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I am submitting herewith a thesis written by Justin Samuel Garr entitled “Reduction of Human Factors-Related Accidents During the Flight Test of Homebuilt Aircraft Through the Application of Professional Flight Test Practices.” I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

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Reduction of Human Factors-Related Accidents During the Flight Test of Homebuilt
Aircraft Through the Application of Professional Flight Test Practices

A Thesis Presented for the Master of Science Degree in Aviation Systems

University of Tennessee

Tullahoma, TN

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DEDICATION

This thesis is dedicated to my family and to Dave Hickman, who loved aviation and dedicated his life to making it safer.

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ABSTRACT

Homebuilt aircraft have a high accident rate during the flight test period, particularly during their first and second flights. For the 2002-2004 period, over 1.0% of homebuilt aircraft were involved in an accident on their first flight, and 3.3% were involved in accidents in the first 40 hours of operation. Untrained, low time in aircraft type amateur flight test participants, unorthodox flight test procedures, and lack of clear guidance as to who should and how to conduct safe and effective flight test lead to unsafe conditions and the accident statistics support this hypothesis. In the accidents analyzed, lack of experience was specifically cited by the NTSB as a causal factor in 15.6% of the accidents. Poor decision-making was also a common thread, with 15.6% involving faulty decision-making by the pilot-builder. Shappell and Wiegmann's Human Factors Analysis and Classification System (HFACS) is applied to interpret the statistics and the model is applied to the current state of homebuilt flight test in comparison to professional flight test. Detailed comparison is made between amateur and professional flight test practices and case studies are provided to support the analysis. The author proposes that ideally, flight test is left to trained professionals. The training, experience, and support structure of professional testers and their organizations can effectively mitigate the lack of time in type and training characteristic of the typical homebuilt flight tester. Accepting that this is not always practical in the homebuilt flight test world, it is recommended that professional practices be applied to amateur flight testing. Furthermore, it is suggested that the guidance available to amateur flight testers be improved and that regulations

require that the homebuilder meet with an FAA-designated engineering representative regarding the conduct of flight test.

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LIST OF ABBREVIATIONS

9G	9G Aerospace Solutions, LLC
AC	Advisory Circular
AOPA	Aircraft Owners and Pilots Association
ATP	air transport pilot
CFI	certificated flight instructor
CFR	Code of Federal Regulations
DAR	designated airworthiness representative
DER	designated engineering representative
DoD	Department of Defense
DR	deficiency report
DVD	digital video disc
EAA	Experimental Aviation Association
EFIS	electronic flight information system
ERAU	Embry Riddle Aeronautical University
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FTE	flight test engineer
FTM	Flight Training Manual
GA	general aviation
HFACS	Human Factors Analysis and Classification System
HPAT	High Performance Aircraft Training, Inc.

ILS	instrument landing system
IMC	instrument meteorological conditions
NAS	naval air station
NAVAIR	Naval Air Systems Command
NFO	naval flight officer
NTPS	National Test Pilot School
NTSB	National Transportation Safety Board
OJT	on-the-job training
PIC	pilot in command
PIO	pilot induced oscillation
POH	pilot's operating handbook
RTR	report of test results
RV	Van's RV aircraft
SETP	Society of Engineering Test Pilots
SFTE	Society of Flight Test Engineers
TAWS	terrain awareness and warning system
TCAS	traffic collision avoidance system
TIS	traffic information system
TPS	test pilot school
UAV	unpiloted aerial vehicle
USAF	United States Air Force
USAFTPS	U.S.A.F. Test Pilot School
USN	United States Navy

USNTPS	U.S. Naval Test Pilot School
UTSI	University of Tennessee Space Institute
VMC	visual meteorological conditions
WSO	weapons system officer

INTRODUCTION

Expertise in an aircraft's handling, performance, and systems is essential to flying it with precision and preventing an accident in the case of an emergency by breaking the chain of causal events. It is for that reason that advanced aircraft require specific type ratings to ensure that the cockpit crew is intimate with the aircraft. The opposite is borne out by statistics that show that pilots with low time in type are more likely to be involved in an accident than those with extensive experience in the type of aircraft. It is not likely that the low time in type pilot simply loses control of the aircraft or otherwise directly causes the accident under normal operating conditions. More likely, the pilot who is unaccustomed to the aircraft that he is flying has difficulty coping with a developing emergency situation. Unfamiliar with the aircraft's handling and systems, he is more likely to make a mistake or simply not act in time to avoid the accident. In effect, a low time in type pilot becomes a *test pilot* in an emergency – he is suddenly flying an unknown aircraft with unknown characteristics. Professional test pilots mitigate the risks associated with flying in these conditions through extensive training and, in general, large amounts of overall experience. Both of these factors not only offset the risks associated with flying an unknown aircraft, but also allow the test pilot to fly with the necessary precision to perform his primary mission – to collect accurate data and evaluate the aircraft.

Unfortunately, in the world of homebuilt aircraft, the tendency is to place untrained, low time in type pilots in the aircraft during the flight test process, resulting in a high accident

rate and questionable flight test results. These low time in type pilots are more prone to accidents due primarily to human factors. These factors are not limited to pilot behavior in the cockpit, but rather span the entire continuum of potential failures that can lead to an accident. National Transportation Safety Board (NTSB) statistics [1-10] and Shappell and Wiegmann's Human Factors Analysis and Classification System (HFACS) model for human factors causes [11] as well as several case studies illustrate the weaknesses in the current state of homebuilt flight testing. The elements of the HFACS also highlight the methods by which professional flight testers overcome the very same challenges.

The fundamental issue is that homebuilt aircraft have a high accident rate during the flight test period, particularly during their first flights. Untrained, low time in aircraft type amateur flight test participants, unorthodox flight test procedures, and lack of clear guidance as to who should and how to conduct safe and effective flight test lead to unsafe conditions which not only provide a fertile breeding ground for emergency situations to develop, but also tend to exacerbate these emergencies and lead to accidents. Accident statistics support this hypothesis. In this analysis, the HFACS is applied to interpret the statistics and analyze the status quo. Within this context, a detailed comparison is made between amateur and professional flight test practices in an effort to develop solutions to this problem.

CHAPTER 1 - BACKGROUND

SURVEY OF THE LITERATURE

Unfortunately, only a limited amount of information regarding flight testing is available to members of the general public. Most of the publications available are military publications which, although not classified, are in limited distribution. Persistent members of the public can, at the very least, often obtain outdated copies of these documents. In addition to the military publications, a few texts have been published about flight testing. Two of the most common texts, by Sonja Englert [12] and Vaughan Askue [13], are specifically about flight testing homebuilt aircraft and another, Ward and Strganac's text about flight test engineering [14], is often used as a university text on the subject. The most common reference used by homebuilt flight testers is the Federal Aviation Administration (FAA) Advisory Circular (AC) which specifically addresses the subject, AC90-89A [15]. Also available is an advisory circular which outlines test techniques used to satisfy the regulations regarding the certification of certified aircraft, AC23-8B [16]. This document also contains information relevant to homebuilt flight testing. FAA Order 8130.2F [17] addresses airworthiness certification of aircraft and specifically outlines the limitations imposed on experimental amateur-built aircraft during the flight test period. Following is a partial listing of the literature available regarding flight testing and homebuilt aircraft:

U.S. Naval Test Pilot School Flight Test Manual USNTPS-FTM-No. 103, Fixed Wing Stability and Control [18]

FTM-103 [18] is one of the primary texts used by students at the U.S. Naval Test Pilot School (USNTPS) at NAS Patuxent River, Maryland. It covers both the theory and flight test techniques used by naval aviators and flight test engineers (FTEs) in the testing of fixed wing aircraft stability and control and handling qualities, although the theory is provided primarily as a reference and is covered more extensively in other texts. U.S. Navy flight test personnel often use this text as their primary flight test reference following graduation. A similar publication, FTM-107 [19], covers rotary wing stability and control flight test. Other test pilot schools, including the U.S. Air Force Test Pilot School (USAFTPS) and the civilian National Test Pilot School (NTPS) in Mojave, CA, have similar publications.

U.S. Naval Test Pilot School Flight Test Manual USNTPS-FTM-No. 108, Fixed Wing Performance [20]

FTM-108 [20] is the other primary text used by students at the U.S. Naval Test Pilot School. Similar in presentation to FTM-103 [18], FTM-108 covers both the theory and flight test techniques used by naval aviators and flight test engineers in the testing of fixed wing aircraft performance characteristics. Again, the theory is provided primarily as a reference and is covered more extensively in other texts. Much as with FTM-103, U.S. Navy flight test personnel often use this text as a reference following graduation. A

similar publication, FTM-106 [21], covers rotary wing stability and control flight test. Other test pilot schools have similar publications.

NAVAIR Instruction 3960.4A, Project Test Plan Policy and Process for Testing Air Vehicles, Weapons, and Installed Systems [22]

The Naval Air Systems Command (NAVAIR) Test Plan Instruction [22], as it is known, is an internal U.S. Navy document. It is not classified and can be obtained through open-source methods. NAVAIR 3960.4A outlines the policies, processes, and team member responsibilities associated with U.S. Navy flight test programs. It is an excellent example of the guidance provided by management to flight test teams in large organizations.

FAA Order 8130.2F, Airworthiness Certification of Aircraft and Related Products [17]

Several sections of FAA Order 8130.2F [17] pertain to the certification of experimental category aircraft. Of the greatest interest to homebuilt flight testers is the section that defines the flight test period (the 25- and 40- hour rule) and the limitations imposed on the operation of the aircraft therein. Described within this document are FAA procedures for experimental aircraft certification, evaluation, and issuance of operating limitations.

Code of Federal Regulations 14 CFR Part 91, General Operating and Flight Rules [23]

Federal Aviation Regulations (FAR) Part 91 specifically addresses aircraft with experimental certificates in Part 91.319 [23]. This section addresses the flight test period and the operation of experimental certificated aircraft for hire.

FAA Advisory Circular AC90-89A, Amateur-Built Aircraft and Ultralight Flight Testing Handbook [15]

AC90-89A [15] outlines a comprehensive flight test program and provides guidance to homebuilders regarding the conduct of flight test. Unfortunately, this document is poorly organized and often provides, in the author's opinion, poor guidance. For example, it begins with a 2-paragraph section on test planning and then moves on to a lengthy discussion of the selection of the airport from which to conduct flight test, implying that this is the most important aspect of the flight test program. Not until the fourth section does it address the test pilot, and then it provides extremely low suggested test pilot flight time requirements. The comprehensive test program suggested is a "one-size-fits-all" approach to flight test and does not address the need to focus on different areas of flight test depending on whether the aircraft being tested is a kitplane, plans-built aircraft, or one-of-a-kind design.

FAA AC23-8B, Flight Test Guide for Certification of Part 23 Airplanes [16]

AC23-8B [16] is the companion to FAR Part 23 [24], which governs the certification of most general aviation aircraft. This flight test guide describes the typical flight test

methods used to obtain the data required by FAR Part 23. It is very useful to homebuilders as it shows many of the data reduction techniques and plotting tools that are used by professional flight testers to organize flight test results and synthesize the information into a useful format. Furthermore, it directly connects flight test techniques with data collection objectives.

Homebuilt Aerodynamics and Flight Testing, Sonja Englert [12]

Sonja Englert's text [12] is commercially available and is a fairly comprehensive guide to both the theory and practice of flight testing. The theory is presented at a level that is appropriate for the average homebuilder. Test methods are clearly presented and specifically tailored for light, piston-engine single flight testing. Each test method is described in detail and accompanied by example test cards which outline the data to be collected. Instructions on how to reduce the data and interpret the results are also included. The text's primary weakness is that it does not substantively address test team members and their qualifications.

Flight Testing Homebuilt Aircraft, Vaughan Askue [13]

Askue's text begins with the words "Test Pilot" in enormous font. What follows is a description how real test pilots are highly-trained professionals and not the mythological archetypes portrayed in Hollywood movies. He then proceeds to say that amateurs, with "a few basic methods and techniques" can properly flight test their aircraft. Later, he

suggests rather casually that it is not just possible, but desirable, for the builder to fly the tests (including first flight) himself. The bulk of the text is presented as a series of short sections addressing each test item, some of which are detailed and others which do not fully explain test methods, data collection, and data reduction. Each section is followed by suggestions for further reading.

Kitplane Construction, Ronald J. Wanttaja [25]

Wanttaja's text [25] is extremely popular with homebuilders and focuses primarily on construction of the aircraft. He provides an excellent history of the homebuilt aircraft industry and detailed information on aircraft selection, powerplant selection, construction techniques, and avionics selection. With respect to flight testing, Wanttaja discusses pilot preparation and suggests letting a pilot experienced in the aircraft type perform the first flight.

Introductions to Flight Test Engineering Volume One by Donald T. Ward, Thomas W. Strganac, Rob Niewoehner (formerly Introduction to Flight Test Engineering by Ward and Strganac) [14]

Recently revised, Ward and Strganac's text [14] is commonly used as a text in university flight test engineering courses. It describes data collection and reduction in detail and provides appropriately advanced mathematics. As a result, it is to a great degree above

the average homebuilder's level of comprehension and is useful primarily to those who want a deeper understanding of flight test engineering.

Understanding Performance Flight Testing: Kitplanes and Production Aircraft by Hubert C. Smith [26]

Smith's text [26] is dedicated to performance testing, but includes in its introduction some general information on flight testing in general. He includes test and data reduction methods for the full range of performance tests. Also included is a disk of Microsoft Excel worksheets developed for data reduction. The text describes how a homebuilder can develop performance charts that are similar to those found in the pilot's operating handbooks of certified aircraft.

Introduction to Aircraft Flight Test Engineering by Hubert C. Smith [27]

Used as a university-level text on flight test, Smith's text [27] describes data collection and reduction in a manner similar to Ward and Strganac. Also similarly, it is generally above the average homebuilder's level of comprehension.

Society of Flight Test Engineers Reference Handbook [28]

Distributed only to members of the Society of Flight Test Engineers (SFTE), a professional society for FTEs, the SFTE Handbook [28] provides basic theory and standard calculations typically used during flight test planning and data reduction.

A BRIEF HISTORY OF HOMEBUILT AIRCRAFT

Throughout this paper, the author has used the terms homebuilt, kitplane, and experimental aircraft somewhat interchangeably. The first term, homebuilt, encompasses all aircraft that are built by individuals rather than manufactured by a corporation for commercial purposes. “Kitplane” refers more specifically to a homebuilt aircraft that is sold as a kit for assembly by the individual. Even this term is broad, as kitplanes come in many varieties. Some kitplanes come in thousands of small pieces, requiring the builder to construct nearly every subassembly of the aircraft. Some parts may require holes drilled or shaping. Others may have all parts pre-cut and ready to assemble and still others, often known as fast-build or quickbuild kits, come with large portions of the aircraft pre-assembled, requiring only large-scale mating of subassemblies. “Experimental aircraft” are an even broader group that includes all aircraft certified in the Experimental category. This includes all homebuilts, as well as many warbirds and prototype commercially manufactured aircraft. The term “plans-built” refers to a homebuilt that is built from scratch from plans only. The builder must manufacture or purchase every part of the aircraft himself.

Homebuilt aircraft date back to the origins of powered flight. Prior to World War I, all aircraft were homebuilts. Even in factories, the aircraft were hand built, and plans for production aircraft were readily available. As a result, people not associated with the manufacturer could build the aircraft themselves [25]. The first kitplane was the Heath Parasol, which emerged in the late 1920s in response to the growing cost of production aircraft. Kitplane production grew substantially after 1947, when the amateur-built category was introduced [25].

Much of the popularity of homebuilt aircraft can be attributed to the advantages offered by the Experimental category. The homebuilder can essentially do whatever he wishes to his aircraft. He can install any engine, any type of avionics, or any airframe modification that he desires. He can also perform all of his own maintenance, saving thousands of dollars per year. Also enticing to the homebuilder is the breadth of aircraft choices available at a given price point. If one has \$150,000 to spend on a four-seat airplane, the certified world offers only used aircraft. Most, if not all, of these choices will be over 20 years old and based on even older designs. For that same amount of money (albeit with a great deal more time and effort), the builder can have a brand new homebuilt aircraft configured as he wishes.

