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CT-114 TUTOR

EVALUATION OF GLIDE PROFILES

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Charles Albert Ellis

May 1996

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I would like to take this opportunity to thank the men and women of AETE for their enthusiasm and support during the flight testing that provided the background for this thesis.

Finally, and most importantly, I would like to thank my wife for her patience, love and support .

ABSTRACT

The Aerospace Engineering Test Establishment was tasked to evaluate the CT-114 Tutor glide profile under various conditions including engine out and all combinations of landing gear and flaps extension. This thesis records the activities and results of that project [1].

Engine out glide performance was quantified for the clean gear up and clean gear down cases. Results of this first phase verified the current best glide speed of 130 KIAS for the clean gear up case. Accordingly, it was recommended that the current procedures and rules of thumb for clean gear up glide be retained. Flight testing with the landing gear extended determined that the best glide speed was significantly lower. During consultation with the CT-114 community, testing was directed to continue but only using 130 KIAS. Simulated engine out testing was completed to determine the engine RPM to be used to most accurately simulate engine out glide performance. Sixty-three percent RPM was recommended as most accurately simulating actual engine out conditions.

Phase two determined the effects upon glide performance of landing gear D Doors, flaps, external pylons, and external fuel tanks. Extension of the landing gear (D Doors closed) increased the flight path (descent) angle by 1.93° The D Doors alone increased the flight path angle by 0.43°. Half flaps increased descent angle by 1.62° and 3.24° for full flaps. External pylons had little effect (0.1°) while external pylons and fuel tanks caused a 0.47° increase in flight path angle.

Phase three utilized phase two data to develop the forced landing pattern. The same 360° turning pattern was used but the key altitudes were calculated using wings

level (phase two) data extrapolated to account for the turning effects. It was determined that the current Aircraft Operating Instructions procedures and key altitudes were adequate for the clean configuration but were incorrect for all other cases. The requirements for accuracy and simplicity in estimating altitude requirements led to the recommendation that pilots increase the ideal high key altitude by 200 ft if in any configuration other than clean. Phase three culminated in four successful forced landings at 4 Wing Cold Lake.

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LIST OF ABBREVIATIONS

The following abbreviations appear in this thesis:

AETE	Aerospace Engineering Test Establishment
AGL	Above Ground Level
AOI	Aircraft Operating Instructions
AUW	All-up Weight
A/C	Aircraft
CFB	Canadian forces Base
FL	Forced Landing
HR	Hours
ICS	Intercommunications System
IFR	Instrument Flight Rules
IG	Imperial Gallon
KEAS	Knots Equivalent Airspeed
KIAS	Knots Indicated Airspeed
L/D	Lift to Drag
MSL	Mean Seal Level
NM	Nautical Mile
PD	Project Directive
PLER	Primrose Lake Evaluation Range
psi	Pounds Per Square Inch
RPM	Revolutions Per Minute

VHF	Very High Frequency
γ	Wings Level Descent Angle
q	Dynamic Pressure
C_L	3 Dimensional Wings Level Lift Coefficient
W	Total Weight

1. INTRODUCTION

1.01 The CT-114 Tutor has had several cases of in-flight engine failures or compressor stalls requiring forced landings. A recent incident [2] prompted questions about the accuracy of the Tutor glide profile, and particularly the effect of different configurations. The Aerospace Engineering Test Establishment (AETE) was tasked [3] to investigate the Tutor glide profile for various aircraft configurations.

2. OBJECTIVES

2.01 The general objective of this project was to evaluate the CT-114 glide profile under various configurations [3]. To achieve the general objective, several specific objectives were assigned [3]:

a. verify that the configuration of 65% engine RPM with speed brakes extended reflects a windmilling Tutor engine accurately ;

b. establish the actual glide profiles and forced landing key altitudes for the following configurations:

(1) gear up, D doors closed, pylons only;

(2) gear down, D doors closed, pylons only;

(3) gear down, D doors open, pylons only;

(4) gear down, D doors open, tanked aircraft;

(5) gear down, D doors open, clean aircraft; and

c. estimate the impact on the glide profiles of a seized engine vice one that is windmilling.

3. TEST METHODS AND CONDITIONS

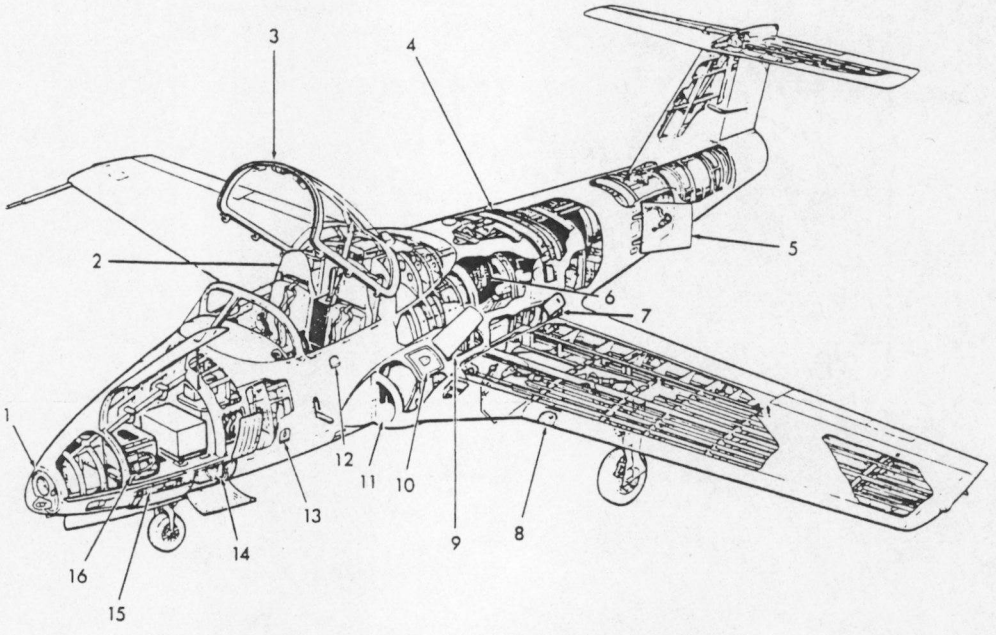
TEST ITEM DESCRIPTION

General

3.01 The CT-114 Tutor is a low wing, single-engine turbojet aircraft designed for military pilot training (Fig 3-1)[5]. It features side-by-side ejection seats for a crew of two in a pressurized and air-conditioned cockpit. The aircraft is instrument flight rules (IFR) certified, and instrumentation is provided for navigation, instrument, and night-flying training. Production of the CT-114 Tutor fleet was completed by Canadair Aircraft Corporation of Montreal, Canada between 1964 and 1967. The engine is a General Electric J85-CAN-40 axial flow turbojet with an eight stage compressor and two stage turbine. The basic weight of the aircraft is approximately 5,000 lb. Maximum permissible take-off weight is 8,500 lb.

Hydraulic System

3.02 The CT-114 Tutor is equipped with a 1,500 psi hydraulic system to operate the landing gear and doors, nose-wheel steering, wing flaps and speed brakes [5]. The system is a closed circuit, constant pressure system. System pressure is provided by an engine driven pump. Normal operating pressure can be maintained with a windmilling engine. A remote reservoir holds one imperial gallon (IG) of fluid and incorporates a standpipe (Fig 3-2) to retain sufficient fluid for manual gear extension in the event of a fluid leak.



1 TAXI AND GROUND OBSERVER LIGHTS
2 UPWARD EJECTION SEAT (TWO)
3 ELECTRICALLY OPERATED JETTISONABLE CANOPY
4 FUSELAGE BREAK
5 SPEED BRAKE (ONE EACH SIDE)
6 ENGINE COMPARTMENT
7 GROUND POWER RECEPTACLE
8 LANDING LIGHT (ONE EACH SIDE)
9 PERSONAL BAGGAGE STOWAGE (ONE EACH SIDE)
10 OXYGEN CYLINDER (ONE EACH SIDE)
OXYGEN FILLER VALVE (LEFT SIDE ONLY)
11 ENGINE AIR INTAKE (ONE EACH SIDE)
12 CANOPY EXTERNAL OPERATING CONTROLS
13 CANOPY EXTERNAL JETTISON CONTROLS
14 BATTERY (ONE EACH SIDE)
15 ELECTRICAL RELAY PANEL (ONE EACH SIDE)
16 ELECTRONIC EQUIPMENT COMPARTMENT

Figure 3-1. Tutor Aircraft - General Arrangement

Source: Anonymous, "C-12-114-000/MB-000 Aircraft Operating Instructions" National Defence, Canada, 1 May 1993

