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NLR-TP-2016-268 | June 2020

Safe flight tests:
A contradiction or achievable

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Problem area

In recent years the flight test society has seen a lot of accidents, and assumable more incidents we don't even know of, during flight tests. On a worldwide scale the accidents are still very rare, but …. each one is one too much. Of course most flight tests are executed to search for and find the boundaries of a flight envelop and therefore are in principal very risky for the chance of exceeding the limitations of the aircraft or of the crew. But pushing our boundaries with new technology is something mankind has been doing for centuries and by doing so we are trying to make the world a better and more exciting place to live in. But are we aware of the balance between Performance and Safety?

Description of work

In the paper the framework will be sketched with current rules and regulations that are defined to improve the safety during potential high risk performance flight tests. Rules and regulations shouldn't be barriers for innovation but should improve the awareness of things that can go wrong. Maybe a solution can be found in procedures and open communication between all team members in order to prevent that time and cost overruns will be the driving factors for mishaps that may ultimately lead to more fatalities during future flight tests.

Results and conclusions

The major conclusion is that the balance should be on safety because the human life is valuable and almost priceless. However, there will never be a one hundred percent guarantee that we can achieve safe flight tests, but a contradiction between safety and flight testing we can exclude ourselves from by careful preparations before every test flight.

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AUTHOR(S)
C.G. Kranenburg

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Summary

Scope: In recent years the flight test society has seen a lot of accidents during flight tests, and assumable more incidents we don’t even know of. On a worldwide scale the accidents are still very rare, but …. each one is one too much. Of course most flight tests are executed to search for and find the boundaries of a flight envelop and therefore are in principal very risky for the chance of exceeding the limitations of the aircraft or of the crew. But pushing our boundaries with new technology is something mankind has been doing for centuries and by doing so we are trying to make the world a better and more exciting place to live in. But are we aware of the balance between Performance and Safety?

Objectives: In the paper the framework will be sketched with current rules and regulations that are defined to improve the safety during potential high risk performance flight tests. Rules and regulations shouldn’t be barriers for innovation but should improve the awareness of things that can go wrong. Maybe a solution can be found in procedures and open communication between all team members in order to prevent that time and cost overruns will be potential driving factors for mishaps that may ultimately lead to more fatalities during future flight tests. Although in this paper the emphasis will be on the prevention of fatalities it should be noted that every incident during flight tests may have other unwanted effects like wounded people, damage of material, delays, additional costs and sometimes also loss of image for the flight test organisation.

Major conclusion: The balance should be on safety because the human life is valuable and almost priceless. However, there will never be a one hundred percent guarantee that we can achieve safe flight tests, but a contradiction between safety and flight testing we can exclude ourselves from by careful preparations before every test flight.


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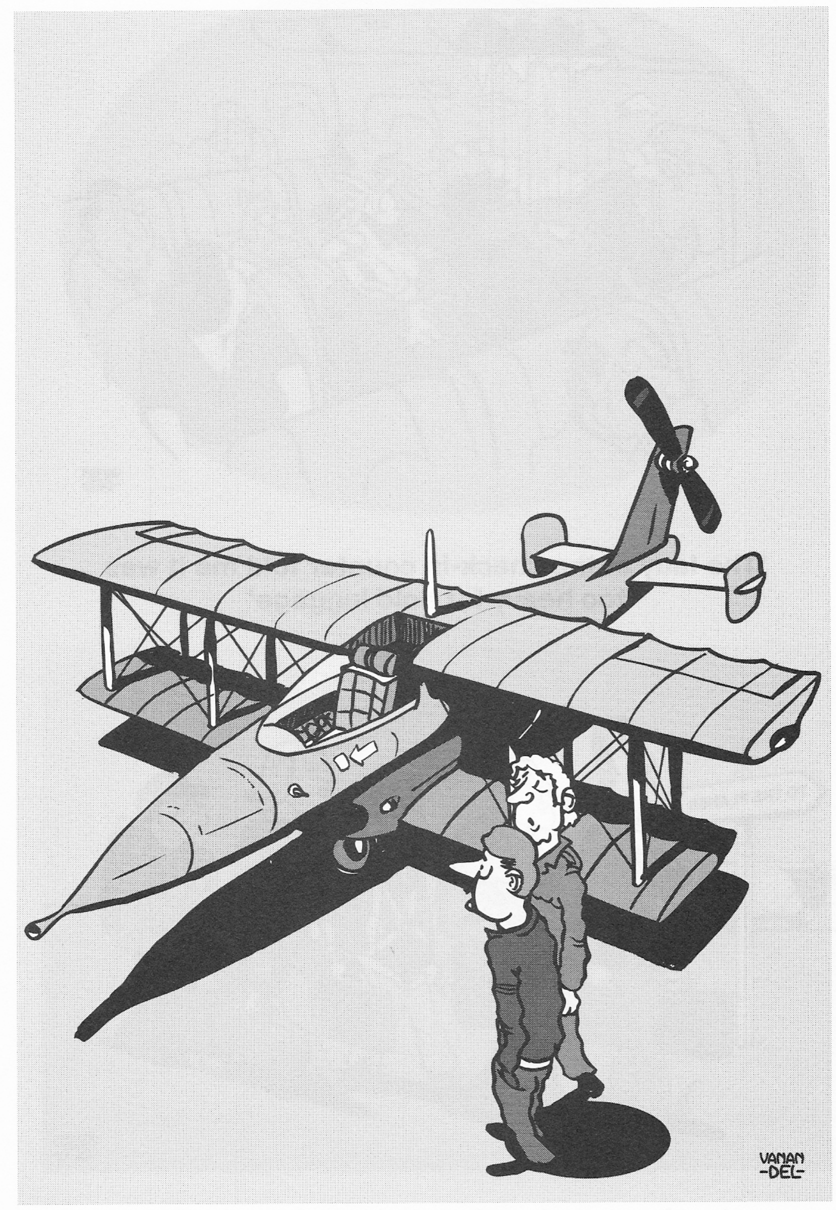
Contents