Perhaps the most appealing aspect of homebuilt aircraft is also their greatest weakness. Unencumbered by the Federal Aviation Regulations (FAR) Part 23 (airworthiness standards for normal, utility, acrobatic, and commuter category airplanes [24]) that certified aircraft must satisfy, designers of homebuilt aircraft can achieve superior

performance than their certified counterparts. This is accomplished through design tradeoffs, such as trading reduced stability for increased maneuverability. Just as fighter aircraft are designed with relaxed stability so that they can be easily maneuvered, the homebuilt designer can choose to relax his aircraft's stability to improve its maneuverability, as he does not have to meet the regulations in FAR Part 23, which state that certified GA aircraft must demonstrate positive stability. Likewise, the homebuilt aircraft can be designed with a very sleek laminar flow wing that allows for blistering speed at the cost of higher stall speed and poor stall warning. [25] The result is that many homebuilts are faster and more maneuverable than similar certified aircraft while simultaneously being more difficult to fly and, most importantly, less forgiving of poor pilot technique or pilot error.

All told, the general decline of the GA manufacturing industry after 1980 and the above factors have accounted for a general increase in the popularity of homebuilt aircraft [29]. From 1993 to 1999, the FAA reported a 585% increase in the estimated number of active amateur-built aircraft and a 218% increase in the estimated number of annual flight hours for amateur-built aircraft [8]. By 2007, the Experimental Aircraft Association (EAA) reported that, "amateur-built aircraft have come to comprise over 15% of the registered U.S. civil, single-engine general aviation fleet" [30].

CHAPTER 2 - THE STATE OF HOMEBUILT FLIGHT TEST

WEAKNESSES IN THE GUIDANCE CURRENTLY AVAILABLE TO HOMEBUILDERS

The aforementioned growth in the homebuilt aircraft segment has, of course, resulted in a corresponding increase in the number of homebuilts being tested and operated. Accident statistics, described in greater detail later in this chapter, show that homebuilt aircraft are involved in a greater number of accidents than similar certified aircraft. Moreover, homebuilt aircraft have a very high accident rate during their first 25 to 40 hour flight test period. There are several probable causes for this trend. The majority of the pilots conducting these test flights have received limited and unclear guidance as to how to conduct flight test. Complicating this situation is that the sources of this guidance are somewhat disparate. Of equal importance is that these pilots tend to have no training as test pilots and have low time in aircraft type.

The first problem that the homebuilder faces when approaching flight test is basic guidance. Unlike building techniques, about which countless books, magazine articles and websites exist, little guidance is available to the homebuilder with regard to flight test. Even the answer to the most basic question that the homebuilder might ask, “what is the main objective of flight testing my aircraft?” is not readily available. In a perfect world, the objective of homebuilt flight test would be based on the type of aircraft being tested. There are vast differences between a docile, mass-produced kitplane such as the

Van's RV-6, and complex, ultra high performance kitplanes such as the Lancair IV-P, and plans-built scale warbirds. It would be shortsighted and perhaps irresponsible to paint the canvas of homebuilt flight test with a broad brush, but unfortunately that is exactly what much of the guidance available to homebuilders does.

If one follows AC90-89A [15], the primary homebuilt flight test guidance resource available from the FAA, one will easily fill a 25-hour flight test period with a very comprehensive series of tests. Engine runs, fuel flow and usable fuel tests, in-depth propeller inspections, and logical low-speed taxi, high-speed taxi, and first flight tests are prescribed. These detailed suggestions are very similar to the procedures followed in commercial and military flight test and are appropriate for all aircraft. The AC90-89A, however, then recommends fifteen hours of dedicated stability and control tests.

An airplane such as a Glasair or (Van's) RV, representative of a type of aircraft that is widely produced and has, to at least some extent, known flying qualities, probably does not require this large amount of stability and control testing. Characterization of the flying qualities and stability of the aircraft might be interesting, but, if the aircraft is typical of a type, not necessary. Rather, a more appropriate goal would be to confirm that the aircraft behaves in a manner similar to other aircraft of the type and to characterize any situations where it does not. With that objective, the flight test of such an aircraft would far more closely resemble the production flight test that is conducted by certified aircraft manufacturers. The primary goal of this type of flight test program is confirmation that the aircraft has been constructed properly, meets expected performance

and handling standards, and is safe. In such a case, it is acceptable to examine the aircraft's flying qualities at a selected small group of points within the aircraft's flight envelope. Testing should always be performed in accordance with accepted test methodology and as precisely as possible, but need not be performed to the kind of "resolution" suggested in the available resources with respect to the number of flight conditions at which testing is conducted. Flight regimes where behavior is nonlinear should be examined closely, but in other parts of the envelope testing of the "endpoints" might be adequate.

The opposite case is true with a plans-built airplane, original design, or highly modified kit aircraft. In this situation, a comprehensive flight test program is in order. Unlike a standard, commercially available kitplane, nearly all characteristics of this type of aircraft will be unknown. In addition to confirming that the aircraft has been constructed in a proper manner, the flight test program must confirm, for example, that, to use the terminology of FAR 91.319 [23], that the aircraft is controllable throughout the normal range of speeds. In this case, the "resolution" with respect to the number of flight conditions at which testing is conducted must be very high so as to avoid overlooking a portion of the envelope where flying qualities or performance aspects are nonlinear and therefore not easily extrapolated. With these types of homebuilts, the goal is to actually define the aircraft's behavior and performance and the aircraft must be considered completely unknown. Furthermore, major deficiencies may be discovered, such as dangerous stall characteristics in a specific configuration. The testers then must decide how to address these deficiencies. Solutions could range from a recommendation to avoid

a specific flight regime to the addition of aerodynamic devices such as vortex generators to, in extreme cases, wholesale design changes. Thus, the test program will more closely resemble a developmental test program, where characteristics are defined and design deficiencies resolved, than a production test program where defects are identified and corrected.

In many cases, the actual flight test program will lie somewhere in between these aforementioned extremes. Flight test of homebuilts should be viewed as a continuum. Few mass-produced kitplanes are constructed without some significant modifications, and most of them incorporate avionics and instrumentation that require more than cursory flight test, such as electronic flight information system (EFIS) units that are marketed solely to homebuilders and therefore themselves not subject to FAA certification. Likewise, in the case of a plans-built aircraft, it is likely that there are several examples of the aircraft already flying. This at least gives the tester some idea as to what to expect from the aircraft. Of course, it is far safer to expand the testing of a commercially available kitplane than it is to omit tests from the testing of a plan-built aircraft.

The FAA regulations and AC90-89A [15], unfortunately perhaps, conflict with this philosophy. By requiring a 25 to 40-hour test period, the FAA implies that all homebuilts require a great deal of flight test. AC90-89A corroborates this implication, as it dutifully prescribes just that – 25 to 40 hours worth of comprehensive flight test. More appropriate than this monolithic approach would be a requirement for an educated, well-developed test program that is *appropriate to the specific aircraft under investigation* to be

implemented. Boeing does not re-fly the entire matrix of FAA certification tests on every 737 that comes off the assembly line, so why should the builder of a Lancair IV, who has utilized the company's extensive builder assistance program, have to fly tests that are actually developmental in nature rather than production-type tests?

Many factors must be considered, however, when proposing to customize flight test for homebuilt aircraft. One factor is the level of quality control in both the kit construction and assembly (one reason that Boeing does not have to fly the entire matrix of FAA certification tests on every 737 that comes off the assembly line is because they have a great deal of confidence that that airplane is very nearly identical to the one(s) flown for certification). Quality control varies from company to company and certainly from builder to builder. One anecdotal account tells of a builder who simply forgot to install the bolts that connected the wings of his airplane to the fuselage. The skin and paint were sufficient to hold the wings in place during ground tests, but once the airplane was in the air and the wings loaded, they separated from the aircraft (with predictably catastrophic results). A proposed solution to these problems is discussed in Chapter 6.

The most disconcerting aspect of the current guidance available to homebuilders, and consequently throughout the culture of homebuilt flight testing, is the prevailing attitude toward test piloting. The available guidance is not only lacking in that it fails to address the aforementioned breadth of flight test, it also tends to push homebuilders toward conducting the tests themselves. In addition, the available texts and resources provide incomplete guidance as to how to conduct safe and effective flight test. All of the popular

references for homebuilders address in some manner the abilities and preparation of the test pilot, but they all take a very cavalier approach toward them.

AC90-89A [15] clearly leads builders toward performing their own flight testing. The AC provides some recommendations as to test pilot qualifications, but the minimal amount of experience recommended – 100 hours solo time before flight testing a kit plane or an aircraft built from a time-proven set of plans or 200 hours solo time before flight testing for a “one of a kind” or a high performance aircraft [15] would barely qualify a commercially rated pilot to tow a banner. AC90-89A entirely ignores the possibility that a pilot who has flown only one or two different aircraft types, and likely has never experienced anything other than a simulated engine failure and private-pilot style unusual attitude recoveries, may not have the requisite skills to perform flight testing. The AC makes no mention of control system failures or recovery from out-of-control flight – both of which are situations that the pilot of an aircraft on its first flight might encounter. AC90-89A dedicates more text to aeromedical factors than it does to test pilot credentials and experience.

In her book *Homebuilt Aerodynamics and Flight Testing* [12], Sonja Englert dedicates only two vague sentences to test pilot qualifications. “The first flight should be done by you only if you have enough recent flying experience and preferably some time in type. Otherwise, it is a lot more prudent to leave it to someone qualified for it” [12]. Readers of this reference will likely refer back to AC90-89A [15], as it provides some quantitative information. Once again, the text does not address control system failures or recovery

from out-of-control flight. Although Englert is correct to suggest that the pilot have some time in type, this may be difficult for the builder of an unusual or unique design. No further discussion is provided to assist the reader in understanding the influence of time in type on accident rates and factors mitigating this influence, which are addressed in detail in Chapter 3.

Vaughn Askue's *Flight Testing Homebuilt Aircraft* [13] is one of the most popular resources for homebuilders and dedicates nearly two pages to test pilot flying skills and mental attitude. As for the decision to test fly the aircraft oneself or to find a more qualified test pilot, Askue states that, "To answer this you must review your experience and compare it with the probable characteristics of the airplane you've built" [13]. There is no discussion as to what actually qualifies someone to act as a test pilot. The last sentence of the paragraph has a somewhat sinister undertone, "If you do get someone to do your flying, remember that it's your airplane and the pilot must fly it the way you want it flown" [13]. The way that this sentence is written appears to suggest that it is better to test fly one's own aircraft than let someone else do it. Furthermore, it implies that the builder is the best qualified to determine how an airplane should be flight tested. This is a preposterous concept, considering that there are accepted industry standards and doctrine regarding flight test. If the builder was actually best qualified to test fly an aircraft, why would manufacturers maintain staffs of test pilots and flight test engineers? Why would the military invest millions of dollars each year in the training of these personnel? Askue's attitude is particularly disturbing considering that he works for a large airframe manufacturer and is a former flight test engineer himself.

Askue's statements in the paragraphs following the one quoted above confirm his cavalier attitude:

If you have decided to [test fly your airplane] yourself it is time to brush up on your basic skills ... If there are no taildraggers available and yours is, it is worth a trip to shoot some landings in an airplane with the little wheel on the back end.

In your practice flying, emphasize steep turns and spins if the airplane can do them. You should be striving to fly the airplane as accurately as possible. Now do some takeoffs, full-stop landings, and go-arounds. Again, emphasize precise airspeed control and accurate patterns [13].

This guidance is somewhat ridiculous. The idea that it is simply a nice idea to get tailwheel experience prior to the first flight of a tailwheel airplane is a severe and dangerous understatement. Even more dangerous is his statement regarding the emphasis on performing "steep turns and spins if the airplane can do them." What if the airplane that the potential test pilot is practicing in cannot safely perform steep turns and spins? It is inconceivable that a pilot might conduct a first flight without having practiced necessary maneuvers. Flying the plane "as accurately as possible" is also quite an understatement, considering that Askue dedicates the rest of the book to precision flying, data collection, and data reduction. Without precision flying, accurate data collection is impossible. Perhaps most telling is the casual tone in Askue's writing. He writes about one of aviation's most dangerous activities as one would expect a magazine writer to write about a pilot preparing for the first flight of the summer in his Aeronca Champ with the doors removed.

The reason for the prevalence of the attitude that homebuilt flight test should be conducted by the builder is not well-defined. One reason may be simply that, to date, the majority of homebuilt flight test is performed by the builder, and none of the authors of the above references have the goal of changing the status quo. Most disturbing is that none of the sources ask the potential amateur test pilot to compare his skills and abilities to that of the true standard – the professional test pilot. It would seem logical that if one were to embark on a hazardous endeavor that, far from being arcane and mysterious, is well-defined and performed by numerous professionals on a daily basis, one would at the very least examine their training and skill set to gain a general understanding of what might be required to perform such an endeavor. Another problem is that many builders consider the first flight as simply part of the building process. It is considered the capstone of the project and a source of great pride for the builder. Indeed, in many cases, against the advice published in some of the resources and certainly opposed to the normal practices of professional testers, builders invite friends and family to observe the first flight of their aircraft. Ego likely plays a prominent role in the decision to test one's own airplane. It is not easy for someone to go to their EAA meeting, packed with other pilots who performed their own flight tests, and admit that you do not have the "courage" to do it yourself. It is also an opportunity for the average private pilot to play test pilot. Many in the aviation community consider test pilots like Chuck Yeager and Scott Crossfield to be their heroes, and the opportunity to be like them is captivating. Finally, there is an element of ignorance. Although, as previously mentioned, the field of flight test is well-defined and performed by numerous professionals on a daily basis, its details are not well known by the average pilot. Many believe that test pilots merely "kick the tires and light

the fires” and do not understand the training, precision, and patience involved. A small amount of research would reveal the true nature of flight test, but consider the average homebuilder’s experience. He spends months or years researching the aircraft that he wants to build, then years actually doing so. Along the way, he researches building techniques, materials, tooling, and parts. The first flight of the aircraft seems like a distant event, so research regarding flight test is a low priority. Throughout the process, however, the builder’s peers are likely passively, but negatively, influencing his understanding of the requirements of flight test as described above.

Regardless of the reasons for the trend toward builders conducting their own flight tests, the status quo is such that most builders do so, and most of these builders are ill prepared to act as test pilots. In addition to the aforementioned deficiencies in the guidance available to builders regarding flight test, few have an appropriate amount or applicable type of experience. Whereas the average military test pilot enters test pilot school with over 1000 hours as pilot in command of high performance aircraft and graduates a year later with extensive classroom training and having flown a dozen different aircraft of widely varying types (high-performance jets, multiengine turboprops, light single engine pistons, and warbirds), the typical homebuilder has never even simulated precision flight for the purposes of data collection or an out of control flight condition. Furthermore, he has likely only flown a few types of general aviation (GA) aircraft in his flying career and even fewer types to a high level of proficiency or with extreme attention to detail. The lack of homebuilders’ relevant experience and the effect of this phenomenon are examined further in Chapter 3.

As previously mentioned and examined in greater detail in Chapter 3, the statistics support the hypothesis that this combination of piecemeal, poorly-targeted, and often inappropriate guidance has a negative impact on the risks associated with testing homebuilt aircraft. This fact has not gone unnoticed by the Experimental Aircraft Association, the largest organization of homebuilders and homebuilt aircraft enthusiasts. One of the EAA's publications, *Sport Aviation* magazine, routinely publishes articles on homebuilt safety. More significantly, the EAA has established what is known as the Flight Advisor program. This program matches builders with an EAA volunteer who helps the builder evaluate his own flying skills for the purpose of determining if they are ready to perform the first flight of their aircraft. The flight advisor does not actually evaluate the builder, but serves rather as an experienced sounding board that the builder can use to help him perform a self-evaluation [31].

Although the Flight Advisor Program is an unequivocally positive effort, it has its limitations. Flight Advisors are volunteers, and although the EAA requires that they meet certain experience requirements (described below), they are not trained, professional testers. Their advice is also subject to very limited oversight, so there are no guarantees that Flight Advisors will not give advice that exceeds their level of knowledge or violates their mission statement. The EAA's experience requirements are listed below:

To qualify to become an EAA Flight Advisor, you must be a current member of EAA and conform to **any one** of the following experience measures:

- First flights or test flown three or more aircraft (homebuilt, restoration or ultralight).