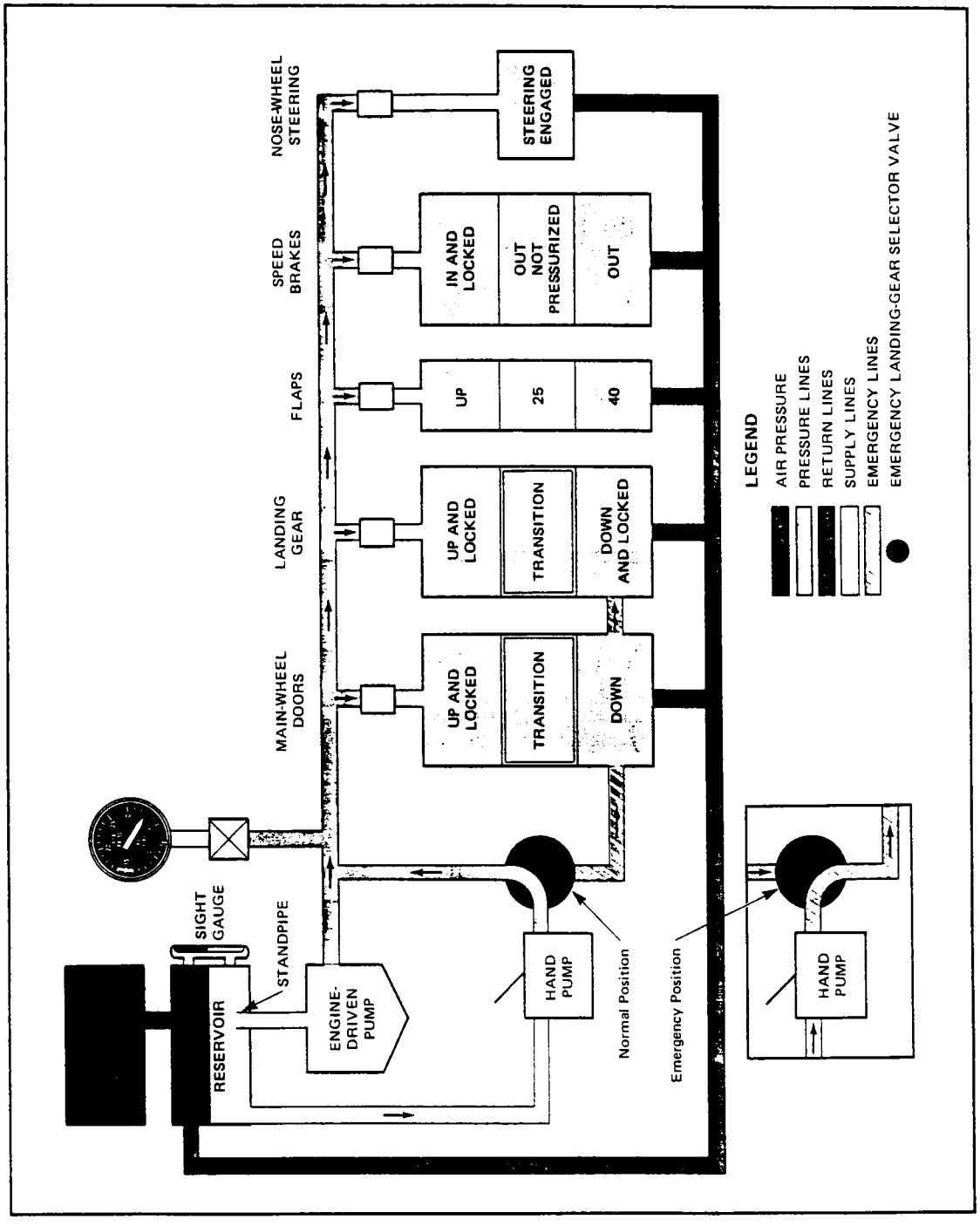


Figure 3-2. Hydraulic System Schematic - Standpipe

Source: Anonymous "C-12-114-000/MB-000 Aircraft Operating Instructions"National Defence, Canada, 1 May 1993

Landing Gear

3.03 Tricycle retractable landing gear is electrically controlled and hydraulically powered [5]. During normal extension, landing gear doors extend (open), landing gear extends, and main landing gear doors (commonly referred to as "D-doors" because of the approximate shape) retract to cover the main wheel wells. The extension sequence is detailed in Figure 3-3.

3.04 If electrical control is unavailable, manual extension of the landing gear is available using a hand pump situated to the left of the pilot (Fig 3-4) [5]. In this case, the landing gear doors remain extended and do not close to cover the open wheel well.

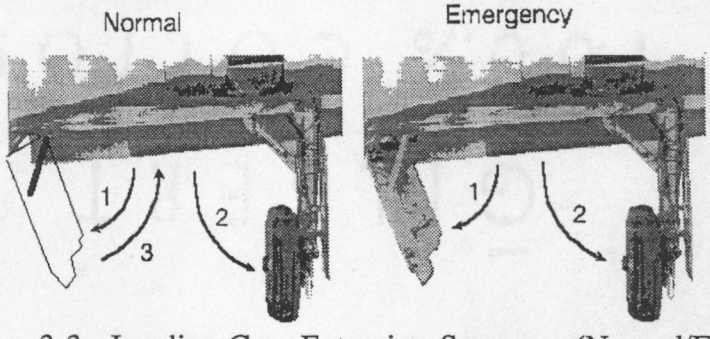


Figure 3-3. Landing Gear Extension Sequence (Normal/Emergency)

Source: Ellis, Charles A, "Project Report 9332 CT-114 Tutor Evaluation of Glide Profiles", Aerospace Engineering Test Establishment, CFB Cold Lake, Alberta, Canada, 1995.

Flaps

3.05 The CT-114 aircraft is fitted with mechanically selected, hydraulically operated slotted flaps mounted on the inboard trailing edge of each wing [5]. The flaps are interconnected mechanically and controlled by a lever mounted on each throttle quadrant. Three flap positions of 0°, 25°, and 40° correspond to detents for UP, TAKE OFF, and DOWN positions respectively.

External Stores

3.06 The CT-114 aircraft is capable of carrying two external fuel tanks, each with a capacity of 41.7 IG or 325.5 lb [5]. Two S2 bomb racks are utilized as carrying pylons for the external tanks (Fig 3-5). The pylons are bolted to front and rear hard points on the left and right sides of the centre fuselage and are not jettisonable. The fuel tanks are attached to the pylons by the use of front and rear hooks and were jettisonable. A crutch assembly prevents the fuel tanks from contacting the aft fuselage after jettison.

Speed Brakes

3.07 Electrically selected, hydraulically operated speed brakes are located on each side of the rear fuselage (Fig 3-6) [5]. Hydraulic pressure is required to keep the speed brakes fully extended. In the event of pressure loss, the speed brakes retract under airloads to an indeterminate position. An instrument panel indicator light on the centre annunciator panel provides indication when the right speed brake is not fully closed.

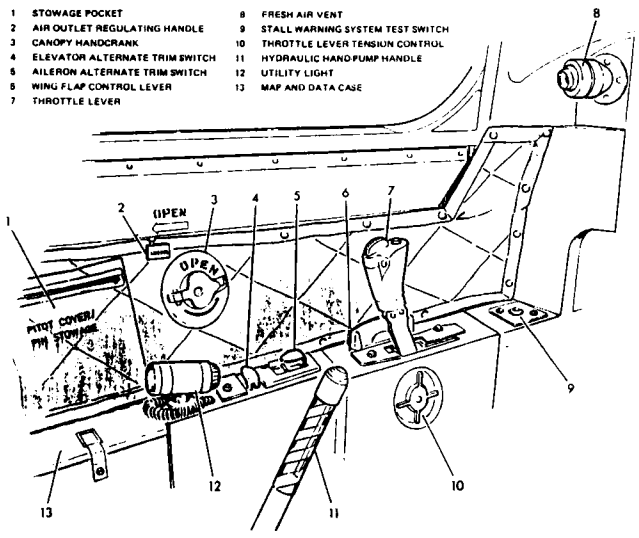


Figure 3-4. Cockpit - Left Console (Hydraulic Hand Pump Handle)

Source: Anonymous, "C-12-114-000/MB-000 Aircraft Operating Instructions" National Defence, Canada, 1 May 1993



Figure 3-5. External Pylons and Tanks

Source: Ellis, Charles A, "Project Report 9332 CT-114 Tutor Evaluation of Glide Profiles", Aerospace Engineering Test Establishment, CFB Cold Lake, Alberta, Canada, 1995.



Figure 3-6. Speed Brake Detail

Source: Ellis, Charles A, "Project Report 9332 CT-114 Tutor Evaluation of Glide Profiles", Aerospace Engineering Test Establishment, CFB Cold Lake, Alberta, Canada, 1995.

Sortie Summary

3.08 Table 3-1 details the sorties flown in support of this project [1]:

Table 3-1. Sortie Summary

DATE	A/C	CREW	HR	DATE	A/C	CREW	HR
27 Jan 94	147	Horton/Payne	1.1	9 Jun 94	024	Granley/Payne	1.4
8 Feb 94	147	Horton/Baker	1.4	10 Jun 94	024	Ellis/Baker	1.2
16 Feb 94	024	Ellis/Payne	1.5	16 Jun 94	024	Granley/Payne	1.1
21 Mar 94	024	Ellis	0.6	17 Jun 94	024	Ellis/Baker	1.4
23 Mar 94	024	Girard/Payne	1.7	20 Jun 94	024	Girard/Payne	1.2
23 Mar 94	024	Ellis/Payne	1.6	21 Jun 94	024	Girard/Payne	1.2
31 Mar 94	024	Ellis/Payne	1.0	23 Jun 94	024	Ellis/Payne	1.2
31 May 94	024	Ellis/Payne	1.5	24 Jun 94	024	Girard/Baker	1.7
8 Apr 94	024	Ellis/Payne	1.6	27 Jun 94	024	Girard/Baker	1.7
18 Apr 94	024	Ellis/Payne	1.1	15 Jul 94	024	Ellis/Baker	1.5
19 Apr 94	024	Ellis/Payne	1.3	11 Aug 94	024	Ellis/Baker	0.9
21 Apr 94	024	Ellis/Payne	1.1	19 Aug 94	024	Ellis/Baker	0.5
26 Apr 94	024	Ellis/Payne	1.5	25 Aug 94	147	Ellis/Payne	1.2
29 Apr 94	024	Ellis/Payne	1.5	30 Aug 94	024	Girard/Payne	0.6
2 May 94	024	Ellis/Payne	1.3	31 Aug 94	024	Ellis/Baker	0.5
4 May 94	024	Ellis/Payne	0.6	7 Sep 94	024	Girard/Payne	0.5
9 May 94	024	Ellis/Payne	0.7	13 Sep 94	024	Ellis/Payne	1.5
2 Jun 94	147	Ellis/Kowal	2.2	15 Sep 94	081	Granley/Baker	1.3
2 Jun 94	147	Ellis/Kowal	2.2	16 Sep 94	081	Ellis/Baker	1.1
						Total (hours)	47.2

Source: Ellis, Charles A, "Project Report 9332 CT-114 Tutor Evaluation of Glide Profiles", Aerospace Engineering Test Establishment, CFB Cold Lake, Alberta, Canada, 1995.