Abbreviations

ACRONYM	DESCRIPTION
AMC	Acceptable Means of Compliance
ANSP	Agenza Nazionala per la Sicurezza del Volo
ARP	Aerospace Recommended Practices
CDM	Critical Decision Making
CS	Certification Specification
CVE	Compliance Verification Engineer
EASA	European Aviation Safety Agency
ECU	Electronic Control Unit
ED	EUROCAE Document
EDA	European Defence Agency
ESRG	European RPAS Steering Group
EU	European Union
EUROCAE	The European Organisation for Civil Aviation Equipment
FHA	Functional Hazard Analysis
FTOM	Flight Test Operational Manual
LSA	Light Sports Aeroplanes
MS	Master of Science
MTBF	Mean Time Between Failure
NLR	Royal Netherlands Aerospace Centre (Dutch acronym)
NTSB	National Transportation Safety Board
RADO	Research Aircraft Design Organisation
RPA	Remotely Piloted Aircraft
RPAS	Remotely Piloted Aircraft System
SFTE	Society of Flight Test Engineers
SMARD	Scale Model Aircraft Research & Development
SSA	System Safety Analysis
TUD	Delft University of Technology
UAS	Unmanned Aircraft System
USA	United States of America
VSS	Virgin SpaceShip

1 Introduction

Usually most people are thinking that safety is a boring subject and flight testing should be exciting and not boring. The main question is how can we make safety less boring and of primary importance in flight test preparation to save human lives? Everybody in aerospace knows the Law of Murphy: “if anything can go wrong, it will go wrong”. But hopefully for us it will last long enough before Murphy strikes again. However safety is not luck and luck is not safety. In a recent incident with an unmanned system in the USA the comment was that it was not unsafe because no one was hurt. In this test with an UAS with long wings, one of the wings fell off during standard conditions for a flight. Of course the UAS crashed and fortunately there were no fatalities on the ground. However, it should be noted that we can only pronounce ‘luck’ when a manned aircraft crashes and everybody in the plane survives.



'A product of European cooperation'

Can we expect to increase safety if we accept luck as an option for flight tests? We can only have safety *if nobody could get hurt* in case of a malfunction of an airframe or an aircraft system. There are several options for flights test engineers and flight test pilots to reduce the number of incidents that may ultimately lead to fatalities during flight tests, but the general denominator is the awareness of risks. This awareness starts by the individual, but should end by the team that prepares the flight test program and the mechanics who prepare the aircraft.[1]

It should be clear that awareness of risks is only the starting point for actions to reduce the risks by a number of mitigating measures. These measures have to be taken all along the trajectory from the design of an aircraft until the final flight test for the initial certification of a new type of aircraft but also during every flight test that needs to be done to prove the continued airworthiness of the aircraft. Sometimes all possible measures may reduce the risks but there will be a small residue that should be judged as acceptable within the conditions for the flight test.

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[1] All cartoons are from Ton van Andel (see Ref. 11)

There is still a chance that we are not aware of all the possible risks and therefore every flight test program should be based on standard techniques like an incremental approach to prove the performance of the aircraft.

Flight tests for certification are performed for two purposes:

1. to demonstrate compliance with the requirements in the applicable EASA Certification Specifications (CS);
2. to demonstrate that the aircraft performs it's intended functions to the standard required for certification and should continue to do so during its service life.

All flight tests shall be conducted in accordance with conditions for such flight testing specified by the Agency. In this paper the emphasis will be on the goal for the initial certification: compliance validation and verification that the aircraft meets the needs and the expectations of the customer. Flight tests are also intended to show the best performance of the aircraft under all circumstances that can be expected during its lifetime and its intended use.

We may assume that every flight test organisation is trying to find the right balance between the search for the optimal performance and the maximum of safety during these flight tests (see Figure 1). Although in reference to the recent fatalities somebody may argue that this balance is unbalanced towards performance now. In general it can be assumed that a new aircraft is developed stepwise and with a thorough evaluation after each step. This stepwise or incremental approach should work also for the reduction of risks in flight test programs.

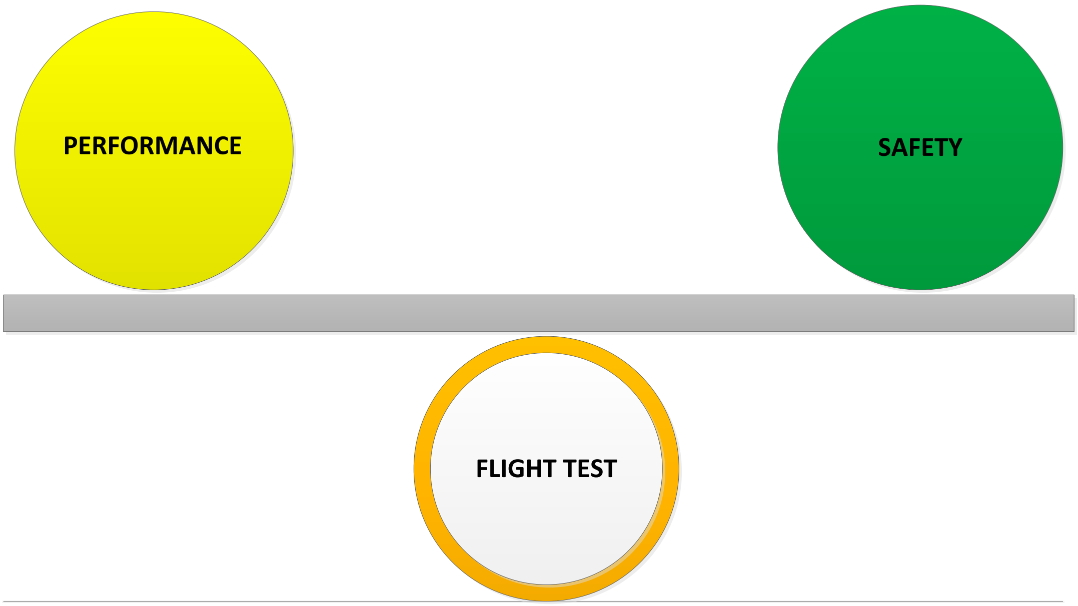


Figure 1: The Flight Test balance

2 Regulations

Safety is, and should be, the key element in the regulations for the design, production and operation of aircraft (see Figure 2). The regulations are meant to be the basis for the product that our airlines are offering to their customers: a safe and reliable means of transport between A and B. Public transport by air has developed in the last century from an exciting and dangerous activity of adventurers to an “almost boring” routine activity by professional pilots.

