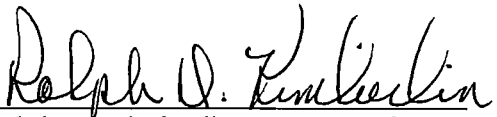


To the Graduate Council

I am submitting herewith a thesis written by Ryan J Smith entitled "A Flight Test Methodology for the Determination of a Reference Approach Airspeed for General Aviation Aircraft Modified with a STOL Kit " I have examined the final 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

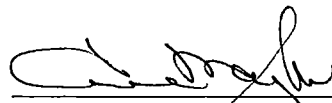

Ralph D Kimberlin, Major Professor

We have read this thesis and
recommend its acceptance.


F Collins


F Stellar

Accepted for the Council


Interim Vice Provost and
Dean of the Graduate School

**A FLIGHT TEST METHODOLOGY FOR THE DETERMINATION OF A
REFERENCE APPROACH AIRSPEED FOR GENERAL AVIATION AIRCRAFT
MODIFIED WITH A STOL KIT**

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Ryan J Smith
December 2000

ABSTRACT

This thesis presents a test methodology for establishing reference approach speeds for General Aviation (GA) aircraft that have been modified with Short Take Off and Landing (STOL) kits. Supplemental certification information included with the kits usually lists aircraft performance after modification as "equal to or better than" performance listed in the original aircraft flight manual. As the aircraft may still be operated in accordance with the original flight manual procedures, the supplemental information may not address changes in aircraft operational speeds. However, to realize actual performance gains, pilots must become familiar with the stability and control characteristics of the aircraft at speeds slower than those listed in the flight manual.

Kit manufacturers desire to claim the greatest decrease in landing distance possible and thus advocate the slowest flyable approach airspeed. However, the variability of aircraft condition and mechanics' skills may introduce a large disparity in aircraft performance and handling qualities following kit installation. Thus, it is impractical to apply one best approach speed for all aircraft. The task of determining this best approach speed is left to individual owner/operators of modified aircraft.

The goal of developing the test methodology presented in this thesis is to create a step-by-step checklist of practical flight test techniques that will allow owner/operators to determine the best reference approach speed for STOL kit modified GA aircraft. The objective is to develop and validate the use of a handling qualities tracking task as a means of identifying the limiting approach airspeed. A balance of performance and handling qualities concerns were addressed while following Federal Aviation Regulation (FAR) Part 23 and Advisory Circular 23-8A guidelines for small aircraft certification. Actual flight test data was collected for demonstration purposes using a 1953 Cessna 170B modified with a Horton STOL-CRAFT aftermarket STOL kit.

TABLE OF CONTENTS

CHAPTER	PAGE
1 INTRODUCTION	1
Background	1
Test Execution	2
STOL Definition	3
Test Objectives	5
Test Aircraft Description	6
2 DISCUSSION OF LANDING THEORY	8
Definition of Landing Distance	8
Landing Theory	9
3 PERFORMANCE FLIGHT TESTING	13
Aircraft Performance Testing	14
4 HANDLING QUALITIES FLIGHT TEST METHOD	21
Proposed Test Methodology	21
Handling Qualities Stress Testing	22
5 HANDLING QUALITIES FLIGHT TEST PROGRAM	27
FTT Development Test Methodology	27
Flight Test Execution	29
Flight Test Results and Analysis	32
6 CONCLUSIONS AND RECOMMENDATIONS	39
Recommended Flight Test Methodology	41
BIBLIOGRAPHY	42
APPENDICES	46
Appendix A – Expected Benefits of Modification	47
Appendix B – Aircraft Modification Forms	51
Appendix C – Handling Qualities Stress Testing	59
VITA	64

LIST OF ABBREVIATIONS

STOL	short takeoff and landing
GA	general aviation
POH	pilot's operating handbook
SPAS	slowest practical approach speed
FTT	flight test technique
MSL	mean sea level
NASA	National Aeronautics and Space Administration
VASI	visual approach slope indicator
ILS	instrument landing system
FAR	Federal Aviation Regulation
HQST	handling qualities stress testing
STC	supplemental type certificate
AGL	above ground level
I A S	indicated airspeed
mph	miles per hour
C-H	Cooper – Harper
FAA	Federal Aviation Administration
MIL-STD	military standard
L/D	lift to drag ratio
V _{so}	stall speed at idle power in the landing configuration

Chapter 1 – Introduction

Background

Aftermarket Short Take Off and Landing (STOL) performance kits are designed to impart slower stall speeds and better slow speed handling qualities, increasing landing performance by permitting the slowest approach airspeed flyable. However, differences in General Aviation (GA) pilot proficiency and aircraft condition will cause actual performance gains to vary. This thesis reports on a flight evaluation into the factors that influence the pilot's selection of landing approach speeds during STOL operations and develops a test methodology for determining the Slowest Practical Approach Speed (SPAS) based on a combination of aircraft performance and handling qualities. Use of the test methodology should allow any GA pilot owning a STOL kit modified aircraft to extract maximum performance while providing adequate handling qualities to ensure safe operations. This thesis presents the results of the feasibility in determining the SPAS for a Cessna 170B modified with a Horton STOL-CRAFT STOL kit.

The vast majority of STOL kit modified aircraft are single-engine, fixed-gear aircraft (1). According to the 1999 Nall Report published by the Aircraft Owners and Pilots Association (AOPA) Air Safety Foundation, there was “nearly one landing accident each day” of 1999 in this category of GA airplanes. Over 36% of all accidents in this category occurred in the landing phase (2). It is precisely this demanding phase of flight that pilots of STOL aircraft are attempting to extract the maximum in performance.

The two competing interests of performance and safety must be balanced in determining the reference approach speed of a modified aircraft. GA pilots need a flight

test methodology allowing them to determine the slowest practical approach airspeed. This speed may vary from pilot to pilot and aircraft to aircraft, however, it will represent the speed that each pilot can comfortably and safely extract the maximum performance from a modified aircraft. Both performance and handling qualities flight test techniques (FTTs) are necessary to allow the pilot to become familiar with the stability and operation of the aircraft at speeds below those listed in the Pilot's Operating Handbook (POH). Armed with this knowledge, individual pilots will be able to balance the two competing interests of safety and performance to determine an approach speed based on their individual proficiency and aircraft performance.

Test Execution

This flight investigation consisted of three phases. In the initial phase, the performance of the aircraft was determined in terms of stall speed and flight path angle (γ) versus airspeed at various power settings. Once the possible flight envelope was determined, the second phase of testing began by evaluating aircraft flying qualities and by determining those factors used by pilots in performing spot-landings. From these data, a handling qualities tracking task was developed for use in determining the SPAS based on handling qualities deterioration as airspeed decreases. The third and final phase verified the validity of the flight test technique and the operational suitability of the determined SPAS by performing mission representative STOL approaches. Four flights and a total of 3.9 hours flight time were required to complete the testing.

Two evaluation pilots were used during the flight investigation. Both pilots were military test pilot school graduates. Pilot A was a U.S. Air Force F-15 pilot with over 2,800 hours of flight experience in numerous aircraft. He had approximately 800 hours in

taildragger aircraft and limited prior STOL experience in GA aircraft. Pilot B was a U S Navy F-18 pilot with over 2,200 hours of flight experience in numerous aircraft, but with less than 20 hours in taildragger aircraft and no previous experience in STOL operations with GA aircraft.

STOL Definition

The large variety of types of STOL aircraft makes the characterization of STOL-mode operations difficult (3). Although the goal of STOL landing operations is to achieve short landing distances, typical divisions have been along the lines of aircraft design (such as those utilizing powered lift or very low wing loadings) rather than any performance specification. Most GA aircraft, typified by Pipers and Cessnas, do not fit well into these classifications even after modification. As such, for the purposes of this report, STOL-mode operations will refer to any operation where the pilot technique during a landing approach is to use throttle to control long-term flight path changes and pitch attitude to control long-term speed changes ($h \rightarrow \delta_T$ and $V \rightarrow \theta$).

The STOL mission task was defined as safe operations from "backcountry" airstrips located in mountainous areas. As a guide, the representative airfields were estimated to be at an elevation of between 2,000 – 5,000 feet MSL and 2,000 feet or less in length. The evaluation task for STOL operations was defined as flying a stabilized approach on a visually-tracked 7.5° glide-slope. STOL operations require precise glide-path control to consistently clear objects located along the approach path and accurately manage the touchdown location while providing a flare capability at slow speed. A stabilized approach refers to a constant airspeed, constant descent angle final approach. Maintaining a relatively constant airspeed during the approach has been shown to allow

more time for judging the flight path angle and the projected touchdown point, thus increasing the accuracy of touching down at the desired point (4) Standardized descent gradients have not yet been developed for STOL aircraft certification The descent gradient was chosen based on STOL instrument approach procedures for short-haul transports developed by NASA Ames (5) The glide-slope was visually-tracked because most "backcountry" airstrips do not provide supplementary flight path angle information such as a VASI or ILS glide-slope Therefore, the pilot's ability to perceive and visually-track the descent angle was considered an essential element of the mission tasking

Two additional requirements were added with respect to the planned mission scenario and flight safety First, as mountainous airstrips often do not permit straight-in approaches due to obstacles located along the approach path, the aircraft had to be capable of turns up to 30° in bank This bank angle was chosen to be in accordance with Federal Aviation Regulation (FAR) landing requirements and because "ground shyness" often prevents pilot's from banking any steeper at low altitude (6,7) The second requirement was a restriction of vertical descent velocity to no more than 500 feet per minute The limit was intended to prevent damage to the aircraft in case of a loss of sink rate control during final approach or an insufficient flare at touchdown FAR 23.473 requires that certificated aircraft demonstrate the capability of the landing gear to withstand a vertical descent velocity of at least 7 feet per second or 420 feet per minute (6) The aerodynamic effects associated with any attempt by the pilot to rotate to the flare attitude combined with "ground effect" could be expected to reduce the vertical descent rate from 500 ft/min to a sufficiently safe vertical velocity to prevent aircraft damage Table 1 summarizes the evaluation task elements

TABLE 1 – Evaluation Task

TASK ELEMENT	REQUIREMENT
APPROACH METHOD	Stabilized approach with constant airspeed and descent angle
GLIDE-PATH ANGLE	7.5°
GLIDE-PATH GUIDANCE	Visual
DESCENT RATE	500 feet per minute maximum
TURN CAPABILITY	30° bank angle

Test Objectives

The general objective was to develop a test methodology suitable for determining the slowest practical approach speed flyable in a STOL-kit modified GA aircraft based on aircraft handling qualities. Emphasis was on the development of a flight test technique using a specialized piloting technique, referred to as Handling Qualities Stress Testing (HQST), and data measurable from standard GA aircraft instrumentation and pilot opinion. The validity of this flight test technique to accurately determine a limiting approach speed was then assessed.

This report presents the results of using HQST for determining the SPAS on a Cessna 170B aircraft equipped with a Horton STOL-CRAFT STOL kit. The specific objectives in direct response to FTT development and SPAS determination were to

1. Determine the applicable performance flight envelope allowing the accomplishment of the evaluation task elements defined in Table 1. Performance testing, although integral to the test process, was secondary to the development and validation of the handling qualities flight test method of determining the slowest practical approach speed.