PHASE 1A - DETERMINATION OF ACTUAL GLIDE PERFORMANCE

Test Method

3.09 To determine the actual engine out glide performance, the engine was flamed out overhead CFB Cold Lake [1]. Fuel weight and glide speed were varied to develop a relationship between lift to drag (L/D) ratio, aircraft weight and glide speed. Following determination of best glide speed and performance with gear and flaps up, the test procedure was repeated to the determine best glide speed and performance with landing gear down.

3.10 Sawtooth descents were completed through a 2,000 ft altitude band [1]. The altitude was chosen to allow sufficient margin to recover the aircraft safely in the event of an unsuccessful airstart. Two descents per condition were completed, flown in opposing directions at 90° to the prevailing winds. Time to descend through each 500 ft altitude band was recorded. Indicated airspeed was recorded and used to estimate data quality. The flight path angle (Gamma or γ) was calculated from the ratio of vertical velocity to total velocity. L/D is the inverse of γ. All data were "hand held" recorded using the production flight instruments.

PHASE 1B - PERFORMANCE MATCHING

3.11 Once the actual glide performance had been calculated, the configuration required to simulate actual engine out performance was determined [1]. The current CT-114 procedure was to select speed brakes out and set 65% RPM. To account for thrust differences at lower altitudes, the data band was lowered to match the normal training altitudes. Check descents were flown as before, but constant airspeed and engine RPM were maintained.

Test Matrix

3.12 Table 3-2 details the test point matrix completed during Phase 1 of this project [1].

Table 3-2. Phase 1 Test Point Matrix

TEST POINT	CONFIGURATION				AIRSPEED (KIAS)
	ENGINE	GEAR	D DOORS	FLAPS	
1	Out	Up	Closed	Up	100
2	Out	Up	Closed	Up	110
3	Out	Up	Closed	Up	120
4	Out	Up	Closed	Up	130
5	Out	Up	Closed	Up	140
6	Out	Down	Closed	Up	90
7	Out	Down	Closed	Up	130
100	Out	Down	Closed	Up	100
101	Out	Down	Closed	Up	110
102	Out	Down	Closed	Up	120
8	Vary RPM/SB	Up	Closed	Up	130

Table 3-2. (continued)

TEST POINT	CONFIGURATION				AIRSPEED (KIAS)
	ENGINE	GEAR	D DOORS	FLAPS	
9	Vary RPM/SB	Up	Closed	Up	130
10	Vary RPM/SB	Up	Closed	Up	130
11	Vary RPM/SB	Up	Closed	Up	130
12	Vary RPM/SB	Up	Closed	Up	130
14	Vary RPM/SB	Down	Closed	Up	130
15	Vary RPM/SB	Down	Closed	Up	130
16	Vary RPM/SB	Down	Closed	Up	130
17	Vary RPM/SB	Down	Closed	Up	130

Source: Kowal, H, "Test Plan 9332 CT-114 Tutor Evaluation of Glide Profiles", Aerospace Engineering Test Establishment, CFB Cold Lake, Alberta, Canada, 1994.

Constraints and Limitations

Location

3.13 To minimize test risk, engine out glide testing was completed at an altitude high enough to allow an airstart attempt, and subsequent forced landing [4]. A 2,000 ft buffer was also included to allow for manoeuvring to high key. The data band was chosen as 15,000 ft to 13,000 ft MSL. Also, engine out testing was completed within gliding distance of CFB Cold Lake.

3.14 Performance matching descents were completed at lower altitudes [1]. The thrust output of the engine was assumed to be dependent solely on engine RPM and not vary with altitude.

Weather

3.15 Weather requirements required clear of clouds and sufficient visibility to allow a transition to high key in event of engine problems [4]. To insure the best data quality, smooth air was required.

3.16 The actual wind and temperature profile was obtained using PLER meteorology section [1]. A radiosonde was released before flight and the data were relayed to the test aircraft. An average wind over the data band was calculated and used to determine descent headings. The temperature data were used during data reduction to correct to standard conditions. PLER is located 20 NM from CFB Cold Lake. It was considered an acceptable error to assume that the wind and temperature profiles determined using the PLER radiosonde was the same at CFB Cold Lake for testing. A second radiosonde was released after flight and the actual weather conditions were averaged for data reduction.

Battery Capacity

3.17 Battery capacity limitations allowed only four restart attempts per flight thus allowing only two engine out data points to be flown per sortie [4,6].

Customer Requirements

3.18 The current CT-114 forced landing pattern is flown at 130 KIAS regardless of configuration [4]. It was clear that performance gains (i.e., reduced altitude requirements) could be gained by flying the pattern at configuration-dependent optimum airspeeds. This would require significant changes to the training syllabus and it was deemed essential to have customer concurrence with the plan before proceeding on the next phase.

3.19 The CT-114 training community was unwilling to change the pattern airspeed [7]. They had concerns about minimum manoeuvring airspeeds in the turn and elected to retain the current procedure of maintaining 130 KIAS throughout the pattern. It was recognized that performance gains could be achieved but the training cost was deemed to be too high. Accordingly, testing was directed to continue but to only consider 130 KIAS.

Test Results and Discussion

Actual Glide Performance

3.20 Figure 3-7 shows the effect of aircraft weight on L/D ratio [1]. As expected, there is a clear dependence of best glide speed on total aircraft weight. This result verifies the theoretical prediction that best L/D speed, but not L/D ratio, increases with weight [8]. To establish a reference weight, it was decided to use 7,000 lb all-up weight (AUW) as a standard weight. This value was arrived at by estimating the reasonable worst case as an engine failure soon after take off in a clean (non-tanked) aircraft. For

simplicity, an empty weight of 5,500 lb and 1,500 lb of fuel and crew weight was assumed to achieve a total of 7,000 lb.

3.21 Interpolation between the 6,000 lb and ,7400 lb curves indicated at 7,000 lb standard weight, the best glide speed was 130 KIAS which matched the recommended speed [4,5]. Maximum L/D was approximately 14.2:1 which was 6.6% less than the Aircraft Operating Instructions (AOI) prediction of 15.2:1. This reduction was similar to the loss of range that would be encountered if flying into a 10 kt wind. The current rule of thumb (2.5 NM per 1,000 ft) for estimating the glide range of a clean Tutor was reasonably accurate and simple to use. The current glide range formula should be retained for the clean, gear up case.

3.22 Examination of glide data with landing gear extended (Fig 3-8) [1] shows a trend similar to that described above. In this case, the best glide speed for 7,000 lb standard weight, approximately 108 KIAS, was significantly lower than currently recommended. This result demonstrates that the currently recommended forced landing pattern speed of 130 KIAS is faster than the optimum for configuration other than gear and flaps up, speed brakes in [1].

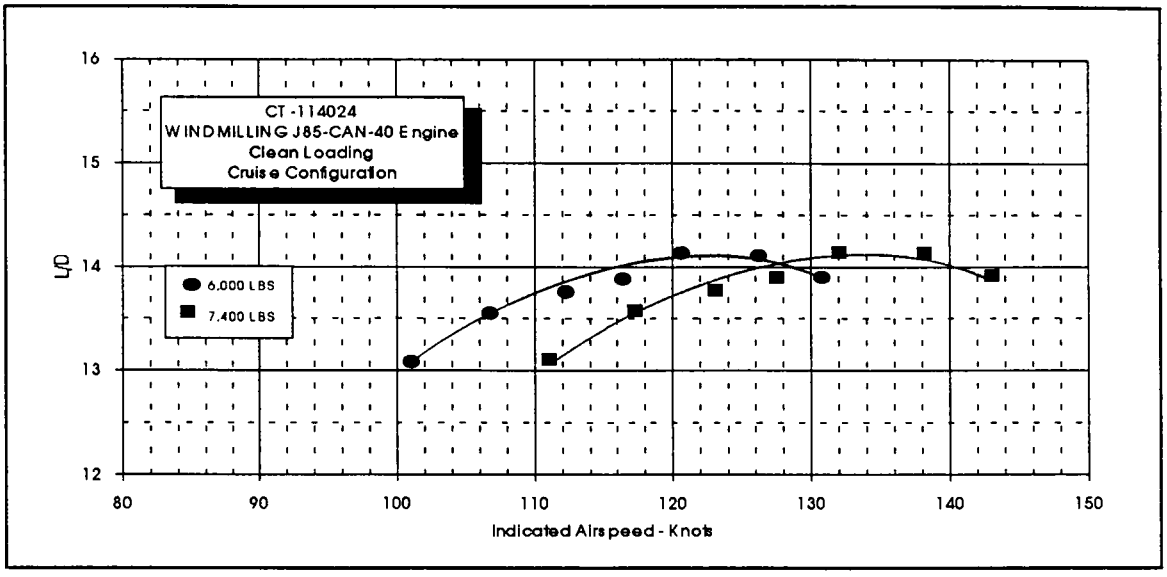


Figure 3-7. L/D Ratio Variation with Airspeed

Source: Ellis, Charles A, "Project Report 9332 CT-114 Tutor Evaluation of Glide Profiles", Aerospace Engineering Test Establishment, CFB Cold Lake, Alberta, Canada, 1995.

