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The Feasibility of Turnback from a Low Altitude Engine Failure During the Take-off Climb-out Phase

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Abstract

Engine failure in a single engine aircraft at a low altitude is a critical evolution which demands immediate implementation of established procedures. The purpose of this study is to evaluate the feasibility of executing a 180° turn and forced landing when engine failure occurs at 500 ft. following takeoff and transition to the climb-out phase of the flight. Using a variable stability flight simulator set for the performance of a light single engine aircraft and a computer-controlled automatic data acquisition system, various procedures for turning back to the airfield and landing were tested and optimized. Pilots ranging in experience from students with 40 hours, to FAA certified flight instructors, to veteran military pilots with more than 5000 hours were tested in the simulator controlled circumstances. The computer-controlled data acquisition system continually recorded the critical parameters of the flight and later processed the data for analysis. The final computer output consisted of eight graphs (airspeed, rate of climb, angle of attack, and bank angle vs time and altitude) and four different views of a graphic computer drawing of the actual flight path. With a data base of 28 pilots, an analysis of the processed output revealed that it is feasible to turn a light single engine aircraft 180° from 500 ft. and land the aircraft somewhere on the airfield. The data also show that the theoretical optimum bank of 45° with coordinated rudder does indeed turn the aircraft 180° with the least loss of altitude. However, the study also shows that 30° of bank with coordinated rudder produces only slightly inferior results with a much higher safety factor.

Nomenclature

AR	aspect ratio
b	wing span
C_D	total drag coefficient
C_{D_0}	drag coefficient at zero lift
C_L	lift coefficient
C_e	rolling moment coefficient
C_m	pitching moment coefficient
C_n	yawing moment coefficient
D	drag
e	efficiency factor
F_c	centripetal acceleration
g	gravitational acceleration
h	altitude
I_{xx}	roll moment of inertia
I_{yy}	pitch moment of inertia
I_{zz}	yaw moment of inertia
k	$1/\pi ARe$
L	lift
MAC	mean aerodynamic chord
p	roll rate
q	pitch rate
r	yaw rate
S	wing area
t	time
V	true airspeed
Y	inertial coordinate system
y	aircraft coordinate system
W	weight
Z	inertial coordinate system
z	aircraft coordinate system
α	angle of attack
β	side slip angle
δ_a	aileron deflection
δ_e	elevator deflection
δ_F	flap deflection
δ_r	rudder deflection
θ	pitch angle
ϕ	roll angle
Ψ	yaw angle
ρ	density

Introduction

The loss of power in a light single engine aircraft is a critical evolution under any circumstances. Moreover, when the engine failure occurs at a low altitude during the takeoff/climb-out phase of the flight, the pilot must respond immediately with the correct procedures in order to increase the probability of a successful emergency landing. When this type of emergency occurs, the current FAA approved procedures, as taught by certified flight instructors, call for the pilot to establish a glide at the velocity for maximum L/D and then attempt to restart the engine. If restart is unsuccessful, the pilot is to continue the glide straight ahead to a forced landing.

Time is one critical factor which distinguishes this emergency from engine failure at a higher altitude. At a higher altitude, the pilot has time to diagnose the problem and to attempt to restart the engine. If restart is unsuccessful, the pilot has time and altitude to select a suitable landing area and maneuver into an acceptable approach pattern. When engine failure occurs during climb-out at a low altitude (say 500 ft. above ground level (AGL)), the pilot has very little time to attempt to restart the engine and a very limited selection of landing areas if currently approved emergency procedures are followed. The problem of a suitable landing area can become critical if the airfield is surrounded by buildings, houses, woods or water. In fact, there are many airports in the United States where the only clear area in the vicinity of the end of the runway is the airfield itself. When emergency occurs at night, it does not matter how much clear area there is around the airfield if the pilot can't identify it until he is too low and already committed to a specific area. The purpose of the paper, then, is to propose and determine the feasibility of an alternative emergency procedure for engine failure at a low altitude during the takeoff/climb-out phase of the flight. The proposed procedure is to execute a 180° turn back to the vicinity of the airfield.