- 2 Identify flying qualities attributes which may influence aircraft handling qualities at STOL approach airspeeds
- 3 Identify dominant closed-loop control variables used during STOL approaches and spot landings
- 4 Using data from Objectives 2 and 3, develop a handling qualities flight test technique based on a tracking task using the Handling Qualities Stress Test piloting method
- 5 Assess the validity of the handling qualities flight test technique to accurately forecast handling qualities difficulties that may limit STOL approach speeds

Test Aircraft Description

The test aircraft was a 170B Businessliner, tail number N1846C, built in 1953 by the Cessna Aircraft Company. The 170 was a four-seat, high-wing all metal aircraft with a conventional landing gear. The aircraft was powered by a six-cylinder Continental Model C-145-2 engine, rated at 145 horsepower at 2,700 RPM. Engine RPM was controlled by a single large, round throttle knob located slightly left of center on the instrument panel. Conventional wheel and rudder pedal controls were provided for the occupants of both front seats to operate the primary flight control surfaces. The wing flaps were conventional Fowler flaps and controlled with a manual flap handle located between the front two seats. The flap setting was selectable to the 0, 20, 30 and 40-degree positions. The aircraft was equipped with hydraulic brakes on the main wheels conventionally operated by applying toe pressure to the upper part of the pilot's or co-pilot's rudder pedals. The maximum gross weight of the aircraft operated in the utility category was 1,900 lbs.

The test aircraft was modified in 1991 with a Horton STOL-CRAFT conversion kit manufactured by Horton STOL-CRAFT, Incorporated. The kit was installed in accordance with Supplemental Type Certificate (STC) SA989CE. The STC was granted

in January, 1974 and included the following design changes: wing leading edge cuffs, drooped wing tips, stall fences on the wing and aileron gap seals. (For a discussion of the expected modification benefits, refer to Appendix A.) In addition, a supplement was added to the basic aircraft flight manual for limitations, procedures and performance information. A copy of the STC and flight manual supplement are located in Appendix B. With the exception of the conversion kit, the aircraft was considered production representative. A photograph of the aircraft is presented in Figure 1.



Figure 1 – Cessna 170B Test Aircraft

Chapter 2 – Discussion of Landing Theory

Definition of Landing Distance

The term landing distance is specifically defined in Advisory Circular 23-8A, “Flight Test Guide for Certification of Part 23 Airplane,” as “the horizontal distance from a point along the flight path 50 feet above the landing surface to the point where the airplane has come to a complete stop” It is evident that the landing will consist of three successive phases the approach down to 50 feet, the descent from the 50 foot point to flare/ground impact and the ground roll

It is easy to see that the air-phase of landing distance will be strongly influenced by pilot technique, especially in the flare Pilot decisions as to flare altitude, rate of pitch attitude change and time/rate of throttle movements are but a few factors that will cause significant dispersion in results

In order to achieve the shortest landing distance possible, the aircraft needs to have a descent from the 50-foot point to impact which requires as little horizontal ground distance as possible and a touchdown velocity as slow as possible This is typically achieved by flying a steep approach at the minimum safe velocity allowing sufficient margin above stall and providing satisfactory control

AC 23-8A provides guidance concerning acceptable means of complying with FAR Part 23 73 and 23 75 to determine landing distance As such, it places particular constraints on the landing distance demonstration First, the approach must be a “steady gliding approach,” however, power may be used during approach to control sink rate The intent of the requirement appears to be a “stabilized approach” Second, no changes

in configuration are permitted on final. Although guidance of AC23-8A is not mandatory for private operators, the restrictions do seem prudent and should be considered in any test plan to determine a reference approach airspeed.

Landing Theory

Landing tests, more than any other test, are affected by factors that cannot be accurately measured and properly compensated for in-flight (31). Landings are greatly a function of pilot judgment and technique, therefore, they are subject to considerable variation for any given aircraft and set of conditions.

Example Piloting Techniques Affecting Landing Tests

- 1 Power handling during approach, flare and touchdown
- 2 Altitude of flare initiation
- 3 Rate of rotation in flare
- 4 Length of hold-off time
- 5 Touchdown speed
- 6 Rapidity of initiation of braking
- 7 Use of available drag devices
- 8 Brake pedal pressure (31)

Because the pilot is a largely unpredictable variable, it is neither possible nor practical to make exact predictions or corrections of landing performance. Rather, it is possible only to estimate the approximate capabilities of an aircraft within very broad limits. Consequently, a discussion of landing performance will be developed from a general point of view, considering only the major variables.

Air Distance

The total energy of an aircraft is assumed to decrease from the passage of the 50-ft obstacle to the point where the aircraft impacts the ground. Setting work done equal to the change in energy, it is possible to write

$$\int_0^{L_e} F - D = \Delta Z_t \quad \text{EQN 2-1}$$

where

L_e = ground distance covered in flight
 F = thrust
 D = drag
 Z_t = total energy

None of the terms under the integral are constant during the descent and an exact evaluation is virtually impossible. However, it is reasonable to assume that the entire quantity remains constant at some average value (35) yielding

$$L_e F - D \approx \Delta Z_t \quad \text{EQN 2-2}$$

Total energy (Z_t) is the sum of the potential and kinetic energy of the aircraft. The total energy at the obstacle height (h_{50}) is

$$Z_{t1} = mg(h_{50} + \frac{V_{50}^2}{2g}) \quad \text{EQN 2-3}$$

and at touchdown

$$Z_{t2} = mg(0 + \frac{V_{TD}^2}{2g}) \quad \text{EQN 2-4}$$

where V = velocity, m = mass and g = force of gravity. Therefore, the total change in energy is

$$\Delta Z_t = Z_{t2} - Z_{t1} \quad \text{EQN 2-5}$$

Combining equations 2-1 and 2-5 yields

$$L_e (F - D) = -mg(h_{50} + \frac{V_{50}^2 - V_{TD}^2}{2g}) \quad \text{EQN 2-6}$$

Rearranging signs for a consistent form and solving for L_e yields

$$L_e = \frac{mg(h_{50} + \frac{V_{50}^2 - V_{TD}^2}{2g})}{(D - F)} \quad \text{EQN 2-7}$$

Examination of EQN 2-7 shows that the air distance is minimized by three factors

- 1 Minimum touchdown speed is maintained throughout the final descent (i.e. no flare with $V_{app} = V_{imp}$)
- 2 Aircraft weight is a minimum (Weight = mg)
- 3 A high drag / low thrust configuration (steep glide path angle) is used. The coefficient of drag C_D in the drag (D) term is

$$C_D = C_{DP} + \frac{C_L^2}{\pi A Re} \quad \text{EQN 2-8}$$

consisting of profile drag (C_{DP}) and drag due to lift (C_L). The coefficient of drag is maximized by deploying drag devices (speed brakes, flaps) and by flying in a high lift configuration while at low speed.

Ground Distance

Although not the focus of this paper, an examination of the factors affecting the ground distance can help shape the approach speed by identifying the most desirable touchdown elements.

In addition to the usual forces of lift, weight, thrust and drag, an aircraft on landing roll is affected by an additional resistance force. This resisting force includes wheel bearing friction, brake drag, tire deformation and energy absorbed by the wheels as rotation speed decreases (35). This force will become larger as the weight on the wheels is increased and can be mathematically expressed as $\mu(W-L)$. Typical values of μ , the coefficient of resistance, range between 0.03 and 0.05 for a dry concrete runway and 0.05 to 0.07 for a dry turf runway (26).

The equation for the landing ground roll is similar to the landing air-distance equation, where the ground roll is given by L_s .

$$\int_0^{L_s} [F - D - \mu(W - L)] ds = \frac{mg}{2} (0 - V_{TD}^2) \quad \text{EQN 2-8}$$

where V_{TD} is the speed at touchdown. The required integration is accomplished using the same assumptions as above and the equation becomes

$$L_s = \left(\frac{mg}{2}\right) \frac{V_{TD}^2}{[F - D - \mu(W - L)]_{avg}} \quad \text{EQN 2-9}$$

Touchdown speed is obviously one of the most important determinants of distance required to stop and should be as slow as possible. The ground run is related to the square of the touchdown speed, thus a 10% excess landing speed would cause a 21% increase in ground run distance.

The denominator of the right-hand side of the equation can be referred to as "excess thrust." It is the difference between forward thrust and the retarding forces. In order to make this term as small as possible, the engine thrust, F , should be reduced to the minimum practical once on the ground. "The thrust from a windmilling propeller with the engine at idle can produce large negative thrust early in the landing roll but the negative force decreases with speed. The large negative thrust at high speed is valuable in adding to drag and braking friction to increase the net retarding force (36)."

Chapter 3 – Performance Flight Testing

Aircraft performance is typically the driving factor in determining aircraft approach airspeeds. FAR 23.73¹ requires aircraft manufacturers to use a speed of $1.3V_{so}$ as the minimum reference landing approach speed. (6) V_{so} is the power-off stalling speed in the landing configuration. This speed provides a 30% safety margin above the stall and is the speed typically used by manufacturers to claim the best landing performance possible. For a STOL kit manufacturer to obtain FAA concurrence to recommend a speed of less than $1.3V_{so}$, as determined in the original aircraft certification, in a POH supplement, they would have to apply for an exemption and explain how the granting of the exemption would be in the public interest and not reduce the level of safety. Even if the kit manufacturer successfully completed a detailed performance flight test program, the possibility of the FAA granting an exemption would be unlikely. (13) On the other hand, private operators may operate an aircraft below $1.3V_{so}$ on approach, without an FAA waiver of approval, if they so desire in order to achieve as slow a touchdown speed (and thus as short a landing distance) as possible. The FAA approved Airplane Flying Handbook, FAA-H-8083, even recommends a speed of not more than $1.3V_{so}$ for short-field approaches in the absence of a manufacturer's recommended approach speed. (14) No guidance is provided for the minimum speed a private operator should fly during a final approach.

Rather than rely on an arbitrary speed of $1.3V_{so}$ or a "trial and error" determined speed below $1.3V_{so}$, a systematic evaluation of the aircraft handling qualities is recommended for determining the minimum reference approach speed. However, the

objective in STOL landing operations is to perform a safe spot-landing at the slowest speed possible in order to achieve the shortest landing roll. To meet this objective, the feasibility of STOL operations is based on aircraft performance such as the rate of climb available in the landing configuration, the availability of drag for glide-path control and high lift for a low landing speed.

Aircraft Performance Testing

Performance testing was conducted in three phases to determine a flight envelope in which STOL operations may be performed. The first phase determined the stall speed of the aircraft in the landing configuration at various power settings. Aircraft stall speeds represent an obvious limitation on minimum airspeeds that can be flown. In addition, they provide a safety limit for all further testing. The second phase consisted of creating a rate of climb/sink diagram. This chart provides information as to the flight path angles obtainable at various power settings and airspeeds. The third phase of the testing was to calibrate the airspeed indicator. The descent rates obtained in phase two were in true altitude. To accurately calculate the descent flight path angle being flown during an approach, true airspeed corrected for static position error was necessary. Typically, an airspeed calibration is accomplished first, however, it was delayed due to GPS technical difficulties.