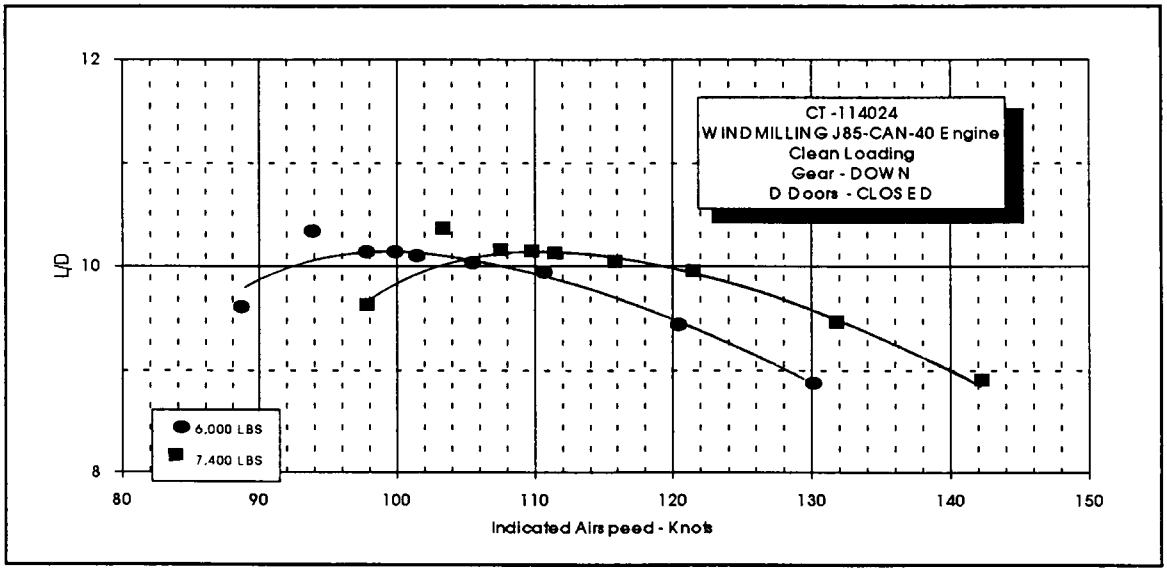


Figure 3-8. Glide Data with Landing Gear Extended

Source: Ellis, Charles A, "Project Report 9332 CT-114 Tutor Evaluation of Glide Profiles", Aerospace Engineering Test Establishment, CFB Cold Lake, Alberta, Canada, 1995.

RPM Matching

3.23 The results of this test are shown in Figure 3-9 [1]. Sixty-three percent RPM and speed brakes out approximates the actual engine out performance. It must be pointed out that this is valid only at 130 KIAS as the actual engine thrust will vary as a function of airspeed. In addition, the variance in thrust output under different temperature conditions will cause the simulated "engine out" performance to vary slightly. This variance is considered an acceptable trade-off for the extra complication of accounting for thrust variations.

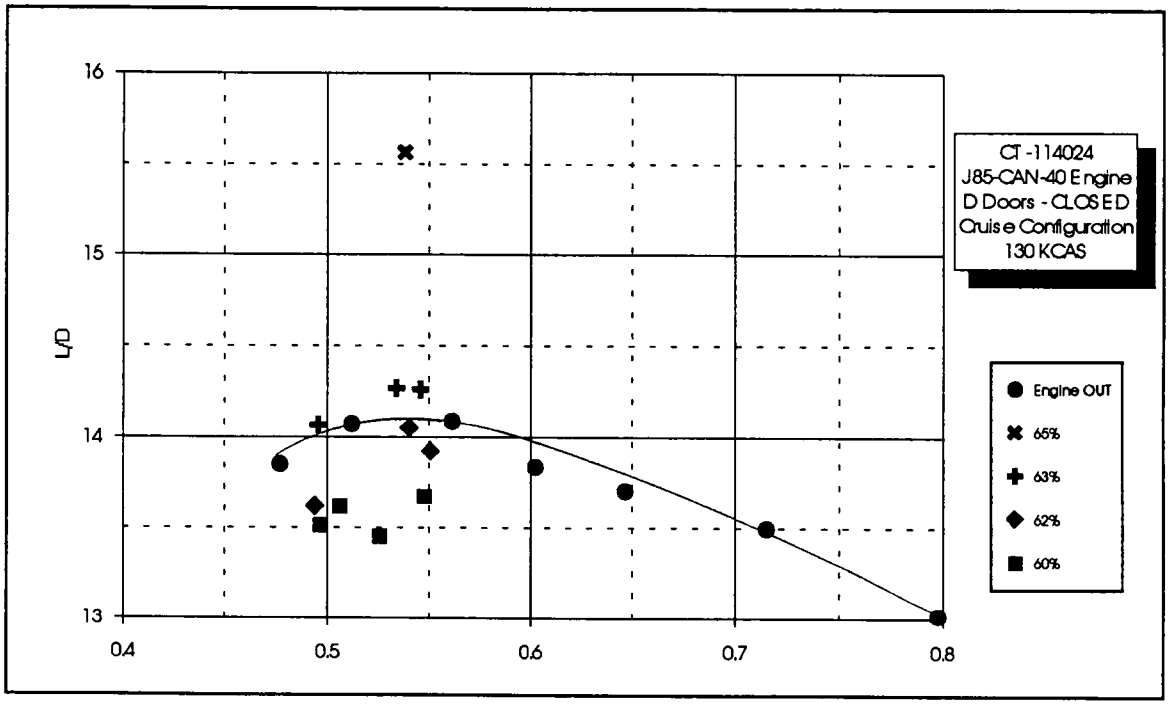


Figure 3-9. RPM Matching Test Results

Source: Ellis, Charles A, "Project Report 9332 CT-114 Tutor Evaluation of Glide Profiles", Aerospace Engineering Test Establishment, CFB Cold Lake, Alberta, Canada, 1995.

Conclusions

3.24 The following conclusions were made [1]:

a. the currently recommended best glide speed of 130 KIAS is valid for the clean, gear and flap up configuration;

b. the current rule of 2.5 NM per 1,000 ft for estimating the glide range of a clean Tutor is reasonably accurate and is simple to use;

c. the currently recommended forced landing pattern speed of 130 KIAS is faster than the optimum for configurations other than gear and flaps up, speed brakes in; and

d. the current engine failure simulation is slightly optimistic. Sixty-three percent RPM and speed brakes out simulates actual performance at normal training altitudes. This RPM does not account for ambient temperature variations.

Recommendations

3.25 The following recommendations were made [1]:

a. the current AOI best glide speed of 130 KIAS be retained;

b. the current rule of 2.5 NM per 1,000 ft in the clean configuration for estimating the glide range of the Tutor should be retained; and

c. the engine out simulation configuration be changed to 63% RPM and speed brakes.

PHASE 2 ANCILLARY EFFECTS

Objective

3.26 The objective of this phase was to determine the glide performance for all combinations of ancillaries for the three configurations[4]:

a. clean, gear up or down, D doors open or closed, flaps up, half or full;

b. pylons, gear up or down, D doors open or closed, flaps up, half or full; and

c. tanks, gear up or down, D doors open or closed, flaps up, half or full.

Test Methods

3.27 Sawtooth descents were completed as per Phase 1 [1]. For this phase, indicated engine RPM was maintained at 62.5% to correct for instrument calibration errors determined during ground testing [11] to achieve an actual 63% engine RPM. Speed brakes were extended. Throttle position was adjusted during each descent to maintain 62.5% on the RPM indicator as closely as possible. This technique introduced a small variation in the aircraft thrust output but more closely matched the actual technique used during flying training. The same desktop computer spreadsheet file used in Phase 1 was used to calculate flight path angle for each configuration and ancillary combination flown.

Test Matrix and Configurations

3.28 The Test Matrix used is reproduced as Table 3-3 [4].

Table 3-3. Phase 2 Test Matrix

TEST POINT	CONFIGURATION					AIRSPEED (KIAS)
	ENGINE	GEAR	D DOORS	FLAPS	EXTERNALS	
31	63%/SB	Down	Closed	25°	Pylons	130
36	63%/SB	Down	Closed	40°	Pylons	130
40	63%/SB	Down	Open	Up	Pylons	130
45	63%/SB	Down	Open	25°	Pylons	130
50	63%/SB	Down	Open	40°	Pylons	130
54	63%/SB	Down	Open	Up	Pylons and Tanks	130
59	63%/SB	Down	Open	25°	Pylons and Tanks	130
64	63%/SB	Down	Open	40°	Pylons and Tanks	130
68	63%/SB	Down	Open	Up	Clean	130
73	63%/SB	Down	Open	25°	Clean	130
78	63%/SB	Down	Open	40°	Clean	130
90	63%/SB	Down	Closed	25°	Clean	130
95	63%/SB	Up	Closed	Up	Pylons and Tanks	130
99	63%/SB	Down	Closed	Up	Pylons and Tanks	130

Source: Kowal, H, "Test Plan 9332 CT-114 Tutor Evaluation of Glide Profiles", Aerospace Engineering Test Establishment, CFB Cold Lake, Alberta, Canada, 1994.

Results and Discussion

Landing Gear

3.29 As discussed previously, extension of the landing gear reduces the best glide speed. Conversely, if a constant 130 KIAS is maintained, extension of the landing gear will cause an increase in profile drag. No testing was completed to quantify the effects of landing gear in other than the flap up configuration [1].

Extension of the landing gear with the doors sequencing closed increased the flight path angle by an average of 1.93° [1]. The effect was less noticeable when external fuel tanks and pylons are installed.

Landing Gear Doors

3.30 The increase in flight path descent angle induced by the extended landing gear doors was 0.43° [1]. As with the landing gear alone, the percentage increase in profile drag depended on aircraft configuration. As flaps were extended, the effect of the gear doors became less noticeable. With external fuel tanks and pylons, full flaps extended, no additional drag was caused by the gear doors within the resolution of the test instrumentation. There was an increase in drag caused by the gear doors but the percentage increase became insignificant.

Flaps

3.31 Extension of half flap increased the descent angle by 1.62° [1]. Full flap extension increased the descent angle a further 3.24° for a total increase of 4.86° from the flap up descent angle [1].

External Pylons

3.32 The increase in flight path descent angle was barely observable at 0.10° [1]. The uncertainty of the descent angles is substantially larger than the test result. Accordingly, the effect of external pylons on forced landing pattern altitudes was considered negligible.

