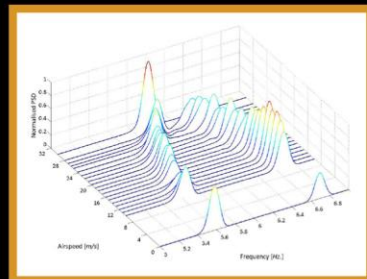
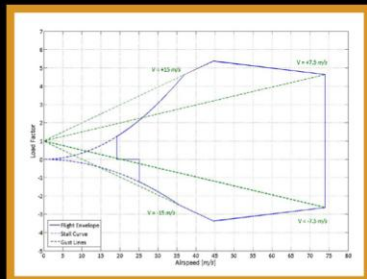
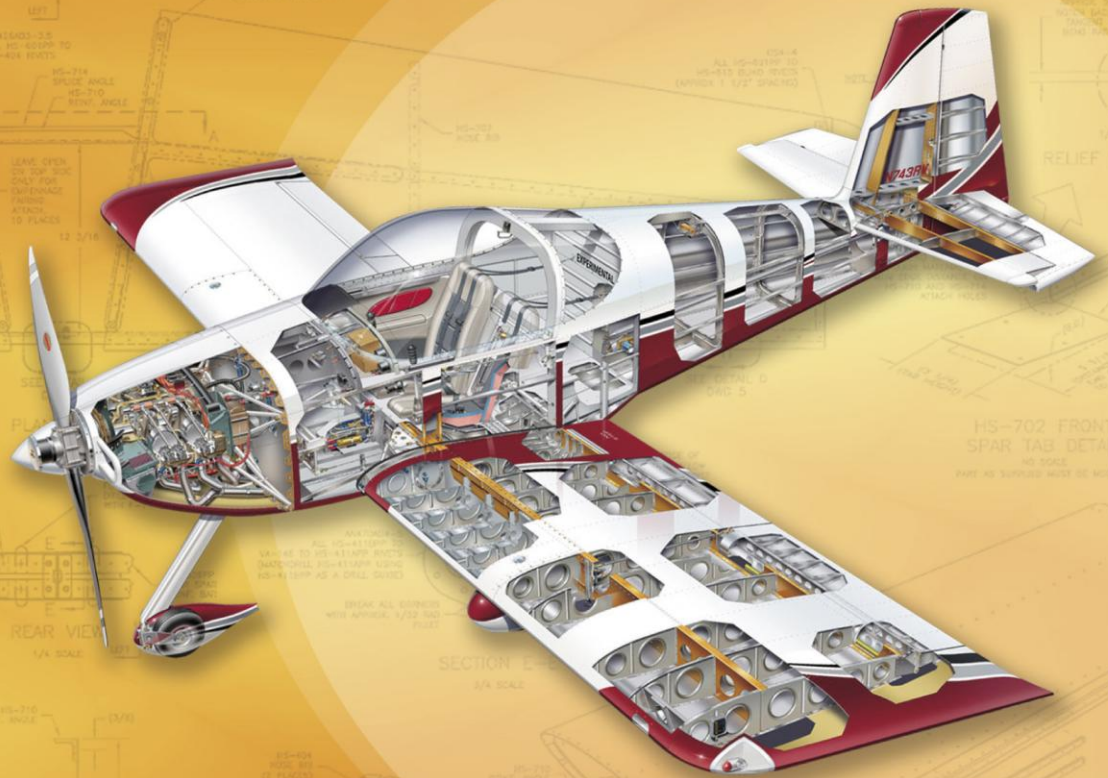


# Flight Test Guidelines for Homebuilt/Experimental Aircraft

Maj. Gen. (SAAF Rtd.) Desmond Barker (CSIR)  
 Alan Sutherland (CSIR)



An 'aide-mémoire' of flight test procedures and techniques for flight testing of non-type certified aircraft in the Republic of South Africa

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**the dti**  
 Department:  
 Trade and Industry  
 REPUBLIC OF SOUTH AFRICA



Aerospace Industry Support Initiative

an initiative of the dti

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our future through science



## Foreword



The Department of Trade and Industry (the dti), in its bid to provide a conducive environment for industry to thrive, has dedicated programmes to enhance the competitiveness of the aerospace and defence industry. These programmes are anchored on the development of lower sub-tiers within the industry, to strengthen the country's supplier base for its firm integration into the global supply chains.

The aviation engineering sciences have advanced faster than any of the other sciences and today are at the forefront of many advanced and radical technologies. The progress of the aviation industry today is built on the blood of those test pilots and flight-test engineers that have gone before. While the world of certificated aircraft design and development is strictly regulated in contrast to non-type certificated aircraft, the domain of the amateur home builder, aviation enthusiast and amateur aircraft designer, flight-test is essentially a "free for all" with minimal oversight by the regulator.

Within this regulatory environment, the dti through its AISI (Aerospace Industry Support Initiative) based at the CSIR, is providing a certification and accreditation programme, and amongst others has developed this "aid memoire" of flight-test procedures and technologies for flight-testing of non-type certified aircraft in the country. We understand that flight-test, by its very nature involves varying levels of risk, so to try and pass specific safety advice relating to the multitude of potential flight-test scenarios, is not practicable; instead, this handbook is presented to provide some background fundamentals to flight-test safety.

This manual therefore attempts, in general, to address the provision of resources for a safety-conscious flight-test and evaluation programme, including test planning principles, hazard analysis, risk management procedures and processes that are pertinent during the conduct of flight-test operations. Not all relevant information is necessarily presented and the recommendation is that the references and other authoritative publications should also be consulted for a fuller understanding of the topic.

However, the dti and CSIR believe that this booklet will be of great value to the Small-Medium-Sized Enterprises in this field of flight-testing non-type certificated aircraft.

**Ms Nomfuneko Majaja,  
Chief Director: Advanced Manufacturing, Aerospace and Defence and Electro-Technical  
The Department of Trade and Industry (the dti)**



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- Mr Brian Wilford, for reviewing the contents of the book.
- Lt Col Charl Coetzee, Chief Test Pilot, SAAF for reviewing the contents of the book.



## Author Biographies

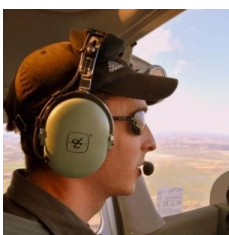


### **Maj. Gen. Desmond Barker (SAAF Rtd.)**

Maj. Gen. Des Barker (SAAF, Rtd.), former Commanding Officer of the South African Air Force's Test Flight and Development Centre (TFDC) is a member of the Flight-test Society of South Africa (FTSSA), the Society of Experimental Test Pilots (SETP) and the Royal Aeronautical Society (RAeS). He is currently the manager of the Aeronautic Systems Competency (ASC) at the Council for Scientific and Industrial Research (CSIR). He graduated as a fixed wing experimental test pilot in 1985 and to date has forty-four years of flying experience totalling approximately 7,000 flying hours on forty-five different variants of military aircraft, nearly all in the flight-test environment. He holds a Commercial Pilot's Licence with a Class I test pilot rating.

During his twenty-eight years of military flight-testing, he was involved in the fixed wing fighter programmes and weapons development testing and amongst others, he was the project test pilot on the Cheetah C, the Mirage IIRZ/Atar 09K50 engine integration and the Mirage F1 fitted with the Russian MiG-29's RD-33 engine derivative. He served as the evaluation pilot on the strategic defence package evaluation team, flying the Mirage 2000, the Hawk 100, the Aerovodochody L-159 and the Aermacchi AM-339. In 1990, he was awarded the Southern Cross Medal for his contribution to flight-testing in the South African Air Force and in 2011, he was awarded the SETP European Flight-test Safety Award for his contributions to flight-test safety.

He is the author of the quintessential book on display flying safety, "Zero Error Margin - Display Flying Analysed" and has published in the SAAF's aviation safety magazine *NYALA*, the Brazilian Air Force magazine *FORCA AEREA*, SETP's quarterly technical publication *COCKPIT*, the South African National Defence Force magazine *SALUT/South African Soldier*, *African Armed Forces Journal* and extensively in the South African general aviation magazine, *World Airnews*.



### **Alan Sutherland (CSIR)**

Alan Sutherland is an aeronautical engineer at the Aerostructures Research Group of the CSIR and is an associate member of the Flight-test Society of South Africa (FTSSA). He graduated from the University of the Witwatersrand in 2006 with a BSc. (Eng.) (Aero.) degree and in 2011 with a MSc. (Eng.) degree (with distinction) in low speed unsteady aerodynamics and control (aero-servoelasticity).

His primary focus is the design and development of flutter excitation systems for flutter flight-testing. He has also been involved in numerous ground vibration tests for flutter clearances of civilian and military aircraft, both locally and internationally. He has presented his research in aero-servoelasticity at two international conferences (ICAS 2008 and ICAS 2010), where he won an award for the best student presentation at the 2008 conference. In 2011, he was invited, as a civilian, to attend the South African Air Force (SAAF) Operational Test and Evaluation (OT&E) course presented to SAAF pilots and engineers. The course focused on operational and post-maintenance flight-testing techniques within the SAAF. On completion of the course, he was pleased to be awarded first place.

He holds a private pilot's licence and night rating and is in the process of completing a multi-engine commercial pilot's licence with an instrument rating.





## Author's Comments

Following on from several aircraft accidents to the homebuilt and light sport aircraft during flight-testing, it is evident that the hazards involved in taking an aircraft from concept design through first flight up to receiving Authority to Fly (ATF), are not fully understood by the non-flight-test community. Understandable of course, since experimental test pilot training is rather expensive and can only be presented by an accredited flight-test training school. The result thereof is that there are many pilots in the general aviation (GA) community going "out on a limb" in conducting flight-tests.

The CSIR Aeronautics Research Group employs more than forty-five aeronautical and mechanical engineers who, in some way or the other, are involved not only in research, but also in forms of flight-testing and as such, are able to provide several safety lessons learned and "flight-test traps" to those aviation enthusiasts who are desirous of building and test flying their own designs.

This guideline would not have been possible without the major efforts by the Federal Aviation Administration (FAA), the Experimental Aircraft Association (EAA) and the United States Ultralight Association's (USUA) efforts to address the flight-testing of Amateur-Built Aircraft and Ultralights. This contribution and in particular that by Mr William J. White, Deputy Director, Flight Standards Service, must be acknowledged for overseeing the development of the Aeronautical Circular Federal Aviation Authority Handbook AC 90-89, "Amateur- Built Aircraft Flight-testing Handbook", dated 18 September 1989.

The FAA Administrator, T. Allen McArtor, and EAA President, Paul H. Poberezny, signed a Memorandum of Agreement as far back as 1 August 1988, which addressed the need for educational and safety programmes to assist amateur-builders in test flying their aircraft. In accordance with that agreement, an Advisory Circular (AC) was developed to provide guidelines for flight-testing amateur built aircraft as part of the FAA's continuing efforts to improve the safety record of all types of general aviation aircraft. This AC was subsequently revised as US Department of Transportation, Federal Aviation Administration Advisory Circular AC No: 90-89A, "Amateur-Built Aircraft and Ultralight Flight-testing Handbook" dated 24 May 1995, to include flight-testing recommendations for canard-type and ultralight aircraft.

In an effort, to support the safety efforts of amateur-built and ultralight aircraft flight-testing in South Africa, this earlier work by the FAA has been used as a baseline with the additions of 'lessons learned', and 'traps' as well as the introduction of appropriate regulations and risk management processes for application by the non-type certificated aircraft community.

The reader should not expect a "bedtime novel" but rather a handbook as recommended reading prior to embarking on a flight-test campaign for Non-Type Certificated Aircraft. It should not be used as a Flight-test Manual, and has no legal standing. A list of additional selected reading material on amateur-built/ultralight flight-testing and first flight experience may be found in Appendix A.



# Table of Contents

Foreword .....	i
Acknowledgements .....	iii
Author Biographies.....	v
Author’s Comments.....	vii
Table of Contents .....	ix
List of Figures.....	xv
List of Tables .....	xvi
Abbreviations .....	xvii
<b>Chapter 1    The World of Non-Type Certificated Aircraft .....</b>	<b>1</b>
1.1    Purpose .....	1
1.2    South African NTCA Growth.....	1
1.3    South African CAA Regulatory Involvement .....	2
1.4    Legislation .....	3
1.4.1    Current Regulations.....	3
1.4.2    Shortcomings in the Regulations.....	3
1.4.3    Safety Standards.....	4
1.4.4    Oversight Capacity by Regulatory Bodies.....	4
1.4.5    Challenges Facing NTCA .....	4
1.4.6    Operational Restrictions.....	6
1.4.7    Design Approval and Production Approval Requirements for NTCA .....	6
<b>Chapter 2    Airworthiness Definitions.....</b>	<b>9</b>
2.1    Introduction .....	9
2.1.1    Amateur Built Aircraft .....	9
2.1.2    Ultralight Aircraft.....	9
2.1.3    Prototype.....	10
2.1.4    Type Certificate .....	10
2.1.5    Airworthiness Certificate .....	11
2.1.6    Supplemental Type Certificate .....	11
2.1.7    Certification Process.....	11
2.1.8    Continued Airworthiness.....	12
2.1.9    Airworthiness Directives.....	12
2.1.10    Service Bulletins .....	13
<b>Chapter 3    Flight-test Safety.....</b>	<b>15</b>
3.1    Flight-test Safety Statistics.....	15
3.2    Safety Review Board .....	16
3.3    Safety Review Board Agenda .....	17
3.4    Flight Briefings .....	18
3.5    Formal Flight-test Report.....	18
<b>Chapter 4    Flight-test Plan.....</b>	<b>19</b>

4.1	Introduction.....	19
4.2	Flight-test Plan Structure.....	19
4.2.1	Main Heading. Flight-test Plan Aircraft .....	19
4.2.2	Scope of Modifications .....	19
4.2.3	Conditions Relevant .....	20
4.3	Flight-test Programme.....	21
4.3.1	Pre-Taxi Tests .....	22
4.3.2	Ground Testing.....	22
4.3.3	Cockpit Evaluation.....	22
4.3.4	Cockpit Night Lighting Evaluation .....	22
4.3.5	Oxygen System .....	22
4.3.6	Sign Out Aircraft to First Flight .....	22
4.3.7	High Speed Taxi Tests.....	22
4.3.8	Structural Testing .....	23
4.3.9	Aeroelastic Testing .....	23
4.3.10	Static/Dynamic CG Margin .....	23
4.3.11	Pitot-Static System .....	23
4.3.12	Performance Testing .....	23
4.3.13	Stability and Control.....	24
4.3.14	Engine/Fuel System Functional Tests.....	24
4.3.15	Example Provisional Flight-test Schedule .....	24
<b>Chapter 5</b>	<b>Flight-test Risk Management Process .....</b>	<b>29</b>
5.1	Fundamentals .....	29
5.1.1	Hazard .....	29
5.1.2	Risk.....	29
5.1.3	Hazard Analysis .....	29
5.1.4	Risk Management .....	29
5.1.5	Team Safety Philosophy .....	29
5.2	Risk Management Process (Prior to Flight-testing) .....	30
5.2.1	Identify the Test Technique Involved.....	30
5.2.2	Identify the Hazard(s) Associated with the Test Technique.....	30
5.2.3	List the Cause of Each Hazard .....	30
5.2.4	List the Effect of Each Hazard .....	30
5.2.5	Perform a Subjective Risk Assessment.....	30
5.2.6	Describe the Steps for Mitigation of Causes for Each Hazard.....	32
5.2.7	Describe Emergency Procedures .....	33
5.2.8	Document and Accept Risk Management.....	33
5.3	Risk Management Process (During the Conduct of Flight-testing).....	33
5.3.1	Pre-flight Briefing Checklists .....	33
5.3.2	Maintaining Configuration/Conformity .....	33
5.3.3	Constantly Re-assess Risk.....	34
5.3.4	Procedures for Changes to Test Profile.....	35
5.4	Risk Management Process (After Completing Flight-testing).....	35

	5.4.1	Post-flight Briefing.....	35
	5.4.2	Capturing Lessons Learned.....	35
	5.4.3	Programme Debrief.....	35
<b>Chapter 6</b>		<b>Preparation for Flight-testing of NTCA .....</b>	<b>39</b>
6.1		The Test Pilot .....	39
	6.1.1	CAA Licensing Standards .....	39
	6.1.2	Experimental Test Pilot Training.....	40
	6.1.3	Test pilot requirements SA CAA Class II Test Pilot.....	41
	6.1.4	Test Pilot Requirements for NTCA.....	42
	6.1.5	Suggested Minimum Preparation for NTCA Test Pilots.....	42
6.2		Support Infrastructure .....	43
	6.2.1	Airports.....	43
	6.2.2	Hangarage .....	43
	6.2.3	Runway Selection .....	43
	6.2.4	Emergency Landing Fields .....	44
	6.2.5	Hospital Location.....	44
	6.2.6	Fire Rescue Services .....	44
	6.2.7	Fire Extinguisher .....	44
	6.2.8	Fire Protection .....	44
	6.2.9	Communications.....	44
	6.2.10	Ground Crew Support.....	45
	6.2.11	Emergency Planning .....	45
	6.2.12	Emergency Plans Briefing .....	45
6.3		The Aircraft .....	46
	6.3.1	Assembly and Airworthiness Inspection .....	46
	6.3.2	Control Stick/Wheel .....	46
	6.3.3	Brakes.....	46
	6.3.4	Main Undercarriage .....	47
	6.3.5	Control Surfaces .....	48
	6.3.6	Instrument Panel.....	48
	6.3.7	Carbon Monoxide.....	48
	6.3.8	Engine and Propeller Controls.....	48
	6.3.9	Pitot/Static System .....	49
	6.3.10	Altimeter/Vertical Speed.....	49
	6.3.11	Fuel System .....	49
	6.3.12	Hydraulic System .....	50
	6.3.13	Avionics and Electrical Checks.....	51
	6.3.14	Cowling and Panel Checks.....	51
	6.3.15	Canopy/Door Lock Checks.....	51
	6.3.16	Parachute .....	51
	6.3.17	Safety Belt and Shoulder Harness .....	51
	6.3.18	Ballistic Recovery System .....	52
	6.3.19	Weight and Balance.....	53

	6.3.20	Empty Aircraft .....	53
	6.3.21	Takeoff Configuration (Additional Items Added) .....	54
6.4		The Engine .....	56
	6.4.1	Engine Testing .....	56
	6.4.2	New/Overhauled Engine Run-In Procedures .....	56
	6.4.3	Used Engine Run-In Procedures .....	57
	6.4.4	Pre Run-in Checks .....	57
	6.4.5	Test and Support Equipment .....	57
	6.4.6	Safety Precautions .....	58
	6.4.7	The First Engine Run.....	58
	6.4.8	Engine Cool Down .....	59
	6.4.9	Recording the Engine Run-In Data .....	59
	6.4.10	After Shut-Down .....	60
	6.4.11	Ground Test of Engine Operation Simulating Flight .....	60
	6.4.12	Mixture and Idle Speed Check .....	60
	6.4.13	Magneto Check .....	60
	6.4.14	Cold Cylinder Check .....	61
	6.4.15	Carburettor Heat.....	61
	6.4.16	Fuel Flow Check .....	62
	6.4.17	Changing Fuel Flow or Pressure .....	62
	6.4.18	Compression Check.....	62
	6.4.19	Last Check .....	62
6.5		Propeller Serviceability Testing .....	62
	6.5.1	Safety Hazards of Propeller Operation .....	63
	6.5.2	Propeller Blade Tracking Check.....	63
	6.5.3	Metal Propeller Inspection.....	64
	6.5.4	Metal Blade Nicks.....	65
	6.5.5	Propeller Inspection .....	65
	6.5.6	Composite Propeller Inspection.....	66
6.6		Documentation.....	67
	6.6.1	Traceability.....	67
	6.6.2	Weight and Balance .....	67
	6.6.3	Airworthiness .....	67
	6.6.4	Checklists .....	67
	6.6.5	Flight Manual .....	68
	6.6.6	Maintenance Records (Logbooks).....	68
<b>Chapter 7</b>		<b>Flight-test Programme .....</b>	<b>69</b>
	7.1	Introduction.....	69
	7.2	Taxi Tests .....	69
	7.2.1	Low Speed Taxi Tests .....	69
	7.2.2	High Speed Taxi Tests.....	70
<b>Chapter 8</b>		<b>The First Flight Guidelines .....</b>	<b>73</b>
	8.1	First Flight Guidelines .....	73

8.2	First Flight Decreases.....	74
8.3	The Role of the Chase Aircraft .....	75
8.4	Emergency Procedures .....	76
8.4.1	Engine Failure on Takeoff.....	76
8.4.2	Engine Vibration Increases with RPM.....	77
8.4.3	Smoke in the Cockpit.....	77
8.4.4	Engine Fire .....	77
8.4.5	Out of Rig Condition .....	77
8.4.6	Cabin Door Opening in Flight.....	77
8.4.7	Other Possible Emergencies .....	77
8.5	The First Flight.....	77
8.6	The Second Flight.....	81
8.7	The Third Flight .....	81
8.8	Flights 4 through 10 .....	82
8.8.1	Climbs and Descents.....	83
8.8.2	Airspeed Indicator Calibration.....	83
8.8.3	Expanding the Envelope .....	85
8.9	Flights 11 through 20 .....	85
8.9.1	Power Off Stalls .....	86
8.9.2	Power on Stalls .....	88
8.9.3	Best Rate of Climb Speed Tests .....	88
8.9.4	Best Angle of Climb Speed Tests .....	89
8.9.5	Slow Flight-test.....	89
8.10	Flights 21 through 35: Stability and Control Checks .....	90
8.10.1	Stability Definitions .....	91
8.10.2	Static Longitudinal Stability Testing .....	92
8.10.3	Lateral-Directional Stability Control Tests.....	94
<b>Chapter 9</b>	<b>Envelope Expansion .....</b>	<b>97</b>
9.1	Introduction .....	97
9.2	Aeroelasticity: Flutter .....	97
9.3	Spinning .....	99
9.4	Accelerated Stalls.....	101
9.5	Putting it all Together: Flights 36 to 40.....	102
9.5.1	Maximum Gross Weight Tests.....	102
9.5.2	Service Ceiling Tests .....	103
9.5.3	Navigation Systems Testing.....	103
9.5.4	Very High Frequency (VHF) Omni-directional Radio Range (VOR) .....	104
9.5.5	Fuel Consumption Measurement.....	105
9.5.6	Night Lighting Evaluation.....	106
<b>Chapter 10</b>	<b>The Canard Type Amateur Built Aircraft.....</b>	<b>109</b>
10.1	Canards .....	109
10.2	Flight-test Considerations .....	111
<b>Chapter 11</b>	<b>Flight-Testing of Ultralights .....</b>	<b>113</b>

11.1	Ultralights .....	113
11.2	The Test Pilot .....	114
11.3	Pre-Flight Airframe Inspection.....	114
	11.3.1 Undercarriage Inspection.....	116
	11.3.2 Wing Assembly.....	116
	11.3.3 Fuselage Assembly .....	117
	11.3.4 Engine.....	118
	11.3.5 Exhaust System .....	118
	11.3.6 Fan Cooling.....	119
	11.3.7 Reduction Drive.....	119
11.4	Fuel Systems .....	119
	11.4.1 General.....	119
	11.4.2 Test for Alcohol in Automotive Fuel .....	119
	11.4.3 Fuel Primer System .....	120
	11.4.4 Filters, Fuel Lines, and Throttles .....	120
	11.4.5 Causes of High Fuel Consumption.....	120
11.5	Airport Selection.....	121
11.6	Taxiing.....	121
11.7	First Flight Differences.....	121
	11.7.1 Use of Power .....	121
	11.7.2 Control Feel.....	121
	11.7.3 Stalls.....	121
	11.7.4 Steep Turns .....	122
<b>References.....</b>		<b>123</b>
<b>Appendices.....</b>		<b>125</b>
Appendix A	Additional References on Flight-testing.....	125
Appendix B	Safety Review Board Action Item Summary .....	129
Appendix C	Suggested Flight-test Briefing Points .....	131



## List of Figures

Figure 1.1 The Growth Rate of NTCA/Light Sport Aircraft (LSA).....	2
Figure 3.1 Analysis of Flight-test Accident Causal Factors.....	16
Figure 5.1 Subjective Risk Assessment Matrix.....	31
Figure 6.1 Runway Length Chart (Reference 1).....	43
Figure 6.2 Weight and Balance Example: Empty Aircraft (Reference 1) .....	53
Figure 6.3 Propeller Tracking Test (Reference 1).....	64
Figure 8.1 Typical Position Error Correction for Ground Course Pitot/Static Calibration .....	85
Figure 8.2 Typical Plot of Stall Speed versus Aircraft Mass for Different Flap Configurations at 1g .....	87
Figure 8.3 Climb Performance Standardised .....	89
Figure 8.4 Best Angle of Climb Airspeed ( $V_x$ ).....	90
Figure 8.5 Time History for Static and Dynamic Stability .....	91
Figure 8.6 A Typical Stick Force versus Airspeed Curve for a Stable Aircraft .....	93
Figure 10.1 (a) Rutan LongEze Design (b) Quickie (Q2) Design .....	109
Figure 11.1 A Typical Ultralight Aircraft .....	113

## List of Tables

Table 4.1	Example of a Typical High Level Flight-test Schedule .....	26
Table 5.1	Risk Management Item in a Different Format (One Page per Hazard).....	37
Table 6.1	Weight and Balance Data Example (Aircraft Empty) .....	54
Table 6.2	Weight and Balance Data Example (Additional Items Added) .....	55
Table 9.1	Fixed Pitch Power Multiplier .....	106

## Abbreviations

AC	Advisory Circular/Airworthiness Certificate
AIC	Aeronautical Information Circular
AD	Airworthiness Directive
agl	Above Ground Level
amsl	Above Mean Sea Level
ASC	Aeronautic Systems Competency
ASI	Airspeed Indicator
ATC	Air Traffic Control
ATF	Authority to Fly
BRS	Ballistic Recovery System
CAA	Civil Aviation Authority
CAR	Civil Aviation Regulations
CAS	Calibrated Airspeed
CATS	Civil Aviation Technical Standards
CDI	Course Deviation Indicator
CEC	Compressibility Error Correction
CG	Centre of Gravity
CHT	Cylinder Head Temperature
C/L	Centre Line
CSIR	Council for Scientific and Industrial Research
dti	Department of Trade and Industry
EAA	Experimental Aircraft Association
EAS	Equivalent Airspeed
ELOS	Equivalent Level of Safety
ELT	Emergency Location Transmitter
FAA	Federal Aviation Authority
FAR	Federal Aviation Regulations
FTSSA	Flight-test Society of South Africa
GA	General Aviation
GPS	Global Positioning System
IAS	Indicated Airspeed
ICAO	International Civil Aviation Organization
ICAS	International Council of Aeronautical Sciences

IEC	Instrument Error Correction
JAR	Joint Aviation Requirements
KCAS	Knots Calibrated Airspeed
KIAS	Knots Indicated Airspeed
LSA	Light Sport Aircraft
MAC	Mean Aerodynamic Chord
MF	Master File
mph	Miles per Hour
MRI	Master Reference Index
NE	North East
NOTAM	Notice to Airmen
NTCA	Non-Type Certified Aircraft
NTSB	National Transportation Safety Board
NW	North West
OEM	Original Equipment Manufacturer
OT&E	Operational Test and Evaluation
PEC	Position Error Correction
POH	Pilot's Operating Handbook
RAASA	Recreation Aviation Administration - South Africa
RAeS	Royal Aeronautical Society
RAS	Rectified Airspeed
RPM	Revolution per Minute
SAAF	South African Air Force
SACAA	South African Civil Aviation Authority
SAS	Société par Actions Simplifiée
SB	Service Bulletin
SE	South East
SETP	Society of Experimental Test Pilots
SIIP	Strategic Initiative Implementation Unit
SPPO	Short Period Pitching Oscillation
SRB	Safety Review Board
STC	Supplemental Type Certificate
SW	South West
TAS	True Airspeed
TC	Type Certificate

TCA	Type Certified Aircraft
TCDS	Type Certificate Data Sheet
TFDC	Test Flight and Development Centre
US	United States
USUA	United States Ultralight Association
UV	Ultraviolet
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VOR	VHF Omni-directional Radio Range
VOT	VOR Test Facility



# Chapter 1

## The World of Non-Type Certificated Aircraft

### 1.1 Purpose

The purpose of this handbook is to provide guidelines and serve as recommended reading for the Non-Type Certificated Aircraft (NTCA) community in South Africa. Outside of the mainstream regulatory structures governing aviation, the homebuilt, experimental and Warbird category of aircraft are faced with their own particular challenges, more particularly, the lack of comprehensive flight-test safety oversight. A contradiction emanates from the regulator demanding that before registration on the civil aviation register, such aircraft must be subjected to some form of flight-testing to verify the safety of design. The contradiction is that the knowledge of flight-testing principles, philosophies and procedures in the NTCA domain, is extremely limited and as such, the primary purpose of publishing this handbook therefore, as an initiative of the dti's (Department of Trade and Industry's) Strategic Initiative Implementation Unit (SIIP), is to provide:

- Background information to the South African NTCA community in their efforts to bring their design initiatives to safe flight.
- To make amateur-built/ultralight aircraft pilots aware that test flying an aircraft is a critical undertaking, which should be approached with thorough knowledge planning, skill, and common sense. Failure to comply with universal best practice, could result in a catastrophe.

In the interests of universal 'best practice', this book was designed to assist amateur and ultralight builders in developing individualized aircraft flight-test programmes based on the US Department of Transportation, Federal Aviation Administration Advisory Circular AC No: 90-89A, "Amateur-Built Aircraft and Ultralight Flight-testing Handbook" dated 24 May 1995.

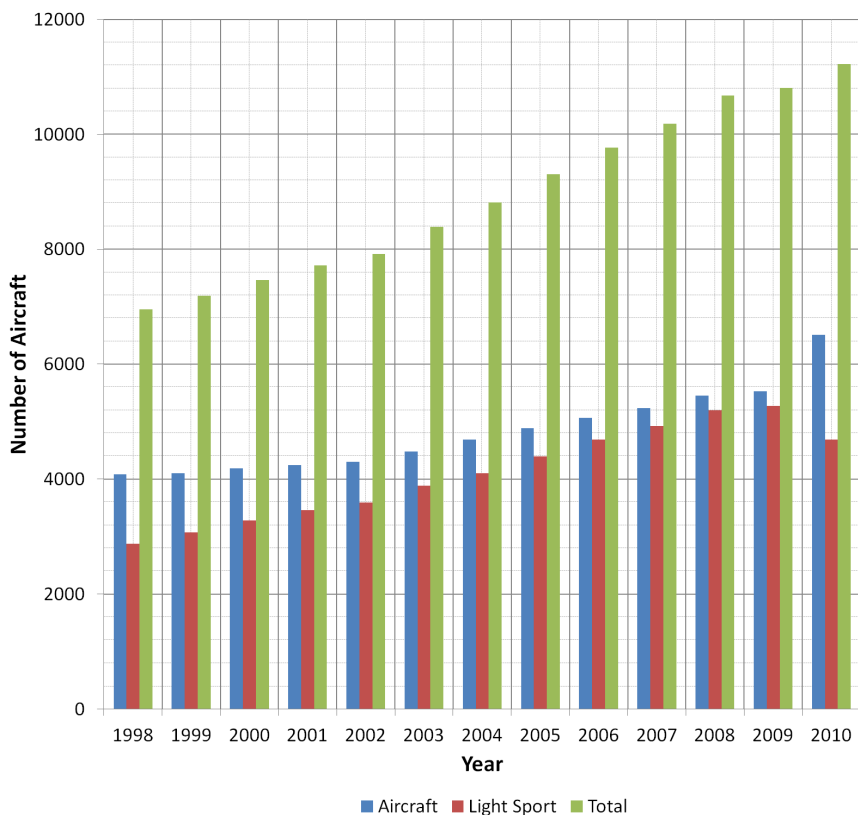
The Civil Aviation Authority (CAA), the Experimental Aircraft Association (EAA) and the Recreation Aviation Administration - South Africa (RAASA) are committed to improving the safety record of amateur-built and ultralight aircraft, during flight-testing. Following on from flight-test accidents in South Africa, a need for educational and safety programmes to assist amateur-builders in test flying their aircraft, was considered essential. This handbook endeavours to provide guidelines for flight-testing Non-Type Certificated aircraft as part of the CAAs continuing efforts to improve the safety record of all types of general aviation aircraft. For the purposes of design and manufacturing, aircraft are generally divided into two major categories:

- Those which have been designed and manufactured under the standards that meet or exceed those of ICAO, otherwise known as type certified aircraft (TCA).
- Those which are not compliant with ICAO standards, known as Non-Type certified aircraft (NTCA).

### 1.2 South African NTCA Growth

The total number of air vehicles on the SACAA register increased since January 1998 from 6,977 to 11,227 by December 2010, equating to an average growth rate of 327 aircraft per annum. This total was constituted by an average growth rate of 187 aircraft per annum, while the rate of increase in light/sport aircraft, averaged a growth rate of 140 per annum. With the numbers of light/sport aircraft increasing significantly due to the lower acquisition and operating costs, a trend that and can be expected to continue,

the requirement for flight-testing of the non-type certificated aircraft has consequently also increased proportionately.



**Figure 1.1** The Growth Rate of NTCA/Light Sport Aircraft (LSA)<sup>1</sup>

### 1.3 South African CAA Regulatory Involvement

Regulatory provisions have been developed by the CAA in an attempt to properly control and regulate this class of aircraft, all in the interest of safety and orderly growth of the aviation industry.

The increase of technical expertise and design software codes amongst aviation enthusiasts, homebuilders, and highly experienced aviation tradesmen making a living from designing and developing their ideas and hand work, has created the environment within which NTCA has prospered significantly. Several companies have been established that are in the business of designing, developing and producing their goods, while others have taken to upgrading or modifying existing designs or ‘bringing back to life’, former military aircraft under the classification of “Warbirds”.

As a result of changes in the forces that influence the development and retention of military aircraft, a large quantity of ex-military aircraft have become available for civilian use, which has also added to the growth and sophistication of the NTCA sub-sector of aircraft. South Africa is one of the countries where this development has seen a rapid growth and increasing complexity of NTCA with a propensity to engage in an increasing variety of activities including those involving hire and reward.

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<sup>1</sup> This figure clearly illustrates how the growth rate of NTCA/LSA has increased significantly in relation to the classical type certificated aircraft class.



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## **1.4 Legislation**

### **1.4.1 Current Regulations**

Historically, NTCA in South Africa were regulated under a set of standards in a document called LS/1, which were not regulations in the proper sense of establishing airworthiness for Non-Type-Certificated Aircraft (Special Airworthiness Certification). With the establishment of the SACAA, work commenced to transform the LS/1 standards into formal Civil Aviation Regulations (CARs) promulgated by the Minister under the provisions of the Aviation Act, 1962. In November 2002, the draft regulations to take over from the LS/1 standards were completed and the Commissioner retired the LS/1 standards by way of issuing a general exemption covering all aircraft that do not meet regulations that give effect to ICAO standards.

The exemption made the draft regulations a condition i.e. the exempted aircraft had to meet provisions of the draft regulations. Although the regulations were intended to be submitted to the Minister for his consideration in time to be made law by May 2004, they were never submitted for such consideration due to factors that were evidently not adequately catered for in their current form.

The following extracts from the CAR; Part 24 of the CARs for Certification and Airworthiness of NTCA are listed while the commercial use of this type of aircraft is limited to a Class III license issued by the Domestic Air Service License Council which allows:

- Acrobatic operations.
- Advertising operations.
- Aerial patrol observation and survey.
- Aerial recording by photographic or electronic means using the licensee's equipment to produce a pictorial end product.
- Agricultural, cloud spraying, seeding and dusting operations.
- Emergency medical service including the provision of casualty equipment and medical personnel.
- Fire spotting, control and fighting.
- Game and livestock selection, culling, counting and herding.
- Parachute dropping operations.
- Semi-aerobatic operations.
- Tug operations.
- Underslung and winching operations.
- "Flipping," i.e. carriage of passengers without landing anywhere other than point of departure.

It should be borne in mind that, in allowing NTCA to undertake these activities, the intent was never to be in direct competition with Type Certificated Aircraft (TCA) that operate under stringent safety standards, or to reduce safety levels in the carrying out of the activities. It is notable however, that some NTCA have capabilities that are comparable with TCA and may on proving such capabilities, be permitted on a case by case basis, to carry out specific activities alongside TCA.

### **1.4.2 Shortcomings in the Regulations**

Since the introduction of the abovementioned draft, parts of the CAR's, significant shortcomings in the regulations and in their implementation were identified. Despite the well meaning intention to facilitate the sub-sector of aviation that utilized NTCA, mainly small general aviation aircraft, some basic principles of aviation safety were missing. As an example, the Regulations providing relief from the ICAO standards were

to be framed in a way that still achieved an Equivalent Level of Safety (ELOS) and in most cases, this would be achieved by mitigating engineering limitations of the aircraft with measures such as:

- Aircraft operational restrictions.
- Limitations on passengers that may be carried, if at all.
- Limitation of exposure of the public on the ground, other aircraft, etc.
- A more focused safety oversight regime.

Without such measures, the public flying on NTCA, particularly as passengers, the public and property on the ground, other aircraft (including ICAO compliant aircraft) would be exposed to unacceptable risks. Consequently, the level of safety expected by the public would be eroded.

### **1.4.3 Safety Standards**

The basis for safety concerns by regulatory authorities revolves around the difference in design and construction between Type, and Non-Type Certificated Aircraft. Type Certified Aircraft are certified/manufactured through a rigorous process by showing compliance with internationally recognized sets of design standards that usually establish an acceptable risk factor estimate putting the probability of a serious event happening, at  $10^{-9}$ . This is what has come to be expected by the second and third parties when involved in international air transport and is the intent behind ICAO Standards and Recommended Practices.

Most NTCA, by their very nature, are such that the risk factor is increased to a level that is not generally perceived by the passengers that may be flown in them, more so the general public that is not flying or is flying in other aircraft, which is nevertheless exposed to risks of occurrences by the NTCA. This risk factor can be controlled by adequately educating operators of these aircraft as to the various levels of risk, and imposing certain restrictions on the operation of NTCA, that will reduce the exposure of the uninformed second and third parties.