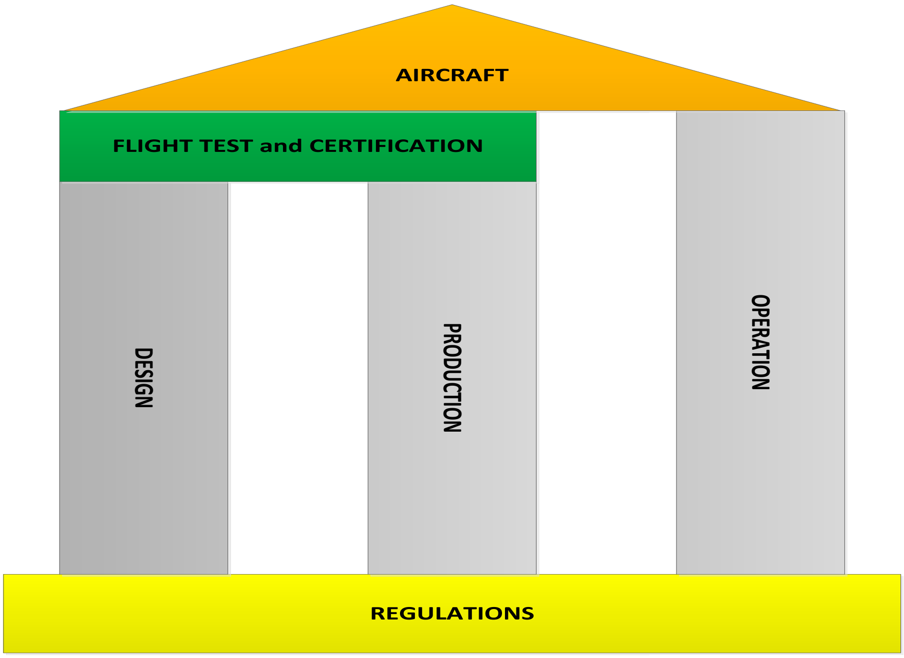
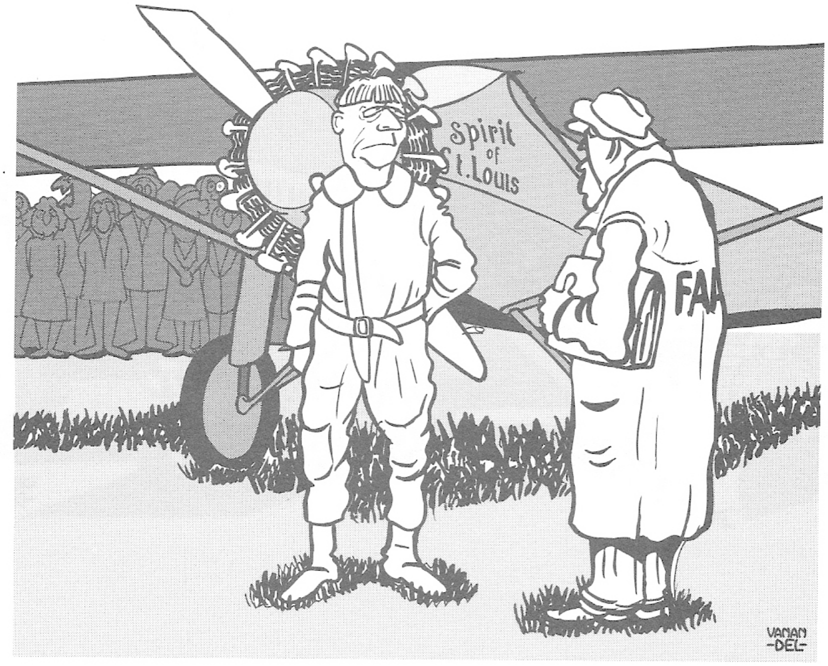


Figure 2: Regulations as basis

This change is one of the main results of the regulations that are in place for the aerospace industry. To protect their citizens the governments have instated national and international authorities to check and control all elements that contribute to our worldwide air transport system. The regulations from these authorities should be internationally accepted and approved because airspace should be open and not limited by national boundaries. This will become even more important if military and civil operators are going to share the same integrated airspace. In manned aerospace the



'You violated Flight Time Limitation rules' regulations are not only meant to protect the ‘third parties’ on the ground, but also the passengers that are inside. It is the ultimate duty of every pilot in command to look after the safety of his or her passengers. This is also true for test pilots if they are accompanied by the test crew or even by a minimum test crew during high risk tests.