3.33 The total increase in flight path angle for external pylons and fuel tanks was determined to be 0.47° greater than the clean configuration [1]. The effect of external tanks and pylons was similar in magnitude to the landing gear doors remaining open.

Conclusions

3.34 The following conclusions were made [1]:

a. extension of the landing gear with the doors sequencing closed increased the flight path angle by an average of 1.93°;

b. the effect was less noticeable when external fuel tanks and pylons were installed;

c. the increase in flight path descent angle induced by the extended landing gear doors was 0.43°;

d. with external fuel tanks and pylons, full flaps extended, no additional drag was caused by the gear doors within the resolution of the test instrumentation;

e. extension of half flap increased the descent angle by 1.62°;

f. full flap extension increased the descent angle a further 3.24°;

g. the increase in flight path descent angle caused only by external pylons was barely observable at 0.10°; and

h. the total increase in flight path angle for external pylons and fuel tanks was determined to be 0.47°.

PHASE 3 - FORCED LANDING PATTERN

Objectives

3.35 In this phase there were two objectives [4]:

a. predict the required altitudes for a forced landing using data gathered in phases one and two, and

b. verify the predicted pattern altitudes under simulated and actual engine out conditions.

Forced Landing Pattern

3.36 In the event of an engine failure requiring a forced landing a standard flight pattern was developed and is practised by all CT-114 pilots [5]. The pattern consists of a 360^{o} descending turn with ancillaries (landing gear, flaps) as required to maintain the desired flight path resulting in a safe landing onto the runway. Typically the following conditions and configuration changes are made:

a. airspeed: 130 KIAS;

b. bank angle: 30^{o};

c. landing gear down at high key (start of forced landing pattern);

d. half flaps extended at final key (270^{o} of turn); and

e. full flaps extended as required to achieve desired touchdown point.

Figure 3-10 presents the forced landing pattern in pictorial format [5].

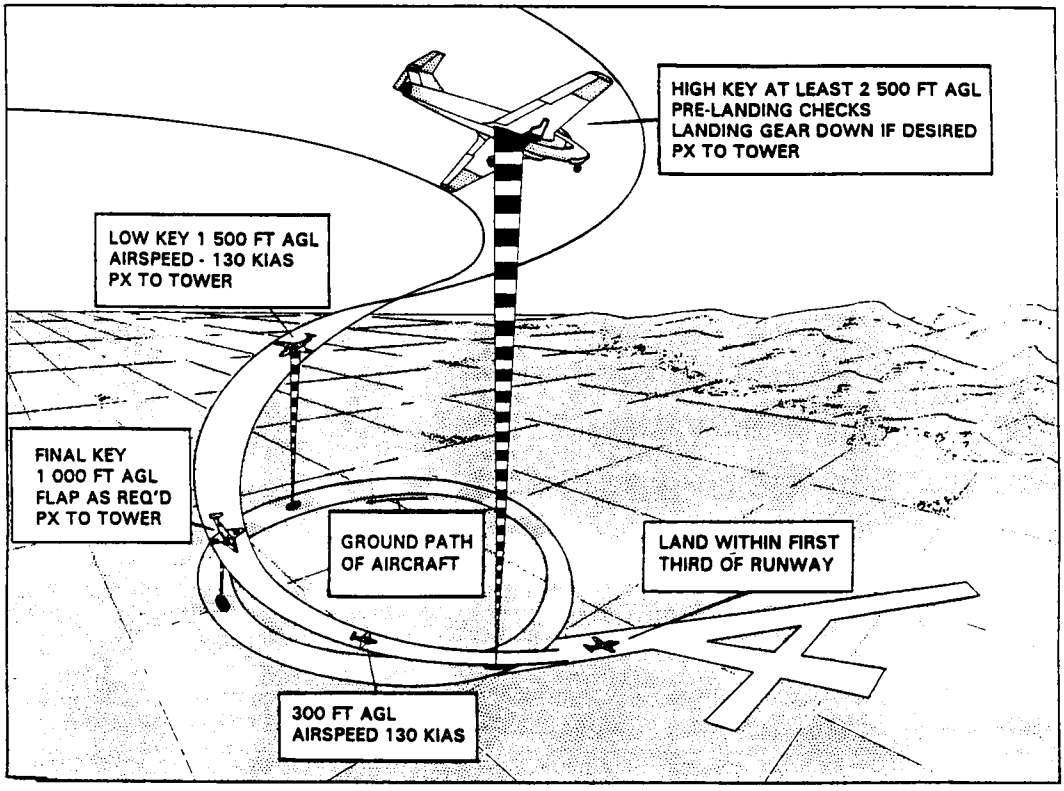


Figure 3-10. CT-114 Forced Landing Pattern

Source: Anonymous, "C-12-114-000/MB-000 Aircraft Operating Instructions" National Defence, Canada, 1 May 1993

Prediction of Required Altitudes

3.37 To predict the forced landing pattern altitudes it was necessary to extrapolate the flight path angle from wings level test data to turning flight [1]. A derivation of the required formulae is presented in Appendix A. The method used to derive the equations differed from the AOI. The AOI predicted the forced landing pattern altitudes by estimating a 2,200 ft requirement for a clean 360° turn then adding a 300 ft buffer [5]. The derivation used in this project accounted for configuration changes at specific points

within the forced landing pattern. No specific buffer was included but delaying ancillary selection provides the pilot with ample opportunity to correct back to the desired profile.

3.38 A desktop computer based spreadsheet program was used to calculate altitude loss for each phase of the forced landing pattern [1]. Flight test data for γ (wings level descent angle), q (dynamic pressure), C_L (wings level lift coefficient) and W (total weight) from phase 2 were used as inputs. The calculated forced landing pattern altitudes for the different configurations are presented in Table 3-4.

Table 3-4. Summary of Configuration Effects on Forced Landing Key Altitudes

CONFIGURATION (Gear Down for all cases)	ALTITUDES (AGL)		
	HIGH KEY	LOW KEY	FINAL KEY
Clean, Doors CLSD	2495	1393	842
Clean, Doors OPEN	2618	1449	864
Pylons, Doors CLSD	2469	1364	812
Pylons, Doors OPEN	2730	1499	883
Tanks, Doors CLSD	2631	1451	862
Tanks, Doors OPEN	2734	1497	879
Expected Tolerance (ft)	117.6	64.9	38.6
Average Doors Effect	162	79	37
Average Pylons Effect	42.9	10.4	-5.8
Average Tanks Effect	125.4	53.4	17.4

Source: Ellis, Charles A, "Project Report 9332 CT-114 Tutor Evaluation of Glide Profiles", Aerospace Engineering Test Establishment, CFB Cold Lake, Alberta, Canada, 1995.

3.39 There was a noticeable effect of aircraft configuration on pattern altitude requirements. The primary input into the calculation of individual key altitudes was the wings level flight path angle determined in phase two flight testing. The calculations were sensitive to variations in flap up γ because ¾ of the pattern is flown in this configuration.

3.40 Table 3-4 shows that extended landing gear doors have the largest effect on altitude required (162 ft at high key) followed by external fuel tanks (125 ft at high key). The effect of pylons alone was not noticeable within the expected data tolerance. The calculation erroneously showed less altitude required at final key in the pylon configuration. This result occurred because the phase 2 full flap flight test data resulted in a lower γ for the pylon configuration than for the clean configuration. The full flap variation of 3.7% was within the expected tolerance of 4.5% [9].

Forced Landing Pattern Verification

3.41 To verify the calculated altitudes, four sorties were flown [1]. Each sortie consisted of several simulated forced landing patterns to collect data for various landing gear and flap configurations. The final pattern of each sortie was completed by bringing the throttle to cut off and completing an actual forced landing. These patterns were completed to verify that the simulated engine out conditions were still representative and to increase the operational community's confidence in the flight test results. Weather conditions for the actual forced landings were restricted to clear visibility to the ground for all phases of the pattern, nil turbulence and maximum of 10 kt of wind.

3.42 The forced landing pattern was flown by adjusting the high key position into wind thereby allowing a constant 30° bank to be maintained. An initial position and altitude were chosen for the run in to high key over the desired landing point [chosen to be the intersection of the runways at CFB Cold Lake (Fig 3-11)].

3.43 The turn to enter the forced landing pattern was started at the calculated high key altitude [1]. Bank angle and airspeed were maintained and time and altitude at each key altitude was recorded. Configuration changes were made as specified in the forced landing procedure.

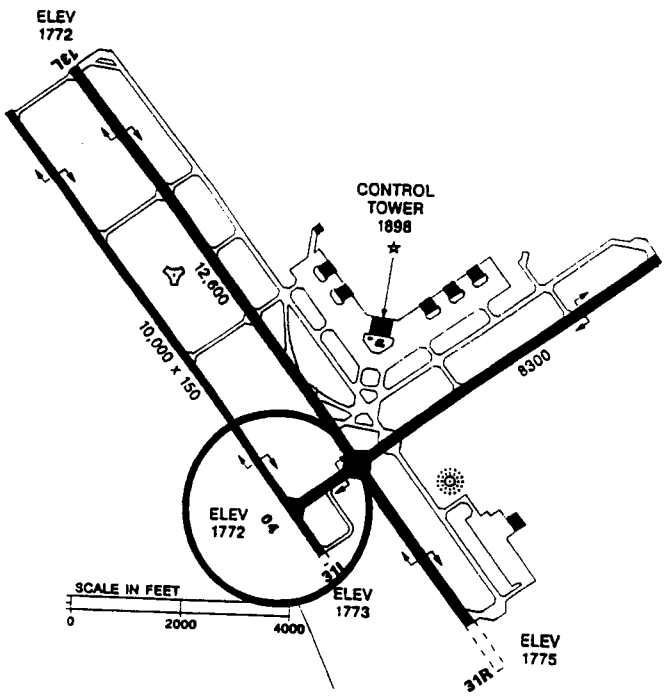


Figure 3-11. Cold Lake Aerodrome Layout Showing Forced Landing Pattern

Source: Ellis, Charles A, "Project Report 9332 CT-114 Tutor Evaluation of Glide Profiles", Aerospace Engineering Test Establishment, CFB Cold Lake, Alberta, Canada, 1995.