To limit the amount of testing necessary, before beginning performance test flights, an analysis was conducted to determine the most appropriate throttle settings for STOL operations. In addition to throttle closed (idle) and maximum thrust settings, mid-range throttle settings were selected based on expected significance to reduced landing distances. The POH does not recommend throttle settings for use during an approach. It

does, however, recommend the use of carburetor heat during approach when closing the throttle below 1600 RPM. As carburetor heat usage affects available thrust, throttle settings of 1700 and 1500 RPMs were selected, 1700 RPMs representing the minimum thrust without the use of carburetor heat and 1500 RPMs being the RPM resulting from addition of carburetor heat at 1600 RPMs. In addition, an RPM setting halfway between 1500 RPMs and idle was selected and resulted in 1200 RPMs. Furthermore, a throttle setting of 2300 RPMs was selected as it is represented as the bottom of the "green arc" on the RPM gage.

Stall Testing

Stall testing was accomplished to determine the highest stall speed. A high stall speed, resulting in the need for a higher approach speed, was determined to be the limiting factor rather than poor flying qualities associated with poor stall characteristics. As such, all stall testing was performed at the maximum aircraft gross weight and forward center of gravity (C G). The effects of C G placement on stall characteristics was not evaluated as the effort was to determine the highest stall speed and not changes in overall stall characteristics. The limits used for maximum gross weight and C G were determined from the Utility Category limits associated with the test aircraft. Aircraft gross weight as tested was approximately 1900 lbs. The C G was approximately 75 index units.

Stall testing was completed in smooth air at an altitude of 5000 feet pressure altitude (PA) with an outside air temperature of 85° Fahrenheit (F). The aircraft was configured with the flaps at 40° and then trimmed at an estimated 1.5 V_{so}, which was approximately 55 mph IAS. The aircraft speed was then reduced at a rate of one (1) mile

per hour (mph) per second until the stall occurred. The indicated airspeed at stall was noted by an observer. The stall was repeated three times at each power setting to ensure consistent results. The results of stall testing are presented in Table 2. Stall testing was terminated above 1500 RPM because the speed was below the minimum readable value of 30 mph on the face of the airspeed indicator.

In each case, the stall was defined by an uncontrollable downward pitching motion. Stall warning was provided by an audible warning system. The stall horn was activated by an angle of attack vane on the wing leading edge. The warning horn tended to sound at approximately the same indicated airspeed of 38-40 mph regardless of power setting. The warning horn did not appear to correlate the range of angle of attack changes that were indicated by the wide range of reduced airspeeds displayed on the airspeed indicator.

TABLE 2 – Stall Speeds

Flight Conditions Altitude 5000 ft PA Temperature 85°F Gross Weight 1905 lbs C G 75 index units Configuration Flaps 40°	
Power Setting (RPM)	Indicated Stall Speed (mph)
Throttle Closed	32
1200	30
1500	Unreadable

Rate of Climb/Sink Testing

Understanding of the relationships between airspeed, power and rate of climb/descent is an essential part of STOL-mode performance testing. A rate of sink diagram was constructed at various power settings and airspeeds. This chart provided key performance indicators that aid in the choice of optimum STOL-mode approach airspeed. In addition, the diagram introduces the pilot to the effectiveness of the throttle for controlling sink and demonstrates the amount of climb and descent capability that the pilot can use to achieve and maintain a desired glide-path.

The curves on the rate of climb/sink diagram represent stabilized descent and climb rates. These are the values of climb or descent toward which the aircraft will *tend* over time. The change is not immediate due to the aircraft weight and inertia. The time required to actually change aircraft performance affects the pilot's ability to maintain and correct aircraft glide-path.

A series of sawtooth climbs and descents were performed at the same approximate flight conditions as the stall testing. The change in altitude, as indicated on the altimeter during a period of one (1) minute, was recorded by an observer. The results are presented in Figure 2 on the following page.

Airspeed Calibration

A handheld Global Positioning System (GPS) unit was used to calibrate the aircraft air data system (ADS) using the technique developed in the United States Air Force Test Pilot School HAVE PACER II program (15). The method was used to correct for static source position error. The instrument error was assumed to be negligible. Data was collected at only at three speeds (40, 50 and 60 mph I A S) and then extrapolated

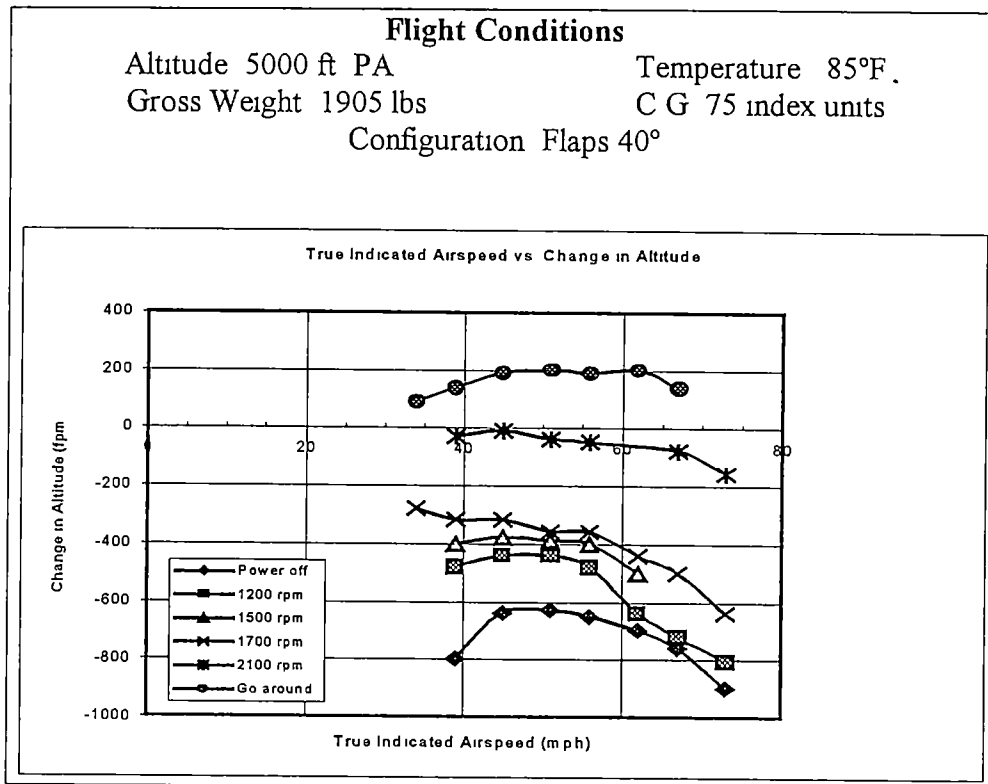


Figure 2 – Rate of Climb/Sink

throughout the expected STOL operations flight envelope Trend results are presented in Figure 3

The airspeed calibration was applied to the data in Figure 2 to compute the flight path angle versus airspeed for the various power settings The results are presented in Figure 4 on the following page

The airspeed corrections were applied to the power-off stall speed to determine if any actual improvement in aircraft stall performance had been achieved with the kit modifications The calibrated stall speed of 39 mph at 1,905 lbs was extrapolated to the maximum gross weight of 2,200 lbs , the maximum allowable aircraft gross weight and the assumed gross weight for the stall speeds printed in the POH Using the assumption of a constant lift coefficient, the calibrated stall speed was determined to be

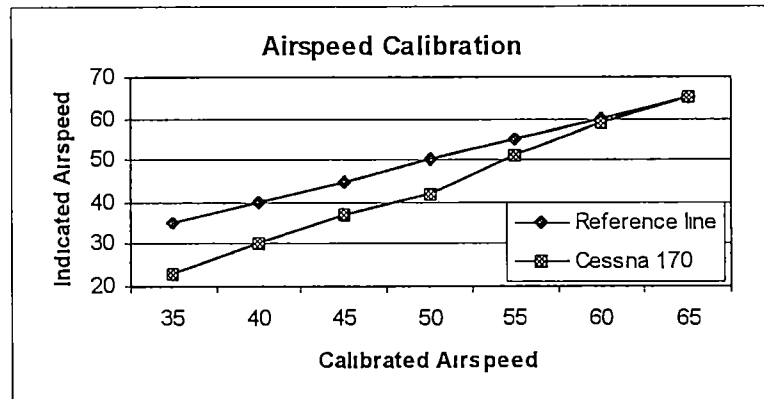


Figure 3 – Extrapolated Airspeed Calibration

$$V_{so_{\max wt}} = 39mph \left(\sqrt{\frac{2200lbs}{1905lbs}} \right) = 42mph \quad \text{EQN 3-1}$$

Given the flight conditions of 5000 ft pressure altitude and 85° (F), this yielded an estimated true calibrated stall speed of 47 mph. The POH provides the wings level, power-off stall speed (V_{so}) as “52 mph True Indicated Airspeed.” True Indicated Airspeed is the former CAR 3 term for calibrated airspeed. Thus, a 10 mph reduction in wings level, power-off stalling speed was achieved with the kit modification.

Summary of Performance Testing

The test aircraft provides a typical example of the difficulty encountered by pilots of modified aircraft. The POH recommended approach airspeed is 70-75 mph IAS. This corresponds to 1.34 to 1.44 V_{so} . It was suspected that the speed was “rounded up” by the manufacturer because 1.3 V_{so} is equal to 67.5 mph and that would be difficult to read on the airspeed indicator. The recommended short-field approach airspeed is 60 mph IAS, or 1.15 V_{so} (52 mph TIAS). Using this as a reference, the approach speed could now be

Flight Conditions

Altitude 5000 ft PA

Temperature 85°F

Gross Weight 1905 lbs

C G 75 index units

Configuration Flaps 40°

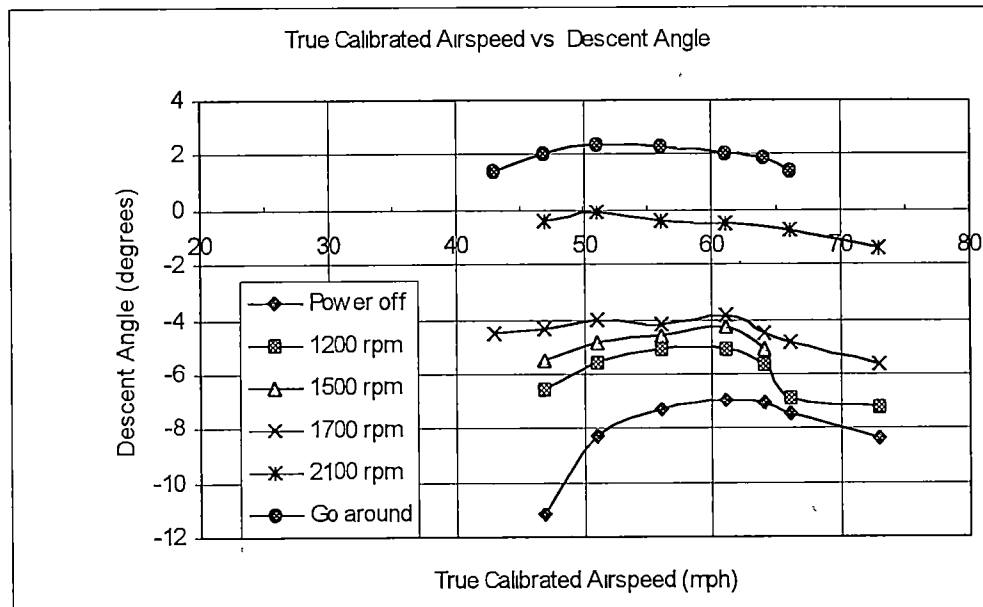


Figure 4 – Flight Path Angle versus Airspeed

lowered to 48 mph I A S at the maximum allowable normal gross weight of 2,200 lbs , provided the handling qualities were satisfactory to permit such a slow speed The extra 12 mph required in the POH would result in a 42% increased landing roll At the mission-planned weight of 1,900 lbs for the Utility category, the speed could be further reduced to 44 mph C A S resulting in a shorter rollout distance