Basically, the formulation of this procedure involves finding the optimum bank angle and airspeed for the 180° turn back to the airfield. This can be found by applying aerodynamic principles to a steady state power-off gliding turn. The feasibility of the maneuver is investigated by testing a wide range of pilots under controlled conditions using a variable stability flight simulator. The theoretical optimum bank angle and airspeed can also be verified experimentally. Data is acquired in real time during the test flights using an automated, computer controlled, data acquisition system. The combination of theoretical analysis and experimental data yields an optimum procedure for turnback to the airfield and shows that a maneuver is within the capability of a typical private pilot.

Theory

The optimum bank angle and airspeed for turnback are those which correspond to the minimum altitude loss in a steady state gliding turn to a new heading (Refs. 1 and 4). When engine failure occurs, drag begins to slow the aircraft. If the pilot trys to maintain altitude by increasing the angle of attack, α, the stall speed of the aircraft will soon be reached and the pilot will then be forced to trade altitude for airspeed to keep the airplane flying. The optimum airspeed for maximum distance in a level glide power off is not the stall speed but rather the airspeed which corresponds to L/D_{MAX}. The point is that the aircraft must expend potential energy to overcome drag. In a banked turn, the lift is inclined at the bank angle, ϕ, (Fig.l). The aircraft now requires more lift to maintain steady state conditions. From Fig. 1 we have

$$L\cos\phi = \frac{1}{2}\rho V^2 S C_L \cos\phi = W \tag{1}$$

Therefore, the pilot must increase the velocity of the aircraft by expending potential energy (altitude) at a greater rate. The greater the bank angle in a steady state gliding turn, the greater the rate of descent necessary to maintain steady state conditions while in the turn. Thus, the time in the turn plays an important role in finding the optimum bank angle and airspeed.

From Fig. 1 we have

$$F_c = L\sin\phi = \frac{V^2}{R}\frac{W}{g} \tag{2}$$

Combining equations (1) and (2) yields

$$F = \frac{V^2}{gtan\phi} \tag{3}$$

Now the time required for the aircraft to turn through the angle Ψ is

$$t = \frac{\Psi}{\dot{\Psi}} \tag{4}$$

for a steady state turn

$$\dot{\Psi} = \frac{d\Psi}{dt} = \frac{V}{R} = \frac{\Psi}{t} \tag{5}$$

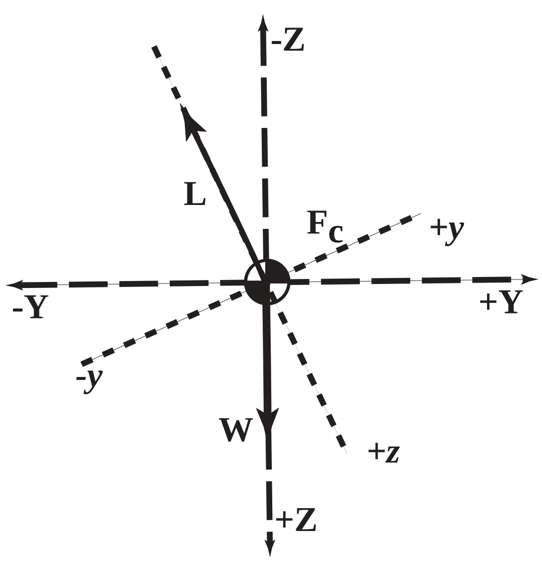

Figure 1. Forces in the yz plane acting on an aircraft in a steady state gliding turn.

The rate at which the aircraft is losing potential energy (altitude) must be equal to the rate at which energy is being expended to overcome drag. Thus,

$$W\frac{dh}{dt} = DV \tag{6}$$

For steady state conditions

$$W\frac{h}{t} = DV \tag{7}$$

which may be written as

$$h = \frac{D}{W}Vt \tag{8}$$

Combining with equations (3) and (5) yields

$$h = \Big(\frac{DV}{W}\Big)\frac{V}{g}\frac{\Psi}{\tan\phi} \tag{9}$$

Noting that

$$\frac{D}{W} = \frac{C_D}{C_L}\cos\phi$$

and

$$V^2 = \frac{2W}{\rho S C_L \cos\phi}$$

equation (9) becomes

$$h = \left[\frac{C_D}{C_L^2}\frac{2W}{\rho S g}\frac{1}{\cos\phi\sin\phi}\right]\Psi \tag{10}$$