3.44 Comparison of predicted key altitudes and actual flight test data reveals good correlation. With the exception of one point, all results were within 1.5% of predictions. Figures 3-12 and 3-13 graphically portray the force landing altitude loss as a function of "key position" for the various configurations tested. For the clean, doors closed configuration (Fig 3-12) the current AOI agrees closely with the prediction and actual results. When the landing gear doors remain open, as when the landing gear is extended manually, the AOI prediction is 120 ft optimistic (i.e., actual altitude loss is greater than predicted). The new prediction agrees quite closely with actual results. With external tanks installed (Fig 3-13), the AOI does not predict accurately the altitude required to complete the forced landing pattern. The new predictions are generally accurate.

3.45 While the PD 9332 predictions were more accurate than the AOI for configurations other than clean, it was felt that adjusting pattern altitudes for each configuration was too complicated [1]. A compromise of adding 200 ft to the clean high key altitude for any other condition was more reasonable. This would account for all conditions except for the external tanks, landing gear doors extended case. The single addition of 200 ft to high key was chosen for several reasons:

a. the probability of a pilot having to complete a forced landing with manual landing gear extension in a tanked aircraft is extremely remote. If required, the external tanks could be jettisoned thus reducing the altitude required;

b. addition of too much altitude at high key would change the timing of ancillary selection and increase the difficulty in completing the forced landing pattern. As mentioned previously, 200 ft extra altitude accounts for nearly all possible scenarios; and

c. the mental mathematics required of the pilot to recalculate the various key altitudes is reduced if an even multiple of hundreds of feet is used. For example, two hundred feet extra at high key easily translates to one hundred ft extra at low key.

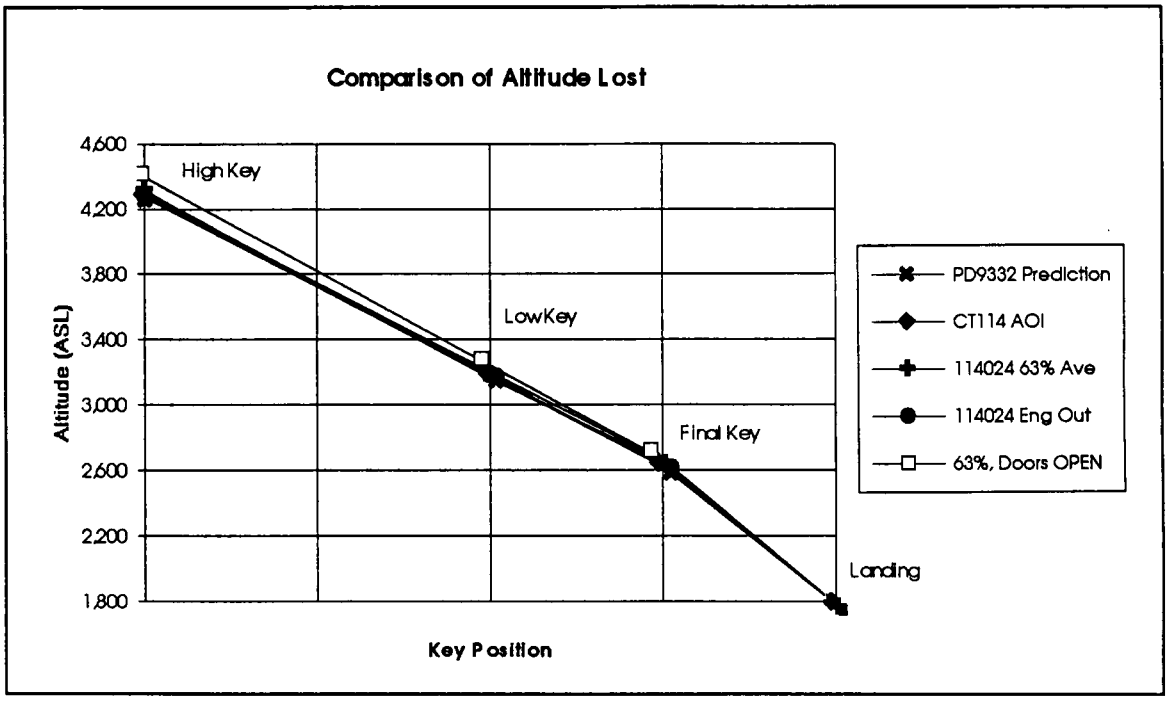


Figure 3-12. Comparison of Predicted and Actual Altitude Lost (Clean Configuration)

Source: Ellis, Charles A, "Project Report 9332 CT-114 Tutor Evaluation of Glide Profiles", Aerospace Engineering Test Establishment, CFB Cold Lake, Alberta, Canada, 1995.

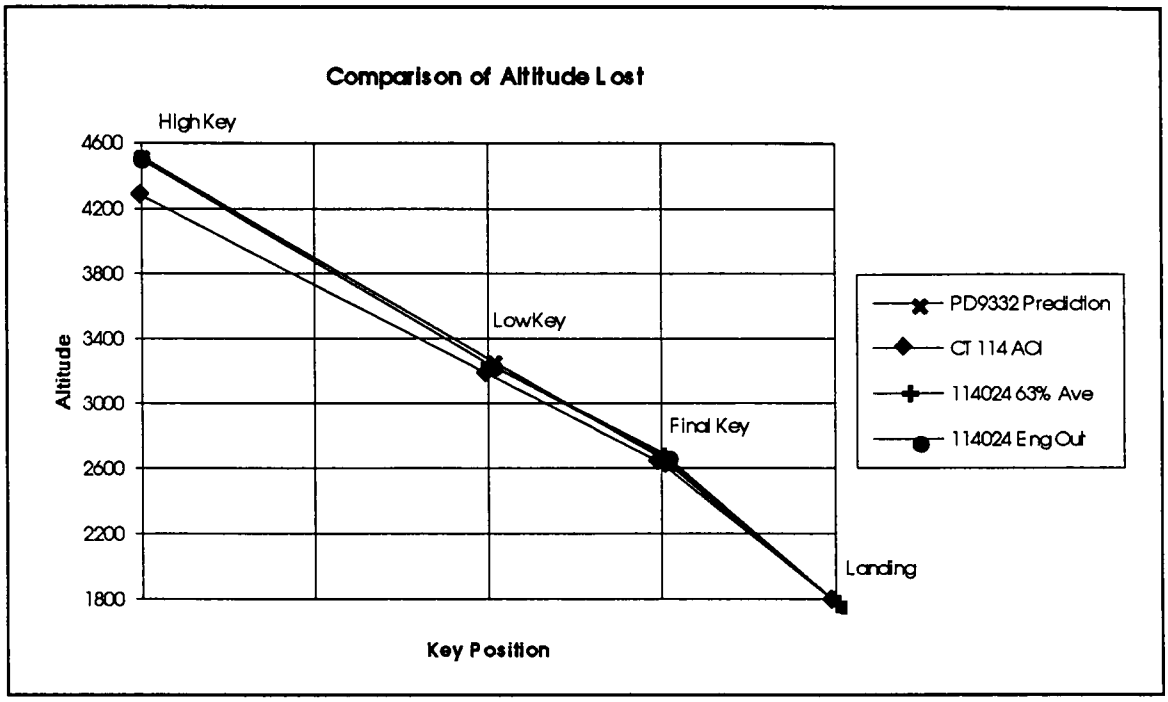


Figure 3-13. Comparison of Predicted and Actual Altitude Lost (Tanker Configuration)

Source: Ellis, Charles A, "Project Report 9332 CT-114 Tutor Evaluation of Glide Profiles", Aerospace Engineering Test Establishment, CFB Cold Lake, Alberta, Canada, 1995.

Conclusions

3.46 It was concluded that [1]:

a. the AOI pattern altitudes are accurate for the clean configuration;

b. the AOI does not predict accurately the pattern altitudes for extended landing gear doors or external stores;

c. the predicted pattern altitudes were accurate within expected error tolerance for all cases;

d. extended landing gear doors have the largest effect on altitude required (162 ft at high key) followed by external fuel tanks (125 ft at high key); and

e. comparison of predicted key altitudes and actual flight test data reveals good correlation.

Recommendation

3.47 It was recommended that the AOI high key altitude should be increased by 200 ft if the aircraft is in any configuration other than clean [1].

PHASE 4 - AIRFRAME VARIATION AND SEIZED ENGINE EFFECTS

Airframe Variations

General

3.48 During any flight test program there is a risk of reporting results based upon an article that is not fleet representative. It is impractical to test the entire fleet but some attempt to quantify normal variations within the fleet must be made.

Objective

3.49 The objective of this phase was to verify that the results of the testing were fleet representative [4].

Method

3.50 AETE had two CT-114 aircraft on hand as support and test aircraft [1]. These aircraft were used to compare the results of testing with the test aircraft, CT-114024, in an attempt to estimate airframe variation effects. Sawtooth descents under similar conditions were completed with each aircraft. Engine RPM was varied and the resultant

descent angle was compared to CT-114024 results. The different engine RPMs required to achieve the same descent angle was used as an estimate of individual airframe effects.

Detailed Airframe Comparison

3.51 Tutor CT-114024 was assigned temporarily to AETE and was the primary test article for this project [1]. Extensive modifications to renew the airframe electrical wiring were completed and tested under AETE PD 9308 [10]. Externally, the aircraft had fresh paint and a VHF antenna (Fig 3-13). Internally the aircraft was fitted with static inverters (allowing the radios to function with the engine shut down), VHF radio and modified intercom (ICS) system. Qualitatively, this aircraft had the highest performance of the three Tutors used for testing.