It is however the responsibility of the CAA to ensure that measures are in place to ensure that the original construction of the aircraft is to an acceptable standard for the intended use and that the continued airworthiness of the aircraft can be maintained through acceptable practices. In addition, a comprehensive set of requirements that will provide the general public with the equivalent level of risk management as is perceived for TCA, must be enforced.

### **1.4.4 Oversight Capacity by Regulatory Bodies**

A known acceptable level of safety can only be sustained when the resources for quality assurance and control of a safety system are available and effectively deployed. Worldwide, the growth of the NTCA sub-sector has in recent years been significant and can no longer be adequately overseen and controlled under approaches envisaged in the past years. In this context, it is recognised that the NTCA contribution to resources required for total national safety oversight, is typically low, while the highest number of occurrences of accidents and incidents typically occurs in this category; the public perception of accidents, however, does not distinguish between NTCA and TCA.

### **1.4.5 Challenges Facing NTCA**

The challenges facing NTCA essentially stems from the fact that the Original Equipment Manufacturer (OEM) is not, or is no longer responsible for the integrity of the air vehicle which has been passed on to the owner/builder or aircraft restoration enthusiast.

### *Lack of Manufacturer Support*

In most cases of TCA, the level of safety achievable is through the participation of a number of parties, of which the most critical, is the manufacturer. Manufacturer's support, which provides such invaluable components such as expertise and field experience on the behaviour of their product, is relied upon by both the operator and the safety oversight authority. In the case of NTCA, where in most cases manufacturer's support is not available, compensatory mechanisms are therefore, necessary. The lack of manufacturer's support is obviously more critical with complex aircraft, which most recent ex-military aircraft happen to be. The lack of manufacturer's support requires the CAA to ensure that the owner of the aircraft has in place suitable alternatives, and the CAA itself, must have oversight measures that are accordingly informed.

### *Type Certification Capacity*

The type certification of NTCA requires that the CAA undertake a certain level of investigation and assessment of the design standards and criteria. The lack of such capacity in the CAA and indeed the industry, particularly when it comes to ex-military, light sport and homebuilt aircraft, poses a serious safety challenge to the entire industry.

### *Shortage of Aircraft Knowledge and Expertise*

Due to the large variety and differences from one aircraft to another in the NTCA sub-sector, availability of expertise per aircraft is usually low, a situation aggravated in the case of ex-military aircraft, where essential knowledge, documentation or other forms of information relating to the aircraft, may be classified, outdated or not even exist. Furthermore, cognizance needs to be taken of the fact that no two ex-military aircraft may be treated as the same for the purposes of type acceptance and continued airworthiness, due to a variety of possible modifications that may have taken place on it, either as specialised deliveries, or while in service. The true state of the aircraft's fatigue levels and accidents the aircraft may have experienced while in military service, provides additional concerns.

### *Complexity of the Aircraft*

As a result of increasing expertise and technological advances, NTCA have since the 1970's, increased in complexity, clearly outstripping the knowledge and skill levels determined to be sufficient in the initial maintenance and operating personnel provisions. Consequently, many NTCA are more complex than even some TCA, significantly increasing the operational risks associated with NTCA. However, the rules and the regulations that are in existence to govern NTCA, do not seem to cater for the oversight of such complex aircraft.

### *Social Impact*

The aviation community is well aware that without certain engineering and flight-test interventions undertaken in the design, manufacturing and operation of an aircraft, the consequences thereof would invariably be unacceptable rates of incidents and accidents. Any rate or absolute number of incidents and accidents perceived to be unacceptable to the public, will have a negative impact on the whole of the aviation industry, particularly air transport industry insurance, and other parts of the national economy supported by air transport, such as tourism. NTCA on the other hand, constitute a large portion of the grassroots aviation, which supports and bolsters development in the upper levels of industry. It is prudent therefore, that measures put in place to facilitate the development and growth and participation of NTCA for social and economic reasons, do not result in undermining public confidence in aviation itself.

#### 1.4.6 Operational Restrictions

In an effort to cater for NTCA oversight challenges, several restrictions have been imposed on their operation:

- No person shall operate an NTCA except for the purpose for which an Authority to Fly Permit has been issued. In addition, due to the possible reduced safety oversight of the design, no person shall be carried on a NTCA unless that person is:
  - A flight crew member.
  - A flight crew member trainee.
  - A crew member performing an essential function in connection with the purpose of the operation for which the aircraft has an Authority to Fly Permit.
  - A crewmember that is necessary to accomplish the work activity directly associated with that special purpose.
- In terms of flight-testing, no person shall operate NTCA:
  - Over built up areas.
  - Over or near public gatherings or populated recreational areas where the aircraft many constitute a nuisance to persons therein, unless in an activity associated with such gathering or area and under provision of Part 91 of the regulations and subject to other conditions that may be imposed by the Director.
  - In or near congested airways.
  - Near a busy airport where passenger transport operations are conducted.
  - Near terminal and airways used by international air traffic.
- Owing to the criticality of safety issues relating to ex-military aircraft, the Director will apply his powers in imposing appropriate limitations when issuing all new Authority to Fly Permits for ex-military aircraft under the existing Part 24 of the Civil Aviation Regulations.

#### 1.4.7 Design Approval and Production Approval Requirements for NTCA

- The South African Civil Aviation Authority, Aeronautical Information Circular, AIC 60.2 10-050-06, "Procedures for Registration and Issuance of Flight Authority on Non-Type Certified Aircraft", provides information for Part 24 of the Civil Aviation Regulations, 1997 as amended, and the "Civil Aviation Technical Standards Airworthiness Requirements (SA-CATS-NTCA)", require that the Director must be furnished with such data relating to the design, construction, performance and maintenance of the aircraft and so requires such tests, including ground static tests and flight-tests, as deemed necessary for the purpose of issuing or granting of an Authority to Fly in respect of a Non-Type Certified Aircraft. The specific requirements for NTCA are as follows:
  - Amateur built NTCA are not required to have been issued a NTCA Approval Certificate by the SACAA. The design of these aircraft are considered on a case-by-case basis, and is substantiated through the process leading up to the issuance of an Authority to Fly by submission of the Design Criteria, Static Tests , Structural Analysis , Flight-tests, etc.
  - Production built NTCA to be manufactured or assembled by a local organisation, and to be sold to the general public, require both a NTCA Design Approval and a Production Approval.
  - A Design Approval of a NTCA type is granted in the form of a NTCA Approval Certificate.

- A NTCA Approval is required for the first-of-type production built and ready-to-fly aircraft, before being placed on the SA Civil Aircraft Register.
- NTCA Design Approvals may only be applied to aircraft which have demonstrated compliance to an acceptable airworthiness design standard, e.g. JAR-VLA, ASTM F2245, BCAR S, LTF-UL, FAR 23, etc.
- A NTCA imported as a “ready to fly” or production built from a foreign facility is required to be issued with a NTCA Design Approval if the aircraft meets an acceptable airworthiness design standard.
- Any changes or deviations from the type design, build standard or construction manual, including major modifications to amateur built aircraft, are to be approved by the Director in the form of a modification approval.



# Chapter 2

## Airworthiness Definitions

### 2.1 Introduction

Understanding the policies, philosophies and regulations governing flight-test is an essential starting point for the development of a professional flight-test programme. Knowledge of the underlying concepts defined in Type Certificates, Airworthiness Certificates, Airworthiness Directives, Service Bulletins, and Supplementary Type Certificates complement an understanding of the processes applicable to flight-test, both Type Certified Aircraft and Non-Type Certificated Aircraft.

#### 2.1.1 Amateur Built Aircraft

“Amateur-built aircraft” means an aircraft issued an Experimental Airworthiness Certificate under the provisions of Federal Aviation Regulations (FAR) § 21.191 (g).



#### **SA CAA Incident Report 0399 - 3 April 2005**

*“The owner/builder/pilot had completed building the aircraft (Rainbow Cheetah) from a kit he purchased from the manufacturer. The aircraft was scheduled for its final inspection and test flight the next week. The owner/pilot was involved in taxi operations to set-up the propeller pitch and clear out an engine defect when the nose landing gear collapsed. It occurred at approximately 40 mph on the centre-line of Runway 02. The owner/builder*

*discovered that the nose landing gear strut was manufactured of a material that was thinner than what was specified in the approved drawing. The aircraft was not registered at the time of the incident. Besides the ground running of the engine, it had zero time recorded in flight. The preliminary airframe inspection during the building process was certified on 2 April 2005. The aircraft sustained minor damage when the nose landing gear failed and the propeller contacted the runway surface. The aircraft also sustained minor damage to the tail and wings when it nosed over.*

*Probable Cause: The nose landing gear of the aircraft collapsed due to the failure of the nose landing gear strut. The strut was found to be manufactured from a tube with a thinner gauge material than that required by the approved manufacturing drawings.”*

Note: The aircraft shown above is not that actual aircraft involved in the accident, but merely an example of the specific type.

#### 2.1.2 Ultralight Aircraft

The term “ultralight” means a vehicle that meets the requirements of FAR § 103.1 and also includes a two-place training vehicle of 496 pounds or less, operating under an EAA or RAASA exemption to FAR Part 103. Refer to Chapter 11 for flight-testing of ultralight aircraft.

### 2.1.3 Prototype

An initial design sample, known as a prototype, is built and may refer to either the aircraft, the engines or the propeller, depending on the basis of the certification. For flight-test purposes several prototypes may be built, each the subject of different test programmes. The prototypes are first used for ground and system tests, with one of the prototypes, known as the "static airframe", being subject to destructive testing, i.e., the prototype is subject to stress beyond normal and abnormal operations until destruction, the test-results of which are compared with initial submitted calculations to establish the ultimate structural strength. Other prototypes will undergo systems compliance tests until accepted by the regulators based on the principle of successful demonstration and compliance with specifications and regulations. With all ground tests completed, prototypes are then made ready for flight-tests.

The flight-tests are flown by specially approved flight-test pilots who will fly the prototypes to establish the ultimate flight limits, which should comply with the airworthiness rules. In parallel with aircraft testing, the applicant also draws up a maintenance programme to support continued airworthiness after approval of the design. The maintenance programme is compiled with inputs from flight and ground test results and also from the engineering test reports and is then submitted to the regulators for comment and approval. After successful completion of ground and flight-tests, along with an approved maintenance programme, the prototype is approved and the company is granted the Type Certificate for the prototype. The legal term for the applicant is now the "Type Certificate Holder" with the prototype subsequently serving as a template for aircraft production.

### 2.1.4 Type Certificate

A "Type Certificate" (TC) is awarded by aviation regulating bodies to aerospace manufacturers after it has been established that the particular design of a civil aircraft, engine, or propeller, has fulfilled the regulating bodies' current prevailing airworthiness requirements for the safe conduct of flights under all normally conceivable conditions (military types are usually exempted). The TC is the basis for other approvals, including production and airworthiness approvals and normally includes:

- the type design,
- the operating limitations,
- the Type Certificate Data Sheet (TCDS),
- the applicable regulations, and
- other conditions or limitations prescribed by the CAA.

Aircraft produced under a type certified design are then issued a standard airworthiness certificate which is essentially the design approval issued by the CAA when the applicant has successfully demonstrated that a product has complied with the applicable regulations.

Often the basic design is enhanced further by the Type Certificate holder and major changes beyond the authority of the service bulletins, require amendments to the Type Certificate. For example, increasing or decreasing an aircraft's flight performance, range and load carrying capacity by altering its systems, fuselage, wings or engines resulting in a new variant, may require re-certification. Again, the basic process of type certification is repeated but unaltered items from the basic design need not be retested. Normally, one or two of the original prototype fleet are remanufactured to the new proposed design and as long as the new design does not deviate significantly from the original, static airframes do not need to be built. The resultant new prototypes are again subjected to a flight-test programme to validate and verify design changes.



Upon successful completion of the certification programme, the original type certificate is amended to include the new variant (normally denoted by a new model number additional to the original type designation). Typical examples are the Boeing 737NG (737-600, 737-700, 737-800 and 737-900) which replaced the 737 Classic family (737-100, 737-200, 737-300, 737-400 and 737-500) and the A340-500 and the A340-600 which is based on the Airbus A340-200 and the A340-300.

The Type Certificate holder keeps the Type Certificate valid by continuously following airworthiness directives, issuing service bulletins and as well as providing spares and technical support to keep the aircraft current within the prevailing regulations, even after the production of the type has stopped. This is what is meant by supporting the type and in this manner many out-of-production aircraft continue useful lives. STCs are also bound by the same regulations. When the OEM decides to stop supporting the aircraft type, the type certificate is returned to the regulators and the remaining aircraft fleet permanently grounded, it was in this manner that the whole Concorde fleet was finally grounded when Airbus SAS (Société par actions simplifiée) surrendered its type certificate.

### **2.1.5 Airworthiness Certificate**

An "Airworthiness Certificate" (AC) is only issued to an aircraft that is properly registered and was found to conform to its TCDS and be in a condition for conducting safe operations. The Airworthiness Certificate is valid and the aircraft may be operated as long as it is maintained in accordance with the rules issued by the CAA.

### **2.1.6 Supplemental Type Certificate**

A "Supplemental Type Certificate" (STC) is issued by the regulatory authority approving a product, aircraft, engine, or propeller modification and defines the product design change and states how the modification affects the existing type design. It also identifies the certification basis listing specific regulatory compliance for the design change. Information contained in the certification basis is helpful for those applicants proposing subsequent product modifications and evaluating certification basis compatibility with other STC modifications.

Any additions, omissions or alterations to the aircraft's certified layout, built-in equipment, airframe and engines, initiated by any party other than the type certificate holder, need an approved supplementary ("supplemental" in FAA terminology) type certificate, or STC. The scope of an STC can be extremely narrow or broad. It could include minor modifications to passenger cabin items or installed instruments while more substantial modifications may involve an engine replacement, as in the Blackhawk modifications to the Cessna Conquest and Beechcraft King Air turboprops, or a complete role change for the aircraft, such as converting a Boeing B-17 or a Stearman into an agricultural aircraft.

STCs are frequently raised for out-of-production aircraft types or conversions to fit new roles, but before STCs may be issued, procedures similar to type certificate changes for new variants are followed, most likely including a comprehensive flight-test programme. STCs belong to the STC holder and are generally more restrictive than type certificate changes.

### **2.1.7 Certification Process**

Initially, the applicant submits documents to the CAA, detailing how the proposed design would fulfil the airworthiness requirements. After investigations by the regulator, the final approval of such documents becomes the basis of the certification. The applicant follows the SACAA process and compiles a proposed timetable of actions required for certification tests. With the application, the regulations to be applied will

usually be frozen for a given amount of time in order to avoid a situation where the applicant would have to change the design as a result of changed regulations.



**SACAA Accident Report 7887 - 27 November 2004**

*“The aircraft (Druine Turbulent) was subjected to a test flight after extensive repairs were carried and a different engine was fitted. After the required pre-flight checks were carried out the pilot took-off from Runway 04 at Nelspruit Aerodrome. The pilot stated that since the take-off, he was only able to obtain a 200 feet per minute rate of climb. The engine started to lose power approximately 5 minutes after take-off, while still in the climb attitude. The pilot stated that the engine further lost power from a higher RPM to idle in approximately a minute. He had no other option than to carry out a forced landing in a sugar cane field in the late downwind area of the circuit. During the landing his face impacted the instrument panel, but besides smaller lacerations he was not seriously injured. The aircraft was extensively damaged. The pilot was the holder of a valid Airline Transport Pilot license, but although his test pilot rating was approved, the process of endorsing the rating on his pilot license was not completed. The Annual Inspection and repairs of the aircraft was certified on 24 October 2004, but it still needed to be registered in the name of the owner and an Authority to Fly needed to be issued. The test flight was carried out before these documents were issued. During the investigation no tentative cause for the engine power loss could be established, however a point of concern was the play in the ignition timing advance/retard system.*

*Probable Cause: The aircraft suffered an engine power loss during the test flight. However the exact cause of this engine power loss could not be determined.”*

Note: The aircraft shown above is not that actual aircraft involved in the accident, but merely an example of the specific type.

**2.1.8 Continued Airworthiness**

In service operations subject the aircraft to operational wear and tear, which may cause performance degradation so the approved maintenance programme must serve to maintain the aircraft airworthiness during its lifecycle. The maintenance may be light or heavy (such as overhauls) as dictated by the schedules and tasks in the aircraft's maintenance programme. Importantly, users must comply in order to maintain their aircraft's airworthiness certificate.

**2.1.9 Airworthiness Directives**

Occasionally during in-service operations, the aircraft may encounter problems that may compromise the aircraft's safety, which were not anticipated or detected during prototype testing. The aircraft design is thus compromised and the regulators will now issue an Airworthiness Directive (AD) to the Type Certificate holder and to all owners globally. The directive normally consists of additional maintenance or design actions that are necessary to restore the type's airworthiness; compliance is mandatory and if an operator does not comply with an AD, then the datum aircraft is no longer considered airworthy. ADs may also be raised with changes to the local or global aviation rules and requirements, e.g. requirement to fit armoured cockpit doors for all airliners post “9-11”.

The certifying authority issues an AD when an unsafe condition is found to exist in a product of a particular type design. AD's are used by the certifying authority to notify aircraft owners and operators of unsafe conditions and to require their correction and prescribe the conditions and limitations, including inspection, repair, or alteration under which the product may continue to be operated.

**2.1.10 Service Bulletins**

With increasing in-service experience, the Type Certificate holder may find ways to improve the original design resulting in either lower maintenance costs, or increased performance. These improvements, normally involving some alterations, are suggested through Service Bulletins (SBs) to their customers as optional and possibly extra cost, items. The customers may exercise their discretion whether or not to incorporate the bulletins, although there may be occasions in which SBs can become mandated by relevant ADs.



# Chapter 3

## Flight-test Safety

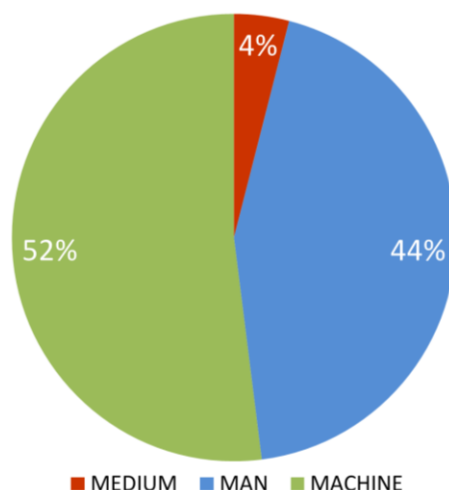
### 3.1 Flight-test Safety Statistics

So just how safe or unsafe is NTCA flight-testing? The prudent question should arguably be to ask: “Is there evidence to support the requirement for such a manual?” This question is best answered by an interrogation of the SACAA accident statistics, in particular, accidents emanating from flight-testing which revealed that over the period 1 July 1999 to 31 December 2012, a total of 33 accidents were recorded in which two pilots were killed, arguably, unnecessarily.

Typical accident summary comments extracted from the SA CAA database included both maintenance and experimental accident causal factors. As can be expected, MAN, MACHINE AND MEDIUM were all evident and were manifested by pilots’ lack of flight-test knowledge of the risks and in some cases, non-rated pilots conducting flight-test programmes. In terms of MACHINE, mechanical failures were evident and manifested in terms of maintenance issues, mechanical and structural failures. Typical examples of the accident report findings are included below:

- Pilot lost directional control during taxi tests when aircraft inadvertently got airborne.
- Left hand main undercarriage collapsed on landing due to torque link failure.
- Engine failure due to ring seizure. Forced Landing.
- Engine power loss during approach; Fuel Control Unit not properly tightened after servicing; forced landing.
- Unable to maintain altitude with left engine failed; test flight requirement; forced landing; fire.
- On completion of two high-speed taxi runs, right-hand main undercarriage leg collapsed due to overheated brake causing undercarriage leg to melt.
- Unlicensed pilot with zero flying hours attempted taxi test; directional control lost, right undercarriage collapsed.
- Engine failure due to fuel starvation caused by manoeuvring which uncovered fuel pumps; tanks 1/4 fuel; post maintenance test flight.
- Loss of directional control during high-speed taxi test following brake repairs; groundloop.
- On landing from a test flight, burst all four main tyres due to pilot induced anti-skid operations attempting to vacate at taxiway.
- Test flight; near inadvertent wheels up landing; electrical failure distraction; prop scrape; go-around; normal landing.
- Test flight; Air Traffic Control (ATC) informed after takeoff nosewheel not up; test flight continued and completed with undercarriage down; nosewheel collapsed on landing; rigging.
- Engine power loss after takeoff for test flight; forced landing in cane field; test pilot rating not endorsed on licence.
- Nosewheel assembly collapsed during taxi test; homebuilt; strut material thinner than specification.
- Premature rotation of aircraft on which pilot not rated; stalled from low height; hard landing; Class 2 Test Pilot.
- Engine failure in-flight, connecting rod failure; forced landing.

- Engine failure; cause not determined; forced landing.
- Pilot aborted takeoff for test flight; abnormal acceleration on wet grass; overran runway; aircraft nosed-over.
- Throttle torque tube retaining bolt fell out; directional control during rollout lost; main undercarriage collapse.
- Left wing strut failed in flight; design strength of wing leading edge strut attachment plate, exceeded; aircraft crashed to the ground.
- Door not properly secured on bottom rail, separated in-flight; collided with main rotor blades; forced landing.
- During spin testing, entered a flat spin, pilots bailed out, aircraft crashed into sea.
- Aircraft crashed after becoming airborne during high-speed taxi tests. Engine cowling removed; stalled; invalid licence; not type rated.
- Forced landing following loss of power.
- Engine failure due fuel exhaustion.



**Figure 3.1** Analysis of Flight-test Accident Causal Factors

The weak links in the flight-test safety chain (MAN and MACHINE) illustrate the hazardous nature of flight-testing. Fortunately however, the fickleness of both MAN and MACHINE in flight-test safety, can be mitigated through processes, procedures, knowledge and judgement. It is therefore evident that within the realm of NTCA flight-testing, there is scope to share knowledge in flight-testing with the view to improving the safety of flight-test. There are fortunately oversight mechanisms available that have been developed over the years to support any flight-test effort, be it experimental, modification or maintenance flight-test.

Mitigation of risk while simultaneously providing logic and structure to the flight-test campaign, can prove beneficial from a legal perspective in which traceability could be vital during any accident investigation. The forums and mechanisms available include a Flight-test Plan, a Risk Management Plan, a Safety Review Board (SRB) and Daily Flight Briefings and Debriefings.

### 3.2 Safety Review Board

The SRB is a forum which provides an opportunity to review the safety of the flight-test programme prior to the commencement of the flight-test programme. Most of the technical details and issues should be resolved prior to the SRB (unless they have no impact on testing) in order to permit a clear focus on the safety aspects of the tests. Experience has shown that knowledgeable, non-project personnel who are

similarly involved in other projects, provide valuable contributions to this process since they can identify areas possibly overlooked by the project team. The Safety Review Board must interrogate the:

- test plan,
- test techniques,
- test equipment,
- aerodynamic data,
- structural data,
- test schedule,
- define safety of flight criteria, and
- flight manual changes, etc.

**NOTE:** The SRB must precede the first ground runs, taxiing and first flight and must reconvene should any changes be required to the test plan.

The entire flight-test safety programme should be managed by the flight-test team with oversight by the Safety Review Board that should be comprised of at least the following portfolio members:

- Chairperson. A manager, a flight safety officer, test pilot or flight-test engineer.
- Project manager and/or project engineers.
- Project test pilot and flight-test engineer.
- Outside observer with the appropriate experience (desired for independent look at safety issues).
- The Aircraft Maintenance Engineer in charge of the technical support team.
- Safety Officer.
- The SACAA Certification Engineer allocated to the project.

The decisions will be recorded on a typical briefing record form presented in Appendix B.

### **3.3 Safety Review Board Agenda**

The following agenda is provided as a guideline for discussion topics in a safety review:

- Description of aircraft configuration to be tested (especially all recent configuration changes, software changes, and changes to control laws, etc.).
- The results of applicant's ground and structural tests, and flutter test analysis results, if applicable. Specifically address any configuration changes or aircraft limitations that have resulted from tests conducted to date.
- The aircraft operating and airspeed limitations, and any unique operating procedures required for safety reasons.
- The results of any critical flight-tests flown by the applicant. This should include a summary of any "open" certification test requirements not yet pre-flown by the applicant and a review of the applicant flight-test report to date.
- The test plan with emphasis on test requirements and test procedures that may present an increased risk.
- The risk management plan, evaluating each element of procedures planned for the certification tests.
- The test installations, test equipment and non-standard or non-test systems (e.g., ballast, temperature sensors, etc.).

- Review plans with the help of the FAA Flight-test Briefing Guide and the internet based NASA Flight-test Safety Database located at: <http://ftsdb.grc.nasa.gov>.
- Document SRB conclusions and recommendations.
- Gain approval of the risk management plan and document approval.
- It would be prudent at this stage to include a Class 1 test pilot on the Review Board for oversight, particularly with regard to spin and flutter flight-testing.

### **3.4 Flight Briefings**

Each flight must be planned, a test card prepared, and a formal briefing concluded prior to the test flight and should include a hazard analysis for each test and the appropriate steps taken to minimise risk to the pilots and aircraft, and to plan emergency actions.

A post-flight debriefing session will be held by the test team for each flight-test to ensure that all test data have been successfully acquired. If all relevant data were not captured, additional tests may need to be performed on the next flight. On conclusion of each flight-test, the de-briefing record form and defects report should be captured and defects, including technical issues related to the aircraft and instrumentation, must be cleared prior to the following flight-test.

If any aspect of the aircraft performance, stability or control is found to be unsatisfactory, the necessary modifications will need to be introduced and some or all of the flight-tests repeated or flight restrictions imposed.

### **3.5 Formal Flight-test Report**

The results of the flight-tests will eventually be presented in a formal flight-test report based on the data obtained during the flight-test programme to the Safety Review Board. If the flight-test programme validated modifications, the existing flight manual will have to be updated and submitted to the CAA for approval.

Satisfactory results of the flight-test programme will be considered as the adequate demonstration of the performance, stability and control requirements of the chosen airworthiness standard (FAR 23). It will be on this basis that the SACAA will be requested to issue an Authority to Fly the homebuilt experimental or Warbird category aircraft.



# Chapter 4

## Flight-test Plan

### 4.1 Introduction

On the critical path to the successful flight-test of any aircraft, is the development of a comprehensive Flight-test Plan. This plan should be individually tailored to meet the requirements of the aircraft's specific level of performance, stability and control, and handling qualities. It is therefore important that the entire test plan be developed and completed before the aircraft's ground tests commence.

This test plan should be compiled by the team members involved in the test campaign, including the designer, the engineering staff, the test pilot, the flight-test engineer, etc. However, depending on the scope of the test campaign, it could also be compiled by the designer, or the test pilot or a flight-test engineer, provided of course that they have some formal training in flight-test engineering. The bottom line is that there MUST be a flight-test plan that objectively considers the comprehensive requirements of the vehicle under test and the concomitant safety oversight.

The objective of a test plan is to develop a strategy to safely determine the aircraft's controllability throughout the flight envelope and to detect any hazardous operating characteristics or design features. This data should be used in developing a Flight Manual that specifies the aircraft's performance and defines its operating envelope. Importantly, the flight-test plan should address the entire scope of the test campaign, down to the finest detail and although much of the considerations in this chapter may be considered "basic" requirements, they are nevertheless listed for completeness.

### 4.2 Flight-test Plan Structure

There are no "hard and fast" rules for a flight-test plan format, but the following Main Headings and Sub Headings are suggested for inclusion of a formal test plan that must be submitted to the Director Civil Aviation for approval. The format is closely aligned to that used by the South African Air Force's Test Flight and Development Centre.

#### 4.2.1 Main Heading. Flight-test Plan Aircraft

- Background. Explain the why, when, what, how of the specific flight programme.
- Objectives of Flight-test Programme.

#### 4.2.2 Scope of Modifications

Some typical examples of the sub-headings addressed under the Scope of Modifications introduced to the aircraft or the build programme, are included below:

- Engine.
- Propeller.
- Engine mounting frame.
- Nose Undercarriage.
- Canopy.
- Winglets.

- Fuel System.
- Oxygen System.
- Dorsal Fin.

### 4.2.3 Conditions Relevant

Some typical examples of the sub-headings addressed under Conditions Relevant to the flight-test programme, are included below:

- Test Aircraft. Description of test aircraft.
- Flight Proving Authority. CAA Proving Authority reference.
- Flight-test Team. List members of the flight-test team, their experience levels and their roles in the flight-test team. Typically:
  - Flight-test co-ordinator.
  - Test Pilot.
  - Flight-test Engineer.
  - 2<sup>nd</sup> Pilot.
  - Maintenance Officer.
  - CAA Oversight Representative.
- Location. Description of the airfield from where tests will be conducted, including resources and capabilities.
- Period. Start date of the flight-test programme, duration and expected date of completion.
- Weather. Minimum weather requirements to be specified, depending on aircraft type and modification status. Typically, for first flight, wind speed less than 10 kts, ceiling 2000 ft or higher with adequate visibility. Thereafter, all flight-testing to be conducted in VMC with no more than 3/8<sup>ths</sup> cloud cover, in sight of ground and visibility adequate to be able to conduct a forced landing should the need arise. Specify maximum crosswind.
- Referenced Documents. The substantiation documentation being used for the design and flight-testing of the aircraft and associated systems, eg:
  - Reference A: Aircraft Flight Manual for [Aircraft name], Change 1, [date] 1 August 1970.
  - Reference B: Light Aircraft Performance for Test Pilots and Flight-test Engineers.
  - Certification Criteria. The aircraft will be test flown to stipulations in the Normal and Utility category as defined in FAR Vol III, Part 23".
  - Original Certification. Reference to the original certification documentation.
- Configuration Management. The onus of responsibility for managing the configuration status of the aircraft, the design specifications, drawings, etc. Particularly important is the traceability of all modifications and changes to the original aircraft configuration and flight-test documentation. A Master Reference Index (MRI) and Master File (MF) should be established.
- Certification Category Limitations. All limits and prohibitions included in the original certification, if relevant, will be described, eg, "no sustained negative g manoeuvres including inverted flight and outside loop (due to engine oil sump location)". The exact flight envelope proposed must consider structural modifications and fatigue introduced during the build or modification programme.

- Structural Reports. Whether a prototype experimental homebuilt aircraft or a modification to a Warbird, particular focus should be on the results of the structural modifications and test results, which must be presented to the SRB.
- Test Measuring Equipment. The test equipment required and fitted should be described eg stick force gauge, on-board video, control displacement measurement, accelerometer, moveable ballast, etc.
- Data Reduction. Specify who will be responsible for the data reduction and the construction of the necessary performance and handling information for the final flight-test report to the CAA. Also include the reference to the data reduction algorithms, equations, etc.
- Flight-test Cards. Flight-test Cards for all aspects of the testing and each air and ground test, must be developed. This paragraph identifies the responsible person/group.
- Daily Reports. The test pilot and/or flight-test engineer as a team, should be responsible for the compilation of a 'daily report' after each flight.
- Flight Manual. The authority responsible for the compilation and the scope of the Flight Manual, and for the final flight-test report to the CAA, must be identified.
- Flight-test Instrumentation. If any flight-test instrumentation is to be used, this should be specified, including the specification requirements, the units of measurement, calibration of flight-test instrumentation, etc.
- Performance Manual. If there is going to be a separate Performance Manual, the specific content should be described, which would typically include the following:
  - Pitot/Statics.
  - Runway Crosswind Limitations.
  - Takeoff Performance for Different Flap Settings.
  - Climb Performance.
  - Level Cruise Performance.
  - Stalling Speeds.
  - Level Speeds.
  - Payload Range.
  - Descent Performance.
  - Landing Performance.
- Test Point Definition. A breakdown of the test points, at least at a high level, should be included and could be defined and in conjunction with FAR 23.

**NOTE:** In the event of an accident, the first stop off by an accident investigator after visiting the accident site, is the design and development documentation including minutes of the Safety Review Board, ground test reports, flight-test reports, etc.

### 4.3 Flight-test Programme

The scope of the test campaign should be described, including the flight envelope boundaries in terms of mass & balance, airspeeds, structural limitations and envelope expansion philosophy, more particularly, what build-up approach will be adopted. All the foregoing will provide the test team with the proposed structure of the test plan.

#### 4.3.1 Pre-Taxi Tests

Describe the essential conditions that must be complied with and signed off by an independent inspector/auditor/engineer prior to advancing to the initial taxi tests, e.g. Pre-installation Checks, Post-installation Checks, Aircraft Weighing, and Rigging Checks and reports to be presented to the SRB.

#### 4.3.2 Ground Testing

Describe the ground tests required to demonstrate functionality of all normal and emergency systems, viz. canopy jettison, undercarriage emergency extension, which must be conducted and reports presented to the SRB.

#### 4.3.3 Cockpit Evaluation

Specify the extent to which the cockpit will be evaluated, particularly the assessment of ergonomic changes to the cockpit and the effect of the changes on the aircraft's mission, if any.

#### 4.3.4 Cockpit Night Lighting Evaluation

Specify the extent to which the cockpit night lighting will be evaluated, particularly the assessment of the effect of modifications on the cockpit night lighting resulting from changes to lighting induced by upgraded avionics and instrument panel layout.

#### 4.3.5 Oxygen System

Define the scope of the Oxygen System tests, both ground and in-flight in a build-up programme with specific reference to the operational utility of the system from a safety perspective.

#### 4.3.6 Sign Out Aircraft to First Flight

Specify the minimum conditions that must be met prior to first flight in terms of the airframe, engine and aircraft systems e.g. Prior to first flight, an engine ground run for at least 30 minutes with all systems running to verify all system's functional integrity representing the approximate time of the first flight, etc.

#### 4.3.7 High Speed Taxi Tests

Describe the build-up of power and groundspeed during taxi tests in determining the effective airspeeds for elevator, aileron and rudder in different configurations with particular reference to power output and the concomitant effects on aircraft stability and control about all axes.



#### **SACAA Accident Report J10/2/7076 - 20 July 1999**

*"The pilot of a Parker Teenie with zero hours on type, was engaged in taxi trials along the main runway when he unexpectedly became airborne and was unable to fly the aircraft. He lost directional control of the aircraft and crashed approximately 900 metres from the threshold of the runway and 30 metres right of the centre line.*

*Probable cause: Due to lack of experience the pilot was unable to maintain directional control after the aircraft unexpectedly became airborne during the taxi trials."*

Note: The aircraft shown above is not that actual aircraft involved in the accident, but merely an example of the specific type.

**4.3.8 Structural Testing**

Specific structural concerns and the validation and verification methods should be described, both in terms of ground and airborne testing through pre-installation, post installation and specific post flight structural inspections conducted on all structural modifications, viz, engine cradle, fuel system, winglets, etc.

Structural inspection frequencies should be defined and agreed upon and should include combinations of pre-maiden flight, immediately after first flight, at 5hr intervals of flight-testing, 10 hours of flight-testing, 20 hours of flight-testing, each following 20 hours of operation up to 100 hours of total time and at each MPI e.g. 100 hours/12 months.

**4.3.9 Aeroelastic Testing**

Describe the requirements for aeroelastic testing, both finite element modelling, ground vibration testing, and flutter flight-testing, specifying flutter excitation methods where appropriate, limits and acceptance criteria.

**4.3.10 Static/Dynamic CG Margin**

Centrogrammes for the aircraft in different configurations and fuel states, including the forward and aft limits, should be developed and provided for review at the SRB. In addition, flight-test techniques to validate and verify the static and dynamic margins with due consideration of the destabilizing 'power on' effects, should be addressed. The methodology and CG control in flight through ballast must be stipulated.

**4.3.11 Pitot-Static System**

Depending on the pitot/static configuration of the aircraft, the effects of any modifications to an existing aircraft, or the initial pitot/static in-flight calibrations, the methodology to be used and the support requirements, must be described e.g. either Tower Flyby, Pace/Chase, Ground Course, Trailing Cone or GPS methods for the calibration of the airspeed indicator (ASI) and the altimeter. The airspeed and altimeter instrument error corrections must be provided for review by the SRB and the position error corrections must be graphed or tabled in the Flight/Performance Manual.

**4.3.12 Performance Testing**

The scope of performance testing, in consideration of both CAA and Flight Manual requirements, must be stipulated, including test techniques, data acquisition, data analysis, data reduction and should include amongst others:

- Takeoff distance for different configurations.
- $V_x/V_y$  determination.
- Climb Time; Fuel Used, Distance.
- Service Ceiling.
- Level Cruise. Fuel Flow versus Airspeed for different power settings.
- Maximum level flight airspeed.
- Specific Excess Power.
- Gliding performance with engine feathered, and un-feathered.
- Descent; Time, Fuel Used, Distance.
- Take-off and Landing performance baseline.

#### **4.3.13 Stability and Control**

Static and dynamic Longitudinal and Lateral/Directional Stability testing must address the permutation of mass and CG available throughout the entire flight envelope. Including amongst others:

##### *Longitudinal Stability*

The scope of stability and control testing, in consideration of both CAA and Flight Manual requirements, must be stipulated including test techniques, data acquisition, data analysis, data reduction and should include as a minimum, typically:

- Pitching moment characteristics, Short Period Pitching Oscillation (SPPO) and Long Period Oscillations (Phugoid).
- Static stability.
- Dynamic longitudinal stability.
- Trimmability.
- Stability margin.
- Speed stability.

##### *Lateral/Directional Stability.*

The scope of stability and control testing, in consideration of both CAA and Flight Manual requirements, must be stipulated, including test techniques, data acquisition, data analysis, data reduction and should include as a minimum:

- Steady heading sideslips.
- Spiral Stability.
- Dutch Roll damping.
- Trim.
- Crosswind limit determination.

