fixed power setting and the percentage of non-compliance detections.

Power setting	idle		75%		maximum available power	
Manoeuvre type	total number	percentage of non-compliance	total number	percentage of non-compliance	total number	percentage of non-compliance
A	4	0%	4	0%	-	-
B	16	0%	20	30%	20	45%
C	8	0%	10	70%	13	100%
D	8	0%	10	0%	-	-
E	8	0%	10	0%	-	-
F	4	0%	4	0%	-	-
G	4	0%	4	50%	-	-
H	16	0%	22	45%	2	50%
All	**68**	**0%**	**84**	**30%**	**35**	**66%**
B, C, H	40	0%	52	44%	35	66%

Table 7: Numbers and relative numbers of non-compliant occurrences (Power setting 50%: 6 Manoeuvres total, 50% non-compliance)

Without discussing the distribution of manoeuvres in detail and neglecting the small sample at 50%, it can be concluded that increasing power does indeed downgrades aircraft stall behaviour.

8.6.3 Height loss during recovery

As stated in previous Sections, most accidents start at heights below 1000 ft. The current FAR23 regulation does not include any requirement concerning height loss during recovery. Finally, it is essential to recover before the aircraft hits the ground.

Therefore, the correlation of height loss and non-compliances with the requirement were investigated.

The following chart shows the number of manoeuvre entries which resulted in a height loss within a given 50 feet loss of height band in the following categories:

1. No tendency to spin. This shows manoeuvres that (i) comply with the requirement, or (ii) fail to meet the requirement but nevertheless do not result in a spiral dive or tendency to spin.
   This category is divided for manoeuvre type H as follows: no tendency to spin in manoeuvre type H contains all manoeuvres that comply with the requirement.
2. Manoeuvres type H that fail to meet the requirement but never-the-less do not result in a spiral dive or tendency to spin.
3. Spiral dive.
4. Tendency to spin.

If the height loss is zero then even a gain in height may have occurred due to the power setting. The bar charts for each manoeuvre type can be found in annex 13.10. All flown manoeuvres were combined in the two bar charts shown on the next page.

Conclusion

It can be concluded that any height loss of more than 300 ft is linked to a detected “tendency to spin”, “spiral dive” and, in case of manoeuvre type H, to non-compliance with the interim requirement.

It must be noted that the manoeuvres were not flown to demonstrate a minimum height loss for each manoeuvre. So we presume that it can be demonstrated that normally the height loss is below 300 ft when no non-compliance is detected.

It must be kept in mind that all these outcomes have been measured on Cessna F 172N, but similar results are expected on other types. Despite the large number of investigated manoeuvres the statistical conclusions must be drawn carefully and shall be seen as tendencies.

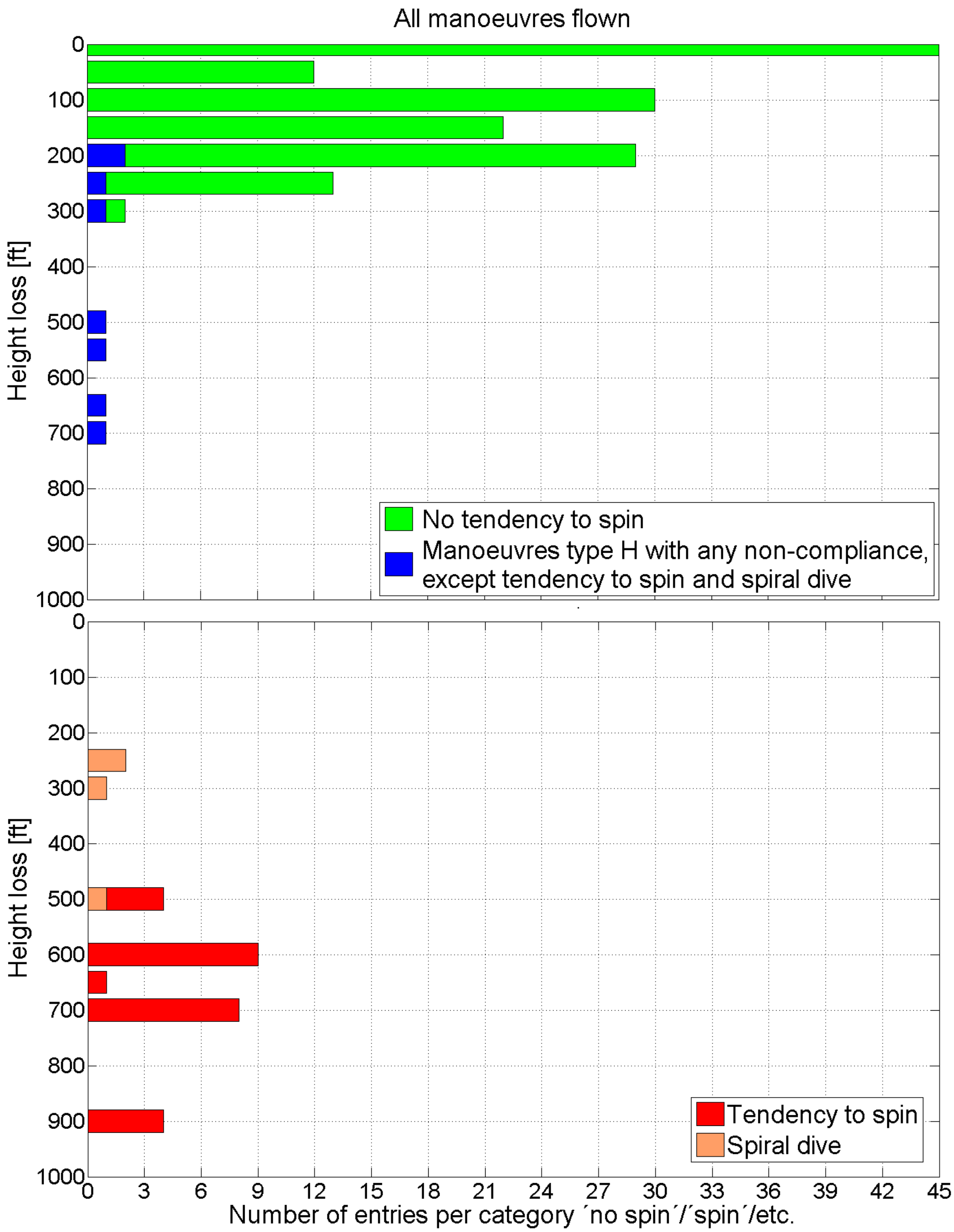


Figure 15: Height loss vs. number and kind of compliance

9 Outcomes

This Section presents the findings of the project and how they are combined with regard to finding a proposal for a code for a European spin resistance requirement. Firstly, the findings of the review on spin resistance (Sections 6 and 7) and of the flight trials within this project (Section 8) are summarised. Subsequently, these findings are combined, resulting in the code proposal which is presented and commented.

9.1 Summarised outcomes of review

Literature reviews revealed that research activities by NASA were targeting at technical measures to prevent aircraft from entering spins. The activities were initially dealing with configurations, wing modifications and stall deterrent systems, and then concentrated on one technical measure: the modified outboard leading edges. The abilities of this measure were analysed by trying to enter a spin by performing a set of manoeuvres with varying parameters such as speed rate, aileron position or power setting. The flight trials revealed that the measure was mostly able to prevent the aircraft from entering a spin. But they also revealed that even aircraft with this modification may enter a spin if a high power setting is applied, especially when combined with a high rate of speed reduction.

The aim was to significantly reduce the number of stall/spin-related accidents as a result of this measure being brought into widespread operation. To this end, a requirement for implementation into FAR23 was formulated based on the abilities of the modified outboard leading edges. To simplify the certification process, and because the modification was found to make recovery from spins more difficult, no proof of recoverability from spins is necessary if an applicant aspires certification as spin resistant. As the majority of stall/spin-related accidents starts at low height where the recoverability from spins is irrelevant, this can be interpreted as an "exchange deal": Preventing stall/spin-related accidents, especially those starting at low height, can justify that proof of recoverability is omitted, which, regarded separately, represents a decrease in the level of safety as regards stall/spin-related accidents starting from larger height.

Compared to the time period in which the NASA and FAA activities were carried out, it is now possible to analyse some years of operational experience with spin resistant aircraft. Two main conclusions can be drawn from analysing these accident data. First, the proportion of stall/spin-related accidents among all fatal accidents is of the same order as, or even higher than with conventional aircraft. Second, there are no principal differences neither in the distribution of occurrences within the traffic pattern nor in the sequence of events during the occurrences. It can be concluded that the aim to reduce stall/spin-related accidents is not achievable with the existing two spin resistant aircraft designs.
A general analysis of stall/spin-related accidents revealed that accidents occur distributed during both the descending and ascending phases of the traffic pattern, and revealed hints on steep pull ups and high bank angles in the sequence of events of many accidents.

The topic was also discussed with manufacturer-independent experts in a workshop, in interviews, and with European manufacturers and authorities during a survey. The answers to the survey showed that the topic can and needs to be considered under a range of aspects (see Sections 6.3 and 6.4). The survey also embedded the European manufacturers into the process of creating a European spin resistance requirement right from the beginning and helped to increase awareness for the topic of spin resistance and the intended rulemaking process.
During the interviews with the experts, a wide range of aspects was discussed. In summary, the main statements concentrated on operational accident situations, which are not covered by the current FAR spin resistance requirement, on the necessity for improved stall warning systems and envelope protection measures and on the necessity to combine technical measures with concepts for pilot training.

Based on these findings, it can be concluded that a wider range of possible measures should be considered with the aim of reducing stall/spin-related accidents, starting from flight mechanical measures to influence the behaviour of the aircraft at stall to improved stall warning systems, envelope protection measures and concepts for pilot training. The central aspects to be considered are the situational awareness of the pilot and the sequence of events during an operational accident. Considerations on this are presented in Section 7.2. The concept of spin resistance can only be one issue within this range.

As the mode of action of spin resistance is not adequately defined from today's point of view, the following definition is proposed:

The term 'spin resistance' describes the ability of an aircraft, due to design, to counter entry into the flight state of spinning or other stall-related flight states resulting in unfavourable height loss and long recovery time. Its aim is to prevent the pilot substantially from entering a stalled flight state that cannot be recovered within certain limits (height, time).

In the context of the range of possible measures, the flight mechanical measures investigated by NASA and realised in current spin resistant aircraft designs can be generalised as a passive partial envelope protection measure.

9.2 Outcomes of flight trials

To investigate the effects of parameter variations as regards control inputs on the behaviour of the aircraft during stall and the entry phase to a spin, flight trials were performed with a Cessna F 172N. Controllability of the aircraft at stall and the behaviour of the aircraft when performing manoeuvres for attempted spin entry were analysed. Based on the FAR spin resistance requirement and on manoeuvres proposed by EASA, parameters related to control inputs were also varied.

Results of the flight trials show that the behaviour of the aircraft changes significantly when varying the parameters. Even as a non-spin resistant aircraft, the Cessna F 172Ncomplies with most of the items of EASA-V5. Applying maximum available power or a speed rate of 5 kn/s results in an obviously higher amount of attempts where the behaviour of the aircraft does not comply with the requirement Thus, a sound assessment of the behaviour of an aircraft is only possible if a broad set of parameters is tested in flight trials.

Any height loss of more than 300 ft is linked to a detected non-compliance with the interim requirement.

9.3 Fusing results of topic reviews and flight trials

As only one type of aircraft (with one weight-and-balance setting) was investigated, the conclusions must be drawn very carefully to ensure they are global and not limited to the type tested.

The following four findings can be ascertained as a result of the topic review and the results of the flight trials:

1) As stated in Section 6.2.4, the Cessna 172 had the lowest rate of "fatal mishaps per year" in 2007 and 2008 in the USA, and a slightly lower rate of stall/spin-related accidents than the SR22. Although the Cessna F 172N has a low "tendency to spin" (5% of EASA-V5 criteria, 10% of FAR23.221(a)(2) criteria) about 20% of fatal accidents are stall/spin-related. It can be reasoned that those pilots killed in stall/spin-related accidents had very likely flown one of the manoeuvres demonstrated in flight trials to enter stalled flight states.

2) Looking at the Section *Statistical occurrence of accidents with different types of aircraft* (6.2.4), it can be stated that both aircraft SR20/22 and C350 (both FAA-certified as spin resistant, not considering special conditions) do not stand out in the statistics. The rate of stall/spin-related accidents of the SR20/22 is not detectably lower than for other types.

3) Assuming that
    - the typical mission profiles of a Cessna 172 and an SR20/22 are equivalent (same flight time in low speed phases), and
    - the SR20/22 complies with the requirements according FAR23.221(2),

   it must be ascertained a contradiction that the SR20/22, as the aircraft with a lower "tendency to spin", has more than double the rate of "stall/spin-related fatal mishaps per year" than the Cessna 172 (see 6.2.4), as the aircraft which complies only with the spinning code but not with the FAA spin resistance option.

4) The distribution of location of accidents does not show any effect of the current spin resistant requirement, see Section 6.2.3.

The following conclusions can be made:

I. SR20/22 pilots killed in stall/spin-related accidents had flown some of the manoeuvres that are not covered by FAR23.221(a)(2). If the manoeuvres in a regulation are considered to be aiming at representing accident-prone operational situations, it must be ascertained that the representatives of operational situations in FAR23.221(a)(2) are not complete.
II. Maximum available power should be included in the requirement, because stall/spin-related accidents during take off and climb are not rare; see Section 6.2.3.
III. Speed reduction rate of 5 kn/s are recommended in addition to all 1 kn/s requirements.

These findings and conclusions were taken into consideration during the development of a proposal for the requirement code, based on a former proposal generated by EASA. This former proposal ("EASA-V5") can be found in annex 13.5.

9.4 Code proposal and discussion

As described in the previous Sections (see Section 7 and 9.3), a European requirement for spin resistant aircraft from today's point of view must contain some essential additions compared to the FAR requirement - mainly higher speed rates, maximum available power, banked turns with pro-spin control inputs, maximum allowable height loss, and clearer information to prevent pilots from spinning are necessary to ensure that spin resistance fulfils the definition and aims given in Section 9.1.

The Sections of the proposed code for implementation into CS23 and some remarks on the Sections are presented in the following. According to the EASA proposal, it is intended to insert the following paragraph into CS23.221 and rename (b) and (c) as (c) and (d) respectively:

(b) "Normal Category Aeroplanes – Spin Resistant. At the applicant's option, the aeroplane may be demonstrated to have spin resistant characteristics in lieu of spin handling described in paragraph (a) as follows:"

Remark: Implementing spin resistance in this way would mean that it is only applicable to normal category aeroplanes. The question of whether it would be useful to extend it for utility aircraft arose but could not be answered within these considerations.

The chosen wording follows EASA-V5 and omits the proof of spin recoverability. The code proposal is aligned to current passive flight mechanical measures (MOLEs) that are known as downgrading spin recoverability. If other technical measures are applied the chance to incorporate spin recoverability should be reviewed.

(1) Power and aeroplane configuration for all manoeuvres must be set in accordance with 23.201(e) and additionally with maximum available power without change during the manoeuvre.

Remark: Flight trials by NASA revealed that the behaviour of aircraft can change significantly when applying maximum power instead of 75% of maximum continuous power. The analysis of accident data showed that 12 of the 38 considered accidents in the traffic pattern occurred during initial climb or turn to crosswind, 10 of them were supposed to have at least a very high power setting applied. There is an additional unknown ratio of occurrences where maximum power was applied temporarily during descent, maybe even as a reaction to the stalled flight condition. It is certain that operational pilots will use the performance of the aircraft, which conforms to the statements of the interviewed experts. Additionally, the maximum available power determined during flight tests (for non-charged piston engines) will usually be lower than the maximum available power in the traffic pattern due to density proportional decrease of available power.

The inclusion of maximum power setting is a central aspect of the proposal for the spin resistance requirement. The fact that this is not included in the FAA regulation is seen as one of the reasons why we cannot rate the FAA regulation as successful yet, after some years of operation.

The Flight Test Guide (FTG) clarifies that maximum available power means engine and propeller are in take-off setting with the exception that the engine setting is density-adapted such as to get the maximum power output in the actual altitude of the flight trials. Guidelines for a maximum acceptable density altitude have been defined; this avoids a “free selection” of the altitude for demonstration of compliance, which would oppose the intention of this Section.

(2) Height loss must not be excessive.

Remark Primarily, it was intended to define 300 ft as the maximum allowable height loss, based on flight testing the Cessna F 172N. Any higher height loss was connected to non-compliance with the preliminary requirement. The discussion revealed that the requirement should provide the possibility for any applicant with a someway more deviant aircraft to provide reasonable argumentation and define an adapted amount for the height loss. For this reason, 300 ft will be reasoned in the FTG as an applicable number for a typical single-engine 4 place aircraft.

To define a maximum rate of descent instead would not reproduce the demands for safety in daily operation: The rate of descent is very unsteady. A high rate for a short period may be not problematic if the aircraft can be recovered quickly before hitting the ground.

(3) If an uncontrollable nose down pitch does not occur during the stall manoeuvres contained in 23.201, controllability must be demonstrated with the pitch control held against the stop. It must be possible to roll from 30° bank to 30° bank in the other direction with the stick in the fully aft position (without assistance from the rudder) without encountering abnormal characteristics.

If an uncontrollable nose down pitch does occur during the stall manoeuvres contained in 23.201, the stick must be held fully aft for at least 2 seconds while maintaining wings level within 15° bank (without assistance from the rudder). At the end of the 2 seconds, standard stall recovery control inputs must produce an immediate return to unstalled flight without any tendency towards spin entry.

Remark: This section investigates the lateral controllability of the aircraft at stall. Respective flight trials within this study are named “manoeuvre type A”.

FTG explains that “without assistance” means that the position of the rudder, which has to be applied for coordinated flight at stall before starting the roll movement, is held.

(4) Reduce the aeroplane speed using pitch control until the pitch control reaches the stop; then, with the pitch control pulled back and held against the stop, apply full rudder control in a manner to promote spin entry for a period of seven seconds. At the end of seven seconds or a 360degree heading change, the aeroplane must respond immediately and normally to primary flight controls applied to regain coordinated, unstalled flight without reversal of control effect, without exceeding the temporary control forces specified by 23.143(c). There must be no characteristics during the manoeuvre that might lead to disorientation of the pilot.

This manoeuvre must be performed using a rate of speed reduction of approximately one knot per second and then approximately 5 knots per second.

This manoeuvre must be performed first with the ailerons in the neutral position held in the trimmed position, and then with the ailerons deflected opposite the direction of rudder input in the most adverse manner.

Remark: This manoeuvre investigates the behaviour after application of pro-spin control inputs from wings level flight. This was already a central aspect within the NASA flight trials and was implemented into the FAR regulation as FAR 23.221(a)(2)(ii). Respective flight trials within this study are named “manoeuvre type C”.

This section was mostly adopted from the FAA regulation, the 7 seconds date from NASA flight tests.

It is stated in the FTG that the tests at 1 and 5 kn/s both provide different information on the stall and post-stall behaviour of the aircraft. Flight tests revealed that the behaviour of aircraft can change significantly when varying the rate of speed reduction. It can be assumed that pilots in critical operational situations definitely apply high rates of speed reduction.

An explanation on the aileron input (“most adverse manner”) is given in the FTG.

To prevent disorientation of the pilot, FAR requires that the 360° heading change must have taken no fewer than 4 seconds. This was replaced here by a more general requirement.

(5) Establish and maintain a coordinated turn in a 45° bank and perform the manoeuvre of (4) from this attitude. Rudder must be applied against and with the direction of turn.

Remark: This manoeuvre investigates the behaviour after application of pro-spin control inputs from banked turns. Respective flight trials within this study are named “manoeuvre type B with dynamic rudder input (No 33-38)”.

Flight testing of NASA as well as the flight tests with Cessna F 172N within this project revealed that the behaviour of the aircraft when stalling from a banked turn differs from wings-level stalls. Whether the behaviour is more benign (Cessna 172) or more critical (PA28) is dependant on the type of aircraft. Analysis of the accident data showed that 17 of the 38 considered accidents started from “turning sections” within the traffic pattern.

(6) The manoeuvres described in 23.203 (a) must be conducted at 45 degs bank. The conditions given in the following must be used in lieu of the corresponding conditions in 23.203 (a) and (b):

- Accelerated stalls must be conducted at 5 knots per second.

- No tendency to spin is permitted.

- The resulting maximum roll in both (b)(4) and (b)(5) is 60° in the original direction of the turn or 15° in the opposite direction.

Remarks: This section investigates turning flight and accelerated turning stalls. Respective flight trials within this study are named “manoeuvre type B”. This section is based on the EASA proposal EASA V5(b)(3).

(7) Compliance with 23.201 and 23.203 must be demonstrated with the aeroplane in uncoordinated flight with a fixed rudder angle. The rudder should be held at the angle which results in 15 degrees sideslip at 1.1Vs or full rudder if 15 degrees cannot be achieved.

Remarks: This section investigates stalls in uncoordinated flight. It is based on FAR 23.221(a)(2)(iii). Respective flight trials within this study are named “manoeuvre types F, G and H”.

The required bank angle of 15° can be compared to a landing at a crosswind of 0.2 VS0, which results in a slip angle of 11.3° at the moment of touchdown.

The guiding instrument for the manoeuvre shall be the ball displacement of the slip-skid indicator. The ball displacement must be determined for every configuration by using simple instrumentation as described in AMC/FTG material.

(8) A placard "AVOID STALL! DO NOT SPIN! Spin recovery has not been demonstrated." must be placed in a highly visible position at the instrument panel.

Remarks: Most pilots are probably not aware that their aircraft is designed under a principally different regulation as regards the stall and spin behaviour (e.g. the difference between C350 and C400). As a result, they risk entering a flight state that is not recoverable. Clearer information must be given to the pilot to prevent intentional and unintentional spinning. The following measures may improve pilot awareness:

1. A placard as described above.
2. The training procedure for type rating must address the concept of spin resistance and the fact that the aircraft may enter a non-recoverable flight state if the pilot disregards the limits. This requires the necessity of a type rating for spin resistant aircraft.
3. AFM must contain a distinct explanation to sensitise pilots that the aircraft is spin resistant but not spin-proof.
4. An improved stall warning system.

In fact, a combination of measures will be necessary to sustainably improve pilots' awareness. As the project focuses on 23.221, the first item is the only way to incorporate one of these measures. That's why it is highly recommended to require a placard with the content defined in the code proposal.

As most of the pilots are not aware of the conceptual difference between spin recoverable aircraft and spin resistant aircraft, the wording of the placard must differ from the standard placard. "Spins prohibited" is not appropriate for spin resistant aircraft.

Final remark:

This proposal is limited to the application to passive flight mechanical measures. Active measures, e.g. rudder limiters, must be regarded separately.

In the interest of a confined set of requirements the following three flight test items were not included in the code with adapted manoeuvres:

- Application of maximum available power at stall starting from idle within 2 seconds
- Retraction of flaps at stall as fast as possible
- Consideration of gust effects

It is expected that the proposed requirements will cover probable unsafe aircraft behaviour with regard to these items.

9.5 Proposal for the Flight Test Guide (FTG)

The proposed Flight Test Guide for implementation into the AMC can be found in annex 13.12 supplementing the proposed code. The content is explained in the code discussion in the previous Section.

9.6 Implications

After implementation into CS23, this code will give European manufacturers the opportunity to develop and certify spin resistant aircraft. Compared to the current FAR spin resistance requirement, this code has the advantage that some years of operational experience with spin resistant aircraft have been considered.

As harmonisation between FAR23 and CS23 is generally aspired, this code proposal can be the basis for a joint implementation of new spin resistance requirements into both FAR23 and CS23.

The proposed requirement is oriented on the necessities of safety to provide an adequate level of safety. The authors are conscious of the fact that these necessities of safety are always in conflict with the efforts of development and certification for the applicant.

The amount of manoeuvres to demonstrate compliance for certification will be higher compared to the current FAR regulation, but the fact that the set of manoeuvres representing operational situations must be extended is inevitable, see Sections 7 and 9.3.