One of the major problems with the test aircraft concerned the effects of the reduction in engine power required to obtain low effective lift-to-drag ratio (L/D) values for steep descents The aircraft drag characteristics are such that the induced drag does not increase appreciably before stall As engine power is reduced, the minimum approach speed must be increased because the stall speed increases and the control power decreases

Chapter 4 – Handling Qualities Test Method

Proposed Test Methodology

The proposed test concept concentrates on evaluating aircraft handling qualities rather than the more traditional method used to evaluate unaugmented aircraft, that of evaluating flying qualities and then inferring the handling qualities from the data. For purposes of this discussion, handling qualities are defined as the characteristics of the pilot plus airplane dynamics, flying qualities are defined as the characteristics of the airplane without pilot-in-the-loop dynamics. A three-phase method was used for performing a handling qualities evaluation, employing a “build-up” approach from gentle maneuvering to more aggressive maneuvering and finally performing an operationally representative task. The proposed methodology was developed from techniques used at the United States Air Force Test Pilot School since 1995. The three phases are

- **Phase 1** Gentle open-loop and semi-closed loop maneuvers are performed, such as doublets and bank angle captures. Open-loop maneuvers are used in this phase to allow the pilot to become familiar with aircraft dynamics and expected aircraft responses to pilot inputs.
- **Phase 2** The pilot performs a tracking task slowly increasing the aggressiveness, in terms of amplitude and quickness, of inputs. The specialized piloting technique is referred to as HQST. This phase is used to evaluate the full range of pilot dynamics by artificially reducing pilot compensation. The limiting approach airspeed in terms of handling qualities is determined in this phase.
- **Phase 3** The pilot performs a mission representative task with operationally representative performance criteria. Pilots assign Cooper-Harper ratings and assess mission suitability in this phase. Limits on performance other than handling qualities may be discovered in this phase.

Phases 1 and 3 are traditional steps and widely used throughout the flight test community (22) Phase 2, or HQST, is somewhat unique and not typically used to evaluate unaugmented aircraft However, HQST is recommended as an evaluation tool for two primary reasons First, open-loop tests provide data which can be compared to characteristics experimentally determined to provide adequate handling qualities in various mission tasks An accepted catalogue of flying quality requirements, such as MIL-STD-1797A, that can accurately predict STOL performance for all types of aircraft does not yet exist (3) Second, open-loop test techniques to identify the dynamic response characteristics of an aircraft do not adequately evaluate the dynamic modes of the aircraft during high gain, pilot-in-the-loop mission related tasks such as precision landings (8)

Handling Qualities Stress Testing

The HQST technique is designed to rapidly explore a wide range of pilot dynamics, including potentially stressed pilots reacting to hazardous and extreme conditions such as those performing STOL landings to short, mountainous airstrips The piloting technique is to intentionally fly the aircraft the way a stressed pilot would to uncover the handling qualities of the aircraft under those conditions The technique places the aircraft handling qualities under maximum "stress" so that the worst case handling qualities can be explored in a controlled environment (22) The intent is to reduce pilot compensation and evaluate aircraft handling qualities under the full spectrum of conditions likely to be experienced during years of operational use There are three primary components of HQST testing

- 1 Specialized piloting technique
- 2 Test maneuver
- 3 Pilot evaluation

Piloting Technique

The evaluation pilot's task in HQST is to track a precision aimpoint as aggressively as possible. Even the smallest excursions must be immediately, positively and aggressively corrected. Aircraft with poor handling qualities have been shown to be sensitive to the precision required of the task being accomplished (9). Specifically, when low precision tracking was required, deficient handling qualities were masked and good task performance was possible. However, when task difficulty was increased, pilots were forced into the control loop. Closed-loop control bandwidth is proportional to open-loop system gain and changes as task demands, pilot aggressiveness and/or pilot technique varies. Pilot bandwidth is used to describe the "aggressiveness" of pilot inputs and consists of the combination of speed of control stick movement and amplitude of the input. The effect of this technique is to increase the bandwidth of the pilot's control inputs. Experience at the Air Force Flight Test Center has shown that pilots switch to a high bandwidth piloting technique when their level of excitement or anxiety exceeds a certain threshold (7). Pilots performing a STOL approach to a mountainous airstrip could be expected to have a high level of anxiety and thus demonstrate a high bandwidth of control.

The second aspect of the specialized piloting technique is that pilot inputs (to correct the error) must be held constant (stick force/displacement) until the tracking error is zero. The objective is to minimize the pilot compensation. In typical operational tracking, pilots tend to relax their inputs and allow the aimpoint to "float" over the target. In fact, a significant element of pilot compensation is to not fly the aircraft if the desired performance is being met. The emphasis in HQST is to "drive" the aimpoint to the target.

with the pilot continually in the control loop. Refer to Appendix C for a more detailed description of the HQST piloting technique.

Test Maneuver

The test maneuver is the second component of HQST. The test maneuver should involve a mission-oriented tracking task. In the case of landings, tracking flight path angle or pitch angle may be acceptable. The tracking test technique is based on the idea that a pilot who is attempting to perform a precision tracking task will be able to easily identify flying qualities deficiencies which make the task difficult to perform well (8). The maneuver should be designed to evaluate approach and landing handling qualities at a safe altitude rather than just a few feet above the ground during a real landing.

Pilot Evaluations

Pilot evaluations are the third component of HQST. Pilots do not attempt to assign performance ratings during HQST. Performance ratings, such as Cooper-Harper, are not compatible with the HQST technique because a major element of their evaluation is an assessment of pilot workload and compensation. The HQST piloting technique is designed to remove pilot compensations. Secondly, attempts to evaluate performance tend to cause deviations (i.e. lead compensation or change of input amplitude) from the desired HQST piloting technique in order to improve task performance. Rather, pilot comments are the primary evaluation tool and generally consist of difficulties encountered with control and how the aircraft responses "felt."

Advantages of the HQST Technique

In general, the HQST technique is considered to provide three primary advantages.

- 1 HQST focuses the pilot on evaluating closed-loop stability, which is the essential control issue for pilot plus airplane integration and task accomplishment (10)
- 2 HQST allows discrimination of subtle differences in flight control system performance, such as changes in stick sensitivity or control power
- 3 HQST is independent of experience, training and task replication that can often contaminate Cooper-Harper ratings. The use of rating scales and definitions of piloting tasks is more applicable to determining task performance rather than a means of characterizing handling qualities (10)

Chapter 5 – Handling Qualities Flight Test Program

FTT Development Test Methodology

Flight testing was accomplished in three phases, with the overriding goal being to develop a handling qualities flight test technique for use in determining the slowest practical approach airspeed. The first phase was conducted in two parts to gather data for use in constructing the HQST Test Maneuver. Open-loop aircraft flying qualities that change with decreasing airspeed and which may affect the spot-landing task performance or pilot opinion ratings were noted. In addition, this phase, similar to Phase 1 in the proposed methodology, gave the pilot an opportunity to become familiar with aircraft dynamics and expected responses to pilot inputs at slow airspeeds prior to progressing to more aggressive testing. The second part consisted of flying approaches at the POH recommended airspeed to a long, safe runway. The testing concentrated on determining the dominant closed-loop control variables used by pilots in performing a spot-landing. The data from this phase were used to construct the handling qualities test maneuver tracking task.

The second phase of testing was an actual application of the HQST test technique at continually decreasing airspeeds. It consisted of an aggressive, high bandwidth tracking task. An attempt was made to quantify the results of the HQST test technique based on observed results such that an assessment of handling qualities degradation could be measured. While this was not an attempt to forecast pilot opinion ratings during mission representative tasks, it was used to sense when the handling qualities had been sufficiently degraded that control difficulties existed. The scale used for this evaluation is shown in Figure 5.

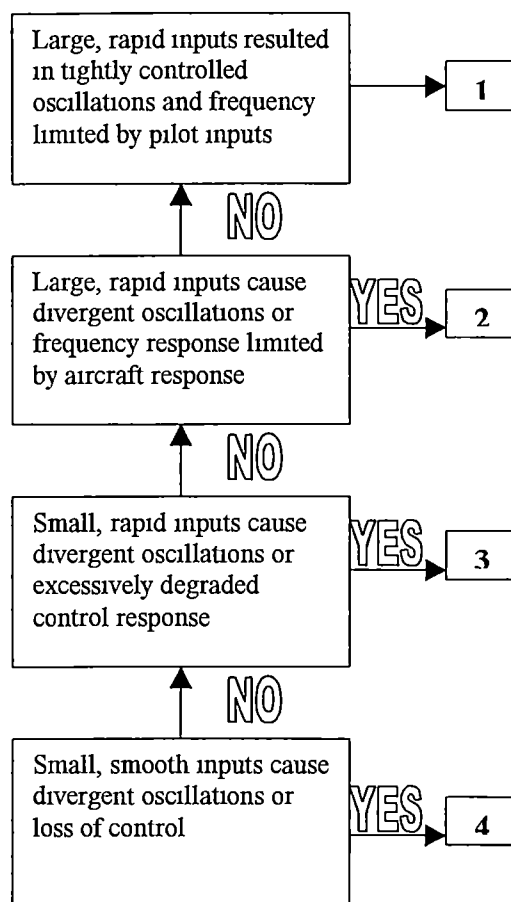


Figure 5 – HQST Rating Scale For Minimum Speed Determination

The minimum acceptable rating was estimated to be a “2” This rating was expected to produce Cooper-Harper ratings of 6 or less, indicating minimal acceptable performance

The third phase consisted of performing mission representative landing tasks Approaches were flown to runways 27L and 27R at Boulder City, Nevada at an elevation of 2200 feet MSL Runway 27L was 4800 feet x 75 feet and was considered to be a long, safe runway Runway 27R was 2200 feet x 60 feet with a ditch at the departure end of the runway and powerlines at the approach end Runway 27R was considered to be a sufficiently mission representative runway A build-up approach was used by flying

approaches at continually decreasing airspeeds first to the long, safe runway, then to the mission representative runway. Speeds were decreased until receiving a Cooper-Harper rating of 6 or worse. Speeds at which a 6 rating was obtained were then compared to the predicted HQST speeds. The correlation between the ratings was used to assess whether the technique was truly capable of identifying a limiting approach speed based on handling qualities deficiencies. Approaches were terminated after receiving a 6 or higher rating and no attempt was made to fly slower in the interest of safety.

Flight Test Execution

Open-Loop Testing

A maneuver block of open-loop test maneuvers was executed at three different indicated airspeeds: 60, 50 and 40 mph. The maneuvers are listed in Table 3. Forty mph was chosen as the limit airspeed because it was the slowest readable airspeed that provided a maneuver margin for 30° bank turns. All testing was conducted at 5000 feet pressure altitude in the full flaps configuration. The throttle was closed to minimize propeller slip stream effects.