How are flight tests for certification linked to the regulations? The EASA CS’s are the basis for the design of new airworthy aircraft. The CS provides a minimum set of safety, functional and operational requirements [Ref. 1], besides all the additional requirements from a manufacturer itself or its stakeholders, the operators. For certification the applicable requirements are selected and presented to the Authority in a Certification Plan. In this plan the applicant selects how the compliance to these requirements is proven. There are several ways to prove them as shown in Table 1. Flight tests with code MC6 can be selected as a final, but usually expensive, ‘proof of the pudding’.
Ref. 2: EASA AMC 21.A.20(b)

Table 1: Means of Compliance codes

Type of Compliance	**Means of Compliance**	**Associated Compliance Documents**
Engineering evaluation	MC0: - Compliance statement - Reference to Type Design documents - Election of methods, factors - Definitions	- Type Design documents - Recorded statements
	MC1: Design review	- Descriptions - Drawings
	MC2: Calculation/ Analysis	- Substantiation reports
	MC3: Safety assessment	- Safety analysis
Tests	MC4: Laboratory tests	- Test programmes - Test reports - Test interpretations
	MC5: Ground tests on related product	
	MC6: Flight tests	
	MC8: Simulation	
Inspection	MC7: Design inspection / audit	- Inspection or audit reports
Equipment qualification	MC9: Equipment qualification	Note: Equipment qualification is a process which may include all previous means of compliance.

EASA has recently published some first ideas on new regulations for the contents of Flight Test Programmes for Light Sports Aeroplanes (LSA). In an initial issue of an Example Document for LSA applicants – v1 of 17.02.16 [Ref. 3] the contours for a standardised regulation on flight tests are presented.

3 Flight testing

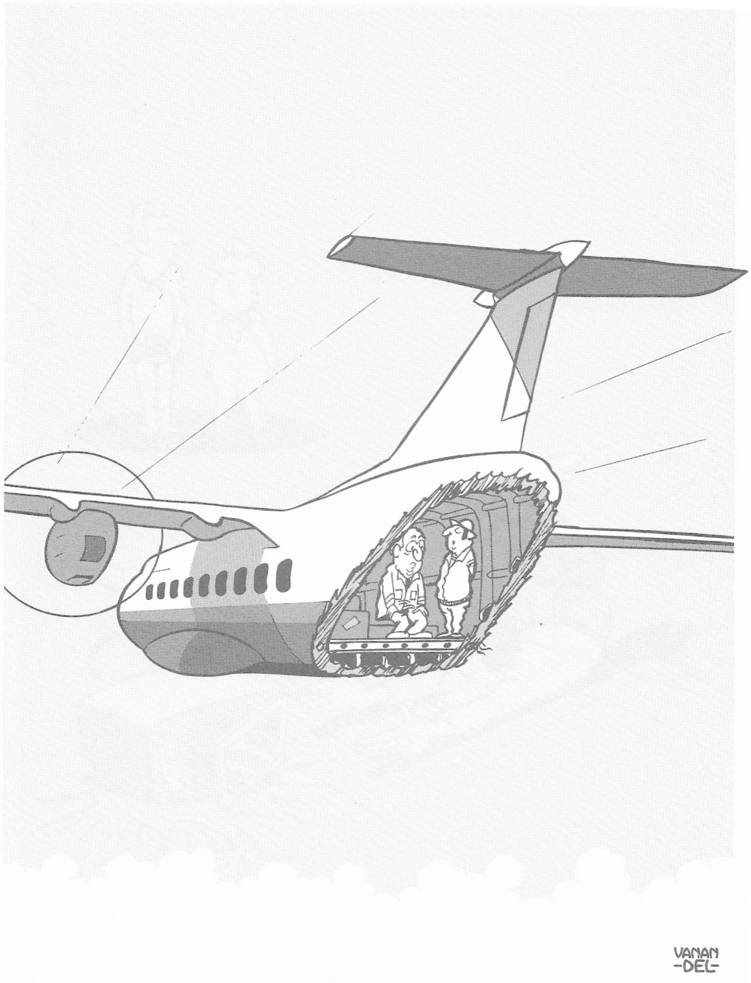
Flight testing new aircraft or flight testing a major modification to existing aircraft types re-established a little of the excitement that our ‘aviateurs’ from the beginning of the previous century have experienced. Conquering gravity is one of the dreams mankind has had since we were able to use tools to fulfil our dreams. Unfortunately the realization of this dream has resulted in a large number of victims. It is a long list and there must be sites where you can find our heroes who died for the progress we have made in aviation. You can also find their names on hangars, buildings and streets. However, producing heroes should not be the goal of current flight tests, but on the contrary to prove that our products are safe and reliable.

Performance and handling qualities flight tests are in principal the way to explore the flight envelop of the aircraft and consume the larger part of any flight test program. Looking for boundaries in height, speed, Mach number and other principal parameters of flight is potentially dangerous, not only for flutter, but also:

- What will happen when the boundaries are unintentionally passed?
- What will happen when an essential system fails when a boundary is approached?

Most of our flight test pilots and flight test engineers should have asked the above questions to themselves. And maybe you know other questions that are relevant for your own safety in flight? The main question is: “Is it enough to ask them once in your career or should you be aware of these questions every time the engines are started for a new test flight?”

Looking at our regulations you may wonder how they can help to find the answers to these questions. In the civil world of aerospace a number of parts of the EASA CS documents deal with performance and request for instance for validation and verification of safe operations under conditions of one engine inoperative for multi-engine aircraft, or prove of the limitation on the maximum allowed crosswind during landing.
Especially near the ground during Take-Off and Landing the risks are clear and you will be aware of these risks. Recent accidents have shown that also in other parts at the boundaries of the flight envelope little mistakes can have fatal results.



'Tailscrape'

In the USA the crash with the VSS Enterprise of Virgin Galactic on Oct. 31, 2014 has got a lot of attention. It is very worthwhile to read the National Transportation Safety Board (NTSB) report on this crash [Ref. 4} and to learn how small changes in procedures or crew actions could have prevented the vehicle's catastrophic structural failure. This SpaceShip Two (SS2) crash was caused by a premature[2] repositioning of the vehicle's tail wings after the co-pilot unlocked the feathering system while still in the ascent to the apogee of their flight. The aerodynamic forces at that stage were too high for the feathering system to work properly. The NTSB concluded that the probable cause of the accident was the failure of the manufacturer to consider and protect against the possibility that a single human error could result in a catastrophic hazard to the SpaceShipTwo vehicle. Here the lesson learned is to inhibit any unlock of the feathering system outside the Mach region it is designed for. This inhibit function should have been incorporated in the design phase if a system safety analysis would have indicated a catastrophic event in case of this 'unintended functioning' of the feathering system.