The chosen representatives of operational situations represent today's knowledge and understanding of the topic. Future aircraft designs may have principally different in-flight characteristics, so that the chosen manoeuvres will be unsuitable to represent the stall behaviour of the aircraft. As the topic of spin resistance is comparably new, the necessity to advance the spin resistant code in the future is almost inevitable.

10 Conclusions

Recognitions regarding the concept of spin resistance can be based on the main aspects:

Aircraft behaviour

Technical measures to influence the behaviour of aircraft at stall have been developed by NASA. Aircraft equipped with modified outboard leading edges have an enhanced lateral controllability at stall and are less likely to enter a spin than conventional aircraft. To enable a wide spread of this technology within General Aviation, a requirement conforming to the abilities of this technical measure was formulated and implemented into FAR23.

Flight tests within this project as well as an analysis of NASA flight tests show that the behaviour of the aircraft is highly dependent on the flight state, control inputs and parameters before and at stall. Aircraft with modified outboard leading edges can enter a spin if a high rate of speed reduction or a high power setting is applied. This is despite the fact that these aircraft meet the FAA spin resistance requirements, as it is not required to demonstrate these manoeuvres.

Pilot behaviour

Speed rates in critical operational situations are often high, as a pilot under stress may apply control inputs rather abruptly. The awareness of the pilot for the stalled flight condition is a very central aspect. To interrupt the sequence of events leading to a fatal accident, it is necessary to create this awareness in the pilot's mind. A mere extension of the time span until the aircraft enters a flight condition with decreased controllability does not create this awareness.

Operational experience with existing spin resistant designs

Compared to the time period in which the NASA and FAA activities were carried out, it is now possible to analyse some years of operational experience with spin resistant aircraft. The conclusion can be drawn that the aim of preventing stall/spin-related accidents is not achievable with the existing spin resistant aircraft designs because decisive operational accident situations are not covered by the current FAR spin resistance requirement. In many of the accidents investigated, the pilots had presumably applied a very high power setting, whereas demonstration of

manoeuvres with pro-spin control inputs at maximum available power is not required. It is also noted that, for aircraft with non-charged piston engines, testing for handling with power on is normally conducted at a safe altitude where the power is reduced relative to that at sea level, and therefore may not be representative.
About 26% of the fatal accidents with aircraft certified as spin resistant according to the current FAR23.221(a)(2) are stall/spin-related.

This leads to an <u>evaluation of the current FAR spin resistance regulation:</u>
Pilots killed in stall/spin-related accidents with spin resistant aircraft had flown manoeuvres that are not covered by FAR23.221(2). Considering the manoeuvres in the regulation to be aiming at representing accident-prone operational situations, it must be ascertained that the representatives of operational situations in FAR23.221(2) are not complete. The set of manoeuvres must be extended.

Possible measures

In considering the aim of reducing the amount of stall/spin-related accidents from a more general point of view, a range of possible measures should be regarded and combined. This includes measures to enhance the stall characteristics of aircraft, but also improved stall warning systems, envelope protection measures and concepts for pilot training.

Proposed requirement

Concentrating on the first aspect, it can be concluded that a requirement must contain the above-mentioned essential additional manoeuvres and parameters. A proposal for a requirement code for implementation into CS 23 has been worked out, additionally containing a higher rate of speed reduction (5 kn/s), maximum available power, banked turns with pro-spin control input, a maximum allowable height loss and a requirement for clearer information to the pilot. A flight test guide for the code has been worked out containing additional indications to the flight tests. The proposed code can be used by European manufacturers as a basis to develop and certify spin resistant aircraft.

11 Recommendations

- It is recommended to implement the spin resistant option into the CS23, including the following items additionally to those in the current FAR23.221(a)(2) requirement:
  - Higher rate of speed reduction (5 kn/s),
  - Appliance of maximum available power
  - Banked turns with pro-spin control input
  - Maximum allowable height loss for recovery and
  - Requirements for clearer information to the pilot

  The proposal for the codes includes all these items. The proposed section of the Flight Test Guide is balanced with the proposed code and is recommended to be implemented this way.

- It is recommended to continue investigating the following items to improve safety regarding stall/spin related accidents:
  - Improvement of training methods and regulations to promote pilots' situational awareness, especially of the stall/spin issue
  - Enhanced stall warning systems
  - Stall barrier systems and true envelope protection

- Requirements for parachute recovery systems should be re-evaluated.

12 References

12.1 Abbreviations

AMC	Acceptable Means of Compliance
AOPA	Aircraft Owners and Pilots Association
ASF	AOPA Air Safety Foundation
C/G	Centre of gravity
CS	Certification specification
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EASA	European Aviation Safety Agency
ECCAIRS	European Coordination Centre for Accident and Incident Reporting Systems
EGAST	European General Aviation Safety Team
ERCO	Engineering and Research Corporation
FAA	Federal Aviation Authority
FAR	Federal Aviation Regulation
FTG	Flight Test Guide
GA	General Aviation
GAMA	General Aviation Manufacturers Association
ICAO	International Civil Aviation Organisation
MOLE	Modified outboard leading edge
NASA	National Aeronautics and Space Administration
NTSB	National Transportation Safety Board
TDPF	Tail Damping Power Factor

12.2 Bibliography

General

[1] EASA: Specifications attached to the Invitation to Tender - EASA.2008.OP.03 - Safety Aspects of Light Aircraft Spin Resistance Concept, 05/19/2008

Regulations

[2] FAA: FAR 23.221, Airworthiness standards: normal, utility, acrobatic, and commuter category airplanes, Subpart B--Flight - Spinning, effective as of March 1996

[3] FAA: FAA Advisory Circular 23-8B, Flight Test Guide for Certification of Part 23 Airplanes, 2003

[4] FAA: FAA Advisory Circular 23-15A, Small Airplane Certification Compliance Program, 2003

[5] FAA: FAR Final Rule, amendment No. 23-50, 1996

[6] FAA: FAR Final Rule, amendment No. 23-42, 1991

[7] FAA: Small Airplane Airworthiness Review Program Notice 2, 1989

[8] British Ministry of Defence: Defence Standard 00-970 Part 1 Section 2, 2007

[9] British Ministry of Defence: Defence Standard 00-970 Part 1 Section 3, leaflet 18, 2007

[10] Deutsche Versuchsanstalt für Luftfahrt: Bauvorschriften für Flugzeuge, 1928

[11] EASA: CS-23, 11/14/2003

General overview and literature dedicated to pilots

[12] Stowell, R.: The Light Airplane Pilot’s Guide to Stall / Spin Awareness, Rich Stowell Consulting, Ventura CA 2007

[13] Hankers, T.: Erhöhung der Flugsicherheit durch “spin-resistant aircraft”?, Vortrag im Seminar für Luft- und Raumfahrttechnik, Technische Universität Braunschweig 2009

[14] Oppenheimer, P.: The Last Spin, www.planeandpilotmag.com 2008

[15] Gaubatz, B.: Rundum neues Cessna-Feeling, Aerokurier 08/2008

[16] Brill, J.: Cirrus G3 Turbo, Pilot und Flugzeug 09/2007

[17] User Ericg: Diagram illustrating the legs of a typical left-hand traffic pattern as flown at an airport, http://en.wikipedia.org/wiki/File:Airport_traffic_pattern.jpg 2005

[18] Thomas, D.: Das bewußte Heranführen an die Probleme des Überziehens und des Trudelns in der Flugausbildung, Neue flugtechnische Schriften 2003

[19] Ambros, G.: Trudeln mit Segelflugzeugen, Dresden 2003

[20] Bourque, J.: The Spin Debate, Air&Space Magazine 2003

[21] Guillemette, R.: ERCO Ercoupe, U.S. Centennial of Flight Commission 2003

[22] Gillespie, M.: Ercoupe History, ercoupe.com 2008

[23] Stowell, R.: Emergency Maneuver Training, Rich Stowell Consulting, Ventura CA 1996

[24] DeLacerda, F.: Surviving Spins, Iowa State University Press 1989

[25] DeLacerda, F.: Facts about Spins, Iowa State Press 1989

[26] Bingelis, T.: Homebuilders and Stall/Spin Safety, Sport Aviation 4/1981

Scientific studies and results

[27] Stough, DiCarlo: Spin Resistance Development for Small Airplanes - A Retrospective, SAE Technical Paper 2000-01-1691, 2000

[28] Langevin, G.: Spin Technology, NASA Concept to Reality, 2003

[29] Langevin, G.: Spin Resistance, NASA Concept to Reality, 2003

[30] Manuel, DiCarlo, Stough, Brown, Stuever: Investigations of Modifications to Improve the Spin-Resistance of a High-Wing, Single Engine, Light Airplane, SAE Paper 891039, 1989

[31] Stough, DiCarlo, Patton: Flight Investigation of the Effects of an Outboard Wing-Leading-Edge Modification on Stall/Spin Characteristics of a Low-Wing, Single-Engine, T-Tail Light Airplane, NASA Technical Paper 2691, 1987

[32] Stough, Patton, Sliwa: Flight Investigation of the Effect of Tail Configuration on Stall, Spin, and Recovery Characteristics of a Low-Wing General Aviation Research Airplane, NASA Technical Paper 2644,1987

[33] Stough, DiCarlo, Patton: Evaluation of airplane spin resistance using proposed criteria for light general aviation airplanes, AIAA paper 87-2562, 1987

[34] DiCarlo, Stough, Glover, Brown, Patton: Development of Spin Resistance Criteria for Light General Aviation Airplanes, AIAA paper 86-9812, 1986

[35] Chambers, Stough: Summary of NASA stall/spin research for general aviation configurations, AIAA paper 86-2597, 1986

[36] DiCarlo, Glover, Stewart, Stough: Discontinuous Wing Leading Edge to Enhance Spin Resistance, Journal of Aircraft Vol. 22 No. 4, 1985

[37] Stough, DiCarlo, Patton: Flight Investigation of Stall, Spin and Recovery Characteristics of a Low-Wing, Single-Engine, T-Tail Light Airplane, NASA Technical Paper 2427, 1985

[38] Stough, Jordan, DiCarlo, Glover: Leading-Edge Design for Improved Spin Resistance of Wings Incorporating Conventional and Advanced Airfoils, NASA CP 2397, Langley Symposium on Aerodynamics 1985

[39] Bradshaw, C.: A Spin-Recovery Parachute System for Light General-Aviation Airplanes, NASA Technical Memorandum 80237, 1980

[40] Langley Research Center: Exploratory Study of the Effects of Wing-Leading-Edge Modifications on the Stall/Spin Behavior of a Light General Aviation Airplane, NASA Technical Paper 1589, 1979

[41] Burk, Bowman, White: Spin-Tunnel Investigation of the Spinning Characteristics of Typical Single-Engine General Aviation Airplane Designs, NASA Technical Paper 1009, 1977

[42] Burk, S.: Summary of Design Considerations for Airplane Spin-Recovery Parachute Systems, NASA Technical Note TN D-6866, 1972

[43] Bowman, J.: Summary of Spin Technology as related to light general-Aviation Airplanes, NASA Technical Note TN D-6575, 1971

[44] Grafton, S.: A study to determine effects of applying thrust on recovery from incipient and developed spins for four airplane configurations, NASA Technical Note TN D-3416, 1966

[45] Barber, Jones, Sisk, Haise: An evaluation of the handling qualities of seven general-aviation aircraft, NASA Technical Note TN D-3726, 1966

[46] Gadeberg, B.:The effect of rate of change of angle of attack on the maximum lift coefficient of a pursuit airplane, NACA Technical Note 2525, 1951

[47] Kamm, R.: Spin-Tunnel Tests of Airplane Models with extreme Variations in Mass Distribution along the three Body Axes, NACA Wartime Report, Advance Restricted Report L5C09, 1945

[48] Neumann, H.: Small Aircraft Spin Investigations, Idaflieg-Berichtsheft XXXII, 2006

[49] Neumann, H.: “Drooped Leading Edge”, Flight Test Evaluation with a small General Aviation Airplane, presentation, SETP Symposium 2006

[50] Neumann, H.: Flugeigenschaften – Trudeln, Vorlesungen FT Flight Test GmbH 2005

[51] Pätzold, F.: Messtechnische Möglichkeiten zur Erfassung komplexer Flugzustände, Idaflieg-Berichtsheft XXXII, 2006

[52] Zahle, Sörensen, Johansen: CFD Study of a NACA 63-415 Aerofoil Fitted with Stall Strips, Risö National Laboratory, Roskilde 2002

Accidents and statistics

[53] AOPA Air Safety Foundation: Stall/spin: Entry point for crash and burn?, www.aopa.org 2008

[54] Hankers, Pätzold, Cremer, Troelsen: Investigation of the technical feasibility and safety benefit of a light aeroplane Flight Data Monitoring (FDM) system, Research Project EASA.2007/2 Final Report, 2008

[55] AOPA Air Safety Foundation, Landsberg, B.: Spinning In, Volume 46 Number 2 2003

[56] NTSB: Aviation Accident Database, Reports

[57] UK Air Accidents Investigation Branch: Bulletin 3/2008

[58] Kommission der Europäischen Gemeinschaft: Agenda für eine nachhaltige Zukunft der allgemeinen Luftfahrt und der Geschäftsreiseluftfahrt, Mitteilung der Kommission KOM(2007)869

[59] General Aviation Manufactureres Association: 2007 General Aviation Statistical Databook

[60] NTSB: Annual Review of Aircraft Accident Data, US General Aviation 2003

[61] Office of Public Affairs, NASA Langley Research Center: NASA´s Aviation Safety Accomplishments, 1998

[62] Silver, B.W.: Statistical Analysis of General Aviation Stall/Spin Accidents, Society of Automotive Engineers Paper 760480, 1976

[63] http://www.whycirrus.com/safety/2008-ga-safety-record.aspx, 06/16/2009

Stall warnings and envelope protection

[64] Jaroslaw Kaleta Avionics: Stall Warning System SP-3, www.olk.com.pl 2008

[65] Weber, F.: Überziehwarnung bei Segelflugzeugen? - und mehr!, dg-flugzeugbau.de 2008

[66] Safe Flight Instrumentation Corporation: Lift Transducer, www.safeflight.com 2008

[67] Forum-Diskussion: Flugsicherheit - kein Thema?, www.streckenflug.at 2008

[68] Bennett, Owens: Flight Test of a Stall Sensor and Evaluation of its Application to an Aircraft Stall Deterrent System Using the NASA LRC General Aviation Simulator, NASA-CR-146324, 1976

[69] MIL-STD-1797A, Appendix A

[70] ONBASS – Onboard Active Safety System, Publishable final activity report, Revision 1.0, Euro Telematik AG, 18 4/18/2008

[71] ONBASS – Onboard Active Safety System, Application Domain Definition (D1.1), Revision 2.2, London Metropolitan University, August 2005

[72] ONBASS – Onboard Active Safety System, Principle of active system safety/ functional and reliability models (D1.2), Revision 0.3.4, London Metropolitan University

[73] www.onbass.org, 01/12/2008

Certification of the Cessna 300 family and Cirrus SR20/22

[74] Englert, S.: Lancair Columbia 400 Spin Recovery Testing

[75] FAA: Requesting Review of ELOS, FAA memorandum 98-190S-581

[76] FAA: Requesting Review of ELOS, FAA memorandum 98-190S-608

[77] JAA: JAA special condition for the Cirrus SR20 Validation of the FAA Certification, CRI No B-2 Issue No 3, 2005

[78] Cessna: Flight Manual Cessna 350 / 400

Flight testing

[79] Stinton, D.: Flying Qualities and Flight Testing of the Airplane, Loughborough University of Technology, UK

[80] Stinton, D.: The Design of the Aeroplane

[81] Schmidt, T.: Trudelschirmsystem für die Mü30, Diplomarbeit, Lehrstuhl für Flugmechanik und Flugregelung, TU München 2003

13 Appendixes

13.1 Modifications for flight testing

13.1.1 Grumman American AA-1X

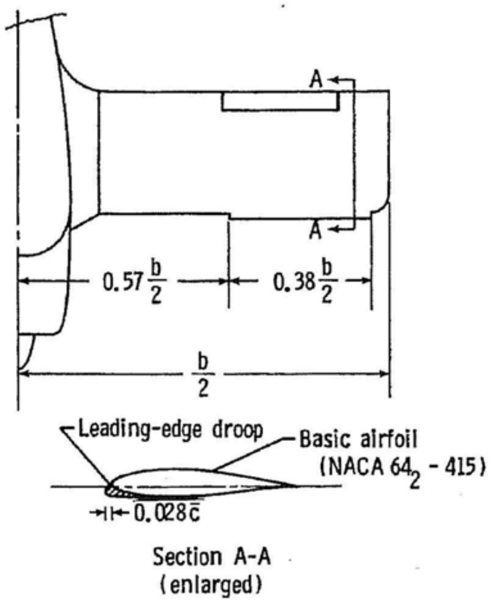


Figure 7. Wing leading-edge modification.

Figure 11. AA-1X research airplane with outboard wing leading-edge modification.

Figure 16: Grumman American AA-1X with outboard wing modification [27]

13.1.2 Piper PA-28X

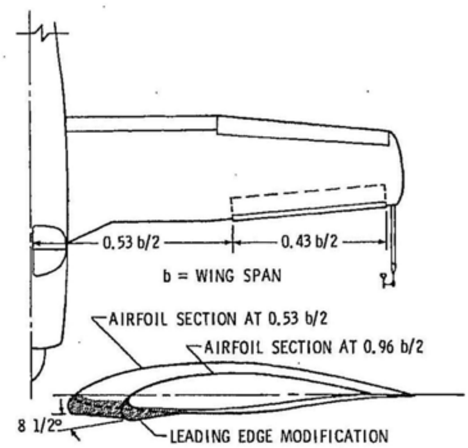


Fig. 3 Wing leading-edge modification to outboard wing panel of airplane T.

Figure 20. PA-28RX research airplane with outboard wing-leading-edge modification.

Figure 17: Piper PA-28X with outboard wing modification [36],[27]

13.1.3 Beechcraft CS-23X Sundowner

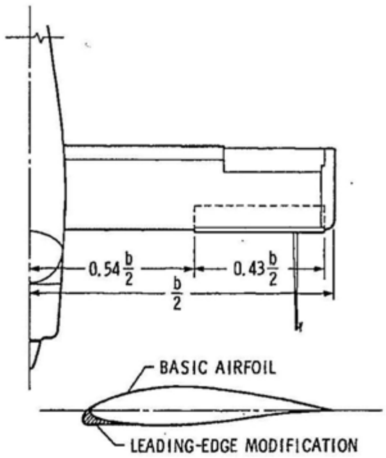


Fig. 4 Wing leading-edge modification to outboard wing panel of airplane R.

Figure 19. C-23X research airplane with outboard wing-leading-edge modification.

Figure 18: Beechcraft CS-23X Sundowner with outboard wing modification [36],[27]

13.1.4 Cessna C-172X

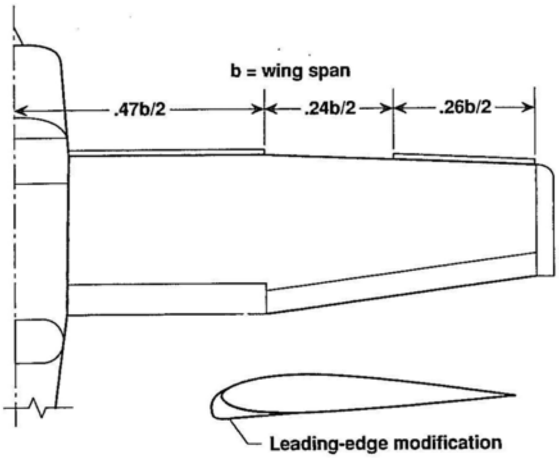
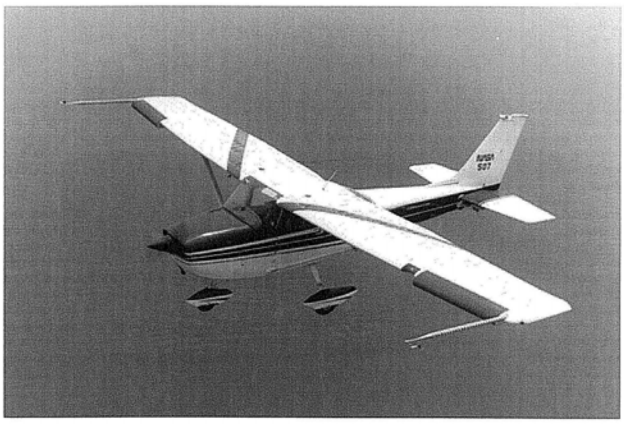


Figure 3.- Location of wing leading-edge-droop segments.



Cessna 172 research aircraft with outer wing leading-edge-droop modification.

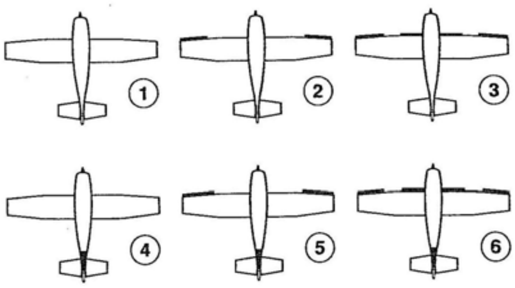


Figure 5.- Test configurations using combinations of wing leading-edge droop and ventral fin.

Figure 4.- Location of ventral fin on airplane.