No attempt was made to quantify data other than cases where the pilot could not provide an accurate qualitative assessment for comparison between the different airspeeds.

Table 3 – Open-Loop Maneuver Block

Step Input – Pitch/Roll/Yaw	Doublet – Pitch/Roll/Yaw
Response to throttle step inputs	Static stability – stabilized method all 3 axes
30°-30° Roll performance	Sinusoidal stick pump

Dominant Control Variable Determination for Spot-Landings

Approaches were evaluated to determine the key control parameters used by pilots during precision landings. As this test did not relate directly to the SPAS determination or the ability of the HQST test technique to determine the limiting reference approach airspeed, no effort was made to control aircraft configuration or weight. The pilot was given the task of performing a spot-landing at the POH recommended short-field approach airspeed of 60 mph I A S. The target was defined as the leading edge of the "touchdown zone marker" located approximately 1000 feet from the approach end of runway 27L. Pilot comments were collected for control variable determination. No effort was made to specify task performance criteria other than to "hit the spot."

HQST Testing

Based on the information obtained from the above testing, a tracking task was designed for use with the HQST piloting technique. The tracking task consisted of tracking a reference aimpoint, or pipper, against a stationary ground target. A reference mark was placed on the windscreen with a grease pencil at the projected flight path angle for the airspeed tested. This mark served as the pipper and was used to track a bright red automobile parked on a dry lakebed. The target was tracked with the pipper in a descent from 2,500 feet AGL for approximately 30 seconds. In all cases, testing was terminated at the safety altitude of 2,000 feet AGL.

Two additional marks were placed on the windscreen representing flight path angle changes equal to two degrees above or below the desired glide-path. This was achieved by assuming a two degree pitch change equaled a two degree change in flight

path at constant airspeed. The ability to change the glide-path by at least two degrees and track the new flight path angle was evaluated by flying one of these other pippers to the ground target.

A third variation was performed to stimulate the lateral-directional handling qualities. A simulated offset landing approach was performed with the ground target starting in the center of the windscreen. This forced the pilot to perform a large lateral correction to acquire the target.

Throughout the evaluations, pilot comments were recorded and HQST ratings assigned immediately after the tracking exercise using the HQST rating scale in Figure 5.

Landing Evaluations

Landing evaluations were initially flown to the long, safe runway 27L as a safety measure before progressing to the mission representative approaches to 27R. Approaches were flown at decreasing speeds until pilot comfort or lack of adequate task performance dictated termination of the task. Cooper-Harper ratings were assigned and pilot comments recorded. Task performance criteria are presented in Table 4.

Table 4 – Landing Task Performance Criteria

Task	Adequate Performance Criteria
Maintain Glide Slope	+/- 3 degrees
Touchdown Location	Longitudinal: +/- 100 feet of target Lateral: +/- 10 feet of centerline
Airspeed	Approach: +/- 10 mph Touchdown: +/- 5 mph
Sink Rate at Touchdown	"Medium" firmness
Task	Desired Performance Criteria
Maintain Glide Slope	+/- 2 degrees
Touchdown Location	Longitudinal: +/- 25 feet of target Lateral: +/- 5 feet of centerline
Airspeed	Approach: +/- 5 mph Touchdown: +/- 2 mph
Sink Rate at Touchdown	"Soft" firmness

Cooper-Harper ratings and pilot comments were then directly compared to the HQST ratings to determine if the HQST test technique was a satisfactory indicator of the slowest practical approach speed.

A summary of the flight test maneuvers is presented in Table 5.

Flight Test Results and Analysis

HQST Task Development

The significant flying qualities that were judged by the pilot to qualitatively change as airspeed was decreased are presented in Table 6. They are listed in order of perceived influence on the landing task.

Table 5 – Test Maneuver Summary

EVENT	ALTITUDE	AIRSPEED	DESCRIPTION
Open-Loop Maneuver Block	5000 ft. PA	60 mph – 40 mph	Reference Table 5
Spot Landings	2200 ft. MSL	60 mph	Determination of pilot control variables
Air-To-Ground HQST	2,500 ft. AGL – 2,000 ft. AGL (4,000 ft. MSL)	Decreasing HQST limit of 3	Precision flight path angle tracking
Landing Evaluation	2200 ft. MSL	Decreasing to C-H rating of 6	Safety check to long runway then mission representative

Table 6 – Significant Open-Loop Characteristics

FQ Characteristic	Description
Increased Roll due to Yaw	Wing drop with ½ rudder pedal step deflection increased dramatically. At 40 mph wing drop was sharp, quick and approached 30° of bank.
Reduced Longitudinal Stability	Stick force reduction on the order of 1/3
Reduced Directional Stability	At 45 mph, aircraft nose began to hunt +/- 3° from heading
Reduced Longitudinal Control Power	Stick displacement increased significantly for pitch angle captures
Reduced Aileron Control Power	Time to roll 60° doubled from 0.9 seconds at 60 mph to 1.8 seconds at 40 mph
Aileron Induced Yaw	Heading change in excess of 10° with rapid, full deflection aileron step input
Pitch Response to Step Throttle Input	Aircraft nose tended to pitch up and the increase in forward stick force to maintain airspeed was significant at 40 mph.

Approaches were evaluated to determine the key control parameters used by pilots during glide-path control and flare for precision landings. The primary parameters for the approach phase were identified as control of the flight path angle and airspeed. Research by NASA also indicates that these are also the two primary factors influencing a pilot's choice of landing approach speeds (11). The flightpath and airspeed response characteristics of interest were determined to be

- 1 Control authority, as described by long-term flight path changes, $\Delta\gamma$. This provided the ability to correct perceived deviations from the intended touchdown location.
- 2 Steady-state coupling between flight path and airspeed, $\Delta V/\Delta\gamma$. This determined the attention level the pilot had to devote to maintaining airspeed during a flight path correction. The pilot devoted a significant amount of attention to airspeed control to prevent stall and to prevent excess speed excursions resulting in long landings.

Several independent aerodynamic characteristics not directly affecting the flight path angle or airspeed, but which contributed to the effort and attention required of the pilot during the approach were also identified.

- Lateral control power
- Directional stability
- Trim forces and variations
- View of the landing area

Flare evaluations were performed by using either pitch attitude or a coordinated application of pitch and thrust as the primary control of descent rate and touchdown location. Thrust alone was not evaluated because at altitudes below approximately 20 – 30 feet AGL, the pilot had a natural tendency to increase back stick pressure and rotate

the aircraft Landing approach studies conducted by NASA indicate that pilot's have a definite tendency to flare when close to the ground because of an instinctive reaction to the appearance of an abrupt increase in sink rate (11) This action was attributed to the sensation of ground rush associated with steep descent angles and prior learning from normal landing techniques

Pilot concerns were identified as the ability to substantially reduce the sink rate in nearly immediate terms and whether this reduction could be sustained for a sufficient length of time to permit the flare to be accomplished The requirement to reduce the sink rate had to be accomplished within the acceptable attitude limits imposed by airframe geometry

The pilot did not consciously control airspeed or flight path during the flare In fact, the pilot did not admit to the closed-loop control of any aircraft variables other than achieving a reduction in sink rate Rather, the flare attempts were typically of sufficiently short duration to permit only open-loop pitch attitude captures of the desired touchdown attitude When the reduction in sink rate was judged by the pilot to be inadequate, thrust was used in a coordinated manner to help prevent a hard landing

The above data was used to develop a tracking task based on tracking flight path angle and pitch attitude changes An immediate difficulty arose as to the minimum flight path angle change necessary for detection by the pilot in a visual approach Unpublished results from a separate test performed in a U S Air Force F-16 aircraft suggested that at steep descent angles, the minimum flight path angle change necessary for pilot detection is 2° based on the available visual cue environment The primary degradation in visual cues was due to the significantly increased apparent distance between the top of the

runway and the horizon. Thus, the tracking task would have to verify the pilot could control flight path changes of at least 2° .

Performance data from Figure 4 in Chapter 3 indicated the range of airspeeds allowing for a descent angle between 9.5° - 5.5° was from 30 – 37 mph. In order to achieve the 9.5° descent angle, idle power was necessary. To meet the mission requirement of 30° bank turns, the acceptable speed range was determined to be exactly 37 mph. This one speed was tested using the HQST technique. An HQST rating of 4 was attained because of a loss of control of the flight path angle as the aircraft was partially stalled during the FTT.

Because of the limited range of descent angles permitted by the airframe aerodynamics, a decision was made to decrease the desired flight path angle to 5° . This would permit a large speed range from the POH recommended speed of 60 mph down to the previously determined limit of 37 mph.

The task appeared to work well for an evaluation of the longitudinal handling qualities, however, the suspect lateral-directional flying qualities also demanded that the task involve lateral-directional tasks. The simulated offset landings were an attempt to stimulate the lateral-directional handling qualities. However, the task was determined to be primarily open-loop rather than a closed-loop tracking exercise. The offset maneuver was really an open-loop bank angle capture where the pipper was allowed to “float” to the target. As such, a lateral-directional tracking exercise was designed to permit use of the specialized HQST piloting technique in the roll axis. This task simply involved stabilizing the aircraft on the desired glide-path with the pipper slightly offset from the target along the lateral axis. A roll was then started in an attempt to “drive” the pipper to

the target and start the HQST tracking process. This technique appeared more worthwhile than the offset landing approach. HQST was thus performed in pitch and then in roll. The minimum approach speed was determined to be the highest speed determined with either technique.

HQST Task Correlation

The HQST technique showed good correlation with the mission representative task ratings. However, discrepancies were seen at both the extreme high and extreme low end of the speed range. Landing task ratings from landings on the long, safe runway are correlated with the average HQST ratings in Figure 6. The minimum recommended speed using HQST was determined to be 45 mph I A S using the roll HQST test technique. Below this airspeed, it was possible to keep the pipper on the target only for short periods of time and the aircraft had a very "imprecise" feeling overall due to frequent wing drops. The minimum speed determined from safe landing tasks was 50 mph I A S. Mission representative landing task rating on the short runway are correlated with the average HQST ratings in Figure 7. Correlation was even better because of the increased pilot gains associated with the mission representative task. The minimum speed determined from the mission representative landing task was 50 mph I A S.