#### **4.3.14 Engine/Fuel System Functional Tests**

The scope and detail of engine and fuel system testing should be described as a function of the status of the aircraft, whether prototype or the modification of an existing type. The demonstration of the functionality of the various modes of operation must be described throughout the envelope expansion programme. The following additional tests are required for the prototype only:

- Air starts if practically feasible.
- Throttle sweeps.
- Failure cases of the engine and fuel system must be evaluated and appropriate recovery procedures developed.

#### **4.3.15 Example Provisional Flight-test Schedule**

The test plan should include a high-level breakdown of the flight-test programme envisaged for the full 'Approval to Fly' stipulations from the CAA. A typical flight-test schedule and time budget for inclusion in the plan, is included in

Table 4.1.

Table 4.1 Example of a Typical High Level Flight-test Schedule

Flight No	Profile	Duration	Description of Event
1	First Flight	1.0	<p>The primary objective is a 'safe landing'. The emphasis is on qualitative evaluation of the aircraft's handling qualities. First flight can only be attempted after the successful completion of the high-speed taxi test phase.</p> <p>Only a single take-off, stability and control assessment and landing followed by a comprehensive inspection of engine plus structural inspection of attachments. CG at mid position.</p> <ul style="list-style-type: none"> <li>• Start, taxi, takeoff and climb to 3000 ft agl over the airfield.</li> <li>• Climbing turns with control singlets.</li> <li>• Stall to <math>V_{\text{buffet}}/V_{\text{horn}}</math> at flight idle in clean and landing configuration.</li> <li>• Qualitative evaluation of longitudinal stability with flaps UP and flaps DOWN building up to a simulated 'go-around'. (Wave-off)</li> <li>• Verify engine operation to small 'g' transients.</li> <li>• Return for full-stop landing.</li> <li>• Conduct investigation into structural integrity of engine attachments and electro-mechanical fittings.</li> <li>• First order measure of take-off and landing distance.</li> </ul>
2	Stalling as per test matrix	1.0	All configurations at fwd, mid and aft CG locations.
3	Pitot/Static Calibration	1.0	Even if there is no reason to suspect that the original pitot/static calibrations will have changed, in keeping with universal best practice, a verification flight will be required to confirm manufacturer's calibration data.
4	Flutter Flight-testing	5.0	Aeroelastic testing at three altitudes as directed by the ground vibration testing results. Utilization of experimental test pilot highly desirable.
4 - 6	Stability and Control	4.0	Static and dynamic longitudinal and lateral/directional stability to determine stability margins. Initially use a forward position between mid CG and predicted forward limit. Use an aft CG position between mid and predicted aft CG limit. Once the mid forward and mid aft CG position tests have been completed, handling qualities at the predicted CG limits must be conducted.



7 - 8	Stability and Control	3.0	Handling qualities, stability and control of aircraft at forward, mid and aft CG.
9	Performance	1.0	Specific Excess Power; Level acceleration tests at 2000 ft intervals from 4000 ft to 14000 ft.
10	Performance	1.0	Climb performance testing; Sawtooth, Level accelerations.
11	Performance	1.0	Level cruise performance testing; Range & Endurance.
12	Performance	1.0	Descent performance testing, gliding performance.
13	Systems Testing	2.0	Navigation and Communication system testing.
14 - 17	Spinning	3.0	If applicable for aircraft category/class/type. Build up spin programme by an experimental test pilot is highly desirable.
18 - 20	Mission Relation	6.0	Navigation. Sea level proving flights/alternatively, hot and high testing.
21 - 22	Mission Relation	2.0	Development of operating flight procedures, including aerobatic speeds, roll rate determination, manoeuvre height determination. Verification of Range and Endurance figures. Paradrrops, crop spraying, game counting, etc.
23 - 28	Owner Conversion	5.0	Five additional hours proving flight as per CAA stipulation. To include familiarisation for new owner.
	<b>Total Hours:</b>	<b>37.0</b>	



# Chapter 5

## Flight-test Risk Management Process

### 5.1 Fundamentals

Risk Management (RM) processes for flight-test-related operations are essential in understanding some basic “concepts” of flight-test safety and are an integral part of the flight-test programme. The requirement for the oversight provided by a Safety Review Board (SRB) must be understood; the SRB provides the ‘sanity check’ for the safety assumptions of the flight-test programme, before flight-testing, during flight-testing and after flight-testing. Risk management is fundamentally the process by which:

- hazards are identified,
- an assessment is made of the risks involved,
- mitigating procedures are established to reduce or eliminate the risks, and
- a conscious decision is made, at the appropriate level, to accept or reject residual risks.

In the flight-test environment, risk management is normally conducted through a safety review process in which a flight-test plan, and its ongoing application, is examined by project specialists in order to draw out potential hazards and recommend mitigating (or minimising) procedures. Applicable conceptual definitions follow.

#### 5.1.1 Hazard

A condition, event, or circumstance that could lead to an unplanned or undesired event (injury to personnel, damage to equipment, loss of material, or loss of function).

#### 5.1.2 Risk

Expression of the impact of an undesired event in terms of event severity and probability.

#### 5.1.3 Hazard Analysis

The process of identifying hazards and systematically quantifying or qualifying the degree of risk they pose for exposed individuals or equipment.

#### 5.1.4 Risk Management

The process of reducing vulnerability to the identified risks through eliminating, mitigating, minimising or controlling them and then making a conscious decision to accept the residual risk.

#### 5.1.5 Team Safety Philosophy

A flight-test philosophy to enhance safety, should define some underlying risk management principles the team will embrace as the basis of their operations:

- Accept no unnecessary risks. An “unnecessary risk” is any risk that, if taken, will not contribute meaningfully to the task.
- Reduce risks to an acceptable level. Risk is a part of flight-test, but by applying risk management principles, flight-testing can be accomplished in a safe and efficient manner by using all available resources to reduce risk as much as possible.

- Manage risks in the concept and planning stages of operations since it is easier to accomplish many risk management objectives when they are addressed early in the programme. For example, if safety mitigations for flight-test are considered when designing an aircraft, it is much easier to incorporate safety equipment such as spin chutes or flight-test instrumentation instead of trying to add those things when the aircraft is complete.
- Make risk management decisions at the appropriate level. The level of risk management decisions must be commensurate with the level of risk, i.e., the higher the risk, the higher the level of management supervision.
- Focus on test-related risk. Risk that is associated with normal flying operations, which have no increased chance of occurrence on the test mission, need not be specifically addressed, instead, focus on the hazards that are more likely due to the configuration being tested and the test being performed.
- Review all plans. Risk management plans are normally put through a safety review process in which project and non-project personnel review the flight-test plan to identify potential hazards.
- Utilize all available resources. Review the results of previous tests for lessons learned and consult colleagues within the CAA and designers, builders and test pilots who may have conducted similar tests. The NASA Flight-test Safety Database (<http://ftsdb.grc.nasa.gov>) is recommended as a reference for the development of risk management plans.

## **5.2 Risk Management Process (Prior to Flight-testing)**

### **5.2.1 Identify the Test Technique Involved**

As an example, consider the case of “Minimum Control Speed Air - Static ( $V_{MCA}$  Static) testing. Generally, risk associated with flight-test results from specific test techniques that place the crew and/or aircraft at a risk higher than that associated with operational flying, must be considered.

### **5.2.2 Identify the Hazard(s) Associated with the Test Technique**

As an example, consider “Loss of control” and ask: “What adverse events might occur when using this specific test technique?” Note that one test technique may have several hazards and each should be addressed (e.g., another hazard with this test technique would be engine failure caused by inlet distortion, or fuel starvation).

### **5.2.3 List the Cause of Each Hazard**

Ask: “Why might the hazard happen?” Example - reducing speed below stall.

### **5.2.4 List the Effect of Each Hazard**

Ask: “What will be the effect?” Example - ground impact, loss of crew/aircraft. These should be related to either injury/loss of life or damage to aircraft/property.

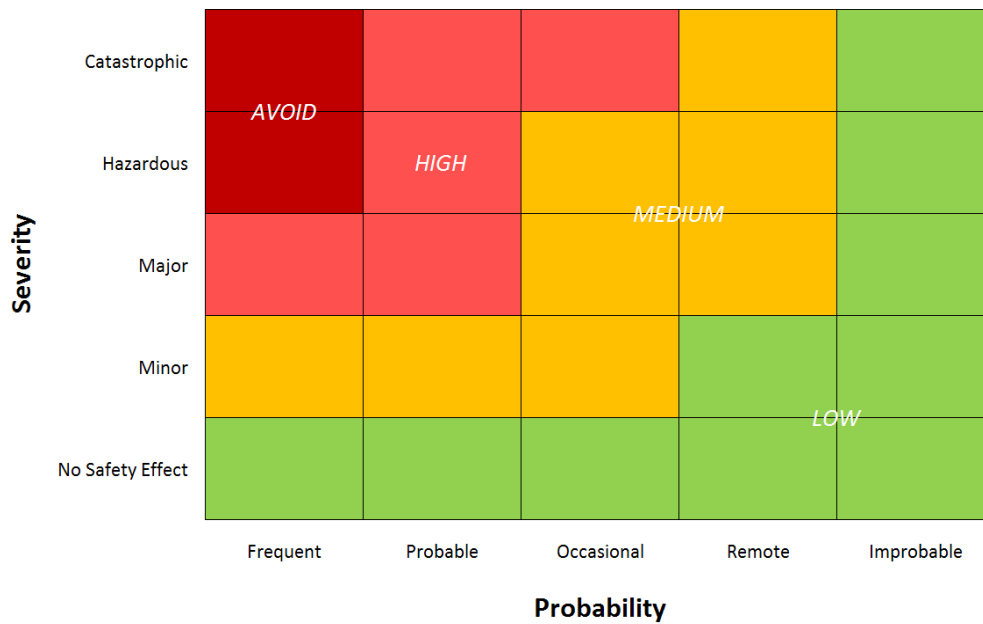
### **5.2.5 Perform a Subjective Risk Assessment**

Perform a subjective risk assessment by:

- Estimating the probability of each hazard occurring. Defined as improbable, remote, occasional, probable, or frequent. *Example: occasional.*
- Estimating the severity of each hazard, if it occurs. Defined as no safety effect, minor, major, hazardous, or catastrophic. *Example: catastrophic.*

- Defining the risk of each hazard as a combination of the probability and severity. Defined as low, medium, high, or avoid.

Figure 5.1 provides a notional depiction of how probability and severity are combined to produce a simplified, overall description of risk which is assigned prior to risk mitigation so as to ensure the proper level of safety management oversight.



**Figure 5.1 Subjective Risk Assessment Matrix**

Contributors to consider when performing subjective risk assessments includes the following examples of factors that should be considered in assigning a risk rating to specific test techniques. This is not a comprehensive list, nevertheless, it is a list of items to consider. Further reference is made to ICAO Doc 9859, Safety Management Manual, 2006.

- Workload.
- Altitude and airspeed in relation to terrain and/or airplane recovery equipment.
- Configuration (gross weight, centre of gravity, etc.).
- Environment (weather, air traffic control, particular airport conditions, darkness, turbulence, etc.).
- Airplane internal environment (smoke, temperature, pressurization level, noise, etc.).
- Design maturity.
- Test condition sequencing. (Has proper “build-up” been considered?)
- Adverse system or software effects.
- Specific aircraft limitations.
- Consequence of failure in technique, system, or structure.
- Intentional failure conditions.
- Simulator/laboratory results/historical experiences/predictive studies.
- Test pilot proficiency/currency/familiarity with the type of test aircraft.

### 5.2.6 Describe the Steps for Mitigation of Causes for Each Hazard

What is needed is to develop controls that mitigate all risks to an acceptable level. Mitigations are essentially actions to minimize, understand, prepare or respond to causes of the hazards that the test team have control over, or events that the test team can confirm have occurred. Mitigations will address reducing either the probability of a cause, the severity of the effect, or both, and should be detailed and specific in nature. The following items should be considered when formulating mitigations; although not a comprehensive list, a beginning list of items to consider, nevertheless.

- Is the test condition really needed in its present form? Is concurrent testing feasible? Can it be done adequately in the laboratory or simulator or even by analysis instead?
- Set limits on test conditions (e.g., minimum weather, altitude, minimum/maximum speed, maximum angle of attack, minimum crew size).
- Clearly define and brief “knock-it-off” criteria and who will make calls. (“Knock it off” is usually a term used by pilots during air combat manoeuvring. Other terms that would maybe be more applicable are “ABORT”, or “STOP”.)
- Review test techniques and specifying steps to reduce the risk.
- If practical, practice the test technique on another aircraft first.
- Design the test for a conservative build-up of manoeuvre parameters.
- For build-up tests, utilize technically qualified personnel to evaluate the data and plan for subsequent tests. Allow adequate time to evaluate the build-up test points prior to continuing tests.
- Provide predictions and expectations to prepare participants. Close the loop by updating performance predictions with flight-test data whenever possible.
- If available, pre-fly test in simulator, laboratory, etc.
- Provide special training and consultation (e.g., spin training).
- Provide special safety equipment and training (helmets, goggles, masks, oxygen, escape provisions, parachutes, fire extinguishers, etc.).
- Use of chase aircraft to provide visual data and test team alerts.
- Use of photo/video coverage.
- Use of telemetry or onboard instrumentation to monitor the tests in “real time” by either onboard personnel or ground monitors.
- Install hardware to protect structure and personnel (e.g., Vmu tailskid).
- Limit personnel onboard to the absolute minimum required to conduct the test safely.
- Schedule flight crews based on test pilot qualifications and recent experience relative to the required tests being conducted.
- Request a thorough briefing of the applicant’s testing, techniques and results. On tests that are highly dependent on pilot technique, consider having the test pilot conduct the initial tests or demonstrate an example and observe his or her performance before conducting the tests.
- On certain potentially hazardous ground tests (e.g., high energy rejected takeoffs), experienced ground crews should be included in the pre-flight briefing and be immediately available to support the tests if necessary (e.g., cooling fans, fire trucks, aircraft jacks). The ground crews should be briefed regarding when support will be required and whom it will be that can order support.
- Ensure local emergency personnel are briefed, on standby and/or nearby for quick response.

- Review weight and balance computations by weighing the loaded aircraft if possible. This is particularly important on critical handling qualities tests at the extremes of the weight/cg envelope and on Weight/Altitude/Temperature (WAT)-limited performance tests.
- Minimize the number of actual engine cuts during runway performance testing if spool-down thrust can be properly accounted for by analysis and related systems failures can be accurately simulated.
- For high altitude flights, all crewmembers must be briefed on oxygen use/ location and have current physiological training.
- For over-water flights, all crewmembers must be briefed and trained on the location of water survival equipment and its use.
- Test personnel involved with cold/hot weather testing should be briefed on appropriate survival skills and be properly equipped to endure the anticipated environment. If flying in these environments, adequate survival gear must be provided.
- Verify conformity. How long has it been since the conformity on the test airplane configuration was last conducted? Has anything changed since the design was reviewed?
- When elevated risk flight-testing requires airfield takeoffs (e.g. field performance takeoffs, landings,  $V_{mu}$ ,  $V_{mcg}$ , braking tests, etc.), or includes manoeuvres where it is possible for the test aircraft to become airborne, all efforts should be made to avoid flying over densely populated airport environments. For these tests, select a suitable airfield without significant population density in close proximity to the airport boundaries.

### 5.2.7 Describe Emergency Procedures

Describe emergency procedures to accomplish if the hazard occurs, despite mitigation steps. For example, for a spin test you would describe the specific spin recovery procedures and the use of the spin chute to affect recovery in the event that the spin is irrecoverable.

### 5.2.8 Document and Accept Risk Management

The risk management plan must be formalised, the complexity and depth of which, will depend on the types of tests conducted. For projects with only low risk tests, a simple statement in the test plan may be sufficient but for tests involving increasing levels of risk, a more thorough risk management plan is required and these plans should be an integral part of the project test plan (such as a section in the test plan) or even a stand-alone document. The objective is to plan properly to manage the risk and eventually to communicate that plan simply, clearly, and explicitly to the test crews.

Review of the risk management plan will vary depending on the complexity and test risk level and must be conducted prior to the commencement of the flight-test campaign. The key is to review the plan and document the review for approval by the Safety Review Board.

## 5.3 Risk Management Process (During the Conduct of Flight-testing)

### 5.3.1 Pre-flight Briefing Checklists

The flight-test crew must make use of checklists. Refer to Appendix C for a typical pre-flight briefing checklist.

### 5.3.2 Maintaining Configuration/Conformity

To achieve safe operation, it is important to maintain the conformity of the aircraft prior to and during the flight-test campaign, particularly when project delays occur. Conformity and inspection requirements

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identified must be carefully reviewed when project delays are encountered. If the project is delayed, aircraft conformity is limited to 90 days unless it is documented by a member of the project team that a longer period does not adversely affect flight-test safety.

### 5.3.3 Constantly Re-assess Risk

Risk contributors and assumptions should be checked for accuracy during the conduct of flight-test programmes while new contributors (example: unplanned weather) should constantly be considered. If, at any time, it becomes apparent that the risk involved in any test event has been underestimated, that test event should be discontinued and the risk re-evaluated. The post-flight briefing for such an event must include reference to any risk levels that were inaccurately assessed or considered unsatisfactory. The risk management process must then be re-evaluated for adequacy and approval to fly the event on a subsequent flight is contingent on reassessing the risk and risk mitigation measures in accordance with the CAA. It should be stressed that any ground or flight crewmember should have the ability to stop the test process if they are of the opinion that the risk of continuing is unacceptable.



#### **SACAA Accident Report 7435 - 2 December 2001**

*“Extensive repair/refurbishing work was carried out on the aircraft (Beechcraft A60 - Duke). As a requirement for the reissue of its Certificate of Airworthiness the aircraft was subjected to a performance test flight. The right-hand engine was shut down and the propeller feathered. The left-hand engine power setting was increased to maximum continuous power, but the aircraft was unable to maintain altitude. The pilot attempted to trim the aircraft more accurately in an attempt to obtain a positive rate of climb but to no avail. Attempts were made to start the right-hand engine again, but to no avail. The aircraft was losing height, necessitating intervention by the crew and it was decided to execute a forced landing. The post-impact fire destroyed the aircraft, but the occupants escaped unharmed. The pilot was the holder of a valid pilot license and the aircraft type was endorsed on his license. Although his test pilot rating was approved it was not endorsed on his pilot’s license. The Certificate of Airworthiness of the aircraft was not valid as the test flight was a requirement for the C of A inspection. However all the other maintenance and repair work was appropriately certified.*

*Probable Cause: The aircraft was unable to maintain altitude with only the left-hand engine operational after the right-hand engine was shutdown as required for the flight performance test. The pilot was unable to re-start the inoperative right-hand engine and it was impossible to determine the exact cause for the right-hand engine not to re-start. The aircraft descended until a forced landing was inevitable. A contributing factor to this accident was the pilot’s choice to carry out the performance test flight over an area that was not suitable for such an operation.”*

Note: The aircraft shown above is not that actual aircraft involved in the accident, but merely an example of the specific type.



### 5.3.4 Procedures for Changes to Test Profile

Risk management is a deliberate team approach, however, in situations where it may be necessary to make changes to the flight-test points (between flights and/or in-flight) due to unusual circumstances and operational considerations (such as remote locations, aircraft availability, weather), these changes are only permitted if they fall within the scope of the previously approved risk management plan, without an increase of risk, and with concurrence of all test crew members. Involvement of the on-site project team is preferable if questions of benefit are raised, or increased risk is suspected. Care must be taken that all foreseeable scenarios are considered in making this determination; changes should not exceed the limits of the approved test plan nor compromise build-up to the desired test condition.

## 5.4 Risk Management Process (After Completing Flight-testing)

### 5.4.1 Post-flight Briefing

Debriefing is critical in the flight-test process. A thorough debrief reviews and documents what was accomplished during the test, how successful the tests were and how well the tests were conducted. Pay particular attention to the effectiveness of the risk management process. Questions should be addressed, such as:

- “Were the risk levels accurate for what was done?”
- “Were there any new hazards encountered?”
- “Are there any new mitigations that can or should be implemented?”

### 5.4.2 Capturing Lessons Learned

There are always lessons to be learned during the conduct of flight-test. Disciplined flight-testers spend the time to pass these lessons along to others in the hope of improving the safety of future flight-test programmes. Many avenues exist for capturing lessons learned, including:

- Verbal or documented debrief to the safety officer and the test team.
- Formal feedback to the Safety Review Board.
- Formal feedback to the internet-based NASA Flight-test Safety Database, residing at: <http://ftsdb.grc.nasa.gov>.
- Feedback to the applicant’s safety officer and/or lessons-learned database.

### 5.4.3 Programme Debrief

In the same sense that each flight should be debriefed, at the conclusion of a test programme, a stand-alone debriefing event should also be planned to review the test programme in its entirety from initial planning to completion. Participants should include, at a minimum, ground and flight-test personnel, programme management and discipline engineers, with representatives from all organizations involved in the flight-test programme. If an event, or series of events, of interest included other organizations such as maintenance, fire rescue, or air traffic control, efforts should be made to include appropriate personnel from those organizations. Items to be discussed should include, but not be limited to:

- validity of initial assumptions,
- effectiveness of test planning, risk assessment/alleviation efforts,
- lessons-learned,
- difficulties encountered during testing, unexpected events or results, and
- recommendations for the planning and conduct of future test programmes of a similar nature.

The results of this meeting should be documented and included in appropriate databases, such as the NASA Flight-test Safety Database so as to future flight-test programmes from suffering the same fate.

**Table 5.1 Risk Management Item in a Different Format (One Page per Hazard)**

HAZARD NO.:		RISK ASSESSMENT					
A13	Severity	Catastrophic	Avoid	High	High	Medium	Low
TEST PLAN:		Hazardous	Avoid	High	Medium	Medium	Low
Aero 1		Major	High	High	Medium	Medium	Low
TEST TECHNIQUE:		Minor	Medium	Medium	Medium	Low	Low
V <sub>mca</sub> static		No Safety Effect	Low	Low	Low	Low	Low
HAZARD:							
Loss of control							
CAUSE:							
Low altitude stall							
EFFECT:							
Ground impact, Loss of aircraft and crew							
			Frequent	Probable	Occasional	Remote	Improbable
			<b>Probability</b>				
<b>MINIMIZING PROCEDURE:</b>							
<ol style="list-style-type: none"> <li>The pilots must be familiar with the aircraft's handling characteristics at low-speed, high angle-of-attack, and stall departure recovery techniques.</li> <li>Monitor structural loads real-time.</li> <li>Pre-flight briefing to include engine failure procedures, the quick-start procedure, along with ditching procedures if over water.</li> <li>Directional control handling qualities testing and Light/Aft stall characteristics will be completed prior to any V<sub>mca</sub> test.</li> <li>Entry altitude should be a minimum of [height in feet] ft agl.</li> <li>Spin-chute (if installed) must be operational and pilot familiar with its operation.</li> <li>Minimum crew only.</li> </ol>							
<b>EMERGENCY PROCEDURES:</b>							
Reduce angle-of-attack, increase airspeed and retard throttle as necessary to maintain directional control.							
<b>WEATHER REQUIREMENT AND/OR FLIGHT CONDITIONS:</b>							
VMC, no clouds below.							
<b>MINIMUM ESSENTIAL AIRCREW:</b>		YES	NO	<b>PARACHUTE:</b>	YES	NO	
<b>RISK ASSESMENT:</b>			LOW	MEDIUM	HIGH	AVOID	



# Chapter 6

## Preparation for Flight-testing of NTCA

### 6.1 The Test Pilot

Arguably the next most important item on the critical path to a successful flight-test programme, is the test pilot. NTCA flight-test requirements do not necessarily call for an experimental test pilot, in other words, one that has been formally trained at an internationally recognised flight-test school. However, successful flight-testing is critically dependent on the theoretical knowledge and flying skills of the test pilot in assuring the success of the flight-test programme. Ideally, the test pilot should be competent in an aircraft of similar configuration, size, weight, and performance as the aircraft to be tested. If the aircraft's builder is the test pilot, the costs involved in maintaining pilot competence should be budgeted with the same level of commitment and priority that is assigned to the plans and materials to complete the project.

#### 6.1.1 CAA Licensing Standards

CAA regulations enable an approved Class I test pilot "to act as pilot-in-command of an experimental, prototype aircraft which is engaged in experimental, developmental or investigative test flying in accordance with the test schedule approved by the Director, for the purpose of experimental test flying, development, certification, type certification, or for the purpose of issuing, validating or rendering effective a certificate of airworthiness of such aircraft provided that he/she is the holder of a valid class rating". A Class I test pilot is essentially an experimental/engineering test pilot that has received formal training from an internationally recognised flight-test training school.



#### **SACAA Incident Report 0321 - 9 February 2004**

*"The owner of the aircraft (Bush Baby) lost directional control of the aircraft during an attempted taxi test, and allowed the aircraft to veer-off the runway, resulting in substantial aircraft damage. The right-hand main landing gear collapsed, the right-hand wing and the fuselage were also damaged. The owner was neither licensed nor allowed to taxi or fly the aircraft. Although the aircraft was substantially damaged, the owner was not injured.*

*The owner failed to comply with the applicable regulations with respect to the running and taxiing of the aircraft.*

*Probable cause: The owner of the aircraft lost directional control of the aircraft during an attempted taxi test, and allowed the aircraft to veer-off the runway, resulting in substantial aircraft damage. The owner failed to comply with the applicable regulations with respect to the running and taxiing of the aircraft."*

A Class II approved SACAA test pilot is essentially authorised for the same scope of testing provided it is under supervision of a SACAA Class I test pilot. The 'reasonable man' test asks whether this is adequate oversight to conduct exploratory flight-tests? What formal training is presented to Class II test pilots? If none, it could be argued by the prosecution during post accident litigation, that the scope of testing

authorised by the Class II rating in the realm of exploratory flight-testing, is irresponsible. In terms of NTCA, there is even less supervisory oversight and therein lies the danger to the homebuilder or amateur aircraft designer.

Within the certification environment, qualified experimental test pilots are mandatory in conducting flight-test programmes and as background, it is insightful to understand the training regimen of test pilots to better understand the seriousness in which flight-testing is regarded amongst the professional flight-test community.

### **6.1.2 Experimental Test Pilot Training**

Test pilot training essentially aims at developing a pilot into a specialist, much the same as in the medical profession's definition of a 'specialist'. The training is focussed on delving into the deep theory, mathematics and science of aeronautics and in some cases, aerospace, all in an effort to provide the test pilot with the academic tools required to interrogate performance, handling qualities, stability and control, ergonomics and aircraft systems amongst a vast range of subject matter.

Most of all, it enables the test pilot to identify areas in flight dynamics that pose hazardous challenges to safe mission accomplishment. In effect, the test pilots are taught to 'know what it is they don't know' and how to evaluate an aircraft safely from first principles, if necessary. Risk management lies at the heart of all test pilot training, more specifically, the ability to understand the risks imposed by the particular test being conducted versus the skills of the test pilot. Obviously, test pilots and flight-test engineers are taught what processes, procedures and flight-test techniques to apply to mitigate risk in the test programme. What are the minimum entry qualifications to enter test pilot training? Typically, the following minimum requirements are imposed:

- An above average flying assessment.
- Class I medical category.
- A minimum of 1500 hours as pilot in command.
- A current instrument rating.
- Completed at least one operational squadron tour other than an instructional tour, or a line tour in an airline operation.
- Satisfied a selection board of his/her suitability for test flying duties.
- Meet the academic entrance criteria for one of the recognised test pilot schools. The desired minimum academic qualification is a BSc degree although each country has the prerogative to train pilots without tertiary qualifications on the proviso that they can meet the minimum academic standards in mathematics, science and physics.

During the intensive fifteen month course, the aspirant test pilot, besides overcoming a huge mass of theoretical training, will fly in excess of 20 different aircraft types, covering the entire range of aircraft categories from low to high speed, 100 kts single engine light sport aircraft to Mach 2.0 military fighters, from gliders to four engined Boeings or Airbus, and even the odd helicopter thrown in for fixed wing pilots; all this equivalent to approximately 120 hours. The bane of the test pilot of course is the administrative load on flight-testing; for every one hour flight-testing, approximately 6 to 8 hours is required for data reduction and report writing followed by debriefing or oral presentation. The importance of documenting every aspect of the flight-test programme cannot be overemphasised since in the event of an accident or system malfunction, traceability is essential. Substantiation of decisions and modifications introduced need to be available for examination.



#### ***What a Test Pilot is Not!***

A test pilot, contrary to the images conjured up by the movie “The Right Stuff”, is not necessarily the best ‘stick’ in the world, does not ‘walk on water’, does not have all the answers, is not a mathematical genius, does not necessarily go around winning ‘medals for bravery’ or any other of the melodramatic portrayals of the ‘super hero’ in the movies.

*“What a test pilot is not! Not necessarily the best looking “hotshot” in the business!”*

#### ***What a Test Pilot Is!***

An experienced aviator that has successfully graduated from an internationally recognised flight-test school and been certified as an experimental, engineering or research test pilot. Such schooling is only provided in the USA at the military schools (USAF Test Pilot School and United States Navy Test Pilot School), the UK (Empire Test Pilot School), France (EPNER), Russia (Russian Test Pilot School) and in India at the Indian Air Force’s Test Pilot School. The only recognised civilian flight-test school is the National Test Pilot School at Mojave in the USA, which essentially follows the USAF Test Pilot School syllabus and is staffed by former military flight-test personnel, but has a slight shift in emphasis, focussing on both FAA certification standards in addition to the military standards. For certification as an experimental/research or Class I test pilot, the incumbent must have graduated from a test pilot’s course at one of the Society of Experimental Test Pilots (SETP) recognised test pilot schools.

### **6.1.3 Test pilot requirements SA CAA Class II Test Pilot**

Air Navigation Regulation (ANR) 1976 ,Test Pilot’s Ratings Regulation 3.16D states the following:

- An applicant for a Class II test pilot’s rating shall be the holder of a private pilot’s or higher grade licence.
- Have completed not less than 500 hours’ flight time of which not less than 300 hours were as pilot-in-command.
- Be the holder of a appropriate aircraft category rating.
- Be the holder of the appropriate aircraft class rating; and
- Satisfy the Director that he has adequate knowledge of test flying techniques.

Aeronautical Information Circular, (AIC) 30.6 03-03-15:

Air Navigation Regulation (ANR) 2.9D states the following:

- No person shall act as a test pilot of an aircraft unless he is the holder of a valid pilot’s licence with a test pilot’s rating. The requirements for a test pilot’s rating are laid down in ANR 3.16D which clearly states that an applicant for a Test Pilot rating (class I or II) must be the holder of a valid Private Pilot or higher-grade licence with certain criteria.
- Test Flights will therefore be performed only by suitably rated pilots; this means rated on type and rated as a Test Pilot. A type rating is not applicable to a Class I Test Pilot.

#### **6.1.4 Test Pilot Requirements for NTCA**

As a guideline for pilots involved in NTCA homebuilt/experimental flight-testing, such a pilot should at least meet the following minimum qualifications:

- Be physically fit with a current medical.
- Be rated, current, and competent in the same category and class as the aircraft being tested.

The following FAA suggested number of flight hours is only an indication of pilot skill, not an indicator of pilot competence and each test pilot should assess if their level of competence is adequate, or if additional flight training is necessary. If an individual determines they are not qualified to flight-test an unproven aircraft, someone who is qualified, must be found:

- 100 hours solo time before flight-testing a kit plane or an aircraft built from a time-proven set of plans.
- 200 hours solo time before flight-testing for a “one of a kind” or a higher performance aircraft.

#### **6.1.5 Suggested Minimum Preparation for NTCA Test Pilots**

In terms of specific preparation, the test pilot should:

- Take additional instruction in similar type certificated aircraft. For example, if the aircraft to be tested is a tail dragger, a Bellanca Citabria or Super Cub is appropriate for training. For testing an aircraft with a short wingspan, the Grumman American Yankee or Globe Swift is suitable for training.
- Talk with and, if possible, fly with a pilot in the same kind of aircraft to be tested.
- Fully understand the technical details of the aircraft and the emergency procedures.
- Be considered competent when having demonstrated a high level of skill in all planned flight-test manoeuvres in an aircraft with performance characteristics similar to the test aircraft.
- Study the ground and in-flight emergency procedures developed for the aircraft and practice them in aircraft with similar flight characteristics.
- Have logged a minimum of 1 hour of training in recovery from unusual attitudes within 45 days of the first test flight.
- If appropriate, have logged a minimum of ten tail wheel take-off and landings within the past 30 days.
- Study the performance characteristics of the aircraft to be tested. Refer to the designer’s or kit manufacturer’s instructions, articles written by builders of the same make and model aircraft, and study actual or video tape demonstrations of the aircraft.
- Memorise the cockpit flight controls, switches, cocks, and instruments. A thorough knowledge of the cockpit will result in controlled and coordinated mental and physical reactions during emergencies.
- Be familiar with the airport and the emergency fields in the area.
- Review the FAA/National Transportation Safety Board (NTSB)/SACAA/EAA accident reports for the same make and model aircraft to be aware of problems the aircraft type has experienced during previous operations.



## 6.2 Support Infrastructure

### 6.2.1 Airports

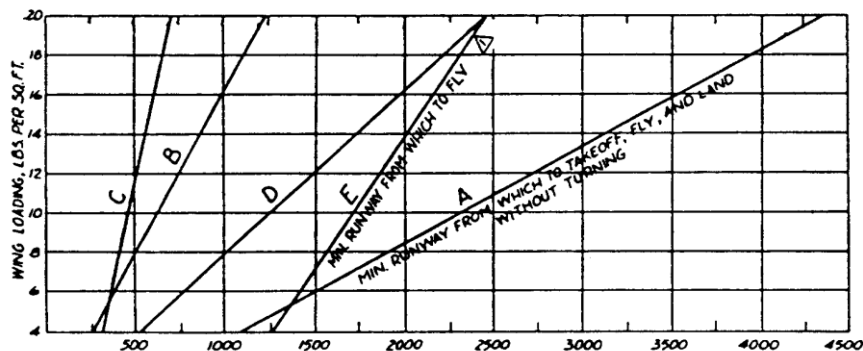
The location of the flight-test programme, particularly in the early stages, is an important safety consideration in terms of the communication, control and emergency service support. The airport should have one runway aligned into the prevailing wind with no obstructions on the approach or departure end. Hard surface runways should be in good repair and well maintained to avoid foreign object damage (FOD) to the propeller and undercarriage, while grass fields should be level with good drainage. Airports in densely populated or developed areas and those with high rates of air traffic should preferably be avoided since the traffic intensity could severely disrupt the test pilot's ability to get the test programme completed in the budgeted time. The runway should have the proper markings with a windsock or other wind direction indicator nearby.

### 6.2.2 Hangarage

The availability of hangar space and ramp areas is considered prudent since these facilities will provide protection from inclement weather and vandalism while the aircraft is being tested, maintained, and inspected.

### 6.2.3 Runway Selection

To determine an appropriate runway, use the chart in Figure 6.1 (sea-level elevation), or the following rule-of-thumb: "The ideal runway at sea-level elevation should be at least 4,000 feet long and 100 feet wide. For each 1,000 feet increase in field elevation, add 500 feet to the runway length requirement due to density altitude effects. If testing a higher performance aircraft, the airport's runway at sea level should be at least 6,000 feet long with the insidious effects of density altitude being factored into the equation for best initial flight-testing runway".



- A - Distance to takeoff at minimum smooth lift-off speed, fly for 5 seconds at that speed without climbing, land and stop straight ahead.*
- B - Distance to reach minimum smooth lift-off speed.*
- C - Distance covered in 5 seconds of flight at minimum smooth lift-off speed.*
- D - Distance to stop from minimum smooth lift-off speed (includes air and ground distance).*
- E - Distance to takeoff at slow approach speed and climb thereafter at an angle of 1 in 20 to 50 ft. altitude —this distance will allow most airplanes to accelerate to normal climb speed before crossing end of runway.*

**Figure 6.1** Runway Length Chart (Reference 1)

#### **6.2.4 Emergency Landing Fields**

Identify emergency landing fields located within gliding distance from anywhere in the airport pattern altitude since engine failures are second only to pilot error as the major cause of amateur-built aircraft accidents. Preparations for this type of emergency are a mandatory part of the test plan.

#### **6.2.5 Hospital Location**

The ground crew should know the location and telephone numbers of the hospitals and fire rescue squads in the vicinity of the airport and the flight-test area. If the test pilot is allergic to specific medications, or has a rare blood type, a medical alert bracelet or card should be carried or worn to alert medical personnel of the condition.

#### **6.2.6 Fire Rescue Services**

Survival in an accident is often a function of the response time of the emergency teams. If the airport does not have a fire rescue unit, it is suggested the ground crew have a four wheel drive vehicle equipped with a portable radio, first aid kit, metal-cutting tools, and a fire extinguisher and a minimum of one person who should be trained in First-Aid.

If the airport provides a fire rescue unit, the test pilot should ensure that the rescue unit and the ground crew are briefed, trained and competent in performing ground emergency functions as identified in the test plan, particularly egress from the cockpit and operating the aircraft's emergency egress controls. The airport should have a telephone and fire fighting equipment, the latter being in compliance with relevant municipal codes (e.g., fire codes).

#### **6.2.7 Fire Extinguisher**

Fire extinguishers should be available to the ground crew, and a fire extinguisher should be securely mounted in the cockpit within easy reach of the test pilot if appropriate for the aircraft category. A fire axe, or other tool capable of cutting through the canopy, should also be positioned in the cockpit.

#### **6.2.8 Fire Protection**

There is always danger of a flash fire during test flights, so it is prudent that the pilot should wear an aviation/motorcycle helmet, NOMEX coveralls/gloves and smoke goggles to prevent burns in the event of fire. If NOMEX clothing is not available, cotton or wool clothing will offer some protection from heat and flames.

**WARNING:** Pilots should never wear nylon or polyester clothing because synthetic materials melt when exposed to heat and will stick to the skin.

#### **6.2.9 Communications**

Good radio communications are essential to the overall level of safety and reduces cockpit workload, so it is advisable to perform flight-tests from an airport with an active air traffic service or tower, even if the aircraft does not have an electrical system or is not equipped with a radio. Even at an uncontrolled field, a communications base should be improvised. For both situations, a hand held radio with aviation frequencies and a headset with a mike and a push-to-talk switch on the stick/yoke, is recommended.