3.1 Risks

In the regulations, and especially in all articles with the number 1309, you will find advice on methods how to design aircraft systems that provide a reasonable margin with respect to the acceptable risk for failures that could lead to fatalities. The principles are documented in the nineties of the previous century as part of the Aerospace Recommended Practices and EUROCAE Document series [Ref. 5 and Ref. 6]. For this analysis every aircraft system is defined by what it is doing: objective(s), service, interfaces and environment. In the first step the criticallity of a system during the different phases of a flight should be established. With a Functional Hazard Analysis (FHA) the different failure modes of an aircraft system are defined and the effect on the operation of the aircraft is estimated. Note that in the design phase there is an option to change the architecture of a system or a combination of systems to mitigate the effects of failures. A simple duplication or triplication of a critical system may do the trick to reduce the risk. The goal of the FHA is to prevent likely to occur incidents that cause unwanted effects already in the design process of the aircraft and the ultimate goal is to prevent a catastrophic event when a functional hazard occurs or an aircraft system fails. In case of system failures it is advised to proceed with a System Safety Analysis (SSA) and to look for mitigations. Mitigations are intended to reduce the risk to an acceptable level for the flight test but mitigations should certainly prevent a situation that falls within the catastrophic category, because this will lead for certain to victims in manned aviation.

Copy of CS 25, Amendment 17, Book 1, Art. 25.1309:

(a) The aeroplane equipment and systems must be designed and installed so that:
  (1) Those required for type certification or by operating rules, or whose improper functioning would reduce safety, perform as intended under the aeroplane operating and environmental conditions.
  (2) Other equipment and systems are not a source of danger in themselves and do not adversely affect the proper functioning of those covered by sub-paragraph (a)(1) of this paragraph.
(b) The aeroplane systems and associated components, considered separately and in relation to other systems, must be designed so that -
  (1) Any catastrophic failure condition
    (i) is extremely improbable; and
    (ii) does not result from a single failure; and
  (2) Any hazardous failure condition is extremely remote; and

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[2] Not in the correct Mach region as indicated on the flight test data card and as practised in a simulator.

(3) Any major failure condition is remote.

(c) Information concerning unsafe system operating conditions must be provided to the crew to enable them to take appropriate corrective action. A warning indication must be provided if immediate corrective action is required. Systems and controls, including indications and annunciations must be designed to minimise crew errors, which could create additional hazards.

In the first step of the FHA the following failure conditions should be analyzed for every function:

1. Total loss of function
2. Partial loss of function
3. Inadvertent / un-commanded function
4. Erroneous function

Un-annunciated failures of systems can be detected by the senses of the operator (smell, motion, visual,etc.)
The different failure conditions and their classification are derived from the EASA document CS25 Book 2 [Ref. 1] and summarized in Table 2.

FAILURE CONDITION CLASSIFICATIONS AND PROBABILITY TERMS

a. Classifications. Failure Conditions may be classified according to the severity of their effects as follows:

(1) No Safety Effect: Failure Conditions that would have no effect on safety; for example, Failure Conditions that would not affect the operational capability of the aeroplane or increase crew workload.

(2) Minor: Failure Conditions which would not significantly reduce aeroplane safety, and which involve crew actions that are well within their capabilities. Minor Failure Conditions may include, for example, a slight reduction in safety margins or functional capabilities, a slight increase in crew workload, such as routine flight plan changes, or some physical discomfort to passengers or cabin crew.

(3) Major: Failure Conditions which would reduce the capability of the aeroplane or the ability of the crew to cope with adverse operating conditions to the extent that there would be, for example, a significant reduction in safety margins or functional capabilities, a significant increase in crew workload or in conditions impairing crew efficiency, or discomfort to the flight crew, or physical distress to passengers or cabin crew, possibly including injuries.

(4) Hazardous: Failure Conditions, which would reduce the capability of the aeroplane or the ability of the crew to cope with adverse operating, conditions to the extent that there would be:

(i) A large reduction in safety margins or functional capabilities;

(ii) Physical distress or excessive workload such that the flight crew cannot be relied upon to perform their tasks accurately or completely; or

(iii) Serious or fatal injury to a relatively small number of the occupants other than the flight crew.

(5) Catastrophic: Failure Conditions, which would result in multiple fatalities, usually with the loss of the aeroplane.

Table 2: Classification of Failure Conditions w.r.t. Safety

Classification of Failure Condition	**No safety effect**	**Minor**	**Major**	**Hazardous**	**Catastrophic**
Effect on Aircraft	No effect on operational capabilities or safety	Slight reduction in functional capabilities or safety margins	Significant reduction in functional capabilities or safety margins	Large reduction in functional capabilities or safety margins	Normally with hull loss
Effect on Flight Crew	No effect on flight crew	Slight increase in workload	Physical discomfort or a significant increase in workload	Physical distress or excessive workload impairs ability to perform tasks	Fatalities or incapacitation
Effect on Flight Test Engineers	No effect on people in cabin	Physical discomfort	Physical distress, possibly including injuries	Serious or fatal injury to a small number of people in cabin	Multiple fatalities

The risk of an event is the combination of the effect of a failure and the expected occurrence of the failure during the (test) flight:

$$\text{RISK} = \text{Severity X Occurrence}$$

In the design phase of an aircraft the estimation of an occurrence is based on statistics, on the Mean Time Between Failure (MTBF), the design life of the aircraft and on experience. The safety of flight tests can be based on the results of simulations, on results from flights with scaled models and on extrapolation of previous results. But for flight test to the limit of the capabilities of the aircraft or a system the only basis for this estimation of a risk can be experience.