- Built/restored and test flew own aircraft **and**
 - is a Technical Counselor with significant flight test experience
 - or has significant experience in requested specialty, i.e., homebuilts, vintage and more than 1,000 hours pilot in command (PIC) time.
- Built and test flew own ultralight **and**
 - is a Technical Counselor with significant flight test experience
 - or has more than 300 hours in ultralights
- Air transport pilot (ATP)/certificated flight instructor (CFI) with significant "show plane" experience, i.e., vintage, homebuilt, **and** more than 1,000 hours pilot in command PIC.
- Military flight test experience with "show plane" experience, i.e., vintage, homebuilt, ultralight **and** more than 1,000 hours PIC

Source: EAA [31].

Although these requirements are generally strong, they nevertheless have some weaknesses. For example, the first experience requirement of having accomplished first flights or test flown three or more aircraft is somewhat vague. A pilot can claim this experience after simply flying three undemanding level flight performance flights that did not even yield any usable data. Furthermore, a pilot is not a qualified test pilot simply because he survives three first flights. Many first flights are uneventful, and thereby provide the pilot with only a limited amount of useful "flight test" experience. Again, the act of flying the first flight is not itself conducting flight test. Flight test is the overall experience of planning the flight, flying the flight, maneuvering the aircraft with the required precision, observing the aircraft's behavior critically, and reporting the results, even if that report is limited to entering accurate data into one's own pilot's operating handbook (POH).

PROFESSIONAL FLIGHT TEST RESOURCES AVAILABLE TO HOMEBUILDERS

In light of the serious nature of flight testing, one would expect that the homebuilt aviation world would be awash in professional flight testers. Unfortunately, as mentioned earlier, the current state of the homebuilt flight test industry is one characterized primarily by a “do-it-yourself” attitude. It is actually fairly difficult for the average builder to locate a professional test pilot or flight test service. An internet search of the terms “homebuilt flight test” results in a long list of places to purchase the aforementioned books on the subject, but only one individual who lists flight testing as one of his services, and even that seems an afterthought.

In spite of the difficulties in locating them, there are individuals and companies who perform flight test of homebuilt aircraft for hire. The majority of the individuals are experienced professional (CFI, corporate, or commercial) pilots who also have considerable time in homebuilt aircraft. Few have any formal flight test training and many have learned what they know of flight test doctrine from Askue and Englert’s texts [13, 12]. Virtually all of them work alone and approach the flight test exclusively from the pilot’s point of view. Similarly, few of them are engineers themselves.

Several companies also offer professional flight test services to homebuilders. High Performance Aircraft Training (HPAT) has offered such services since the 1990s and specializes in the flight test of Lancair Aircraft. HPAT’s pilots are primarily very highly experienced civilian test pilots, and HPAT’s president is an aeronautical engineer. HPAT

maintains a strong relationship with the Lancair factory and has access to expert engineering services from the actual aircraft designers as well. Flight test is conducted in accordance with AC90-89A [15] and selected elements of FAR Part 23 [24] and military standards. The author's company, 9G Aerospace Solutions (9G), offers similar services, but differs slightly from HPAT in its approach to flight testing in that a complete test plan is authored, briefings and reviews are conducted formally, and a complete report of test results is delivered. 9G's flight test programs are provided by a test pilot / flight test engineer team and are patterned after those conducted by the U.S. Navy and the methodology taught at the U.S. Naval Test Pilot School, of which the author is a graduate.

Other than in the case of the aforementioned companies and some other isolated services, an absence of an engineering presence most distinctly differentiates homebuilt flight test for hire from true professional flight test. The pilots who do perform homebuilt flight test for hire may fly the same maneuvers that professional test pilots fly and may even fly them to the same precision and collect the same data, however differences exist. These differences are twofold. The first difference is that simply flying the maneuvers suggested by "the book" (whichever text the pilot is using to guide him) does not necessarily mean that constructive flight test is being accomplished. The concepts of envelope expansion, build-up and regression testing require significant forethought and analysis. The suggested order of tests may not be appropriate for the particular aircraft being flown and the decision to fly the next test may be predicated on the successful completion of the previous test. In the professional flight test world, the determination of

the success or failure of a particular test is generally an engineering decision made in concert with the test pilot. The failure of the test team to apply proper doctrine or having only the test pilot make this decision exclusively from his point of view is, at the very least, limiting. The engineer is considered a necessary check and balance and he is often able to identify characteristics, deficiencies, and risks from outside the cockpit that are not readily identified from inside the cockpit. This leads directly to the second major difference between professional and homebuilt flight test. The test pilot may diligently and accurately collect large amounts of data, but unless the data is reduced properly and the results subsequently used to make sound decisions, the endeavor may be in vain. The engineer is trained not only in the proper manipulation of the data, but also in using an engineering approach to data analysis.

Professional flight testers have a characteristic combination of highly developed skills and knowledge in addition to a strong support structure available to them to help overcome the myriad risks that they face. The backgrounds of the numerous individuals conducting homebuilt flight test are as varied as the aircraft that they test, but overall, they compare unfavorably to formally-trained professional flight testers. Specifically, untrained, low time in aircraft type amateur flight testers following flight test procedures of varying quality, without clear guidance or, essentially, management and oversight of their test program, do not have the tools available to them that professionals have to conduct safe and effective flight test. The differences between amateur and professional flight testers are examined in greater detail in Chapter 5.

CHAPTER 3 - THE HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM (HFACS) AND ACCIDENT STATISTICS

As discussed in detail later in this chapter, statistically, low time in type pilots are at a disadvantage even in certified aircraft. The low time in type pilot involuntarily becomes a test pilot in an emergency, flying an unknown aircraft with unknown characteristics, and he does so without any of the training or experience that a professional test pilot has to aid him in guiding the situation to a successful resolution. With the current guidance directly placing under-trained, low time in type homebuilders into the hazardous world of flight test without the support structure that professional flight testers lean on to keep themselves safe, homebuilders are thus encouraged to put themselves in exactly the position where their lack of experience is a distinct disadvantage.

OVERVIEW OF THE HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM

The HFACS, introduced in the late 1990s, is a general human error analysis framework that has been used within the military, commercial, and general aviation sectors to systematically examine underlying human causal factors in aviation accidents [11]. HFACS draws upon the James Reason's "Swiss cheese" model of human error, where potential system failures are likened to layered slices of Swiss cheese. The layers represent the latent and active failures in the system. Each layer, like Swiss cheese, has holes representing the actual failure. Consider the latent failure of a pilot who is not diligent in his VFR scan. The failure is always present (the layer), but only if another

aircraft is on a collision course will it become a problem (the hole). If a failure occurs, it is possible that the holes in each layer will not line up, breaking the chain of causal events that lead to an accident. However, if the holes do line up, the errors can “fall through” and lead to an accident.

A real life example of such a system is as follows: An air traffic controller has radar that allows him to see aircraft on a potential collision course. The radar has built-in algorithms to warn the controller of a potential collision should he not notice it himself. The aircraft themselves have collision avoidance equipment such as traffic collision avoidance systems (TCAS) or traffic information systems (TIS) to warn them should the controller and his system fail. Finally, at least in visual meteorological conditions (VMC), the pilots themselves can see oncoming traffic and avoid a collision. Only if all four of these “layers” fail will a midair collision occur. Shappell and Wiegmann’s adaptation of Reason’s model is depicted in Figure 1.

The HFACS model establishes four layers of Reason’s model to characterize the aviation accident causal environment. The first three represent latent failures in the system, while the lowest one, *Unsafe Acts*, represents the active failure that leads to an accident. The lowest layer is the only one that must be present for a human factors related accident to occur.

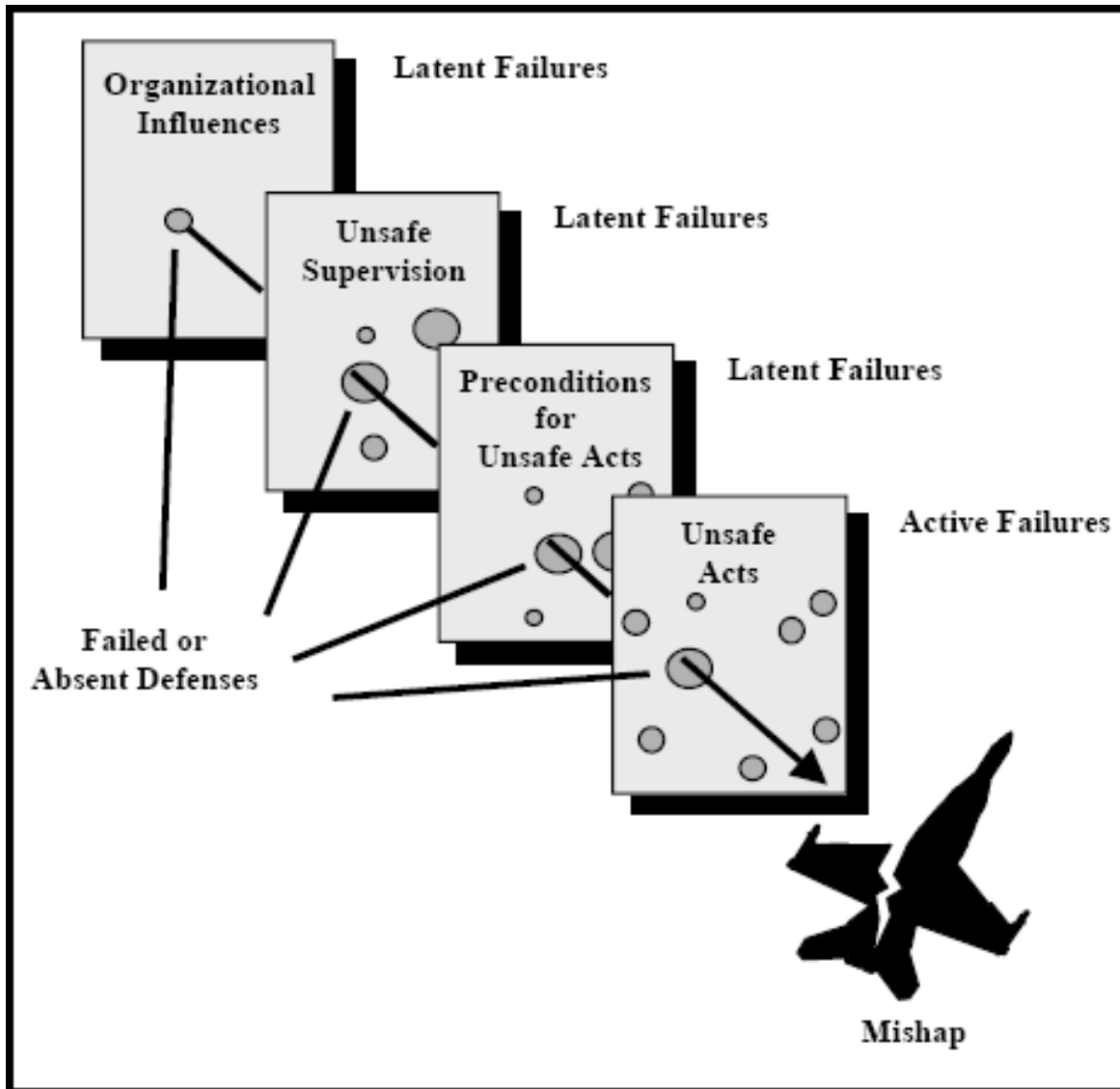


Figure 1 – The HFACS Model

Source: U.S. Department of Transportation. Federal Aviation Administration. 2000. *The Human Factors Analysis and Classification System – HFACS (February 2000)*, by Scott A. Shappell and Douglas A. Wiegmann [11].

The uppermost layer, *Organizational Influences*, represents the culture of the organization within which the situation occurs and its failings. Management, the overall climate of the organization, and the quality of and adherence to processes in place are all organizational influences. [11] An example of this would be an airline which, finding itself in bankruptcy, decides to cut back its training hours.

The next layer down in the HFACS model is *Unsafe Supervision*. This layer represents the quality of the supervision of the participants in the accident. The failure of supervisors to address problems or even notice problems in the first place, is included in this layer. Also taken into account would be the characteristics of the supervision itself, such as an inadequate number of supervisors or inadequate training for them. [11] In the airline example, an example of this would be the promotion of inexperienced pilots to instructor pilots.

The last layer representing latent failures is *Preconditions for Unsafe Acts*. This layer includes substandard conditions and practices of operators. These, in turn, include failures such as adverse physiological states (such as crew fatigue) and crew resource mismanagement (such as failure to communicate) [11] Returning to the airline example, let us consider a situation where the aircraft captain disengages the autopilot, but fails to communicate this to the first officer. He then announces that he is going to the lavatory and simply says “you have it” to the first officer. No positive change of controls takes place and the first officer, believing that the autopilot is engaged, does not maintain control of the aircraft.

This example now leads to the bottom layer of the HFACS model – *Unsafe Acts*. Unsafe acts, or active failures, include errors and violations that directly lead to the accident. These can include decision errors, skill-based errors, perceptual errors, and both routine and exceptional violations [11]. Our airline example has probably already taken into account one unsafe act, as the failure to perform a positive change of controls would likely be a violation of airline policy. Following his failure to control the airplane, the example first officer finally notices the aircraft in an unusual attitude. He is poorly trained in recovery from unusual attitudes, as the airline has reduced the training from ten to two hours due to budget cuts and, to make matters worse, his instructor had never received specific training in recovery from unusual attitudes. The first officer then makes a skill-based error and over controls the aircraft, leading to a catastrophic structural failure and loss of the aircraft. None of these failures, except for the unsafe act at the end, were direct causes of the accident. However, the unsafe act would likely not have occurred at all had the latent failures not lined up in such a way as to lead to the active failure.

In short, HFACS is primarily a method of codifying the well-understood idea that most aircraft accidents are a chain of causal events. Generally, one or more of these events is avoidable and can break the chain that leads to the accident. HFACS further categorizes the events, which leads to deeper understanding of accident prevention. The world of homebuilt flight test is a case study in the application of HFACS. Although the homebuilt flight test world is only loosely organized and supervised, organizational influences and unsafe supervision are likely key players in the high accident rates of homebuilt aircraft

in comparison with other GA aircraft. Better-documented are the effects of what are classified as the precursors to unsafe acts. Finally, the very nature of the homebuilt flight test world leads to a greater number of actual unsafe acts.

GENERAL AVIATION ACCIDENT STATISTICS AND HOMEBUILT AIRCRAFT ACCIDENT RATES

Before analyzing the statistics in terms of the HFACS, it is necessary to describe their sources and limitations. The primary source of data for this analysis was the NTSB's Annual Review of Accident Data [1-10], with the annual Nall Report on Accident Trends and Factors published by the Aircraft Owners and Pilots Association (AOPA) providing supplemental data [32-38]. An additional source of supporting data included Ron Wanttaja's excellent article on homebuilt safety from *Kitplanes* magazine's September 2006 issue [39]. The 10-year period from 1992 to 2001 was used due to the availability of complete data. Statistics appear to have remained similar for the period through 2005 [32-38]. Prior to this period, homebuilt accidents appear to have been more prevalent; however the number of homebuilt aircraft was far lower. As this study is focused on the current and future states of homebuilt flight test, the more recent period, with its more level accident rates and greater correlation to the current period, was examined.

In addition to the above sources, the NTSB accident database [40] was queried directly and both the probable cause and factual reports studied. The query period used was from January 1, 2002 to December 31, 2004, so as to correspond to the time period studied by

Wanttaja [39]. In an effort to capture only incidents that occurred in the flight test period or during subsequent flight test of homebuilt aircraft, the query was limited to amateur built aircraft that included the terms “test” or “first flight”. Approximately 80 records, including rotorcraft accidents, were returned and examined. Although not considered in the aforementioned statistics, several rotary wing accidents were retained due to their general relevance to the flight test of homebuilt aircraft (the fact that the aircraft was rotary wing was irrelevant to the accident). Ultralight accidents were discarded, as ultralights and ultralight operators are regulated differently. Ultimately, 64 total accidents were considered. 60 were considered to be clearly test flights (including post-major maintenance or modification), with an additional 4 accidents included as they were first flights conducted by a new owner immediately after purchase of the aircraft from the builder. This data was not considered to be comprehensive, but rather a more in-depth examination of the data summarized in the other statistical sources cited.