Figure 19: Cessna C-172X with wing and fin modifications [29], [30]

13.1.5 Ruschmeyer R-90

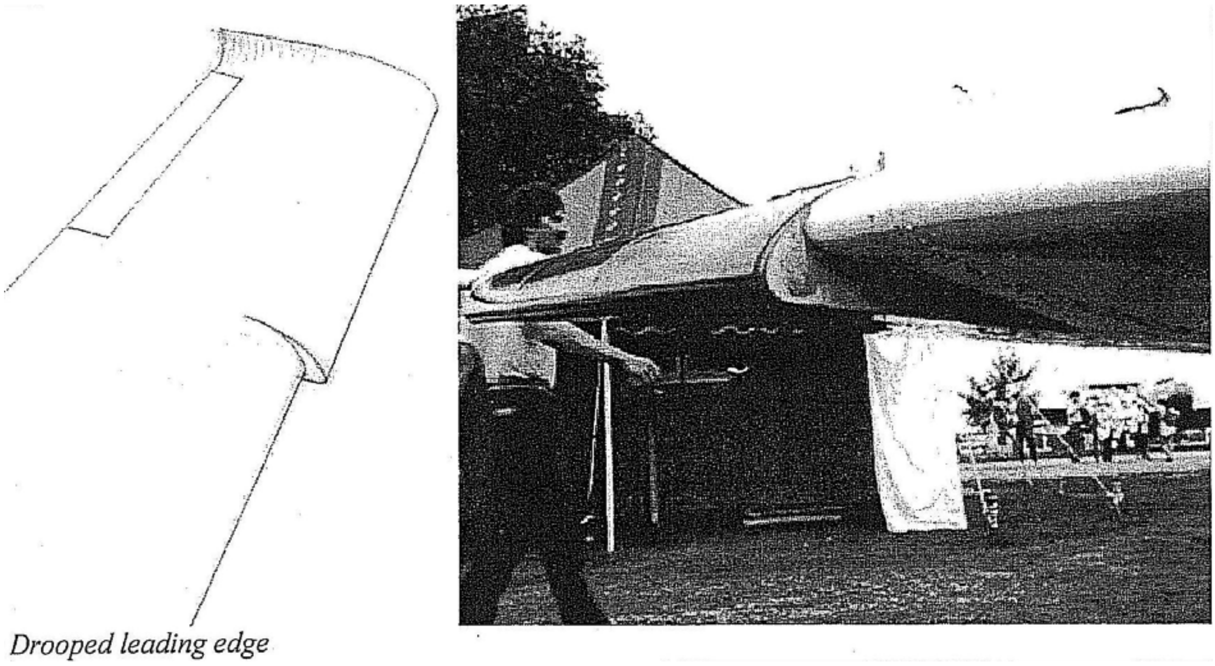


Figure 20: Ruschmeyer R-90 with outboard wing modification [48]

13.2 List of accidents considered in Section 6.2

Initial climb

19.4.04 Cirrus N8157J

23.9.06 Beech F33 N8148R

2.9.06 Beech BE95 N181Y

27.8.06 Curtiss-Wright Travel Air C-4000

30.6.06 Cessna 310 N6867T

4.3.06 Cessna 182N XB-BID

8.1.06 PA-28-235 N9124W

Teardrop:

9.1.06 Cirrus N526CD

17.8.06 Scheibe SF28 N14KG

24.6.06 PC-12 N768H

27.1.06 Bellanca 7ECA N55CW

Turn into crosswind:

11.7.06 Cirrus N8163Q

21.9.06 De Havilland DHC-2 N5154G

3.9.06 Luscombe 8A N71927

10.5.06 Bulmer Lancair IV-P N5473

24.4.06 Lancair 360 N9GX

Downwind:

24.6.06 Miller Zenair Cricket MC-12 N36CZ

Turn into base:

11.7.06 Beech C24 N78MB

22.5.06 Cessna 150 N6242R

21.3.06 Extra 300S N124X

Base:

30.1.06 Cessna 421B N920MC

Turn into final:

10.9.04 Cirrus N1223S

22.12.06 Cessna 340 N808RA

14.6.06 Raytheon B36TC N202EN

8.3.06 Cessna 414A N5601C

13.1.06 PA-30 N7291Y

Final:

10.12.06 Cessna 310 N69677

25.11.07 Cirrus N482SR

27.6.06 Acrojet Special N23AP

23.3.06 Cessna 340A N37JB

22.1.06 Cessna 172 N8540B

5.1.06 Mooney M20K N27ER

Away from usual flight path within traffic pattern:

27.10.06 Cirrus N969ES

21.12.06 PA46 N1AM

13.11.08 Cirrus N827GM

20.3.06 PA34-200T N21RR

22.2.06 Cessna 172R N3536C

1.1.06 Beech D55 N8165W

Outside of traffic pattern, height less than 1000ft:

30.7.06 American Champion N5232X

17.7.06 Piper J3 N6732H

30.12.07 Cirrus N254SR

27.6.06 PA-12 N7658H

26.5.06 Aviat A-1B N166MA

25.3.06 Mooney M-10 N9533V

12.2.06 Glasair II-S FT N540FT

Outside of traffic pattern, height more than 1000ft:

24.4.02 Cirrus N837CD

28.8.06 Cirrus N91MB

27.12.06 Mooney N9596M

18.12.06 Beech D95 N144PG

21.10.06 North American T-28C N470

22.9.96 Beech BE95 N4JV

8.6.06 Cessna 152 N627PA

30.3.06 Rockwell 112 TCA N4641W

Other:

31.12.06 Cessna 150 N50814

9.11.06 Beech D35 N2843V

28.08.06 Cessna 401 N408JC

25.6.06 Mitsubishi MU-2B-60 N316PR

13.3 Blank questionnaire

Questionnaire to research program

"Safety Aspects of Light Aircraft Spin Resistance Concept"

To obtain a better understanding of the position of European aircraft manufactures in this subject, your company is kindly requested to complete the following questionaire. You are also invited to make any additional comments on this subject matter that you find necessary and helpful for this project. The background to the project is given at attachment 2.

Privacy of the results

All data will be made anonymous before they will be passed to EASA or published.

Feedback

If you are interested, we would be pleased to send you the preliminary outcome of this study before conclusion of this project, so that you may comment.

Returning your answers

To send back your answers, you can use the button implemented in this document at the end of the questionnaire.

In case your local e-mail program does not support this function, please be so kind to save this document with your answers and return it as an e-mail-attachment. Alternatively, you can print this document and use fax or mail.

Contact

Please contact us if you have any uncertainty or if you require any clarification, using the contact data listed below.

E-Mail:	easa2008op03@iffserv1.iff.ing.tu-bs.de
Fax:	+49 531 391-9804
Mail:	Institut fuer Flugfuehrung - Questionnaire EASA.2008.OP.03 - Hermann-Blenk-Str.27 D-38108 Braunschweig Germany

You will find a quotation of CS and FAR 23.221 in attachment 1 and background information about this study in attachment 2.

Thank you very much for your cooperation.

Company:

Name:

Telephone:

A. General considerations on stall and spin

1. How do you rate a pilot of average ability to manage spin recovery of non-aerobatic (normal and utility category) aircraft complying with CS 23.221(a) requirement (see attachment 1)?

   a. at higher altitude

   b. at lower altitude, e.g. in landing pattern

Comments:

2. In your opinion, would you rate the parameters applied in CS23.221(a) suitable to describe spin recovery behaviour or would you prefer to apply others?

   ◯ suitable ◯ prefer others

   2A If not suitable please provide detail

Comments:

B. Concept of spin resistance

3. Are you aware of the concept of spin resistant aircraft? ◯ yes ◯ no

4. Are aircraft designs of your company already influenced by this principle? ◯ yes ◯ no

   4A If yes, what different flight characteristics were the designs intended to have relative to a standard design?

Comments:

5. How would you improve the requirements provided by FAR-23.221(a)(2)?

Comments: [ ]

C. Future Concepts

6. Would you consider certifying an aircraft as spin resistant (in a broader sense) if the CS-23 would provide the possibility?

○ yes ○ no

7. Would you like to make any suggestions for technical means to achieve spin resistance to be investigated in this project?

○ yes ○ no

Comments: [ ]

8. Do you see alternative concepts to flight mechanics measures for the increase of level of safety compared with CS-23.221 (a) and spin resistance concept (FAR-23.221(a)(2))?

○ yes ○ no

Comments: [ ]

9. Would you be prepared to take part in an interview on this matter?

○ yes ○ no

10. Are you interested in commenting the preliminary outcomes of this study?

○ yes ○ no

11. Please feel free provide any further comments:

Comments: [ ]

[Send answers by e-mail] [Print]

ATTACHMENT 1

CS.23.221 and FAR23.221

CS 23.221 Spinning (Nov. 14, 2003)	FAR 23.221 Spinning (Nov. 3, 1996)
(a) *Normal Category aeroplanes.* A single engined, normal category aeroplane must be able to recover from a one-turn spin or a three-second spin, whichever takes longer, in not more than one additional turn, after initiation of the first control action for recovery. In addition -	(a) *Normal category airplanes.* A single-engine, normal category airplane must be able to recover from a one-turn spin or a three-second spin, whichever takes longer, in not more than one additional turn after initiation of the first control action for recovery, or demonstrate compliance with the optional spin resistant requirements of this section.
	(1) The following apply to one turn or three second spins:
(1) For both the flaps-retracted and flaps-extended conditions, the applicable airspeed limit and positive limit manoeuvring load factor must not be exceeded;	(i) For both the flaps-retracted and flaps-extended conditions, the applicable airspeed limit and positive limit maneuvering load factor must not be exceeded;
(2) No control forces or characteristic encountered during the spin or recovery may adversely affect prompt recovery;	(ii) No control forces or characteristic encountered during the spin or recovery may adversely affect prompt recovery;
(3) It must be impossible to obtain unrecoverable spins with any use of the flight or engine power controls either at the entry into or during the spin; and	(iii) It must be impossible to obtain unrecoverable spins with any use of the flight or engine power controls either at the entry into or during the spin; and
(4) For the flaps extended condition, the flaps may be retracted during the recovery but not before rotation has ceased.	(iv) For the flaps-extended condition, the flaps may be retracted during the recovery but not before rotation has ceased.
	(2) At the applicant's option, the airplane may be demonstrated to be spin resistant by the following: (i) During the stall maneuver contained in §23.201, the pitch control must be pulled back and held against the stop. Then, using ailerons and rudders in the proper direction, it must be possible to maintain wings-level flight within 15 degrees of bank and to roll the airplane from a 30 degree bank in one direction to a 30 degree bank in the other direction;
	(ii) Reduce the airplane speed using pitch control at a rate of approximately one knot per second until the pitch control reaches the stop; then, with the pitch control pulled back and held against the stop, apply full rudder control in a manner to promote spin entry for a period of seven seconds or through a 360 degree heading change, whichever occurs first. If the 360 degree heading change is reached first, it must have taken no fewer than four seconds. This maneuver must be performed first with the ailerons in the neutral position, and then with the ailerons deflected opposite the direction of turn in the most adverse manner. Power and

	airplane configuration must be set in accordance with §23.201(e) without change during the maneuver. At the end of seven seconds or a 360 degree heading change, the airplane must respond immediately and normally to primary flight controls applied to regain coordinated, unstalled flight without reversal of control effect and without exceeding the temporary control forces specified by §23.143(c); and (iii) Compliance with §§23.201 and 23.203 must be demonstrated with the airplane in uncoordinated flight, corresponding to one ball width displacement on a slip-skid indicator, unless one ball width displacement cannot be obtained with full rudder, in which case the demonstration must be with full rudder applied.
(b) *Utility category aeroplanes*. A utility category aeroplane must meet the requirements of sub-paragraph (a) . In addition, the requirements of sub-paragraph (c) and CS 23.807 (b) (7) must be met if approval for spinning is requested.	(b) *Utility category airplanes*. A utility category airplane must meet the requirements of paragraph (a) of this section. In addition, the requirements of paragraph (c) of this section and §23.807(b)(7) must be met if approval for spinning is requested.
(c) *Aerobatic category aeroplanes*. An aerobatic category aeroplane must meet the requirements of sub-paragraph (a) and CS 23.807 (b) (6). In addition, the following requirements must be met in each configuration for which approval for spinning is requested - (1) The airplane must recover from any point in a spin up to and including six turns, or any greater number of turns for which certification is requested, in not more than one and one-half additional turns after initiation of the first control action for recovery. However, beyond three turns, the spin may be discontinued if spiral characteristics appear. (2) The applicable airspeed limits and limit manoeuvring load factors must not be exceeded. For flaps-extended configurations for which approval is requested, the flaps must not be retracted during the recovery; (3) It must be impossible to obtain unrecoverable spins with any use of the flight or engine power controls either at the entry into or during the spin; and (4) There must be no characteristics during the spin (such as excessive rates of rotation or extreme oscillatory motion) which might prevent a successful recovery due to disorientation or incapacitation of the pilot.	(c) *Acrobatic category airplanes*. An acrobatic category airplane must meet the spin requirements of paragraph (a) of this section and §23.807(b)(6). In addition, the following requirements must be met in each configuration for which approval for spinning is requested: (1) The airplane must recover from any point in a spin up to and including six turns, or any greater number of turns for which certification is requested, in not more than one and one-half additional turns after initiation of the first control action for recovery. However, beyond three turns, the spin may be discontinued if spiral characteristics appear. (2) The applicable airspeed limits and limit manoeuvring load factors must not be exceeded. For flaps-extended configurations for which approval is requested, the flaps must not be retracted during the recovery; (3) It must be impossible to obtain unrecoverable spins with any use of the flight or engine power controls either at the entry into or during the spin. (4) There must be no characteristics during the spin (such as excessive rates of rotation or extreme oscillatory motion) that might prevent a successful recovery due to disorientation or incapacitation of the pilot.

ATTACHMENT 2

Background Information

The European Aviation Safety Agency (EASA) has initiated a research program with the following aims (citation from *Specifications attached to Invitation to Tender EASA.2008.OP.03*):

Introduction: background of the invitation to the inquiry
Traditionally, non-aerobatic light aircraft have been designed so that recovery can be made from spins. Up until 1991, both the FAA and European codes placed restrictions on the number of turns or the time it should take to recover from a spin, and ensuring that even if an incorrect recovery procedure was used, straight and level flight could still be recovered. Studies in the USA in the 1980s and 1990s showed that in the vast majority of accidents attributed to spinning, the initial altitude was insufficient for recovery. It was concluded by the FAA that it would be safer to try to prevent spins rather than ensure recovery can be made once a spin had been entered. The FAA introduced an amendment to FAR 23.221 in 1991, updated in 1996, which allowed aircraft to be certified with spin resistance as an alternative to meeting the spin recovery requirements. No similar amendment has been introduced to the European Codes.

Existing Designs
Two US aircraft are known to have been certified to this alternate FAA code. Both are four seat single engine non-aerobatic aircraft. One of these also incorporates an aircraft parachute recovery system designed to improve the occupants' chances of survival should control of the aircraft be lost. Both of these aircraft have a wing leading edge discontinuity with a drooped outboard leading edge. The principal of this design is that at high angles of attack, the leading edge discontinuity introduces a vortex over the wing upper surface which acts as a wing fence, stopping the stalled flow from the inboard wing spreading to the outboard wing. The drooped outboard leading edge also delays the stall of the outboard wing which allows the ailerons to remain affective at high angles of attack. The elevator stop is set so that the stall angle of attack of the outboard wing is never reached. It has been found that features in this design intended to make the aircraft spin resistant are detrimental to spin recovery, to the extent that aircraft do not meet the original requirements which only deal with spin recovery. Based on limited evidence to date, the spin resistance and spin recovery itself appear to be mutually exclusive; good characteristics in one or the other can be achieved, but not both at the same time.

Situation in Europe

Results from a study of European spin accident statistics are very likely to reflect the US data as there are no fundamental difference in operations. It is considered that, if this is the case, EASA should also promote aircraft designs which minimize the risk of spinning, even if this is at the expense of degraded spin recovery. One of the two above mentioned US aircraft has been certified by EASA for use in Europe based on equivalent safety findings afforded by (i) some spin recovery capability (ii) a parachute recovery system (iii) spin resistance with additional certification review (CRI) items which defined additional manoeuvres beyond those required by FARs. The other type, however, has not been certified by EASA as the aircraft does not meet the CS-23 spin recovery requirements and there are no other features which could afford equivalent safety other than spin resistance itself.

Description of the subject and scope of the contract

The primary objective of the project is to investigate safety criteria and relevant test methods which will form the fundamental basis for proposing a change to CS-23.221. A secondary objective is to increase awareness of the design concept within European industry, and to stimulate European designs. The expected tasks are as follows, but alternative methods which meet the objectives will also be considered:

1. Investigate and report FAA experience and any European or worldwide researches into spin resistant designs and in particular to determine what were the target in-flight characteristics.
2. In co-operation with EASA and based on the research findings, the existing EASA Certification Review Items and the corresponding FAA code, define a limited set of criteria which, if demonstrated, would confirm that a design is adequately spin resistant. These should be in the form of additional requirements to the existing CS-23.221, and any additional explanations for inclusion as interpretive Advisory Material (AMJ) and Flight Test Guide material.
3. Demonstrate the criteria are satisfactory by testing spin resistant aircraft.

13.4 Answers to questionnaire, anonymised

Answers in red letters were given by manufacturers of part 23 aircraft, answers in blue letters were given by other participants of the survey.

1. How do you rate a pilot of average ability to manage spin recovery of non-aerobatic (normal and utility category) aircraft complying with CS 23.221(a) requirement (see attachment 1)?

(a) at higher altitude

1x excellent

- assuming appropriate training has been given.

2x good

3x average

- In our opinion, first question should be concern only Normal Category Airplanes (not about non-aerobatic airplanes, therefore Utility Category mentioned above).

3x fair

- The removal of spin training from PPL training was a disaster which has not stopped aircraft getting into and failing to recover from spins.

4x poor

- It is to expect a lot of trouble without (current) general spin-training.
- Generally there is a low understanding of the mechanism of a spin

1x required

- Ability is tested under regulations for pilot licence.

(b) at lower altitude, e.g. in landing pattern

1x good

1x average

11x poor

- even a pilot with good ability has little chance to recover an aircraft that inadvertently enters a spin at low altitude
- because there is unlikely to be sufficient height.
- Average pilots have a reflex, they pull when the airplane directs towards the ground.
- Spin training is not required to obtain a PPL. The pilot should be able to avoid spin entry but if a developed spin is encountered we believe the average PPL holder would be poorly equipped to recover
- Despite the poor ability of the average pilot to manage spin recovery, we feel that this is not a major problem. Contrarily to the experience of many other Countries (namely the UK), the proportion of accidents due to inadvertent spin are practically unknown in our country, at least for the average pilot in non-aerobatic activity. Obviously, for aerobatic activity this is a major consideration, but the aerobatic training should adequately cope with this fact.
- When pilot recognizes entry to the spin properly and immediately, then he was be very likely able to perform spin recovery. But very important factor is loss of altitude from beginning of spin to spin recovery to level flight. In this case term "loss of altitude" means difference between height of spin entry and its recovery to level flight.
- Cases of unintentional entry into a spin during landing pattern are very rare.

1x required

2. In your opinion, would you rate the parameters applied in CS23.221(a) suitable to describe spin recovery behaviour or would you prefer to apply others?

2A If not suitable please provide detail

Part-23-manufacturers:

4x suitable

3x prefer others

- CS 23.221(a) should be expanded with.'...or from the motion caused by 3 seconds of full pro spin control, …'
- Re introduce spin training and introduce unusual attitude recover to pilot training
- Compared to twin engine airplanes (no spin requirement), the one turn for recovery is to strict, especially for high altitudes.

Others:

6x suitable

- Only for light NORMAL Category airplanes.
- Problem connects mostly with the unintentional entry into a spin. Solution lays in correct stall characteristics. It means in CS23.201, CS23.203 and CS23.207.

1x prefer others

- I think one full turn or three seconds is to long. Most unexperienced pilots will give up the attempt to recover after a half turn and try some other control input

3. Are you aware of the concept of spin resistant aircraft?

7x yes

5x yes

2x no

- YES ....but not very minutely.

4. Are aircraft designs of your company already influenced by this principle?

4A If yes, what different flight characteristics were the designs intended to have relative to a standard design?

3x yes

- None
- The concept of spin resistance has been used in conjunction with a stick pusher system to develop a safer than average Part 23 aircraft.
- The characteristics make an inadvertent spin very unlikely, although the airplanes do not meet the spin resistant requirements according FAR23.221 (a)(2).
- We partly used spin resistant principals when we solved how to improve stall speed characteristics (CS 23.201-CS 23.207). Our aircraft's design isn't bases on spin resistant concept.

3x no

- Our Aircrafts comply partly according to this requirement. It is depending by center of gravity and control-inputs by the pilot.
- Our aircraft is designed as an aerobatic trainer aircraft. The spin resistance concept is therefore not appropriate.
- Design the aircraft to be able to be quick to recover from a spin rather than spin resistant

4x no

- We are not an aircraft manufacturer. But we believe that spin resistance characteristics of the commonly used GA aircraft today are more than adequate.
- None of the producers in our country has designed light aircraft in accordance with these principles yet.
- It is very difficult to design really good plane with spin resistant characteristics.

5. How would you improve the requirements provided by FAR-23.221(a)(2)?

- In principle the FAR 23.221(a)(2) is a well balanced and established requirement. "One ball width displacement" should be defined in terms of lateral acceleration or beta. Slip balls are not standardized. Furthermore, it should make reference to the possibility of an artificial stall barrier system (Ref. FAR 23.691). However, harmonization takes first priority for any aircraft manufacturer.
- FAR23.221(a)(2)(ii) ...Reduce the airplane speed using pitch control at a rate of approximately FIVE knot per second also.

  ...and then with the ailerons deflected INTO the direction of turn in the most adverse manner.

  FAR23.221(a)(2)(iii) ...Rudder deflection corresponding to the temporary control forces specified by §23.143(c) instead of "one ball" displacement.
- I would not change the requirements for normal and utility category aircraft. For acrobatic category, I would make them less stringent (recovery 1 and 1/2 turns after completion of the first control action).
- Less than one turn to recover from established
- The FAR-23.221(a)(2) requirements are reasonable!

- We believe the requirements to be satisfactory.
- The requirements in FAR-23.221 are not good enough. To limit the elevator power to make it impossible to reach high AOA does not solve the problem of dynamic spin entries or from an uncontrolled situation there the airspeed is well below the stall speed.
- Nowise, I thing that FAR-23.221(a)(2) is good chance for different producers.
- This is very reasonable requirement proved by practice.

6. Would you consider certifying an aircraft as spin resistant (in a broader sense) if the CS-23 would provide the possibility?

4x yes

2x no

3x yes

- Our response is from point of view of the aviation authority.

4x no

7. Would you like to make any suggestions for technical means to achieve spin resistance to be investigated in this project?

3x yes

- Artificial stall barrier systems should be allowed in CS-23 as in FAR 23.691 and cross referenced in the Spin Resistance paragraphs.
- In addition to aerodynamic means (for example: leading edge droop, outboard wing design ad airfoil selection) artificial means like stick limiters and stick pushers have to be regarded.
- Spin resistance is very hard to prove. The flight test programme must include a lot of dynamic and very low speed entry attempts

11x no

- No, because many other problems would occur. I think the development of a real spin resistance aircraft is impossible.
- As stated above, we believe the problem is being over-emphasized. A good GA aircraft design should by definition be spin-resistant, at least within its normal operating envelope and handled without foolhardiness. A further level of protection could be provided by a widespread use of BRS (Ballistic Recovery Systems).

8. Do you see alternative concepts to flight mechanics measures for the increase of level of safety compared with CS-23.221 (a) and spin resistance concept (FAR-23.221(a)(2))?

5x yes

- Yes, artificial stall barriers and even more sophisticated fly-by-wire systems with envelope protection.
- The Spin-recovery up to one turn has to be the same procedures than the stall recovery! It should be not required to use opposite rudder. The position of neutral rudder should be usable, defined by force gradient.
- Properly regulated mandatory training in spin awareness and recovery techniques.
- Better training
- Artificial means (as mentioned above) like stick limiters, stick pushers, rudder limiters.

2x no

2x yes

- Train pilots in spin recovery techniques and fit aircraft parachutes.
- The most common spin accident starts with an over-ruddered and under-banked turn. Warning and behaviour in this flight condition should be addressed

5x no

- no additional comment on top of the many studies carried out in the past on design guidelines for improved safety
- It seems to me that more profitable way is to include training in spin recovery into all pilot training programmes.

9. Would you be prepared to take part in an interview on this matter?

6x yes

1x no

5x yes

2x no

10. Are you interested in commenting the preliminary outcomes of this study?

7x yes

5x yes

2x no

11. Please feel free provide any further comments:

- As mentioned above harmonization between FAR 23 and CS-23 is the highest priority. Therefore the concept of spin resistance and artificial stall barriers should be brought into CS-23.
- Die Entwicklung zum wirklichen "spin-resistenten" Flugzeug ist meiner Meinung nach nicht überschaubar. Unmittelbar umsetzbar sind deutlich verbesserbare technische Merkmale hinsichtlich der Standards/Bauvorschriften, welche dem Piloten gesteigerte Möglichkeiten zur Vermeidung von Stall und Spin geben können. Dies betrifft sowohl die Flugmechanik als auch den Einsatz verbesserter bzw. ergänzender Systeme.

- I support the concept of spin resistant designs for normal and utility category aircraft.

- Making an aircraft spin resistant will not help, it will however make the pilots be less aware of the risk and unable to deal with a departure from controlled flight. I.E. wake vortex, wind shear, auto pilot runaway or disorientation

- 1. aerodynamic design dilemma

  Wing designs favourable to docile stall characteristics lead to unfavourable spin recovery characteristics.

  2. Accidents

  At low altitudes the spin recovery is of no importance. It is important not to spin.

  3. Human Factors

  Some Pilots used to traditional single engine airplanes complying with CS-23.221 (a) believe they can spin everything and disregard that the airplane is not certified for intentional spin. Information is required.

  4. Artificial means

  Another design dilemma: full elevator pull in operation is only required for landing with forward cg, slow approach speed, strong headwind (wind shear). Full rudder is necessary only under strong crosswind conditions during take off and landing (and for the demonstration of a stall speed and for spin recovery of course). The artificial limiters and even stick pushers in this flight phases are disturbing. The systems can not easily distinguish between an intentional stall (flair) and an unintentional stall. What about deactivation of those systems by the pilot? What is the criticality of those systems?

- As a former test pilot, display pilot and aerobatic instructor I have done a fair amount of spinning. Spin is a complicated manoeuvre and can be very different even with the same aircraft depending on entry method. The requirements in the FAR can easily be demonstrated with some aircraft types that spins readily with an other entry method.
- I am against an aircraft parachute recovery systems without determined requirements for such systems.