Differentiation with respect to Ψ yields the conditions for minimum loss of altitude with heading change

$$\frac{dh}{d\Psi} = \frac{C_D}{C_L^2}\frac{2W}{\rho S g\sin\phi\cos\phi} \tag{11}$$

Noting that

$$sin2\phi = 2\sin\phi\cos\phi$$

equation (11) becomes

$$\frac{dh}{d\Psi} = \frac{C_D}{C_L^2}\frac{4W}{\rho S g\sin\phi} \tag{12}$$

Examining each term, we note that for a parabolic drag polar

$$C_D = C_{D_0} + kC_L^2 \tag{13}$$

and

$$\frac{C_D}{C_L^2} = \frac{C_{D_0}}{C_L^2} = k \tag{14}$$

which is a minimum at maximum C_L. Thus, the airspeed for minimum loss of altitude occurs at $C^2_{L_{\text{MAX}}}$ or the stall speed. For a given altitude, the second term, $4W/\rho S g\sin 2\phi$, is

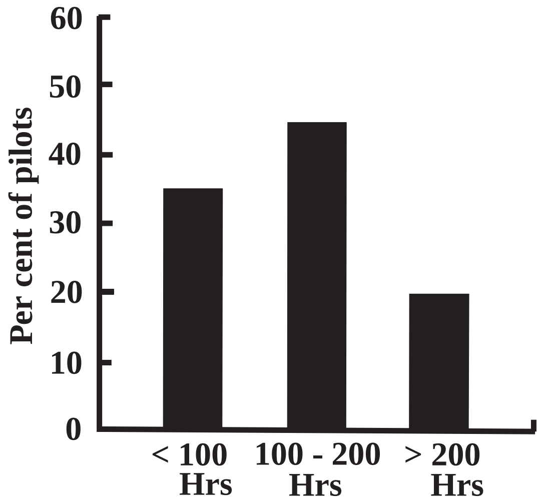

Figure 2. Total flight hours of the test pilots.

a minimum when $\sin 2\phi = 1$ or $\phi = 45°$. Thus, the bank angle for minimum loss of altitude is 45°.

The effect of flaps on this maneuver will depend upon the aircraft being flown. The increased lift and drag which occur with flap deflection will effect the C_D/C_L^2 term of equation (12). For the simulator used in the test flights, flap deflection results in a very slight increase in C_D/C_L^2. However, this increase is so small that the effect of flap deflection can be considered negligble.

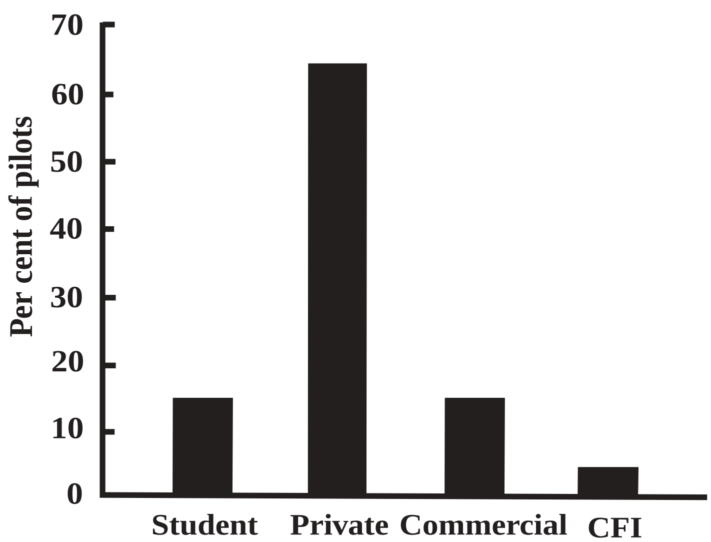

Figure 3. Highest rating achieved by the test pilots.

Figure 4. The GAT-IVS during a simulated flight.