One aspect that the HQST technique did not have the ability to determine was the flare capability. This is believed to be the cause of the discrepancies at both the high and low speed ranges. The maximum speed tested was 60 mph. This speed is very close to the maximum L/D airspeed as seen in Figure 4 of Chapter 3. The touchdown point during flare at this airspeed was hard to judge and tended to float causing only adequate performance even though the approach was well flown on glide-path. Historical

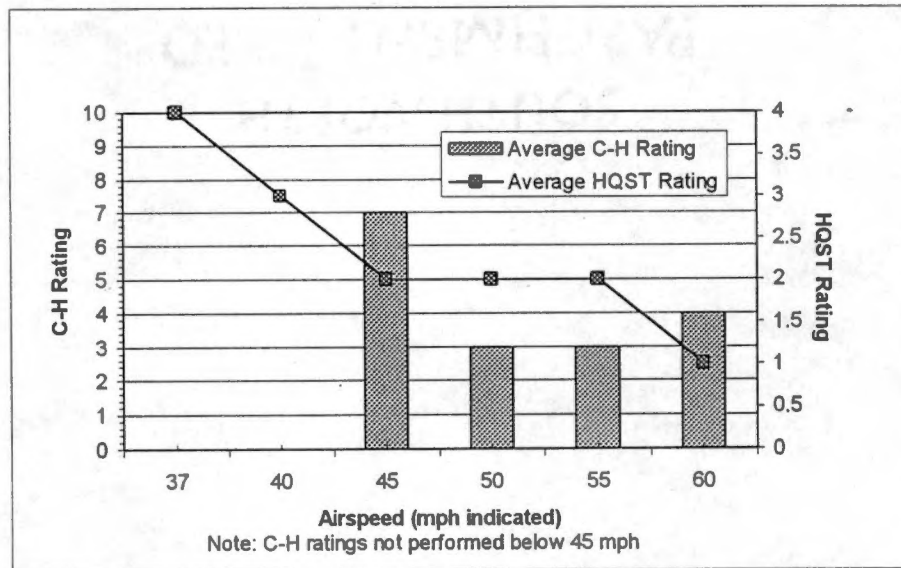


Figure 6 – HQST Correlation with Safe Landing Task

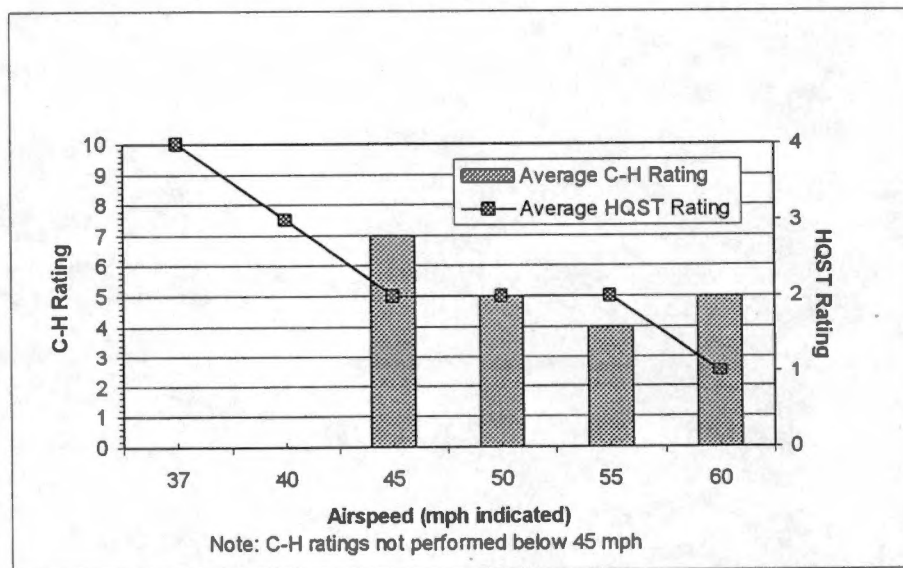


Figure 7 – HQST Correlation with Mission Representative Landing Task

experimental data in MIL-STD-1797 supports the hypothesis that touchdown precision is difficult at the maximum L/D airspeed (33)

At the slow speed end of the spectrum, the control over touchdown vertical velocity was the limiting factor in landing performance. The reduced power settings necessary to achieve the desired descent angle combined with the sensitivity of sink rate to throttle movements made precise control difficult. At reduced power settings, engine response to throttle movement was sluggish and a relatively large movement of the throttle knob was necessary to increase engine RPM. However, Figure 2 of Chapter 3 shows that the rate of sink was very sensitive to any increase in RPM. This combination of engine dynamic response and throttle sensitivity on flight path response resulted in overshoots in path reduction and typically led to ballooning and thus long landings. Pilot preference was therefore established for flares accomplished with pitch attitude changes from stick inputs without a need for a corresponding thrust increase. HQST by itself does not assure this capability. As a result, the average Cooper-Harper rating of 7 reflects both hard landings due to an inability to stop the sink rate as well as landings outside the desired touchdown zone due to ballooning.

Chapter 6 - Conclusions and Recommendations

Conclusion - The use of pitch angle changes at constant airspeed to emulate flight path angle tracking is a sufficient task to evaluate the longitudinal handling qualities associated with a STOL approach

The tracking task appeared to easily identify the deficient flying qualities found in the open-loop testing. In addition, difficulties in closed-loop control of the flight path angle were identified. However, certain problems with the designed task were apparent. First, determining where the flight path intersected the runway (or where to place the spot on the windshield) proved tedious and difficult. The FAA theory of an expansion pattern was used to determine an area of no movement around which all portions of the surrounding terrain and runway moved outwards (12). A limited degree of accuracy was possible. Second, the use of a spot on the windshield as a form of gunsight to initiate and then hold constant the flight path angle can only be used in extremely smooth air. At a 30 inch distance (spot on windshield to pilot's eye), a 2° change in pitch involves only about a ½ inch movement of the spot. Aircraft pitch angles appeared to vary as much or more than 2° as a result of normal variations to turbulence without a corresponding change in long term flight path angle. In addition, any vertical movement of the pilot's head or eyes added error to this method.

Recommendation 1: Supplementary approach path guidance, such as a Visual Approach Slope Indicator (VASI), should be used if possible as the tracking source.

Recommendation 2: Tracking tasks should be performed with a VASI and the Navy Fresnel Lens Optical Landing System as a reference to determine if sufficient fidelity exists for the HQST test technique.

Conclusion - A separate tracking task in the roll axis is necessary to fully evaluate the lateral-directional handling qualities associated with a STOL approach.

The limiting airspeed based on the HQST evaluations of the test aircraft was found during the lateral-directional tracking. Although potential difficulties were noticed during the longitudinal tracking exercise, the lateral-directional characteristics were not sufficiently stimulated to lower the overall HQST rating.

Conclusion - The combination of longitudinal and lateral-directional HQST FTTs is sufficient to determine the limiting airspeed for an approach task but does not guarantee a flare capability.

For aircraft operating on or near the backside of the flight path angle curve, the initial change in flight path following a step change in pitch attitude cannot be sustained. The flight path angle will subsequently decay to a lesser value and the steady state flight path will be steeper than the initial path. The ability to sustain the flight path correction for the duration required to complete the flare was considered to be a factor of significance to the pilot for landing precision. A rapid washout rate of the path correction was considered a possible cause of hard landings, too little washout rate was considered to induce floating, leading to increased landing distances.

Both the initial response magnitude and the response decay time are directly related to the gradient of flight path angle to airspeed (5). The ratio of $\Delta\gamma/\Delta V$ is positive for operating conditions on the backside of the curve and an increasing gradient is associated with operation further on the backside of the curve.

Recommendation 3: Further testing should be completed to provide recommended quantitative values of $\Delta\gamma/\Delta V$ when regulated by use of the stick only to provide an adequate flare capability for STOL aircraft. An estimate of the airspeeds associated with these values could then be determined directly from performance data in Chapter 3.

Recommendation 4: Until quantitative data or an “up and away” flight test technique is developed to determine satisfactory STOL flare characteristics, the use of a “build-up”

approach by performing STOL approaches to touchdown at slower and slower airspeeds should be used.

Conclusion – The Slowest Practical Approach Speed for the test aircraft was determined to be 50 mph I.A.S.

The limiting factor was sufficient flare capability based on touchdown firmness and not aircraft handling qualities during the approach.

Recommended Flight Test Methodology

Based on this flight test program, the test methodology presented in Table 7 is recommended for determining the minimum reference approach airspeed for STOL operations.

Table 7 – Flight Test Methodology Recommended for Determination of the Minimum Reference Approach Airspeed

EVENT	MANEUVER	OBJECTIVE
1	Airspeed Calibration	Calibrate Air Data System by correcting for static source position error.
2	Stall Testing	Determine worst case (highest) stall speed. Typically maximum gross weight and forward C.G.
3	Sawtooth Climb/Descent	Determine range of airspeeds providing desired flight path angle performance. Use 1.15 Vs at the lowest power setting required for performance as minimum speed for further testing.
4	HQST Longitudinal Tracking	Determine minimum acceptable speed for control of flight path and airspeed with aggressive pilot inputs.
5	HQST Roll Tracking	Determine minimum acceptable speed for lateral-directional control with aggressive pilot inputs. Use highest limiting speed between events 3,4,5 for as limit for further testing.
6	Landing Evaluations	Perform landing evaluations slowly decreasing airspeed from known safe airspeed to limit speed found in event 5. Determine if flare capability exists at the limit speed.

BIBLIOGRAPHY

BIBLIOGRAPHY

- 1 Alvin Horton STOL-CRAFT Inc , Telephone interview 13 June 2000
- 2 AOPA Air Safety Foundation Nall Report – General Aviation Accident Trends and Factors for 1999 Aircraft Owners and Pilots Association, 1999
- 3 Mitchell, D G , and R H Hoh Handling Qualities Criteria for STOL Flight Path Control for Approach and Landing American Institute of Aeronautics and Astronautics Atmospheric Flight Mechanics Conference 15-17 August 1983 Gatlinburg, Tennessee, 1983
- 4 Drinkwater III, F and George E Cooper National Aeronautics and Space Administration A Flight Evaluation of the Factors Which Influence the Selection of Landing Approach Speeds Washington NASA, 1958
- 5 Franklin, James A , et al National Aeronautics and Space Administration Design Criteria for Flightpath and Airspeed Control for the Approach and Landing of STOL Aircraft Ames Research Center, California NASA 1982
- 6 United States Department of Transportation Federal Aviation Regulation Part 23 Airworthiness Standards Normal, Utility, Acrobatic and Commuter Category Airplanes Washington GPO, 2000
- 7 Twisdale, Tom United States Air Force Test Pilot School Flying Qualities Testing Edwards AFB, CA United States Air Force, 1997
- 8 Smolka, James W United States Air Force Test Pilot School Analysis and Testing of Aircraft Feedback Augmentation Flight Control Systems Edwards AFB, CA United States Air Force, 1983
- 9 Smith, Rogers E Effects of Control System Dynamics on Fighter Approach and Landing Longitudinal Flying Qualities, Volume 1 n p March 1978
- 10 Smith, Ralph High Plains Engineering Internet interview 12 September 2000
- 11 Hasbrook, Howard Federal Aviation Administration Anatomy of a Landing – Cue by Cue Oklahoma City, OK n d
- 12 Armstrong, Donald Federal Aviation Administration, Aircraft Certification Office, Los Angeles, CA Telephone interview 20 June 2000
- 13 United States Department of Transportation, Federal Aviation Administration Airplane Flying Handbook Oklahoma City, OK 2000