By defining a Flight Test Program the Flight Test Engineer should make the same analysis but usually at a higher level. This requires a thorough knowledge of the aircraft and its systems and therefore the assistance of one or more specialists is necessary. If special manoeuvres are foreseen for this specific flight test, the test pilot should be part of the team that makes an analysis of the risks. In this case he should provide a detailed report on any operational risk during the flight tests. Although this should be the general practice, nowadays it looks like an awareness of hazards by malfunctioning of systems, by errors of the crew and by other external influences like weather conditions is fading. Prepair yourself on any available mitigating action like restrictions on height, speed, weather conditions, etc. before it is needed in flight. Of course this thorough preparation requires processes and procedures to be in place and this takes time, and time is money.

The big difference with mitigations for hazards in the design phase is that for hazards during a flight test the ultimate kind of mitigation[3] should be done by persons and not -for instance- by a duplication of a critical system. In some cases the mitigation can only be provided by the addition of a ‘safety driven flight test provision’ like a parachute or a rocket. That will also mean that these very critical flight tests can only be executed in a test area with very few inhabitants to prevent any fatalities on the ground. This operational restriction is checked by the national authorities in the country of the manufacturer of the aircraft or of the designer of the modification to an aircraft type.

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[3] There are a lot more mitigations like test limitations, an incremental approach in the flight test program and pre-test simulator training but in this paper the emphasis will be on what can be personally done by members of the flight test team.

3.2 Briefing

Every test flight should start with a briefing attended by all persons that are involved in this flight. Prior to this meeting two elements should be prepared:

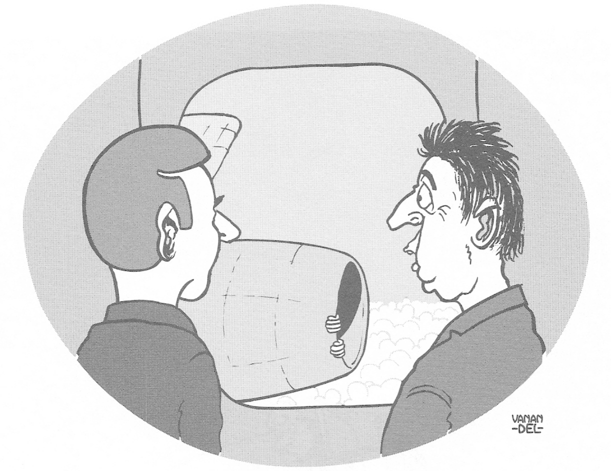
1. A flight test program including all flight test cards with an extensive description of all runs. The results of this process are discussed in a Technical Review Board.
2. An analysis by the test pilots of the planned manoeuvres, including a flight test hazard assessment. The results of such an analysis are discussed during a Safety Review Board.

The last exercise should focus on the risks by stepwise extending the flight envelope of a new aircraft or a modified one. Sometimes the flight test will be executed with two aircraft, for instance in cases a chase aircraft is used or on tests with collision avoidance. This requires a briefing with all the members of the two flight crews. Roles and responsibilities of the pilot, the flight test engineer or observers should be described in a Flight Test Operational Manual (FTOM) and are summarized in the flight test cards. Any actions that are unclear to one or more of the crew should be brought up and explained and all questions must be answered before the flight. For a flight test under very adverse or dangerous conditions a stepwise approach must be considered during the discussion of the flight test cards.
Plan the flight → fly the plan.

Flight tests in Europe depend regularly on weather conditions and are hampered by the limited availability of test areas. Because the preparations for the instrumentation of a test flight used to take more time than planned, and the availability of ground support facilities may affect the schedule, there will always be a tight period for the briefing. Nevertheless the briefing should be an essential element in the preparation of the flight test. It makes everybody aware of what is going to be flown and what can be done to mitigate identified hazards (e.g. malfunctions in the systems) and also how to cope with an error by a member of the crew.

You will need courage to say NO if the risk of a particular flight test is unacceptably high. It is not the kind of courage that will bring you to the headlines of the newspapers, but the courage you will need to defend your decision in front of your boss or of the board of directors of your company.

3.3 Monitoring



'We should notify the pilot'

During the test flight the critical parameters should be monitored by the flight test engineer with the support of the specialists who are responsible for the system under test. There should be tools available to check the parameters on their maximum and minimum values, on their trends and on other responses which indicate a possible failure condition for the airframe or an aircraft system. If equipped with a comprehensive flight test engineer station in the cabin the monitoring can be done on board of the aircraft where the communication links are short. The flight test engineer can inform the captain by intercom in case parameters reach or almost reach the critical values that were defined during the preparation of the flight test. The additional crew for the flight test monitoring is only allowed if the classification of the test flight itself is less than hazardous.