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### 6.2.10 Ground Crew Support

Every test flight of an NTCA aircraft should be supported by a minimum ground crew of two experienced individuals. The ground crew's function is two-fold:

- To ensure that the aircraft is in airworthy condition for safe operation.
- To provide assistance to the test pilot in an emergency.

### 6.2.11 Emergency Planning

One of the most important sections of the Test Plan is the Emergencies Plan, which is essentially the strategy for dealing with the vast matrix of emergencies possible. This effort may appear laborious and 'over the top', but in dealing with the unknown, as one is apt to do in flight-testing, it makes good sense to have thought through any 'worst case scenario' and concomitant emergencies on the ground under calm conditions rather than to deal with them "on the fly", under duress. Ideally, the test plan emergency section should contain two sets of emergency plans, one for In-flight Emergencies and another for Ground Emergencies.

The In-Flight Emergency plan should at least address the following:

- Complete or partial engine failure, especially immediately after takeoff where options are restricted by the height above ground level.
- Flight control problems and severe 'out-of-rigging' conditions.
- Fire in the engine compartment or cockpit.
- The Ground Emergency plan should be developed to train the ground crew and/or the airport fire department crash crew on the following:
  - The airplane canopy or cabin door latching mechanism.
  - The pilot's shoulder harness/seat belt release procedure.
  - The location and operation of the fuel shut-off cock.
  - The Master Switch and magneto/ignition switch location and 'OFF' position.
  - Engine cowling removal procedures to gain access to the battery location or for fire fighting.
  - The battery location and disconnect procedures.
  - Fire extinguisher application and use.
  - How to secure the ballistic parachute system if applicable.
  - How to 'safety' ejection seats or any pyrotechnics on-board the aircraft that could endanger the aircrew or the first responder personnel at the crash scene.

### 6.2.12 Emergency Plans Briefing

It is extremely important is to explain the flight-test programme and emergency plans to the airport manager since they may be able to assist the test effort in obtaining temporary hangarage, providing ground/air communications and supplying emergency equipment for use during the flight-test. A prudent rule of thumb for flight-testing is to: continuously interrogate the environment with "what is the worst thing that could happen now?" and then develop action plans to counter the threats, in essence, a form of continuous, real time, risk assessment, if you like.

## **6.3 The Aircraft**

### **6.3.1 Assembly and Airworthiness Inspection**

If the aircraft must be reassembled after being moved to the airport, take time to do so carefully; this is a critical event because mistakes can easily be made due to the builder's preoccupation with the impending first flight of the aircraft. One of the most common and deadly mistakes is to reverse the rigging on the control surfaces and therefore, to prevent errors in reassembling the aircraft, follow the designer's or kit manufacturer's instructions, and use a written checklist specifically designed as part of the test plan.

Best practice dictates that at the completion of each major operation, have another expert inspect the work. Once the aircraft is reassembled, perform a pre-flight "fitness inspection" similar in scope and detail to an annual inspection even if the aircraft has just been issued a special airworthiness certificate by the CAA. The following additional safety checklist items may not be applicable to all amateur-built make and model aircraft, but are presented for consideration and review.

### **6.3.2 Control Stick/Wheel**

The control stick/wheel should have a free and smooth operation throughout its full range of travel without any binding or contact with the sides of the fuselage, seat, or instrument panel. There should be no freeplay (slack) in the controls through the full range of travel, nor should the static friction of the controls be so high as to require compensation in operation by the test pilot. Similarly, the pedal movement should be smooth with no binding and the test pilot should ensure that shoes will not catch on exposed metal lines, fixtures, or electrical wire harness.

### **6.3.3 Brakes**

Hand and/or toe brake pressure should be firm with no tendency to bleed down or lock up. Spongy brakes that must be "pumped up" or show a drop in the level of brake fluid in the reservoir after a few brake applications, indicates a brake fluid or air leak in the system, or air in the system, which will require "bleeding the brakes".



#### **SA CAA Accident Report 0280 - 4 June 2003**

*“After completion of 2 high-speed taxi trials on runway 06/24 the pilot vacated the runway. As he turned onto the taxiway the right-hand main undercarriage leg collapsed. No one was injured and the aircraft was not further damaged. Investigation revealed that the right main wheel brake disc of the Jabiru had been subjected to severe heating, which caused the main undercarriage*

*leg (fabricated from fibreglass) to melt, causing the leg to fail/collapse.*

*The matter was referred to HOO None Type Certified Aircraft (NTCA) and the manufacturer for further investigation and possible action to prevent a recurrence. (modification to the leg/FM amendment). The aircraft accumulated a total of 202 hours since new and zero hours since the last annual inspection certified on 2 May 2003. The aircraft had a valid Authority to fly issued on 9 May 2003*

*Probable Cause: Due to excessive braking the right hand brake disc was subjected to severe heat causing the undercarriage leg to fail (melt).”*

Note: The aircraft shown above is not that actual aircraft involved in the accident, but merely an example of the specific type.

#### **6.3.4 Main Undercarriage**

Ensure that the undercarriage attachment points, shimmy damper, bungees, wheels, brakes, and wheel fairings are airworthy. If applicable, check that the tailwheel pivot point is centred and vertical in relation to the longitudinal axis of the aircraft. It is critical that the main undercarriage alignment toe in/toe out is zero or matches the specifications for fuselage/undercarriage alignment called out in the plans because even one wheel out of alignment, can cause a ground loop.



#### **SA CAA Accident Report A00-060-7202 - 26 May 2000**

*“On returning from a maintenance check flight of a SAAB 91 Safir, the pilot carried out a normal landing with the main undercarriage touching down first. Approximately 2 seconds after the nose undercarriage touched the ground it collapsed. The aircraft skidded for approximately 60 meters before it came to a standstill. There were no injuries. The propeller and bottom engine cowling was damaged, but there was no other damage.*

*Probable cause: Due to the undercarriage tension cable pulley bracket failure, the nose undercarriage collapsed during landing.”*

Note: The aircraft shown above is not that actual aircraft involved in the accident, but merely an example of the specific type.

### 6.3.5 Control Surfaces

It goes without saying that control surface rigging is extremely important, not only from how an aircraft handles and control harmony, but also from the safety perspective. It is important to check the control mass and balance before assembling the aircraft since it will be easier to address any imbalance issues with the surface not attached to the airframe. Only after control surface balancing has been successfully completed should the rigging checks be conducted to ensure that control input for ailerons, rudder, elevators, and trim tabs results in the correct amount of travel and direction of the associated control surface movement and that contact with the control stops is made. Also ensure that the flaps, if installed, have the correct degree of travel, operate as a single unit, and cannot be extended beyond the maximum extended position.

It is also important to ensure that the control cable tension is correct by checking it with a calibrated tensiometer and confirming that all the attachment hardware is secured and safety wired. If the cable tension is less than the specification requirement, the “in flight” air loads will prevent full travel of the control surface, even if the cockpit control has the right amount of deflection and hits all the stops in the cockpit/wing/tail when tested on the ground. With low cable tension, the desired control movement input will be absorbed by the slack in the cables.

While checking cable tension, make sure there is no “free play” in the flight control hinges and rod ends. Freeplay and loose cable tension combined with control mass imbalance, sets the stage for the onset of control surface flutter. Do not, however, rig the controls at too high a cable tension since this will cause high wear rate on the pulleys and prevent good control feel, especially at low airspeeds.

### 6.3.6 Instrument Panel

It might seem obvious, but all the instruments MUST be properly secured in the panel and have at least preliminary markings on them. The airspeed indicator and engine tachometer should be marked with the expected performance range markings while the oil temperature and pressure gauges must have the engine manufacturer’s recommended operating range marked. As an aid to the test pilot, consider attaching a temporary placard to the instrument panel with the expected stall, climb, and glide speeds as a handy reference in times of emergency. Each amateur-builder should inspect this area to ensure that all line connections are tight, that nothing interferes with control travel, and there are no loose wires or fuel, oil, or hydraulic leaks.

### 6.3.7 Carbon Monoxide

Depending on the positioning of the engine and aircraft vents, the threat of carbon monoxide ingestion remains a safety challenge and every attempt should be made to determine influx areas, therefore, Carbon Monoxide leak tests must also be performed. A very basic first attempt could be to wait until dark time or put the aircraft in a darkened enclosure. Climb into the cockpit and have a torch shined close to the firewall, if light leaks into the cockpit, carbon monoxide can seep in, mark and seal it. After sealing, it will be necessary to fit a carbon monoxide tester in the cockpit to verify adequate sealing, both on ground and in flight.

### 6.3.8 Engine and Propeller Controls

All controls should be visually inspected, positive in operation, and securely mounted. The friction lock on both controls should be checked for operation and each control should have full movement with at least a 1/4 inch of “cushion” at the full travel position. The control cables should be firmly attached to the

fuselage along their runs to prevent whipping of the cable and loss of cable movement at the other end. Control cables with ball sockets should have large area washers on either end of the bolt connection to ensure the control will remain connected, even if the ball socket fails and drops out.

#### **6.3.9 Pitot/Static System**

Another basic method to verify pitot/static system integrity is to slip sufficiently long surgical rubber hose over the pitot head. As one person reads the airspeed, the other should very *slowly roll up* the other end of the tubing, which will apply pressure to the instrument. When the airspeed indicator needle reaches the aircraft's approximate recommended cruise speed, pinch the hose shut, and hold that reading; the airspeed needle should remain steady for a minute if the system is sound while a fast drop off will indicate a leak in the instrument, fittings, lines, or the test hose attachment. NEVER force air in the pitot tube or orally apply suction on a static vent; this could damage the aneroid capsules.

#### **6.3.10 Altimeter/Vertical Speed**

A good way to check the static system is to apply low suction at the end of the static vent port. The easiest way to gain access to the static system is to remove the static line at the static port. If there are two static ports, tape the unused port closed. Next, as in the case of the pitot system test, get two feet of surgical tubing, seal one end, and tightly roll it up. Attach the open end to the static line and *slowly unroll* the tubing to apply a suction, or low pressure, to the static system.

The altimeter should indicate an increase in altitude while the vertical speed indicator should indicate a rate of climb; the airspeed may show a small positive indication. When the altimeter reads approximately 2000 feet, stop and pinch off the tube. There will be some initial decrease in altitude and the vertical speed will read zero; the altimeter should then hold the indicated altitude for at least a minute. If altitude is lost, check for leaks.

**WARNING:** The above airspeed and altimeter field checks should not be considered as pitot/static calibrations or accuracy tests, but only a check of the system for possible leaks. The builder must not deviate in any manner from the designer's original plans when installing the pitot and static system.

#### **6.3.11 Fuel System**

From a review of aircraft accident statistics in the USA, since 1983 (Reference 1), more than 70% of the engine failures in amateur-built aircraft were caused by fuel system problems, many times the direct cause was dirt and debris in the fuel tank and lines left behind during the manufacturing process.

Before the aircraft's fuel tanks are filled, the amateur-builder should vacuum any manufacturing debris from each tank and wipe them down with a 'tack' cloth. Next, the system should be flushed with aviation grade gasoline several times in order to remove any small or hard to reach debris from the tanks and lines. The fuel filter/gasolator screen/carburettor finger screen should also be cleaned. The amount of time spent "sanitizing" the fuel system will pay big safety dividends for the life of the aircraft.



**SACAA Accident Report 7417 - 16 October 2001**

*“The pilot, accompanied by two ground engineers, took off from Rand Airport on a test flight in a Bell 206 after maintenance work was performed on the gearbox and fuel control unit of the helicopter.*

*After a satisfactory test flight of approximately 45 minutes, the pilot made a turn to land on the helipad close to the tower when he suddenly experienced a loss of power. The pilot then executed an autorotation and elected to land on the grass at the Eastern side of Runway 17. However upon landing the right hand main skid made contact with a rain water furrow on the side of Runway 17. The helicopter bounced once causing the main rotor blades to strike the tail boom. The main rotor blades, tail rotor, tail boom, tail rotor drive shaft, horizontal and vertical stabilizers were substantially damaged. There were no injuries. An on-site investigation was carried out and the fuel control to governor tee pneumatic tube ‘B’ nut assembly Part number 6893073 was found completely loose which will result in a minimum fuel flow and/or in fuel flow shutdown.*

*Probable Cause: The most probable cause of the accident was that the fuel control unit to the governor tee pneumatic tube ‘B’ nut was not properly tightened after work was performed on the fuel control unit and vibrated loose during flight.”*

Note: The aircraft shown above is not that actual aircraft involved in the accident, but merely an example of the specific type.

When filling the tanks, place the aircraft in the straight and level cruise position then add fuel in measured amounts to calibrate the fuel tank indicators. While allowing the aircraft to remain static for a short time to observe for possible leaks, inspect the fuel tank vents to see if they are open and clear; also check that the fuel tank caps seal properly. If there are no leaks and the fuel system has an electric booster pump, pressurize the system and again check for leaks. The fuel selector, vents and fuel drains must be properly marked and tested for proper operation.

**NOTE:** Many amateur-built aircraft take several years to build and during that time, many rubber-based oil and fuel lines and cork gaskets that were installed early in the building process, may have age hardened, cracked, and/or turned brittle. The builder should carefully inspect these components and replace as necessary to prevent a premature, unexpected engine failure.

### 6.3.12 Hydraulic System

The hydraulic system should function dependably and positively in accordance with the designer’s intent and as such, the retractable undercarriage should be rigorously cycled on the ground, using both the normal and emergency undercarriage extension system. Retraction and extension times should be measured and used as a baseline metric for the flight-test evaluation of the hydraulic system.



**6.3.13 Avionics and Electrical Checks**

The integrity of the electrical system can be likened to the nervous system of the human; it is a fundamental driver for nearly all systems on an aircraft and is especially critical due to the adverse effects of electromagnetic interference. Electrical system testing remains a bit of a 'black art' and can be reasonably complex as the matrix of various systems interact with each other.

To test the avionics systems, perform an operational check to ensure the radio(s) transmit and receive on all frequencies. Inspect circuit breakers/fuses, microphones, and antennae for security and operation. Electrical systems can be checked for operation of lights, instruments, and basic nav/comm performance in accordance with the manufacturer's specification, including the ELT test for proper operation and battery life. Other electrical systems, such as generator/alternator output must be continuously monitored and checked during the engine run-ins, taxi, and flight-tests. Check the battery and the battery compartment for security and if applicable, ensure that the battery is properly vented to the outside of the aircraft. Check the condition of the engine to airframe bonding (grounding) wire and ensure that all electrical instruments operate properly.

**6.3.14 Cowling and Panel Checks**

Ensure that all inspection panels are in place, the cowlings are secured, the Dzus fasteners (quick fastening screw) make a good lock, and cowl flap operation is satisfactory. Inspect the propeller spinner and its backing plate for cracks.

**6.3.15 Canopy/Door Lock Checks**

Ensure the canopy or doors on the aircraft work as advertised, particularly their emergency modes of operation and double check the canopy or door lock(s) so the canopy and doors will not open in flight and disturb the airflow over the wings. If a canopy jettison system is installed, check for proper operation when the aircraft on the ground.

**6.3.16 Parachute**

The decision to wear a parachute depends on the type of aircraft being tested. Some aircraft have forward hinged canopies that are not equipped with quick release pins or have pusher propellers that increase the chance of injury to the pilot while exiting the aircraft. Other aircraft designs may pose no exit problems. If the decision is made to wear a parachute, check that it has been recently packed within 120 days by a qualified parachute rigger and ensure that the chute has not been exposed to rain/moisture and when worn, does not interfere with cockpit controls operation and management. It goes without saying that in the best interests of safety, that the test pilot must be thoroughly trained on how to exit the aircraft and deploy the parachute.

**6.3.17 Safety Belt and Shoulder Harness**

These items should be checked for condition and proper installation. A review of amateur-built aircraft accidents has disclosed a significant number of accidents in which the seat belt mounting hard points failed. Each seat belt and shoulder harness mounting hard point should be built to the designer's specifications to ensure that it will hold the harness and pilot in the aircraft at the ultimate design "G" load specification, both positive and negative, for the aircraft.

### 6.3.18 Ballistic Recovery System

Ballistic recovery systems (BRSS) are the latest development in dealing with in-flight emergencies and are usually attached to the aircraft so that when activated, it lowers the whole aircraft and the pilot to the ground at the rate of descent of approximately 20 feet per second. Deployment scenarios could typically include:

- Structural failure.
- Mid-air collision.
- Loss of Control/Departure, Stall/Spin.
- Engine failure over inhospitable terrain.
- Pilot incapacitation.

The builder should consider the following when installing a ballistic chute:

- Matching the chute with the aircraft's size, weight, and  $V_{ne}$  speed (check with the chute manufacturer).
- How the chute will be positioned and mounted.
- The chute's effect on the aircraft's weight and balance before deployment and aircraft's touchdown attitude after deployment.
- Compatibility of the opening loads and the aircraft's structural design limits.
- The routing of the bridle and harness and the activating housing.
- The placement of the activation handle in the cockpit.
- Incorporation of chute deployment procedures in the in-flight emergency plan and emergency check list.
- The deployment time, from activation to full chute opening.

If a ballistic chute is installed, the builder should add the appropriate ballistic chute inspection items to the aircraft's pre-flight inspection checklist, the ballistic chute manufacturer's repack/refitting schedule and maintenance inspections to the flight manual and the conditional annual inspection check list. If the aircraft is to be fitted with a ballistic recovery chute, it is essential that the serviceability of the system be fully tested on the ground.

It is imperative that if the BRS is to be used as a recovery mechanism, that the system is fully tested on the ground; by fully is meant, COMPREHENSIVE testing of all the functions. Beware of putting all your faith in the BRS and if there is any risk, it would be advisable to additionally ensure that the flight-test crew are equipped with parachutes.



**SACAA Accident Report CA18/2/3/8756 - 13  
February 2010**

There are a cases in which the BRS failed to operate as advertised as in the case of this accident:

*“The pilot-in-command stated that at 4000 ft amsl, as per emergency protocol, he called for the ballistic parachute deployment. He then reduced the engine power to idle and the second test pilot switched off the magnetos.*

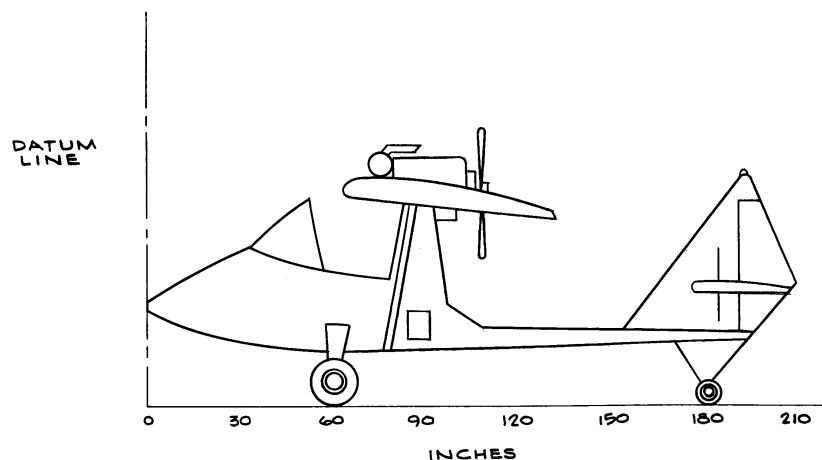
*Once the propeller stopped, the pilot-in-command pulled the release handle for the ballistic parachute. The pilot-in-command stated a deafening bang sounded as the ballistic parachute’s rocket fired and it shot through the opening in the fuselage. As no parachute was visible, he realized that the ballistic parachute had failed to deploy and had remained trapped in the nose section of the aircraft. The aircraft continued to spin at an extremely high rotational velocity and the pilot stated that he could smell burnt gunpowder. At approximately 2500 ft agl, the pilot-in-command gave the bail-out command. The pilot-in-command and second pilot undid their safety harnesses and climbed onto their seats whilst the pilot-in-command unlatched and opened the sliding canopy”.* Fortunately, both pilots escaped from the aircraft.

*Probable Cause: The aircraft entered into an unrecoverable flat spin, which necessitated the crew to bail-out and the aircraft subsequently crashed into the sea.”*

**6.3.19 Weight and Balance**

**6.3.20 Empty Aircraft**

The stability and control and handling qualities of any aircraft is a function of the aircraft’s centre of gravity, FACT! The accurate determination of the aircraft’s take-off weight and ensuring that the centre of gravity (CG) is within the aircraft’s design specification for each flight, is critical to conducting a safe flight-test. An aircraft should be level when weighed, spanwise and fore and aft in accordance with the manufacturer’s instructions, and should be in the level flight position. It is highly recommended that the weighing be done in an enclosed area, using three calibrated scales.



**Figure 6.2** Weight and Balance Example: Empty Aircraft (Reference 1)

The sample airplane in Figure 6.2 for determining empty weight is a single-seater for which the kit manufacturer’s design empty weight was designed for 253 lbs and a gross weight limit of 500 lbs with the datum line located at the nose of the aircraft and a CG range between 69 to 74 inches from the datum. To calculate the CG, determine the EMPTY WEIGHT CG first as illustrated in Figure 6.2 by placing calibrated scales under each of the wheels and recording the weight on each wheel as per the Table 6.1. This process is done with an empty fuel tank.

**Table 6.1 Weight and Balance Data Example (Aircraft Empty)**

Component	Mass (lbs)	Arm (in)	Moment (in-lbs)
	<i>m</i>	<i>d</i>	<i>M = md</i>
Left Wheel	101	60	6060
Right Wheel	99	60	5940
Tail Wheel	42	180	7560
Total	242	80.8 <sup>2</sup>	19560

$$CG_{EMPTY} = \frac{\sum M}{\sum m} = \frac{M_{TOTAL}}{m_{TOTAL}} = \frac{19560}{242} = 80.8$$

Measure the distance in inches from the datum line, or imaginary point identified by the manufacturer (e.g., nose of the aircraft), to the centre line (C/L) of the three wheels. Record the distance of each wheel and place it in the moment arm block beside the appropriate wheel (see Figure 6.2).

Multiply the number of inches (arm) by the weight on each wheel to get the moment (inch pounds) for each wheel. Add the weight on the three wheels and the three moments in inch pounds and divide the total weight into the total moment. The sum is the “EMPTY WEIGHT CENTER OF GRAVITY” in inches. In the sample case, the empty weight CG is 80.8.

**NOTE:** All calculations should be carried out to two decimal places.

**6.3.21 Takeoff Configuration (Additional Items Added)**

Since the aircraft’s empty weight and empty weight CG are fixed numbers, the only way an aircraft’s CG can be changed is by adding weight in other locations. For example, in Table 6.2, the aircraft’s empty weight has been written in the appropriate blocks. The pilot weighs 170 lbs and fuel (5 USG) weighs 30 lbs. Additional equipment, as an example, are a strobe battery, a strobe light and a hand-held radio. Again, all measurements are made from the datum to the centre line of the object that has been added. Weight multiplied by inches from the datum equals moment, then add the weights and moments to find the take-off CG for that particular flight.

<sup>2</sup> Out of limits!

Table 6.2 Weight and Balance Data Example (Additional Items Added)

Component	Mass (lbs)	Arm (in)	Moment (in-lbs)
	$m$	$d$	$M = md$
Aircraft Empty	242	80.8	19560
Pilot	170	65	11050
Fuel	30	70	2100
Strobe Battery	15	75	1125
Strobe	1.5	179	268.5
Radio	1.5	55	82.5
Total	460	74.3 <sup>3</sup>	34186
$CG_{TAKE-OFF} = \frac{\sum M}{\sum m} = \frac{M_{TOTAL}}{m_{TOTAL}} = \frac{34186}{460} = 74.3$			

Add the battery, strobe, and radio numbers in the appropriate locations and calculate the totals. At 460 pounds, the aircraft is still 40 pounds under its design gross weight limit of 500 lbs but is out of balance because the CG has moved 0.3 inches further aft (74.3 inches) than the allowable rear CG limit of 74.0 inches. Since the aircraft is out of balance with an aft CG, it is no longer completely stable in pitch and could be hazardous to fly. Importantly, it is not necessarily the amount of weight added to the aircraft that can cause a major safety problem, but its location.

To bring this aircraft back into the safe CG range, the battery would have to be moved 9 inches forward (66 inches from the datum line). Another alternative would be to install 8 lbs of ballast in the nose (20 inches from the datum). However, that is not an efficient process since payload capability would be reduced.

If the sample aircraft exceeded the designer's gross weight limit (e.g., 300 lbs pilot) instead of the CG limit, its climb, stall, and all round performance capability would be poor and the possibility for in-flight structural failure exists.

**NOTE:** In the sample weight and balance, positive numbers were chosen by placing the datum line on the nose of the aircraft. Some manufacturers prefer to use a datum located somewhere between the aircraft's nose and the leading edge of the wing. This kind of datum will set up a system of positive arms (items located aft of the datum) and negative arms (items located forward of the datum). When working a weight and balance problem with negative and positive moments, subtract the sum of all negative moments from the sum of all positive moments to reach a "total moment" for the aircraft.

<sup>3</sup> Out of limits!

## 6.4 The Engine

### 6.4.1 Engine Testing

The last thing any aircraft designer needs is for the thousands of man-hours sacrifice, ‘making a hole in the ground’ after losing an engine after first takeoff. In South African context, over the period January 1999 to December 2011, out of a total of 2631 accidents, SACAA registered aircraft suffered 397 accidents (15%) attributable to engine failure or power loss. It is obviously essential, therefore, to ensure that the engine has been properly run-in and is safe to operate in all rpm ranges, hence the due diligence required in terms of engine tests.

The engine power output is a direct function of the compression ratio developed in each of the piston cylinders and as such, an engine pre-oil and cold compression should be conducted as follows:

- Remove the rocker-box covers and one spark plug from each cylinder. Using an external oil pump, or by rotating the propeller in the direction of rotation, pump a substantial supply of oil up from the sump into the rocker arms.
- When the engine is pre-oiled, run a cold compression test of each cylinder. The results will serve only as an initial benchmark for comparing other compression tests taken after the engine has been run-up to operating temperature.



#### **SACAA Aircraft Incident CA/18/3/2/0498 - 24 June 2006.**

*“The pilot, accompanied by the owner of the aircraft (Zenair Zodiac) who was also an approved person and the builder of the aircraft, stated that after takeoff from Runway 34 at Howick Aerodrome in Kwazulu Natal, the aircraft engine started losing power at a height of approximately 450 feet agl and approximately thirty seconds later, the engine failed. After the engine failed, the pilot executed a forced landing in an open field he had*

*identified next to the Midmar dam, and an uneventful landing followed with no damage to the aircraft. The pilot and passenger sustained no injuries. The aircraft had a valid Proving Flight Authority to Fly, which was issued on 08 March 2006 with an expiry date of 06 September 2006 or 40 hours, whichever came first. At the time of the incident the aircraft had accumulated 31.4 airframe hours since new. No onsite investigation was conducted.*

*Probable Cause: The pilot executed an uneventful forced landing after the aircraft’s engine failed in flight, for a reason that could not be determined conclusively.”*

Note: The aircraft shown above is not that actual aircraft involved in the accident, but merely an example of the specific type.

### 6.4.2 New/Overhauled Engine Run-In Procedures

Most amateur-builders start with a new or newly overhauled engine and proceed to “run it in” on the airframe, a practice followed due to lack of access to a test cell or a special “club” propeller that is specifically designed to aid in engine cooling during run-in. There are ‘pros and cons’ to using an airframe to run in an engine, but the best advice has always been to follow the engine manufacturer’s instructions

found either in the manufacturer's overhaul manuals, service bulletins, or service letters. Following the manufacturer's instructions is especially important if the engine has chrome cylinders, which require special run-in procedures.

In addition, before running-up the engine, be certain that it has the proper grade oil in the sump. Some new and newly overhauled engines are shipped with a special preservative oil to prevent corrosion that must be drained out and the engine refilled with the correct oil before starting.

#### **6.4.3 Used Engine Run-In Procedures**

Some amateur-builders install a used engine from a flyable aircraft and it is recommended that the same checks and adjustments used on a new or newly overhauled engine, should be applied. New and used engines require special attention to engine cylinder baffling to ensure cylinder cooling is within the engine manufacturer's cylinder head temperature specifications.

#### **6.4.4 Pre Run-in Checks**

Before beginning the engine tests, inspect the engine and propeller carefully, particularly check that all fuel and oil line connections are tight. Check the torque on the engine mount attachment bolts and ensure that there are no tools or rags lying between the cylinders or under the magnetos. Check for the proper amount of oil in the engine and that the dipstick gives an accurate reading of the oil quantity, however, be advised that some engines may have been mounted at an angle in type-certificated aircraft. In this case, such engines have a special part number oil dipstick, which corrects for the different angle of oil in the crankcase. The same engine, mounted level in an amateur-built aircraft with the original dipstick, will not show the correct oil quantity.

#### **6.4.5 Test and Support Equipment**

For the amateur builder/designer, the requirement for establishing the operational readiness of the various components of the aircraft is not always given the attention it deserves. The correct functioning of the aircraft's components, in many cases, may require some form of test equipment, laboratory testing, calibrations, etc. A cylinder head temperature gauge (CHT) is needed to ensure that all cylinders are receiving the proper flow of cooling air. On the newer aircraft engines, the cylinders are drilled and tapped to accept a bayonet type of CHT thermocouple probes. For older engines, the thermocouple is designed like a spark plug washer and fits under a spark plug and can be installed in any cylinder, either under the top or bottom spark plug.

Each type of CHT design can have multiple thermocouples, which are connected to a selector switch in the cockpit from which the pilot then selects the cylinder to be monitored. This also is an excellent troubleshooting tool for identifying fouled plugs and bad ignition leads.

If there is only one CHT thermocouple, attach it to the rearmost cylinder on the right side of the engine (as viewed from the cockpit) and run-up the engine. Run the same test on the opposite rearmost cylinder to be certain the hottest running cylinder was selected. Calibrated oil pressure and oil temperature gauges also are needed to test the accuracy of the engine instruments installed in the aircraft. The following support equipment is needed:

- 50 feet or more of tie-down rope and tie-down stakes,
- two chocks for each wheel,
- fire extinguisher,

- assorted hand tools, safety-wire, cotter-pins,
- ear and eye protection,
- grease pencils,
- logbooks, clip board, pen and paper,
- a stopwatch to time the tests,
- rags, and manufacturer's instructions.

#### 6.4.6 Safety Precautions

Before the first engine run, ensure the aircraft is tied down, brakes are applied, and the wheels are chocked. The test team operating near the aircraft must wear ear and eye protection and all test participants should be checked out on fire extinguisher operation but most importantly, during engine runs, do not allow anyone to stand beside the engine, or in-line or close to the propeller.

**NOTE:** Making minor adjustments to a running engine, such as idle and mixture settings, is a very dangerous procedure and should be done with great care by experienced individuals.

#### 6.4.7 The First Engine Run

The first start of the engine is always a critical operation with many traps for the inexperienced operator. However, using common sense and following the manufacturer's instructions, there should be no real issues. Obviously, the lifeblood of the engine is the oil and as such, the engine should be pre-oiled in accordance with the manufacturer's instructions. For aircraft using other than FAA-approved oil pressure and temperature gauges, the FAA recommends attaching an external calibrated oil temperature and pressure gauge to the 4-cycle engine in order to calibrate the engine instruments. After priming the engine and completing the starting engine checklist items, the first concern is to get an oil pressure reading within the first 20 to 30 seconds. If there is no oil pressure reading, SHUT DOWN! There are three common problems that would cause low or fluctuating oil pressure.

##### **SACAA Accident Report A00-141-7284 - 6 December 2000**

*"According to the pilot, he took off normally from Margate aerodrome in a Cruthley Special for a test flight in the general flying area (GFA). The aircraft was approximately half full of fuel. After flying for approximately 15 minutes, the pilot suddenly experienced an engine failure and executed a forced landing on an open beach south of Port Shepstone. Minimum damage was caused to the aircraft and the nose wheel was only slightly bent. The engine was dismantled and it was established that there was a definite ring seizure caused by overheating of the 1600CC VW engine. There was a sufficient amount of oil in the engine.*

*Probable Cause: It was established that there was a ring seizure caused by overheating of the engine."*

##### *Air in the Oil Pressure Gauge Line*

This is easily fixed by loosening the line connection near the oil pressure gauge and squirting oil into the line until full. Another option is to use a pre-oiler to provide the pressure and carefully bleed the air out of the line near the oil gauge by loosening the B-nut that connects the oil line to the gauge.



#### *A Misadjusted Oil Pressure Relief Valve*

Cleaning the pressure relief ball, checking for the proper number of washers, correcting spring tension, and re-adjusting the setting could solve the problem.

#### *An Internal Problem within the Engine (Most Likely the Oil Pump)*

An engine tear down could be required. With good oil pressure/temperature readings and the engine running smoothly, ensure that the engine oil pressure and temperature gauges in the cockpit match the calibrated oil pressure and temperature gauges, which were attached to the aircraft for the first run. Do not overlook this test as it is critical to determine the accuracy of the cockpit engine gauges, not only for the ground engine run-in period, but also for in-flight engine cooling tests.

Work through the engine manufacturer's run-in schedule. The majority of the engine manufacturers recommend a series of engine runs from low rpm to maximum rpm with each run usually incorporating a 200 rpm increase and which lasts no longer than 10 minutes. The secret to a successful engine run is not to let the engine temperatures exceed the manufacturer's limits during engine runs.

**NOTE:** Engines with chrome cylinders or chrome rings require different high power run-in programs. Follow the manufacturer's run-in instructions to ensure the engine will perform satisfactorily over its lifetime.

#### **6.4.8 Engine Cool Down**

After a ground-run, the cooling off period takes approximately an hour because a newly overhauled engine needs time for the internal parts (e.g., rings, cylinders, valves, bearings, and gear faces) to expand and contract several times to obtain a smooth surface that retains its "memory." This is a lengthy process, but it is important not to skip any of the recommended runs to save time since to do so, is to risk increasing oil consumption and reducing overall engine performance, reliability, and engine life span which could be costly in the long-term.

#### **6.4.9 Recording the Engine Run-In Data**

Engine manufacturers have the luxury of test beds and sophisticated health monitoring systems to track the performance of the engines. In addition, spectral oil analysis programmes (SOAP) check the 'DNA' of the engine through analysis of the oil which enables the engineers to quickly determine impending failures of engine components by detecting and analysing any metal or chemical contamination. The amateur does not have such tools and is thus required to work from 'first principles' and exercise comprehensive configuration management.

Obviously, during the engine run, the cylinder head temperatures, oil temperature, and oil pressure must be monitored with 'eagle eyes'. Also important is to create an 'engine health monitoring system' by recording the readings and adjustments for future reference. If the cylinder head temperatures increase to the red line, reduce power and stop the test. Some causes of high cylinder head temperatures include:

- Using spark plugs with the improper heat range.
- Cylinder head temperature gauges installed on the wrong cylinder.
- Missing or badly designed cylinder head cooling baffles.
- Partially plugged fuel nozzles (applicable to fuel injected engines).
- Fuel lines of improper internal diameter (creates lean mixtures).

- Engine improperly timed either mechanically and/or electrically.
- The carburettor fuel mixture set excessively lean.

#### **6.4.10 After Shut-Down**

After each engine run, check for fuel and oil leaks, loose connections and hot spots on cylinders (burnt paint). The FAA recommends draining the oil and removing the oil screen/filter within the first 2 hours of running the engine and also to check the screen/filter for ferrous metal with a magnet, then wash and inspect the screen/filter for non-ferrous metal like brass, bronze, or aluminium.

A very small quantity of metal in the screen is not uncommon in a new or newly overhauled engine and is considered part of the painful process of “running-in.” If subsequent oil screen checks (2 hours apart) show the engine is “making metal,” this indicates a problem inside the engine and a tear down inspection is essential.

It also is recommended all fuel sumps, filters, and gascolators be checked for debris after each engine run with special attention being given to the fuel system by the builder who constructed fuel tanks out of composite or fibreglass materials. Composite and fibreglass strands can be very fine, making visual detection difficult, therefore, frequent cleaning of the fuel filters and screens early in the flight-testing phase will avoid a gradual build up of loose composite fibres, which would reduce or stop the flow of fuel to the engine.

#### **6.4.11 Ground Test of Engine Operation Simulating Flight**

Engine functional tests conducted statically, so called static testing in simulated ‘level flight’, is all very well, but the ability of the aircraft to move in three dimensions requires, as far as is possible, to assess the fuel system operation at different attitudes. Such tests on the ground are obviously very limited but in terms of flight-testing, it is prudent to accomplish the maximum amount of testing of critical systems such as the engine and fuel system, on the ground to reduce the flight risks.

#### **6.4.12 Mixture and Idle Speed Check**

After completing the initial engine “run-in” tests, check the idle speed and mixture settings by the following methods:

- Warm up the engine until all readings are normal.
- If necessary, adjust the engine rpm to the recommended idle rpm.
- Slowly pull the mixture control back to idle cut-off.
- Just before the engine quits, the engine rpm should rise about 50 rpm if the mixture is properly adjusted. If the rpm drops off without any increase in rpm, the idle mixture is set too lean. If the rpm increases more than 50 rpm, the idle mixture is set too rich.

**NOTE:** Some amateur-builders, after properly setting the idle mixture/rpm to the manufacturer’s specification, increase the engine idle rpm by 100 rpm for the first 10 + hours of flight-testing. This is to ensure that the engine will not quit when the throttle is pulled back too rapidly, or when power is reduced on the final approach to landing.

#### **6.4.13 Magneto Check**

The magneto checks should be smooth and the difference between both magneto’s rpm drops should average about 50 rpm, but most importantly, a “LIVE MAG” check to ensure that the engine will not start

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on its own, MUST be conducted. To perform a “LIVE MAG” check, run the engine until the CHT is in the ‘green arc. At idle rpm turn the magneto switch off; the engine should stop running. If the engine continues to run, one, or both of the magnetos is LIVE and is not grounded. The usual causes for a hot magneto are a broken “P” lead coming out of the magneto, or a bad magneto switch.

**WARNING:** This is an immediate threat to the personal safety of anyone near the airplane and must be repaired at once.