Experimental Verification

Description of Experiment

The basic experimental investigation considered the feasibility of a pilot successfully performing a 180° turn with 45° angle of bank at just above the stall speed. The investigation used pilots of various backgrounds and experience for testing. Their experience levels ranged from a student pilot with 40 hours, to an FAA certified flight instructor, to a former military pilot with more than 5000 hours (Figs. 2 and 3). All total, there were 28 test pilots and 203 test flights of which 20 pilots and 147 flights were considered useful. Using a variable stability flight simulator, the pilots were tested using a series of seven flights. The pilots had no prior knowledge as to the nature of the test flights.

Variable Stability Flight Simulator

The simulator used was the Singer Simulation Products Division's General Aviation Trainer Variable Stability (GAT-IVS) developed for the Naval Academy's Aerospace Engineering Department. The GAT-IVS (Fig. 4) has three degrees of motion about its base (roll, pitch and yaw) and is fully instrumented for IFR flight. Physical motion of the simulator in roll and pitch is less than the actual aircraft motion indicated on the instruments. In roll, the simulator's motion is 1/6 of the actual aircraft motion, and in pitch the simulator's motion is 1/3 of the actual aircraft motion. The yaw motion of the simulator is the same as the actual yaw of the airplane.

The variable stability characteristic of the simulator allows the user to select a wide range of stability and control characteristics, which result in a wide range of flying qualities. The variable stability control panel, shown in Fig. 5, located on the starboard side of the fuselage, has control knobs arranged in four major groups:

- the stability and control derivatives group – the roll, pitch and yaw controls;
- the static trim group – the drag polar slope $C_{D_{C_L^2}}$ and the lift curve slope $C_{L\alpha}$;

Table I

GAT-IVS Standard Flight Parameters

Stability derivatives

Pitch	Static trim
$C_{M_{C_L}} = -0.314$	$C_{D_{C_L^2}} = 0.060$
$C_{M_q} = -0.0928$ slug sec/ft^2	$C_{D_0} = 0.034$
$C_{n_{\delta_e}} = -0.900$	$C_{L_\alpha} = 4.412\,\text{rad}^{-1}$
Roll	Moments of Inertia
$C_{\ell_\beta} = -0.1014\,\text{rad}^{-1}$	$I_{xx} = 870$ slug ft^2
$C_{\ell_\rho} = -0.00481$ slug sec/ft^2	$I_{yy} = 1147$ slug ft^2
$C_\ell = -0.0260$	$I_{zz} = 1700$ slug ft^2
Yaw	Other Parameters
$C_{n_\beta} = 0.0751\,\text{rad}^{-1}$	$S = 157\,\text{ft}^2$
$C_{n_r} = 0.00198$ slug sec/ft^2	$b = 32.7\,\text{ft}$
$C_{n_{\delta_a}} = 0.0024$	$MAC = 4.8\,\text{ft}$
$C_{n_{\delta_r}} = -0.0292$	$W = 1600\,\text{lbs}$
	$\Delta C_{L_{\delta_F}} = 0.65$
	$\Delta C_{D_{\delta_F}} = 0.068$

- the moment of inertia group – I_{xx}, I_{yy}, I_{zz};
- the step function control group – δ_e, δ_a, δ_r.

Figure 6. The GAT-IVS cockpit and instrument panel.