- The Idea is very much promoted from my side, but I do not understand why this should be limited to CS23 only? CS-VLA, CS-22 or future EU-LSA requirements needing the same! I know the background from the FAA initial starting point, but they do not have CS22, and CS-VLA. If you looking into the accident data you will easy find that is fully applicable to all light airplane categories. In CS22 is extreme, the have to demonstrate intentional spin for large wingspan gliders, no one will carry out this in practice. This will improve more safety.

- Useful criteria are defined in def stan 970 (leaflet 18, part 1 section 3) “spinning and spin recovery design criteria for spin resistance and spin recovery”

13.5 CS 23.221 Proposed Amendment to incorporate Spin Resistance Concept V5

Proposed (V5)
Insert the following paragraph into CS23.221 and rename (b) and (c) as (c) and (d) respectively:
(b) *Normal Category Aeroplanes – Spin Resistant.* At the applicant's option, the airplane may be demonstrated to have spin resistant characteristics in lieu of spin handling described in paragraph (a) as follows:
(1) If an uncontrollable nose down pitch does not occur during the stall manoeuvers contained in 23.201, controlability must be demonstrated with the pitch control held against the stop. It must be possible to roll from 30° bank to 30° bank in the other direction with the stick in the fully aft position (without assistance from the rudder) without encountering abnormal characteristics.
(2) If an uncontrollable nose down pitch does occur during the stall manoeuvers contained in 23.201, the stick must be held fully aft for at least 2 seconds while maintaining wings level within 15° bank (without assistance from the rudder). At the end of the 2 seconds, standard stall recovery control inputs must produce an immediate return to unstalled flight without any tendency towards spin entry.
(3) Reduce the airplane speed using pitch control at a rate of approximately one knot per second until the pitch control reaches the stop; then, with the pitch control pulled back and held against the stop, apply full rudder control in a manner to promote spin entry for a period of seven seconds. This manoeuvre must be performed attempting to maintain heading with ailerons deflected opposite the direction of turn. Power and airplane configuration must be set in accordance with 23.201(e) without change during the manoeuvre. At the end of seven seconds or a 360degree heading change, the airplane must respond immediately and normally to primary flight controls applied to regain coordinated, unstalled flight without reversal of control effect and without exceeding the temporary control forces specified by 23.143(c); and

(4) It must be demonstrated that sudden application of rudder to a fixed position at 1.1Vs1 can be controlled by conventional use of pitch and roll control. This must be done in both directions and for the power conditions specified in 23.201 and 23.203. Sufficient rudder must be applied in less than 2 seconds to achieve a heading change of the lessor of: 1- 1100/Vs1 degrees (where Vs1 is in knots) 2- 20 degrees 3- The heading change which results from full rudder.
(5) Compliance with 23.201 and 23.203 must be demonstrated with the airplane in uncoordinated flight. The rudder must be held at the angle required to demonstrate (4) (in the same configuration and power setting and in the same direction).

13.6 List of manoeuvres of flight trials

For each type of manoeuvres mentioned in 8.1 (A - H), a list of the different settings at which the manoeuvre shall be performed is given below.

If critical items are identified, it may be appropriate to repeat the item with varied flap setting or other changes. It is the pilot's choice to set an order and to choose representatives depending on in-flight results.

Manoeuvre No.	Manoeuvre type	Settings					Origin		
		Speed rate	PWR	Flaps	Bank	action	EASA-V5	EASA-V5-Var.	other
1	A	1kn/s	Idle	0°			X		
2	A	1kn/s	Idle	10°			X		
3	A	1kn/s	Idle	20°			X		
4	A	1kn/s	Idle	40°			X		
5	A	1kn/s	75%	0°			X		
6	A	1kn/s	75%	10°			X		
7	A	1kn/s	75%	20°			X		
8	A	1kn/s	75%	40°			X		
9	B	1kn/s	Idle	0°	45°	immediate recover	X		
10	B	1kn/s	Idle	10°	45°	immediate recover	X		
11	B	1kn/s	Idle	20°	45°	immediate recover	X		
12	B	1kn/s	Idle	40°	45°	immediate recover	X		
13	B	1kn/s	75%	0°	45°	immediate recover	X		
14	B	1kn/s	75%	10°	45°	immediate recover	X		
15	B	1kn/s	75%	20°	45°	immediate recover	X		
16	B	1kn/s	75%	40°	45°	immediate recover	X		
17	B	3-5kn/s	Idle	0°	45°	immediate recover	X		
18	B	3-5kn/s	Idle	10°	45°	immediate recover	X		
19	B	3-5kn/s	Idle	20°	45°	immediate recover	X		
20	B	3-5kn/s	Idle	40°	45°	immediate recover	X		
21	B	3-5kn/s	75%	0°	45°	immediate recover	X		
22	B	3-5kn/s	75%	10°	45°	immediate recover	X		

23	B	3-5kn/s	75%	20°	45°	immediate recover	X		
24	B	3-5kn/s	75%	40°	45°	immediate recover	X		
25	B	1kn/s	75%	0°	45°	stick aft 7s		x	
26	B	3-5kn/s	75%	0°	45°	stick aft 7s		X	
27	B	1kn/s	50%	0°	45°	stick aft 7s		X	
28	B	3-5kn/s	50%	0°	45°	stick aft 7s		X	
29	B	1kn/s	100%	0°	45°	stick aft 7s		X	
30	B	3-5kn/s	100%	0°	45°	stick aft 7s		X	
31	B	1kn/s	100%	10°→0°	45°	stick aft 7s			X
32	B	1kn/s	0→100	0°	45°	stick aft 7s			X
33	B	1kn/s	100%	0°	45°	dynamic rudder against turn, stick aft 7s			X
34	B	1kn/s	100%	0°	45°	dyn rudder with, stick aft 7s			X
35	B	1kn/s	100%	0°	45°	dyn rudder with, aileron against, stick aft 7s			X
36	B	1kn/s	100%	0°	45°	dyn rudder with, aileron with, stick aft 7s			X
37	B	3-5kn/s	100%	0°	45°	dyn rudder with, stick aft 7s			X
38	B	3-5kn/s	100%	0°	45°	dyn rudder with, aileron against, stick aft 7s			X
39	B	3-5kn/s	100%	0°	45°	dyn rudder with, aileron with, stick aft 7s			X
	The items in block b represent the turns within the traffic pattern as potential accident situations; range of power settings according to ascending and descending turns.								
40	C	1kn/s	Idle	0°		ailerons opposite “attempting to maintain heading”	X		
41	C	1kn/s	Idle	10°		ailerons opposite “attempting to maintain heading”	X		
42	C	1kn/s	Idle	20°		ailerons opposite “attempting to maintain heading”	X		
43	C	1kn/s	Idle	40°		ailerons opposite “attempting to maintain heading”	X		
44	C	1kn/s	75%	0°		ailerons opposite “attempting to maintain heading”	X		
45	C	1kn/s	75%	10°		ailerons opposite “attempting to maintain heading”	X		
46	C	1kn/s	75%	20°		ailerons opposite “attempting to maintain heading”	X		
47	C	1kn/s	75%	40°		ailerons opposite “attempting to maintain heading”	X		
48	C	1kn/s	100%	0°		ailerons opposite “attempting to maintain heading”		X	
49	C	1kn/s	100%	0°		ailerons neutral			X
50	C	1kn/s	100%	0°		ailerons full opposite			X
51	C	1kn/s	100%	0°		ailerons full with			X
52	C	1kn/s	100%	10°→0°		ailerons neutral			X

53	C	1kn/s	0→100	0°		ailerons neutral			X
54	C	3-5kn/s	75%	0°		ailerons opposite “attempting to maintain heading”			X
55	C	3-5kn/s	100%	0°		ailerons opposite “attempting to maintain heading”			X
56	C	3-5kn/s	100%	0°		ailerons neutral			X
57	C	3-5kn/s	100%	0°		ailerons full opposite			X
58	C	3-5kn/s	100%	0°		ailerons full with			X
59	C	7-10kn/s	100%	0°		ailerons opposite “attempting to maintain heading”			X
	The items in block c represent wings-level sections within the traffic pattern as well as entries to a turn; range of power settings according to ascending and descending flight situations.								
60	D		Idle	0°		rudder applied in less than 2s	X		
61	D		Idle	10°		rudder applied in less than 2s	X		
62	D		Idle	20°		rudder applied in less than 2s	X		
63	D		Idle	40°		rudder applied in less than 2s	X		
64	D		75%	0°		rudder applied in less than 2s	X		
65	D		75%	10°		rudder applied in less than 2s	X		
66	D		75%	20°		rudder applied in less than 2s	X		
67	D		75%	40°		rudder applied in less than 2s	X		
68	D		75%	0°		rudder applied as sudden as possible		X	
69	E		Idle	0°		aileron applied in less than 2s	X		
70	E		Idle	10°		aileron applied in less than 2s	X		
71	E		Idle	20°		aileron applied in less than 2s	X		
72	E		Idle	40°		aileron applied in less than 2s	X		
73	E		75%	0°		aileron applied in less than 2s	X		
74	E		75%	10°		aileron applied in less than 2s	X		
75	E		75%	20°		aileron applied in less than 2s	X		
76	E		75%	40°		aileron applied in less than 2s	X		
77	E		75%	0°		aileron applied as sudden as possible		X	
78	F		Idle	0°			X		
79	F		Idle	10°			X		
80	F		Idle	20°			X		
81	F		Idle	40°			X		
82	F		75%	0°			X		
83	F		75%	10°			X		

84	F		75%	20°			X		
85	F		75%	40°			X		
86	G	1kn/s	Idle	0°			X		
87	G	1kn/s	Idle	10°			X		
88	G	1kn/s	Idle	20°			X		
89	G	1kn/s	Idle	40°			X		
90	G	1kn/s	75%	0°			X		
91	G	1kn/s	75%	10°			X		
92	G	1kn/s	75%	20°			X		
93	G	1kn/s	75%	40°			X		
94	H	1kn/s	Idle	0°	30°	immediate recover	X		
95	H	1kn/s	Idle	10°	30°	immediate recover	X		
96	H	1kn/s	Idle	20°	30°	immediate recover	X		
97	H	1kn/s	Idle	40°	30°	immediate recover	X		
98	H	1kn/s	75%	0°	30°	immediate recover	X		
99	H	1kn/s	75%	10°	30°	immediate recover	X		
100	H	1kn/s	75%	20°	30°	immediate recover	X		
101	H	1kn/s	75%	40°	30°	immediate recover	X		
102	H	3-5kn/s	Idle	0°	30°	immediate recover	X		
103	H	3-5kn/s	Idle	10°	30°	immediate recover	X		
104	H	3-5kn/s	Idle	20°	30°	immediate recover	X		
105	H	3-5kn/s	Idle	40°	30°	immediate recover	X		
106	H	3-5kn/s	75%	0°	30°	immediate recover	X		
107	H	3-5kn/s	75%	10°	30°	immediate recover	X		
108	H	3-5kn/s	75%	20°	30°	immediate recover	X		
109	H	3-5kn/s	75%	40°	30°	immediate recover	X		
110	H	3-5kn/s	75%	0°	30°	stick aft 7s		X	
111	H	1kn/s	75%	0°	45°	stick aft 7s		X	
112	H	1kn/s	0→100	0°	45°	stick aft 7s			X
113	H	3-5kn/s	75%	0°	45°	stick aft 7s		X	
114	H	3-5kn/s	50%	0°	45°	stick aft 7s		X	
115	H	3-5kn/s	100%	0°	45°	stick aft 7s		X	
	As in block b, the items in block h represent the turns within the traffic pattern as potential accident situations; range of power settings according to ascending and descending turns.								

Table 8: List of manoeuvre of 1st set of flight trials

13.7 Documentation of flight trials

EASA.2008.OP.03 – Safety aspects of light aircraft spin resistance concept			
1. Project section:			
2. Date:	3. Airfield:	4. Flight No.	5. Section No.
6. A/C:	7. Registration:	8. Crew:	
9. T/O WT:	10. CG:	11. Fuel @T/O:	12. Fuel @L/D:
13. Description A/C (Modifications?):			
14. Description Measure Equipment:			
15. T/O:	16. L/D:	17. W/X:	
18. Remarks:			

Overview of manoeuvres (exemplary for manoeuvre No. 1 to 17)

Man. No.	Short Manoeuvre, Description	@page	Order of testing
1	1 kn/s, wings level	3	
2	1 kn/s, wings level	4	
3	1 kn/s, wings level	5	
4	1 kn/s, wings level	6	
5	1 kn/s, wings level	7	
6	1 kn/s, wings level	8	
7	1 kn/s, wings level	9	
8	1 kn/s, wings level	10	
9a	45° banked turn until pitch down or stick aft	11	
9b	45° banked turn until pitch down or stick aft	12	
10a	45° banked turn until pitch down or stick aft	13	
10b	45° banked turn until pitch down or stick aft	14	
11a	45° banked turn until pitch down or stick aft	15	
11b	45° banked turn until pitch down or stick aft	16	
12a	45° banked turn until pitch down or stick aft	17	
12b	45° banked turn until pitch down or stick aft	18	
13a	45° banked turn until pitch down or stick aft	19	
13b	45° banked turn until pitch down or stick aft	20	
14a	45° banked turn until pitch down or stick aft	21	
14b	45° banked turn until pitch down or stick aft	22	
15a	45° banked turn until pitch down or stick aft	23	
15b	45° banked turn until pitch down or stick aft	24	
16a	45° banked turn until pitch down or stick aft	25	
16b	45° banked turn until pitch down or stick aft	26	
17a	45° banked turn until pitch down or stick aft	27	
17b	45° banked turn until pitch down or stick aft	28	
	Abbreviations and Notes	29	

Manoeuvres flight test chart (exemplary manoeuvre No. 1)

No. of Man.:	Description of Manoeuvre:					Configuration:
1	1 kn/s, wings level → *uncontrollable nose pitch down?* If no: roll 30° to 30° bank without rudder, stick aft → *abnormal characteristics?* If yes (pitch down): stick aft 2s, no rudder, then standard stall recovery → *max bank more than 15°?* *Return to unstalled immediate?* *Any tendency to spin?*					PWR: Idle Flaps: 0° Bank: 0° ASR: 1kn/s
Probably relevant parameters:	Θ pitch	Φ bank	ξ aileron	ζ rudder	Nose pitch down? Return immediate? Tendency to spin?	Remarks:

Attempt	Altitude begin / Event begin / Altitude end / Event end	Perception of parameters				Other observances	Notices
1							[ ] Attempt failed [ ] Attempt succ.
2							[ ] Attempt failed [ ] Attempt succ.
3							[ ] Attempt failed [ ] Attempt succ.
4							[ ] Attempt failed [ ] Attempt succ.

Manoeuvres flight test chart (exemplary manoeuvre No. 9a)

No. of Man.:	Description of Manoeuvre:	Configuration:
9a	45° banked turn until pitch down or stick aft, then regain level flight, no power change → *loss of altitude more than 300ft?* *Undue pitch-up?* *Any tendency to spin?* *Max bank more than 60°/15°?* *Exceeding max speed or load?* <u>Action: immediate recover</u>	PWR: Idle Flaps: 0° Bank: le45° ASR: 1kn/s

Probably relevant parameters:	Θ pitch	Φ bank	Max n_z	Max IAS	Loss of ALT? Pitch-up? Bank? Tendency to spin?	Remarks:

Attempt	Altitude begin / Event begin / Altitude end / Event end	Perception of parameters				Other observances	Notices
1							[ ] Attempt failed [ ] Attempt succ.
2							[ ] Attempt failed [ ] Attempt succ.
3							[ ] Attempt failed [ ] Attempt succ.
4							[ ] Attempt failed [ ] Attempt succ.

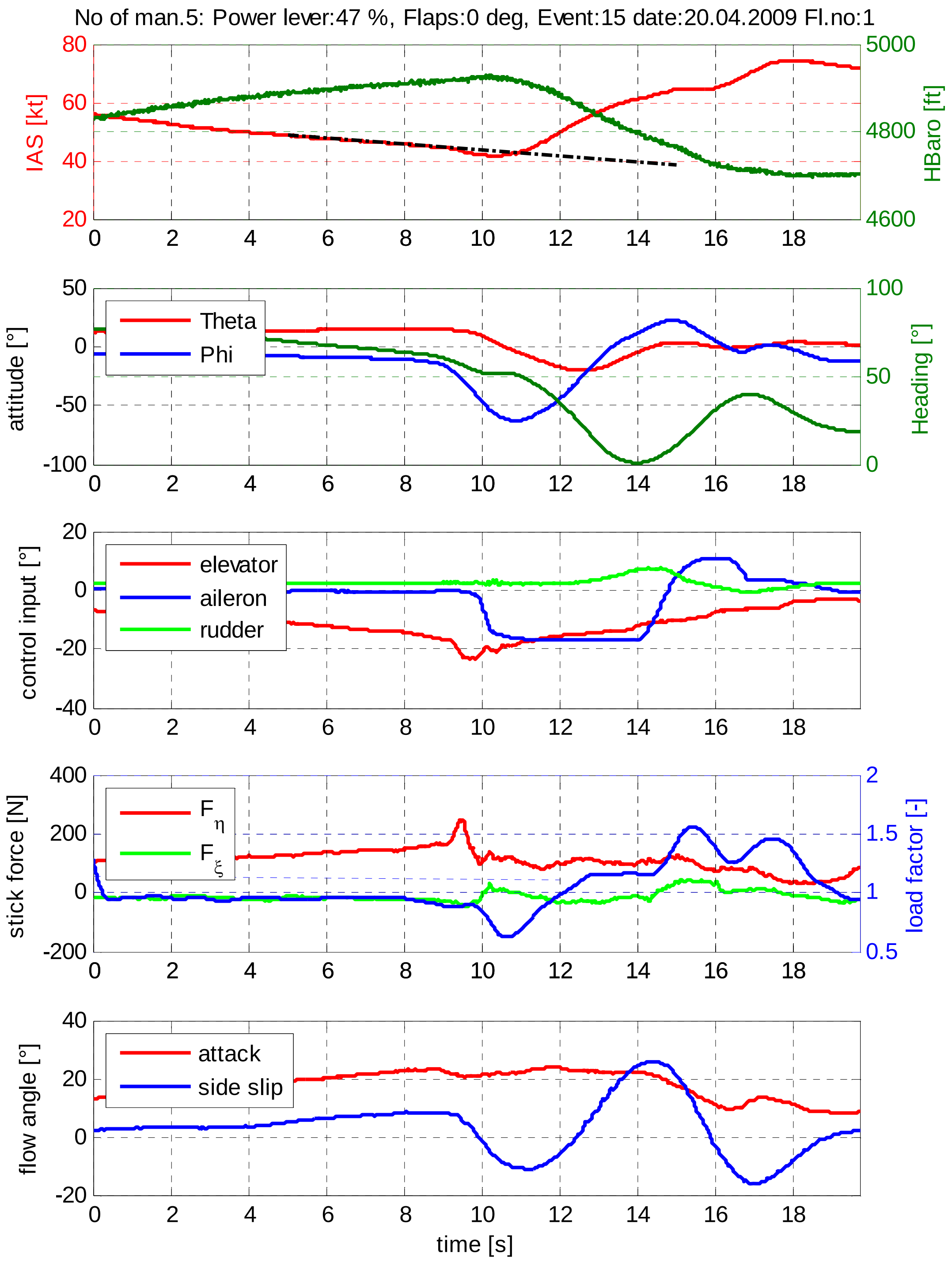
Manoeuvres flight test chart (exemplary manoeuvre No. 9b)

<table>
<tr><td colspan="2">No. of Man.:

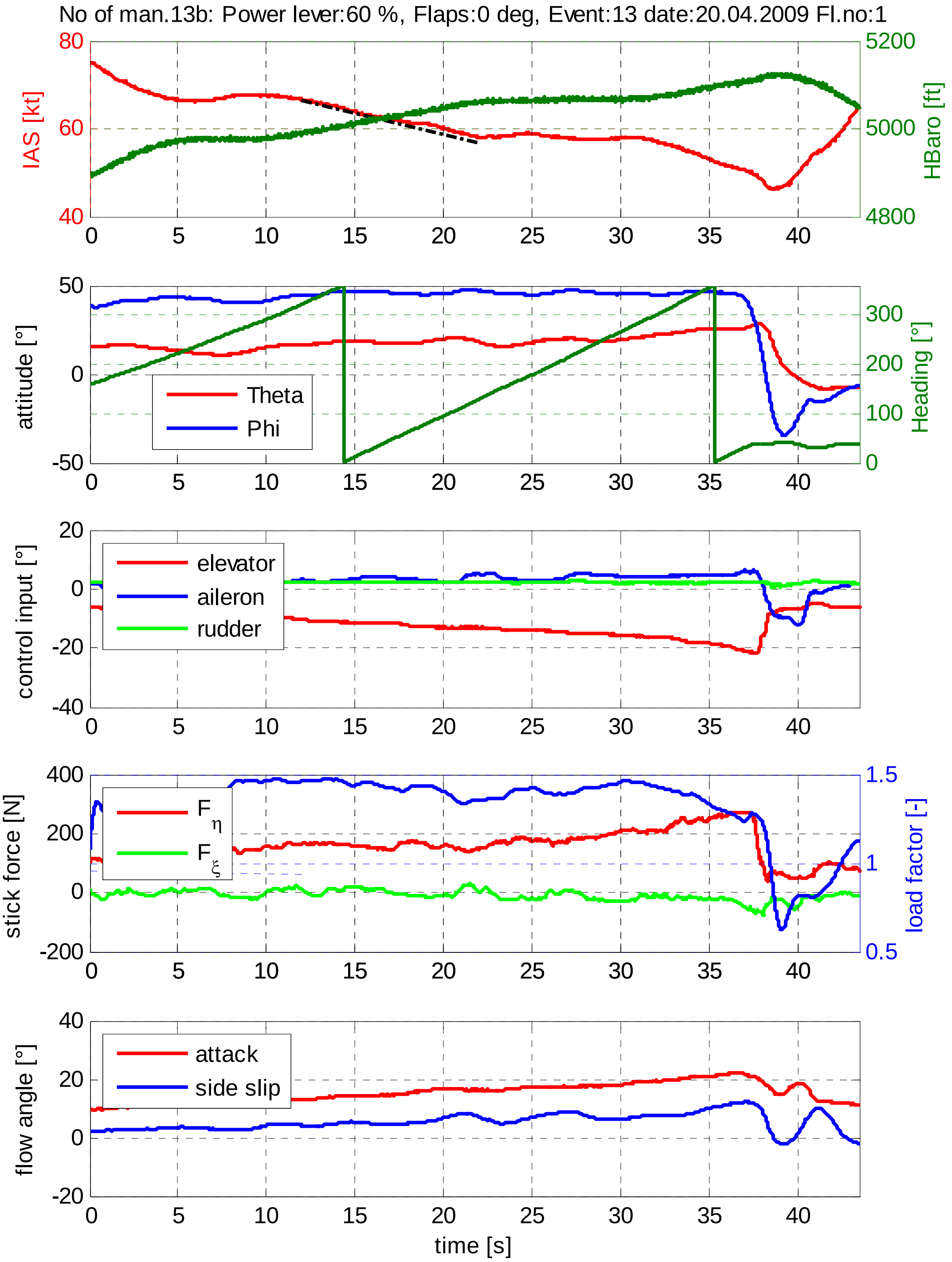
9b</td><td colspan="5">Description of Manoeuvre:
45° banked turn until pitch down or stick aft, then regain level flight, no power change
→ loss of altitude more than 300ft?
Undue pitch-up?
Any tendency to spin?
Max bank more than 60°/15°?
Exceeding max speed or load?
<u>Action: immediate recover</u></td><td>Configuration:
PWR: Idle
Flaps: 0°
Bank: ri45°
ASR: 1kn/s</td></tr>
<tr><td colspan="2">Probably relevant parameters:</td><td>Θ
pitch</td><td>Φ
bank</td><td>Max
n_z</td><td>Max
IAS</td><td>Loss of ALT?
Pitch-up? Bank?
Tendency to spin?</td><td>Remarks:</td></tr>
<tr><td>Attempt</td><td>Altitude begin
Event begin
Altitude end
Event end</td><td colspan="4">Perception of parameters</td><td>Other observances</td><td>Notices</td></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td>[ ] Attempt failed
[ ] Attempt succ.</td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td></td><td></td><td>[ ] Attempt failed
[ ] Attempt succ.</td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td><td></td><td></td><td>[ ] Attempt failed
[ ] Attempt succ.</td></tr>
<tr><td>4</td><td></td><td></td><td></td><td></td><td></td><td></td><td>[ ] Attempt failed
[ ] Attempt succ.</td></tr>
</table>