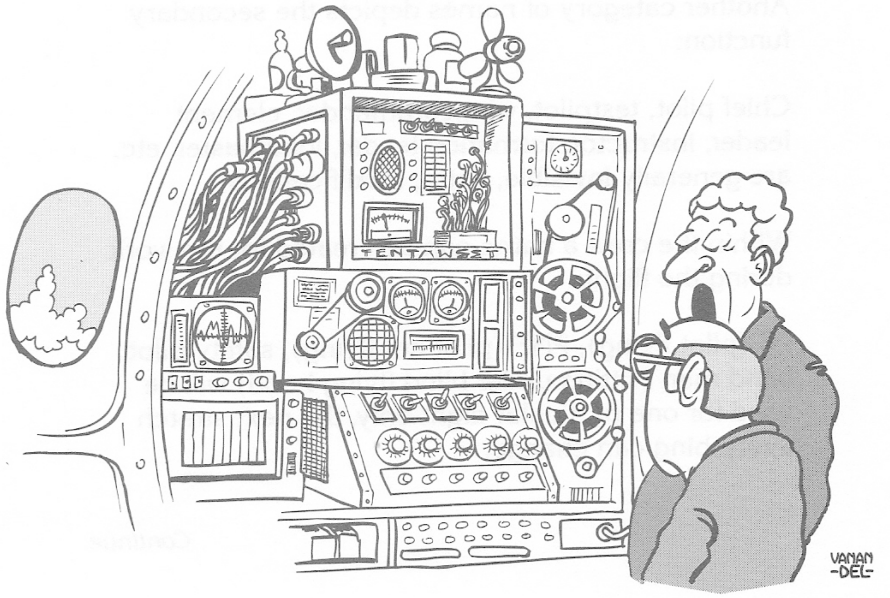
For test flights with a high, but still acceptable risk, there will be a minimum crew on board and the monitoring should be done on the ground. All the critical parameters should be sent to a ground station by telemetry and monitored by the flight test engineers and the specialists responsible for the validation and verification of the system under test. A direct communication channel with the flight crew should be available to report any anomalies in the expected behaviour of the aircraft or a system. This role is typically fulfilled by the lead flight test engineer of that particular test flight domain. Pre-defined mitigation actions should be part of the safety procedure that would be discussed in the briefing. The ultimate responsibility of the pilot in command of the flight is to guard the safety of the persons on board and on the ground as much as possible if a crash cannot be prevented.

3.4 Debriefing

After the test flight a debriefing must be scheduled to discuss the flight and report test results and anomalies in the conduct of the test flight. Not only the standard reports on the recordings of the results of the test flight are exchanged, but the ‘lessons learned’ have to be taken into account for the next flight or the next program. The first impression after the flight is usually more helpful than an extensive written report in the days afterwards. A historical archive must be kept for all source data including meta data, flight test reports, crew comments, etc.

Note that the debriefing should always have an open communication structure to promote an open mind by the participants. Nobody should be looking for blame by failures, but looking for the things that can be improved next time. Even minor details on discrepancies in the procedures can be important to prevent bigger problems during the next flight. Therefore the ranking or seniority of any participant may not harm an open discussion on issues that were noticed during the flight. The communication characteristics of what is nowadays known as Critical Decision Making (CDM) in the training of pilots should be extended in the debriefing to all people who have contributed to the flight test.

The notes of the debriefing may need a follow up. A list of action items with the person responsible and the time period for this action will be composed at the end of the meeting. This list will be discussed in the briefing before the next flight and the consequences of any omission defined.



'It's the latest development for cockpit voice recorders. It filters smalltalk'

3.5 Lessons learned

A good example of the lessons learned process can be found in the analysis after the fatal accident with the Gulfstream G650 on April 2, 2011 in Roswell, NM, USA. The accident itself was caused by too low flying over the runway when one wing struck the ground and the aircraft caught fire. In a presentation for the Workshop 2013 of the Flight Test Safety Committee in Amsterdam [Ref. 7], not only the assumptions that lead to the cause of this accident are presented, but also the measures that would have prevented the fatalities. Gulfstream introduced fire suppression techniques, because without the fire the impact was survivable. They also introduced a Safety Manager that now introduces 'critical thinking' for Flight Tests and the use of checklists [Ref. 8].

In Europe we have seen accidents with the Airbus A400M on May 9, 2015 in Spain and the AgustaWestland tiltrotor AW609 on October 30, 2015 in Italy.

In a number of publications it was stated that Airbus had already revealed that the fatal crash with the military transport was caused by an 'accidental wipe' of a critical part of the configuration data – known as "torque calibration parameters" – in three of the aircraft's four Electronic Control Units. The missing data made it impossible for the aircraft's central control system to interpret data coming from the engines' sensors. The aircraft's software is designed to shut down malfunctioning engines to prevent them from affecting the operation of the aircraft. But a software failure of more than two engines was never taken into consideration. The data was wiped during the installation of the software. No cockpit alert about this data fault would appear in the cockpit while the aircraft was on the ground; only at altitude the pilot would have been alerted about the missing data. It will be clear from this scenario that software changes should be checked and re-checked after installation changes and the pre-flight check procedure must be adapted to detect mistakes on the ground. In this accident 4 of the 6 crew members were killed.

Details on the mid-air break-up during high speed tests of the AW609 are published by the Italian investigators (ANSV) in May 2017 [Ref. 9]. They determined that repeated contacts by the AgustaWestland AW609's proprotor blades with the leading edge of its wing precipitated an in-flight break up and an in-flight fire due to sparks. This happened during high speed dives which initiated oscillation that became divergent and led to sideslip angles above the maximum allowed in those high speed conditions. With the flawed flight control logic in the flight control software the pilot inputs to counter the excessive roll, and then yaw, had the effect of simply amplifying them. The investigators noted that this was not the first time the AW609 displayed similar behaviour. In July 2014 the same aircraft sustained damage when its right hand proprotor hit the wing leading edge during "a significant sideslip [which] developed due to lateral acceleration" after a wing stalled. In this case the previous experience was not taken into account in the preparation of the flight test for high-speed dives. Both pilots were killed.

4 Remotely piloted aircraft systems

A special case will be the flight tests with Remotely Piloted Aircraft Systems (RPAS). These systems are also known as ‘drones’ or ‘UAS’, but the RPAS is a limited subset of these categories. The essential element of an RPAS is that there is a remote pilot who is responsible for the flight with the RPA, the unmanned aircraft. Of course autonomous flight or part of the flight is allowed as long as the pilot in command has the ability to interfere with the control of the RPA.