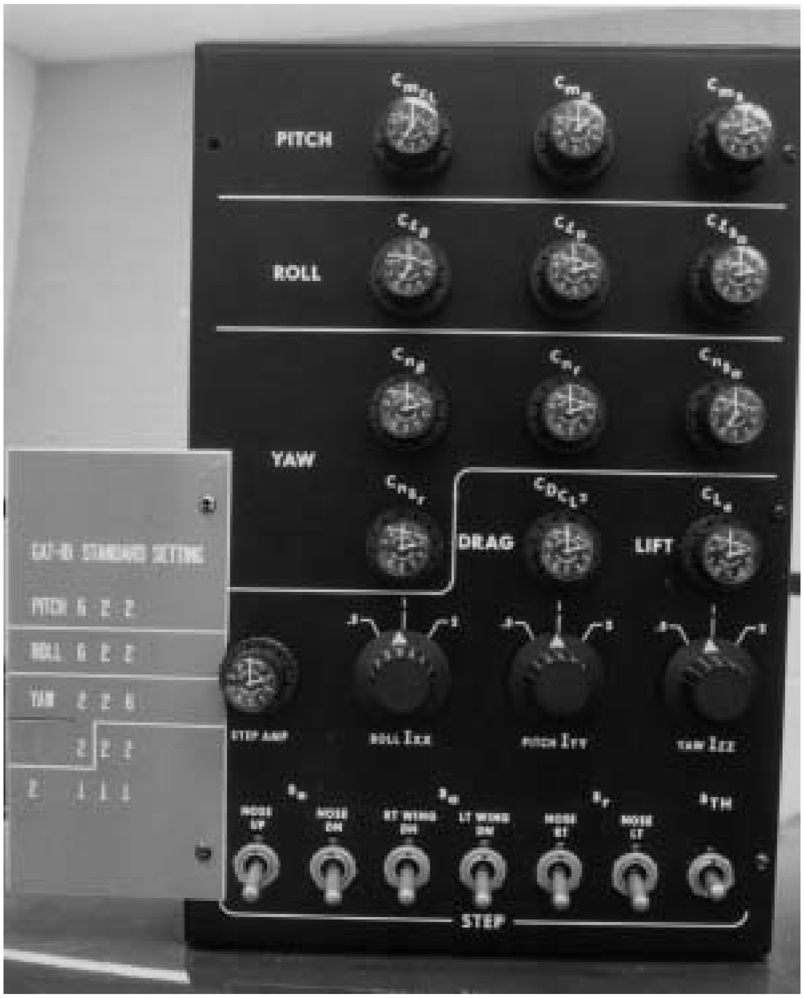

Figure 5. The GAT-IVS variable stability control panel.

The basic GAT-IVS settings were used for the experiment and are listed in Table I along with other basic flight parameter values (Ref. 3). The basic GAT-IVS settings result in the simulator approximating the behavior of a “single-engined, light utility/sport airplane” (Ref. 3).

The simulator cockpit (Fig. 6) is representative of a standard light single engine aircraft. During the experiment, the simulator was set for a fixed pitch, fixed gear aircraft. The pilots were not required to use any communications equipment during the experiment. All instructions were issued directly to the pilot.

The instructor control panel (Fig. 7). located on the starboard side of the GAT-IVS allows the experimentor to control various aircraft and environmental parameters. The standard settings were used and are listed in Table II (Ref. 3). Notice that the instructor control panel contains the engine failure switch. Figure 8 shows the physical location of both control panels.

Figure 7. The GAT-IVS instructor control panel.

Data Acquisition System

The computer system used to record, process and display the simulator flight test data consisted of the following (Fig. 9):

a Tektronix 4051 Computer Graphics System with 32K memory;

a Tektronix 4907 File Manager;

a Tektronix 4051 #01 ROM Expander;

a Tektronix 4631 copier.

The 4051's capabilities were enhanced by using four Read Only Memory (ROM) modules, which incorporated various additional features. A Transera data acquisition ROM module contained the analog to digital conversion capability necessary to record the flight parameters of the simulator in real time. A real time clock and all the matrix multiplication routines required for graphic displays were contained in two other ROM modules. The fourth ROM module was exclusively for manipulating and managing data files on the 4907.

The 4907 File Manager recorded all the flight data in real time onto a flexible disc storage device. This flexible disc also held the eight computer programs necessary for data

Figure 8. The GAT-IVS control panels, cockpit and instrument panel.

acquisition, processing and display. The 4631 produced copies of the graphic displays on the 4051's cathode ray tube (CRT). Figure 10 shows the complete simulator test flight and the data acquisition system.

The Computer Programs for Data Acquisition, Processing and Display

The data acquisition computer program uses the analog to digital capability of the Transera ROM module to record 11 different flight parameters (Ref. 3 and Table III). Actually, the flight parameters correspond to 11 voltages on 11 different output channels from the simulator. These voltages are recorded in real time as each channel is scanned at the rate of once per second. The data is stored in a 'packed' format on the disc of the 4907 File Manager.