According to its introduction, The NTSB’s Annual Review of Accident Data is a statistical compilation and review of general aviation accidents that occurred in the particular year and includes accidents involving U.S.-registered aircraft operating under 14 CFR Part 91 (Code of Federal Regulations, also known as FAR Part 91), as well as public aircraft flights that do not involve military or intelligence agencies [10]. Aircraft operating under Part 91 include aircraft that are flown for recreation and personal transportation and certain aircraft operations that are flown with the intention of generating revenue, including business flying, flight instruction, corporate/executive flights, positioning or ferry flights, aerial application, pipeline/power line patrols, and news and traffic reporting [10]. As such, the overall statistics are somewhat broad and

probably not relevant as baseline data for comparison to homebuilt accident statistics. As most homebuilt aircraft are single-engine piston aircraft, the statistics for this class of aircraft were generally used as a baseline. In the last 7 of the 10 years studied (1995-2001), specific data on accident pilot time in type was available. Furthermore, the data specified the total number of flight hours by category (e.g., single engine piston). Due to the specificity of the data available, average accident rates were extracted from the 1995-2001 period.

Overall, homebuilt aircraft averaged 32.23 accidents per 100,000 flight hours, compared to 8.37 accidents per 100,000 flight hours for single engine piston aircraft in general. Homebuilt aircraft averaged 8.78 fatal accidents per 100,000 flight hours, compared to 1.46 fatal accidents per 100,000 flight hours for single engine piston aircraft in general. It should be noted that trends over the 10-year period showed all accident rates declining. At the beginning of the analysis period, in 1995, single engine piston aircraft had an accident rate 10.09 of accidents per 100,000 flight hours and homebuilt aircraft had an accident rate of 44.50 accidents per 100,000 flight hours. Both rates declined over the next 6 years, and in 2001, homebuilt aircraft averaged 26.76 accidents per 100,000 flight hours, compared to 7.99 accidents per 100,000 flight hours for single engine piston aircraft in general. Fatalities also declined; By 2001, homebuilt aircraft averaged 6.88 fatal accidents per 100,000 flight hours, compared to 1.41 fatal accidents per 100,000 flight hours for single engine piston aircraft in general in that year (compiled from NTSB reports [1-10], and Wanttaja [39]. In spite of this decline, the pilot of a homebuilt aircraft

was nearly four times as likely to be in either an accident or a fatal accident as his certified aircraft counterpart.

More specifically, examination of the detailed NTSB reports reveals many causal factors that are common failures cited in the HFACS [11]. These failures will be discussed in greater detail in Chapter 4. Failure to maintain control or airspeed was cited as a contributing causal factor in 18 (28.2%) of the reported accidents. These included three pilot induced oscillation (PIO) accidents that were correlated to weaknesses in airmanship or experience. Lack of experience (low time in type) was specifically cited by the NTSB as a causal factor in 15.6% of the accidents. Poor decision-making was also a common thread, with six of the accidents (9.4%) involving inadvertent flight during high-speed taxi tests, two accidents involving flight of aircraft with known deficiencies, and two accidents involving test flights conducted in adverse weather conditions. Startlingly, six of the accidents involved deliberate violations. In three cases, passengers were carried despite the fact that the aircraft was still in its designated flight test period. Furthermore, in three other cases, the pilot did not have a valid pilot's license and medical certificate.

In addition to the human factors failures listed above, the overall hazardous nature of homebuilt flight test was shown by the fact that 11 of the accident reports (17.2%) cited improper construction as a cause and 12 reports (18.8%) were clearly due to engine failure. It should be noted, however, that human factors were contributors to five of the 12 engine failure accidents, as lack of suitable terrain and improper pilot procedure were

also cited as causes. This calls into question the pilot's judgment in planning and preparing for the test flight. Finally, first flight was clearly the most hazardous event of all, as 23 of the 64 accidents (35.9%) occurred on first flight. In 20 of these 23 cases, time in type was reported. The average time in type for the pilots on these first flights was only 1.6 hours, with 13 of the 20 accident pilots reporting no time in type whatsoever.

THE EFFECT OF PILOTS WITH LOW TIME IN AIRCRAFT TYPE ON ACCIDENT STATISTICS

From 1995 to 2001, the NTSB provided more detailed information on accident pilot time and time in type of aircraft. Although this data is not broken out by category and class of aircraft, the statistics still become far more informative. Over that 7-year period, it is clear that as pilots gain experience, their likelihood of being involved in an accident decreases. Pilots with 0 to 200 hours of total experience accounted for an average of almost 18% of the total accident pilots, while each increment of 200 hours experience resulted in a decrease in the % of total accident pilots [4-10]. Figure 2, illustrates this. Even more telling with respect to homebuilt aircraft is the percentage of accident pilots with low time in type of aircraft, as shown in Figure 3.

The clear indications from these numbers are that pilots who have less experience are more likely to be involved in an accident and, more significantly, pilots who have low time in the type of aircraft that they are operating are even more likely to be involved in

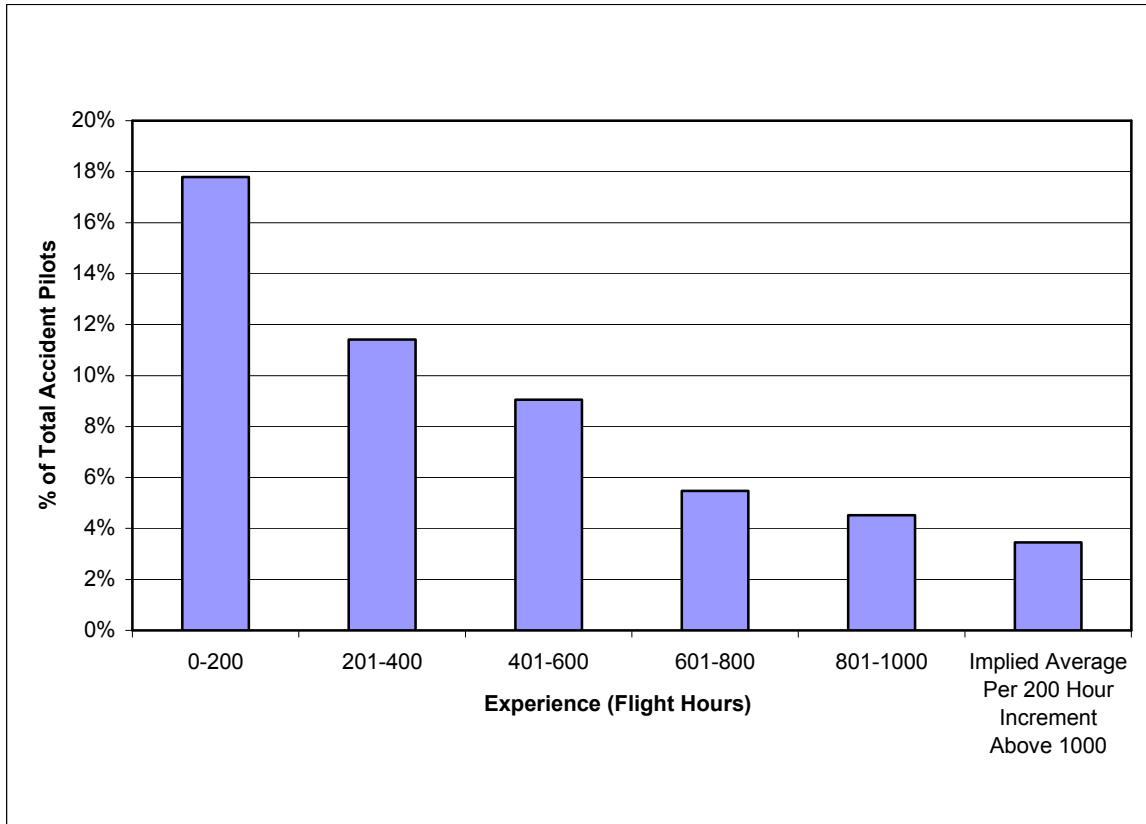


Figure 2 - Percentage of Accident Pilots by Total Experience

Sources – U.S. Dept of Transportation Annual Reviews of Aircraft Accident Data, U.S. General Aviation Calendar Years 1995-2001 [4-10] and Wanttaja, Ronald J. “Part 1: Homebuilt Aircraft – How Safe Are They?” [39].

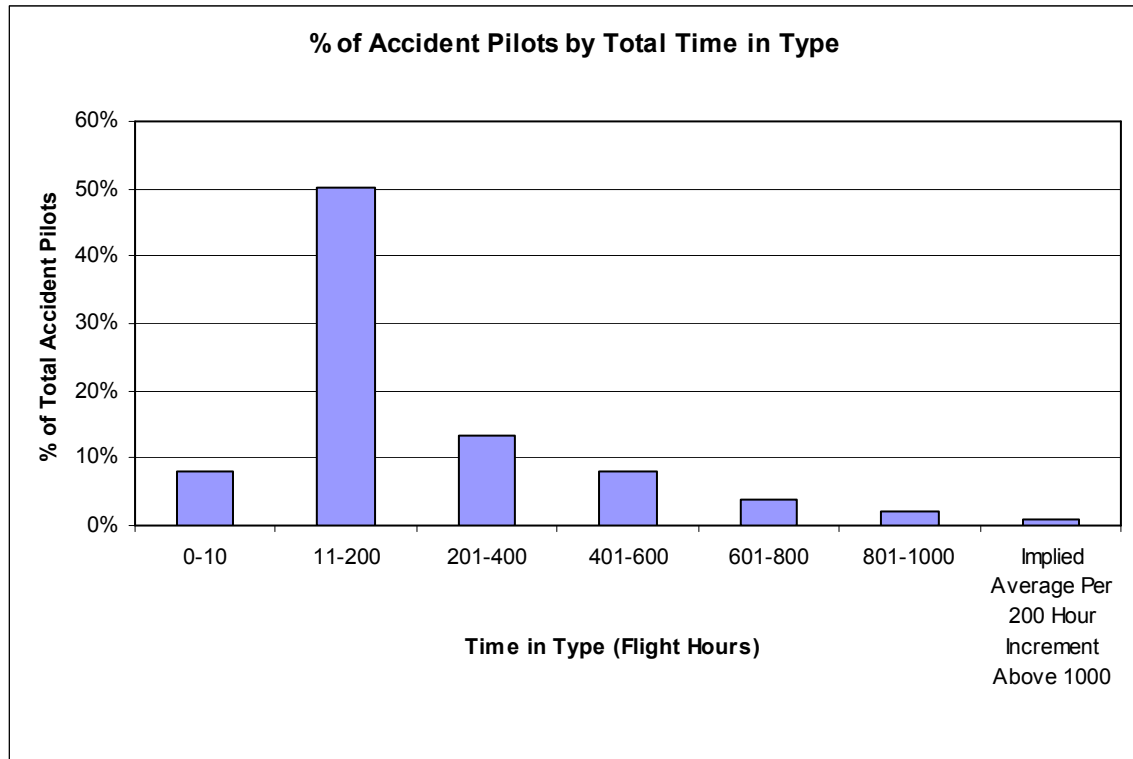


Figure 3 - Percentage of Accident Pilots by Time in Type

Sources – U.S. Dept of Transportation Annual Reviews of Aircraft Accident Data, U.S. General Aviation Calendar Years 1995-2001 [4-10] and Wanttaja, Ronald J. “Part 1: Homebuilt Aircraft – How Safe Are They?” [39].

an accident. Homebuilt pilots, especially those in the flight test phase (the first 25 to 40 hours) generally fall clearly into the latter category. It is often difficult (or even impossible in the case of a unique design) to even find a flying example of the aircraft that one is building. Even in the case of a common kit, finding an aircraft with the same engine and avionics package can prove to be very difficult. As mentioned previously, in the sample of NTSB reports studied, the average number of hours of time in type for accident pilots on first flight was only 1.6 hours and lack of experience was specifically cited by the NTSB as a causal factor in 15.6% of the accidents..

The myriad of aerodynamic modifications available for kits only compounds this problem. One might argue that experience in the basic airframe is enough; however it is more likely that the contrary is the case. For example, emergency procedures requiring fast interpretation of the flight instruments could be very challenging for a pilot who is not experienced with the particular EFIS installed in the aircraft. Engine and aerodynamic differences can influence both performance and handling qualities, both of which are more critical in an emergency situation that places the pilot near the edge of the operating envelope. For example, a pilot used to flying his friend's aircraft with a 115 hp. engine might overspeed his own aircraft, equipped with a 150 hp. engine, during a recovery from an unusual attitude. An additional consideration is that, in general, builder pilots who fly someone else's example of the aircraft that they are building are often flying with the owner, who is presumably an experienced operator of that aircraft. This may reduce the attention to detail by the builder pilot, as he is aware that in an emergency, he has an experienced pilot in the airplane to assist him.

AMATEUR TEST PILOTS AND EFFECTIVE LEVEL OF EXPERIENCE IN AIRCRAFT TYPE

Stepping back from the actual numbers, many homebuilt pilots, again especially in the flight test phase, also can be placed into the first category of pilots with less experience overall. This is due to their lack of recent experience. Although many builders are seasoned pilots, many have also neglected their pilot skills during the long process of building their airplane. Flying, like other neuro-muscular skills and complex behaviors which require the assimilation of numerous sensory inputs, coordination of outputs, and resource management, is a perishable skill. The value of recent experience is well understood and illustrated by the presence of currency requirements and routine flight reviews for all pilots. Even a private pilot who simply wishes to take his friend up sightseeing must have logged three takeoffs and landings within the past 90 days.

Another consideration is type of experience. Professional test pilots typically not only have thousands of hours of flight time, but that flight time is in a variety of aircraft and in a professional environment. While flying, the test pilot is flying specific maneuvers, carefully observing the aircraft's responses, and collecting data. There is a significant difference between flying with precision and extreme focus on the behavior of an unknown aircraft for an hour and flying to the next field over for a "\$100 hamburger". This difference stretches beyond the aircraft as well. Prior to the flight, the test pilot must study the aircraft and the test plan and be prepared to identify even the smallest of deficiencies. Upon arrival, he must condense his thoughts, articulate them to the test

team, and assist in the data reduction and reporting. An hour of flight test might occupy 20 or more hours of the test pilot's attention, all of which increase his experience. The private pilot going for lunch may have dedicated an hour to flight planning, checking weather, and preflighting the aircraft. Upon his return, he is likely (and justifiably) more concerned with avoiding an automobile accident on his way home from the airport than with any sort of postflight introspection.

It is the kind of experience that test pilots acquire that helps them offset the risks associated with low time in type. The types of failures that can be associated with low time in type, such as loss of control or failure to properly respond to an emergency, can be avoided by the experience of the test pilot. The test pilot is more comfortable with a wide range of aircraft handling qualities and his close attention to the aircraft's behavior makes him more likely to identify a controllability issue before entering a critical flight regime. Finally, his preflight study of the aircraft, its systems, and procedures puts him in a better position to execute emergency procedures than the average private pilot, should the need arise. This is not to say that the test pilot eliminates the risks associated with low time in type, merely that he mitigates them. Although no causal link is explicit in the statistics, the two dominant initiators of homebuilt accidents from 2002 to 2004 (in accidents where a probable cause was determined) were *pilot error – failure to control* and *power loss due to engine mechanical problems* [39], precisely the types of situations in which a professional test pilot's training and experience would give him an advantage over a low time in type pilot. In the NTSB reports studied, 17.2% of the accidents were also cases of improper construction, another situation that places any pilot at a distinct

disadvantage. The low time in type pilot is poorly equipped to deal with this type of situation, one which likely requires what Shappell and Wiegmann call a “novel solution” [11]. It should also be noted that in this period, Van’s aircraft accounted for just one of the 27 confirmed first flight accidents and 7% of the crashes during the 40-hour test period. [39] It is a logical assumption that, since Van’s aircraft are the most popular kitplanes in the United States, accounting for over one-third of the aircraft registered, most pilots accumulate some amount of experience in the aircraft prior to first flight [39].