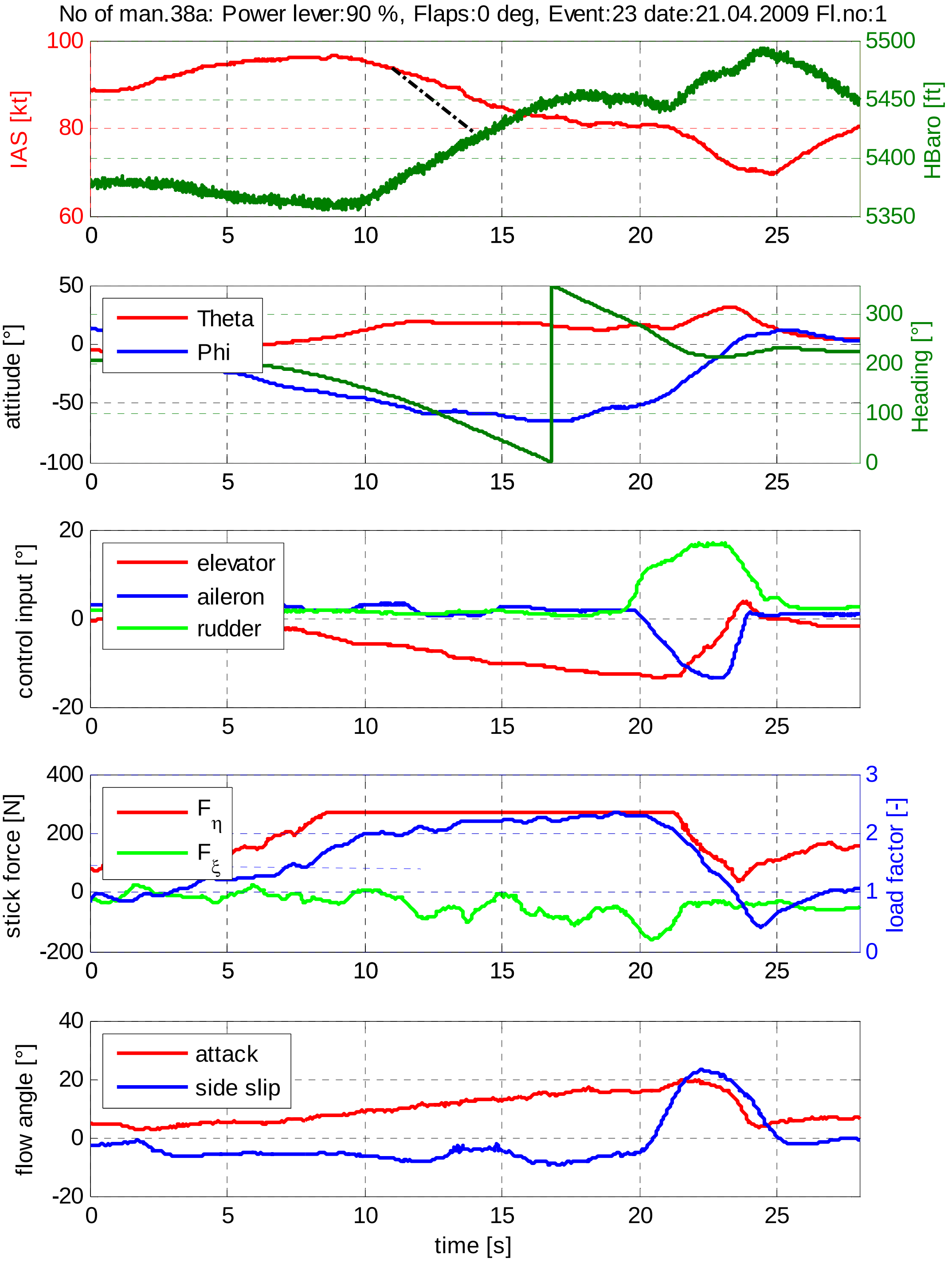
13.8 Representative diagrams for each manoeuvre type

Manoeuvre type A:

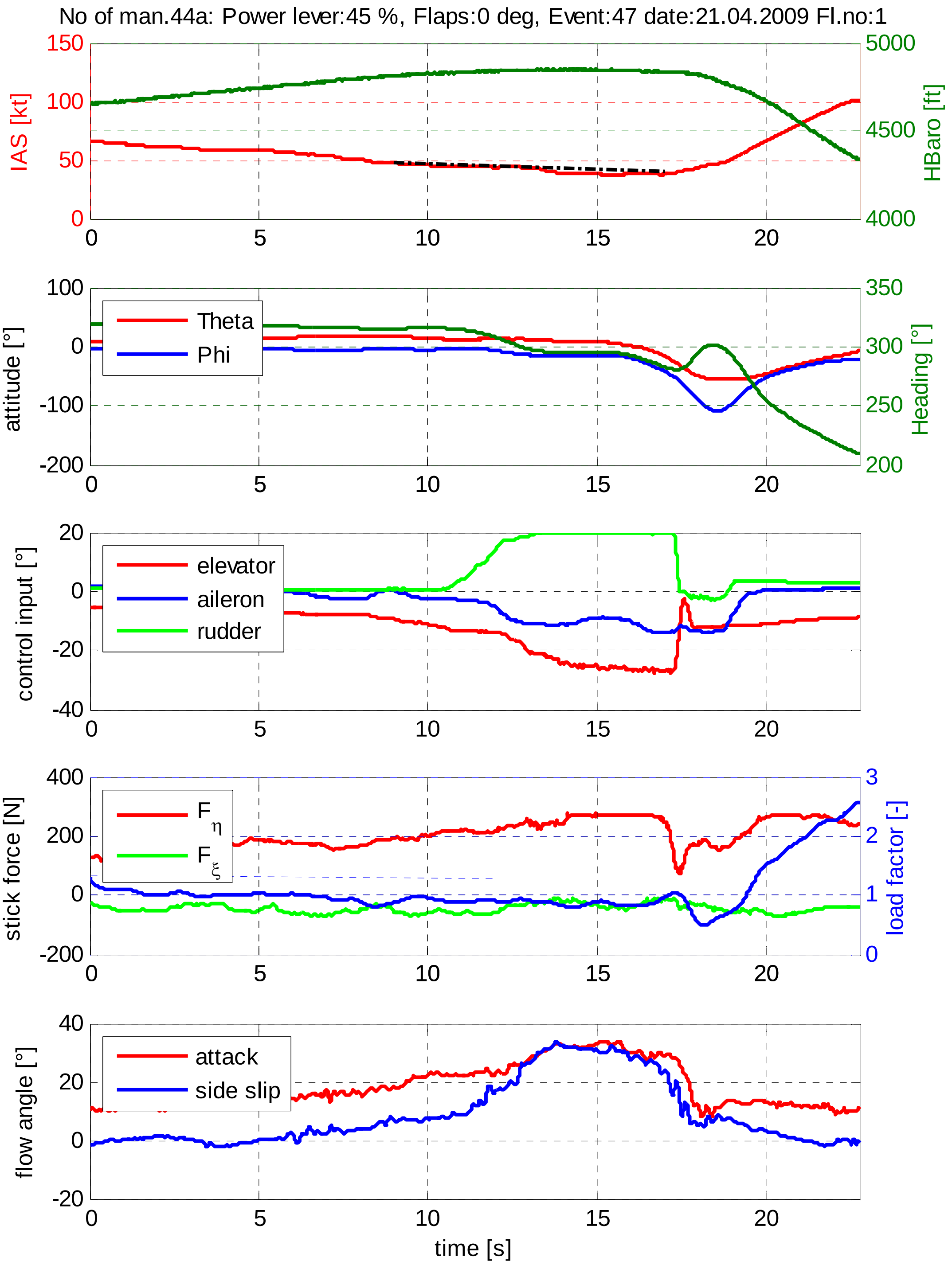


Manoeuvre type B:

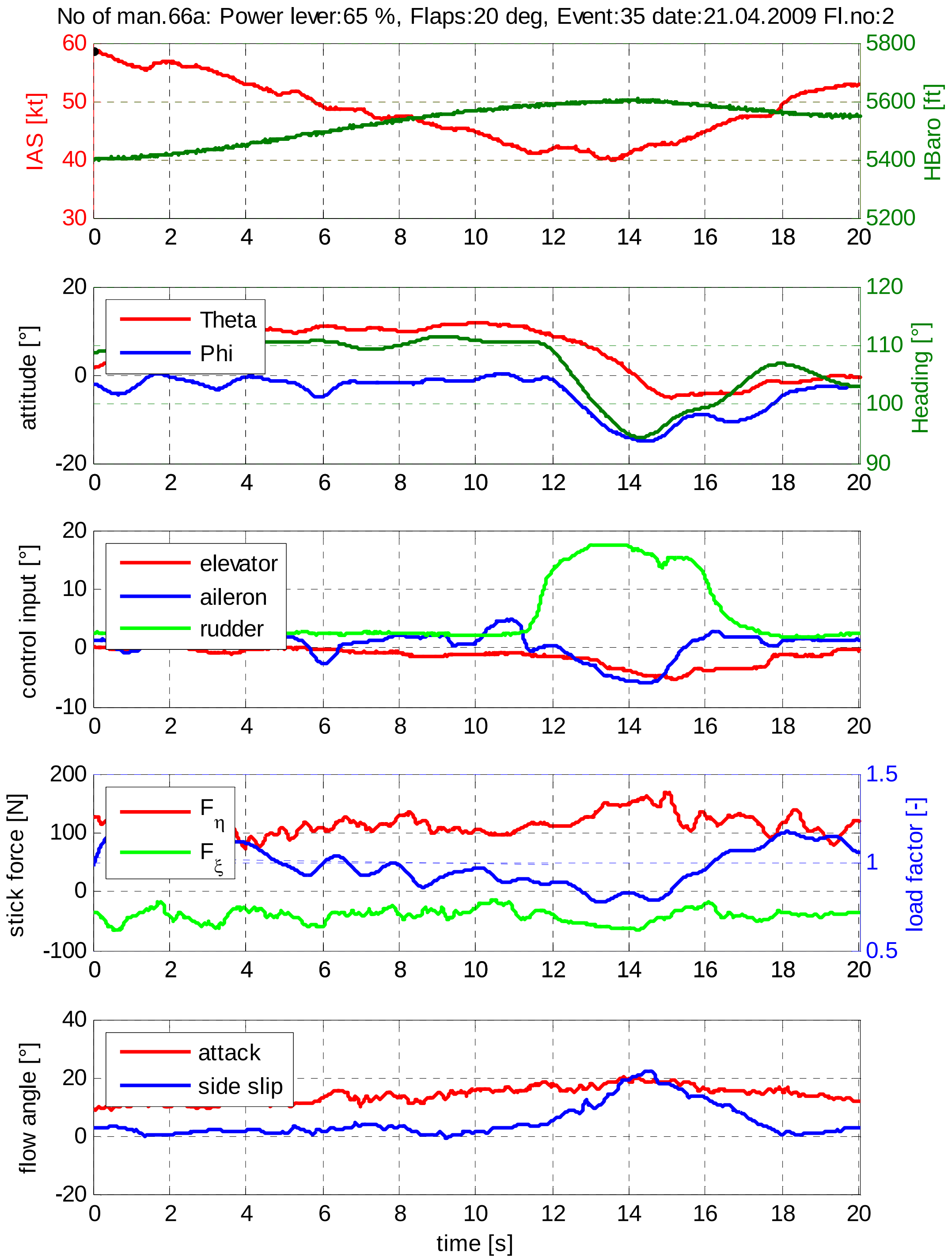



No of man.38a: Power lever:90 %, Flaps:0 deg, Event:23 date:21.04.2009 Fl.no:1
IAS [kt]
HBaro [ft]
100
80
60
5500
5450
5400
5350
attitude [°]
Heading [°]
Theta
Phi
50
0
-50
-100
300
200
100
0
control input [°]
elevator
aileron
rudder
20
0
-20
stick force [N]
load factor [-]
F_η
F_ξ
400
200
0
-200
3
2
1
0
flow angle [°]
attack
side slip
40
20
0
-20
0 5 10 15 20 25
time [s]

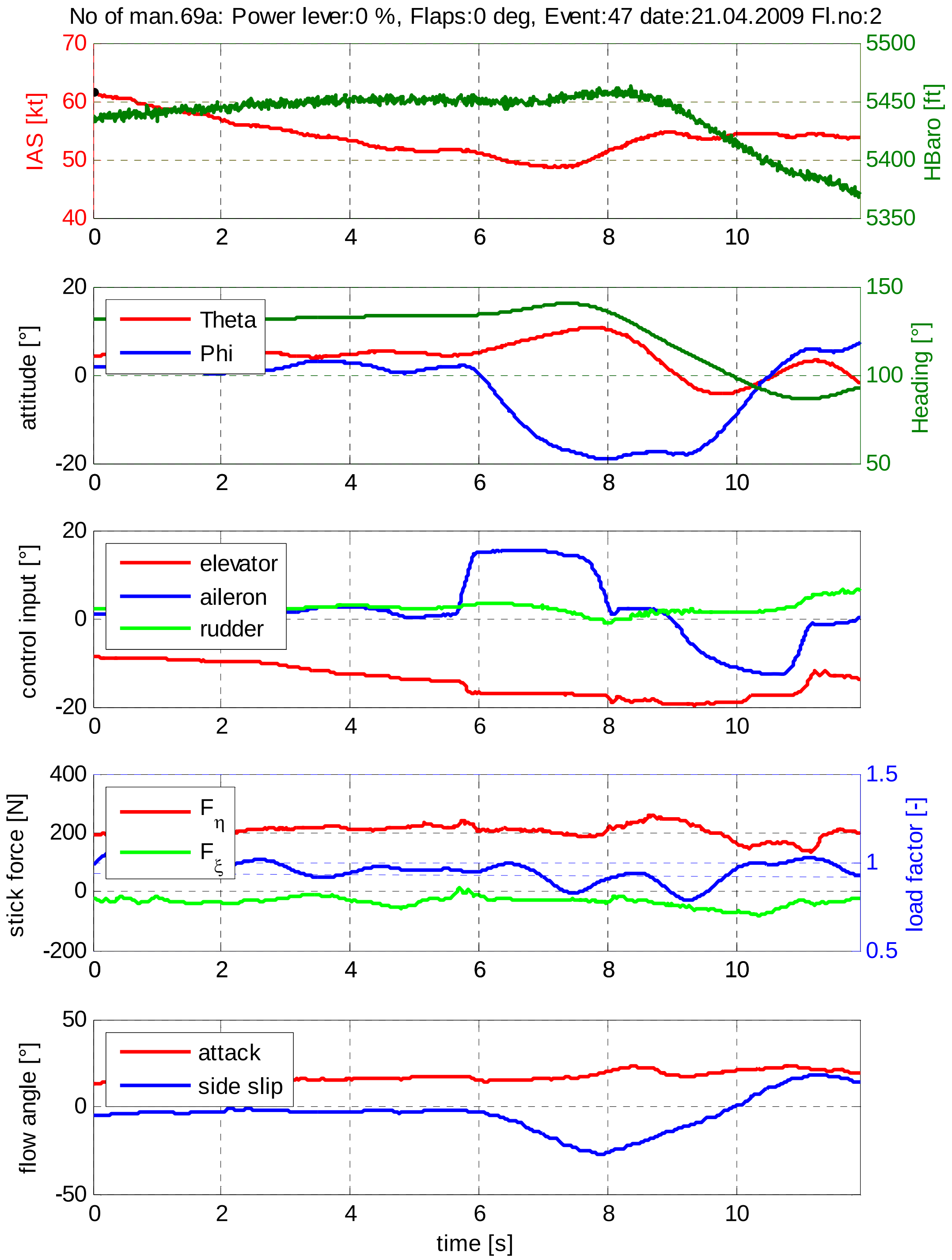
Manoeuvre type C:



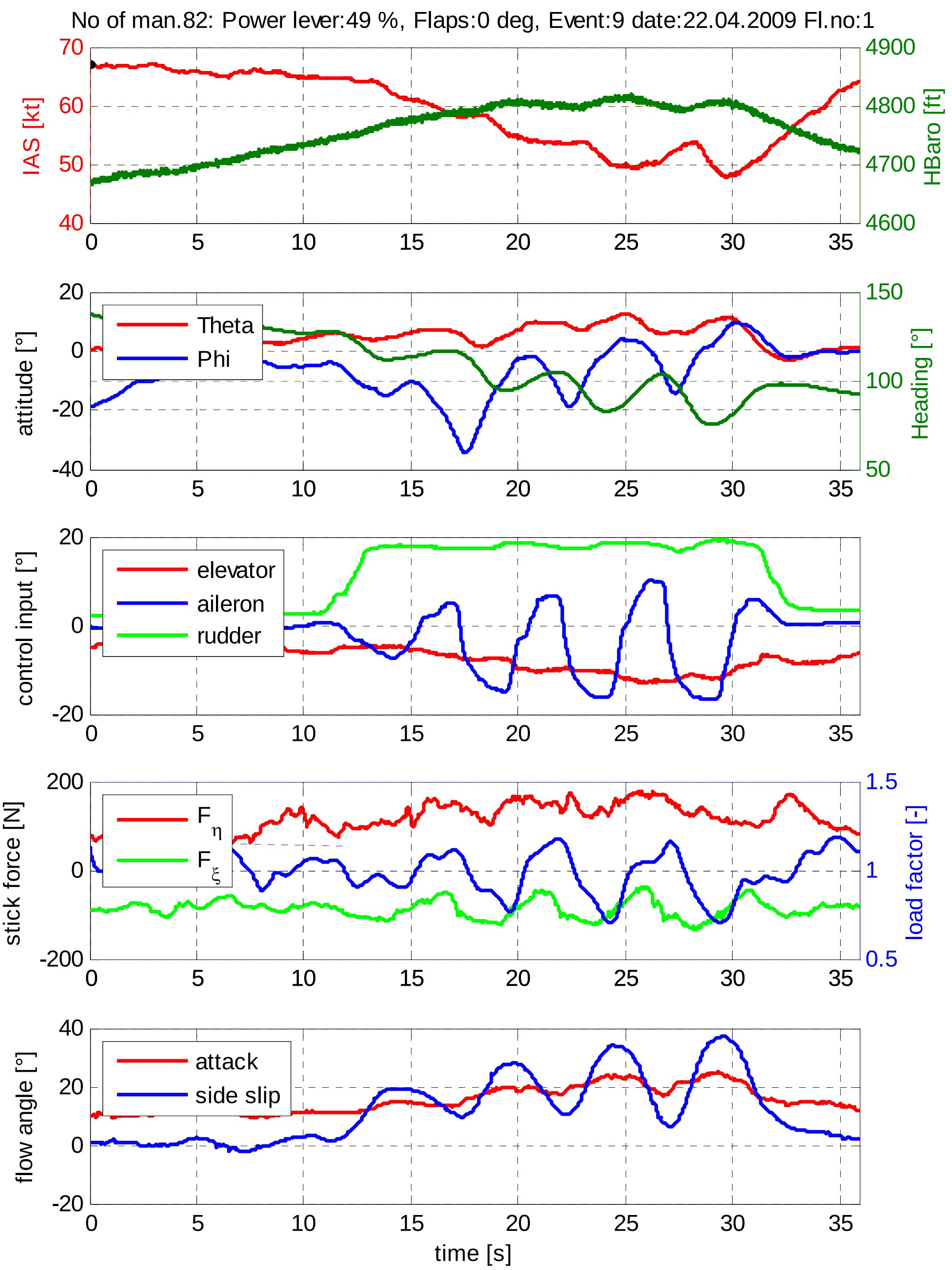
Manoeuvre type D:



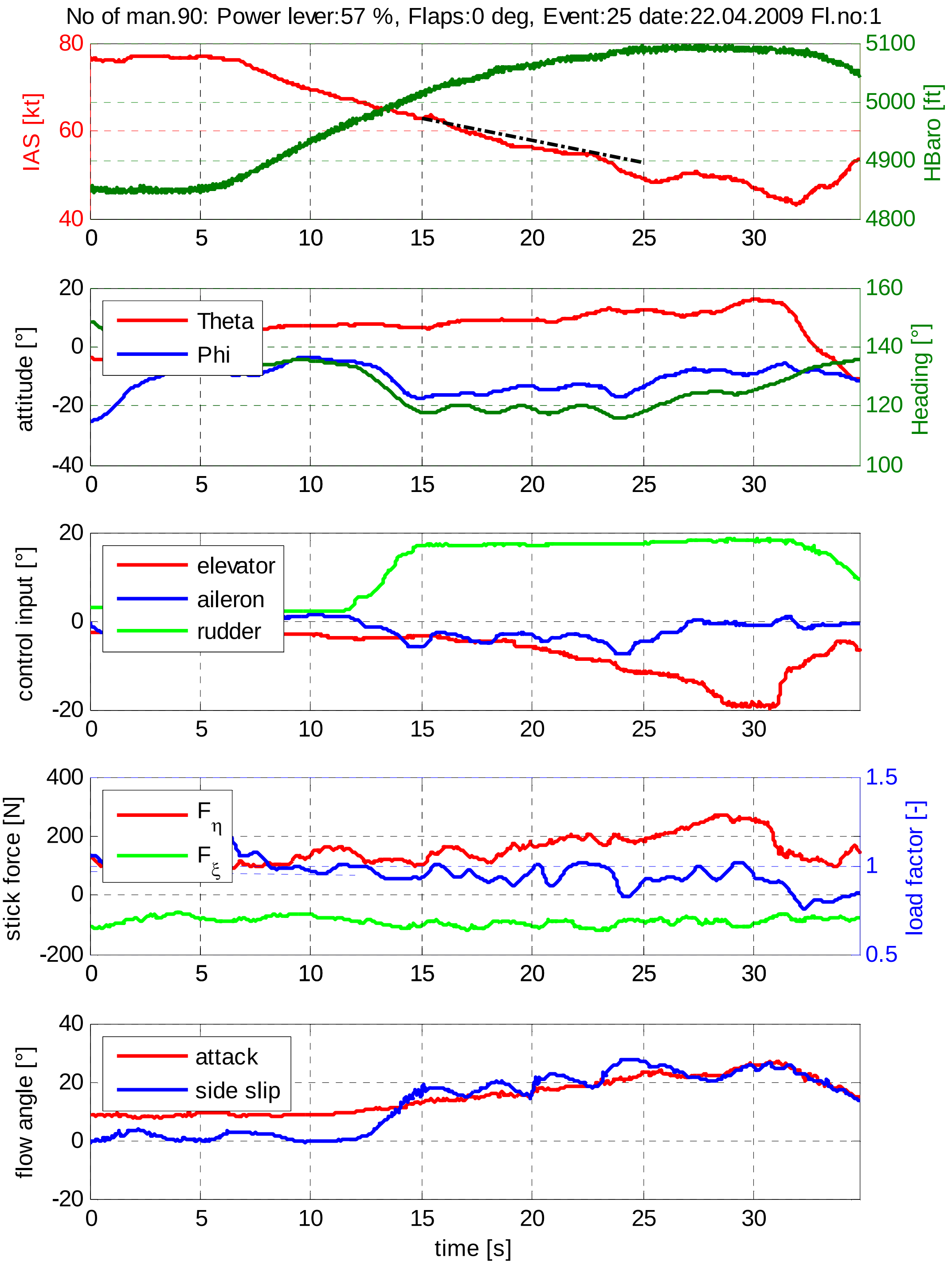
Manoeuvre type E:



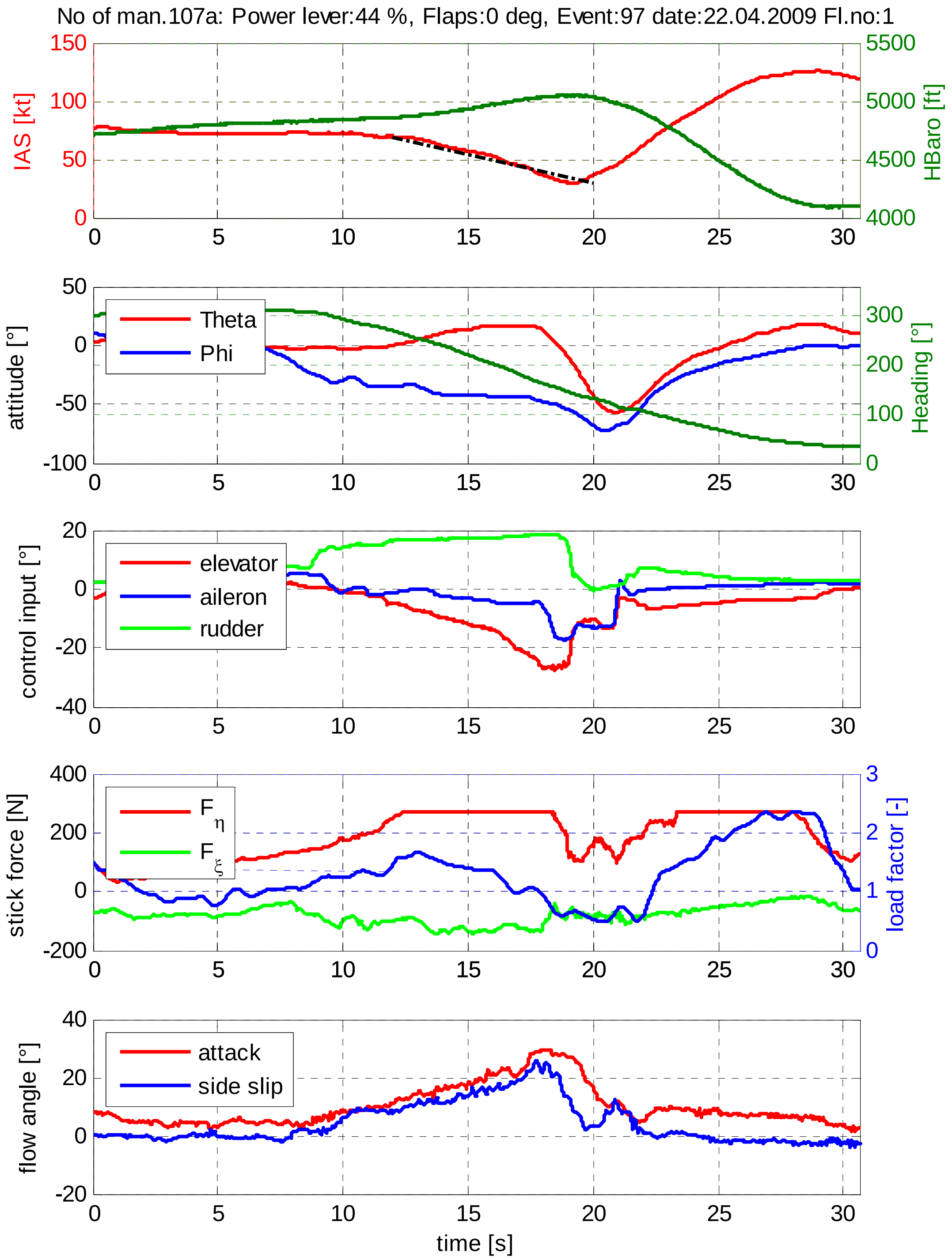
Manoeuvre type F:



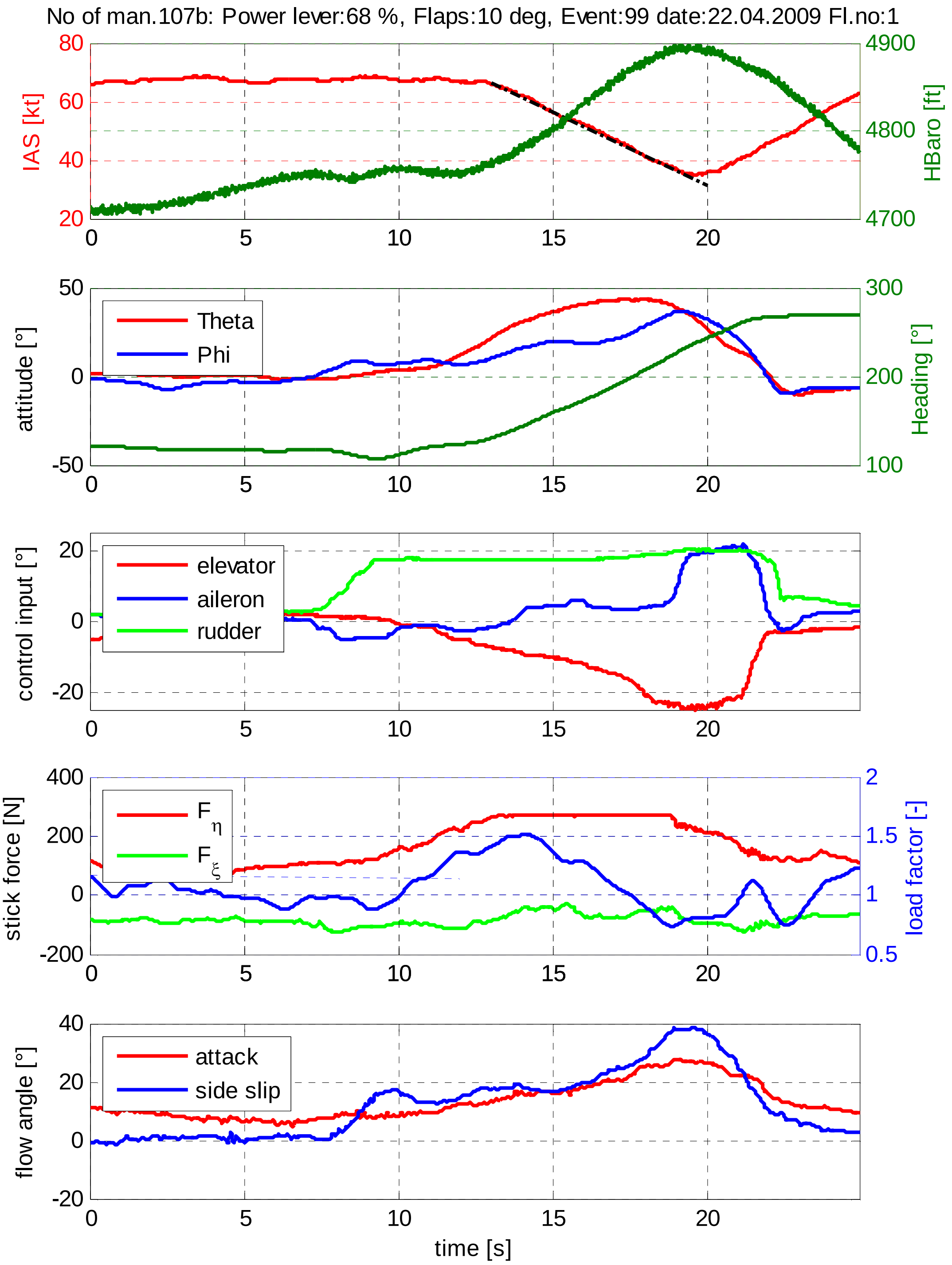
Manoeuvre type G:



Manoeuvre type H: Example 1



Manoeuvre type H: Example 2



13.9 Overview of results for each manoeuvre type

<u>Colour legend:</u>

The background colour of the manoeuvre number indicates whether the manoeuvre can be used to demonstrate compliance with EASA-V5 and FAR23.221(a)(2) or not. In the second group of columns the background colour is green in case of compliance with the interim requirement and red in case of non-compliance. In case of an undetermined result an orange colour and the letter b for *borderline* is used.

Manoeuvre type A

Manoeuvre type A				Primary manoeuvre related results						Secondary results		
EASA-V5-conform / EASA-V5- and FAR23-conform					If NO:	If YES:						
No.	Speed Rate	PWR	Flaps	uncontrollable nose pitch down? (Y/B/N)	roll+/-30° abnormal charact.? (Y/B/N)	|bank| > 15°? (Y/B/N)	[sign deg]	Return to unstalled immediate? (Y/B/N)	Any tendency to spin? (Y/B/N)	Altitude loss? [ft]	realised speed rates? [kn/s]	V_{S1} [kn]
1	1kn/s	Idle	0°	n	n			y	n	300	1	50
2	1kn/s	Idle	10°	n	n			y	n	270	1	45
3	1kn/s	Idle	20°	n	n			y	n	250	1	44
4	1kn/s	Idle	40°	n	n			y	n	300	1	43
5	1kn/s	75%	0°	n	n			y	n	200	1	42
6	1kn/s	75%	10°	n	n			y	n	150	1	40
7	1kn/s	75%	20°	n	n			y	n	150	1	38
8	1kn/s	75%	40°	n	n			y	n	200	1	35

Manoeuvre type B, part 1/3

Manoeuvre type B						Primary manoeuvre related results					bank					Secondary results		
EASA-V5-conform / EASA-V5- and FAR23-conform / a - bank left / b - bank right	Speed rate	PWR	Flaps	Bank	Action	Altitude loss > 300ft? (Y/B/N)	Altitude loss? [ft]	Undue pitchup? (Y/B/N)	Any tendency to spin? (Y/B/N)	bank > 60°/15°? (Y/B/N)	turn dir? [le/ri]	max |bank| with [deg]	max |bank| against [deg]	Exceeding max speed? (Y/B/N)	Exceeding max load? (Y/B/N)	realised speed rates? [kn/s]	V_{S1} [kn]	remarks
9 a	1kn/s	Idle	0°	45°	immediate recover	n	150	n	n	n	le	45		n	n	1	56	
9 b	1kn/s	Idle	0°	45°	immediate recover	n	150	n	n	n	ri	45		n	n	1	55	
10 a	1kn/s	Idle	10°	45°	immediate recover	n	200	n	n	n	le	50		n	n	1	58	
10 b	1kn/s	Idle	10°	45°	immediate recover	n	150	n	n	n	ri	45		n	n	1	53	
11 a	1kn/s	Idle	20°	45°	immediate recover	n	200	n	n	n	le	40		n	n	1	52	
11 b	1kn/s	Idle	20°	45°	immediate recover	n	150	n	n	n	ri	45		n	n	1	50	
12 a	1kn/s	Idle	40°	45°	immediate recover	n	100	n	n	n	le	40		n	n	1	50	
12 b	1kn/s	Idle	40°	45°	immediate recover	n	150	n	n	n	ri	40		n	n	1	45	
13 a	1kn/s	75%	0°	45°	immediate recover	n	0	n	n	n	le	50	0	n	n	1	52	
13 b	1kn/s	75%	0°	45°	immediate recover	n	50	n	n	n	ri	50	0	n	n	1	50	
14 a	1kn/s	75%	10°	45°	immediate recover	n	100	n	n	n	le	50	0	n	n	1	52	
14 b	1kn/s	75%	10°	45°	immediate recover	n	50	n	n	n	ri	50		n	n	1	55	
15 a	1kn/s	75%	20°	45°	immediate recover	n	50	n	n	n	le	60		n	n	1	50	
15 b	1kn/s	75%	20°	45°	immediate recover	n	0	n	n	n	ri	55		n	n	1	52	
16 a	1kn/s	75%	40°	45°	immediate recover	n	100	n	n	n	le	55	30	n	n	1	45	
16 b	1kn/s	75%	40°	45°	immediate recover	n	100	n	n	y	ri	50	-20	n	n	1	45	
17 a	3-5kn/s	Idle	0°	45°	immediate recover	n	200	n	n	n	le	55		n	n	5	60	
17 b	3-5kn/s	Idle	0°	45°	immediate recover	n	200	n	n	n	ri	55		n	n	5	53	
18 a	3-5kn/s	Idle	10°	45°	immediate recover	n	100	n	n	n	le	50		n	n	3	58	
18 b	3-5kn/s	Idle	10°	45°	immediate recover	n	100	n	n	n	ri	50		n	n	4	45	
19 a	3-5kn/s	Idle	20°	45°	immediate recover	n	100	n	n	n	le	45		n	n	4	55	
19 b	3-5kn/s	Idle	20°	45°	immediate recover	n	150	n	n	n	ri	50		n	n	5	47	

Manoeuvre type B, part 2/3

Manoeuvre type B EASA-V5-conform EASA-V5- and FAR23-conform a - bank left b - bank right	Speed rate	PWR	Flaps	Bank	Action	Primary manoeuvre related results: Altitude loss > 300ft? (Y/B/N)	Altitude loss? [ft]	Undue pitchup? (Y/B/N)	Any tendency to spin? (Y/B/N)	bank > 60°/15°? (Y/B/N)	bank: turn dir? [le/ri]	bank: max |bank| with [deg]	bank: max |bank| against [deg]	Exceeding max speed? (Y/B/N)	Exceeding max load? (Y/B/N)	Secondary results: realised speed rates? [kn/s]	V_{S1} [kn]	remarks
20 a	3-5kn/s	Idle	40°	45°	immediate recover	n	100	n	n	n	le	50	40	n	n	5	55	
20 b	3-5kn/s	Idle	40°	45°	immediate recover	n	100	n	n	n	ri	40		n	n	5	38	
21 a	3-5kn/s	75%	0°	45°	immediate recover	n	50	n	n	n	le	50	0	n	n	5	50	
21 b	3-5kn/s	75%	0°	45°	immediate recover	n	100	n	n	n	ri	60	40	n	n	5	42	
22 a	3-5kn/s	75%	10°	45°	immediate recover	n	100	n	n	n	le	60	0	n	n	5	50	
22 b	3-5kn/s	75%	10°	45°	immediate recover	n	200	n	n	y	ri	50	-70	n	n	5	35	
23 a	3-5kn/s	75%	20°	45°	immediate recover	n	100	n	n	n	le	50	0	n	n	5	45	
23 b	3-5kn/s	75%	20°	45°	immediate recover	n	200	n	n	y	ri	50	-60	n	n	5	32	
24 a	3-5kn/s	75%	40°	45°	immediate recover	n	150	n	n	n	le	50	0	n	n	5	43	
24 b	3-5kn/s	75%	40°	45°	immediate recover	n	150	n	n	y	ri	50	-50	n	n	5	32	
25 a	1kn/s	75%	0°	45°	stick aft 7s	n	0	n	n	n	le	50	0	n	n	4	55	
25 b	1kn/s	75%	0°	45°	stick aft 7s	n	0	n	n	y	ri	40	-60	n	n	4	46	
26 a	3-5kn/s	75%	0°	45°	stick aft 7s	n	0	n	n	n	le	50	0	n	n	5	53	
26 b	3-5kn/s	75%	0°	45°	stick aft 7s	n	0	n	n	y	ri	50	-70	n	n	5	40	
27 a	1kn/s	50%	0°	45°	stick aft 7s	n	0	n	n	n	le	50	0	n	n	1	54	
27 b	1kn/s	50%	0°	45°	stick aft 7s	n	0	n	n	y	ri	40	-40	n	n	1	48	
28 a	3-5kn/s	50%	0°	45°	stick aft 7s	n	0	n	n	n	le	50	0	n	n	5	55	
28 b	3-5kn/s	50%	0°	45°	stick aft 7s	n	0	n	n	y	ri	50	-60	n	n	5	40	
29 a	1kn/s	100%	0°	45°	stick aft 7s	n	0	n	n	n	le	50	10	n	n	1	53	
29 b	1kn/s	100%	0°	45°	stick aft 7s	n	0	n	n	y	ri	45	40	n	n	1	53	
30 a	3-5kn/s	100%	0°	45°	stick aft 7s	n	0	n	n	n	le	50	0	n	n	4	58	
30 b	3-5kn/s	100%	0°	45°	stick aft 7s	n	100	n	n	y	ri	45	-60	n	n	5	45	

Manoeuvre type B, part 3/3

Manoeuvre type B EASA-V5-conform EASA-V5- and FAR23-conform a - bank left b - bank right	Speed rate	PWR	Flaps	Bank	Action	Primary manoeuvre related results: Altitude loss > 300ft? (Y/B/N)	Altitude loss? [ft]	Undue pitchup? (Y/B/N)	Any tendency to spin? (Y/B/N)	bank > 60°/15°? (Y/B/N)	bank: turn dir? [le/ri]	bank: max |bank| with [deg]	bank: max |bank| against [deg]	Exceeding max speed? (Y/B/N)	Exceeding max load? (Y/B/N)	Secondary results: realised speed rates? [kn/s]	V_{S1} [kn]	remarks
31 a	1kn/s	100%	10°→0°	45°	stick aft 7s	n	0	n	n	n	le	45		n	n	1	60	
31 b	1kn/s	100%	10°→0°	45°	stick aft 7s	n	200	n	n	y	ri	45	-50	n	n	1	44	
32 a	1kn/s	0→100	0°	45°	stick aft 7s	n	100	n	n	n	le	45		n	n	1	55-60	
32 b	1kn/s	0→100	0°	45°	stick aft 7s	n	0	n	n	n	ri	45	20	n	n	1	50	
33 a	1kn/s	100%	0°	45°	dynamic rudder against turn, stick aft 7s	n	0	n	n	y	le	50	-70	n	n	1	52	
33 b	1kn/s	100%	0°	45°	dynamic rudder against turn, stick aft 7s	n	50	n	n	y	ri	60	-70	n	n	1	60	
34 a	1kn/s	100%	0°	45°	dyn rudder with, stick aft 7s	n	0	n	n	n	le	45	60	n	n	1	60	
34 b	1kn/s	100%	0°	45°	dyn rudder with, stick aft 7s	n	0	n	n	y	ri	70	20	n	n	1	55	
35 a	1kn/s	100%	0°	45°	dyn rudder with, aileron against, stick aft 7s	n	0	n	n	n	le	45	0	n	n	1	55	
35 b	1kn/s	100%	0°	45°	dyn rudder with, aileron against, stick aft 7s	n	50	n	n	n	ri	55	0	n	n	1	55	
36 a	1kn/s	100%	0°	45°	dyn rudder with, aileron with, stick aft 7s	n	200	n	n	y	le	70	20	n	n	1	55	not reasonable
36 b	1kn/s	100%	0°	45°	dyn rudder with, aileron with, stick aft 7s	n	200	n	n	y	ri	70	20	n	n	1	55	not reasonable
37 a	3-5kn/s	100%	0°	45°	dyn rudder with, stick aft 7s	n	0	n	n	n	le	60	70	n	n	3	60	
37 b	3-5kn/s	100%	0°	45°	dyn rudder with, stick aft 7s	n	100	n	n	n	ri	50	60	n	n	4	50	
38 a	3-5kn/s	100%	0°	45°	dyn rudder with, aileron against, stick aft 7s	n	0	n	n	n	le	50	0	n	n	3	70	
38 b	3-5kn/s	100%	0°	45°	dyn rudder with, aileron against, stick aft 7s	n	100	n	n	n	ri	60	0	n	n	3	50	
39 a	3-5kn/s	100%	0°	45°	dyn rudder with, aileron with, stick aft 7s	n	200	n	n	y	le	80	60	n	n	3	55	not reasonable
39 b	3-5kn/s	100%	0°	45°	dyn rudder with, aileron with, stick aft 7s	n	200	n	n	n	ri	60	25	n	n	3	50	not reasonable

Manoeuvre type C, part 1/2

Manoeuvre type C EASA-V5-conform EASA-V5- and FAR23-conform a - rudder left b - rudder right	Speed rate	PWR	Flaps	Action	Primary manoeuvre related results Immediate respond to flight controls? (Y/B/N)	Reversal of controll effect? (Y/B/N)	Temporary control forces above limit? (Y/B/N)	State of flight achieved before recovery?	Critical? (Y/B/N)	Any tendency to spin? (Y/B/N)	Secondary results Altitude loss? [ft]	realised speed rates? [kn/s]	V_{S1} [kn]	Aileron deflection? Direction (le/ri)	Aileron deflection? [deg]	remarks
40 a	1kn/s	Idle	0°	ailerons opposite "attempting to maintain heading"	y	n	n	normal	n	n	200	1	45	both	5	
40 b	1kn/s	Idle	0°	ailerons opposite "attempting to maintain heading"	y	n	n	normal	n	n	250	1	45	le	5	
41 a	1kn/s	Idle	10°	ailerons opposite "attempting to maintain heading"	y	n	n	normal	n	n	200	1	45	ri	0-10	
41 b	1kn/s	Idle	10°	ailerons opposite "attempting to maintain heading"	y	n	n	normal	n	n	250	1	43	le	5	
42 a	1kn/s	Idle	20°	ailerons opposite "attempting to maintain heading"	y	n	n	normal	n	n	200	1	43	both	5	
42 b	1kn/s	Idle	20°	ailerons opposite "attempting to maintain heading"	y	n	n	normal	n	n	250	1	42	le	4	
43 a	1kn/s	Idle	40°	ailerons opposite "attempting to maintain heading"	y	n	n	normal	n	n	200	1	41	both	5	
43 b	1kn/s	Idle	40°	ailerons opposite "attempting to maintain heading"	y	n	n	normal	n	n	150	1	42	le	3	
44 a	1kn/s	75%	0°	ailerons opposite "attempting to maintain heading"	y	n	n	spin entry	y	y	650	1	38	ri	10	stop after 6 s
44 b	1kn/s	75%	0°	ailerons opposite "attempting to maintain heading"	y	n	n	spin entry	y	y	700	1	40	le	20	stop after 2 s
45 a	1kn/s	75%	10°	ailerons opposite "attempting to maintain heading"	y	n	n	spin entry	y	y	700	1	35	re	10	stop after 1 s
45 b	1kn/s	75%	10°	ailerons opposite "attempting to maintain heading"	y	n	n	spiral dive	b	n	300	1	38	le	10	stop after 3 s
46 a	1kn/s	75%	20°	ailerons opposite "attempting to maintain heading"	y	n	n	spin entry	y	y	500	1	35	ri	10	stop after 3 s
46 b	1kn/s	75%	20°	ailerons opposite "attempting to maintain heading"	y	n	n	spiral dive	b	n	250	1	37	le	10	stop after 2 s
47 a	1kn/s	75%	40°	ailerons opposite "attempting to maintain heading"	y	n	n	spiral dive	b	n	250	1	32	ri	10	stop after 2 s
47 b	1kn/s	75%	40°	ailerons opposite "attempting to maintain heading"	y	n	n	spin entry	y	y	700	1	35	le	5	stop after 1 s
48 a	1kn/s	100%	0°	ailerons opposite "attempting to maintain heading"	y	n	n	spin entry	y	y	600	1	40	ri	5	stop after 2 s
48 b	1kn/s	100%	0°	ailerons opposite "attempting to maintain heading"	y	n	n	spin entry	y	y	500	1	38	le	10	stop after 2 s
49 a	1kn/s	100%	0°	ailerons neutral	y	n	n	spin entry	y	y	700	1	38			stop after 1 s
49 b	1kn/s	100%	0°	ailerons neutral	y	n	n	spin entry	y	y	500	1	36			stop after 2 s