Table II

Standard Instructor Panel Settings for GATIVS

Control/Parameter	Value/Position
Center of Gravity	25% MAC
Gross Weight	1600 lbs
Outside Air Temperature	standard
Rough Air	off
Barometric Pressure	29.92 in Hg
Wind Velocity	0 knots
Wind Direction	0 degrees
Pitch, Roll Yaw motion	on
Communications Frequency	disregard
Engine Controls Group	normal

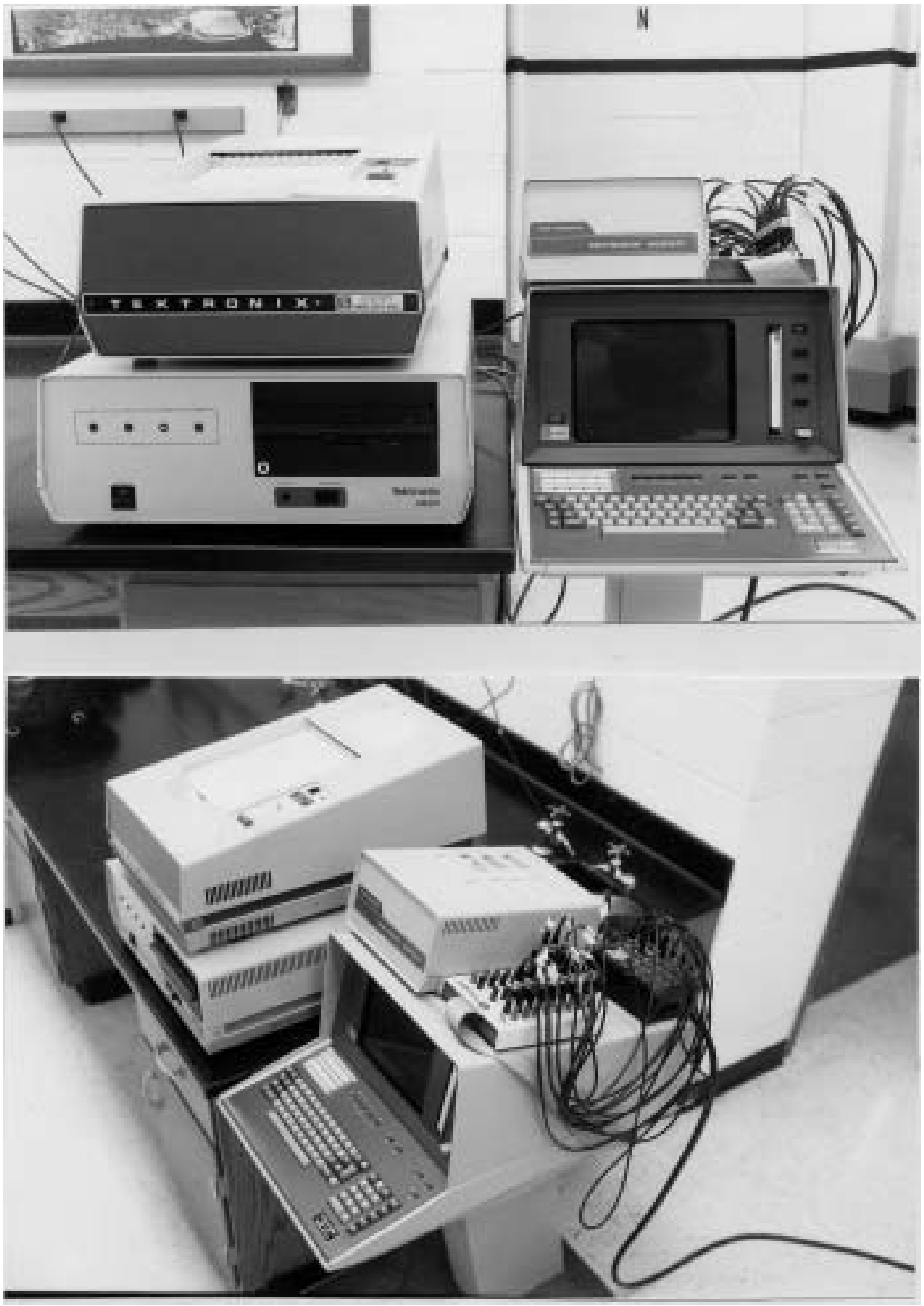

Figure 9. The computer controlled data acquisition system.