#### 6.4.14 Cold Cylinder Check

If the engine is running rough, it may be an ignition problem and performing the following checks could prove beneficial:

- Run the engine on the bad magneto for about 30 seconds at 1200 rpm, then without switching the magneto switch back to “both,” shut off the engine.
- Use a grease pencil to mark an area of the exhaust stacks approximately an inch from the flange that attaches the stacks to the cylinders.
- Check the marks on the stacks. If one or more of the exhaust stacks with a grease mark has NOT been burned to a greyish-white colour and the mark on the stack still retains most of the original colour of the grease pencil, the “cold cylinder” has been identified.

Probable causes of the cold cylinder problem are defective spark plugs, ignition leads, or a cracked distributor in one of the magnetos. To detect if the spark plugs are bad, switch both plugs to another cylinder and if the grease pencil proves the problem moved to the new cylinder, the spark plugs are unserviceable. If the problem remains with the original cylinder, the ignition lead or magneto could be unserviceable.

#### 6.4.15 Carburettor Heat

It is strongly recommended that all amateur-builders install a carburettor heat system that complies with the engine manufacturer’s recommendation. If no recommendation is available, the FAA suggests a carburettor heat system for a sea level engine and a conventional venturi should be designed so that it will provide an approximately 90°F (32°C) increase in the venturi at 75% power. For altitude engines using a conventional venturi carburettor, 120°F (32°C) increase in venturi temperature at 75% power will prevent or eliminate icing.

During the engine tests, make numerous checks of the carburettor heat system. To avoid overly rich mixtures from oversized carburettor heat ducts, ensure that the carburettor heat duct is the same size as the inlet of the carburettor. Be certain there is a positive reduction in rpm each time “Carb Heat” is applied. If there is no reduction, or the rpm drop is less than expected, check the “Carb Heat” control in the cockpit and on the 'carb heat' air box for full travel. Also check for air leaks in the “SCAT TUBE” that connects the heat muff to the carburettor air box.

**NOTE:** Too little carburettor heat will have no significant effect on carburettor icing while too much carburettor heat will cause an overly rich mixture, which will reduce power and may shut the engine down.

#### 6.4.16 Fuel Flow Check

This is a field test to ensure the aircraft engine will get enough fuel to run properly, even if the aircraft is in a steep climb attitude. This test requires that the aircraft's pitch attitude be increased to an angle 5° above the highest anticipated climb angle. A rather crude but effective test technique which is the easiest and safest way to do this with a tailwheel aircraft, is to dig a hole and place the aircraft's tail in it. For a nosewheel aircraft, build a ramp to raise the nose gear to the proper angle.

The fuel flow with a gravity flow system should be 150% of the fuel consumption of the engine at full throttle, however, with a fuel system that is pressurized, the fuel flow should be at least 125%. Since the fuel consumption of most modern engines is approximately 0.55 lbs per brake horsepower per hour for a 100 horsepower engine, the test fuel flow should be 82.5 lbs (13.7 USG) per hour for gravity feed, or 68.75 lbs (11.5 USG) per hour for a pressurized system. The pounds per hour divided by 60 equals 1.4 pounds and 1.15 lbs per minute fuel rate respectively.

**NOTE:** The formula for fuel flow rate gravity feed is  $0.55 \times \text{engine horsepower} \times 1.50 = \text{pounds of fuel per hour}$  divided by 60 to get pounds per minute, divided by 6 to get gallons per minute. For a pressurized system, substitute 1.25 for 1.50 to determine fuel flow rate.

#### 6.4.17 Changing Fuel Flow or Pressure

If the aircraft's fuel flow rate is less than planned, there is a volume or pressure problem and an increase in the fuel flow volume may necessitate the installation of larger fuel line fittings on the fuel tanks, fuel selector and carburettor in addition to larger internal diameter fuel lines. To increase fuel pressure, install an electrically driven or engine driven mechanical fuel pump prior to the first flight.

#### 6.4.18 Compression Check

When the engine run-in procedures have been completed, perform an additional differential compression check on the engine and record the findings. If a cylinder has less than 60/80 reading on the differential test gauges on a hot engine, that cylinder is suspect; a possible method of determining the cause is to hold the propeller at the weak cylinder's top dead centre and with compressed air still being applied, LISTEN carefully.

- If air is heard coming out of the exhaust pipe, the exhaust valve is not seating properly.
- If air is heard coming out of the air cleaner/carb heat air box, the intake valve is unserviceable.
- When the oil dip stick is removed and air rushes out, the piston rings are the problem.

#### 6.4.19 Last Check

With the taxi test phase drawing nearer, drain the oil and replace the oil filter, if applicable. Check the oil and screens for metal, visually inspect the engine, and do a run-up in preparation for the taxi tests. Do not commit the aircraft to taxiing if the aircraft is not perfectly serviceable. The sky, like the sea, is an unforgiving and uncompromising environment.

### 6.5 Propeller Serviceability Testing

It is obviously pointless to spend an exhaustive amount of time in getting an engine fully serviceable and then to make a sub-optimal propeller installation, after all, the efficiency of the powerplant is a combination of the engine and propeller. Due diligence and an inspection programme on the propeller is

therefore, essential. There are three kinds of propeller designs, metal, wood, and composite, each with its own unique considerations.

Because of weight considerations, metal propellers are used more on amateur-built while wood and composite propellers are the overwhelming choice for ultralight aircraft. Wood propellers are light, reliable, and inexpensive, however, they require more frequent inspections, conversely, composite carbon-graphite material props are more expensive than wood, but are stronger and require less maintenance.

All types of propellers have one thing in common - they are constantly under high levels of vibration, torque, thrust, bending loads, and rotational stress. Even small nicks in the leading edge of the blade can very quickly lead to a crack, followed by blade separation. Propeller tip failure and a subsequent violent, out of balance situation can cause the propeller, engine, and its mounts to be ripped from the airframe in a few seconds. It is essential therefore that the make and model propeller is carefully chosen and that the manufacturer's recommendations are always followed.

**CAUTION:** If experimenting with different makes and models of propellers, remember that a propeller with the wrong size and pitch, will produce a poor rate of climb and cruise, or could cause the engine to "over-rev".

### 6.5.1 Safety Hazards of Propeller Operation

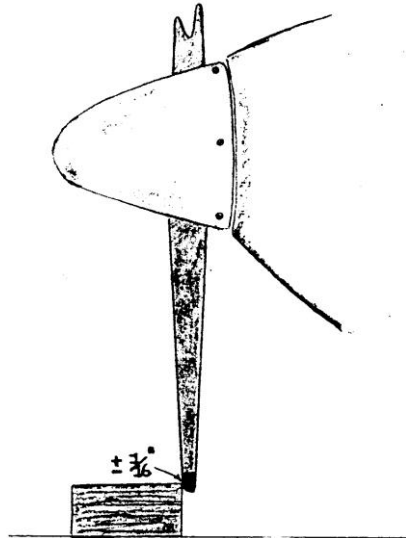
The hazards imposed by the rotating mass of the propeller is well borne out by loss of life over the history of aviation and as such, in terms of risk management, it is essential that all personnel operating in and around a propeller driven aircraft, are comprehensively briefed and instructed on the threats posed by propellers. That is:

- Before working on a propeller, make sure the engine's ignition is OFF!
- Never stand in front of, or in-line with a rotating propeller.
- Never "PROP" an engine on uneven or wet/snow covered ground.
- Never use a propeller for a tow bar when moving the aircraft.
- Always inspect the propeller before and after a flight.
- Always maintain the propeller in accordance with the manufacturer's instructions.
- To avoid nicks and cuts, do not perform run-ups near gravel/loose stones.
- Apply a coat of automotive wax once a month to protect the finish and keep out moisture.
- Assume a propeller is not airworthy if it has suffered any kind of impact or ground strike.
- After any repair or repainting, or if vibration or roughness is noted, re-balance the propeller.
- Propeller blades should be balanced within 1 gram of each other to avoid over stressing the gear reduction system and propeller shaft.
- Check the bolt torque on all newly installed propellers every hour of operation for the first 10 hours and once every 5 hours thereafter.
- After torquing the propeller, track the blades.

### 6.5.2 Propeller Blade Tracking Check

Ensuring good engine operation first starts with a properly installed propeller. Each propeller blade must be checked for proper tracking which ensures that the blades are rotating in the same plane of rotation. The following procedure is simple and takes less than 30 minutes:

- Chock the aircraft so it cannot be moved and remove one spark plug from each cylinder to make the propeller easier and safer to turn.
- Rotate the blade so it is pointing straight downwards.
- Place a wooden block that is at least a couple inches higher off the ground than the distance between the propeller tip and the ground next to the propeller tip so it just touches.
- Rotate the propeller slowly to see if the next blade “tracks” through the same point (touches the block, see Figure 6.3). Each blade should be within 1/16” from one another.



**Figure 6.3** Propeller Tracking Test (Reference 1)

If the propeller is out of track, it may be due to one or more propeller blades that are bent, a bent propeller flange, or propeller mounting bolts that are over or under torqued. An out-of-track propeller will cause vibration and stress to the engine and airframe and may cause premature propeller failure.

### **6.5.3 Metal Propeller Inspection**

Perhaps the two biggest problems affecting the airworthiness of metal propellers are corrosion and nicks on the leading edge. Corrosion can be identified by the following means:

- Surface corrosion can occur on the surface of metal blades due to a chemical or electrochemical action, the oxidation product usually appearing on the surface of the metal as a white powder.
- Pitting corrosion causes small cavities or pits extending into the metal surface. This is an advanced form of corrosion, appearing as small dark holes that usually form under decals or blade overlays.
- Inter-granular corrosion, rare and difficult to detect in propellers, is the most dangerous form of corrosion. It attacks the boundary layers of the metal, creating patches of lifted metal and white/gray exfoliation on the surface of the propeller. It is sometimes found in propellers that have previously suffered a ground strike and have been straightened during the repair scheme.

If any of these signs of corrosion are found, do NOT fly the aircraft and refer to the manufacturer’s maintenance manual for corrosion limits and repairs or FAA AC 43.4, “Corrosion Control for Aircraft,” and FAA AC 20-37D, “Aircraft, Metal Propeller Maintenance,” for additional maintenance information and corrective actions.



**SACAA Accident Investigation Report CA18/2/3/8363 - 10 September 2007**

*“On 10 September 2007 at approximately 1450Z, during daytime conditions, the pilot took off on a local flight from a private aerodrome in order to test a new propeller fitted to the aircraft (Thunderbird Mk. IV). During the flight the design strength of the wing leading edge strut*

*attachment plate on the left hand wing was exceeded, causing the wings to collapse.*

*The pilot sustained fatal injuries during the event and the aircraft was destroyed by the impact and the ensuing fire. The pilot was correctly licensed to conduct the flight and was the holder of a valid unrestricted medical certificate. According to the manufacturer, the performance test on the newly fitted propeller entails entering a shallow dive. This is followed by pulling the aircraft’s nose up and then monitoring the climb performance of the propeller. It was during the pull-up that the left wing leading edge strut attachment plate failed, causing the wing to collapse.*

*Probable cause: During the flight the design strength of the wing leading edge strut attachment plate on the left-hand wing was exceeded, causing the wings to collapse.”*

Note: The aircraft shown above is not that actual aircraft involved in the accident, but merely an example of the specific type.

#### 6.5.4 Metal Blade Nicks

Nicks in the leading and trailing edge of a metal blade are usually V-shaped, being caused by high speed impact between the propeller and a stone or piece of gravel. Specialist technicians can “dress out” the crack if the nick is not too wide and/or deep, however, before each nick is dressed out, the surrounding area must be inspected with a 10-power magnifying glass for cracks. If an area looks suspicious, inspect the area again using the propeller manufacturer’s approved dye penetrant or fluorescent penetrant method.

If the nick is left unattended, the high propeller rotational stresses will be concentrated at the bottom of the nick’s “V” and, in time, will generate a crack which could migrate across the blade until the blade fails, producing a massive imbalance between the propeller and the engine, ultimately causing structural failure.

**WARNING:** Cracks in metal blades CANNOT be repaired. A cracked propeller must be marked unserviceable and discarded.

#### 6.5.5 Propeller Inspection

Wooden propellers should be inspected before and immediately after a flight by ensuring the following:

- The drain holes are open on metal edged blade tips.
- The metal/composite leading edge is secured and serviceable.
- The blades, hub, and leading edge have no scars or bruises.
- The mounting bolt torque and safety wire or cotter pins are secure.
- There are no cracks on the propeller spinner (if applicable), and the safety wire is secure.
- There are no small cracks in the protective coating on the propeller which are caused by UV radiation.

- The charring around the mating surface of the propeller and the engine flange are both indications of a loose propeller.

It is important to note that a new, wooden propeller should have the mounting bolts checked every hour for 10 operational hours thereafter. After 10 hours, check the bolt torque every 5 hours thereafter while the mounting bolt torque should also be checked prior to flight if the aircraft has been in storage for a period longer than 3 months.

**WARNING:** Metal propellers are matched/tuned to the engine and airframe resonant frequency by being manufactured with a particular diameter to minimize vibration. DO NOT SHORTEN METAL BLADES for any reason unless the manufacturer specifically permits this major alteration.

If the bolts need to be torqued, it is suggested all the bolts be loosened for an hour to allow the wood to relax before “finger tightening” the bolts until snug and then tightening the attachment bolts in small increments, moving diagonally across the bolt circle. It is good practice to check the propeller track as the bolts are torqued down and the torqued bolts are safety wired in pairs.

If nylon/fibre insert type nuts are used, they should be changed every time the propeller bolts are re-torqued and should never be used with a bolt with a cotter key hole in the threaded area because the sharp edges around the hole will cut the nylon/fibre insert and reduce the fastener’s effectiveness. All self-locking nuts should have at least two bolt threads visible past the nylon/fibre insert after torquing.

If any of the following damage is found, a wooden propeller must be removed from the aircraft and sent back to the manufacturer for repair. If the propeller cannot be saved, it should be marked unserviceable.

- Any cracks in the blades or hub.
- Deep cuts across the wood grain.
- Blade track that exceeds 1/16 inch limits after attempts to repair.
- Any warping or obvious defect.
- Extreme wear (leading edge erosion, bolt hole elongation).
- Any separation between lamination.

**NOTE:** When parking the aircraft, always leave the wooden propeller in the horizontal position. This position will allow the wood to absorb small amounts of moisture evenly across its entire span rather than concentrating the moisture (weight) in the low blade and creating a vibration problem.

### 6.5.6 Composite Propeller Inspection

There are generally two types of composite propellers: thermo-plastic injection moulded propellers and the carbon/graphite fibre composite propellers. The thermo-plastic injection moulded propeller is a low cost, thin bladed propeller used on engines of 80 horsepower or less. Propeller inspection is straight forward, by examining the blades and hub for cracks and nicks. If a crack is found, do not fly until the propeller is replaced, while small nicks of 3/16 of an inch or less, can be dressed out and filled using a two-part epoxy.

Carbon/graphite composite propellers are primarily used on engines of 40 horsepower and more. Inspection for small hairline cracks in the gel coat is essential since such spider cracks are usually caused by vibration generated by a mismatch of the engine and propeller combination. If a crack in the base material



of the propeller other than the gel coat is found, do not fly with that propeller fitted until the manufacturer has inspected the propeller.

Nicks of 1/2 inch or less in the leading or trailing edges of carbon/graphite propellers can be dressed out and filled using a two-part epoxy, but if the nick has severed the fibreglass roving (looks like a fibreglass wire bundle) that runs hub to tip on the leading and trailing edge, do not fly the aircraft. In this case, the propeller has been severely damaged and must be sent back to the factory for inspection and repair. Before making even small repairs on a composite propeller, check with the manufacturer first and as a “rule of thumb”, larger nicks must go back to the factory for inspection and repair.

## **6.6 Documentation**

### **6.6.1 Traceability**

It is imperative that a basic level of configuration management is applied to the entire flight-testing process, in particular, concerning the documentation. It is essential that all records of the design, development, flight-testing and approval processes are traceable, especially those records of changes made to the aircraft which must be supported by the proper documentation trail. Failure to keep track of each and every change to the configuration could place the entire programme in jeopardy with the regulator or the courts during litigation.

### **6.6.2 Weight and Balance**

The weight and balance for the aircraft should be carefully done and recorded. The gross weight and CG range should be determined prior to every flight.

### **6.6.3 Airworthiness**

Airworthiness/Registration/Operating Limitations/Placards/Weight and Balance must be on board, or the aircraft is not legal to be operated.

### **6.6.4 Checklists**

In addition to the assembly/airworthiness checklist previously discussed, the builder should prepare the following checklists:

- pre-flight;
- before starting;
- starting the engine;
- before takeoff;
- take-off/cruise;
- descent/before landing;
- after landing;
- securing the aircraft;
- emergency procedures, both ground and air.

A checklist to cover the above procedures may seem a tedious task, but it will only be the size of a 5x8 inch card, similar to a checklist for a Cessna 150 or a Piper PA-28-140.

### 6.6.5 Flight Manual

It is imperative that a flight manual describing the performance and handling qualities of the aircraft be compiled by the aircraft builder/kit manufacturer. The manual will be revised several times during the flight-test phase until it accurately reports the aircraft's behaviour throughout the flight envelope.

**NOTE:** The amateur-builder should anticipate several revisions to the checklists derived from findings of the test programme.

### 6.6.6 Maintenance Records (Logbooks)

Operators of amateur-built aircraft are required only to record the annual condition inspections in accordance with the aircraft's operating limitations. The CAA recommends, however, that every amateur-built aircraft/ultralight owner record in the aircraft's logbooks, all inspections and maintenance performed which will create an aircraft's maintenance history and will be invaluable in spotting trends.

# Chapter 7

## Flight-test Programme

*“In my opinion, about 90% of your risk in a total programme comes with a first flight. There is no nice in-between milestone. You have to bite it off in one chunk.” Deke Slayton*

### 7.1 Introduction

The fundamental safety approach to a flight-test programme is to expand the flight envelope in a ‘build-up’ process which essentially requires taking small step increases in the test points, working from the known, to the unknown. The flight-test programme is usually comprised of different sub sections viz, ground tests, taxi tests, flight-tests, etc.

### 7.2 Taxi Tests

Prior to beginning taxi tests in a ‘tail dragger’, the tail should be raised until the aircraft is in the approximate take-off position; the pilot should spend time in the cockpit to become accustomed to the aircraft’s takeoff attitude. This small but important aspect of training will help the pilot avoid overreacting to an unexpected deck angle on the first flight.

**NOTE:** Initial taxi tests should always be monitored by a minimum of one other member of the flight-test team, who will watch for evidence of fire/smoke or other problems not visible to the pilot.

#### 7.2.1 Low Speed Taxi Tests

In the build up to first flight, the obvious starting point is the low speed taxi tests, the objectives of which are to:

- Ensure that the aircraft “tracks” straight and there is adequate directional control at 20% below the anticipated take-off speed.
- Determine if the aircraft’s engine cooling and the brake system is adequate.
- Allow the pilot to become proficient with the handling and braking characteristics of the aircraft.

The taxi tests should begin with a taxi speed no faster than walking pace during which time the pilot should spend this period getting acquainted with the aircraft’s low speed handling characteristics by practicing 90, 180°, and 360° turns and braking action. The pilot should also remember that monitoring the oil pressure, oil temperature, cylinder head temperature and maintaining them within limits, is a critical function that must not be overlooked.

**NOTE:** The test pilot should be aware that some aircraft brake manufacturers have specific brake lining conditioning procedures (‘break-in’) for metallic and non-asbestos organic linings. Proper brake lining conditioning should be completed before starting the low and high-speed taxi tests since, if not properly conditioned, the brake lining will wear quickly and give poor braking action at higher speeds.

The test pilot should check the flight instruments and navigation systems for operation each time the aircraft is taxied out, including the compass, which should be checked against the magnetic heading of the runway, or taxiway the aircraft is actually on. When making a turn (e.g., right hand turn), the turn coordinator/turn and bank should indicate a right hand turn but the ball should skid to the left, and vice versa. The vertical speed indicator should read zero and the artificial horizon should indicate level. After each taxi run, inspect the aircraft for oil and brake fluid leaks; no leak should be considered a minor problem and every leak must be repaired and the system serviced prior to the next taxi test.

**NOTE:** All taxi tests, low and high speed, should be made as if it were the first flight, the pilot should be wearing the proper clothing, seat belt/shoulder harness and helmet and be mentally and physically prepared for the possibility of flight.

### 7.2.2 High Speed Taxi Tests

The high speed taxi test is the next step to progressing to first flight and which allows the test pilot to determine the aircraft's high speed ground handling qualities and braking performance. Importantly, it also serves as an opportunity to develop the takeoff trim settings. If the aircraft's engine is not a U.S. type certificated engine, the pilot should determine which way the propeller rotates since propeller rotation will determine which rudder pedal must be applied to compensate for the asymmetric thrust of the propeller blades. For example, when viewed from the cockpit, an automotive engine mounted in a tractor configuration that rotates the propeller counter-clockwise, will in this case, require the test pilot to apply left rudder pedal for high speed taxi and take-off.

As with every part of the flight-test programme, the high speed taxi tests should follow the test plan via a build-up methodology, starting slowly and not progressing to the next step until all members of the test team are thoroughly satisfied with the aircraft's behaviour and performance.

**CAUTION:** Heavy braking action at high speeds in tail wheel aircraft may cause directional problems, ground loops, or nose-overs.

Each taxi run should be 5 mph/kts faster than the last run until the aircraft is within 80% of the predicted stall speed. Prior to reaching the 80% predicted stall speed test point, the pilot should test control effectiveness about each axis by inputting control deflections to determine the minimum airspeed at which each control becomes effective.

In a nosewheel aircraft, the pilot should be able to raise the nose of the aircraft to a takeoff attitude at 80% of the stall speed. If the nose cannot be raised at this speed, the weight and balance and CG range should be rechecked since there is most likely a forward CG problem or the main wheels are too far aft.

In a tailwheel aircraft at 80% of stall speed, the pilot should be able to lift the tail and assume a take-off position. Again, if the tail cannot be raised, recheck the weight and balance and CG range since there is most likely a rearward CG problem or the main wheels are too far forward.

If runway conditions permit, expand the envelope on each taxi test to eventually also include flaps in the take-off and landing configuration in an effort to understand the aircraft's behaviour within ground effect in consideration of moving on to the first flight. It is already possible to begin recording the flap effects on directional control and inserting the information into the draft copy of the aircraft's flight manual. The taxi

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tests also provide the first determination of the approximate point on the runway where lift-off will occur and could be marked with a green flag if no other existing reference is available.

**CAUTION:** Ongoing heavy braking action may result in brake fade or even, brake fires. Brake cooling periods must be allowed between taxi tests, particularly if the distance to the runway is relatively far or a crosswind will require continuous excessive use to maintain directional control.

It is advisable to determine how much runway the pilot will need if it becomes necessary to abort the take-off. This is usually accomplished by accelerating to 80% of lift off speed, bringing the engine back to idle, and applying heavy braking action to bring the aircraft to a full stop. After each take-off/abort test, the brakes must be allowed to COOL DOWN, the linings must be examined carefully and replaced if necessary.

After determining the distance required to come to a full stop after aborting, add 30% to the distance and then measure that distance from the OPPOSITE end of the active runway which will be used. If no existing reference is available, mark it with a red flag. The taxi tests are completed when the test pilot is satisfied with both the aircraft's and the test pilot's performance. Prior to advancing to first flight, the aircraft should once again be thoroughly inspected with special attention given to the undercarriage, brake system, engine, and propeller.

**NOTE:** The first high speed taxi tests should be made in no wind, or a light head wind condition. It is good practice for the pilot to ensure that the tests will not interfere with the normal airport operations or create a safety hazard for other aircraft.

During this inspection all discrepancies must be declared serviceable prior to sign out to first flight. From an engine perspective, examine the screens/filters for metal, flush the fuel system, and clean all the screens/filters. Perform a leak check on the engine and the fuel system by running-up the engine.

**WARNING:** Pilots of tailwheel aircraft must always be aware that ground loops are possible at any speed, especially if the main landing gear is located too far forward of the aircraft's CG.



# Chapter 8

## The First Flight Guidelines

*“It is critically important that a test pilot never succumbs to the temptation to do too much too soon, for that path leads but to the grave.” Richard Hallion (1987)*

### 8.1 First Flight Guidelines

The flight-test procedures described herein should first be learnt under guidance of a test pilot since flight-test techniques are a lot like a golf swing; they cannot be learnt from a book, but must be taught and practiced.

**IMPORTANT RULE OF THUMB:** The primary objective of a first flight is to bring the aircraft back safely and as such, every precaution to ensure that the first test flight is an “uneventful” one, must be taken.

The first flight should be flown a thousand times: the first 500 on paper, the next 499 flights in the test pilot’s mind, and once in actuality. The first flight-test should be so well-rehearsed by the test pilot and ground crew, that the first flight is a non-event.

The really good aircraft designers worldwide are recognised and acknowledged through their abilities to design aircraft which pilots find relatively easy to fly and enjoy the harmony between handling and performance. Take the example of RJ Mitchell, designer of the Spitfire – his name will live forever more in the annals of aviation history - his design skills manifested in the Spitfire’s performance and handling qualities have been recorded by WWII fighter pilots describing the aircraft by the term, “a fighter pilot’s fighter”.

#### **CAA Aircraft Accident Report A00-123-7266 - 3 November 2000**

*“The pilot took off on runway 19 at Stellenbosch Airfield for the first proving flight after construction of a Skytramp Mk. 1 aircraft. After takeoff the pilot realized that he had to apply substantial back-pressure on the control column and apply power to keep the aircraft level. On landing the pilot had just decreased power when the nose dropped dramatically resulting in a bounced landing, which caused the under carriage to collapse. The aircraft came to rest next to runway 19. Although the aircraft was substantially damaged, the pilot sustained no injuries.*

*The aircraft was issued with a special flight permit on 3 November 2000. According to the pilot, the aircraft was loaded within the fore and aft CG limits of 20% and 31% MAC (Mean Aerodynamic Chord) respectively at 25.44% MAC. According to the designer of the aircraft, it is possible that the tail plane incidence angle was either designed incorrectly or constructed incorrectly, which could have resulted in decreased elevator efficiency. According to CAA records, the pilot did not have the type endorsed in his licence, nor did he obtain permission from the Director to act as pilot in command for this flight.*

*Probable cause: Undetermined, but possible incorrect tail plane incidence angle, resulting in inadequate elevator authority or incorrect trim position.”*

From a specification and regulatory point of view, the formal regulations such as the USAs Federal Aviation Authority (FAA) and the British Joint Airworthiness Regulations (JAR), may specifically spell out aircraft behaviour and response criteria, in many cases, quantitatively. On the military front, the MIL-SPEC 8785C is a typical specification according to which military aircraft are certified. In some cases, the regulatory criteria are described qualitatively. In all cases though, irrespective of the specification, regulation or standard, the common denominator is that the aircraft should be easily controllable by the average pilot.

The first flight is an important event for an amateur-builder, but as important as it is, it should not be turned into a social event since this puts enormous peer pressure on the test pilot to fly an aircraft that may not be airworthy or to conduct the flight in inclement weather. A “professional” will avoid this trap by following the test plan under the conditions approved by the Safety Review Board and inviting only those members of the crew needed to perform specialized tasks when testing the aircraft.

### 8.2 First Flight Decreases

A safe and uneventful first flight begins with verifying all emergency equipment and personnel are standing by, radio communications are functional, members of the crew are competent and briefed, weather is ideal, and the aircraft is airworthy.

The best time to test fly an aircraft is usually in the early morning when the winds are calm and the pilot is well rested. In addition to a pilot’s kneepad, a small portable tape recorder or video camera properly mounted to the aircraft is an excellent way to record data. Good communication with the ground is essential for data exchange and safety.

Prior to the first flight, the aircraft should be given a good pre-flight inspection by the pilot and at least one other experienced individual. A thorough aircraft pre-flight inspection should ensure that:

- The fuel on board is four times the amount of usable, clean, and proper octane fuel than is actually needed for the first flight. If a 2-cycle engine is used, check that the oil to fuel mix ratio is correct.
- A current weight and balance check has been completed ensuring that the aircraft’s CG should be in the forward half of the CG margin. This will reduce the possibility of instability during approach to a stall and enhance recovery from one.
- Check oil, brake fluid, and hydraulic system for the correct fluid and quantity.
- Canopy or cabin door latches lock securely and will not vibrate loose in flight.
- The fuel cock is in the proper position and vent lines are open.
- The trim tabs set in the take-off position.
- The altimeter is set to the field elevation and crosschecked with the local altimeter setting.
- The complete control system has been given a functional check.
- Check of all required ground and air communications frequencies for proper operation.
- The engine cowling and airframe inspection plates/fairings are secured.
- The airspeed indicator marked with sticky tape at the “predicted” BEST CLIMB speed, BEST GLIDE speed and MANEUVERING speed. If these speeds are not available from prototype flight-test data, the following are conservative guidelines to initially determine the referenced speeds:
  - Best Angle of Climb ( $V_x$ ) = 1.5 times the aircraft’s predicted lift-off speed.
  - Best Glide Speed = 1.5 times the aircraft’s predicted lift-off speed.
  - Manoeuvring Speed ( $V_a$ ) = 2 times the aircraft’s predicted stall speed.



For applicable aircraft, it is advisable to put the maximum undercarriage operating speed ( $V_{io}$ ) and maximum flap extension speed ( $V_{fe}$ ) on a piece of masking tape and attach it to the instrument panel for reference.



**SACAA Aircraft Accident Report CA18/2/3/8042 – 15 November 2005**

*“The pilot stated that, he was initiating his test flight (for a proving flight of a Cayotte II) and after conducting a pre-flight inspection and engine runs, he taxied to the end of Runway 30. The acceleration was normal. During the take off roll at 45 Miles Per Hour (MPH), the aircraft became airborne of its own accord. The aircraft climbed*

*to approximately 20 feet agl when the engine power started to decay. The aircraft, due to loss of power, started to sink back onto the ground and as the aircraft was close to the ground, the pilot closed the throttle. The torque effect was for the aircraft to swing to the left, rather than opposite side. He used it to good effect and applied more left rudder to cause the aircraft to ground loop to the left. The pilot sustained no injuries and the aircraft had damage to the propeller, fuselage and left wing tip. It is possible that the aircraft was rotated prematurely and continued to climb to an unknown altitude before it stalled and started to sink back into the ground, resulting in a hard landing. The pilot knowingly flew an aircraft, which he was not rated on, as he had a Class 2 test pilot rating. The aircraft was a new kit built and was on proving flight and was operated for 0.6 hours prior to the accident.*

*Probable Cause: The accident was attributed to a premature rotation of the aircraft resulting in a stall and a subsequent hard landing and the pilot had not trained on type thus the lack of experience on type.”*

Note: The aircraft shown above is not that actual aircraft involved in the accident, but merely an example of the specific type.

### 8.3 The Role of the Chase Aircraft

The use of a chase plane for a first flight is not essential, however, there are several reasons why it would be beneficial and the decision to use, or not to use a chase plane, should be the advised by the Safety Review Board. If a chase plane is used, it must serve a specific set of functions identified in the test plan, its overall purpose being to contribute to gathering flight-test data and flight safety. Importantly, the chase plane should not serve as a distraction to the test pilot, or only as a platform for a home camcorder/camera. The primary functions of the chase plane are as follows:

- To watch the parts/systems of the test aircraft not visible to the test pilot and report any problems.
- To assist the test pilot in following the test plan.
- To provide an extra pair of eyes in providing situational awareness and traffic avoidance.
- To provide mutual support in any emergency situation that may develop.

If a chase plane is used, the following suggestions are offered:

- A single chase plane should be used on the first two flights and the first time the amateur built aircraft’s landing gear is retracted. The chase plane pilot should obviously be experienced in

formation flying and thoroughly briefed prior to each flight. The 'pickup' at takeoff is a particularly skilled procedure and should ideally be practiced in similar type aircraft before the time.

- There should be at least two pilots on board the chase plane. One pilot's sole duty is to fly the aircraft and maintain a safe distance from the aircraft while the other pilot serves as an observer whose duties include checking for other traffic, the condition of the test aircraft, and communicating with the pilot on the frequency assigned by air traffic control.
- A good chase plane position is about 100/200 feet off the right side and slightly behind and below the test aircraft. Chase should avoid flying directly behind the test aircraft because it is not uncommon that on first flights, fuel and oil leaks develop and small hardware and fasteners could vibrate off the aircraft.

**NOTE:** Pilots of both aircraft must keep each other informed of their intended action or manoeuvre prior to execution.

In an emergency situation, the following procedures should be adopted:

- If the test aircraft's radio fails, the chase plane should serve as an airborne communication relay with the tower/ATC facility for the test aircraft.
- For other emergencies, the chase plane should provide the test pilot with information and assistance as required, including reviewing emergency checklists.
- If necessary, the chase plane can guide the test pilot to a safe landing at the airport or an emergency field.
- If the test aircraft goes down off the airport, the chase plane can serve as an overhead spotter that can direct emergency personnel to the test aircraft location.

### 8.4 Emergency Procedures

*"At the worst possible time, the worst possible thing will happen." Murphy's Law*

It is essential to develop a complete set of in-flight emergency procedures for the aircraft that are designed to make unmanageable situations manageable, prior to first flight. Such emergencies should be understood technically and procedurally, and if possible, should be refined during the ground phase of the development programme.

The test plan must have a special section on emergency procedures that should have been developed based on the aircraft's predicted flight characteristics, airport location, surrounding terrain, and nearby emergency fields. The following is a partial list of possible emergencies that may arise during the flight-test phase and includes suggested responses.

#### 8.4.1 Engine Failure on Takeoff

**RESPONSE: Fly the aircraft!** Establish best glide speed. If time permits, try to restart engine. If altitude is below 800 feet and the engine will not start, land straight ahead or 20° on either side of the runway centreline because in most cases, the aircraft will run out of altitude or airspeed as the pilot attempts a 180° turn back to the airfield.

Declare an emergency and shut off the Master Switch, fuel cock, and magnetos to reduce the possibility of fire on landing. Depending on the aircraft type, above 800 feet, the chances of making a 180° turn to land downwind on the runway or another emergency field nearby, are directly proportional to the wind velocity,

the engine out glide performance, the numbers of practice emergency landings the pilots has made in similar category of aircraft - and of course, pilot judgement and skill.

#### **8.4.2 Engine Vibration Increases with RPM**

RESPONSE: **Fly the aircraft!** Reduce power or increase power to minimize the effect of vibration, but maintain safe airspeed and altitude while running through the emergency checklist and land as soon as possible.

#### **8.4.3 Smoke in the Cockpit**

RESPONSE 1: **Fly the aircraft!** If the smoke smells like burnt plastic wire, shut off the Master Switch, put on smoke goggles, open the fresh air vents to clear the cockpit, and land as soon as possible.

RESPONSE 2: **Fly the aircraft!** If the smoke is bluish/grey and has an acrid door like burning oil, shut off the fresh air/hot air vents and put on the smoke goggles. Monitor oil pressure and temperature and be prepared to shut the engine down and land as soon as possible.

#### **8.4.4 Engine Fire**

RESPONSE: **Fly the aircraft!** Shut off the fuel selector, mixture, Master Switch, and magnetos and land as soon as possible.

#### **8.4.5 Out of Rig Condition**

RESPONSE: **Fly the aircraft!** Try to use the appropriate trim to offset adverse control pressures while keeping the airspeed high enough to maintain control and altitude. Keep the aircraft balanced, make small control inputs, reduce power slowly to avoid controllability problems, and land as soon as practical.

#### **8.4.6 Cabin Door Opening in Flight**

RESPONSE: **Fly the aircraft!** A partially open door could affect the airflow over the tail causing reduced control response and vibration, therefore, reduce airspeed, maintain level flight and yaw/slip the aircraft left or right to reduce vibration. Open the side vent window to reduce air pressure resistance in the cabin and attempt to shut the door. Sometimes putting the aircraft into a skid will assist in closing a partially open door.

#### **8.4.7 Other Possible Emergencies**

Other possible emergencies to plan for include:

- Canopy opening unexpectedly.
- Loss of communications.
- Throttle stuck in one position.
- Oil on the windshield.
- Propeller throws a blade.

### **8.5 The First Flight**

*“Always leave yourself a way out.” Chuck Yeager*

The aims of the first flight are to determine engine reliability and flight control characteristics while bringing the aircraft back safely. After completing the pre-flight inspection, the test pilot should ensure that the seat/shoulder harness is properly fitted and allows easy access to all the cockpit controls (verified by a crewmember).

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Following the test plan and using the starting checklist, warm up the engine until the engine instruments indicate normal operating temperatures and pressures. A complete check of each aircraft system should be performed (e.g., carb heat, magnetos, static rpm, and brakes).

If the airport does not have a tower available, the pilot should transmit blind the following message: “This is experimental aircraft [*callsign*] on the first test flight, departing runway [*runway in use*] at [*airfield name*] airfield, and will remain in the local area for the next hour.” Transmit the aircraft’s callsign, location, and intentions every ten minutes.

If the airport is equipped with a tower, notify them that an experimental aircraft is on its maiden test flight. After being given clearance to take-off, clear the holding area, line up on the runway centreline, release the brakes, and slowly add power to provide “thinking time.” When the throttle is fully advanced, glance at the oil pressure gauge and tachometer to confirm they are in the green and indicating take-off rpm. A type-certificated engine of a 100 horsepower will produce between 2100 to 2300 rpm on the take-off roll, depending on the type of propeller installed. If any of the engine or flight instruments readings are incorrect, abort the takeoff! If there is any unusual vibration, rpm exceeding the red line, or engine hesitation, abort the takeoff!

If in a ‘tail dragger’, keep the tail on the runway until the rudder is effective which usually happens at approximately 35 mph/28 kts on most light experimental aircraft. As the aircraft accelerates and approaches the predicted/manufacture’s lift off speed/point (green flag), gently ease back on the stick. The first take-off should be a gentle and well-controlled manoeuvre with the aircraft doing all the work. If the aircraft does not want to rotate or unusual stick forces are experienced, abort the takeoff, regroup, and analyse the problem.