Wanttaja also provides details regarding homebuilt accidents during the flight test period. The statistics are startling. For the 2002-2004 period, the accident rate on first flight was 1.01% and over the first 40 hours it was 3.3% [39]. Considering that the overall accident rate for GA aircraft from 1992 to 2001 was 7.71 *per 100,000 hours* [1-10], first flight and the flight test period appear to be extremely hazardous endeavors. Thus the chances of crashing on the first flight of a homebuilt are on the same order of magnitude of the risk that a NASA astronaut faces of being killed in an accident in the space shuttle (two fatal accidents over approximately 120 flights). This is significant, as spaceflight is well-understood to be a dangerous activity that is, to date, only conducted by trained individuals with a clear understanding of the risks involved.

CHAPTER 4 – APPLICATION OF THE HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM (HFACS) TO THE CURRENT STATE OF HOMEBUILT FLIGHT TEST PRAXIS

Returning to HFACS terminology, the homebuilt pilot is far more likely to commit the unsafe act that causes an accident, especially in the critical flight test period. The weaknesses in the system within which most amateur flight testers operate, however, affect the pilot's ability to overcome the problems associated with low time in type at several levels. In fact, the differences between professional and amateur flight test are responsible for many of the failures at each of the layers in the HFACS model. Before examining in depth the types of unsafe acts associated with amateur flight testers, we will look at the other side of the failure continuum and examine the latent failures from the top of the model down.

LATENT FAILURES - ORGANIZATIONAL INFLUENCES

In traditional HFACS analysis, *negative* organizational influences are cited as latent failures. These include influences such as the management of an airframe manufacturer pushing its flight test organization to cut corners or other, “fallible decisions of upper-level management [which] directly affect supervisory practices, as well as the conditions of operators” [11]. Shappell and Wiegmann list the specific categories of organizational influences as resource management, organizational climate, and organizational process [11]. It should be noted that none of these are intrinsically negative influences. In fact,

good resource management, a positive organizational climate, and a solid organizational process would all make flight test safer. The issue in the case of homebuilt flight test is that very few organizational influences, either positive or negative, exist.

Some of this is, of course, by design. One factor that makes homebuilts so appealing is the flexibility afforded by the Experimental category. Free of the restrictions of FAA certification, kits designers can trade handling qualities and safety features for raw performance, allowing builders to acquire airplanes with performance specifications of those double the cost. Similarly, builders are free to modify plans and kits, mate any powerplant they wish to the airframe, and install any avionics that they desire. The FAA enjoys benefits due to this arrangement as well, needing only a small number of relatively inexpensive designated airworthiness representatives (DARs) to inspect aircraft and publishing only a minimal number of advisory circulars and orders governing homebuilt aircraft.

As a result, the homebuilder finds himself in a loose organization with inconsistent influences. The FAA, as mentioned before, tells him to engage in a professional-league flight test program, but encourages him to perform the tests himself. The EAA, an organization that nearly all homebuilders are members of, provides plenty of advice and even flight advisors to help homebuilders determine if they are ready to act as test pilots. Finally, the homebuilder's organizational influences include the influence of the amateur test team that he assembles. This may include fellow builders, flight instructors or experienced pilots, or even well-meaning friends and family members. At the very least,

it is unlikely that a solid organizational process is in place to govern the homebuilder's flight test program. The loose structure of the typical homebuilder's flight test "organization" clearly represents a latent failure, as the quality of guidance and oversight provided by this organization is directly proportional to its ability to protect the pilot from danger. Also important to consider is that this loose organization has no authority over the builder and cannot stop him from making a bad decision, thereby negating one of the major benefits of an organization. The case studies presented later in this chapter illustrate the weaknesses of an organization which is only advisory in nature. If one looks at the selected examples of negative organizational influences provided by Shappell and Wiegmann, many of these are present in a typical homebuilt flight test program [11].

Most notable are:

Standards and Instructions – as discussed in depth in Chapter 2, the sources of flight test guidance for homebuilders come from a myriad of unregulated sources. Professional testers typically follow published military, regulatory, or corporate standards and instructions.

Deficient planning - the builder himself, not likely to be experienced in flight test planning, is doing the planning.

Clearly defined objectives – again, the builder himself is defining the test objectives. Objectivity is sacrificed and test objectives may be oversimplified or too broad.

Instructions – as discussed in depth in Chapter 2, the sources of flight test guidance for homebuilders comes from a myriad of unregulated sources.

Risk management – few homebuilders are trained in implementing organizational risk management methods.

Safety programs – large flight test organizations have programs established to ensure safety and to catalog lessons learned from previous efforts. No such organized program exists for the homebuilder.

It is clear from these examples that amateur flight testers are highly susceptible to latent failures due to organizational influences (or lack thereof). Amateur testers, already handicapped by their lack of experience, are put at additional risk due to the absence of a support structure that could provide guidance as to how to conduct safe and effective flight test. Furthermore, the presence of an effective support organization would provide oversight to ensure that tests are performed in accordance with this guidance and to review decisions made by the builder.

LATENT FAILURES – UNSAFE SUPERVISION

The next level down in the HFACS model is *Unsafe Supervision*. Similar to the case with organizational influences, oftentimes homebuilt flight test is characterized by the absence of any supervision. When supervision does exist, it is generally a matter of self-policing or supervision by individuals who are not specifically qualified. The direct relevance of many of the potential latent failures suggested by Shappell and Wiegmann to the homebuilder's flight test program warrants a more detailed study. Shappell and Wiegmann list some examples of failures associated with unsafe supervision in Table 1.

Homebuilt flight test, with its weak or nonexistent supervision, is characterized by nearly all of the latent failures listed in Table 1. It should also be emphasized that the HFACS was developed as an analysis tool for all aviation accidents – not only flight test [11]. The high level of intrinsic risk and the fact that flight test is a complicated process that

contains risks at all levels leads to a strong correlation between the failures suggested and those encountered in flight testing.

The first main heading in Table 1, *Inadequate Supervision*, sums up the typical homebuilt flight test experience. More accurately, in the homebuilt world, there is generally no

Table 1 – Excerpt from Shappell and Wiegmann, U.S. Dept. of Transportation 2000.

Selected examples of Unsafe Supervision (Note: This is not a complete listing)

Inadequate Supervision	Failed to Correct a Known Problem
Failed to provide guidance	Failed to correct a document in error
Failed to provide operational doctrine	Failed to identify and at-risk aviator
Failed to provide oversight	Failed to initiate corrective action
Failed to provide training	Failed to report unsafe tendencies
Failed to track qualifications	
Failed to track performance	
Planned Inappropriate Operations	Supervisory Violations
Failed to provide adequate brief data	Authorized unnecessary hazard
Failed to provide adequate brief time	Failed to enforce rules and regulations
Improper manning	Authorized unqualified crew for flight
Mission not in accordance with rules/regulations	
Provided inadequate opportunity for crew rest	

Source: U.S. Department of Transportation. Federal Aviation Administration. 2000. *The Human Factors Analysis and Classification System – HFACS (February 2000)*, by Scott A. Shappell and Douglas A. Wiegmann [11].

supervision. As mentioned above, there are loose organizational influences, but none of these influences, except, to a limited degree, the FAA, have any authority over the builder. The difference between advice and supervision is the ability of the advisee to ignore the advice. The builder is left with only advice and, therefore, is his own

supervisor. Again, this is illustrated later in the case studies. Thus, examining each of the subheadings:

Failed to provide guidance – the homebuilder often receives guidance, but the quality of this guidance varies greatly. Even within the EAA flight advisor program, the qualifications are somewhat broad. Furthermore, this guidance comes in the form of advice, which may be rejected by the homebuilder.

Failed to provide operational doctrine – the homebuilder receives only advice regarding any sort of flight test doctrine. The intrinsic value of doctrine is that it is based on authoritative sources and effective when it is followed without variance. As mentioned before, the advice received by homebuilders comes from often contradictory sources of varying quality.

Failed to provide oversight – except in the case of the FAA, which is concerned with the airworthiness inspection, flight test area, and duration of the test period - no oversight exists with respect to homebuilt flight test. Without an actual supervisor, the homebuilder can choose to perform (or omit) any test. This is discussed further below.

Failed to provide training – Any training that the homebuilder receives, other than that required by the FAA to meet the qualifications to operate the type of aircraft, is at his own discretion.

Failed to track qualifications and Failed to track performance – these are entirely the responsibility to the builder, although the former is to some degree influenced by insurance requirements.

With respect to homebuilt flight test, the second main heading in Table 1, *Planned Inappropriate Operations*, reflects the lack of clear guidance as to how to safely conduct a flight test program. In two of the case studies, builders chose to conduct high speed taxi tests in adverse wind conditions. This is a classic example of planning inappropriate operations, as professional flight testers treat high speed taxi as flight (and therefore would only conduct these tests under conditions appropriate for flight test) due to the high likelihood of an inadvertent liftoff. Without any supervision, the homebuilder is left to piece together a flight test program from the various sources of information. This area

is particularly critical, as it is in the test planning that risks are identified and mitigated. The subheading “Mission not in accordance with rules/regulations” can be interpreted broadly in this case. Assuming that the homebuilder follows FAA regulations, he is still left without any such regulations regarding test operations. Whereas a military flight tester might have a regulation that he must bail out if out of control below a certain altitude or not conduct certain tests in certain weather conditions, the homebuilder has no such safety-based regulations to protect him. He may plan to conduct a spin test on a day with limited visibility, for example. The remaining subheadings suggest that a supervisor fails to allow for safe operations such as proper briefings and crew rest. In the case of the homebuilder, he may not allow for these as well.

The next heading in the table, *Failed to Correct a Known Problem*, can also be similarly expanded to apply to the homebuilder acting as his own supervisor. The final heading, *Supervisory Violations*, is subsumed by the unsafe act itself if no supervisor exists. Overall, the lack of supervision has a similar influence on homebuilt flight test as the absence of positive organizational influences in that another layer of latent failures is introduced to an environment that is already rife with risk due to the shortcomings of its participants.

LATENT FAILURES – PRECURSORS TO UNSAFE ACTS

Precursors to unsafe acts, or unsafe aircrew conditions, are factors directly associated with the aircrew that immediately set the stage for the unsafe act. These precursors,

according to Shappell and Wiegmann, are either mental or physiological states or limitations, or failures by a multi-person crew to work together (poor crew resource management) [11]. Of the greatest concern to homebuilders are the single-pilot issues, as most homebuilts are operated by a single pilot. Table 2, also excerpted from Shappell and Wiegmann, lists many of these potential unsafe aircrew conditions.

Although almost all of the conditions listed in Table 2 are potentially present in the flight test of homebuilt aircraft, the first heading, *Adverse Mental States*, contains the unsafe aircrew conditions that are most relevant to homebuilt accidents in the flight test phase. Factors such as complacency, haste, misplaced motivation, and task saturation are likely to be present in a homebuilder's cockpit during flight test, particularly in the case when a builder unqualified to perform the tests chooses to do so. It is at this layer in the HFACS model where the amateur pilot's lack of time in type becomes a significant factor.

In many situations, many of these adverse mental states are present. Consider the homebuilder who, buoyed by the achievement of completing his aircraft (and misled by the prevalent information), chooses to perform his own tests despite having little or no understanding of flight testing. In this case, the evolution begins with misplaced motivation. Complacency may be an issue as well, particularly if the builder has many hours of total flight time and believes that, as an experienced aviator, there are few situations that he cannot handle. Now consider a hypothetical situation where, once in the air, the builder discovers that the ailerons are misrigged and that, despite a large, continuous lateral stick input, the aircraft will roll without the application of opposite

Table 2 – Excerpt from Shappell and Wiegmann, U.S. Dept. of Transportation 2000. Selected examples of Unsafe Aircrew Conditions (Note: This is not a complete listing)

SUBSTANDARD CONDITIONS OF OPERATORS	SUBSTANDARD PRACTICE OF OPERATORS
Adverse Mental States	Crew Resource Management
Channelized attention	Failed to back-up
Complacency	Failed to communicate/coordinate
Distraction	Failed to conduct adequate brief
Mental Fatigue	Failed to use all available resources
Get-home-it is	Failure of leadership
Haste	Misinterpretation of traffic calls
Loss of situational awareness	
Misplaced motivation	
Task saturation	
Adverse Physiological States	Personal Readiness
Impaired physiological state	Excessive physical training
Medical illness	Self-medicating
Physiological incapacitation	Violation of crew rest requirement
Physical fatigue	Violation of bottle-to-throttle requirement
Physical/Mental Limitation	
Insufficient reaction time	
Visual limitation	
Incompatible intelligence/aptitude	
Incompatible physical capability	

Source: U.S. Department of Transportation. Federal Aviation Administration. 2000. *The Human Factors Analysis and Classification System – HFACS (February 2000)*, by Scott A. Shappell and Douglas A. Wiegmann [11].

rudder. In addition, one cylinder's temperature is steadily climbing toward the limit. Now, faced with a poorly flying aircraft with a suspect powerplant, the builder's attention becomes channelized and he focuses on only one of his two major issues. The heavy workload associated with the controllability issue could in itself be considered task saturation. Under these adverse conditions, factors such as haste (in decision making), distraction, and loss of situational awareness are likely to develop. It is not difficult to imagine this pilot, under these adverse circumstances, committing an unsafe act such as failure to control the aircraft.

ACTIVE FAILURES – UNSAFE ACTS

Finally, HFACS brings us to the “pointed edge of the spear” – the unsafe acts themselves. Every accident caused by pilot error must, by definition, be caused by one or more unsafe acts. The other layers alone, as mentioned above, describe only factors which establish an environment in which the unsafe act can occur and result in an accident. As shown in Table 3, Shappell and Wiegmann classify unsafe acts into four categories: *Skill-Based Errors*, *Decision Errors*, *Perceptual Errors*, and *Violations*. The inexperienced, low time in type test pilot of a homebuilt aircraft who encounters an emergency on the first flight of the aircraft and crashes is likely to have committed several of these errors. Furthermore, by Shappell and Wiegmann's definition of violations, he has likely committed some of these as well [11].

Human error is by far the most common cause of GA aircraft accidents, both homebuilt and certified. Specifically, failure to control the aircraft is the most common cause, accounting for over 40% of homebuilt aircraft accidents [39]. Many of the errors listed in Table 3 can result in loss of control, including inadvertent use of controls, poor technique, over-controlling the aircraft, wrong response to an emergency, or any of the perceptual errors. The inexperienced homebuilder on his first flight is, in all but a few cases, very inexperienced in flight testing procedures, techniques, and operations. Unless he is an aerobatic pilot, he has not received any training in how to deal with controllability issues. Even with aerobatic training, his loss of control training is limited to addressing issues which develop in a generally predictable manner, not in the sometimes sudden and unpredictable manner in which controllability issues can develop during flight test. Similarly, unless he has professional-level training such as an ATP rating, he is not trained or experienced in precision flying. Again, this type of training only correlates to a finite degree, as the ability to fly an instrument landing system (ILS) approach to ATP standards does not necessarily translate to flying a windup turn to test pilot standards. This lack of experience and training engenders an environment where the pilot is at an increased risk of making decision errors. Shappell and Wiegmann state:

... errors can, and often do, occur when a situation is either not recognized or misdiagnosed, and the wrong procedure is applied. This is particularly true when pilots are placed in highly time-critical emergencies like an engine malfunction on takeoff.

However, even in aviation, not all situations have corresponding procedures to deal with them. Therefore, many situations require a choice to be made among multiple response options. Consider the pilot flying home after a long week away from the family who unexpectedly confronts a line of thunderstorms directly in his path. He can choose to fly around the weather, divert to another field until the weather passes,

Table 3 – Excerpt from Shappell and Wiegmann, U.S. Dept. of Transportation 2000.