- 14 Bailey, William, et al United States Air Force Test Pilot School HAVE PACE II Investigation of Using Global Positioning System for Air Data System Calibration of General Aviation Aircraft Edwards AFB, CA United States Air Force, 1995
- 15 Conrad, Peter Sierra Industries Telephone interview 20 June 2000
- 16 Preston, Mike The New Piper Aircraft Corporation Telephone interview 6 July 2000
- 17 Williams, Russ The Cessna Aircraft Company Telephone interview 6 July 2000
- 18 Maule, Ray Maule Aircraft Inc , Telephone interview 7 July 2000
- 19 Ritchie, Don Maule Aircraft Inc , Telephone interview 7 July 2000
- 20 Lazerson, David Air Force Flight Test Center Telephone interview 7 July 2000
- 21 Hoh, Roger Hoh Aeronautics Telephone interview 4 August 2000
- 22 Prosser, Kevin and Andrew J Thurling United States Air Force Test Pilot School Handling Qualities Stress Testing Edwards AFB, CA United States Air Force, 2000
- 23 Ecole du Personnel Navigant d'Essais et de Réception (French Test Pilot School) Mécanique du Vol de l'Avion Istres Centre d'Essais en Vol, 1996
- 24 United States Air Force Test Pilot School Aerodynamics Edwards AFB, CA United States Air Force, 1999
- 25 Roe, Robert B "Exploring the STOL Mode " Flying June, July 1974
- 26 Nicolai, Leland M Fundamentals of Aircraft Design San Jose Mets Inc , 1975
- 27 Schiff, Barry The Proficient Pilot II New York MacMillan Publishing Company, 1987
- 28 Askue, Vaughan Flight Testing Homebuilt Aircraft Ames Iowa State University Press, 1992
- 29 Hoh, Roger and David Mitchell STOL Handling Qualities Criteria for Precision Landings AFWAL-TR-86-3050 Hawthorne, CA Systems Technology Inc , 1986
- 30 McRuer, Duane T Pilot Induced Oscillations and Human Dynamic Behavior NASA CR-4683 Washington NASA, July 1995

- 31 Ecole du Personnel Navigant d'Essais et de Réception Pratique Des Essais En Vol Des Avions, Tome I and II Istres Centre d'Essais en Vol, 1996
- 32 Schiff, Barry The Proficient Pilot, Volume 1 Charlottesville Thomasson-Grant, 1994
- 33 United States Department of Defense Flying Qualities of Piloted Aircraft, Military Standard 1797A Washington D C Department of Defense, 1987
- 34 United States Department of Transportation, Federal Aviation Administration Flight Test Guide For Certification of Part 23 Airplanes, Advisory Circular 23-8A Oklahoma City, OK 2000
- 35 United States Air Force Test Pilot School Aircraft Performance Edwards AFB, CA United States Air Force, 1999
- 36 United States Navy Aerodynamics for Naval Aviators Summit Aviation Computerized Aviation Reference Library, 2000

APPENDICES

Appendix A – Expected Modification Benefits

The first step in any flight test project is to know the test aircraft. All the modifications of a STOL kit are intended to produce some change in either the performance or handling qualities of the aircraft. It will fly differently than it flew before the modifications, essentially making the first flight after modification a first flight in an unknown aircraft. The prudent pilot will examine the effects of each individual modification in order to predict the changes in performance and handling qualities.

High Lift Devices

High lift devices are used to increase C_{lmax} . The section on landing theory discussed how an increase in C_{lmax} directly relates to landing performance by directly increasing lift generated by a wing which in turn allows flight at slower speeds and increased drag. “Basically, increasing the total lift of a wing can be accomplished by any one or combination of three methods. The first would be increase the wing area, the second, increase the camber of the wing, and the third would be to delay separation through some means of boundary layer control” (24)

Cuffed Leading Edge

A permanent “droop” was built into the wing’s leading edge by adding a circular-radius cuff. Cessna has included the drooped leading edge on most models built since 1972 (15). The cuff is essentially a form of leading edge flap. When the leading edge is rotated downward, the camber of the airfoil is effectively increased, with a consequent increase in C_{lmax} for the wing. In addition, the air flowing over the airfoil at high angles

of attack is allowed to change direction more gradually. Separation is delayed by reducing the adverse pressure gradient over the top of the airfoil, thus allowing wing to achieve higher angles of attack. "The same wing with a conventional leading edge cannot be flown as slowly or at as large an angle of attack" (27). The cuffed leading edge increases the stall angle of attack significantly.

Flaps

Trailing edge flaps operate by changing the camber of the airfoil section. The camber is made more positive in the region of the trailing edge which increases $C_{l_{max}}$ and makes the angle of attack for zero lift, α_{0L} , more negative. The addition of flaps does not change the slope of the lift curve, rather it simply shifts the curve parallel to itself. Therefore, any required value of lift coefficient occurs at a lower angle of attack. The change results in a flatter pitch attitude which improves forward over-the-nose visibility.

The Fowler flap is similar to the plain flap, but there is a gap between the main wing section and the leading edge of the flap. High pressure air from the lower wing surface is ducted to the flap upper surface when the flap is deflected. Airflow is increased along the flap's upper surface and the boundary layer is re-energized delaying flow separation. The effect of the slot, plus the increased wing camber, plus the increased wing area created when the flap travels rearward during extension, enables the Fowler flap to achieve greater increases in lift than a plain flap (27).

The Fowler flaps found on the test aircraft are not a part of the modification package, but rather standard equipment on most Cessna aircraft. They are mentioned here because of their significant affect on STOL performance.

Drooped Wing Tips

Drooped wing tips increase the effective span of a wing, with a resulting increase in the lift coefficient and a decrease in induced drag, and reduce the dihedral effect of the aircraft. The actual effectiveness of drooped wing tips is controversial and they are sometimes added simply for “looks” (16)

Lift theory states there is a net difference in pressure on the top and bottom of a wing. The result of the pressure differential is that the high pressure air on the bottom “seeks” the low pressure region on the top. A secondary flow toward the tip of the wing is created as the air spills over the wing tip generating a vortex behind the wing. The vortex creates a downward component of flow velocity which increases the local angle of attack, α_i . The induced α creates a drag component called induced drag, D_i , which is related to α_i as

$$D_i = L \sin \alpha_i \text{ where } L \text{ is lift}$$

α_i is defined as

$$\alpha_i = \frac{C_L}{\pi AR}$$

The aspect ratio, AR is defined as

$$AR = \frac{b^2}{S} \quad \text{EQN A-1}$$

where b is the wing span from tip to tip and S is the wing area. Thus, by effectively increasing the span, b , of the wing, the induced drag is reduced. In a similar manner, the span has a qualitative effect on the lift curve slope, noting that for a given α , C_L will be high for a longer span wing.

Control Power

Stall Fences

Ailerons can lose effectiveness because of flow separation or stall across the control surface. The local separation can occur on the wing forward of the aileron or from the spanwise flow across the wing. The stall will appear as a dramatic loss of roll control at low speed. Fences serve to delay stalling of the outboard wing section by acting as a barrier to the separated flow.

During an approach with power-on, the flow from the prop wash allows the aircraft to be forced deeper into a stall, involving more of the wing area. Although the type of aircraft discussed in this report generally display stall characteristics beginning at the inboard wing root, with enough power, they may be flown into a stall deep enough to involve the ailerons. The stall fences serve to impede separation outboard of the mid-span that would affect the ailerons.

Aileron Gap Seals

Aileron effectiveness is determined by aileron area, control deflection, flow separation over the control surface, torsional stiffness of the wing, the required stick force, and the leakage around the control surface (28). Small metal extensions are placed along the radius of the surface to reduce leakage around the leading edge of the control surface. The reduced leakage allows for an increased pressure gradient and thus more effective controls.

Appendix B – Aircraft Modification Forms

Documentation associated with the installation of a Horton STOL-CRAFT conversion, to include

- Major Repair and Alteration Approval, FAA FORM 337
- Supplemental Type Certificate, FAA FORM 8110-2
- FAA Approved Airplane Flight Manual Supplement
- Horton STOL-CRAFT Memo for Operation

is contained within this appendix

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

MAJOR REPAIR AND ALTERATION
(Airframe, Powerplant, Propeller, or Appliance)

Form Approved
Budget Bureau No. 04-R060 1
FOR FAA USE ONLY
OFFICE IDENTIFICATION

INSTRUCTIONS: Print or type all entries. See FAR 43.9, FAR 43 Appendix B, and AC 43.9-1 (or subsequent revision thereof) for instructions and disposition of this form.

1. AIRCRAFT	MAKE <i>Cessna</i>	MODEL <i>170</i>
	SERIAL NO <i>25990</i>	NATIONALITY AND REGISTRATION MARK <i>1846C</i>
2. OWNER	NAME (As shown on registration certificate) <i>LIEUTENANT LEMOND A</i>	
	ADDRESS (As shown on registration certificate) <i>505 CONRAGE PARK DR. RD 1069 KIRKSVILLE, MO. 63501</i>	

3 FOR FAA USE ONLY

4 UNIT IDENTIFICATION				5 TYPE	
UNIT	MAKE	MODEL	SERIAL NO	REPAIR	ALTERATION
AIRFRAME	***** (As described in item 1 above) *****				X
POWERPLANT					
PROPELLER					
APPLIANCE	TYPE				
	MANUFACTURER				

6 CONFORMITY STATEMENT

A AGENCY'S NAME AND ADDRESS <i>Jay F. Kiddes Box 736 Cordova, KS 67235</i>	B KIND OF AGENCY ☒ U.S. CERTIFICATED MECHANIC ☐ FOREIGN CERTIFICATED MECHANIC ☐ CERTIFICATED REPAIR STATION MANUFACTURER	C CERTIFICATE NO <i>AF574242625</i>
---	--	--

D I certify that the repair and/or alteration made to the unit(s) identified in item 4 above and described on the reverse or attachments hereto have been made in accordance with the requirements of Part 43 of the U.S. Federal Aviation Regulations and that the information furnished herein is true and correct to the best of my knowledge.

DATE <i>12/16/91</i>	SIGNATURE OF AUTHORIZED INDIVIDUAL <i>Jay F. Kiddes</i>
-------------------------	--

7 APPROVAL FOR RETURN TO SERVICE

Pursuant to the authority given persons specified below, the unit identified in item 4 was inspected in the manner prescribed by the Administrator of the Federal Aviation Administration and is ☒ APPROVED ☐ REJECTED.

BY	FAA RT STANDARDS INSPECTOR	MANUFACTURER	INSPECTION AUTHORIZATION CANADIAN DEPARTMENT OF TRANSPORT INSPECTOR OF AIRCRAFT	OTHER (Specify)
	FAA DESIGNEE	REPAIR STATION		

DATE OF APPROVAL OR REJECTION <i>12/16/91</i>	CERTIFICATE OR DESIGNATION NO <i>AF574242625</i>	SIGNATURE OF AUTHORIZED INDIVIDUAL <i>Jay F. Kiddes</i>
--	---	--

FAA Form 337 (7-87) (8320)

United States of America
Department of Transportation - Federal Aviation Administration
Supplemental Type Certificate

Number SA989CE

This certificate, issued to: Horton STOL-Craft, Inc.
Wellington Municipal Airport
Wellington, KS 67152

*certifies that the change in the type design for the following product with the limitations and conditions
therefor as specified herein meets the airworthiness requirements of Part 23 of the Civil Air*

*Regulations dated Dec. 15, 1946, as amended by 3-1 through 3-4 for the 170A
and dated Nov. 1, 1949, as amended by 3-1 and 3-2 for the 170B.*

Original Product - Type Certificate Number A-799

Make Cessna

Model 170A and 170B landplane, floatplane,
skiplane

Description of Type Design Change

Install STOL kit (wing leading edge cuffs, drooped tips, stall fences
and aileron gap seals) per drawings and data called out on FAA approved
copy of STOL-Craft Drawing List #1.