Manoeuvre type C, part 2/2

Manoeuvre type C (EASA-V5-conform; EASA-V5- and FAR23-conform) a - rudder left, b - rudder right	Speed rate	PWR	Flaps	Action	Primary manoeuvre related results: Immediate respond to flight controls? (Y/B/N)	Reversal of controll effect? (Y/B/N)	Temporary control forces above limit? (Y/B/N)	State of flight achieved before recovery?	Critical? (Y/B/N)	Any tendency to spin? (Y/B/N)	Secondary results: Altitude loss? [ft]	realised speed rates? [kn/s]	V_{S1} [kn]	Aileron deflection? Direction (le/ri)	Aileron deflection? [deg]	remarks
50 a	1kn/s	100%	0°	ailerons full opposite	y	n	n	spin entry	y	y	900	1	35			stop after 2 s
50 b	1kn/s	100%	0°	ailerons full opposite	y	n	n	spin entry	y	y	600	1	37			stop after 2 s
51 a	1kn/s	100%	0°	ailerons full with	y	n	n	spin entry	y	y	700	1	37			stop after 1 s
51 b	1kn/s	100%	0°	ailerons full with	y	n	n	spin entry	y	y	600	1	37			stop after 2 s
52 a	1kn/s	100%	10°→0°	ailerons neutral	y	n	n	spin entry	y	y	700	1	37			stop after 2 s
52 b	1kn/s	100%	10°→0°	ailerons neutral	y	n	n	spin entry	y	y	600	1	34			stop after 3 s
53 a	1kn/s	0→100	0°	ailerons neutral	y	n	n	spin entry	y	y	700	1	45			stop after 3 s
53 b	1kn/s	0→100	0°	ailerons neutral	y	n	n	spin entry	y	y	600	1	46			stop after 5 s
54 a	3-5kn/s	75%	0°	ailerons opposite "attempting to maintain heading"	y	n	n	spin entry	y	y	500	7	30	ri	15	stop after 3 s
54 b	3-5kn/s	75%	0°	ailerons opposite "attempting to maintain heading"	y	n	n	spin entry	y	y	600	7	27	le	20	stop after 3 s
55 a	3-5kn/s	100%	0°	ailerons opposite "attempting to maintain heading"	y	n	n	spin entry	y	y	900	5	30	ri	18	stop after 2 s
55 b	3-5kn/s	100%	0°	ailerons opposite "attempting to maintain heading"	y	n	n	spin entry	y	y	600	6	28	le	20	stop after 2 s
56 a	3-5kn/s	100%	0°	ailerons neutral				*not flown*								
56 b	3-5kn/s	100%	0°	ailerons neutral				*not flown*								
57 a	3-5kn/s	100%	0°	ailerons full opposite				*not flown*								
57 b	3-5kn/s	100%	0°	ailerons full opposite				*not flown*								
58 a	3-5kn/s	100%	0°	ailerons full with	y	n	n	spin entry	y	y	600	4	35			stop after 1 s
58 b	3-5kn/s	100%	0°	ailerons full with				*not flown*								
59 a	7-10kn/s	100%	0°	ailerons opposite "attempting to maintain heading"				*not flown*								
59 b	7-10kn/s	100%	0°	ailerons opposite "attempting to maintain heading"				*not flown*								

Manoeuvre type D

Manoeuvre type D EASA-V5-conform EASA-V5- and FAR23-conform a - rudder left b - rudder right	PWR	Flaps	Action	Primary manoeuvre related results: Controllable by conventional use? (Y/B/N)	Any tendency to spin? (Y/B/N)	Secondary results: Altitude loss? [ft]	Speed at rudder deflection [kn]	Deflection of Rudder? Direction (le/ri)	[deg]	time to max deflection [sec]
60 a	Idle	0°	rudder applied in less than 2s	y	n	200	50	le	18	0,3
60 b	Idle	0°	rudder applied in less than 2s	y	n	100	50	ri	15	0,2
61 a	Idle	10°	rudder applied in less than 2s	y	n	100	49	le	18	0,3
61 b	Idle	10°	rudder applied in less than 2s	y	n	100	50	ri	15	0,3
62 a	Idle	20°	rudder applied in less than 2s	y	n	150	49	le	18	0,3
62 b	Idle	20°	rudder applied in less than 2s	y	n	50	48	ri	15	0,3
63 a	Idle	40°	rudder applied in less than 2s	y	n	100	45	le	18	0,6
63 b	Idle	40°	rudder applied in less than 2s	y	n	100	47	ri	15	0,3
64 a	75%	0°	rudder applied in less than 2s	y	n	50	53	le	15	0,5
64 b	75%	0°	rudder applied in less than 2s	y	n	10	50	ri	8	0,5
65 a	75%	10°	rudder applied in less than 2s	y	n	0	47	le	15	0,7
65 b	75%	10°	rudder applied in less than 2s	y	n	0	48	ri	12	0,8
66 a	75%	20°	rudder applied in less than 2s	y	n	0	41	le	18	1,5
66 b	75%	20°	rudder applied in less than 2s	y	n	0	46	ri	15	1,5
67 a	75%	40°	rudder applied in less than 2s	y	n	0	43	le	18	0,8
67 b	75%	40°	rudder applied in less than 2s	y	n	0	41	ri	15	0,8
68 a	75%	0°	rudder applied as sudden as possible	y	n	0	50	le	18	0,15
68 b	75%	0°	rudder applied as sudden as possible	y	n	0	48	ri	15	0,15

Manoeuvre type E

Manoeuvre type E EASA-V5-conform EASA-V5- and FAR23-conform a - aileron left b - aileron right	PWR	Flaps	Action	Primary manoeuvre related results: controllable by conventional use? (Y/B/N)	Primary manoeuvre related results: Any tendency to spin? (Y/B/N)	Secondary results: Altitude loss? [ft]	Secondary results: Speed at ail. deflection [kn]	Deflection of aileron?: Direction (le/ri)	Deflection of aileron?: [deg]	Deflection of aileron?: time to max deflection [sec]
69 a	Idle	0°	aileron applied in less than 2s	y	n	100	51	le	15	0,3
69 b	Idle	0°	aileron applied in less than 2s	y	n	50	52	ri	10	0,3
70 a	Idle	10°	aileron applied in less than 2s	y	n	100	47	le	15	0,4
70 b	Idle	10°	aileron applied in less than 2s	y	n	0	50	ri	10	0,6
71 a	Idle	20°	aileron applied in less than 2s	y	n	0	46	le	12	0,5
71 b	Idle	20°	aileron applied in less than 2s	y	n	50	46	ri	8	0,5
72 a	Idle	40°	aileron applied in less than 2s	y	n	50	46	le	13	0,5
72 b	Idle	40°	aileron applied in less than 2s	y	n	0	47	ri	10	0,3
73 a	75%	0°	aileron applied in less than 2s	y	n	0	48	le	12	0,4
73 b	75%	0°	aileron applied in less than 2s	y	n	0	50	ri	12	0,5
74 a	75%	10°	aileron applied in less than 2s	y	n	0	47	le	12	0,5
74 b	75%	10°	aileron applied in less than 2s	y	n	0	44	ri	9	0,4
75 a	75%	20°	aileron applied in less than 2s	y	n	0	44	le	15	0,5
75 b	75%	20°	aileron applied in less than 2s	y	n	0	44	ri	12	0,5
76 a	75%	40°	aileron applied in less than 2s	y	n	0	44	le	15	0,7
76 b	75%	40°	aileron applied in less than 2s	y	n	0	44	ri	11	0,5
77 a	75%	0°	aileron applied as sudden as possible	y	n	0	46	le	21	0,2
77 b	75%	0°	aileron applied as sudden as possible	y	n	0	48	ri	17	0,2

Manoeuvre type F

Manoeuvre type F			Primary manoeuvre related results					Secondary results	
EASA-V5-conform; EASA-V5- and FAR23-conform									
No.	PWR	Flaps	roll possible? (Y/B/N)	roll control reversal? (Y/B/N)	yaw possible? (Y/B/N)	yaw control reversal? (Y/B/N)	Any tendency to spin? (Y/B/N)	Altitude loss? [ft]	Airspeed? [kn]
78	Idle	0°	y	n	y	n	n	0	55
79	Idle	10°	y	n	y	n	n	0	50
80	Idle	20°	y	n	y	n	n	0	48
81	Idle	40°	y	n	y	n	n	0	45
82	75%	0°	y	n	y	n	n	0	50
83	75%	10°	y	n	y	n	n	0	42
84	75%	20°	y	n	y	n	n	0	42
85	75%	40°	y	n	y	n	n	0	38

Manoeuvre type G

Manoeuvre type G				Primary manoeuvre related results					Secondary results				
EASA-V5-conform / EASA-V5- and FAR23-conform													
No.	Speed Rate	PWR	Flaps	max |roll| > 15°? (Y/B/N)	max bank [sign deg]	max |yaw| > 15°? (Y/B/N)	max yaw [deg]	Any tendency to spin? (Y/B/N)	Altitude loss? [ft]	realised speed rates? [kn/s]	V_{S1} [kn]	time stick@aft [sec]	
86	1kn/s	Idle	0°	n	-5	n	5	n	200	1	52	3	
87	1kn/s	Idle	10°	n	-10	n	12	n	150	1	49	4	
88	1kn/s	Idle	20°	n	-8	n	11	n	200	1	48	5	
89	1kn/s	Idle	40°	n	-6	n	10	n	150	1	45	3,5	
90	1kn/s	75%	0°	n	-12	n	12	n	0	1	44	2,5	
91	1kn/s	75%	10°	n	-12	n	12	n	0	1	40	2	
92	1kn/s	75%	20°	n	12	y	40	n	150	1	40	5	
93	1kn/s	75%	40°	y	-20	n	8	n	150	1	37	0	pitch down

Manoeuvre type H, part 1/2

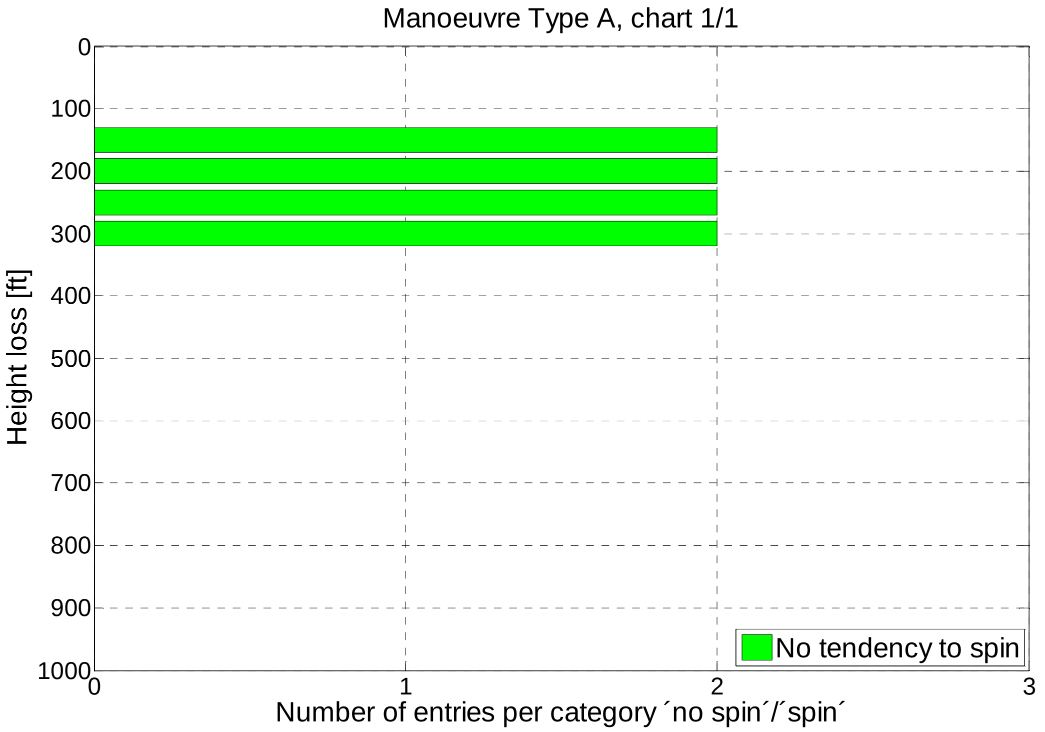
Manoeuvre type H EASA-V5-conform EASA-V5- and FAR23-conform a - bank left b - bank right	Speed rate	PWR	Flaps	Bank	Action	Primary manoeuvre related results: Pitch down or stick aft? (P / S)	Immediate recovery to wings level possible? (Y/B/N)	Altitude loss > 300ft? (Y/B/N)	Alitude loss? [ft]	Undue pitchup? (Y/B/N)	Uncontrollable tendency to spin? (Y/B/N)	bank > 60°/30° resp. 90°/60° (Y/B/N)	turn dir? [le/ri]	max |bank| with [deg]	max |bank| against [deg]	Exceeding max speed? (Y/B/N)	Exceeding max load? (Y/B/N)	Secondary results: realised speed rates? [kn/s]	V_{S1} [kn]
94 a	1kn/s	Idle	0°	30°	immediate recover	s	y	n	200	n	n	n	le	40	10	n	n	1	53
94 b	1kn/s	Idle	0°	30°	immediate recover	s	y	n	250	n	n	n	ri	20	-10	n	n	1	53
95 a	1kn/s	Idle	10°	30°	immediate recover	s	y	n	200	n	n	n	le	30	0	n	n	1	50
95 b	1kn/s	Idle	10°	30°	immediate recover	s	y	n	200	n	n	n	ri	25	0	n	n	1	51
96 a	1kn/s	Idle	20°	30°	immediate recover	s	y	n	250	n	n	n	le	35	0	n	n	1	48
96 b	1kn/s	Idle	20°	30°	immediate recover	s	y	n	200	n	n	n	ri	30	0	n	n	1	48
97 a	1kn/s	Idle	40°	30°	immediate recover	s	y	n	200	n	n	n	le	30	0	n	n	1	47
97 b	1kn/s	Idle	40°	30°	immediate recover	s	y	n	200	n	n	n	ri	30	0	n	n	1	47
98 a	1kn/s	75%	0°	30°	immediate recover	both	n	y	700	n	y	y	le	110	0	n	n	1	46
98 b	1kn/s	75%	0°	30°	immediate recover	s	y	n	200	n	n	y	ri	20	-45	n	n	1	43
99 a	1kn/s	75%	10°	30°	immediate recover	s	y	n	200	n	n	n	le	40	0	n	n	1	43
99 b	1kn/s	75%	10°	30°	immediate recover	s	y	n	50	n	n	n	ri	25	-15	n	n	1	44
100 a	1kn/s	75%	20°	30°	immediate recover	both	n	y	650	y	n	y	le	95	0	n	n	1	38
100 b	1kn/s	75%	20°	30°	immediate recover	s	y	n	100	n	n	n	ri	30	0	n	n	1	44
101 a	1kn/s	75%	40°	30°	immediate recover	p	n	y	700	y	n	y	le	70	0	n	n	1	36
101 b	1kn/s	75%	40°	30°	immediate recover	p	y	n	100	n	n	n	ri	30	0	n	n	1	41
102 a	3-5kn/s	Idle	0°	30°	immediate recover	s	y	n	100	n	n	n	le	15	-5	n	n	3	45
102 b	3-5kn/s	Idle	0°	30°	immediate recover	s	y	n	100	n	n	n	ri	15	0	n	n	5	50
103 a	3-5kn/s	Idle	10°	30°	immediate recover	s	y	n	100	n	n	n	le	30	0	n	n	3	48
103 b	3-5kn/s	Idle	10°	30°	immediate recover	s	y	n	100	n	n	n	ri	35	0	n	n	3	49
104 a	3-5kn/s	Idle	20°	30°	immediate recover	s	y	n	150	n	n	n	le	40	0	n	n	5	43
104 b	3-5kn/s	Idle	20°	30°	immediate recover	s	y	n	100	n	n	n	ri	30	0	n	n	5	45

Manoeuvre type H, part 2/2

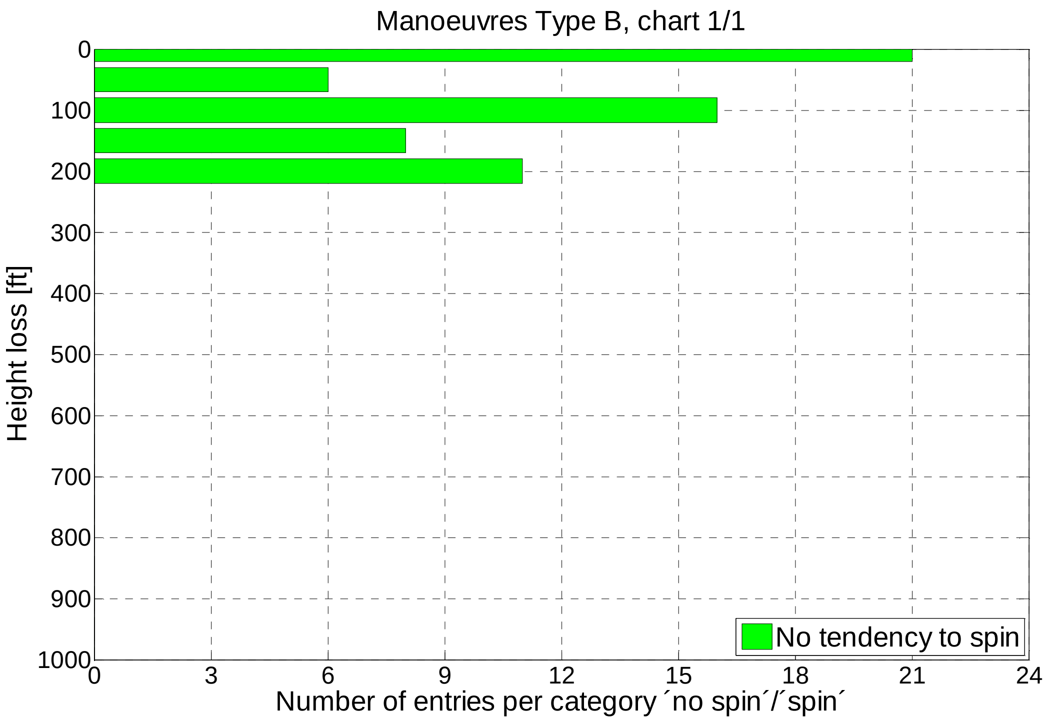
Manoeuvre type H (EASA-V5-conform; EASA-V5- and FAR23-conform) a - bank left, b - bank right	Speed rate	PWR	Flaps	Bank	Action	Primary manoeuvre related results: Pitch down or stick aft? (P / S)	Immediate recovery to wings level possible? (Y/B/N)	Altitude loss > 300ft? (Y/B/N)	Alitude loss? [ft]	Undue pitchup? (Y/B/N)	Uncontrollable tendency to spin? (Y/B/N)	bank > 60°/30° resp. 90°/60° (Y/B/N)	turn dir? [le/ri]	max |bank| with [deg]	max |bank| against [deg]	Exceeding max speed? (Y/B/N)	Exceeding max load? (Y/B/N)	Secondary results: realised speed rates? [kn/s]	V_{S1} [kn]
105 a	3-5kn/s	Idle	40°	30°	immediate recover	s	y	n	150	n	n	n	le	35	0	n	n	5	43
105 b	3-5kn/s	Idle	40°	30°	immediate recover	s	y	n	150	n	n	n	ri	35	0	n	n	4	44
106 a	3-5kn/s	75%	0°	30°	immediate recover	s	y	n	200	n	n	n	le	35	0	n	n	5	40
106 b	3-5kn/s	75%	0°	30°	immediate recover	s	y	n	300	n	n	y	ri	25	-60	n	n	5	39
107 a	3-5kn/s	75%	10°	30°	immediate recover	s	n	y	900	y	y	y	le	75	0	n	n	5	30
107 b	3-5kn/s	75%	10°	30°	immediate recover	s	y	n	150	n	n	n	ri	40	-10	n	n	5	35
108 a	3-5kn/s	75%	20°	30°	immediate recover	s	y	n	250	n	n	y	le	80	0	n	n	5	40
108 b	3-5kn/s	75%	20°	30°	immediate recover	s	y	n	150	n	n	n	ri	30	-10	n	n	5	35
109 a	3-5kn/s	75%	40°	30°	immediate recover	s	y	n	200	n	n	y	le	65	0	n	n	5	37
109 b	3-5kn/s	75%	40°	30°	immediate recover	s	y	y	600	n	y	y	ri	30	-80	n	n	5	30
110 a	3-5kn/s	75%	0°	30°	stick aft 7s	s	y	y	900	n	y	y	le	140	0	n	n	5	44
110 b	3-5kn/s	75%	0°	30°	stick aft 7s	s	y	n	250	n	n	n	ri	40	-10	n	n	5	45
111 a	1kn/s	75%	0°	45°	stick aft 7s	s	y	n	250	n	n	n	le	50	0	n	n	1	54
111 b	1kn/s	75%	0°	45°	stick aft 7s	s	y	n	250	n	n	n	ri	35	0	n	n	1	53
112 a	1kn/s	0→100	0°	45°	stick aft 7s	s	y	y	500	n	n	spiral dive	le	55	0	n	n	3	59
112 b	1kn/s	0→100	0°	45°	stick aft 7s	s	y	n	200	n	n	n	ri	40	0	n	n	3	47
113 a	3-5kn/s	75%	0°	45°	stick aft 7s	s	y	n	250	n	n	n	le	50	0	n	n	5	51
113 b	3-5kn/s	75%	0°	45°	stick aft 7s	s	y	n	250	n	n	n	ri	35	0	n	n	5	47
114 a	3-5kn/s	50%	0°	45°	stick aft 7s	s	y	y	500	n	n	y	le	65	0	n	n	4	51
114 b	3-5kn/s	50%	0°	45°	stick aft 7s	s	y	n	250	n	n	n	ri	40	0	n	n	5	45
115 a	3-5kn/s	100%	0°	45°	stick aft 7s	s	y	y	550	n	n	y	le	85	0	n	n	5	51
115 b	3-5kn/s	100%	0°	45°	stick aft 7s	s	y	n	150	n	n	n	ri	40	0	n	n	5	47