Selected examples of Unsafe Acts of Pilot Operators (Note: This is not a complete listing)

ERRORS	VIOLATIONS
Skill-based Errors	Failed to adhere to brief
Breakdown in visual scan	Failed to use the radar altimeter
Failed to prioritize attention	Flew and unauthorized approach
Inadvertent use of controls	Violated training rules
Omitted step in procedure	Flew and overaggressive maneuver
Omitted checklist item	Failed to properly prepare for the flight
Poor technique	Briefed unauthorized flight
Over-controlled the aircraft	Not current/qualified for the mission
Decision Errors	Intentionally exceeded the limits of the aircraft
Improper procedure	Continued low-altitude flight in VMC
Misdiagnosed emergency	Unauthorized low-altitude canyon running
Wrong response to emergency	
Exceeded ability	
Inappropriate maneuver	
Poor decision	
Perceptual Errors (due to)	
Misjudged distance/altitude/airspeed	
Spatial disorientation	
Visual illusion	

Source: U.S. Department of Transportation. Federal Aviation Administration. 2000. *The Human Factors Analysis and Classification System – HFACS (February 2000)*, by Scott A. Shappell and Douglas A. Wiegmann [11].

or penetrate the weather hoping to quickly transition through it. Confronted with situations such as this, choice decision errors (Orasanu, 1993), or knowledge-based mistakes as they are otherwise known (Rasmussen, 1986), may occur. This is particularly true when there is insufficient experience, time, or other outside pressures that may preclude correct decisions. Put simply, sometimes we chose well, and sometimes we don't [11].

Finally, there are occasions when a problem is not well understood, and formal procedures and response options are not available. It is during these ill-defined situations that the invention of a novel solution is required. In a sense, individuals find themselves where no one has been before, and in many ways, must literally fly by the seats of their pants. Individuals placed in this situation must resort to slow and effortful reasoning processes in an environment where time is a luxury rarely afforded. Not surprisingly, while this type of decision making is more infrequent than other forms, the relative proportion of problem-solving errors committed is markedly higher [11].

The trained and experienced test pilot is better prepared to make the correct decisions in a timely manner and, when called upon, to develop the “novel solution” that Shappell and Wiegmann refer to.

Shappell and Wiegmann define violations as “a willful disregard for the rules and regulations that govern safe flight” [11]. As there are (unknown to many homebuilt flight testers) industry standard rules that govern flight test, those who are not qualified to perform flight test, expand the envelope too rapidly (flying overaggressive maneuvers), or fly maneuvers that they did not specifically prepare for (fail to adhere to the “brief” – formal or otherwise) are all committing violations. All of the above violations can directly result in either a structural failure or loss of control of the aircraft.

The large-scale picture is that in the amateur flight testing of homebuilt aircraft, many of the latent failures that are present in aviation operation occur with greater frequency,

resulting in a larger number of “holes” in Reason’s Swiss cheese model. As a result, the holes line up more often for homebuilt flight testers than they do in the broader world of GA. This sets the stage for the unsafe acts which can cause accidents, and, again, homebuilt flight testers are placed in a situation where they are more likely to commit these unsafe acts than their counterparts taking their Cessna 182 for a “\$100 hamburger” or the King Air pilots racing to Hilton Head to pick up the company president after a round of golf. Taken as a whole, the inexperienced, low time in type test pilot of a homebuilt aircraft who encounters an emergency on the first flight of the aircraft is likely to have fallen through to the bottom layer of Reason’s Swiss cheese model prior to starting his engine. Once the emergency occurs, he is likely to find himself committing multiple skill-based and decision errors which compound the problem rather than mitigate it, ultimately resulting in an accident.

CASE STUDIES

To further illustrate the application of the HFACS to homebuilt flight test, the following case studies are examined. In the first case, the pilot made a series of poor decisions that resulted in the testing of an intrinsically unsafe aircraft in non-optimal conditions. The pilot knew that the airplane had controllability deficiencies and was also concerned about the crosswind conditions which might exacerbate these problems. In spite of this, he proceeded to attempt the high speed taxi tests. He had only planned to conduct taxi tests, but for some reason changed his mind and decided to attempt flight. He then made another poor decision when he chose to takeoff instead of aborting when he began to run out of runway.

In the second case, the pilot, who had no flight experience, was killed when he apparently entered a PIO situation on the aircraft's first flight. The pilot was urged by friends to perform his first flight at another airport which had emergency fire and rescue services. The pilot also did not accept an offer to receive flight training in a similar airplane to the one he had built. The pilot also had an antihistamine in his system that could cause drowsiness and slowing of cognitive and motor skills.

In the third case, the pilot was conducting high speed taxi tests and was concerned about gusty wind conditions. In spite of this, he proceeded and became airborne. He appeared to have PIO problems and lost control of the aircraft when attempting to bring the aircraft back for a landing.

CASE ONE - NTSB Identification: CHI02LA143. May 25, 2002

The following is an excerpt from the NTSB's probable cause report on the crash of a 75% Scale Fokker D8, registration number N2188X, in Derby, KS [41]. The pilot received only minor injuries.

The airplane contacted trees following a loss of directional control during takeoff. The pilot reported he was short on runway when he initiated the takeoff so he had to "prematurely pull the aircraft off the ground..." The pilot stated that once airborne the wind pushed the airplane toward a line of trees. He reported that he attempted to straighten the airplane heading, but instead the airplane hit the trees at an altitude of about 10 feet above the ground. The airplane contacted trees along the right side of the runway. The pilot reported the winds were out of the west at 15 knots. The pilot reported that the ailerons are ineffective until reaching 60 mph. He also reported that the rudder was so sensitive that at 50 mph, 1- inch of rudder pedal displacement would result in a 180 degree flat turn.

The National Transportation Safety Board determines the probable cause(s) of this accident as follows:

Inadequate preflight planning and inadequate compensation for the wind conditions which resulted in a failure to maintain directional control of the airplane. Factors associated with the accident were the crosswind and the trees which the airplane contacted during the takeoff [41].

In this case, the private pilot, with no noted flight test experience, had already flown the aircraft for 20 hours and was aware of its dangerous flying qualities. The aileron ineffectiveness at low speed and the extreme rudder sensitivity would make the aircraft extremely difficult to control in the lateral-directional axes. The later factual report revealed that, “The pilot reported that his original intention was to perform a high speed taxi test after which he was going to return to the hangar. He reported the airplane ran good during the test. Following the taxi test, he then pulled the power back to idle, but instead of going to the hangar, he decided to takeoff, fly around the traffic pattern, and land [42].”

This accident fits neatly into the HFACS model. At the highest level, a lack of oversight allowed an intrinsically dangerous aircraft to be operated in spite of known deficiencies (poor risk management). A lack of supervision was also a factor, as the pilot, with no flight test experience, indicated that he was concerned about the crosswinds [42]. He chose, however, to test anyway. An adequate “supervisor”, either a trained tester or simply an experienced person aiding in the test process, could have helped the pilot make a better decision. Furthermore, a supervisor would have stopped the pilot from conducting an unplanned (equivalent to unbriefed) operation (the flight itself). The precursors to the unsafe acts are evidenced by the pilot’s obvious complacency and

misplaced motivation – he chose to conduct an unbriefed test in an aircraft with questionable controllability and in non-optimal weather conditions. He also failed to conduct an adequate “brief” for himself. Finally, he committed a series of errors and “violations” that led to the accident itself. He made the aforementioned poor decisions to initiate the testing, then the flight, considering the aircraft and the test environment. His decision to conduct high speed taxi tests in gusty wind conditions was risky in and of itself. Professional testers treat high speed taxi as a flight test due to the high likelihood of inadvertent liftoff. As such, the weather conditions should have been suitable for flight. He then made the poor decision to take the aircraft flying instead of aborting on the runway. Most importantly, he violated his test plan. Whether the plan was formal or informal, he chose to adhere to his original plan to limit his operations to ground tests.

CASE TWO - NTSB Identification: LAX03LA237. July 20, 2003

The next case study is that of a fatal accident involving a Thompson Quickie aircraft in Tehachapi, CA, registration number N218DT. The probable cause report follows.

The airplane entered a pilot induced oscillation during takeoff, collided with the runway, and was destroyed by a post impact fire. The accident occurred during the pilot's maiden flight in his experimental homebuilt airplane. Witnesses saw the airplane initially climb about 25 feet above the runway. Thereafter, the airplane descended until landing hard on the runway in a nose low pitch attitude. The airplane bounced/porpoised and impacted again whereupon it nosed over, slid to a stop, and was consumed by fire. Examination of the thermally destroyed composite airplane revealed no evidence of a preimpact mechanical malfunction or failure, and the reason for the pilot's failure to maintain control was not ascertained. No evidence of any preexisting physical disability was noted during the pilot's autopsy. Evidence of diphenhydramine was found in the pilot's blood and urine. This drug is an over-the-counter antihistamine preparations and typically results in drowsiness, and is associated with degradation of cognitive and motor tasks.

The National Transportation Safety Board determines the probable cause(s) of this accident as follows:

The pilot's inadvertent entry into a pilot induced oscillation and failure to maintain airplane control during the takeoff initial climb. A contributing factor was the pilot's likely impairment by an over-the-counter drug substance that degraded his physical and mental performance [43].

The information in the above report and the later factual report [44] showed that the pilot made a series of errors that led to this accident and his death. In contrast to the first case study, this pilot did have an “organization” to support him in the sense that he asked for help and advice from some friends. Unfortunately, he failed to heed their advice, which is one of the severe shortcomings of having organizational and supervisory influences that are advisory only – the pilot is not compelled to listen. In this case, “Work associates having technical expertise in experimental aircraft design, construction, and propulsion systems examined the pilot's airplane within a few days preceding the accident flight. The associates suggested that the pilot perform his maiden flight at a nearby airport having emergency fire and rescue facilities. The pilot declined the recommendation. The associates reported that the pilot did not accept an offer to receive flight training in an airplane model similar to the one he had built [44].” In effect, he received inadequate organizational influences and supervision only because he did not have to listen. The pilot’s decision not to listen was itself one of the preconditions for unsafe acts. In doing so, the pilot exhibited complacency and failed to use all available resources as noted in the HFACS [11]. He was also, as noted in the report, self-medicating, which added yet another unsafe aircrew condition. The actual unsafe act was actually the least dramatic of the failures. The pilot likely over-controlled the aircraft or simply exceeded his ability to

fly the aircraft. Unfortunately, the previous failures had placed him in a position where an error's effects would only be exacerbated.

CASE THREE - NTSB Identification SEA03LA118. June 26, 2003

The third case study is that of an accident involving a Herrin Hornet aircraft, registration number N1424 in Newberg, OR, in which the pilot was killed when, again, he conducted unplanned flight tests in gusty wind conditions. The NTSB's probable cause report follows.

A witness to the accident reported that the pilot of the accident airplane made numerous high-speed taxi runs prior to the accident flight. After completing the taxi maneuvers, the pilot told the witness he was apprehensive about trying to fly the airplane on account of localized gusty winds. After talking to the witness, the pilot taxied back to the runway and resumed the taxi tests. The witness reported that after completing a number of passes down the runway, he observed the airplane takeoff. He reported that the airplane appeared to be porpoising as it ascended over the runway. Additional witnesses reported that they observed the airplane in a climbing right turn over the airport. The airplane climbed to about 200-300 above ground level (AGL) and appeared to be in a modified downwind for runway 25. The witnesses reported that as the pilot turned from right base to final, the airplane abruptly pitched nose down (approximately 60 degrees). The witnesses reported that the airplane momentarily returned to a level flight attitude, but pitched down a second time just before impacting terrain in a nose low attitude. Maintenance records indicated that the airplane was issued a special airworthiness certificate, experimental category, on April 23, 2003. The accident flight was the airplane's first flight subsequent to receiving the airworthiness certificate. Post accident examination of the aircraft revealed no evidence of a mechanical failure or malfunction.

The National Transportation Safety Board determines the probable cause(s) of this accident as follows:

Aircraft control not maintained while maneuvering for landing [45].

As in the second case study, the factual report indicates this pilot ended up conducting his first flight on a day that he had only planned to conduct high speed taxi tests [46]. Furthermore, much as in the first case study, the weather was such that even high speed taxi should have not have been conducted, as the weather conditions were not conducive to flight. Once again, the accident pilot indicated to a witness that he was concerned, but allowed his other motivations to lead him to commit violations of his own, albeit informal, protocol and to make poor decisions thereafter. The witness's report that the airplane appeared to be "porpoising" after takeoff suggested that the pilot experienced PIO or a general controllability problem with the aircraft. With no time in type and no reported test pilot experience [46], the pilot was in what ended up being an untenable situation. It is possible that had he waited until a calm day and properly prepared for the flight, he would have had more success at controlling the aircraft and brought it down successfully.

Thus, the pilot in this case study made similar errors to those in the first two, conducting tests with no organizational support or supervision. Again, he exhibited an adverse mental state such as complacency, haste, or misplaced motivation, although it is unclear as to which one was the precursor to the poor decisions to test on that day, and then conduct first flight, the latter of which could also be seen as a violation (failure to adhere to his "brief"). Finally, the unsafe act itself was probably a combination of the above decisions, the pilot exceeding his ability and several skill-based errors such as poor technique and over-controlling the aircraft.

In summary, these three case studies are just examples of the types of failures that are exhibited by homebuilders in the conduct of their flight test. All three pilots placed themselves in very high risk situations based on their failures at the upper levels. Then without the proper training, experience, and support, they experienced failures at the lower levels which led to accidents, and in two of the three cases, fatalities.

**CHAPTER 5 – COMPARISON OF PROFESSIONAL FLIGHT TEST
METHODOLOGY WITH TYPICAL HOMEBUILT AIRCRAFT FLIGHT TEST
PRAXIS**

Contrary to the practices of the homebuilt flight test industry, participants in the professional flight test world addresses the potential failures described in the HFACS model at every level and strive to mitigate the associated risks. In fact, the Society of Engineering Test Pilots' mission statement is as follows:

To broaden professional relationships through the sharing of ideas and experiences which promote and enhance safety, communication and education. To prevent accidents and loss of life by improving safety, design and flight test of aerospace vehicles and their related systems. To provide a forum to disseminate information to those in the aerospace industry for the benefit of all aviation users [47].

The very first stated goal is the prevention of accidents. Although most homebuilt testers would probably agree with this attitude in principle, their actions are, as we have seen, often to the contrary. Prior to examining how professional flight test teams conduct their programs so as to minimize the likelihood of an accident (while simultaneously maximizing the likelihood of obtaining good data), it is beneficial to understand what exactly comprises professional flight test.

DEFINITION OF PROFESSIONAL FLIGHT TEST

At some level, any flight test endeavor conducted for compensation could be considered professional flight test. For the moment, however, we will consider professional flight

test to include all flight test conducted for compensation by trained personnel. The latter part of that statement can also be interpreted rather broadly. Flight test personnel throughout the aerospace industry are trained in a variety of different ways. Test pilots and, to a lesser extent, flight test engineers, are often graduates of one of the test pilot schools. Other flight test engineers receive only on-the-job training, sometimes under the tutelage of a test pilot school graduate. Of course, in both of these cases the individuals have the requisite underlying training and experience - general flight training and typically a minimum number of hours for pilots, and an engineering degree for engineers (and all but a small number of test pilots). The above cases are the norm, but are by no means the only methods by which flight test professionals are trained. Many test pilots and engineers have taken short courses at one of the test pilot schools, thereby gaining portions of the training provided in the typical year-long courses. Some test pilots, especially in the commercial sector, are simply very experienced airline or corporate pilots who have received on-the-job-training as test pilots. Some professional test pilots of homebuilt aircraft are self-trained, studying and practicing the techniques found in books on the subject such as Askue and Englert's texts [13, 12].

Short courses, on-the-job training (OJT), and self-training are not necessarily negative. If the short courses are applicable to the specific type of testing that the tester is going to be involved in, then much of the relevant content from the long course might be gleaned without the time and monetary investment. OJT can be comprehensive and effective if implemented correctly with a strong mentor. Furthermore, an ex-military graduate of test pilot school who is expert in the handling qualities of high-performance aircraft may be

very well trained, but not the optimal person to conduct production flight test of a corporate jet, for example. In this case, a 10,000 hour ATP might be the most appropriate choice. A disciplined student who chooses the right source material (often generated by a graduate of a test pilot school) can also develop the necessary skills and knowledge to conduct effective flight tests, although this is very challenging.

Since the definition of training is so amorphous, it is better to refine our definition and define professional flight test as *flight test conducted for compensation by trained personnel adhering to accepted flight test doctrine*. It is both the training and the doctrine that clearly separates professional from amateur flight test. An inexperienced, untrained tester who simply follows the doctrine as a recipe is not a professional. Likewise, the most well-trained test pilot who simply “kicks the tires and lights the fires” is also not a professional. A competent individual or test team led by a competent individual following accepted doctrine is performing professional flight test.