3.52 CT-114081 was used for airframe loads testing under a previous test program in addition to support duties [1]. The paint was slightly worn. A nose-mount for an angle of attack and sideslip probe was installed (Fig 3-15). The probe, which attached to the mount, was not installed during this project. External wires and sealant were present along the external flap tracks (Fig 3-16). Internally the aircraft was fleet representative although a slightly different UHF radio was installed. Qualitatively, this aircraft had performance similar to the rest of the CT-114 fleet.

3.53 CT-114147 was strictly used for support duties [1]. Internally and externally, the configuration was representative of the CT-114 fleet. The paint was worn substantially. Qualitatively, this aircraft had the lowest performance of the AETE Tutor fleet.



Figure 3-14. CT-114024 - VHF Antenna Detail

Source: Ellis, Charles A, "Project Report 9332 CT-114 Tutor Evaluation of Glide Profiles", Aerospace Engineering Test Establishment, CFB Cold Lake, Alberta, Canada, 1995.



Figure 3-15. CT-114081 - Nose Mount Detail

Source: Ellis, Charles A, "Project Report 9332 CT-114 Tutor Evaluation of Glide Profiles", Aerospace Engineering Test Establishment, CFB Cold Lake, Alberta, Canada, 1995.

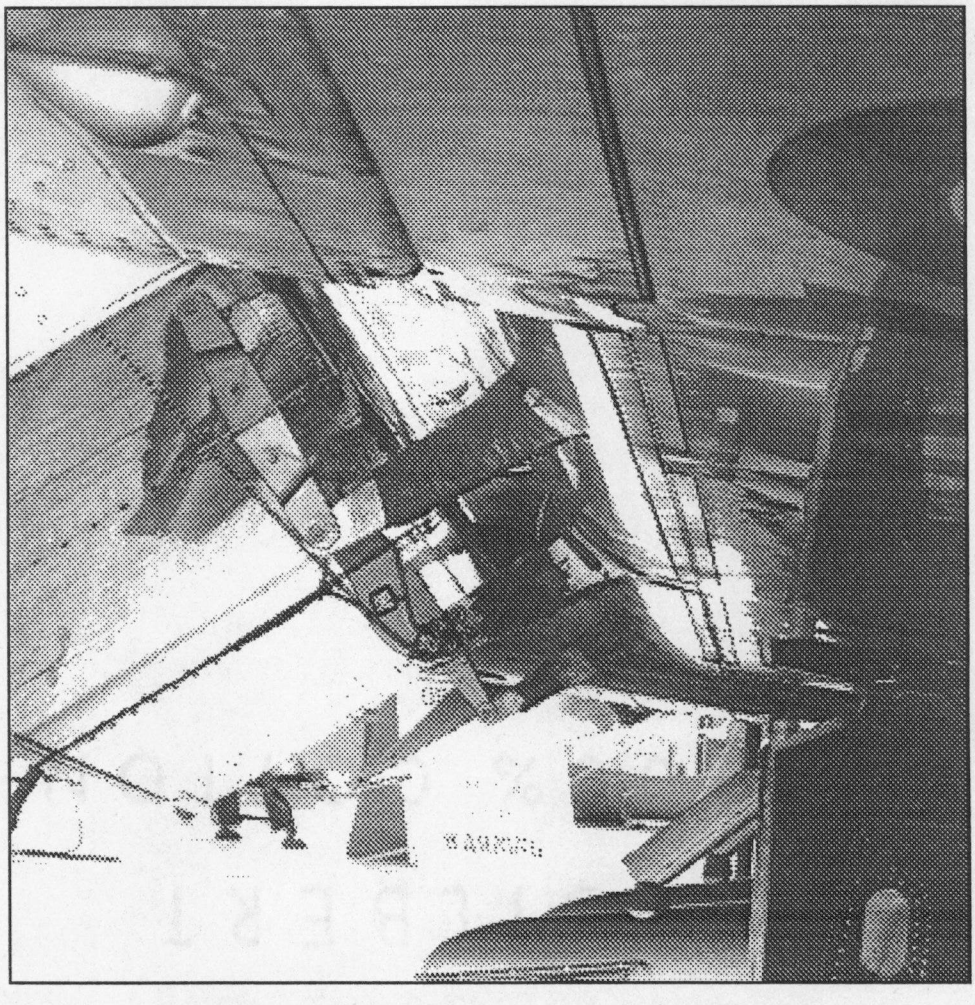


Figure 3-16. CT-114081 - Flap Sealant Detail

Source: Ellis, Charles A, "Project Report 9332 CT-114 Tutor Evaluation of Glide Profiles", Aerospace Engineering Test Establishment, CFB Cold Lake, Alberta, Canada, 1995.

Results and Discussion

3.54 A comparison of flight path angle for varying engine rpm under similar conditions of configuration and weight is presented as Figure 3-17.

3.55 Examination of the Figure 3-17 shows that CT-114081 performed approximately the same as CT-114024. CT-114147 required approximately 1% greater RPM to achieve the same flight path angle as CT-114024. These results support the premise that there are performance variations between individual aircraft within the CT-114 fleet but these variations do not change the glide performance substantially when simulating engine failure. It can be concluded that the results gained using CT-114024 are fleet representative.

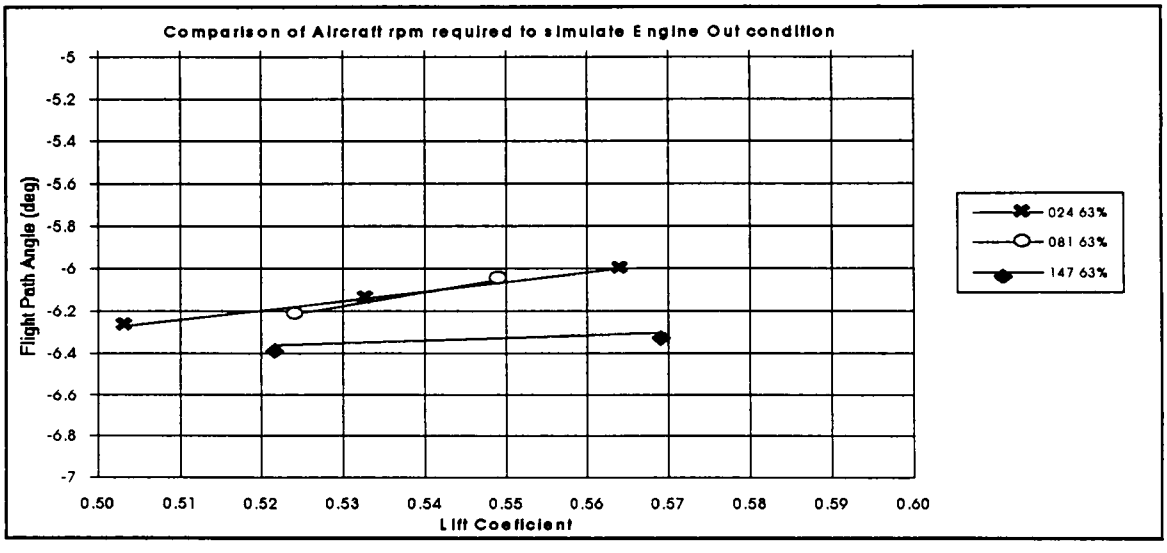


Figure 3-17. Comparison of Individual Airframe RPM

Source: Ellis, Charles A, "Project Report 9332 CT-114 Tutor Evaluation of Glide Profiles", Aerospace Engineering Test Establishment, CFB Cold Lake, Alberta, Canada, 1995.

Conclusions

3.56 The results gained using CT-114024 are fleet representative [1].

Seized Engine Performance

3.57 It proved impractical to accurately quantify the effects of a seized engine upon the glide performance of the CT-114 Tutor [1]. Analysis of the airflow as a function of engine RPM indicated that little air flows through the engine at low windmill RPM (6 - 8%). The effects of a seized engine would primarily consist of increased spillage of air out of the engine intakes and suction of ambient air into the exhaust duct. As the engine airflow is likely low under windmilling conditions the increased drag of a seized engine should be small.

3.58 If a forced landing with a seized engine were required, wing flaps or speed brakes would probably not be selected. These ancillaries would either not be available (total electrical failure for speed brakes) or would require constant pumping of the manual hydraulic pump to maintain the selected ancillary in the desired position. In either case, it may be considered prudent to not select either flaps or speed brakes and carry out the forced landing in a flapless configuration.

3.59 If a flapless forced landing were to be completed, aircraft energy management would be more critical than if ancillaries were available. The total drag of the aircraft is much lower in the flapless case and excess energy is not easily dissipated. The most likely outcome of a poorly flown flapless forced landing would result in crossing the runway threshold too high and too fast.

Conclusions

3.60 It was impossible to quantify the effects of a seized engine upon the glide performance of the CT-114 Tutor but the increased drag of a seized engine should be small [1].