The data processing programs are completely automated and only require the user to start the first program in the sequence. From then on, the computer automatically processes the data from each test flight on the disc, displays each result on the 4051 CRT and copies each display with the 4631 copier. An unlimited number of test flights can be processed without any manual input. The only restriction is the amount of storage space on each disc.

Figure 10. The simulator test flight and data acquisition system.

The first program in the processing sequence unpacks the data into a usable form. Then, another program converts the voltages recorded during the test flight into the actual flight parameters (airspeed, altitude, etc.). The conversion factors for each flight parameter were obtained from the GAT-IVS laboratory manual and the routine was calibrated by performing several calibration test flights.

With the flight parameters now available, the next program in the processing sequence calculates the flight path of the aircraft. First, a three dimensional velocity vector is calculated at time t_l. The position of the aircraft one second later, at time t_2, is approximated by assuming a constant velocity for the entire second. Then a new three-dimensional velocity vector is calculated for time t_2. The position of the aircraft one second later, at time t_3, is determined by the same method. Since the initial position of the aircraft is known (the end

Table III

Flight Parameters Recorded From GAT-IVS

Angle of attack (α)
Side slip angle (η)
Pitch angle (θ)
Roll angle (ϕ)
Heading - (two channels required)
Altitude (h)
True airspeed (V)
Thrust
Gear extension
Flap deflection

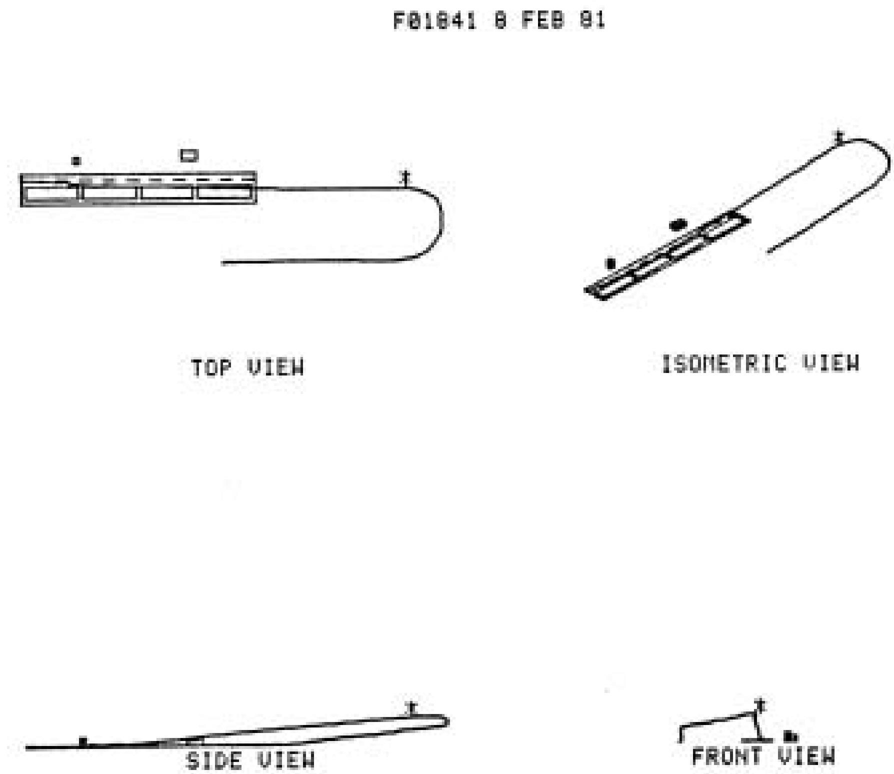

Figure 11a. Flight path drawings and digital output of a successful test flight.