Limitations and Conditions: 1. Flight Manual Supplement dated January 29,
1974, is required equipment for the airplane. Delete all references to
intentional spins from the utility category placard, and adjacent to it
add a new placard which reads "INTENTIONAL SPINS PROHIBITED." 2. This
approval should not be extended to other specific airplanes of this
model on which other previously approved modifications are
incorporated, unless it is determined that the interrelationship
(See Continuation Sheet)

*This certificate and the supporting data which is the basis for approval shall remain in effect until sur-
rendered, suspended, revoked, or a termination date is otherwise established by the Administration of the
Federal Aviation Administration*

Date of application April 6 1973

Date received May 26, 1977

Date of January 29 1974

Date

1985



18

United States of America
Department of Transportation—Federal Aviation Administration
Supplemental Type Certificate
(Continuation Sheet)

Number SA989CE

Limitations and Conditions, Continued

between this change and any of those other previously approved modifications will introduce no adverse effect upon the airworthiness of that airplane.

Any alteration of this certificate is punishable by a fine of not exceeding \$1,000, or imprisonment not exceeding 3 years, or both

(10 69)

This certificate may be transferred in accordance with FAR 21.47

PAGE 2 OF 2 PAGES June 4, 1990

STOL-CRAFT, INC.
WELLINGTON MUNICIPAL AIRPORT
WELLINGTON, KANSAS 67152

FAA APPROVED

AIRPLANE FLIGHT MANUAL SUPPLEMENT

For

CESSNA 170B MODEL
CESSNA 170A MODEL
Reg. No. _____
Ser. No. _____

This Supplement must be attached the the FAA Approved Airplane Flight Manual dated September 28, 1950 when STOL-CRAFT Conversion Kit is installed in accordance with STC SA989CE. The information contained herein supplements the information of the basic Airplane Flight Manual; for limitations, procedures and performance information not contained in this Supplement, consult the Basic Airplane Flight Manual.

I. LIMITATIONS:

A. Normal Category Only:

B. Placard: This airplane must be operated as a normal category airplane in compliance with the Airplane Flight Manual.

NORMAL

"No acrobatic maneuvers including spins approved."

"Both tanks on for takeoff and landing."

II. PROCEDURES

A. No Change.

III. PERFORMANCE

The performance of this airplane equipped with a STOL-CRAFT Conversion is equal to or better

Page 2 of 2
FAA APPROVED
Date

than the performance as listed in the original
flight manual.

FAA APPROVED Charles D. Temple

for William J. Thievon, Chief
Engineering & Mfg. Branch
Central Region
Kansas City, Missouri

DATE January 29, 1974



A DIVISION OF **HORTON INC.**
WELLINGTON MUNICIPAL AIRPORT
WELLINGTON KANSAS 67152

This aircraft with HORTON STOL CRAFT CONVERSION installed may be operated in the same manner as called out in the AIRCRAFT HANDBOOK provided by CESSNA. To obtain MAXIMUM PERFORMANCE from an aircraft equipped with a HORTON STOL CRAFT CONVERSION, it is suggested that each pilot FAMILIARIZE himself or herself with the aircraft at a SAFE ALTITUDE to assure them of the STABILITY AT SLOWER AIRSPEEDS THAN CALLED OUT IN the STANDARD CESSNA HANDBOOK. Because of PILOT PROFICIENCY and CONDITION VARIATIONS of each aircraft, STOL PERFORMANCE will vary with each aircraft.



FINEST QUALITY, ALL-METAL STOL CONVERSIONS • STC FAA-PMA APPROVED

Appendix C – Handling Qualities Stress Testing

Handling Qualities Stress Testing is based on the Handling Qualities During Tracking (HQDT) flight test technique developed at the Air Force Flight Test Center in 1972 by B Lyle Schofield (7) HQDT was designed as a tool to investigate aircraft susceptibility to Pilot-Induced Oscillations (PIO) by having pilots mimic the high bandwidth, synchronous control strategy typified in PIOs In order to elicit such a piloting strategy, a specialized pilot tracking technique was developed which required pilots to immediately, aggressively and positively correct even the smallest excursions from zero error Handling Qualities Stress Testing uses this specialized pilot tracking technique to evaluate the full spectrum of high bandwidth handling qualities, in addition to PIO susceptibility, in relation to required mission elements While it is expected that the results of Stress Testing will provide information on handling qualities deficiencies and the pilot's ability to precisely control the aircraft during a required mission element, the information gathered cannot be extrapolated to reflect specific operational mission effectiveness (such as landing distance expected at typical mission airfields)

Theory for the specialized piloting technique

The specialized piloting technique is based on four hypotheses

- 1 The pilot must track a reference signal in order to experience aircraft handling qualities
- 2 Handling qualities are closely associated with pilot bandwidth
- 3 Pilots track only when an error signal exceeds a tracking threshold
- 4 Pilots switch to a high bandwidth piloting technique when their level of excitement or anxiety exceeds a certain threshold (7)

The purpose of a tracking task is to ensure the combined airframe and pilot dynamics are continually excited. When a pilot is not tracking, he is not closing the control loop and there are no pilot dynamics, thus no handling qualities. Only the aerodynamic airframe characteristics, known as flying qualities, exist without a pilot and a closed-loop task.

Low pilot gain and high pilot gain can yield very different handling qualities. This observation may offer a partial explanation of the variation often seen in handling qualities ratings and comments. Undesireable and even hazardous handling qualities events are usually associated with a switch from low to high bandwidth tracking (22,30).

The following example is taken directly from a USAF Test Pilot School text book.

“Consider the case of the F-86, which had a lightly damped, high frequency dutch roll mode. F-86 pilots did not regard this mode as being objectionable during normal, everyday operations or during mock combat engagements. Under these unstressed conditions, a low bandwidth ‘operational’ piloting technique allowed the pilots to avoid exciting the dutch roll dynamics. But in real combat engagements over Korea, pilots complained bitterly that the mode was costing them Mig kills. The oscillation is (sic) most noticeable when the target is (sic) maneuvering and the pilot is (sic) tracking aggressively, with high bandwidth. The resulting high level of excitement caused the pilot to switch from smooth, low bandwidth tracking to high bandwidth tracking that excited the dutch roll mode (7).”

As low bandwidth handling qualities deteriorate, the likelihood of encountering hazardous high bandwidth handling qualities increases. For the purposes of this test program, the low bandwidth handling qualities are expected to deteriorate based on a reduction in approach airspeed. Therefore, it is possible the high bandwidth handling qualities will degrade sufficiently to impose a limit on the minimum airspeed flyable for the mission task.

Most models of the human pilot include the concept of “indifference thresholds.” Pilots are indifferent, either consciously or unconsciously, to errors that are below the

threshold When performing a task, pilots attempt to achieve some acceptable, but imperfect level of performance Perfect task performance is impossible to attain for more than a few moments at a time due to numerous factors, such as atmospheric turbulence for example In a sense, this drives the pilot to maintain a suitably small error, and not a zero error signal As long as the error remains within a suitably small threshold, pilots do not track When the error signal exceeds the threshold limit, pilots track the reference signal until the error is again suitably small, at which time they again stop tracking (10) This infers that any flight test technique designed to evaluate handling qualities must force the pilot to track

When the indifference threshold is surpassed and it is necessary for pilots to track, they adopt the lowest bandwidth piloting technique consistent with acceptable task performance As discussed above, lower bandwidth tracking results in better task performance through better handling qualities However, under conditions of stress and anxiety, experienced pilots can resort to high bandwidth control inputs (7,10,22) For example, when a wind gust suddenly and violently causes a wing to drop 15 - 20° on a landing approach, the pilot might instinctively respond with a large, rapid lateral stick input The fear of collision with the ground may raise the pilot's level of stress to cause a transition from low to high bandwidth control inputs

Piloting Technique

The HQST piloting technique is quite simple A prominent, precision aimpoint is selected An aiming index, or pippet, is then used to track the precision aimpoint as aggressively as possible The following guidance is provided to prospective test pilot candidates at the USAF Test Pilot School

“During a tracking test, the tracking pilot must devote his entire mental concentration and physical effort to keeping the pipper on the precision aimpoint. Even the smallest pipper excursion from the precision aimpoint must be immediately, positively and aggressively corrected. It is imperative that the tracking pilot make a continuous and concerted effort to immediately return the pipper to the aimpoint on the target every time it wanders off. The pipper must not be allowed to float near the target, to float onto the target, or to stabilize in order to facilitate returning the pipper to the aimpoint (8).”

Control inputs to drive the pipper to the precision aimpoint are held until the tracking error is zero with reversals made each time the pipper indicates zero error on the target. The intent is to remove all pilot compensation in the task, approaching synchronous control.

Pilots should slowly progress from smooth to aggressive control using small inputs while tracking the precision aimpoint. In other words, the pilot should progress from small amplitude, low frequency tracking inputs to aggressive, small amplitude, high frequency inputs. Once achieving small amplitude, synchronous control, the pilot should increase the amplitude of the inputs while observing aircraft limits.

The important characteristic of the piloting technique is high bandwidth control. The frequency of control inputs will be governed by aircraft dynamics, such as the short period. Bandwidth, however, is measured by the “frequency content” of control. It consists of the combination of the speed of stick movement and the amplitude of the input. The key to the piloting technique is high bandwidth, not just frequency. If incorrectly performed with relatively large, slow, constant amplitude inputs, this technique would degrade to an open-loop step input.

Degraded tracking performance is an inevitable by-product of the high bandwidth piloting technique. The maneuver produces an intrinsic oscillation of the aircraft-pilot system. This oscillation should be regarded as a result of the piloting technique and not necessarily unwanted. The pilot must be self-aware and recognize if aircraft motion is

becoming degraded due to loop instabilities. Typically, aircraft motions degrade into ever increasing amplitude oscillations, indicating susceptibility to PIO, or sluggish aircraft movement indicating an airframe limiting frequency response.

An acquisition task is usually used to initially excite the aircraft-pilot dynamics. The precision aimpoint is captured after beginning from a slight offset in the aircraft axis being tested. For the remainder of the tracking test, the specialized piloting technique is used. A duration of 20-30 seconds is typical for the test and sufficient for gathering the necessary information.

Tracking Task

Any tracking task which allows the pilot to use the specialized piloting technique is sufficient. However, three specific elements should be considered. First, the tracking task should involve a mission oriented task. For example, tracking the flight path angle may be appropriate for a landing task. Second, the maneuvers involved should be repeatable. They should be simple enough to be easily and accurately repeated from day to day. Third, the maneuver must require the tracking pilot to excite the aircraft and flight control dynamics to be investigated.

VITA

Ryan Smith was born in Newport News, Virginia on March 2, 1967. He graduated from Greenwood Community High School in Greenwood, Indiana in 1985. He then attended the United States Air Force Academy, graduating with a Bachelor of Science in Space Physics in 1989. Upon graduation, he was commissioned in the United States Air Force and served as an operational fighter pilot. In 1996 he attended the École du Personnel Navigant d'Essais et de Réception, French Test Pilot School. He is currently serving as a test pilot in the United States Air Force.