Regulations for flight tests with civil RPAS are not in place yet and according to the roadmap ESRG, 2013 [Ref. 10] it will still take a lot of years before we can expect to have multinational requirements for the operation of RPAS in civil airspace. In the meantime there are a lot of research projects, both military (EDA) and civil (EU), in support of the on-going definition of minimal requirements for the safe integration of RPAS in our airspace. All flight tests need approval by the national authority who can require limitations in the operation and conditions for the execution of the test. It can be expected that the main concern of the authorities for RPAS will be on a prevention of mid-air collisions or a crash in populated areas. A simple solution will be to do the flight testing with RPAS in restricted areas above see or in remote areas of Europe. A Safety Management Plan will almost certainly become a prerequisite for the approval of these test flights.

At NLR we have started a research project, called SMARD (Scale Model Aircraft Research & Development). The objective of SMARD is to investigate whether a scale model of an aircraft type can be used for compliance verification to requirements that are potentially dangerous to demonstrate with a manned prototype. It may reduce the risks during a flight test program, it may reduce the costs and it may extend the possibilities for training of pilots to recognize stall conditions and practice upset recovery techniques in real flight.

5 Conclusion

If we want to proceed and if we want to compete …… we have to take risks. And we need awareness of risks to improve safety. Maybe our balance during flight tests must be unbalanced to safety in order to prevent fatalities. Of course the consequences in time and costs for the flight test program have to be taken into account. Mitigation of risks will be necessary in every flight test program to collect the right data within a project in a safe way but also to finish the project within time and within budget and without damage to the image of the flight test organisation.

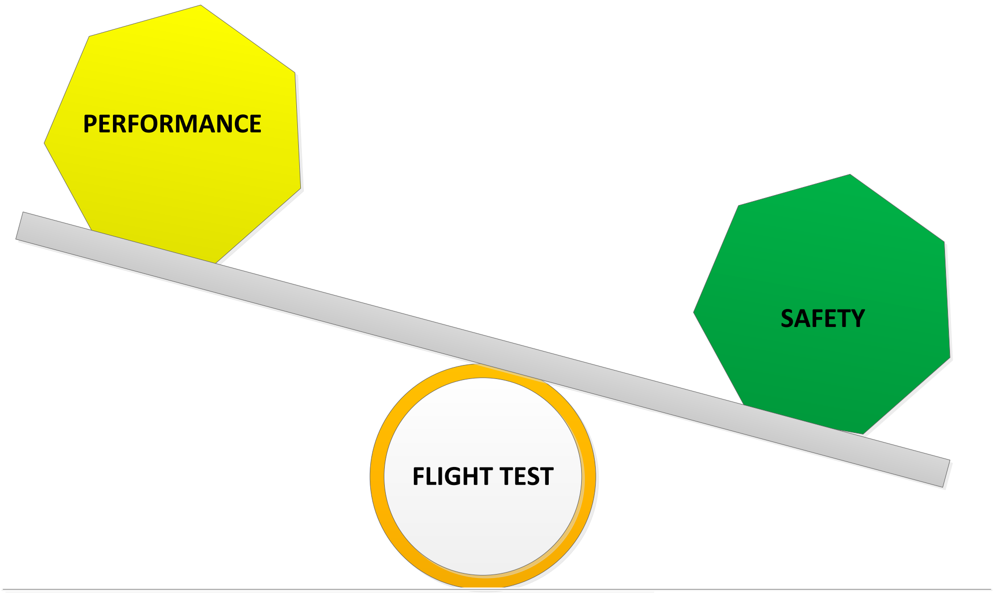


Figure 3: The improved Flight Test balance

In Figure 3 Performance and Safety are presented with sharp edges instead of circles as in Figure 1. To prevent them from slipping away we need to be sharp on all the things that can cause unnecessary risks. Sharp minds could cause the sharp edges that we need if the balance between Performance and Safety shifts to Safety as in this figure. Regulations will help to sharpen these minds and introduce critical thinking, but in the end only the whole team for the flight test preparation can really make a contribution to save our most precious assets: the lives of our test pilots and flight test engineers.

However, there will never be a one hundred percent guarantee that we can achieve safe flight tests, but a contradiction between safety and flight testing can we exclude ourselves from by careful preparations before every flight.

6 References

1. EASA CS-25 Large Aeroplanes, Amendment 17, 16/07/2015.
2. EASA AMC/GM to Part-21 - Issue 2, Amendment 6, 26/04/2016.
3. NTSB, In-Flight Breakup During Test Flight Scaled Composites SpaceShipTwo, N339SS Near Kpehn Dry Lake, California October 31, 2014.
4. EASA ABCD-FTP-01-00, Flight Test Programme, Example document for LSA applicants – v1 of 17.02.16, initial issue.
5. ED-79/ARP4754, Certification considerations for highly-integrated or complex aircraft systems, EUROCAE, November 1996.
6. ARP4761, Guidelines and Methods for conducting the Safety Assessment Process of Civil Airborne Systems and Equipment, December 1996. EUROCAE ED-135 is to be published.
7. A Tragic First – Gulfstream G650 Flight Test Accident, Jake Howard and Paul Donovan, Flight Test Safety Workshop 2013, Amsterdam, The Netherlands.
8. Critical thinking to improve Flight Test safety ... and ways to implement it, Ben Luther, 27th SFTE European Chapter Annual Symposium, May 2016, Nuremberg, Germany.
9. ANSV, Final Report Accident occurred to the AgustaWestland AW609 aircraft registration marks N609AG in Tronzano Vercelles, Italy on the 30th October, 2015.
10. European RPAS Steering Group [ERSG, 2013]. Roadmap for the integration of civil Remotely-Piloted Aircraft Systems into the European Aviation System.
    Final report from the European RPAS Steering Group: main report, Annex I and Annex II, June 2013.
11. Cartoons from ‘Say How’: © Martin Leeuwis and Ton van Andel, Martin Leeuwis Publication, www.humor.aero.

NLR

Anthony Fokkerweg 2
1059 CM Amsterdam, The Netherlands
p) +31 88 511 3113 f) +31 88 511 3210
e) info@nlr.nl i) www.nlr.nl