PROFESSIONAL FLIGHT TEST TRAINING AND DOCTRINE

Flight test doctrine varies slightly from organization to organization, but it can generally be traced back to the curricula of the test pilot schools and universities and, equally importantly, lessons learned during the execution of flight test. This is a circular and symbiotic relationship, as the lessons learned are passed back to the test pilot schools and universities via instructors who come to the schools from out in the industry as well as through the numerous symposia. These lessons are then incorporated into the curricula.

The curriculum changes then filter back down to the testers via the test pilot school graduates and publications, many of which are the industry standard references. As the test pilot schools are clearly the lynchpin of the flight test world, we will look more closely at the long course curricula of the U.S. Air Force and U.S. Naval Test Pilot Schools. The civilian National Test Pilot School follows a similar curriculum.

The two U.S military test pilot schools train three categories of students: Pilots, other winged aircrew officers (USAF weapons systems officers (WSOs) and navigators and USN naval flight officers (NFOs)), and flight test engineers. The two schools differ in how they organize their students in that the USAFTPS keeps their students in a single track while the USNTPS divides their students into three tracks: fixed wing, rotary wing, and systems. USNTPS is responsible for training all U.S. military rotary wing pilots, necessitating the rotary wing track. The USAF program is somewhat of a merger of the USNTPS's fixed wing and systems tracks. All USAF students are trained in performance, flying qualities, and systems flight testing. At USNTPS, all NFOs are assigned to the systems track, which focuses less on flying qualities and performance testing and more on radar, electro-optical, and electronic warfare systems test. FTEs are assigned to all three tracks depending on their specialty. Both schools run two classes simultaneously, staggered by approximately six months. USAFTPS's long course runs 48 weeks, while USNTPS's is 10 months.

Both USNTPS and USAFTPS focus heavily on test management and reporting in addition to flight test flying and data collection methods. USAFTPS dedicates over six

months to test management training and USNTPS spends 1/3 of the curriculum on and provides 11 hours of formal instruction in reporting. Pilots at both schools are trained in similar flying qualities and performance test techniques. At USNTPS, pilots fly progress checks with instructors during which they must demonstrate that they have mastered the techniques. FTEs fly similar progress checks with the instructor at the controls and must demonstrate that they can act as test conductor and take meaningful data.

As mentioned before, nearly all flight test engineers are graduates of an accredited engineering school. Although some may go on to graduate from one of the test pilot schools or short courses, for many flight test engineers the only formal training that they receive is during their undergraduate studies. Unfortunately, most graduates of a typical aerospace or mechanical engineering program do not get any specialized flight test training. Aerospace engineering curricula focus heavily on design, and the typical 4-5 year program is usually very time-constrained and has just enough time to cover the fundamentals and include a strong design class, let alone a class that addresses flight test. This is quite unfortunate, as flight test forces the individual to correlate actual aircraft behavior with design characteristics. Not only would flight test coursework be directly useful to those going into flight test, but it would also be a very powerful way to illustrate the consequences of design decisions.

Unfortunately, there are several barriers to the widespread introduction of flight test coursework in engineering institutions. Firstly, flight test is generally seen as a specialized profession and, correctly, as one that only a small percentage of graduates are

likely to be engaged in. Secondly, also as a result of the size of the flight test industry in relation to the aerospace design industry, there are only a small number of people qualified to teach such courses. An even smaller subset of this group has advanced degrees, the lack of which is a concern to many competitive schools, as they use their “percentage of faculty with advanced degrees” statistic as a marketing tool. Finally, an effective flight test course generally requires the use of a real aircraft (or at least a high-fidelity flight simulator) and a trained test pilot. Some schools, such as the University of Tennessee Space Institute (UTSI) or Embry-Riddle Aeronautical University (ERAU) have access to these resources, but most schools do not. Even schools that do offer such courses typically charge students significant user fees to cover the very high costs of operating aircraft and simulators. As a result, there are few universities that offer flight test courses within their aeronautical / aerospace engineering curricula. In addition to UTSI’s strong flight test program embedded in the Aviation Systems program, ERAU offers a minor in Flight Test and Simulation. This minor includes a 3-credit course titled “Intro to Flight Testing” which provides an overview of flight test planning, execution, and reporting methods as well as risk management. The Western Michigan University also offers a one semester class in flight test engineering which covers similar topics as well as flights in an instrumented Cessna 182 to instruct students in in-flight data collection. Southampton University in the United Kingdom includes a flight test course in its aeronautical engineering program. This course also includes actual data collection flights to give the engineering students and appreciation of in-flight data collection. As with the other courses mentioned, it is focused on flying qualities and performance flight testing.

There are also several sources of short courses in flight test. Among these are the University of Kansas and the National Test Pilot School, both of which are open to civilians. Both schools offer a variety of courses, ranging from the University of Kansas's 1-week Flight Test Principles and Practices course, which provides a general overview of flight testing, to NTPS's modular courses. The latter are actually components of the one-year "long course" offered by NTPS. NTPS has, in the past, also offered to the general public a course on homebuilt flight testing.

Both of the U.S. military test pilot schools also offer short courses. Generally considered internal Department of Defense activities, is difficult for civilians other than those in the employ of the U.S. DoD to take these courses (one reason is that the schools lack the ability to easily accept money other than through intra-agency transfers). These courses allow flight test engineers and oftentimes foreign military personnel to get abbreviated portions of the year-long "long courses". In addition, they offer short courses to fill in gaps in the long course curricula such as unpiloted aerial vehicle (UAV) and turboprop performance flight testing.

APPLICATION OF THE HFACS TO PROFESSIONAL FLIGHT TEST METHODOLOGY AND THE REDUCTION OF FAILURES

Regardless of the weakness and inconsistencies illustrated above, the vast amount of training that flight testers receive, whether formally or informally, provides various defenses against failures (both active and latent) in the HFACS chain [11]. Training affects all levels of the HFACS model. At the *Organizational Influences* level, having

highly-trained (and uniformly-trained) personnel helps to provide a stable and healthy structure. Authority can be effectively delegated as the one delegating the responsibility has confidence in the abilities of his highly trained subordinate while that subordinate is properly trained to accept the authority. The organization's culture is governed by the similar norms and rules and the team members have similar values and beliefs. All are trained to follow the same operational procedures as well. Incorporated in all of this is the improved level of communication between similarly trained personnel.

As one moves down through the layers of the HFACS, the role of training as a defense against failures becomes more pronounced. At the *Unsafe Supervision* level, training serves as protection against nearly every failure suggested by Wiegmann and Shappell. Well-trained test team members are more likely to provide adequate supervision, plan appropriate operations, and correct known problems. Operational doctrine, for instance, is taught at the test pilot schools, which follow strict standard operating procedures and operate strictly in accordance with test plans. Well-trained FTEs follow these practices and provide correct data from which to plan operations. The trained test team analyzes their proposed operations and has the knowledge to provide adequate crew rest and brief times as well as appropriate crew for the mission. Formally-trained testers receive instruction in crew resource management and operational resource management, allowing them to more readily identify at-risk aviators or unsafe tendencies in aviators or general practices. Although this alone cannot prevent the failure to correct a known problem, the problems are more likely to be identified and corrected.

Similarly, well-trained testers are less likely to put themselves in unsafe aircrew conditions. A well-trained test pilot, for instance, is less likely to be distracted or complacent. He is trained specifically not to allow his attention to become channelized and to operate in a task-saturated environment. Part of test pilot training includes simulated test flights with instructors evaluating the pilot's performance. The test pilot must fly with adequate precision while articulating his thoughts, remaining within the test area, managing his fuel state, and avoiding traffic, just as he would in an actual test flight. In addition to training affecting test pilots' individual mental states, it also aids in their crew resource management. Whether they are testing a multi-place aircraft, an aircraft with an FTE or photographer onboard, an aircraft with communications to test team members on the ground, or a combination of these crew configurations, the test pilot is likely to be in a situation requiring effective crew resource management. The test pilot schools specifically address this from the very beginning, as even practice flights begin with a formal brief between the pilot and FTE. Furthermore, test pilots fly with multiple FTEs and learn to communicate with a ground station, broadening their ability to communicate with personnel of varying experience, abilities, and personality types under different circumstances.

Finally, as previously addressed, the trained test pilot is less likely to commit the unsafe act itself. Skill-based errors are less likely, as trained test pilots generally enter training with a great deal of experience and then are specifically trained to carefully observe the aircraft's behavior while simultaneously flying with extreme precision. This is practiced extensively in the test pilot schools and then evaluated in flight as described above. Poor

decisions, such as misdiagnosing or responding incorrectly to an emergency, are less likely when the pilot is well-trained and more comfortable in his environment in the first place. Furthermore, violations are less likely among trained professionals. Test pilot and FTE training emphasizes adherence to the brief, proper preparation, and remaining within the aircraft's cleared envelope. This training, couple with experience in operating in high pressure situations, flying with extreme attention to the aircraft's behavior, and overall depth of knowledge of the aircraft's characteristics and state give the professional test pilot the tools required to develop the aforementioned "novel solution" when necessary to avoid an accident.

Training is not the professional tester's only source of defenses against failures. In both the commercial and military sides of the aerospace industry, the typical flight test team consists of, at a minimum, one test pilot and one flight test engineer. A single test pilot can perform all of the duties required by a small test program himself, but he risks losing objectivity when denied the system of checks and balances that is present with a second test team member. Test teams are often much larger than the minimum - the test effort for a new airframe with a complex mission, such as the U.S. Navy's new P-8 maritime patrol aircraft, might involve dozens of flight test engineers, discipline engineers, program managers, and test pilots. In large test teams, each flight test engineer usually specializes in a specific discipline. There are flying qualities specialists, aerodynamicists, propulsion engineers, and systems engineers, for example. All are generally led by at test team lead engineer and lead test pilot, both of whom report to the program manager.

As projects narrow in scope, the size of the test team shrinks toward the minimum core of a single pilot and engineer. This, of course, also creates additional responsibilities for the test team members. The same pilot(s) and engineer(s) are required to perform every aspect of the test program; initial test planning, safety review, development of test cards, test execution, data reduction, and reporting are no longer performed by specialists. Furthermore, the amount of overall experience in the test team is reduced, as test pilots and flight test engineers vary greatly in experience. A larger team is more likely to have a broader experience base. This is more important than the actual responsibilities levied upon the members of a small test team and pertinent to the case of the homebuilder. As in the aforementioned case of the single person (test pilot) homebuilt test team, the smaller the team, the more difficult it is for the team members to maintain objectivity. External pressures on the test program, such as budget and schedule, have a far greater chance of overcoming the better judgment of two people than that of twenty. A larger group is more likely to have experienced personnel who can identify a hazardous situation developing while also having the confidence to call a halt to the program until the problem is solved. It is also easier to simply neglect a mistake in the test plan or misread an otherwise rational test plan when there are fewer test team members to review the document.

With respect to preventing failures within the context of the HFACS, this structure is especially effective at the lower levels of *Unsafe Acts* and *Unsafe Aircrew Conditions*. During test execution, unsafe acts such as the omission of checklist items or steps in a procedure are prevented by the participation of the broad test team members. For example, during a flight test conducted with an FTE on board or a ground-based test

conductor monitoring the test, the pilot's actions are backed up by the other test team members. Decision errors such as misdiagnosis of an emergency or choosing the improper procedure are also less likely with test team members watching over the pilot's shoulder. One anecdote recounts a test flight during which an F/A-18's canopy was inadvertently jettisoned. Based on the concussion of the pyrotechnic devices, the pilot believed that he had lost an engine and began examining his engine instruments to determine which engine had failed. Although not the case, had he begun to mistakenly secure an engine, the propulsion expert monitoring engine parameters would have informed him that his engines were functioning properly. In fact, it was the test conductor, having observed the canopy jettison via an over-the-shoulder camera, who diagnosed the emergency and prompted the test pilot to look up and see that he was now flying an open-cockpit jet.

The broader test team's participation also prevents what Shappell and Wiegmann refer to as violations [11]. The testers are less likely to fail to adhere to the brief, fly unauthorized maneuvers, or fail to properly prepare for the flight when they are all working together and using their collective experience. As suggested above, in the case of a larger test team, the test team provides a structure of checks and balances that serves to prevent unsafe acts. These checks and balances also help to prevent failures associated with unsafe aircrew conditions, the next level up in the HFACS model. Adverse pilot mental states such as channelized attention and haste are mitigated by test team backup. Personal readiness failures can also be detected more easily when the test pilot does not operate in a vacuum.

Interestingly, failures associated with crew resource management become more likely as the test team grows in size, as there is a larger crew that must be properly led, briefed, coordinated, and, most importantly, properly communicate within its membership. This phenomenon can be observed at the higher levels of *Unsafe Supervision* and *Organizational Influences* as well. Although an established supervisory and organizational structure is generally beneficial, as it provides structure, guidance, oversight, and training, all of these are places where failures can occur. This highlights one of the fundamental aspects of aviation, and particularly flight test: risks can be minimized and mitigated, but not eliminated. The very tools that testers (and all aviators, to varying extents) use to keep themselves safe and efficient are still human endeavors and therefore subject to failure.

Precise test planning, test execution, and reporting protocol are key elements of professional flight test. Although they vary by test purpose, team size, and customer requirements, these elements are all addressed in depth prior to the start of the test program. All three are closely linked, as the team carefully plans and prepares to execute the test so that the proper tests will be conducted and the proper data collected. The test plan is written with the final report in mind. The tests are then executed strictly in accordance with the test plan and with precision so that the data collected is of the highest quality. Finally, the report is written using the data so that it satisfies the customer's requirements.

A flight test program begins, in general, with the decision that flight test is required. In the military, a program manager (usually with the assistance of flight test personnel) will determine the requirements and scope of flight test and provide funding for the test program. In the commercial world, the requirement for flight test is generally dictated by the FARs. The test team then develops the test plan. Most organizations use the test plan as a formal, governing document for the test program. Once signed by management, any existing safety oversight board, and the test team members, it must be followed to the letter. Any subsequent changes require an official amendment and subsequent review by some or all of the original signatories. This type of strict organizational process helps to prevent the types of failures associated with organizational influences in the HFACS. With the program thoughtfully planned from the outset, time pressure and operational tempo can be minimized.

The test plan is scoped to meet the test program's specific requirements. A certification test program for a commercially produced aircraft will be very involved, including tests designed to satisfy all of the applicable FARs. The test plan is generally very detailed, the intent being that the test team could execute a test program using only the test plan and its references. This is very important – although it is highly unlikely that a new test team would be called upon to execute a test from a completed test plan, it is very common that a new test pilot or flight test engineer might join the team. If the test plan is comprehensive, the new team member can study the test plan and immediately become an effective participant in the test program. Another reason for this degree of detail in the test plan is that most organizations use old test plans as templates for creating new ones.

In some cases, such as in production flight test, a team might be called upon to repeat an entire test program almost exactly. In order to meet these needs, the test plan is generally organized in a very formal manner. One section in the test plan that is critical to safety is the test hazard analysis. In the test hazard analysis, the team lists hazards that may be encountered during the test program. This list is compiled from knowledge gleaned from careful analysis of the tests at hand, previous test programs, available literature, and test team members personal knowledge. Each hazard is listed and analyzed individually. The test team determines what might cause the particular hazard, under what conditions that hazard is possible, what actions will be taken to mitigate the risk of the hazard occurring, and what actions should be taken if the hazard is encountered. Finally, the likelihood of the hazard occurring and the severity of the consequences are evaluated. The team will then use a risk category matrix to assign a risk category to the hazard. This allows the team to determine if the risk is acceptable and what qualifications the aircrew will need to operate the aircraft in a regime where that hazard may be encountered. It is difficult to imagine amateur testers having the knowledge or desire to conduct such a meticulous examination of the risks associated with their test activities; however it is precisely this methodology that professional testers use to identify, minimize, and mitigate risks.