4. CONCLUSIONS

4.01 The following conclusions were made as a result of the test program [1]:

a. the currently recommended best glide speed of 130 KIAS is valid for the clean, gear and flap up configuration (para 3.24);

b. the current rule of 2.5 NM per 1,000 ft for estimating the glide range of a clean Tutor is reasonably accurate and is simple to use (para 3.24);

c. the currently recommended forced landing pattern speed of 130 KIAS is faster than the optimum for configurations other than gear and flaps up, speed brakes in (para 3.24);

d. the current engine failure simulation is slightly optimistic. Sixty-three percent RPM and speed brakes out simulates actual performance at normal training altitudes. This RPM does not account for ambient temperature variations (para 3.24);

e. extension of the landing gear with the doors sequencing closed increased the flight path angle by an average of 1.93° (para 3.34);

f. the effect is less noticeable when external fuel tanks and pylons are installed (para 3.34);

g. the increase in flight path descent angle induced by the extended landing gear doors was 0.43° (para 3.34);

h. with external fuel tanks and pylons, full flaps extended, no additional drag was caused by the gear doors within the resolution of the test instrumentation (para 3.34);

i. extension of half flap increased the descent angle by 1.62° (para 3.34);

j. full flap extension increased the descent angle a further 3.24° (para 3.34);

k. the increase in flight path descent angle caused only by external pylons was barely observable at 0.10° (para 3.34);

l. the total increase in flight path angle for external pylons and fuel tanks was determined to be 0.47° (para 3.34);

m. the AOI pattern altitudes are accurate for the clean configuration (para 3.46);

n. the AOI does not predict accurately the pattern altitudes for extended landing gear doors or external stores (para 3.46);

o. the predicted pattern altitudes were accurate within expected error tolerances for all cases (para 3.46);

p. extended landing gear doors have the largest effect on altitude required (162 ft at high key) followed by external fuel tanks (125 ft at high key) (para 3.46);

q. comparison of predicted key altitudes and actual flight test data reveals good correlation (para 3.46);

r. the results gained using CT-114024 are fleet representative (para 3.56); and

s. it was impossible to quantify the effects of a seized engine upon the glide performance of the CT-114 but the increased drag of a seized engine should be small (para 3.60).

5. RECOMMENDATIONS

5.01 The following recommendations were made:

a. the current AOI best glide speed of 130 KIAS be retained (para 3.25);

b. the current rule of 2.5 NM per 1,000 ft in the clean configuration for estimating the glide range of the Tutor should be retained (para 3.25);

c. the engine out simulation configuration be changed to 63% RPM and speed brakes (para 3.25); and

d. the AOI recommended high key altitude should be increased by 200 ft if the aircraft is in any configuration other than clean (para 3.47).

LIST OF REFERENCES

LIST OF REFERENCES

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[11] Anonymous, "PD 9332 Ground Calibration Report", Aerospace Engineering Test Establishment, CFB Cold Lake, Alberta, July 1994

APPENDICES

APPENDIX A

FLIGHT PATH ANGLE DERIVATION
TURNING CONDITION

The purpose of this appendix is to show the derivation of the equations used to extrapolate descending flight path data gained through wings level flight testing to a turning situation. This turning descent angle data will then be used to calculate the altitudes required for a 360^{o} turning forced landing pattern.

Definitions

The following terms will be used during the derivation:

a. γ = flight path angle;

b. T = engine thrust output

c. L = total aircraft lift;

d. W = total aircraft weight;

e. D_{tot} = total aircraft drag;

f. D_i = induced drag;

g. D_w = wave drag;

h. D_p = parasite drag *D_p is assumed constant as airspeed, configuration, are not changing. Engine effects (i.e. airflow patterns around intakes and exhaust) during simulated engine failure are ignored;

i. AR = Wing Aspect Ratio;

j. e = Oswald efficiency factor;

k. q = dynamic pressure;

l. S = aircraft wing area;

m. C_L = 3D lift coefficient of wing;

n. Φ = bank angle of aircraft; and

o. Subscripts "level" and "turn" refer to aircraft bank angle

Consider descending, wings level flight (Fig A-1)

Thrust (T) = 0 for engine out conditions

$\therefore L = W \cos \gamma_L$ and (1)

$D = W \sin \gamma_L$ (2)

Consider Drag term:

$D_{total} = D_p + D_w + D_i$ (3)

but $D_p \approx$ constant

$D_w = 0$, and

$$D_i = \frac{1}{\pi ARe} qSC_L^2 \quad [8]$$

so substituting terms into D_{tot} (eqn 1):

$$D_{total} = D_p + \frac{1}{\pi ARe} qSC^2{}_L \quad (4)$$

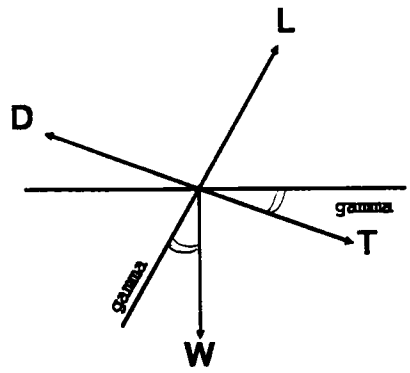
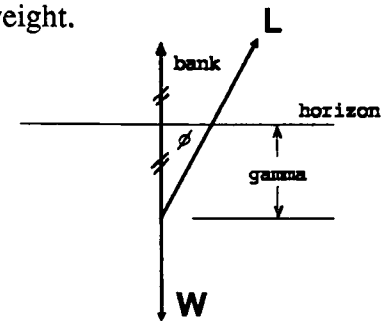


Fig A-1
Forces Acting on Aircraft
(Wings Level Descent)

Now start a turn from wings level glide (i.e. start FL pattern, Fig A-2) Total lift must increase to produce the turning force or the component of lift in the vertical must equal the aircraft weight.



$$L_{turn} = \frac{L_{level}}{\cos\phi} \qquad (5)$$

Figure A-2
Effect of Bank on
Lift Vector During Gliding Descent

This relationship assumes that there is no change in descent angle from wings level to turning case. ∴ since $L=C_L \cdot q \cdot S$ and q,S are constant

$$C_{L_{turn}} = \frac{C_{L_{level}}}{\cos\phi} \qquad (6)$$

The total drag for an aircraft in a turn can be expressed as:

$$D_{total_{turn}} = D_{P_{turn}} + \frac{1}{\pi \cdot AR \cdot e} \cdot q \cdot S \cdot C^2_{L_{turn}} \qquad (7)$$

but from eqn (2) that

$$D_{total_{turn}} = W \sin\gamma_L \qquad (8)$$

substituting into eqn (7) get:

$$D_{P_{turn}} + \frac{1}{\pi \cdot AR \cdot e} q \cdot S \cdot C^2{}_{L_{turn}} = W \sin\gamma_{Turn} \tag{9}$$

the same equation applies for wings level flight:

$$D_{total_{level}} = D_{P_{level}} + \frac{1}{\pi \cdot AR \cdot e} q \cdot S \cdot C^2{}_{L_{level}} = W \sin\gamma_{level} \tag{10}$$

Now subtract wings level from turning case:

$$D_{P_{turn}} + \frac{1}{\pi \cdot AR \cdot e} q \cdot S \cdot C^2{}_{L_{turn}} - D_{P_{level}} + \frac{1}{\pi \cdot AR \cdot e} q \cdot S \cdot C^2{}_{L_{level}} = W \sin\gamma_{Turn} - W \sin\gamma_{level}$$

but as airspeed, configuration are not changing:

$$D_{P_{turn}} = D_{P_{level}}$$

substituting we get:

$$\frac{1}{\pi \cdot AR \cdot e} q \cdot S \cdot (C^2{}_{L_{turn}} - C^2{}_{L_{level}}) = W(\sin\gamma_{turn} - \sin\gamma_{level}) \tag{11}$$

but:

$$C_{L_{turn}} = \frac{C_{L_{level}}}{\cos\phi}$$

substituting:

$$\frac{1}{\pi \cdot AR \cdot e} \cdot q \cdot S \cdot \left(\left(\frac{1}{\cos\phi}\right)^2 - 1\right) \cdot C^2_{L_{level}} = W(\sin\gamma_{turn} - \sin\gamma_{level})$$

rearranging:

$$\sin\gamma_{turn} = \sin\gamma_{level} + \frac{1}{\pi \cdot AR \cdot e} \cdot \frac{q \cdot S}{W} \cdot \left(\left(\frac{1}{\cos\phi}\right)^2 - 1\right) \cdot C^2_{L_{level}} \qquad (12)$$

To calculate altitude loss in turning flight, one must consider that the aircraft will be following a helical flight path where:

$$H = 2 \cdot \pi \cdot (r \cdot \tan\gamma)_{turn} \qquad (13)$$

where H = altitude loss for helix (360^0 of turn)

r = radius of helix

γ = descent angle

To calculate r assume that the descent angles are small therefore the turning radius is equivalent to wings level:

$$r = \frac{V^2}{g\sqrt{n^2 - 1}} \qquad (14)$$

Where:

$$n=\frac{1}{\cos\Phi} \tag{15}$$

Substituting:

$$H=\frac{2\cdot\pi\cdot V^2}{g\sqrt{n^2-1}}\tan(\gamma_{turn}) \tag{16}$$

With the helix radius known, the altitude loss for any particular portion of the forced landing pattern becomes a function of γ_{level}, and $C_{L\ level}$. The total altitude lost for the entire forced landing pattern is the sum of the altitude lost from high to final key (flaps up) plus final key to 45^{o} from runway heading (half flap) and 45^{o} to the runway (full flap).

APPENDIX B

TEST TEAM MEMBERS

Project Officer	Capt C. Ellis Multi-engine and Trainer Evaluation
Project Pilots	Capt C. Ellis Multi-engine and Trainer Evaluation
	Capt M. Girard Fighter Evaluation
Project Engineers	Capt J. Payne (USAF) Fighter Evaluation
	Capt D. Baker 2 Lt R. Sherwood Multi-engine and Trainer Evaluation
	Capt H. Kowal Engineering Evaluation

APPENDIX C

CHRONOLOGY OF EVENTS

Flight Safety Comment Describing Engine Failure - Forced Landing Incident [2]	1 Apr 93
Request to AIRCOM for Testing to Determine Glide Profiles	29 Apr 93
AETE Tasked to Evaluate CT-114 Tutor Glide Profiles [3]	7 Jul 93
Start Flight Test	27 Jan 94
Initial Results, Agreement to Proceed with Further Testing at Only 130 KIAS [7]	1 Jun 94
Flight Testing Completed	16 Sep 94
Interim Report Published	29 Sep 94
Test Results Briefing to 2CFFTS	26 Jan 95
Final Report Published [1]	4 July 95

VITA

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