If the aircraft has a retractable undercarriage, do not raise the undercarriage on the first two flights until the aircraft’s stability and control responses and electro-hydraulic systems have been explored sufficiently to confidently retract and extend the undercarriage.

It is recommended that after establishing a safe climb angle, the test pilot DOES NOT throttle back, switch tanks, or make large inputs into the flight controls for the first 1,000 feet. At the preselected altitude, reduce power slowly to avoid a pitch up or pitch down that might be associated with rapid power reductions.

**NOTE:** Check if there is any additional stick or rudder input pressure during the climb, try reducing any abnormal stick pressures with trim. Each control input should be small and slow. If significant trim changes allude to possible rigging problems, return for landing.

If any unusual engine vibrations, rapid oil pressure fluctuation, oil and cylinder head temperatures approaching the red line, or decreasing fuel pressure is experienced, refer to the emergency checklist and land as soon as possible.

One of the most important value adds to the test programme, is an experienced test pilot; particularly when it comes to assessing the aircraft’s handling qualities. The test pilot will subconsciously be noting changes about all axes with changes in airspeed and altitude and concurrently assessing contributing factors to any untoward characteristics - that is what test pilots are trained to do.

The whole purpose of the first flight is to get the “feel” of the aircraft by assessing response to control inputs about all axes. The test card for the first flight should focus on a series of tests to develop

information of the aircraft that will ensure a safe landing. The first test flight should be conducted within the following guidelines:

- After take-off, climb to a safe height for the aircraft's performance category, (3,000 feet agl) and level off, reduce power slowly and complete the cruise checklist items.
- Following the test plan, circle the airport or emergency field as the engine performance is being monitored.
- Limit the cruise speed to no more than 1.5 the predicted stall speed of the aircraft, which will reduce the probability of flutter. If the engine appears to be operating smoothly, start testing the flight controls.

With the airspeed being monitored, each control input should be gentle and small, starting with the rudder first by yawing the nose of the aircraft 5° left and right and noting the response. Raise the aircraft's nose 3° up, note the response and after the aircraft is stabilized, level off and try 3° nose down, trim, and note the response. Try a gentle bank of no more than 5° to the left, then 5° to the right. If the aircraft is stable and is operating smoothly, do a few 90° clearing turns, followed by two 360° degree turns, one to the left and one to the right at a bank angle of 10°.

If the aircraft is responding to the prescribed specifications, increase the bank angle in succeeding turns to 20°. If no problems are encountered, climb to 5000 feet agl depending on aircraft performance category, level off, fly an imaginary landing pattern, and test the flaps. Practice approach to landing by descending to 4000 ft agl first, then to 3000 feet.

During these manoeuvres, control pressures should increase in proportion to control deflection. If control pressure remains the same as control deflection increases, or if stick forces become lighter as control deflection increases, the aircraft may have a stability problem. Avoid large control movements and land as soon as possible.

Remember to keep informing the tower/chase plane of intentions and the status of the aircraft. For 10 minutes of the anticipated flight time, plan a brief rest period for the pilot by flying straight and level, monitor the gauges, and enjoy the experience.

At low cruise power setting, straight and level, observe how the aircraft trims out.

- Do the 'fixed' trim tabs on the rudder and aileron need adjustment?
- Are the adjustable aileron and elevator trim controls effective?
- Is the control stick/yoke slightly forward of the mid-position in straight and level flight?

Climb slowly back up to a safe height for the aircraft performance category (5000 feet agl) in an effort to answer two questions that must be answered before landing:

- Is the aircraft controllable at low speeds?
- What is the approximate stall speed?

These questions can be answered with an approach to a stall manoeuvre but do NOT perform a FULL STALL check at this time! The necessity for an approach to a stall check is because it will help establish a preliminary stall speed ( $V_{si}$ ) so that the approach speed for landing can be calculated and also that the pilot will have knowledge of the aircraft's handling characteristics at low speed. The suggested procedure is as follows:

- Level off at altitude; make two clearing turns; stabilize airspeed, heading, and altitude; apply carb heat; set the flaps in the landing configuration and reduce power slowly to flight idle and TRIM! If, as is not uncommon on first flights, the aircraft cannot be trimmed properly, the pilot can still proceed with the check as long as the stick forces are not unusually heavy and are in the correct sense ie no stick force lightening.
- With the aircraft airspeed approximately 1.4 mph/knots times (x) the predicted stall speed, it is desirable for the aircraft to decelerate slowly at approximately 1/2 mph/0.5 knot per second. A 30 mph/knot deceleration at 1/2 mph/knot per second will take only a minute.
- As the aircraft decelerates, note all the things that happen as the speed bleeds off. Observe the changing nose-up attitude and how the stick force changes while keeping the turn coordinator or turn and bank 'ball' in the middle to prevent the development of asymmetric roll/yaw moments.
- Note how much rudder it takes to keep the ball centred while making small control inputs to check that the aircraft is operating in the prescribed manner. If the aircraft does not respond to small control inputs, and it should not be expected to respond as quickly as it did at higher speeds, make the inputs a little larger. Increase the amount of input progressively but do not simultaneously put in all three control inputs. Give particular attention to the response to nose down elevator input, which is necessary for recovery.
- Notice any changes in flight characteristics and the speeds at which they occur but be especially alert for the onset of pre-stall buffet. Is the buffet felt through the stick? Through the airframe? Through the seat of the pants? Does the nose of the aircraft want to pitch up or down on its own? How intense is the buffet? Is it continuous? Would it get the pilot's attention if they were concentrating on something else?

**NOTE:** Be aware that on some high performance aircraft and aircraft with unusual wing designs, a pre-stall buffet may not exist and the stall may be abrupt and violent with a large degree of wing drop.

Keep making small control inputs at intervals to check the aircraft's response about all axes and at approximately 5 mph/knots before the predicted stall speed, or at the first sign of a pre-stall buffet, note the airspeed and stop the test. Recover and note the pre-stall indicated airspeed, which should be the reference stall speed for the first landing. The pre-stall recovery response should be a smooth and quick forward stick movement and should only be enough to reduce the angle of attack to the point where the airplane is flying normally again.

A wing drop would be unexpected so early in the approach to a stall, but if it becomes necessary to raise a low wing do it with rudder, NOT OPPOSITE AILERON. The adverse yaw induced by the use of ailerons at lower airspeed, could increase the chances for a stall or a sudden departure from controlled flight resulting from asymmetric roll/yaw forces.

There is no need to gain more airspeed than the extra few mph/knots to fly out of a pre-stall condition and after returning to straight and level flight and using the information learned, the pilot can practice a few more recoveries from a pre-stall condition. Do not get so involved and 'sidetracked' that the overall objective of the first flight is lost, which is getting the pilot and aircraft safely back on the ground.

The test plan for the first flight should call for a maximum of 1 hour of actual flight time so as to reduce pilot fatigue and the possibility of an engine failure or airframe malfunction occurring due to vibration or construction errors.

**NOTE:** The pilot may elect to make several practice approaches to landing at altitude or low approaches to the active runway to get a solid understanding of the lower airspeeds, aircraft attitude and overall feel of the aircraft in the landing configuration. Before each low approach at the airport, the tower/chase plane should be advised of the pilot's intentions.

When the pilot has completed all the tests called for by the test card, notify the tower and chase plane of the intent to land. Complete the landing checklist before entering downwind and keep all turns to less than 20° of bank, avoiding any possibility of flying cross-controlled which if allowed to continue, and with back pressure on the stick, could result in a cross-control stall and a roll to a near vertical bank attitude and departure with insufficient height left for recovery.

On final approach, the aircraft speed should be no less than 1.3 but no more than 1.4 times the recorded "first flight" pre-stall speed. Homebuilt biplanes (high drag) should use an approach speed of 1.5 x stall speed on landings.

Landings, especially the first one in an amateur-built or kit plane, are always exciting. Proceed slowly and do not over control BUT, If the landing conditions are not ideal, be prepared to go around. The actual touchdown should take place within the first 1,000 feet with braking action being applied before the red (abort) flag marker on the runway. After taxiing in, secure the aircraft, debrief the flight with members of the team, then together perform a careful post-flight inspection of the aircraft.

## **8.6 The Second Flight**

With the hype associated with the first flight now on the wane, the objective of the second flight is consolidation and affirmation of the first flight findings. Once again, as in all cases, before the second flight, the pilot should ensure that all discrepancies noted on the first flight are corrected. It is probable that more ground run-ups, rigging adjustments, or taxi tests will be required and under no circumstances should a pilot takeoff in an aircraft with known airworthiness problems. There is no place for shortcuts in a flight-test programme, the first Law of Aeronautics does not often forgive these types of mistakes.

The pre-flight inspection should be the same as performed for the first flight, including draining the oil and inspecting the oil and fuel screens for contamination. The second flight, again lasting approximately an hour, should be a carbon copy of the first one, with the exception that all first flight discrepancies are corrected. If problems are not corrected, all further flight-testing should be cancelled until solutions are found.

## **8.7 The Third Flight**

"Plan the flight, fly the Plan." Sign on the wall at the Naval Test Pilot School, Patuxent River, USA.

No additional test points must ever be included in the test card 'on the spur of the moment' – any variations or additions to a test plan must be carefully deliberated on. The objective of the third flight, is to validate the engine reliability and should concentrate on engine performance. Engine oil pressure, oil temperature, fuel pressure, and cylinder head temperatures should be monitored and recorded from 55% through 100% rpm. At the higher rpm, be sure not to exceed 80% of the maximum cruise speed so as to avoid the possibility of encountering a flutter condition at this early stage of the test campaign. Do not forget to record the engine responses to any applications of carb heat, leaning the fuel mixture, changes to

the power settings (RPM and Manifold pressure), changes to airspeed, and its response to switching fuel tanks.

Some good advice at this stage: resist the temptation to explore the more exciting dimensions of flight, just stick to the test plan and perform a conscientious evaluation of the engine. After landing, review the data with the team members, make adjustments as needed, perform another post-flight inspection of the aircraft, and record oil and fuel consumption. After three hours of flight-testing, the pilot should be able to make the initial determination that the aircraft is stable and engine is reliable in cruise configuration.

### **8.8 Flights 4 through 10**

“Keep your brain a couple steps ahead of the airplane.” Neil Armstrong

As the test programme advances in the early stages, the objective is to build on the data established during the first three hours and start expanding on the flight-test envelope in a thorough and cautious manner and the operational performance data gathered to date, should be added to the aircraft’s draft flight manual. These next seven 1-hour test segments should confirm the results of the first 3 hours and further explore the following areas:

- Undercarriage retraction and extension (if applicable).
- Climbs and descents to preselected altitudes monitoring engine performance.
- Pitot static in-flight calibration flights.

Before the undercarriage is retracted in flight for the first time, it is advisable to put the aircraft up on jacks and perform several undercarriage retraction tests, including the emergency undercarriage extension tests. The sequencing must be checked through several cycles to understand the cycling times, both in normal and emergency modes. These tests will determine if, in the last three hours of flight-testing, any structural deformation or systems malfunctions have occurred. In addition to the undercarriage retraction tests, the pilot/chase pilot/ground crew should use this time to review the aircraft’s kit/designer instructions and emergency checklist procedures for malfunctioning undercarriage and plan accordingly. If at any time the aircraft has suffered a hard landing or side loading on the undercarriage during flight-testing, the aircraft and its undercarriage should be tested for operation and condition on the ground.

The first undercarriage retraction test should be conducted with the aircraft flying straight and level at a safe height for the specific aircraft performance category (5000 feet agl), over an airport or emergency field. The airspeed must obviously be well under the maximum undercarriage retraction airspeed and when the undercarriage is cycling; note any tendency for the aircraft to yaw, pitch, or roll and record what changes to the aircraft’s trim are required to maintain straight and level flight. If there are no adverse flight reactions or system malfunctions, cycle the gear several times. When satisfied with the straight and level undercarriage retraction test, try an emergency gear extension but only if this is practical.

With the undercarriage extended, slow the aircraft to 1.3 times the pre-determined stall speed, stabilize, lower the flaps to the take-off position, trim, and maintain straight and level flight. Simulate a normal takeoff by increasing rpm to full power, raising the pitch attitude to 3° nose-up, trimming, and then retracting the undercarriage. Observe the following:

- aircraft reaction such as pitch or roll;
- length of time for undercarriage to retract and extend;
- trim requirements, and
- the time necessary to establish a 1,000-foot climb before levelling off.



Practice a simulated takeoff several times to ensure that the aircraft's response is predictable and the undercarriage retraction system is mechanically reliable.

### **8.8.1 Climbs and Descents**

The purpose of these tests is to monitor engine performance and reliability. The test pilot should start the test only after the aircraft has been flying straight and level for a minimum of 10 minutes to stabilize engine oil pressure and temperatures. Engine oil pressure and temperatures must be kept within the manufacturer's limits at all times during these tests remembering that high summer temperatures may place restrictions on the flight-test programme because both oil and cylinder head temperatures will increase 1° for each 1° increase in outside temperature.

#### *Climbs*

Start the first climb at a 5° climb angle, full power, at a predetermined designated altitude (e.g., 1,000 feet agl). Maintain the climb angle for 1 minute and record the engine temperatures and pressures. Reduce power, stabilize the engine temperature, and repeat the test. For the second climb test, the test plan should call for increasing the climb duration - record the results. When satisfied that an engine cooling problem does not exist at this climb angle, repeat the tests using steeper climb angles until the aircraft has reached 15° or encountered an engine manufacturer's limit or a 5-minute climb period at full throttle has been reached.

#### *Descents*

Descents should begin at a safe height for the aircraft performance category (above 5,000 feet agl) with the engine temperatures and pressures stabilized and carburettor heat applied as required. The first descent should be at a shallow angle, at low rpm and last for 30 seconds, not exceeding 1.5 times the estimated stall speed of the aircraft. During long, low power descents, the pilot must be on the alert for too rapid cooling of the engine usually identified by a significant drop in oil and cylinder head temperature (CHT). If a noticeable drop occurs, increase the engine rpm and reduce the angle of descent since if not corrected, the repeated rapid cooling of the engine may cause thermal shock to the engine cylinders and eventually cause cylinder head cracking or seizure.

Conduct each test as before, but increase the time by 30 seconds until limited by the engine manufacturer's restrictions or 5-minute descents are reached. Record temperatures, pressures, altitudes and airspeed data for climbs and descents for addition into the aircraft's draft flight manual.

### **8.8.2 Airspeed Indicator Calibration**

Arguably one of the most important in-flight calibrations required is that of the pitot/static system, namely, the airspeed indicator and the altimeter. Knowledge of the position error correction of the pitot/static system is essential for the accurate speed measurement and the performance assessment of the aircraft for flight planning purposes. The following simple procedure for airspeed calibration is offered for evaluation, often referred to in the flight-test world, as the 'ground course'.

The logic is to measure the time flown over a known track distance in both directions to get an accurate average groundspeed and then work backwards from groundspeed, back to calibrated airspeed (CAS); the difference between CAS and corrected Indicated Airspeed, is then the position error correction (PEC). The error correction process is derived from the standard true airspeed calculation theory as follows:

- Indicated airspeed (IAS) + Instrument Error Correction (IEC) = Rectified Airspeed (RAS) or Corrected Airspeed.
- RAS + Position Error Correction (PEC) = Calibrated Airspeed (CAS).
- CAS + Compressibility Error Correction<sup>4</sup> (CEC) = Equivalent airspeed (EAS).
- EAS  $\times$  Density Correction ( $1/\sqrt{\sigma}$ ) = True Airspeed (TAS), where  $\sigma$  is the relative air density ( $\rho/\rho_0$ ).

Since Groundspeed = TAS  $\pm$  Wind Velocity and wind velocity is cancelled by flying in both directions, TAS = Groundspeed.

So, what is necessary, is first to calibrate the airspeed indicator to determine the instrument errors since no analogue instrument is perfectly manufactured and all usually have a small residual errors which are measured by subjecting each instrument to a bench test against a calibrated source. The error correction should be recorded for inclusion in the calculation.

A measured course over the ground must be chosen with readily identifiable landmarks at each end. The landmarks should be a known distance apart and the length of course should be at least 1 to 2 miles long; a runway typically provides the perfect measured distance without the hazard of obstacles while the start and end of the runway provide accurate landmarks.

The test pilot must fly the precision course very accurately, maintaining a constant height, at least one wing span height above the surface to avoid ground effect interference on the aircraft's flowfield. At a constant airspeed, at the end of each run, record the temperature, altitude, indicated airspeed and the time over each landmark. In an effort to cancel out the wind effect on groundspeed calculations, the course must be flown in both directions, i.e. the reciprocal heading must be flown as well, the groundspeeds averaged to cancel the wind effect. The average of these speeds is therefore the ground speed of the aircraft over the track distance. A computer will convert the temperature, altitude, and ground speed into true Indicated airspeed for the tests. Such accuracy test runs should start at the lowest safe airspeed and work up to cruise speed using 10 mph/knot increments. A typical plot of pressure error Correction versus calibrated airspeed is illustrated in Figure 8.1.

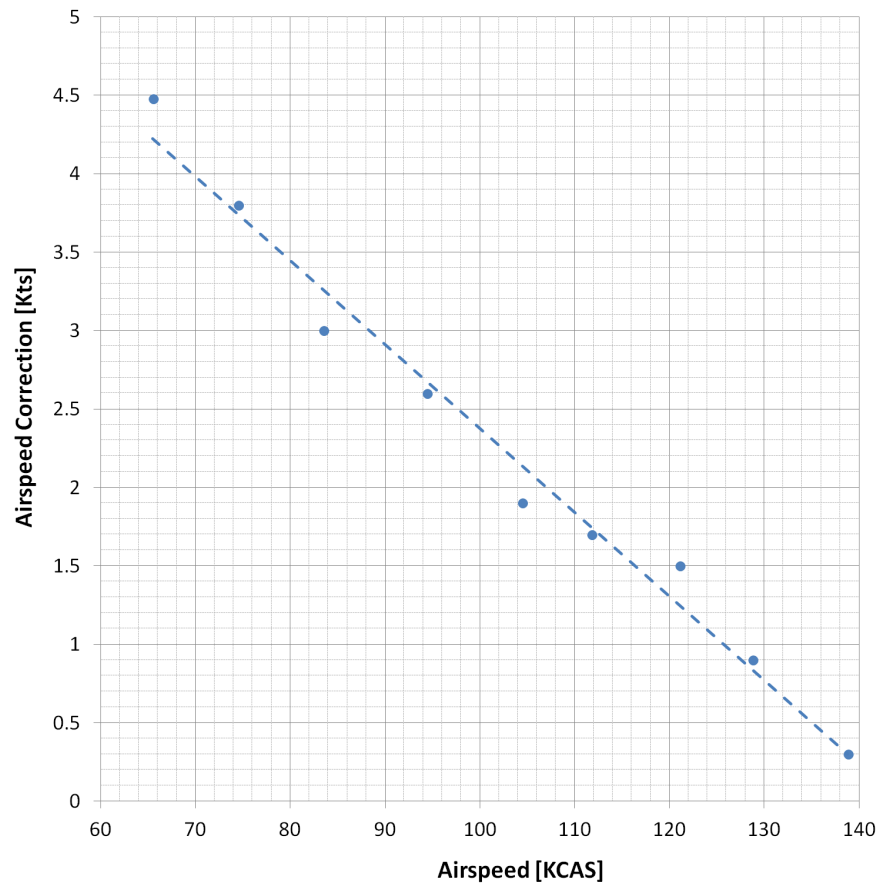
Most errors will be found at the low end of the airspeed range due to the angle of the pitot mast to the relative wind and/or the disturbance to the local flowfield in the vicinity of the static ports. Starting at a low airspeed with sufficient safety margin to control the aircraft, increase the speeds of the runs in 5 kts increments. An alternative method is to use Global Positioning System (GPS) hand held receivers to check groundspeed more accurately.

The simpler method would be to use a calibrated 'pace' aircraft and then fly in formation with the pace aircraft, reading off the differences in IAS and pressure altitude between the two aircraft and using the pitot/static equation, calculating the Pressure Error Correction and Altimeter Error Correction from the 'pace' aircraft.

If the aircraft has retractable undercarriage or flaps, their extended position can adversely affect the flowfield in and around the vicinity of the pitot or static ports and the influence of the configurations on the static pressure, must be determined. Record all the data in order to prepare an airspeed calibration table for the flight manual.

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<sup>4</sup> Compressibility Error Correction is not considered significant within the low speeds usually associated with light sport aircraft and home-builts and can therefore be ignored.



**Figure 8.1** Typical Position Error Correction for Ground Course Pitot/Static Calibration

### 8.8.3 Expanding the Envelope

The flight-test term, “envelope expansion” essentially implies moving from a known flight environment to an unknown flight environment using a series of well-planned and carefully executed steps. Before advancing to the next series of envelope expansion test flights, it is highly recommended that the aircraft undergo a comprehensive inspection because within the previous 10 hours, the aircraft was subjected to what can be referred to as a “shakedown.”

During the inspection, check the torque (paint marks) on the engine mounts, propeller bolts, and undercarriage and double check the flight control hinges and rod end bearings for attachment and play. Check all cable installations, cable tension, and control travel in addition to completing all the standard inspection and maintenance items, which should also include checking the oil and fuel filters for metal or other forms of contamination.

Even if there have been no indications of CO contamination, perform another carbon monoxide (CO) test using the floodlight procedure or an industrial CO test meter since there is a strong possibility that operational vibration and landing stresses may have opened new paths for CO to enter the cockpit.

## 8.9 Flights 11 through 20

*“Fly Scared!” Admiral Jack Ready, U.S.N.*

The next 10 hours of flight-testing should focus on the following:

- stall speed determination, (with weight and CG expansion).
- best rate of climb speed determination,
- best angle of climb speed determination, and
- slow flight.

### 8.9.1 Power Off Stalls

In dealing with the unknown, it is prudent to approach slowly, incrementally, and follow the test plan. To reduce the possibility of inadvertent loss of control, departure or spin, the aircraft should initially be tested with a forward CG loading, developing later to the aft CG limit by means of a build-up programme. At a safe height for the particular category of aircraft, (6,000 feet agl typical for experimental types), stabilise the airspeed at 1.3 times the predicted stall speed and trim. (NOTE: Do not trim within 10 knots of stall.). Starting with the clean (cruise) configuration, conduct a series of three stalls with power off, no flaps, and undercarriage up if applicable.



#### **SA CAA Aircraft Accident Report CA18/2/3/8779 – 12 April 2010**

*“A witness assisted the pilot to move the aircraft (KIS TR-1), from which the engine cowling had been temporarily removed, from the hangar at Petit aerodrome. The pilot then started the aircraft with the intention of test-running the engine. According to this witness, the pilot taxied the aircraft to runway 21 and on his return, taxied*

*faster and became airborne. He lost control and the aircraft’s left wing struck the ground. The aeroplane spun around and skidded for approximately 10m before bursting into flames.*

*According to a second witness, who was also a family member, the pilot went to the airfield to install a new battery in the aircraft. After he had done this, he decided to do an engine ground run-up to check the correct operation of the engine. On the third run-up, the aircraft became airborne, the pilot lost control, and the aeroplane struck the ground, fatally injuring the pilot.*

*The fact that the top engine cowling was not fitted probably disturbed the airflow and caused increased drag, resulting in a stall with an extreme bank to the left. The aircraft was close to the ground at the time, and the left wing struck the ground. The pilot had very limited time to recover from the stall due to the insufficient height available.*

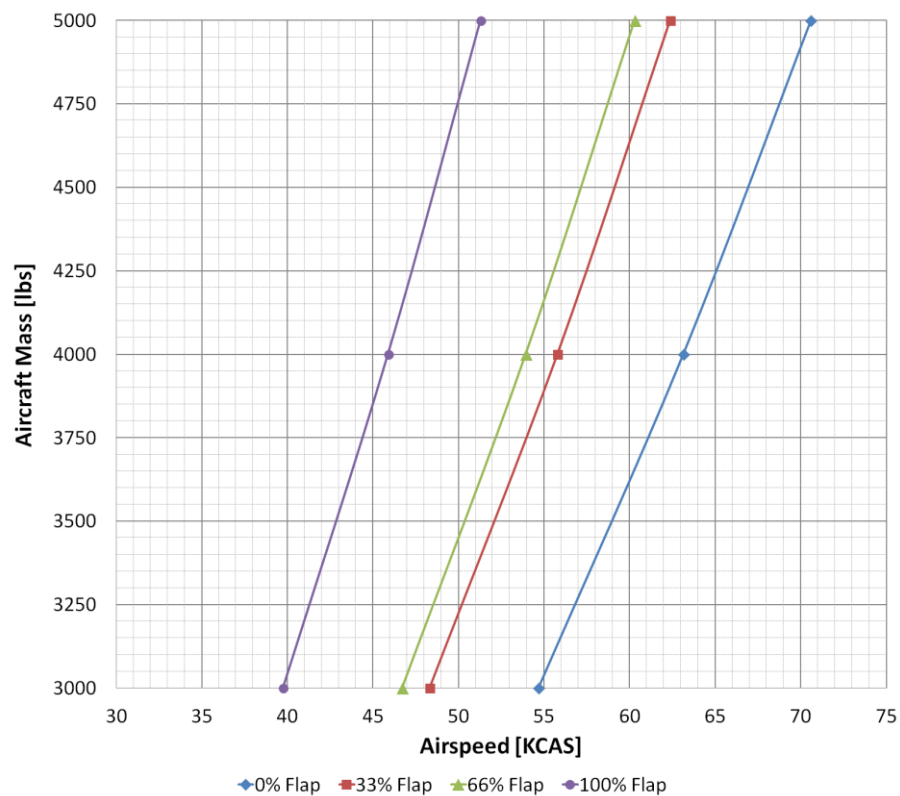
*Probable cause: The aircraft entered a stall from which the pilot could not recover. The left wing struck the ground, followed by the nose.”*

Note: The aircraft shown above is not that actual aircraft involved in the accident, but merely an example of the specific type.

Using the same safety diligence employed on the first flight, secure the cockpit items and select carburettor heat ON. Decelerate slowly at 0.5 MPH/knot a second while making small control inputs, keeping the ball centred, and noting the aircraft’s behaviour, record the stall speed. The preferred pre-stall and stall behaviour is an unmistakable warning buffet starting lightly about 5 to 10 mph/knots above the eventual stall speed, increasing in intensity as the aircraft decelerates.

The desired stall characteristics should be a straightforward nose down pitching moment with no tendency for 'roll off' or 'pitch-up'. This docile and forgiving behaviour implies a stall that has started at the wing root and progressed smoothly outboard and which provides an early warning to the pilot in the form of the buffet from separated airflow over the wings and/or tail. The ailerons should continue to operate in the attached airflow until the aircraft's stall speed is reached and the wing stalls. Note the buffet commencement speed and the stall speed.

Recover by "unloading" the aircraft by reducing the angle of attack and then applying power to assess the height loss for each different configuration. The rate of power application should be a function of the engine's capability for acceleration and if the stall behaviour and recovery is considered satisfactory, continue with the combinations of flap and undercarriage until the matrix of undercarriage and flap combinations have been addressed for the flight phase approach, and landing. The noted buffet speeds, stall speeds, recovery heights and aircraft behaviour, should be developed for inclusion in the flight manual. A typical example of a plot of stall speeds versus Calibrated Airspeed is illustrated in Figure 8.2.



**Figure 8.2** Typical Plot of Stall Speed versus Aircraft Mass for Different Flap Configurations at 1g

**CAUTION:** Some clean, high performance aircraft may not have any noticeable pre-stall buffet; the actual stall may be abrupt and violent with a large amount of wing or nose drop and it would be prudent for the homebuilder/amateur test pilot to have a thorough knowledge of the aerodynamic characteristics of the particular design so as to anticipate the expected stall behaviour.

### 8.9.2 Power on Stalls

As before, use the same procedures moving from the known to the unknown by increasing power incrementally and run a stall test at each new power setting until full power is reached. It is not advisable to advance straight from idle to full power with the resultant large changes in pitch attitude, torque reaction, and slipstream effect on the wing and empennage.

The recommended technique is to stabilize the aircraft at a 'trim speed' in level flight at low cruise power and then by slowly increasing the power to the desired power setting, the test pilot steadily increases the pitch attitude until the aircraft experiences the stall buffet. Power-on stalls are more critical than power-off stalls so it is essential to keep the ball in the centre until the onset of the stall buffet lest the aircraft 'snap roll' and depart.

The power on stall may be more likely to cause uncommanded wing drop than one at idle due to torque reaction and because the propeller slipstream tends to keep the flow of higher velocity air over the inboard (root) section of the wing, despite the higher angle of attack. This allows the root portion of the wing to continue flying after the wing tip stalls, dropping a wing. Tip stalls usually do not provide advance warning and will almost invariably result in some severe wing drop and such stalls are more likely to result in a spin, even if the controls are not mishandled.

If the pilot yields to instinct and tries to correct the wing drop with aileron, it could result in a departure and possible spin. Since a sharp wing drop could be regarded as the onset of spin auto-rotation, the recommended corrective action is to reduce power, exercise prompt application of full opposite rudder, combined with lowering the nose to reduce the angle of attack. Take care to avoid this situation until the aircraft's spin behaviour has been tested.

Perform the same sequence of events for power on stalls as power-off stalls, unless limited by the designer's instructions. Record all findings for the aircraft's flight manual.

**NOTE:** Aircraft with retractable undercarriage will have to go through a separate series of slow flight and stall checks with undercarriage extended, with and without flaps, recording the different stall speeds for each configuration in the aircraft's flight manual.

### 8.9.3 Best Rate of Climb Speed Tests

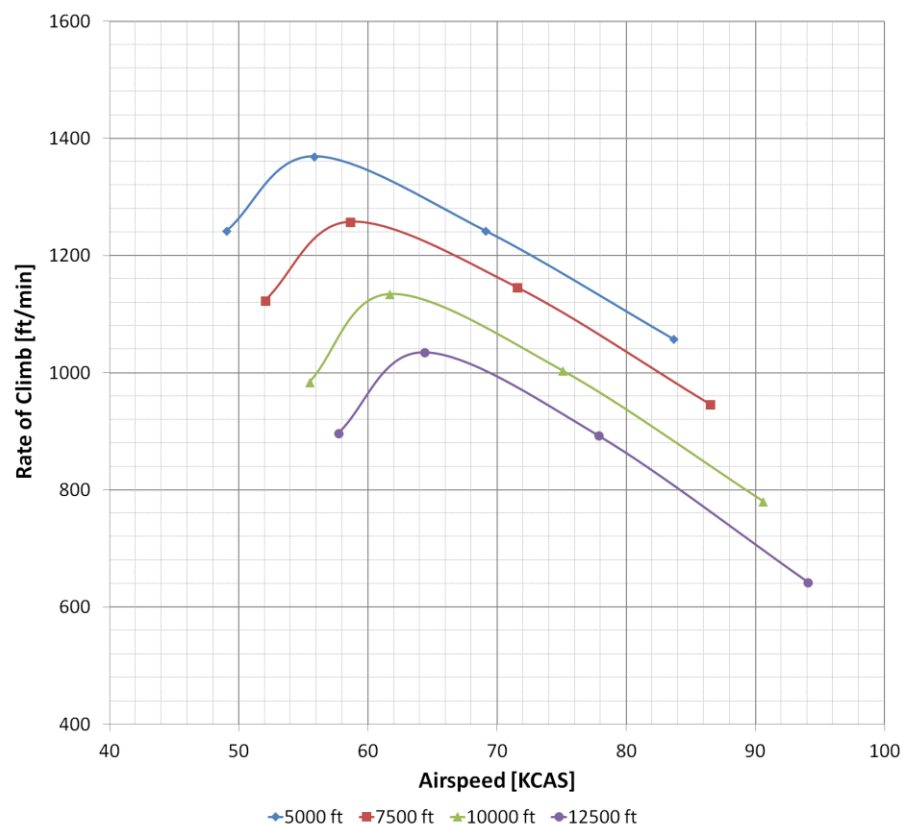
One of the indicators of the efficacy of the design is the aircraft's climb performance and the amateur homebuilder would be monitoring this segment of the test programme closely to get an indicator of the aircraft's performance capabilities. One of the more basic methods to determine the best rate of climb for the aircraft, is the 'saw tooth climb' method.

Obviously, the tests must be performed in smooth air, free from thermal activity; it is critical that there should be no vertical movement of the air mass or else the data gained from the flight-test will be 'nonsense'. Therefore, select an altitude (e.g. 1000 feet agl) as a base altitude and using a heading 90° to the prevailing wind, conduct the climb test.

Begin a full throttle climb well below the predetermined base altitude and stabilize at a preselected airspeed approximately 15 mph/knots above the predicted best rate of climb speed. As the aircraft passes through the base altitude, begin a one-minute time check. At the end of 1 minute, record the altitude gained. Descend down below the base altitude, and then start the next test at a new airspeed 5 mph/knots

lower. After each test, the pilot should decrease the airspeed by 5 mph/knots until reaching an airspeed that is 10 mph/knots higher than the stall speed of the aircraft and then record the airspeed and altitude gained for each climb on a graph similar to Figure 8.3. This data is obviously only applicable for the altitude band for which the aircraft was tested and a range of altitudes must be selected to build a family of curves addressing the intended flight envelope of the aircraft. The airspeed that shows the greatest gain in altitude is the aircraft's best rate of climb speed ( $V_y$ ).

There are of course alternative test techniques available based on the principle of specific excess power determined through level accelerations as a means of determining the points of maximum power available, but this will not be addressed since it requires a more complex form of data analysis not necessarily readily available to the amateur designer/aircraft builder.



**Figure 8.3** Climb Performance Standardised

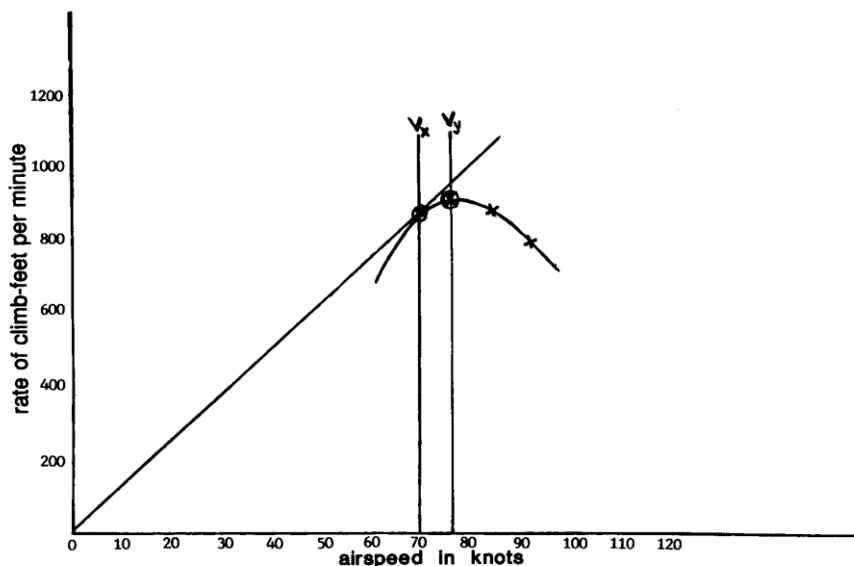
#### 8.9.4 Best Angle of Climb Speed Tests

No experimental flight-testing is required to determine best angle of climb speed, it can be derived from the rate of climb tests previously conducted by drawing a tangent from the zero rate of climb point to a point on the rate of climb airspeed curve. Where the tangent meets the rate of climb curve, draw a line straight down to the airspeed on the X-axis. The airspeed that the line intersects is the best angle of climb airspeed for that particular height, refer Figure 8.4.

#### 8.9.5 Slow Flight-test

In an effort to come to terms with the high angle of attack behaviour of the aircraft, in terms of handling qualities and performance, a series of 'slow flights' should be performed at a safe height appropriate to the

aircraft performance category (typically 6000 feet agl or higher) to allow height for departure and spin recovery. The primary purpose of these tests is for the pilot to become familiar with the aircraft's handling qualities at the minimum undercarriage/down airspeeds and power settings and should include the entire permutation of configurations intended for the aircraft. This should be seen as the initial build-up to future handling and performance testing at maximum all up weight.



**Figure 8.4** Best Angle of Climb Airspeed ( $V_x$ )

The tests should be done with and without flaps by starting the tests at an airspeed of 1.3 times X the stall speed of the aircraft. Once the aircraft is stabilized and maintaining altitude, reduce the airspeed by 5 mph/knots and while maintaining the altitude, continue reducing the airspeed until approaching a stall.

Maintain airspeed at 5 mph/knots above the previously determined stall speed. This figure is the initial slow flight airspeed at which the practice will be conducted at each different flap setting, noting its affect on the aircraft's behaviour. If the aircraft has retractable undercarriage, repeat the tests in all undercarriage and flap combinations. These tests will have to be repeated later in the flight-test programme but with the aircraft at gross weight to determine the actual slow flight airspeed and stall speeds. Additional testing at aft CG will also be required to validate stability and control characteristics.

Remember, to reduce the possibility of unplanned stalls in slow flight configurations and avoid bank angles greater than 5°. When all the test data has been evaluated, and if the aircraft is equipped with a stall warning horn or indicator, set the stall warning at 5 mph/knots above the aircraft's highest stall speed.

### 8.10 Flights 21 through 35: Stability and Control Checks

*“A superior pilot uses his superior judgement to avoid those situations which require the use of superior skill.” Old Aviation Proverb*

Stability and control testing is immensely interesting for the test pilot and of even greater interest and concern to the designer or home builder since it essentially assesses the aircraft's flying qualities and the ease of controlling the aircraft by the average pilot. Pilots obviously require intuitive tactile feedback cues in terms of control forces and displacements, that is what enables a pilot to subconsciously decide whether



the aircraft response is predictable. A pilot needs to know with confidence that the aircraft's response is consistent with the response demanded by the pilot through the controls.

It is obviously essential to determine the aircraft's stability and control limits and range of control available to the pilot before attempting to satisfy the requirements of "Federal Aviation Regulations § 91.319 Aircraft Having Experimental Certificates: Operating Limitations" and declaring that the aircraft is controllable throughout the normal range of speeds. Stability and control checks will be centred around the three axes of the aircraft, i.e. the longitudinal or roll axis (ailerons), the lateral or pitching axis (elevators), and the vertical or yaw axis (rudder).