13.10 Bar charts of height loss for each manoeuvre type

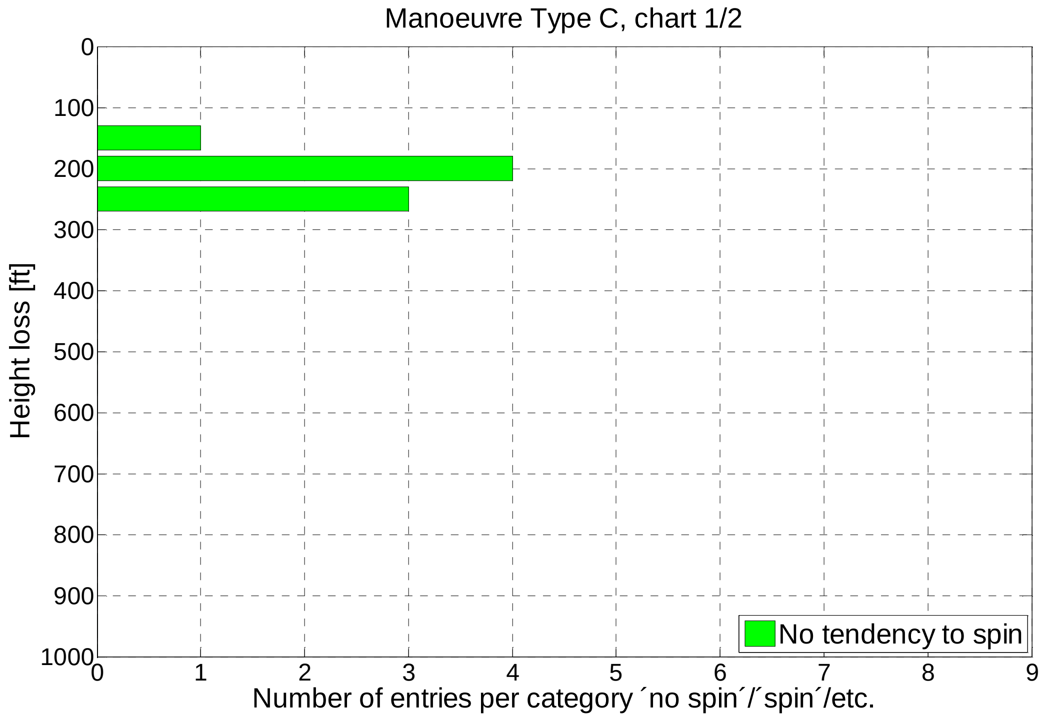
Manoeuvre type A

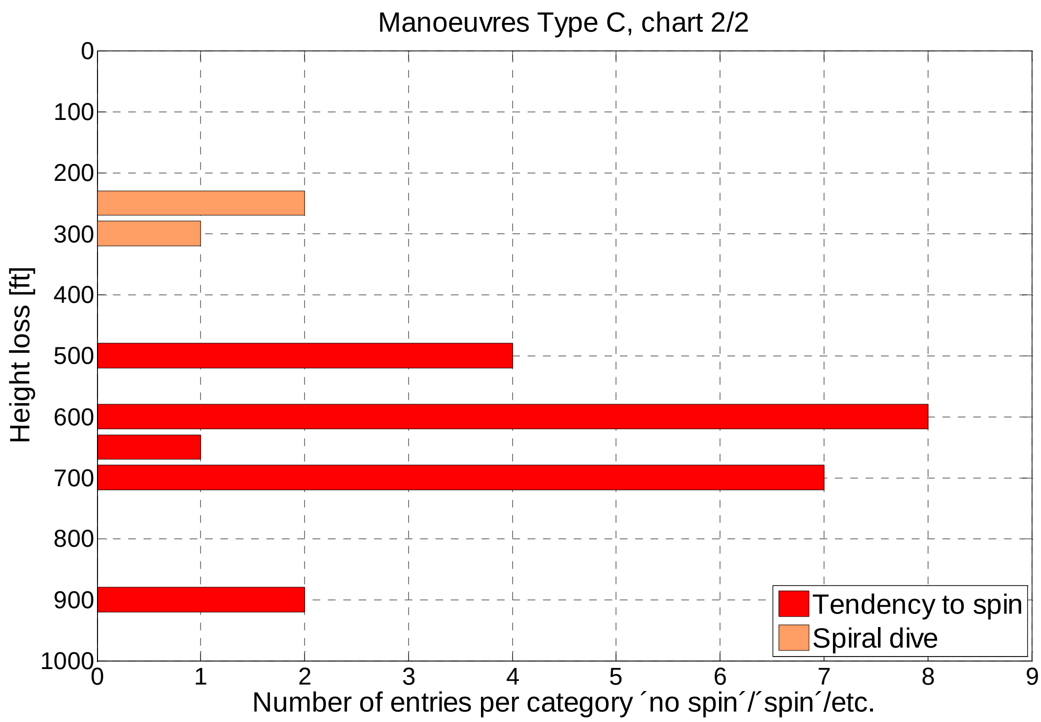


Manoeuvre type B

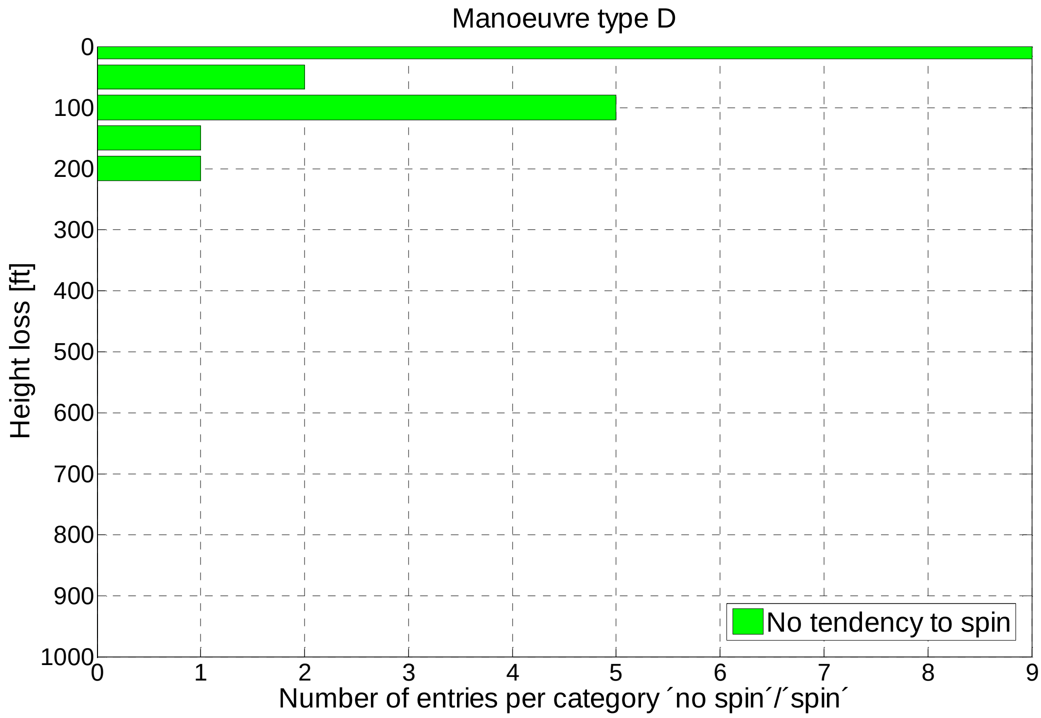


Manoeuvre type C (2 charts)

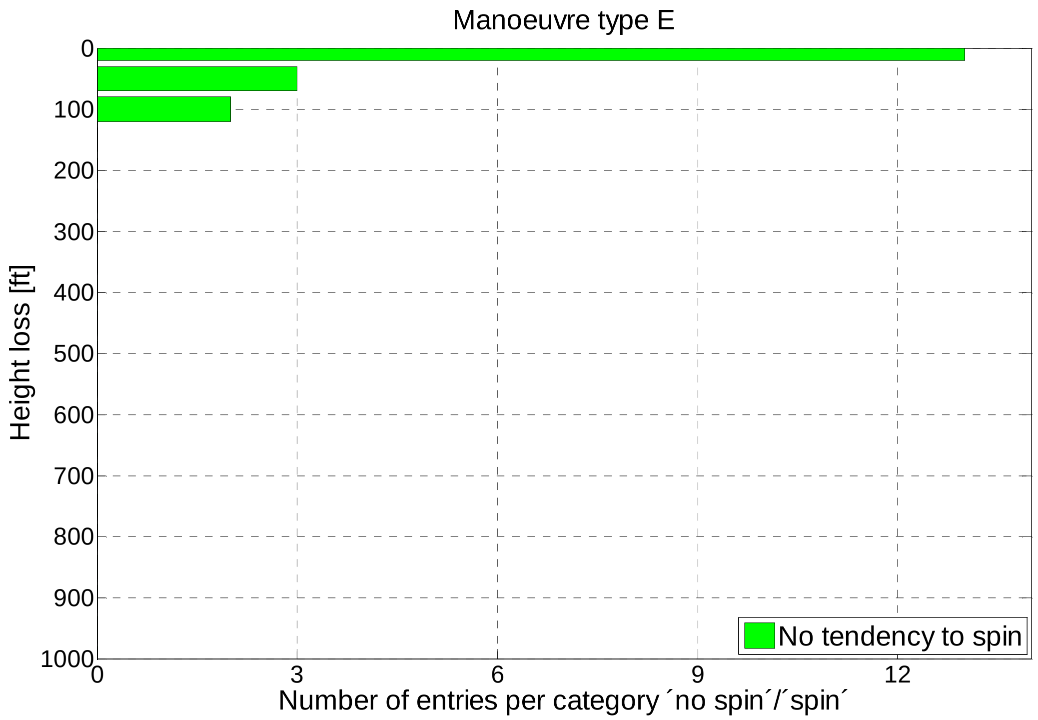




Manoeuvre type D



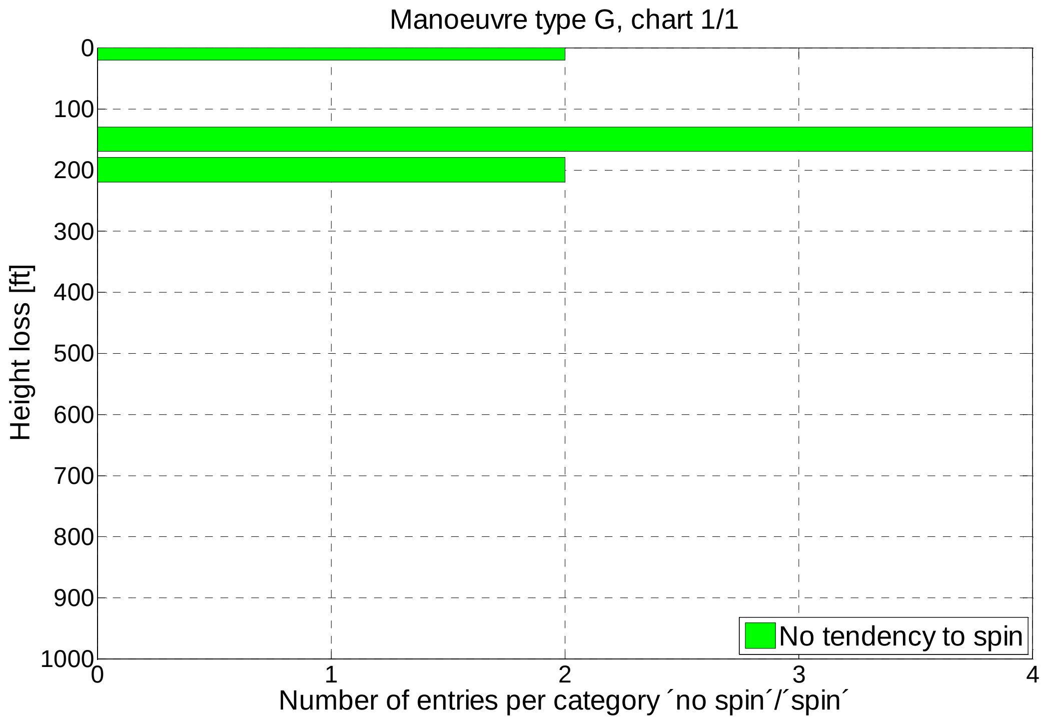
Manoeuvre type E



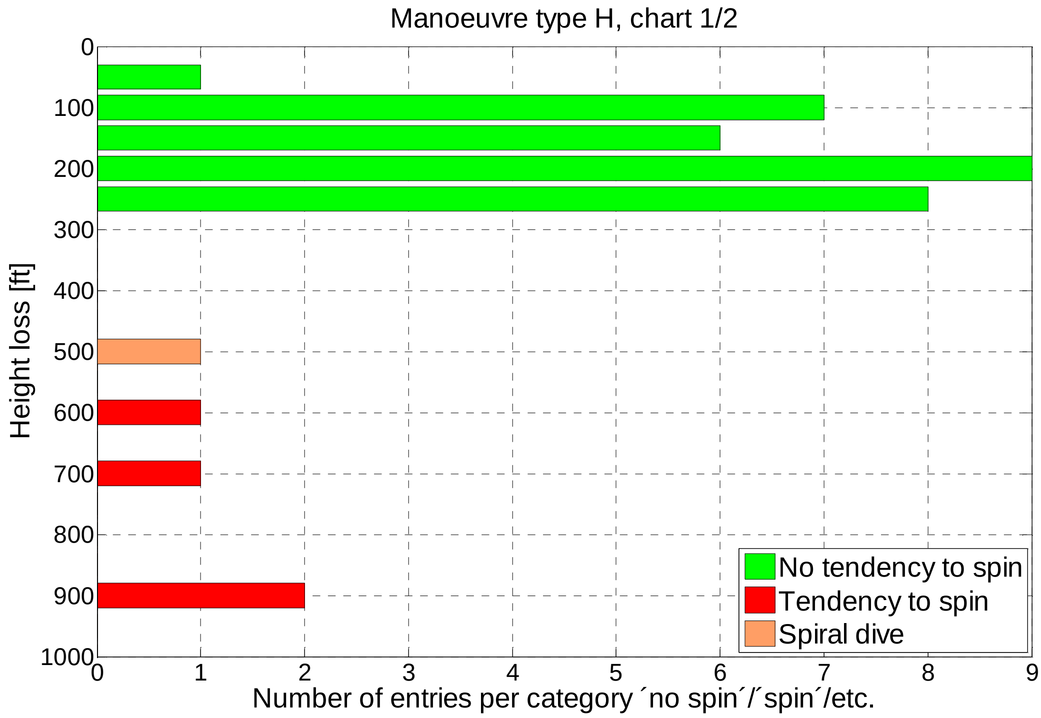
Manoeuvre type F

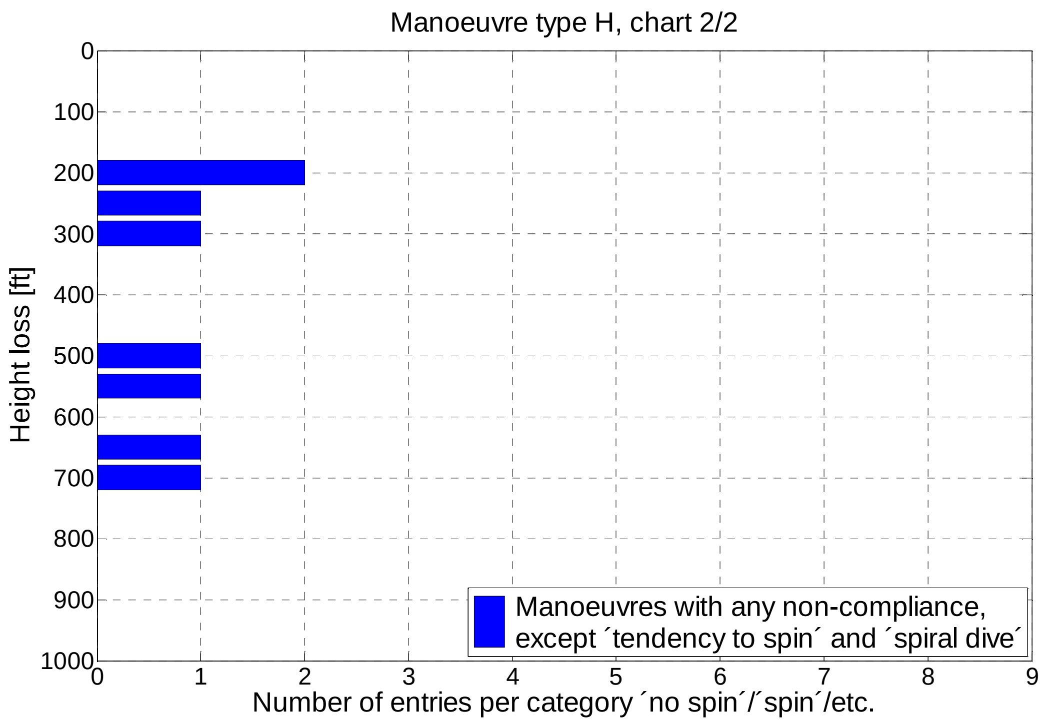
No height loss while executing manoeuvre type F.

Manoeuvre type G



Manoeuvre type H (2 charts)





13.11 Proposal for code amendment

(b) “Normal Category Aeroplanes – Spin Resistant. At the applicant's option, the aeroplane may be demonstrated to have spin resistant characteristics in lieu of spin handling described in paragraph (a) as follows:”

(1) Power and aeroplane configuration for all manoeuvres must be set in accordance with 23.201(e) and additionally with maximum available power without change during the manoeuvre.

(2) Height loss must not be excessive.

(3) If an uncontrollable nose down pitch does not occur during the stall manoeuvres contained in 23.201, controllability must be demonstrated with the pitch control held against the stop. It must be possible to roll from 30° bank to 30° bank in the other direction with the stick in the fully aft position (without assistance from the rudder) without encountering abnormal characteristics.
If an uncontrollable nose down pitch does occur during the stall manoeuvres contained in 23.201, the stick must be held fully aft for at least two seconds while maintaining wings level within 15° bank (without assistance from the rudder). At the end of the two seconds, standard stall recovery control inputs must produce an immediate return to unstalled flight without any tendency towards spin entry.

(4) Reduce the aeroplanes speed using pitch control until the pitch control reaches the stop; then, with the pitch control pulled back and held against the stop, apply full rudder control so as to promote spin entry for a period of seven seconds. At the end of seven seconds or a 360° heading change, the aeroplane must respond immediately and normally to primary flight controls applied to regain coordinated, unstalled flight without reversal of control effect, without exceeding the temporary control forces specified by 23.143(c). There must be no characteristics during the manoeuvre that might lead to disorientation of the pilot.

This manoeuvre must be performed using a rate of speed reduction of approximately one knot per second and then approximately five knots per second.

This manoeuvre must be performed first with the ailerons in the neutral position held in the trimmed position, and then with the ailerons deflected opposite the direction of rudder input in the most adverse manner.

(5) Establish and maintain a coordinated turn in a 45° bank and perform the manoeuvre of (4) from this attitude. Rudder must be applied against and in the direction of turn.

(6) The manoeuvres described in 23.203 (a) must be conducted at 45° bank. The conditions given in the following must be used in lieu of the corresponding conditions in 23.203 (a) and (b):

- Accelerated stalls must be conducted at 5 knots per second.
- No tendency to spin is permitted.
- The resulting maximum roll in both (b)(4) and (b)(5) is 60° in the original direction of the turn or 15° in the opposite direction.

(7) Compliance with 23.201 and 23.203 must be demonstrated with the aeroplane in uncoordinated flight with a fixed rudder angle. The rudder should be held at the angle which results in 15 degress sideslip at 1.1Vs or full rudder if 15 degrees cannot be achieved.

(8) A placard announcing “AVOID STALL! DO NOT SPIN! Spin recovery has not been demonstrated.” must be placed in a highly visible position on the instrument panel.

13.12 Proposal for the Flight Test Guide belonging to proposed code

Flight Test Guide 23.221(b)

Discussion and procedures applicable to spin resistant aeroplanes
(normal category conventional single engine aeroplanes)

a) Explanation

The term “spin resistance” can generally be described as the ability of an aeroplane - due to design - to counter entry into the flight state of spinning or other stall-related flight states resulting in uncontrollability, excessive height loss and long recovery time.

b) Objective
The aim of spin resistance measures is to prevent the pilot substantively from entering a stalled flight state that cannot be recovered within certain limits (height, time).

Paragraph 23.221(b) – on spin resistance - does not require investigation of the controllability in a true spinning condition for a normal category aeroplane. Essentially, the test is a check of controllability in a delayed recovery from stall:

i) The controls are used normally as well as abnormally during the stall.
ii) No aeroplane limitations may be exceeded, including positive load factor and limit speeds.
iii) All height losses must not be excessive.
iv) Sufficient points inside the desired weight and balance envelope should be explored to ensure that all possible operational conditions are covered.

c) Tests and Procedures

(1) *Objective*. The basic objective of spin resistant testing is to ensure that the aeroplane will not become uncontrollable during the stall as described in .221(b), and

that during the stall and the recovery processes no aeroplane design limitations will be exceeded; additionally to ensure the height loss is not excessive.

(2) "*Spin Resistance" Tests*

Matrix: 23.221(b) provides a very detailed description of the manoeuvres to be investigated. However, since it is not possible to conduct all tests under all conditions, a sufficient selection must be made; a sample matrix is given in (10). It is the responsibility of the applicant to explore all critical areas. It may be possible to eliminate the need to conduct some of the additional conditions once the aeroplane responses are known or obviously uncritical.

.221(b) Certification for "spin resistance" is limited to Normal Category aeroplanes. Due to the additional manoeuvres which are allowed in the Utility/Aerobatic Category compliance with .221 c and d (".221b-old" / ".221c-old") must be shown for these aeroplanes.

.221(b)(1) The power settings must be in accordance with 23.201 (e), and additionally with maximum available power without change during the manoeuvre.

Accident analysis has shown that many stall/spin accidents occurred in the traffic pattern with high power settings; so stall tests with maximum available power must be performed.

Power off: The conditions are the same as "throttle closed", i.e. propeller in take off position and engine idle with throttle closed.

Maximum available power:
Maximum power has been found to be the most critical case for demonstrating these requirements. On normally aspirated (non-charged) piston engines, the maximum power achievable at altitudes where testing is normally conducted can be significantly below that at sea level, and is therefore not representative of power settings which could be achieved in the circuit at low altitude airfields. In this case,

final demonstrations should be at altitudes and temperatures that ensure at least 75% of sea level power is achieved.
For charged engines and turbine powered aeroplanes, power setting for maximum available power must be applied.

.221(b)(2) Height loss must not be excessive.

Measuring the height loss start when the aircraft approaches the stalled condition; particularly for highly powered aeroplanes under full power, there may be a gain in height before reaching the stall. Therefore, it is essential that height loss is determined not at the start of the manoeuvre but at the beginning of the stall.
For a typical single engine 4 place aircraft, height losses greater than 300 ft should be considered excessive in this respect.

.221(b)(3) The term “without assistance from the rudder” means that the rudder must be held in the initial position it was in before starting the roll tests. This is normally not the neutral position of the rudder, because a rudder deflection may be required for coordinated flight before starting the rolling manoeuvre.

.221(b)(4) Because flight tests showed that there is a difference in aeroplane’s behaviour when approaching the stall with a speed reduction of 1 kn/s and 5 kn/s, both decelerations must be investigated.

The application of the ailerons “in the most adverse manner” means that during the flight tests different aileron deflections, rates of deflection and chronological sequence relative to rudder deflection (offset -1 to +1 second) must be investigated to find out which inputs result in the most significant aeroplane reaction.

.221(b)(5) Flight tests showed that the stall behaviour in turning flight is different from wings–level stalls.

A turn with a bank of 45° must be coordinated until the pitch control reaches the stop, after which rudder inputs must be applied in both directions.

If possible, the ailerons should be used to maintain the bank angle, yet the limitations under (b)(6) must not be exceeded.

.221(b)(7) The rudder should be applied until a slip angle of 15° at 1.1Vs is achieved, then this deflection must be fixed.

Suitable instrumentation (e.g. wind vane, wool yarn) must be used for measuring the sideslip angle; since the ball displacement in the slip-skid indicator depends on the speed of the aeroplane it is not adequate. However, once the ball displacement related to an accurately measured sideslip angle is established at 1.1Vs, it can be used as the guiding instrument for these manoeuvres.

(3) *Emergency*. It is the responsibility of the applicant to provide adequate provisions for crew restraint, emergency egress, parachutes, and spin–recovery parachutes during the flight tests.

(4) *Flaps*. For the flaps extended condition, flaps may be retracted after initiating recovery to ensure that maximum airspeed for flaps extended is not exceeded. In this case, flap retraction should not be initiated until after the aeroplane has resumed unstalled flight conditions.

(6) *Aerodynamic Forces*. During the tests, all stick and rudder forces must be in accordance with 23.143. No force reversal is allowed.

(7) *Complex Instrumentation*. When complex instrumentation is installed (e.g. wing tip booms, spin chute) this instrumentation may affect the stall characteristics. Critical tests should be repeated without this instrumentation.

(8) *Data Acquisition*. The test aeroplane should be equipped at least with a calibrated airspeed indicator, accelerometer, altimeter, and sideslip indicator. Since the ball slip indicator will not show the actual angle of sideslip but only the lateral acceleration, either a different kind of measurement must be used (e.g. wind vane), or the indication of the ball slip indicator must be calibrated to the angle of sideslip for each relevant airspeed.

To determine height losses, a recording of the altitude must be provided. Recordings of the control inputs, airspeed and sideslip are also strongly recommended.

(9) *Optional Equipment*. If an aeroplane is to be certified with or without optional equipment (e.g. de-icing boots, asymmetric radar pods, outer wing fuel tanks), tests should be conducted to ensure compliance in all configurations.

(10) Sample Matrix

		Flaps up	Flaps approach	Flaps landing	Gear up	Gear down	Cowl flaps closed	Cowl flaps as required	Power off	Power CS 23.201	Power max. available	Speed rate 1 kn/s	Speed rate 5 kn/s	Forward CG	Aft CG	Lateral CG
I.	Roll 30° to 30°	x	x	x				x	x	x	x	x		x	x	
II.	7 s full rudder	x	x	x				x	x	x	x	x	x	x	x	
III.	Banked turn with pro-spin control inputs	x	x	x				x	x	x	x	x	x	x	x	
IV.	Turning flight and accelerated stall	x	x	x	x	x		x	x	x	x	x	x	x	x	
V.	CS 23.201 in uncoordinated flight	x	x	x	x	x		x	x	x	x			x	x	
VI.	Dynamic usage of rudder	x	x	x				x	x	x	x			x	x	
VII.	Dynamic usage of aileron	x	x	x				x	x	x	x			x	x	