In nearly all organizations, the test plan goes through a thorough review by the test team leadership (e.g., project lead test pilot, project lead test engineer) and a review board of some kind. The composition of this review board will vary widely depending on the type of testing that is being conducted, but will usually include representatives of management, test organization leadership, such as the chief test pilot or military test

squadron commander, and discipline leadership, such as the head of the systems development division in the case of testing a new flight system. Regardless of the composition of the board, the members typically scrutinize the test plan page by page to ensure that the test team has planned an appropriate and efficient test program and, most importantly, that they have considered, addressed, and mitigated all foreseeable risks. Some organizations require a series of test plan reviews as the plan is developed. The test plan is typically signed before any ground testing commences, so often there is a first flight readiness review prior to the commencement of the flight phase. These organizational reviews are direct attempts to eliminate the latent failures at the *Unsafe Supervision* and *Organizational Influences* levels in the HFACS. These reviews also ensure that lessons learned from previous programs are disseminated to the test team. Again, amateur testers do not benefit from any type of organizational review. In fact, the FAA is typically not even interested in the details of any planned tests. They are concerned only that the aircraft has been inspected, the flight test period is appropriate, and that the test area is sufficiently unpopulated so as to protect the general public.

Once the test plan has been signed, the test execution phase begins. Prior to each test event, the team, led in general by the test director or test conductor, will determine which tests are to be conducted. One member of the test team will be designated as the test conductor. Generally, the test conductor is an experienced tester who is knowledgeable about the overall operation and systems of the aircraft. The test conductor is usually the day-to-day leader of test execution. Once the tests to be conducted are determined, the deck of test cards is prepared. Typically prepared in advance jointly by the discipline

experts, test conductor, and test pilots, the test cards are excerpts from the test plan printed on kneeboard cards for the aircrew. Each card will typically indicate the flight condition and aircraft configuration at which the test is to be conducted; the test points themselves, and any key factors that the aircrew must be concerned with (such as attitude or engine limits, control input sequencing, or handheld data to be acquired). The cards will also have spaces for the aircrew to write in handheld data. Ground crew members will generally have the same cards printed out for them on regular paper with extra space for additional notes. Finally, test cards usually indicate what the next test event is at the bottom of the card.

The preflight test briefing is the place where all of the efforts of the test team come together to actually execute the test safely and effectively. The briefing ties together the test plan, the test cards, and the personnel and is designed to ensure that all team members are approaching the test in a similar manner. At the briefing, test team members (usually led by the test conductor) will go through a predefined list of topics, such as weather, aircraft maintenance and instrumentation status, and range availability. The team will then review each card and discuss how each event is to be conducted. Go-no criteria, initial conditions, data requirements, and test methodology will all be discussed so that the pilot (or pilots) and engineers all know exactly what to expect. Most importantly, test hazards, especially those specific to the planned events, are reviewed and emergency procedures are specifically briefed. In this way, the briefing is specifically designed to avoid latent failures at several levels.

A comprehensive brief also addresses many of the errors and violations categorized as unsafe acts by the HFACS. Violations such as failure to properly prepare for the flight, briefing an unauthorized flight, failing to be current or qualified for the mission, or intentionally exceeding the aircraft (or, in this case, test) limits are all less likely when the team comes together and reviews the strict requirements outlined in the test plan. Skill-based errors such as omitting checklist items, steps in (test) procedures, or poor technique are also less likely when the checklists, procedures, and techniques are adequately briefed. The likelihood of the pilot committing decision errors such as conducting improper procedures, misdiagnosing or responding incorrectly to an emergency, or conducting an inappropriate maneuver are also similarly reduced. HFACS actually categorizes the failure to conduct an adequate brief as a latent failure in and of itself [11].

Following the flight, the test team reconvenes for a formal debriefing. Best described as the photonegative of the preflight brief, the team again reviews the test event card-by-card and determines if any tests need to be repeated. Also discussed are the impacts of any anomalies encountered on future test events. Any issues with the aircraft or instrumentation are also discussed. Any required data reduction is determined and go/no-go criteria for the next event are established. In addition to determining whether the test events can be considered complete, the team will determine if any deficiencies should be noted (described in detail below).

Data reduction is as varied as test execution. A qualitative test may require only the pilot's debriefing and no quantitative data. On the opposite end of the spectrum is the

structural test of a heavily instrumented aircraft, where electronic data from numerous accelerometers and strain gauges must be analyzed via fast Fourier transform and studied before any determination on data quality or test success can be made. In most cases, however, engineers will study the test results prior to the next test event to ensure that the team is safe to proceed. In addition to safety, poor test results might require that the test be repeated.

The overall goal of any test program is to determine if the aircraft or system is satisfactory. In the professional flight test world, any unsatisfactory performance or characteristics are categorized as deficiencies. Deficiencies are formally categorized as Part I, II, III, depending on their impact to the mission. The deficiency is also associated with a general corrective action. Definitions of Part I, II, and III deficiencies and their associated corrective actions follow:

Part I – Part I deficiencies preclude mission accomplishment and therefore must be corrected as soon as possible. Sometimes, a Part I deficiency will force the test program to stop until the deficiency is corrected.

Part II – Part II deficiencies degrade mission performance and therefore should be corrected as soon as practicable. Generally, Part II deficiencies are characterized by requiring the aircrew to develop a workaround the problem in order to complete the mission.

Part III – Part III deficiencies are non-mission critical and should be avoided in future designs. Part III deficiencies are usually considered nuisance deficiencies.

The corrective actions are deliberately vague and serve primarily as a guideline as to when (rather than how) the deficiency should be corrected. Testers can also note *Enhancing Characteristics*. These are unexpected positive characteristics (expected characteristics would simply be noted as satisfactory) and are accompanied by the general

recommendation that they “be included in future designs”. In a large, long-term test program, deficiencies are often reported in small deficiency reports (DRs) so that they may be addressed before the completion of the program. Specific recommendations from the test team as to how to correct the deficiency would appear in the DR and/or in the final report of test results (RTR).

The final deliverable of most professional test programs is the RTR itself. In a developmental test program, the RTR can be hundreds of pages long, include numerous plots and tables, be accompanied by several DVDs of digital data, and identify dozens of deficiencies. As the debrief is, in many ways, a photonegative of the preflight brief, the RTR is, in many ways, the test plan with all of the questions answered. The RTR describes what tests were conducted, what methods were used, and what the test team discovered. Furthermore, the RTR specifically relates these discoveries to the aircraft’s mission. Like the test plan, an RTR is usually a very structured document. As the RTR is the primary deliverable from the test program, it is intended to be a definitive record of the program and its results. As such, it is typically reviewed at several levels prior to its final presentation to the customer.

In most cases, the results of the flight test program must be delivered not only to personnel who are relatively familiar with the test program, but also to those with only a tangential knowledge of the testing, such as upper managers. As these people typically lack the time to read a large, detailed report, some of the key pages are highlighted (in the U.S. Navy, they are printed on blue paper). These include the summary, the summary of

deficiencies, and the summary of specification compliance. A reader who peruses just these three sections will gain a good understanding of the overall test results.

Professional flight test is a very deliberate, rigid process that has evolved via experience and many safety lessons learned. Most professional testers “speak the same language”, as they are influenced by the test pilot schools, which are in turn influenced by the needs of and feedback provided by their clients. The test pilot schools themselves have exchange programs for both students and instructors, so knowledge is shared between the schools as well. The overall result is that professional flight test is very refined and designed to safely and efficiently produce valuable test results and assessments.

CHAPTER 6 – CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Careful study of the current state of homebuilt flight test and the accident statistics as well as a comparison of the methods used by builders conducting their own flight test and those used by professional flight testers lead clearly to the following conclusions:

- The homebuilt flight test industry is deficient and the accident rate is extremely high.
- The guidance available to homebuilders is insufficient and most homebuilders are encouraged to perform flight test themselves, despite the fact that they are not trained to do so and have few good resources to help them.
- Close examination of the NTSB reports from 2002 to 2004 and the case studies presented, illustrate how, in general, homebuilders are a classic example of HFACS failures leading to an unsafe act.
- Homebuilders, in general, compare poorly to their professional counterparts. Whereas professional flight testers generally have years of training and thousands of hours in varied aircraft, amateurs generally have no training and only limited experience.
- Compounding the problem is the quality of homebuilders' experience – they usually have limited time in the type of aircraft under test and only a limited amount of experience in aircraft of different types to begin with. Whereas professionals have training, a formal process, and a strong organizational structure

which specifically address the challenges of flying a new, unknown aircraft, amateurs have no safety net to protect them from these dangers. Many are building their own airplane specifically to avoid regulations and oversight, thereby willingly relinquishing several layers of protection that professional flight testers enjoy. Furthermore, the independent spirit of many homebuilders leads them to accomplish as many tasks as possible themselves, again placing the dangerous task of flight test in the hands of an untrained, unsupervised amateur.

There are, of course, exceptions to this situation. Some homebuilders to identify their limitations and choose to get professional assistance in the conduct of their flight test. Others are actually well-qualified to conduct their own flight test (they, too understand their limitations). Nevertheless, testers of homebuilt aircraft face the same problems that professional flight testers do, but without many of the tools and training that their professional counterparts have to mitigate the risks. As described earlier, the flight tests prescribed by the FAA for homebuilt aircraft are vague – only the number of hours of flight test required is specifically prescribed. What the tester does with the 25 or 40 hours required is entirely up to him. Different aircraft have different test requirements - the difficulty lies in determining those requirements, and amateurs generally do not have the knowledge base to support this decision. Aside from the safety advantages that having a trained test pilot bring to any test program, the ability to properly scope and plan a test program is the most important advantage to having professional testers involved with the flight test of homebuilt aircraft. A trained FTE could determine if a “production” type flight test might be appropriate, such as in the case of a well-established kit like an RV-6,

or a complete developmental flight test is required, such as in the case of a new or highly modified design. The current situation is, however, somewhat bleak. The safety information is available in the form of magazine articles and AOPA and NTSB reports, but homebuilders either do not grasp the severity of the risks or choose to ignore them.

RECOMMENDATIONS

The safest solution to this problem is to have professionals conduct a larger portion of homebuilt flight test, particularly in the cases of highly modified kitplanes, high performance aircraft, or unique designs. These situations are of high enough risk that amateurs should not be conducting the tests. Considering that the accident rates for homebuilt aircraft include the relatively reliable RVs and other docile aircraft, the number of accidents involving higher risk aircraft is even greater. Even with the more docile aircraft, however, participation by professional flight testers would be extremely beneficial. As we have seen, flight test of even the most docile aircraft is very dangerous in the hands of an untrained, low time in type pilot.

Unfortunately, it is difficult to imagine homebuilders routinely hiring professionals as either consultants or test pilots without wholesale changes in the way that homebuilt flight test is mandated. This change in mandate could be either literally, such as with changes in FAA requirements, or culturally, by changing what homebuilders consider to be appropriate testing. The latter is of particular significance and far more likely to happen, as the homebuilt culture is based on the principles of limited regulation, common

sense, and self-policing. Although not optimal, simply increasing professional flight testers' influence on and participation in the testing of homebuilt aircraft would be an enormous step toward eliminating some of the latent failures that make homebuilt flight test so dangerous.

A first step toward the increased participation of professional flight testers in to the homebuilt industry would be for the EAA and FAA to better educate builders on accepted professional flight test practices. The AC90-89A [15] should be rewritten to focus not on a listing of tests that will conveniently fill up 40 hours of flight testing, but rather a methodology by which the builder can begin to assess the risks associated with his unique test program and the data required for him to gather the necessary and appropriate information about his unique airplane. Once the builder understands the flight test phase's dangers and requirements, he can then make an educated decision as to whether or not he is prepared to act not only as test pilot, but as FTE or test team manager. Going a step further, AC90-89A could go as far as stating that if the builder cannot truly understand the associated risks or appropriate data to be collected, he should seek professional assistance prior to the test planning stage.

If, at the very least, a professional approach is taken by the FAA toward homebuilt flight test guidance, then a parallel professional approach to the flight test requirements is also in order. The FAA should distinguish between "production" type flight test and "developmental" type flight test. Much as the FAA certification office tailors the flight test requirements for aircraft to be certified to the particular type in question, the FAA

could determine into which category a particular homebuilder's aircraft falls using designated airworthiness representatives (DARs) and designated engineering representatives (DERs). Considering factors such as the history of the design or kit, the type and certification status of the powerplant, avionics installed, the builder's experience and education, and the DAR's assessment, the DER could, for example, require only a 6-hour "production" type test program for a basic, well-constructed kitplane with an accepted, certified engine. This program would be focused on safety checks and gathering data for the POH. Likewise, he could require a full 40-hour "developmental" type test program for a plans-built aircraft with an unusual powerplant.

An additional benefit of having a DER make this assessment is that, by necessity, the DER would have to be a flight analyst or flight test pilot - a professional tester. Thus, at the very least, there would be a minimal amount of professional flight test influence on the program. This would provide the builder with a valuable opportunity to actually meet a flight tester and ask questions. The DER could brief the builder on the elements of the HFACS and highlight elements of high risk. Furthermore, following the meeting, the homebuilder might be led to more carefully consider his own capabilities with respect to conducting flight tests, regardless of the DER's determination of requirements. If the additional costs associated with the DER and DAR's time could not be absorbed by the FAA, they could be accounted for through higher registration fees for homebuilders. The latter would likely meet with some resistance from homebuilders and the EAA.

It should be noted that the author is in no way suggesting that passengers be carried in the first 25 hours of a homebuilt aircraft's existence. It is only suggested that in many cases a shorter test period may be appropriate. New aircraft should still be treated with a large degree of caution, as some problems caused by defective or improperly installed parts might not surface until subjected to the flight environment for a period of time. It might be appropriate for the owner to receive transition training in this period, but flights should be for the development of proficiency and limited to professional participants who are well aware that the aircraft is still very new and that there are some potential risks.

Such required interaction with flight test professionals would likely lead to increased discussion within the homebuilder community regarding greater professional participation in the flight test process. Just as the EAA magazines are packed with articles debating the merits of installing a particular piece of equipment, buying used or overhauled engines, and factory builder-assist programs, dialogues regarding the cost vs. benefits of hiring a flight test consultant or professional flight test team would likely arise. Again, at the very least, homebuilders would be provided with an increased amount of information as to how flight testing should be conducted. The frightening lack of guidance that characterizes the current situation would begin to be ameliorated.

In conclusion, the greatest deficiency in the homebuilt flight test world is the absence of the safeguards against the failures that threaten all aircraft operations and are particularly acute in flight test. The most comprehensive way to correct this would be to require or somehow convince builders that homebuilt aircraft be professionally flight tested.

Professionals mitigate the risk of failures and are trained to plan and conduct an appropriate suite of tests to satisfy the test requirements, whether they are mandated by regulation or the customer. The balanced team of test pilots and FTEs provides a unique system of checks and balances and differing points of view to help ensure that the test program is safe and efficient. But requiring professional flight testing of homebuilt aircraft is not realistic in the current culture of homebuilding. It is, however, conceivable that some changes in the FAA's guidance regarding homebuilt flight test could make significant inroads into bringing professional flight test influence and participation to the homebuilt flight test world. The additional step of tailoring flight test programs to different types of homebuilt aircraft could move the industry even further toward this goal. The overall result would be a community of homebuilders with a far greater appreciation of the challenges of flight test, homebuilders with far more accurate knowledge of their aircraft's flying qualities and performance, homebuilders with a better understanding of their aircraft's (and their own) limitations, and, most importantly, a reduced accident rate.

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VITA

Justin Samuel Garr was born in the Bronx, NY on January 10, 1972. He grew up in Greenwich, CT and graduated from Greenwich High School in 1990. From there, he earned a B.A. in English Language and Literature from the University of Virginia in 1994 and a B.S. with highest distinction in Mechanical Engineering from Rutgers College of Engineering in Piscataway, NJ in 1999. Following graduation, he was hired as a flight test engineer at the Naval Air Warfare Center at NAS Patuxent River, MD and participated in the testing of E-2C and C-2A aircraft. Justin was selected to attend the U.S. Naval Test Pilot School in 2001 and graduated from the fixed wing test project engineer course in December, 2002. Following graduation, Justin served as a member of C-130 and E-6 test teams and was lead flight test engineer for the KC-130T electronic propeller control test program. During this time, he pursued an M.S. in Aviation Systems from the University of Tennessee Space Institute and earned his degree in 2007.

Justin continues to work as a U.S. Navy civilian at NAES Lakehurst, NJ, where he is currently working as an air vehicles engineer on the fire protection systems for a variety of naval aircraft. He also operates a flight test consulting company, 9G Aerospace Solutions, LLC.