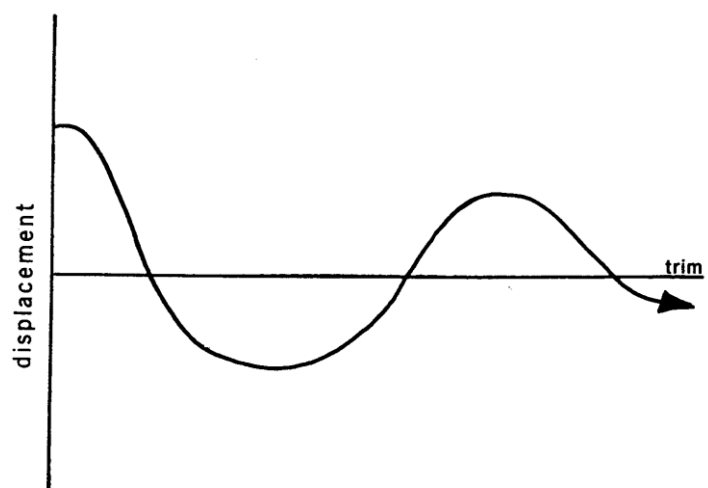
All evaluations need a starting point and the starting point for all stability and control testing is called the 'trim point'. An aircraft is said to be in a state of equilibrium when it experiences no acceleration and remains in a steady trimmed condition until the force or moment balance is disturbed by an atmospheric irregularity or by pilot input. As a starting point for this discussion, a basic overview of some of the definitions is considered appropriate.

### 8.10.1 Stability Definitions

Stability is normally described in terms of the static and dynamic stability characteristics exhibited by the aircraft where static stability deals with the initial behaviour of the aircraft while dynamic stability describes the final state of the aircraft's trajectory, or more technically correct, the time history of the motion following a disturbance. If the motion damps, the dynamic stability is positive, if not, and it diverges, it is negative. If it remains disturbed, the dynamic stability is neutral. In effect, the tests actually address the handling qualities of the aircraft in terms of control forces and deflections. In any stable aircraft, it is essential that positive stick/rudder forces are required to control the aircraft, since the force feedback is what provides the pilot with tactile feedback.

#### *Static Stability*

Positive static stability is when an aircraft tends to return to the state of initial equilibrium following a disturbance as shown in Figure 8..



**Figure 8.5** Time History for Static and Dynamic Stability

Neutral static stability is when an aircraft remains in equilibrium in a "new" position, following a disturbance from an initial equilibrium position.

Negative static stability is when an aircraft tends to move further in the same direction as the disturbance that moved it from the initial equilibrium position.

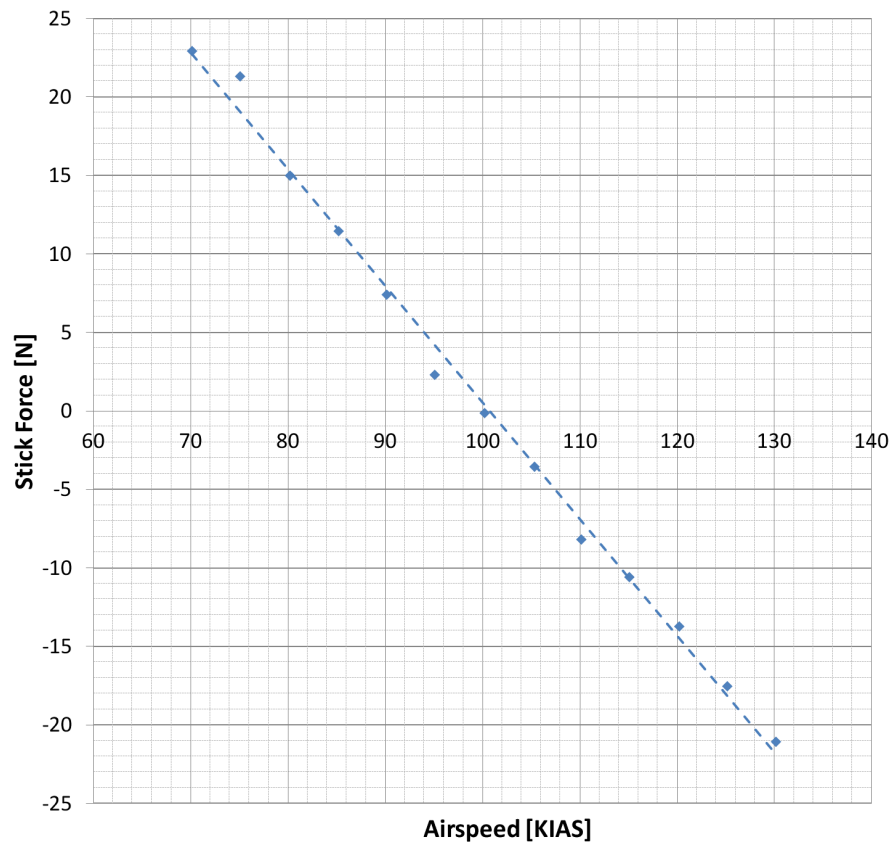
*Dynamic Stability*

Dynamic stability is the time history of the movement of the aircraft in response to its static stability tendencies following an initial disturbance from equilibrium.

**8.10.2 Static Longitudinal Stability Testing**

This test should be done first and as is the case for all flight-testing, should initially be conducted with the aircraft in the forward of centre CG range with the view to eventually expanding the flight envelope to the aft CG limit. Climb to a safe height for the aircraft performance category (typically 6000 feet agl) and trim the aircraft for zero stick force in straight and level flight at low cruising speed. (Note: Do not re-trim the aircraft once the test has begun.) Apply a light “pull” force and stabilize at an airspeed about 10% less than the trimmed cruise speed; at this reduced airspeed, it should require a “pull” force to maintain the slower speed.

If it requires a “pull” force, pull a little further back on the stick and stabilize the airspeed at approximately 20% below the initial cruise trim speed. If it requires a still greater “pull” force to maintain this lower airspeed, the aircraft has POSITIVE STATIC LONGITUDINAL STABILITY.



**Figure 8.6** A Typical Stick Force versus Airspeed Curve for a Stable Aircraft<sup>5</sup>

If at either test points, no “pull” force is required to maintain the reduced airspeeds, the aircraft has NEUTRAL STATIC LONGITUDINAL STABILITY while if either of these test points require a “push” force to maintain the reduced airspeed, then the aircraft has NEGATIVE STATIC LONGITUDINAL STABILITY.

Repeat another series of static longitudinal stability tests using a “push” force on the control stick. Using the same technique, at an airspeed 10% above the trim cruise speed, the control stick should require a “push” force to maintain the airspeed. If a “pull” force is required, the aircraft has NEGATIVE STATIC LONGITUDINAL STABILITY. Such tests are repeated at a range of speeds as determined during the programming of the flight-test campaign. Longitudinal stability considers both the short period, and the long period response. Figure 8.6 illustrates positive static longitudinal stability.

**WARNING:** If the aircraft exhibits negative static longitudinal stability, seek professional advice on correcting the problem before further flight.

#### *Short Period*

After confirming that the aircraft has positive STATIC longitudinal stability, the pilot can check for positive DYNAMIC longitudinal stability by assessing, what in flight-test terms is called the short period pitching oscillation (SPPO), damping characteristics. First, stabilize at the trim point and then with a smooth

<sup>5</sup> This figure illustrates the continuous requirement for pull and push forces of a stable aircraft; there is no stick force lightning or reversal in the gradient of the stick force.

(doublet), but fairly rapid motion, push the nose down a few degrees, then quickly reverse the input to nose up to bring the pitch attitude back to trim attitude. As the pitch attitude reaches trim attitude, release the stick (but guard it). The aircraft with positive dynamic longitudinal stability will oscillate briefly about the trim attitude before stopping back at the trim attitude position. The response of the aircraft to the SPPO in home-builts and experimental aircraft should be very close to 'deadbeat' i.e. without oscillation and it is this response which will determine the aircraft's response to handling the aircraft in turbulence and also provide the test pilot with cues to how easy it will be to 'point' the aircraft attitude in pitch.

#### *Long Period*

To test the aircraft for positive DYNAMIC longitudinal stability is done by what is commonly called the long period or 'phugoid' damping; once again beginning from trimmed, straight and level flight (stick free). Without re-trimming, pull (or push) the stick to a speed about 5 mph/knots off trim point and release the stick. There is no need to stabilize at the new speed but due to the inherent stability or lack thereof, the test pilot can expect the aircraft to oscillate slowly about the trim airspeed a number of times before the motion dampens out. If there is significant friction in the control system, the aircraft may settle at a speed somewhat different from the original trim speed. What is informative to the test pilot, will be the period of the motion and the damping of the motion, which will inform what the level of pilot workload will possibly be following disturbances in flight.

If the amplitude of the disturbance increases with time, the dynamic longitudinal stability is negative or divergent. This is, however, not necessarily dangerous as long as the rate of divergence is not too great, allowing the pilot to intervene in the disturbance and bring the aircraft back to equilibrium. It does mean, however, the aircraft will be difficult to trim and will require frequent pilot attention thereby increasing pilot workload.

An aircraft with "NEUTRAL" dynamic longitudinal stability (long period) will continue to oscillate through a series of increasing/decreasing airspeeds and never return to the original trim airspeed.

#### **8.10.3 Lateral-Directional Stability Control Tests**

As in the case for longitudinal stability requirements, both static and dynamic, the requirement exists for stability about the normal and longitudinal axes of the aircraft. In essence, lateral/directional stability behaviour, similar to the longitudinal testing, provides the designer/builder/test pilot with an indication as to the success of the design but from the perspective of roll/yaw motion. Too much or too little lateral/directional stability will adversely affect the controllability of the aircraft and the workload on the pilot.

The principle of testing for lateral/directional stability remains the same as for longitudinal stability testing requiring all tests to commence from a stable 'trim point' and some typical basic flight-test techniques include steady heading sideslips, Dutch roll damping and spiral stability, to mention just a few.

**CAUTION:** This test may impose high flight loads on the aircraft, particularly the fin; it is possible to break the fin off the aircraft so do not exceed the design manoeuvring speed or any other airspeed limitation.

#### *Steady Heading Sideslip*

To check lateral and directional stability at various points in the flight envelope, the aircraft should be trimmed for level flight at a low cruise setting and a safe altitude for the specific aircraft type). Slowly enter

a sideslip by maintaining the aircraft's heading with rudder and ailerons in what is termed a 'steady heading sideslip'. The aircraft should be able to hold a heading with rudder at a bank angle of 10° or the bank angle appropriate for full rudder deflection. The control forces and deflections, both rudder and aileron, should increase steadily, although not necessarily in constant proportions with one another (in some cases, rudder forces may lighten), until either the rudder or the ailerons reach full deflection or the maximum sideslip angle is reached.

At no time should there be a tendency toward a force reversal, which could lead to an overbalance condition or a 'rudder lock' - a phenomenon caused by the rudder 'overbalancing' as the Centre of Pressure of the control surface moves ahead of the hinge line of the surface. This causes the control surface to float or 'hardover' to the maximum deflection position. Release the ailerons while still holding full rudder. When the ailerons are released, the low wing should return to the level position. Do not assist the ailerons during this manoeuvre.

### *Dutch Roll Damping*

To check static directional stability at various points in the flight envelope, stabilize the aircraft at the trim point and at a safe height for the aircraft performance category. Slowly yaw the aircraft left and right using the rudder, using ailerons to keep the wings essentially level; essentially exciting the aircraft about the normal and longitudinal axes. Once the motion is excited and smoothly progressing, the rudder is released and the aircraft should tend to return to straight flight. As in the case of longitudinal static stability, the time response of the aircraft's trajectory determines whether or not the aircraft exhibits, positive, negative or neutral directional stability. What should be of particular interest to the test pilot is the number of cycles it takes for the motion to damp, the frequency and amplitude of the motion.

### *Spiral Stability*

This is determined by the aircraft's inherent tendency to raise the low wing when the controls are released in a bank. To test for spiral stability, stable at trim point, apply 15° to 20° of bank, either to the left or right, and release the controls. If the bank angle decreases, the spiral stability is positive. If the bank angle stays the same, the spiral stability is neutral, while if the bank angle increases, the spiral stability is negative. Negative spiral stability is not necessarily dangerous, but the rate of divergence, once again, should not be too great or the aircraft will require frequent pilot attention and increased pilot workload, especially while flying on instruments.

**NOTE:** Friction in the aileron control system can completely mask the inherent spiral characteristics.



# Chapter 9

## Envelope Expansion

### 9.1 Introduction

Flight-testing, as mentioned in Chapter 1, is a hazardous ‘past time’ which demands respect; it is only dangerous if the flight-tester “does not know what he does not know”. There are however, some phases of flight-test that are more hazardous than others in which no unqualified test pilot should venture; those fields include aeroelastic testing and spin testing amongst others. In the case of aeroelasticity, it remains a ‘black art’ in which engineering predictions have not yet been perfected while a similar situation exists for the interaction between aerodynamic forces and inertial moments during the spin.

### 9.2 Aeroelasticity: Flutter

Arguably one of the most insidious ‘killers’, is the aeroelastic phenomenon known in flight-test circles as “flutter” and is inherently one of the most hazardous forms of flight-testing and may range from pretty boring ‘non events’ to catastrophic failure of the airframe in a few seconds. Because the flutter mechanism is usually a very sudden occurrence with structural failure occurring in a matter of seconds, it **MUST** be approached with extreme caution, with small incremental build-ups in airspeed/Mach number.

**NOTE:** For the designer, builder and test pilot, it is extremely important to understand the causes and cures for the condition known as “flutter”.



#### **German BFU Accident Investigation Report - 29 November 2006**

*The fatal accident involving a prototype of the Grob SPn Business Jet was caused by tailplane flutter, according to the German BFU investigation report. The aircraft suffered a tailplane separation and crashed during a demonstration flight at the factory airfield, Mindelheim-Mattsies Airport, killing chief test pilot Gerard Guillaumaud. This flight was a demonstration flight for a group of visitors with several fly-bys. The jet took off and as it was lining up for a fly-by, parts from the stabilizer separated, the pilot lost control, and the airplane impacted a field adjacent to the airport. Given the weather circumstances, the flight should have been conducted using Reduced Flight Display specifications, which included a maximum airspeed of 200 knots. The probable speed of the accident airplane was between 240 and 270 kts, which was below the maximum allowed speed for flutter tests, 297 kts. The circumstances that led to the flutter could not be determined clearly due to lack of flight data and limited investigation.*

So, what is “flutter”? Flutter in an aircraft structure is the result of an interaction between aerodynamic inputs, the elastic properties of the structure, the mass or weight distribution of the various elements, and airspeed. To most people, the word “flutter” suggests a flag’s movement as the wind blows across it in a light breeze; the flag waves gently but as the wind speed increases, the flag’s motion becomes more and

more excited. It takes little imagination to realize if something similar happened to an aircraft structure, the effects would be catastrophic.

Think of a primary surface with a control hinged to it e.g., an aileron, and imagine that the airplane hits a gust. The initial response of the wing is to bend upwards relative to the fuselage and if the centre of mass of the aileron is not exactly on the hinge line, it will tend to lag behind the wing as it bends upwards. In a simple, unbalanced, flap-type hinged control, the centre of mass will be behind the hinge line and the inertial lag will result in the aileron being deflected downwards that will result in the wing momentarily generating more lift, increasing its upward bending moment and its velocity relative to the fuselage. The inertia of the wing will carry it upwards beyond its equilibrium position to a point where more energy is stored in the deformed structure than can be opposed by the aerodynamic forces acting on it.

The wing “bounces back” and starts to move downward but, as before, the aileron lags behind and is deflected upwards this time, which adds to the aerodynamic down force on the wing, once more driving it beyond its equilibrium position and the cycle repeats itself.



**NTSB Accident Report NTSB/AAB-12/01 - 16 September 2011**

*“North American Mustang P-51 “Galloping Ghost” lost an elevator trim tab at the Reno Air Race in 2011, killing 11 people and injuring 64 when it impacted near the grandstand. The National Transportation Safety Board (NTSB) determined that the probable cause of this accident was the reduced stiffness of the elevator trim tab system that allowed aerodynamic flutter to occur at racing speeds. The reduced stiffness was a result of*

*deteriorated locknut inserts that allowed the trim tab attachment screws to become loose and to initiate fatigue cracking in one screw, sometime before the accident flight. Aerodynamic flutter of the trim tabs resulted in a failure of the left trim tab link assembly, elevator movement, high flight loads, and a loss of control. Contributing to the accident was the undocumented and untested major modifications to the airplane and the pilot's operation of the airplane in the unique air racing environment without adequate flight-testing.”*

Flutter can occur at any speed, including take-off speed. At low airspeeds, however, structural and aerodynamic damping usually quickly suppress the flutter motion, but as the airspeed increases, so do the aerodynamic driving forces being generated by the aileron. When they are large enough to exceed the structural damping, the motion becomes continuous and could diverge the structure to catastrophic failure. Further small increases could therefore produce a divergent, or increasing oscillation, which can quickly exceed the structural limits of the airframe.

Even when flutter is on the verge of becoming catastrophic, it can still be very hard to detect. What causes this is the high frequency of the oscillation, typically between 5 and 20 Hz (cycles per second) which will take but a small increase in speed (1/4 knot or less) to remove what little damping remaining and the motion will become divergent, very rapidly.



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Flutter also can occur on a smaller scale if the main control surface has a control tab on it. The mechanics are the same with the tab taking the place of the aileron and the aileron taking the place of the wing. The biggest difference is the masses involved are much smaller, the frequencies much higher, and there is less feed-back through the control system which makes tab flutter more difficult to detect. The phenomenon known as “buzz” is often caused by tab flutter and since flutter is more prevalent at higher speeds, it is not recommended that the flight-test plan call for high speed runs within 10% of red line.

What can be done about it? Having described how flutter happens, the following suggestions should help reduce the possibility of it happening to the amateur-builder’s aircraft:

- Perform a mass balance of all flight controls in accordance with the designer/kit manufacturer’s instructions.
- Eliminate all control “free play” by reducing slop in rod end bearings, hinges, and every nut and bolt used in attaching flight controls.
- Ensure that all rigging and cable tension is set accurately to the design specifications using a calibrated cable tensiometer.
- Re-balance any flight control if it has been repaired, repainted, or modified in any way.

**NOTE:** If the pilot experiences flutter, reduce power immediately and land as soon as possible. Do not attempt further flight until the aircraft has been thoroughly inspected for flutter induced damage. This inspection should include all wing/tail attachment points, flight controls, their attach points/hinges, hardware, control rods, and control rod bearings for elongated bolt/rivet holes, cracks, (especially rod end bearings) and sheared rivets. **BOTTOM LINE: RESPECT THE ASI RED LINE OR ELSE PAY THE PRICE FOR IGNORANCE!**

### 9.3 Spinning

The requirement for spin testing is usually contentious and it is essential to determine if spin testing is required for the particular acceptance programme. The challenges facing a spin clearance programme are to find an experimental test pilot who has had experience in spin flight-test programmes and who understands the requirement for a build-up approach, who understands the theory and practice of spinning, who understands and is able to recognise the different modes of spin and the appropriate recovery actions.

**WARNING:** Most importantly, spin recovery cannot be learnt from a book, much like a golf swing; the test pilot must undergo spin recovery training on different categories and aircraft types in an effort to be exposed to the multitude of variations of spin behaviour.

Most probably the most important aspect is to be able to recognise when a spin will most probably not be recoverable after having exercised various anti-spin control options based on the inertial moments and aerodynamic forces and moments. If the manufacturer/designer of the aircraft has not demonstrated satisfactory spin characteristics and safe recovery, avoid all types of high angle of attack flight-testing and placard the aircraft: “SPINS PROHIBITED”. Further tests to prove that the aircraft will recover from a fully developed spin (three turns or more) are not necessary unless the aircraft is designed for, and will be routinely flown in, aerobatic flight.

**NOTE:** All FAA spin tests for type certification require a spin chute attached to the aircraft and it would be prudent to apply the same regulation for NTCA. Even though amateur-built aircraft have no such certification requirement, use of a spin chute during testing must be considered.

During all spin tests, it is strongly recommended that the pilot wear a parachute and that a quick release mechanism to jettison the canopy or door be installed. If the pilot is unable to exit the aircraft because of the design restraints, it is recommended that intentional spins not be conducted even though the design has successfully demonstrated spin recovery.

If any modifications or alterations have been made to the airframe's original design or configuration (e.g., adding tip tanks, winglets or fairings), it is not safe to assume that the aircraft still has the same spin recovery characteristics as the prototype aircraft. Spins in a modified aircraft should not be attempted without consulting a qualified test pilot and/or flight-test engineer.

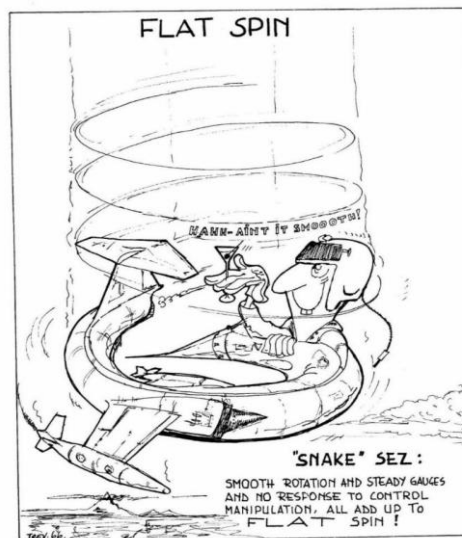
The pilot who conducts the spin tests should have experience in entry into and recovery from fully developed spins, preferably in makes and models similar to the aircraft being tested. If the pilot needs additional experience, aerobatic training with an emphasis on spins from a qualified instructor is highly recommended. In fact, spin training should be an essential requirement for all high angle of attack work.

At this point, nearly all the preparatory work for spin testing has been accomplished. Planning the next flight should be identical to planning for the first flight through stalls.

**WARNING:** IT IS EXTREMELY IMPORTANT THAT THE CENTER OF GRAVITY OF THE AIRCRAFT IS AT THE FORWARD CG LIMIT FOR THE INITIAL TESTING AND ANY BALLAST USED SHOULD BE SECURELY ATTACHED TO THE AIRCRAFT.

The aircraft should be tested with undercarriage (if applicable) and flaps in the UP position. The minimum entry altitude for these tests should be no less than 10,000 feet agl, dependent on aircraft performance category, with the cockpit secured.

The following procedure is one way, but not the only way, of conducting a spin test and executing a recovery. Non-conventional aircraft may require significantly different spin recovery control applications and the test pilot should evaluate these procedures and determine if they are compatible with the aircraft before attempting any spin testing. The basic technique used to get a conventional design aircraft into a clean spin entry is to:



*Analysis of the F-104 aircraft limitations and operating restrictions, written by Glen 'Snake' Reeves, Lockheed Test Pilot and Cartoons by P.P. "Pete" Trevisan - FIAT Test Pilot, Lockheed Report 1967.*

- From a trim point of  $1.3 \times$  Stall Airspeed, decelerate at about a 1 mph/knot a second rate in level flight, carburettor heat on, and the power at idle.
- As the aircraft stalls, APPLY FULL RUDDER in the desired spin direction, followed immediately by full aft movement of the control stick keeping the ailerons neutral.
- The transition from a horizontal to a vertical flight path, takes approximately three turns and is referred to as the incipient stage of the spin.
- During the incipient spin, the aerodynamic and inertial forces have not achieved equilibrium. Interestingly, several aircraft can recover from the incipient spin phase, but may not be able to recover from a steady spin.

The normal spin recovery technique is to first positively identify the direction of the spin (check the turn needle) and then apply full rudder opposite to the direction of yaw. Move the control stick smoothly and fairly rapidly forward towards the instrument panel to un-stall the aircraft.

Centre the rudder as the yaw stops and ease out of the dive but be careful not to pull up too rapidly because the structural limits of the aircraft can easily be exceeded, or the aircraft could re-enter the stall again. Recover from the first deliberate spin after a half a turn.

If the aircraft is not built for aerobatics, no further spin testing is required and it is recommended the instrument panel be placarded "SPINS PROHIBITED". If further spin testing is required, it is strongly recommended the services of a professional flight-test pilot be used.

#### 9.4 Accelerated Stalls

The one side the envelope expansion process investigated up to this stage of the test campaign, is the low airspeed/high angle of attack stall regime. Given that a wing stalls at a specific angle of attack (refer to Section 8.9.2, page 88), there is another side to be considered, that of the high speed or 'accelerated stall' behaviour and it is these characteristics that must be explored.

An accelerated stall is not a stall reached after a rapid deceleration, but rather an in-flight stall at more than 1 g, similar to what is experienced in a steep turn or a pull up, in other words, a 'high speed stall'.

**NOTE:** Do not attempt this or any other extreme manoeuvre unless the designer or kit manufacturer has performed similar tests on a prototype aircraft identical to the amateur-builder's aircraft.

The two standard methods for accelerated stalls are the constant g (constant bank) and constant speed (increasing bank), however, the most preferred light aircraft method of the two, is the constant bank method in which the airspeed is decreased and the angle of bank is held constant, until the aircraft stalls. It is the most preferred because the potential violence of any accelerated stall is largely governed by the increasing g load and airspeed.

As with every test, plan the sequence of events starting from small bank angles of  $30^\circ$  which will produce 1.15 g and decelerating slowly, ball in the centre, without over controlling. Work up incrementally to a 2g,  $60^\circ$  bank. The aircraft does not have to develop a deep stall each time, the pilot needs only to record the airspeed and bank angle in which the aircraft hits the pre-stall buffet, in flight terms, the start of the "buffet boundary". Recover by 'unloading' any g force, adding power and reducing the angle of bank.

## 9.5 Putting it all Together: Flights 36 to 40

### 9.5.1 Maximum Gross Weight Tests

Envelope expansion via a build-up programme not only includes the airspeed, altitude and normal acceleration, but also the effects of mass increase on performance and stability and control with the associated effect on the CG.

Up until this point, all tests have been performed below the test aircraft's maximum gross weight and a forward to mid CG position, but in an effort to expand the envelope, a complete series of flight-tests at maximum gross weight must be conducted. These include stalls, climb performance, stability and control, slow flight, accelerated stalls, etc. must all be investigated - the initial flight-test programme is essentially culminated up to maximum all up weight and the aft CG limit.

These tests should demonstrate that the aircraft has been successfully flown throughout the entire CG range, and will operate in and at the full range of aircraft weights from minimum to full gross weight. The findings must be documented in the aircraft's flight manual. Each phase of the testing should be done slowly, incrementally, with the same careful attention to detail that should characterize all the flight-testing.

Increases in the aircraft weight should be done in a series of 20% incremental steps up to the maximum payload and weight using, sandbags, lead shot, etc to simulate passengers or baggage weight. The ballast must be carefully weighed and secured in the aircraft. Obviously, a new weight and balance and CG location must be worked for each new increase in weight.

The testing up to this point has been done at, or near, the forward CG limit, now, during these tests, the CG should be slowly, but progressively moved aft between each test flight. Limit the change to the CG range to about 20% of the range increments. With each CG change, the aircraft longitudinal static and dynamic stability and stall characteristics should be carefully evaluated by using the same techniques discussed earlier and testing terminated when the designer's, or kit manufacturer's, aft CG limit is reached.

**WARNING:** If the aircraft develops either a neutral or negative longitudinal stability problem, or the aircraft displays unsatisfactory stall characteristics at any CG location being tested, STOP FURTHER TESTING!

These tests should confirm the designer's aft CG limit or establish the last satisfactory aft CG position. If the aft CG range is not satisfactory, consult with the kit manufacturer, aircraft designer, or a flight-test engineering consultant. The test pilot should avoid the temptation to take a "live ballast" weight up for a ride for three reasons:

- The aircraft has not been proven safe for the higher gross weights.
- The pilot and passenger are at risk.
- The pilot will be breaking the stipulations of Authority-to-Fly regulations, which prohibits the carriage of passengers.

**EXTREMELY IMPORTANT:** Pilots should ensure that the added ballast weight in the cockpit is secured, since a seat belt over some sand bags will not stop the weight from shifting and coming loose in a cockpit. The last thing a test pilot needs is a 20-pound lead-shot bag free in the cockpit during a climb test, a landing, or a spin, so ensure that each weight must be tied down individually, and cover all the weights with a cargo net.

Ensure the ropes/nets and airframe attachment points are strong enough to take the added load and make sure the passenger seat can take that much localized weight safely and that the floor loading is not overstressed.

The maximum gross weight test results should be recorded in the flight manual and if there are any changes to the stall speed initially marked on the airspeed indicator, it should be changed to reflect the aircraft stall speed at maximum gross weight.

### 9.5.2 Service Ceiling Tests

An integral part of the performance envelope expansion includes the determination and demonstration of the highest altitude at which an aircraft can continue to climb at 100 feet per minute, the Service Ceiling. As such, this is not a performance climb to measure time to altitude, but rather a functional check on the aircraft engine and systems to reach the maximum altitude; time is not really the issue in this case.

Such a test should take into consideration airspace requirements, which should typically be reserved either through flight planning, or through CAMU waivers. To facilitate the air traffic challenges within controlled airspace, install a transponder (reference FAR § 91.215), and if it is planned to climb above 12,000 feet, ensure that a portable oxygen system is also installed. It goes without saying that communications with an air traffic control must be maintained at all times.

From an engine perspective, the risks of mixture control must be addressed by reviewing and understanding the engine manufacturer's mixture leaning procedures for that particular engine. The most appropriate technique is to climb to the aircraft's service ceiling in a series of step climbs during which engine performance, temperatures and pressures are recorded at regular intervals. At the slightest indication of engine performance or aircraft control problems, the pilot should terminate the test and return for landing and further investigation of the reported anomalies.

**IMPORTANT:** It is essential that the test pilot receives instruction on altitude physiology and is familiar with the symptoms and cures of hypoxia and hyperventilation.

### 9.5.3 Navigation Systems Testing

Along with the integrity of the airframe and powerplant demonstrated, it is also necessary to ensure all the aircraft's systems function correctly and that the navigation system's range performance is equal to, or better than that advertised.

#### The Magnetic Compass and Compass Swing

The magnetic compass should have been checked for accuracy prior to the first flight and subsequently thereafter, on each flight. However, the addition and removal of equipment, changing of wire bundle routing and other airframe modifications, may have affected the accuracy of the instrument. The following recommendations are offered:

- The magnetic compass must be swung to verify compass accuracy by using a compass rose located on an airfield and using a hand held “landing compass”, which is essentially a reverse reading compass with a sighting system mounted on the top of it, as reference heading. With the aircraft facing a cardinal heading and the pilot running the engine at 1,000 rpm, a second individual standing 30 feet away facing due south “shoots,” or aligns the landing compass with the aircraft’s centreline. Using hand signals, the pilot aligns the aircraft with the master compass then runs the aircraft engine up to approximately 1,700 rpm to duplicate the aircraft’s magnetic field and reads the compass.
- Starting on the cardinal headings, North, if the aircraft compass is not in alignment with the landing compass, correct the error by adjusting the north/south brass adjustment screw with a non-metallic screwdriver, which can be made out of stainless steel welding rod, brass stock, or plastic, until the compass reads correctly. Adjustments to North are known as Coefficient C corrections. Taxi the aircraft to the reciprocal heading (South) and remove half the error. On the East/west headings, use the other brass adjustment screw to make the corrections using the same procedures that were used to correct the North/South errors. Adjustments to East/West are known as Coefficient B corrections.
- Check again for errors at each ordinal heading (NE, SE, SW, NW), record the last readings and prepare a compass correction card for installation in close proximity to the compass. The maximum deviation (positive or negative) is 10° on any one heading for the basic compasses, decreasing to 5° for the more expensive ones.
- If the deviation remains outside the limits, it may be necessary to realign the compass by adjusting the compass for Coefficient A due to the magnetic axis of the compass not being aligned on the north south line, or the lubber line not on the centre line of the compass container. If the compass cannot be adjusted to meet this requirement, install another one, however, if a new compass is not available, try a different location in the cockpit, away from all ferrous metals and electrical bundles.

**NOTE:** A common error that affects the compass’s accuracy is the mounting of the magnetic compass on/in the instrument panel with steel machine screws and nuts rather than brass. Also, the landing compass operator and the area, must be free from any metallic interference including spectacles, screw\ drivers, vehicles, etc.

If the aircraft has an electrical system, it is recommended that two complete compass checks be made, one with all electrical accessories switched ON (e.g., radios/navigation lights), and one with all electrical accessories switched OFF. If the deviation in level flight is more than 10° on any heading with the accessories on, make up a separate compass correction card that shows the magnetic heading with the equipment switched ON. Record the findings in the aircraft’s flight manual and create a compass correction card, mounting it near the magnetic compass in the cockpit.

### 9.5.4 Very High Frequency (VHF) Omni-directional Radio Range (VOR)

If the aircraft is to be provided with a navigational aid, typically a VOR, it will be necessary to evaluate the equipment for functionality and performance, which should include ground tests and airborne testing. For a simple ground test of the VOR, a VOR Test Facility (VOT) must be used which is done by tuning in to the VOT frequency on the VOR receiver, normally 108 MHz. With the Course Deviation Indicator (CDI) centred, the omni-bearing selector (OBS) should read 0° with the TO/FROM indicator showing ‘FROM,’ or the omni-

bearing selector should read 180° with the “TO/FROM” from indicator showing “TO.” The maximum bearing error should never be more than 4°, which essentially validates the system operation.

All VORs are calibrated regularly by the CAA and the calibration data is usually available from the Air Traffic and Navigation Services or the appropriate air traffic control organisation. Airborne testing requires evaluation of the reception range and the angular accuracy for which the radio horizon formula is considered appropriate for this level of testing.

$$\text{Range} = 1.25\sqrt{\text{Receiver Height (feet)}} + 1.25\sqrt{\text{Transmitter Height (feet)}}$$

#### *Range Effectiveness*

The first step is to calculate the range at which the VOR signal is predicted to be at its radio range limit, mark it on a map, preferably a visible landmark, then fly at the specific calculated height and record the distance at which the signal is lost. This should be done for several different radials and at a few different heights; the radial being used should obviously not be obstructed by high ground or obstructions. If the radio range requirement is not met, refer to the CAA calibration charts for that specific VOR to determine if there are any contributory geographical or electromagnetic anomalies. Alternatively, the aircraft installation will have to be investigated to determine if the installation losses or possibly even antennae blanking, are not the cause of below specification standards.

#### *Angular Accuracy*

Preferably, at a distance of more than 20 miles from the VOR for the airborne test, select a few prominent ground points along different radials on a large scale map and fly the aircraft directly over the point at a reasonably low height, within radio horizon range, to enable accurate distance estimates. Note the VOR bearing indicated by the receiver when over the targeted ground point and measure the angular variation. The maximum permissible variation between the published radial and the indicated bearing is 6° while if the aircraft has dual VORs, the maximum permissible variation between the two receivers is 4°. If the variations were excessive, the cause could be on aircraft or installation problems and in such a case, it would be advisable to call the VOR system specialist to assess the installation and assist in determining the angular inaccuracy.

### **9.5.5 Fuel Consumption Measurement**

Needless to say, it is essential to understand the fuel consumption characteristics very accurately, however, but without the support of a comprehensive flight-test suite, the amateur homebuilder will face challenges in determining fuel consumption accurately. However, from first principle testing, some degree of fuel consumption determination is possible. Bearing in mind the importance and criticality of accurate fuel consumption and contents, today’s market does provide, light, relatively cheap fuel flow systems for even the smallest air vehicles.

In consideration of some of the basics of fuel consumption, it is necessary to understand that for a new or recently overhauled engine, the fuel consumption should improve each flight hour until the engine finishes its “break in” period, typically after approximately 100 hours of operation.

A very simple methodology for determining fuel consumption for aircraft without the luxury of digital fuel management systems, is to lay out a race track course with 8 to 10 mile legs. If the aircraft has one fuel tank or cannot switch tanks, do the following:

- Determine the approximate fuel burn to reach 1000, 3000, 5000, 7000, and 9000 feet pressure altitude. With full tanks, climb to 1000 feet and run the race track course for half an hour at 55% power.
- Land and measure the fuel used by dipping the tanks with a calibrated fuel stick, or by adding measured amounts of fuel to the tank until the tank is full. Subtract the approximate fuel burn to altitude, and multiply the remainder by two to get the fuel burn per hour.
- The tests are much easier and the results more accurate if the aircraft has two independent fuel tanks by taking off on one tank and then switching to the opposite tank at the test altitude. At the completion of the test, switch back to the first tank, land and measure the amount of fuel added in both tanks and multiply the quantity by two to get the amount of fuel used per hour. Repeat the runs at 65% and 75% power at the same altitude, using the same procedures, before moving up to the next altitude and repeating the same tests.

If the engine has a fixed pitch propeller and is not fitted with a manifold pressure gauge, the rule of thumb extracted from “How to Determine the Part-Throttle RPM of a Fixed Pitch Propeller at a Given Horsepower” by Stan Hall Technical Advisor, Engineering, EAA Chapter 62, can provide the necessary information. Table 9.1 lists a selection of power percentages and multipliers, which go with them. Select the required percentage and multiply the full throttle rpm by the multiplier shown, the result will be the corresponding percentage RPM.

**Table 9.1** Fixed Pitch Power Multiplier

Power Percentage	Multiplier
75%	0.91
70%	0.89
65%	0.87
60%	0.84
55%	0.82
50%	0.79

### 9.5.6 Night Lighting Evaluation

Night operations should be conducted in accordance with the CAA Operating Limitations for that category of aircraft and also the manufacturer’s POH. In some categories and types of aircraft, the night capability could be extremely restricted and limited to normal climbs and descents (e.g., 500 feet per minute), pitch angles of less than 5°, straight and level flight, and coordinated turns of no more than 20° bank angle. In other cases, night flying may even be prohibited.

The objective of the night evaluation is essentially to ensure that all illumination, both cockpit instruments and aircraft external lighting, will enable a pilot to operate the aircraft under night lighting conditions safely, without undue interference to the pilot’s vision and view. (CAR 91.06.10) The test pilot will therefore be assessing for any glare on the windshield or light flicker on the instrument panel, exhaust blinding, balance, adequate dimming capability or light leakage from instruments or panel backlighting, etc.



The main concern for night testing should be the availability of a horizontal reference (e.g., bright moon or artificial horizon). Prior to every night flight, ensure a reliable flashlight with fresh batteries and a test plan to cater for failure cases, is available. Night testing requirements should already have been pre-determined on the ground and included in the test plan, for example:

- An electrical load review of all the lights, pumps, instrumentation and avionics should not exceed 80% of the aircraft's charging system capacity.
- The cockpit instrumentation lighting is adequate and was tested for reliability and duration of operation during daytime flights prior to first night flight. This would typically be done by darkening the cockpit by placing a blanket over it to create the required dark conditions for the cockpit evaluation.
- The pilot has at least 15 minutes of night time taxiing the aircraft, this practice is needed to familiarize the pilot with a different operating environment.
- The position and brightness of instrument panel lights, anti-collision strobe lights, and rotating beacons will not adversely affect the pilot's night vision.

A suggested night flight-test plan is a series of takeoffs and landings and traffic pattern entries and exits which should begin while there is still enough light to allow adequate transition from daylight to true night flying. The actual night flight should consist of an evaluation of the effectiveness of the taxi/landing light system, during taxi, take-off, and landing.



# Chapter 10

## The Canard Type Amateur Built Aircraft

### 10.1 Canards

In dealing with amateur homebuilt and other aerial vehicles, the increased design shift to canards made it prudent for the FAA to introduce sections on Canard configurations and Ultralights in an effort to also consider the specific aerodynamic idiosyncrasies of their flight characteristics, particularly their influence on flight-testing. Canard configured aircraft generally fall into two categories:

- The LongEze design (pusher prop, tandem seats), and
- the Quickie (Q2) design (tractor prop, side by side seats)



**Figure 10.1 (a) Rutan LongEze Design (b) Quickie (Q2) Design**

The most significant variation from conventional designed aircraft of course, is the fact that canard configured aircraft do not “stall” in the conventional sense. All successful “loaded canard” designs have the angle of incidence (AOI) of the canard set higher than the main (rear) wing and as such, as the aircraft’s angle of attack (AOA) increases, the canard should stall first, lowering the AOA of the main (rear) wing. Since the rear wing does not stall, a characteristic “buck” or “nod” takes place and full aft stick results in the canard alternately stalling and flying while the rear wing never reaches its critical AOA and continues to fly. This self-limiting stall characteristic makes a properly designed and built canard aircraft unspinnable. However, it should be noted that the accident rate for canard designs tends to be approximately the same as for conventional designed amateur-built aircraft because of the following:

- During take-off, the transition from ground roll to flight can be a more critical procedure in some canards as compared to more conventional designs, particularly with some combinations of CG and pitch control sensitivity, the pilot would be more likely to over rotate at lift-off. Consideration should be given to marking the canopy with an attitude reference marker to assist the test pilot with rotation attitude reference.
- Some canards have less visible airframe structure in front of the pilot in the peripheral vision which can produce a different reference frame for pilots with many hours of conventional aircraft time and may cause initial errors in pitch attitude control, such as the pitch attitude too high on takeoff and landings.

- In addition, canard aircraft by design, typically have very different take-off characteristics than conventional configured aircraft, in fact, canard aircraft with pusher propellers need a substantially higher rotation speed on take-off.

To rotate a conventional design aircraft, all that is required is sufficient airspeed to generate elevator power to attain a positive angle around the main undercarriage as the axis of rotation. This lift, generated at a relatively low airspeed, makes it possible to rotate the aircraft into the take-off attitude slightly below flying speed and allow the aircraft to accelerate to flying speed and lift off.

In contrast, the canard nose wheel will stay firmly on the ground until an airspeed is reached at which the canard can generate enough lift to equal the following:

- the load carried by the nose wheel, plus
- the nose down moment caused by the friction of the nose and main undercarriage tires with the surface, and
- the down-thrust vector provided by the propeller during the take-off roll.

Since the main wing may reach flying speed before the canard, the nose wheel will stay firmly on the runway until take-off speed is reached and only then, rotation will occur, and the aircraft will literally 'pop-up' off the ground. Canards with a thrust line above the CG will have an appreciable pitch trim change with power changes and forward stick motion may be required when power is reduced. While this may not be of any consequence to an experienced pilot, it could be a serious surprise to an unwary and inexperienced pilot since this unfamiliar flight characteristic might cause pilot-induced pitch oscillations with disturbing consequences under some conditions (e.g., an aborted take-off).

Due to its unique design, the canard aircraft needs a higher nose up attitude when landing compared to conventional configured aircraft and some canard pilots may be reluctant to raise the nose high on landing due to the limited forward visibility while the nose is up. Consequently, many canard pilots tend to make their approach angle shallow which in turn results in approach speeds faster than what is necessary. For pilots who prefer visibility to shorter runways, it is recommended that canard designed aircraft be tested on runways a minimum of 1,000 feet longer than what would be used for a conventional aircraft of the same horsepower and performance capability. However, longer runways should be used until the pilot becomes more experienced with the landing characteristics of the aircraft.

If the nose is held at a too high an angle on landing, the canard will stall while the main wing is still generating lift and the stalled canard could drop the nose rapidly onto the runway with enough force to damage the nose gear.

Quickie (tractor engine designs) configured canard designs have a limited ability to rotate nose up while on the ground, which tends to increase takeoff speeds because the canard and the main wing angle of attack are limited while the aircraft is on the ground. That is why this design appears to "levitate" off the ground without much apparent pitch change.

Some canard designs are very sensitive to rain or other types of contamination on the leading edge and/or top of the airfoil due to the design for laminar flow. Contamination in the form of water droplets, frost, crushed insects, or even poorly applied paint, will disturb the laminar flow over the canard and lift will be lost.

## 10.2 Flight-test Considerations

Technically, a canard type aircraft cannot stall, or at least it will not stall in the normal fashion, however, a pilot testing the aircraft's stability and control characteristics, should approach such testing with trepidation.

There is essentially no difference in the flight-test systems safety approach or test programme management principles compared with conventional aircraft designs, except to understand the aerodynamic and mechanical differences involved in the canard design and the impact on flying qualities. Under certain conditions, usually arising from design deficiencies, mainplane incidence or aft CG problems, the main wing could stall before the canard surface which could result in extreme 'pitch-up' conditions until the canard surface or the strakes stall. The aircraft would then pitch nose-down to a near-level attitude, however, the airspeed would be approaching zero and the angle of attack could approach or exceed 45° and in this condition (high-alpha), could be so stabilized in a deep stall, that recovery might not be possible.

**NOTE:** Testing for pitch stability in a new design or a just-completed aircraft built from a kit or from plans, is a requirement the test pilot needs to seriously consider and must be approached and conducted in a logical and sensible manner.

Some designers and builders have installed adjustable, moveable ballast containers in the aircraft to allow the CG to be adjusted forward or aft during flight. If testing is to be accomplished outside the recommended range, it is advisable to consider the installation of a ballistic recovery system or spin chute system. In addition, the pilot should make a decision about bailing out of the aircraft if the test becomes untenable.



# Chapter 11

## Flight-Testing of Ultralights

### 11.1 Ultralights

Beyond canard designs, lies the category Ultralight for which it would be prudent to include some guidelines to serve as an additional resource for ultralight pilots involved in flight-testing and to help the new owner develop a flight-test plan for the ultralight. Ultralights may be defined as follows:

- A fixed wing vehicle that is powered by a conventional 2 or 4 cycle, gasoline powered engine and is operated under Part 103.
- It has one seat and does not exceed 254 pounds, excluding floats and safety devices.
- In addition, the ultralight can be unpowered, in which case the weight is restricted to 155 pounds.
- The powered ultralight's fuel capacity cannot exceed 5 USG.
- The vehicle should not be able to exceed 55 knots calibrated airspeed at full power in level flight and cannot exceed a power-off stall speed of 24 knots calibrated airspeed.
- The term also includes two-place ultralight training aircraft of 496 pounds or less operated under the EAA exemption to FAR Part 103.



**Figure 11.1** A Typical Ultralight Aircraft

Be aware that both single and dual seat ultralights in this performance class are not restricted only to FAR Part 103 operation. If they qualify, they can be operated under FAR Part 91 if they meet § 21.191(g) amateur-built category or § 21.191(h) operating kit built aircraft in the primary category and that only single seat ultralights of less than 254 pounds empty weight, however, can operate legally under FAR Part 103.

Many in the general aviation community view amateur-built and ultralights as one and the same design category and that all flight-testing procedures should therefore be identical. While in many cases this assumption is true, however, there are several major differences between the two designs.

Most ultralights are assembled from complete kits, unlike amateur-built aircraft of which the major portion, 51% of the aircraft and its component parts, are manufactured by the builder. Most of the kit/ultralight manufacturer's pilot operating handbooks/flight manuals are usually accurate and address the majority of the information covered.

The changes in ultralight ownership are more frequent than amateur-built and general aviation aircraft ownership. Although the ultralight is "used," the new owner is usually unfamiliar with its operating characteristics and as such, a comprehensive flight-testing/training programme should be a high priority safety consideration for the new owner. New flying skills will have to be developed in consideration of the fact that each ultralight pilot/owner should address the effects smaller size, lighter wing-loading, lower weight, and higher drag designs have on low-speed flight.

Due to these differences, the FAA recommends that each "new" ultralight owner design a test plan regardless if the ultralight was bought, used, and/or the ultralight has a Flight Manual supplied by the manufacturer. The ultralight test plan does not have to be as extensive as the one recommended for amateur-built aircraft, but should address all flight conditions and emergencies called for in the ultralight's flight manual. With these differences in mind, the test plan should address problems associated with both NEW and USED ultralight flight-testing, including:

- pre-test flight inspection,
- engine and fuel system operation and inspection, and
- in keeping with that professional approach towards flight-testing, it is suggested that a test plan and other relevant safety recommendations be adopted by the ultralight owner/operator prior to test flying a new or used ultralight.

### **11.2 The Test Pilot**

Whether the ultralight is brand new or used, it needs to be properly evaluated. A new owner should preferably enlist the services of an experienced ultralight flight instructor who is authorized to give dual instruction under the EAA exemption (CAR Part 62). The instructor should test fly the ultralight only after it has been properly assembled, inspected, engine run-in, and taxi tests have been performed. It is not recommended that a "new" pilot and a new/used ultralight "learn" to fly together.

The test pilot should obviously be experienced and competent and should have made a minimum of 100 solo flights in a similar make, model, and type of ultralight and must follow the test plan to the letter. The test plan should examine the ultralight and its performance capability, beginning with the pre-flight inspection and ending only after the test pilot has explored the ultralight's published flight envelope as described in the flight manual.

### **11.3 Pre-Flight Airframe Inspection**

Ultralight owners should remember that the light-weight, thin wall tubing design of an ultralight fuselage/wing structure is particularly susceptible to metal fatigue. When aluminium tubing has been stressed beyond its elastic limit, it takes on a chalky white appearance (corrosion) at the point of highest stress. Warping and deformation are other signs of high stress points and once discovered, the ultralight should be grounded until the damaged is repaired.

The tolerance limit of a tube or fitting can be significantly lowered by over-torquing a bolt, so if a bent or damaged support tube or structure is not repaired, the bend or dent will become a crack, and ultimately the crack will become a structural failure.



If possible, remove the fabric envelope and check the airframe structure underneath for dents, cracks, and corrosion, also check the top and bottom of the spars for compression (wrinkled metal) damage. Double check all wings, undercarriage, strut, engine, and tail surface attachment points for wear, elongated holes, or damage. If any previous repairs are found, check with the manufacturer to see if damage in that area can be repaired and if the repair that was made, is airworthy.



**SA CAA Aircraft Accident Report CA/18/2/3/8265 - 25 February 2007**

*“The pilot reported that he had been accompanied by the owner of the aircraft (Bush Baby) to do performance test flights as part of the Proving Flight Authority. After twenty minutes of local flying, whilst on the base leg for runway 35, the pilot felt something drop onto his foot. He later discovered that it was a retaining bolt from the throttle torque tube. This caused the throttle torque tube to drop onto structural airframe tubes. Although runway 09 was the most suitable runway to use with an easterly wind prevailing at the time, the pilot was unsure about the throttle response and control and therefore elected to land on runway 35 as the aircraft was already positioned on a base leg for this runway. The touchdown was uneventful and the pilot was able to maintain directional control with some right aileron application. When the tail wheel settled at a fast walking pace, the aircraft started to veer to the right. The pilot attempted to compensate with full left rudder, which was insufficient to maintain directional control. He then applied left brake as well but this seemed to have no effect. The aircraft departed the runway at 90 degrees in an easterly direction and struck a sandy verge, causing the main undercarriage to collapse and the aircraft to come to rest on its belly. As part of the investigation, the manufacturer found that the bolt holding the throttle bell-crank in position came loose during normal operation. This problem was an assembly/installation fault and not a design flaw. The manufacturer said that this was the first reported incident; various owners were contacted and none reported a similar experience. A service bulletin was issued by the manufacturer to all owners instructing them to ensure the following on installation: that the bronze bush freely rotated in the welded tab, that Loctite was applied to the bolt thread on final assembly, that the bolt was nipped against the bronze bush so that they could rotate together and that the assembly manual and inspection checklist highlighted this issue.*

*The pilot and passenger sustained no injuries. The aircraft sustained damage to the propeller, fuselage, cowlings, right wing and undercarriage. The aircraft had a valid Proving Flight Authority to Fly, which had been issued on 4 July 2007 with an expiry date of 3 January 2008 or 40 hours, whichever came first. At the time of the accident the aircraft had accumulated 32.0 airframe hours since new.”*

Note: The aircraft shown above is not that actual aircraft involved in the accident, but merely an example of the specific type.

Note: The aircraft shown above is not that actual aircraft involved in the accident, but merely an example of the specific type.

**NOTE:** If a used ultralight has been purchased, it is essential that the owner perform a detailed acceptance inspection on the aircraft, assisted by a specialist who is familiar with the make and model aircraft. It is also recommended that all nuts, bolts and springs be replaced with new aviation quality hardware.

### 11.3.1 Undercarriage Inspection

The undercarriage is the last part of the lightweight aircraft to leave the earth and the first part to arrive. Since the majority of these aircraft fly from unimproved strips, the stress on the undercarriage is high and as such, the inspection items recommended by the manufacturer should be complied with, including inspection of the following:

- The condition of the undercarriage attachment points and alignment of the landing gear and wheels to the longitudinal axis of the fuselage. If the attachment points are misaligned, the undercarriage will not track in a straight line and this will affect directional control during take-offs and landings.
- Elongated bolt holes, bent tubing, condition and attachment of wheels, wheel bearings, tire inflation, tire condition and brakes.
- Brake condition and operation, including chafing of brake lines/cables against the undercarriage struts.
- Condition and operation of the steerable nose wheel, if applicable.
- Condition and attachment of the tail wheel/skid, if applicable.

### 11.3.2 Wing Assembly

The vast majority of ultralight aircraft use a fabricated sailcloth material stretched over a tubular frame. This type of fabric is susceptible to ultra-violet radiation from the sun and if left unprotected, it can become non-airworthy in less than 6 months. The inspection items should include the following:

- Ensure the sailcloth has not suffered any tears or abrasion due to wear or foreign object damage.
- Check the sailcloth for obvious ultraviolet (UV) degradation of fabric strength by examining the condition of the fabric on top of the wing, and then compare it to the fabric on the bottom of the wing. If the top wing fabric shows a significant difference in colour (faded), the fabric should be tested for strength with a fabric tester to see if it tests within the manufacturer's serviceable limits. If no minimum service limits are listed, the fabric should test out at 46 lbs, or 70% or more, of its original tensile strength, whichever is greater, to be considered airworthy. If the fabric fails the tests, it must be replaced before further flight.
- Flying and landing support cables should be checked for tension, routing, attachment points, and condition. Scrutinize the swaged cable ends diligently. It is recommended that a red reference mark (nail polish works fine) be painted on each of the cables abutting the swaged end. If the cable is growing, i.e., a gap forming between the swaged end and the painted referenced mark, there is an impending failure of the swaged terminal. Do not fly the aircraft until the cable is replaced.
- Flight control cables should be checked for frayed wires and proper routing by running a rag over all of the flying and landing wires and control cables (wings and tail). If the cloth snags, this may indicate a frayed wire, which demands further inspection. If possible, bend the cable to form a

“U” and inspect for internal broken wires. Also, check the cable pulleys for wear and operation; extreme wear patterns on pulleys indicate misrouting and must be corrected prior to flight.

- Check wing leading/trailing edge, wing struts, aileron, flaps, spoiler hinges and attachment points for loose rivets, cracks, elongation and wear and ensure that all hardware (nuts and bolts) are of aviation quality.
- Ensure that the bungee or return springs for wing spoilers (if applicable), are serviceable and will keep the spoiler down flat against the top of the wing when not being deployed.
- Check the aircraft’s flight controls rigging every time the aircraft is re-assembled. It is recommended that the cables/rigging for easier assembly be colour coded (e.g., red to red, blue to blue).
- Check for corrosion on all metal surfaces. Corrosion on aluminium usually appears as a white powder, rough to the touch and on steel parts, corrosion takes the common form of rust. Dissimilar metal corrosion occurs when two different types of metal make surface contact.
- Ensure the leading edge of the wing and tail surfaces are clean and free of insects, grass, or mud prior to flight.

### 11.3.3 Fuselage Assembly

The fuselage is the backbone of a light-weight aircraft and all flight and ground operating stresses encountered by the wings, tail, undercarriage, and engine are transferred to the fuselage at the attachment points. Exercise extra care when examining these high stress areas because failure of any of these attachment points and associated hardware will cause catastrophic structural failure.

- Flight controls should be checked for proper operation, travel, and condition of the stops and there should not be any sharp bends in the flight control cables.
- Check engine controls for proper operation; they should be free of bends and properly secured. Ensure that all control cables are securely clamped to the fuselage to prevent the cable from slipping, hence not transferring the desired movement to the engine control.
- Check the instrument panel for security and instruments for attachment, proper operation, and range/limit markings.
- Inspect for bent or damaged structural tubing. If a tube is bent, it must be properly repaired or replaced. Straightening out a bend will only work-harden the tube in the damaged area and hasten the failure.
- Fibreglass structures should be checked for cracks, delaminations, and holes, especially on the bottom of the fuselage.
- Examine the seat, seat brackets, and seat belt/shoulder harness, attach points, clips/rings, brackets or tangs and other hardware, for security, safety (cotter pins or safety wire), and condition. Ensure the installation validity is still current; they are replaceable items that must periodically be checked or replaced, with legal parts only.
- Check the shoulder/seat belt harness for condition and proper operation.
- Check the ballistic chute hardware and mounting assembly.
- The tail, or empennage group, contains two of the ultra light’s three primary control surfaces: the rudder (yaw control) and the elevator (pitch control). In two-axis ultralights, the elevators are the only flight controls on the tail and special attention must be given to the attachments points, hardware, and proper operation for both control systems.

- Ensure that the primary controls and trim systems if applicable, have the proper travel, that control cables are properly tensioned, and that all turnbuckles are safe tied.
- Examine the control hinges and attachment points on the elevator and rudder horn for wear, cracking, and elongation of bolt holes and security of the rudder and elevator stops.
- Check the leading and trailing edges of the flight controls for damage.

### 11.3.4 Engine

Considering the critical importance of the engine and fuel system to the safe operation of an aircraft, it is necessary to provide the amateur builder/ultralight pilot with a suggested engine and fuel system inspection programme in addition to the manufacturer's check list items.

- Check the engine mount, vibration isolation mounts and attachment points before each flight.
- Check all hose clamps for tightness.
- Check for fuel and oil leaks.
- Check air filter for condition and attachment
- Ensure that all spark plugs are the correct ones, properly torqued and also check that the ignition wires, caps, and plug cap restraints on inverted engines are secured and safe tied. Ensure that the 'kill' switch, if applicable, is within easy reach and works as advertised.
- Check that the carburettor and the throttle cable is secured and both operate freely from idle stop to full power stop.
- Check carburettor boots for cracks that will suck air and may create a lean mixture, high CHT and EGT, and possible engine failure.
- Check the fuel on/off valve, fuel filter, and crossover valve for proper operation and position.
- Drain the fuel system of water and sediment.
- Ensure that the fuel tank is secured, full, and if applicable, contains the proper mix (ratio) of fuel and oil.

**NOTE:** If slippage marks are painted across the bolt heads, engine mount, and fuselage at the time the mount bolts are torqued, a break in the paint will give advance warning the mount is coming loose. Red nail polish works adequately.

### 11.3.5 Exhaust System

On most 2-cycle engines, the exhaust system is tuned to the engine in order to have the proper amount of back pressure. Sometimes, due to installation demands, the exhaust system must be modified, so, if such modifications are necessary, rather contact the engine manufacturer before incorporating any exhaust systems changes.

The exhaust system should be mounted on vibration-damping elements and be safety wired. The exhaust system ball-joints should not be mounted under a tension load and they should be lubricated with an anti-seize, heat resistant grease to allow the ball joints to move freely. Some exhaust systems use springs to maintain compression on the ball-joints and if the engine is so equipped, run a piece of safety wire through the spring and secure it to the exhaust system to prevent a broken spring from coming loose and hitting the propeller in a pusher configuration or hitting the top of the wing or tail in a tractor design.

Another approach to prevent propeller damage from broken springs is to lay a bead of high temperature silicon, lengthwise, across the spring. If a spring does break during flight, the silicon bead will hold some or all of the broken pieces of spring material in place until the aircraft lands.

#### **11.3.6 Fan Cooling**

It is particularly important that installations of fan-cooled engines with enclosed cowlings are designed so that the hot cooling air exits the cowl and cannot re-circulate back into the cooling fan intake. If there are any doubts, tests should be carried out by measuring the temperature of the air entering the cooling fan.

In most cases, it is unlikely there will be a problem with cooling belt tension on a new engine, however, on older engines, the belt may have bedded down in the V of the pulley causing a significant reduction in belt tension. If corrosion is present on a pulley, the belt wear rate will be rapid so ensure that during the visual inspection of the fan cooling belt and pulley, look for evidence of wear and corrosion on the pulleys.

#### **11.3.7 Reduction Drive**

A large percentage of engines used on light-weight aircraft are 2-cycle air cooled engines fitted with a rpm reduction drive in which the reduction drive is usually a bolt-on unit which drops the high 2 cycle engine rpm down to a propeller RPM that is more efficient.

To check tension on most 'V' belts on the reduction drive, grab the belt and twist it; the belt should allow no more than approximately a half a turn.

Ensure that the reduction gearbox is filled with oil to the proper level in accordance with the manufacturer's instructions and drain the plug/filter is safe tied.

Grasp the propeller (switch off and spark plugs disconnected) approximately half way down each blade. Try first to move the propeller in an up and down motion, pull it away from the aircraft and then push in the opposite direction - no appreciable bearing slop should be detected in the reduction gear bearings. It would be prudent to conduct a propeller tracking check at this juncture.

Eccentricity of the driving, or driven pulley, will cause variations of belt tension with rotation, possibly leading to rapid failure of the belt and engine or propeller shaft bearings. A technique is to remove the spark plugs and rotate the engine slowly by hand for several turns in small steps (approximately 45° of engine rotation per step). There should be no noticeable change in belt tension at any position and any noticeable change must be investigated further by measuring the run out of the engine pulley and propeller shaft pulley with a dial indicator.

### **11.4 Fuel Systems**

#### **11.4.1 General**

Many problems with lightweight aircraft engines can be directly traced to the type of fuel used. Automotive fuels could contain 10% alcohol without requiring a label stating so, which could create a particular problem. Alcohol can cause serious problems in aircraft engines so first ensure that the fuel source is a reliable one.

#### **11.4.2 Test for Alcohol in Automotive Fuel**

Take a thin glass jar, mark it one inch from the bottom of the jar with tape and fill the jar with water up to that mark, then fill the jar to the top with a sample of the fuel to be tested. There is a clear separation between the water and the fuel. Put the lid on the jar and shake, then let it settle for about a minute and

check. If the “water” line is now above the first mark, the fuel has alcohol in it and another source for fuel should be found and then the test should be repeated.

### 11.4.3 Fuel Primer System

Perform a careful inspection of fuel primer bulbs fitted in suction lines because they deteriorate over time and are a possible source of air leaks, resulting in a lean mixture. Primer bulbs with plastic one-way valves have been known to break loose and completely block the fuel in the fuel line, so positioning the fuel line so that the fuel flows upward through the primer bulb, will help minimize the possibility of this problem occurring. A permanently fitted fuel pressure gauge is recommended because it can check fuel system operation during engine break-in and fuel flow during extreme angles of attack.

### 11.4.4 Filters, Fuel Lines, and Throttles

Finger screens in fuel tanks should be checked every 10 hours for debris or varnish build up from fuel while nylon mesh fuel filters are preferred with 2-cycle engines. Paper element filters should be avoided because they may severely and invisibly restrict the fuel flow due to a reaction between water and oil detergents. The fuel filter should be distinctly located between the fuel pump and the carburetors, to facilitate pre-flight inspection and avoid the possibility of air leaks on the suction side.

Check plastic fuel lines for age hardness, discoloration, and overall condition; fuel line attachment points should be checked before each flight. Always clamp a fuel line at the inlet and outlet since a slip-on line might slip off in flight and always leave a little slack in the fuel lines to minimize cracking from vibration.

If the 2-cycle engine has two carburetors, make sure the throttles are exactly synchronized since if not, one carburetor will run rich while the other runs lean, causing cylinder overheating and a possibility of the piston seizing or being holed.

### 11.4.5 Causes of High Fuel Consumption

- Dirty air filter causes a rich mixture.
- Propeller is not matched to the engine.
- Carburetor float improperly adjusted.
- Fuel pressure set too high.
- Wrong carburetor jets installed.
- Defective float valve.
- Extreme vibration (propeller/engine) that keeps the float valve open.

**NOTE:** Even if the builder/owner or pilot is an B-747 airline captain with 20,000 hours in type, they should NOT climb into an ultralight without first receiving flight instruction from a properly certified or authorized ultralight flight instructor. This must be done in a two-seat ultralight trainer operated in accordance with the EAA exemption to FAR Part 103.

Ultralights by their very nature are highly susceptible to winds above 15 mph and all ultralight aircraft test flights should be conducted in light or no-wind conditions.

Pilots must never underestimate the fickleness of the ultralight aircraft category. Even more so than in the case of fighter pilots, ultralight pilots must manage airspeed. Due to the small speed range between stall and full power, high drag and low weight, airspeed, or in fighter pilot terms, energy, should become the single most important concern of the ultralight pilot.

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## 11.5 Airport Selection

As in the case of the NTCA, the selection of an airport to flight-test the ultralight, is equally important. Most ultralights are flown out of unimproved grass strips, so before test flying the ultralight from one of these locations, ensure that a wind sock or even a flag is installed nearby to give some indication of the wind direction and speed.

Carefully examine the airstrip and note and record in the test plan, the surrounding terrain, structures, power lines, telephone wires, and trees. Record the probability of these factors contributing toward or causing mechanical turbulence during certain times of the day, or presenting a hazard to flight in other ways. Ensure that the runway is orientated into the prevailing winds. Before selecting a strip, make certain emergency landing areas are located close-by in case of an engine failure.

## 11.6 Taxiing

Taxiing should be designed and conducted to achieve the test plan goals. In addition to identifying the ultralight's ground handling characteristics at low and high taxi speeds, braking, monitoring engine operation, and developing pilot proficiency, the test plan should consider developing the following:

- Crosswind handling characteristics during taxiing.
- Addressing the ultralight's response to rapid changes in power (tractor design versus pusher).

**NOTE:** When taxiing a nose wheel ultralight, the input response on the rudder bar will be positive, similar to a car. If operating a tail dragger design, anticipate an initially larger input with a decreasing amount of pressure upon entering the turn. If the pilot is slow in getting the pressure off, the larger moment arm, main undercarriage to the tail versus main undercarriage to the nose wheel, will set the ultralight up for a ground loop.

## 11.7 First Flight Differences

### 11.7.1 Use of Power

One of the biggest differences between a general aviation aircraft and an ultralight, is the effect very quick changes in power can have on aircraft airspeed. In a lightweight aircraft, it is possible to go from cruise speed to a stall in a few seconds. This is due to the low mass, high drag configuration, and smaller speed range characteristic of the majority of ultralights, however, to avoid unplanned stalls, make small power reductions over a longer time period while always monitoring the airspeed.

### 11.7.2 Control Feel

Due to the slow cruise speed and lower weight of ultralights, the predictability to pilot input may be influenced by the flight controls feeling light or sensitive. Once the flight control input has been made, however, the rate of response tends to be slower than inputs on faster and heavier aircraft.

### 11.7.3 Stalls

Because of their high angle of dihedral, most ultralight stalls tend to be straight forward, particularly during a power-off stall. They typically demonstrate very little airframe buffeting and the only stall indications the pilot may recognize, are the ultralight's slowed forward movement, a rapid decrease in height, and flight controls that are suddenly mushy and mostly ineffective.

#### **11.7.4 Steep Turns**

When performing steep turns in an ultralight, the increasing weight (g load) and high drag tends to bleed off energy very quickly. The pilot must monitor the airspeed to avoid inadvertently setting up a departure to stall/spin scenario.



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# Appendices

## Appendix A Additional References on Flight-testing

The following references comprise selected additional information sources on flight-testing and first flight experiences for amateur-built and ultralight aircraft. This list of informational material may help amateur builders in preparing the FLIGHT-TEST PLAN for their aircraft.

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## Appendices

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AC 103-7, "The Ultralight Vehicle"

**Appendix B Safety Review Board Action Item Summary**

<b>TITLE:</b>		
<b>MEMBERS NAMES:</b>	<b>SIGNATURE:</b>	<b>POSITION HELD:</b>
<b>COMMENTS BY THE SRB CHAIRMAN:</b>		
<b>NAME:</b>	<b>SIGNATURE:</b>	<b>POSITION HELD:</b>

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OUTSTANDING ACTION LIST			Page: __ of __ Date: __ / __ / __		
PROJECT:		AIRCRAFT TYPE & NUMBER:			
NUMBER	ITEM DESCRIPTION	ACTION BY	CORRECTIVE ACTION TAKEN	REFERENCE	SIGNATURE



## Appendix C Suggested Flight-test Briefing Points

The Flight-test Briefing Guide is a detailed list of most things that should be covered in a thorough pre- and post-flight briefing. This briefing guide may also be used for ground test as well as flight-test. Many items may not apply, such as chase plane, or you may have unique items to your program that are beyond the scope of this list. It should be tailored to fit your program.

### PRE-FLIGHT

General/Administration:

- Date/Flight no./Test no.
- Purpose of test.
- Roll Call/Crew Info/call sign(s) (including chase crew and telemetry (TM) room).
- Pilot in command, seat assignments, and rules for in-flight changes.
- Test Director.
- FTE(s)/specialists (instrumentation, photographer, etc.).
- Observer(s).
- Emergency duties.
- Personal safety equipment (e.g., helmets, parachutes and their limitations).
- Ground personnel (including Telemetry Room) responsibilities.
- Crash rescue personnel and responsibilities.
- ATC/Range Coordination.

SRB completed (if applicable)

- Time hack.
- Review takeoff time.
- Crew show-time.
- Chase check-in time.
- Range time.

Test aircraft configuration and status:

- Aircraft information (type/model/serial number/registration/...).
- Instrumentation requirements and status of special equipment (e.g., smoke generator, CO monitor, portable O<sub>2</sub>, cone, load banks, ice probes).
- Inoperative systems for special test configurations (e.g., inoperative nose wheel steering for Vmcg test, free float spoilers to evaluate lift control malfunctions, etc.).
- Open maintenance items/flight snags.
- Temporary operating limitations.
- Conformity inspection (currency of the inspection).
- Instrument calibrations (e.g., pitot/statics).
- Changes since last flight (e.g., maintenance, instrumentation, software, cg).
- Weight and Balance.
- Takeoff and target gross weight and CG for test.
- Ballast configuration and movement.
- Fuel on board.

## Appendices

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### Local Information:

- Aircraft performance versus takeoff conditions.
- Airfield environment (runway conditions and obstructions).
- Communications: primary/secondary/emergency/test frequencies.
- Test area: location/altitude(s).
- Mission profile.
- Weather. Go/no-go and/or requirements. Forecast for test area and destination/-alternate.
- Sunrise/sunset.
- NOTAMS.
- Fuel requirements (return to base/min on deck).
- Recovery and landing.
- Primary/alternate/emergency landing sites.
- Expected landing time.

### Test Condition Details:

- Flight-test plan reviewed.
- Lessons learned reviewed.
- Detailed review of flight cards:
- Initial conditions/set-up.
- Tolerances (Airspeed, Altitude, Weight/CG, Wind, etc.).
- Review of flight-test technique.
- Special test limitations.
- Build-up to final conditions.
- Test predictions.
- Instrumentation/data requirements.
- Knock-it-off criteria and procedures (including ground personnel).
- Crew resource management (who is watching what? Who makes what calls?).
- Review unique recovery/emergency procedures.

### Review risk assessment.

### Chase/Support Aircraft:

- Type/registration.
- Crew/call sign.
- Normal duties/procedures.
- Position.
- Intra-flight communications.
- Rendezvous point/join-up.
- Fuel plan.
- Emergency procedures (lost visual/communications, inadvertent IMC, mid-air, search and rescue).

### Emergencies/Contingencies:

- Emergency recovery procedures (primary/secondary)(e.g., spin chute minimum, call-outs).
- Aircraft recovery device procedures (spin chutes).

- Crew escape/egress features/procedures (bail-out or on ground, bail-out minimums).
- Rallying point after egress.
- Emergency/survival equipment.
- Local crash rescue crews briefed on aircraft and procedures.
- Nearby emergency airfields.
- TM room duties.

### **POST-FLIGHT**

Landing/Flight/Block times.

Aircraft Status:

- Aircraft unserviceabilities (snags/squawks).
- Instrumentation snags.
- Post-flight inspection results.

Discussion of test conduct:

- Were tests acceptably performed?
- Were any limits approached or exceeded?
- Was the required data gathered?
- Was build-up adequate?
- Was risk level accurate?
- Any unusual events?
- Chase/ground observations.

Discussion of results:

- Data analysis observations.
- Regulatory compliance.
- Any repeats necessary?

Reports Required?

Accident/Incident.

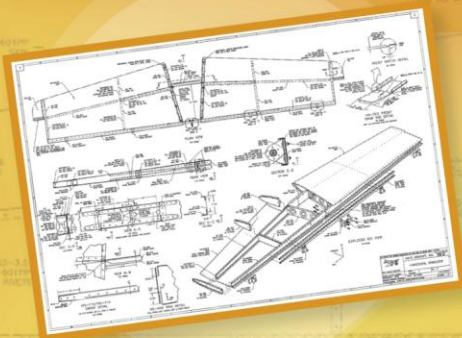
Lessons Learned.

Plan for next flight.



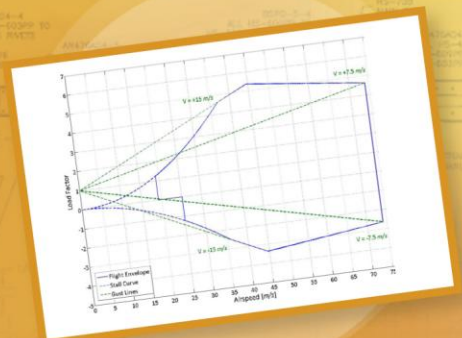
The cut-away detail of the popular non-type certified RV-7A aircraft, designed by Van's Aircraft, shows the intricate airframe design and the various systems of a light aircraft. These aircraft are also sold in kit form and a number of different variants of RV aircraft have been built and are flown in South Africa under "ZU" registrations. In the case of a homebuilt aircraft, all aircraft systems should be properly tested in a structured manner during the initial flight test campaign.

Picture courtesy of Tom Johnson of TJ TechArt (<http://www.tjtechart.com>).

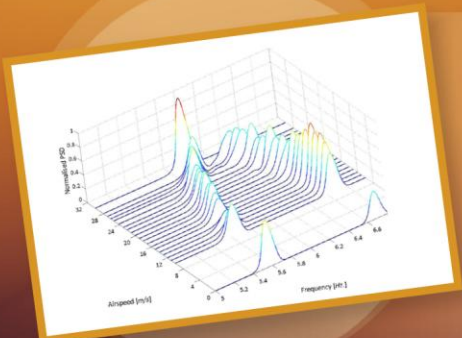


The watermark in the cover is part of the assembly drawing of the horizontal stabiliser of a RV-7 aircraft. Many light aircraft are built by aircraft enthusiasts in South Africa. Building an aircraft exactly according to plan is as important as conducting a structured and thorough flight test programme of a new aircraft.

Picture courtesy of Van's Aircraft (<http://www.vansaircraft.com>).



Aircraft must be able to withstand various types of loads – for example aerodynamic, inertia and landing loads. Two types of aerodynamic loads that require particular attention are gust and manoeuvre loads. Manoeuvring loads are caused by the generation of lift during high g manoeuvres, whilst gust loads are caused by gusts of wind. Aircraft designers typically provide combined gust-maneuvre diagrams (similar to the one on the left) to delineate the safe flight envelope of the aircraft. Pilots should be aware of the structural envelope of their aircraft and always ensure that they remain within it. It should also be noted that flying in the "yellow arc" in turbulent conditions may well put the aircraft out of the structural envelope if a strong gust of wind is encountered.



Flutter is typically the least understood concept by pilots, yet if encountered, is usually fatal. For this reason, flutter clearances are one of the most hazardous aspects of a flight test programme and should ideally be performed in a structured flight test programme by a professional team. Flutter clearances involve recording and analysing data at various speeds up to an airspeed with suitable margin below the calculated flutter speed of the aircraft. The anticipated flutter speed of the aircraft can then be determined based on its sub-critical response. The graph on the left depicts flutter flight test results clearly showing how the bending and torsion frequencies of a wing converge up until the flutter speed. At flutter, a combined bending-torsion structural mode, at a single frequency, is encountered.