FLIGHT DATA FOR F01041 8 FEB 81

DURATION OF FLIGHT: 110 SEC	AIRCRAFT WEIGHT: 1600 LBS
RUNWAY HEADING: 270 DEG	FINAL POSITION (X): 3423 FT
FIELD ELEVATION: 42 FT	FINAL POSITION (2): 1423 FT
MAX ALTITUDE: 481 FT(AGL)	MAX AIRSPEED: 79 KNTS
MAX R/C: 2648 FT/MIN	MIN R/C: 1729 FT/MIN
MAX RIGHT BANK: 40 DEG	MAX LEFT BANK: 3 DEG
MAX ANGLE OF ATTACK: 14 DEG	

of the runway), the entire flight path can be calculated by this method.

The two display programs produce the graphic output shown in Fig. 11. After copies of the output are automatically made by the 4631 copier, the entire sequence starts again on the next flight waiting to be processed. Additionally, there are two manual display programs which will produce full size (8 1/2" x 11") displays of any graph or flight path drawing. The techniques used for the graphic display are detailed in Ref. 2.

Conduct of the experiment

The actual experiment was conducted in the following manner. Each pilot was given a thorough briefing on the simulator and allowed to conduct a familiarization flight. The

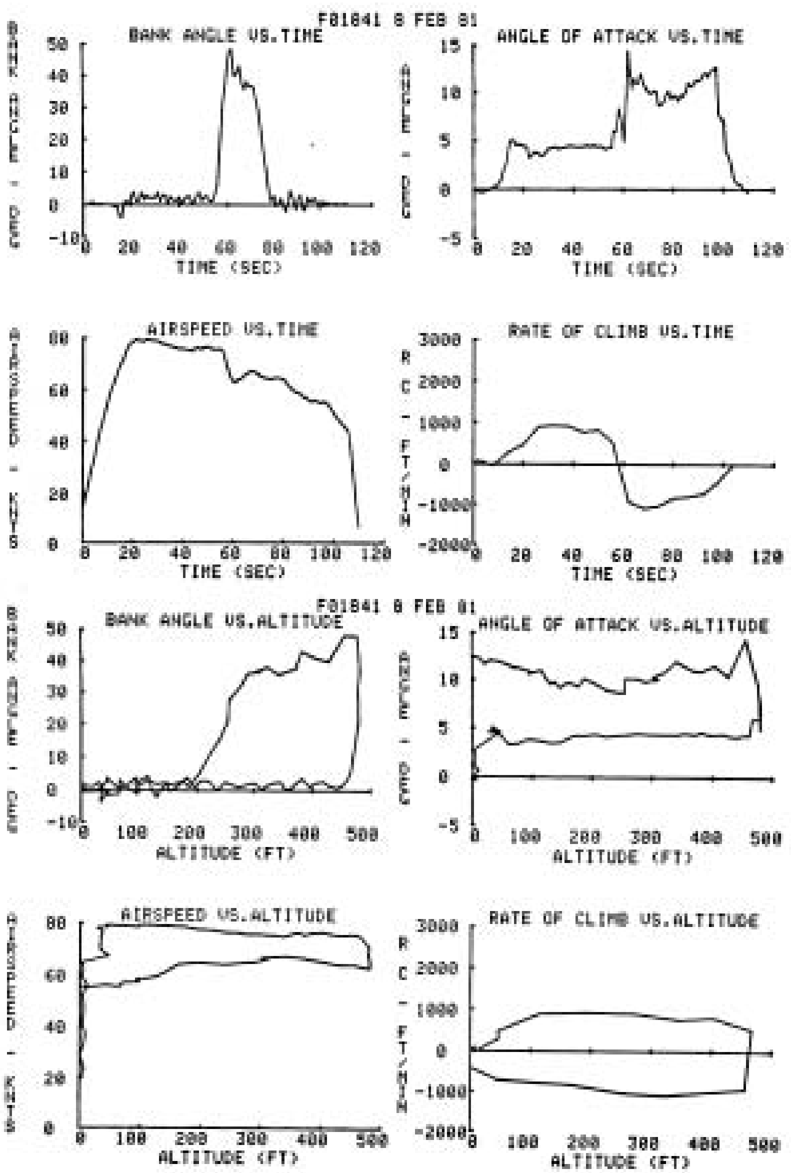

Figure 11b. Graphic output of the flight parameters from a successful test flight.

testing did not begin until the pilot indicated that he felt comfortable flying the simulator. Prior to each test flight, the pilot received a standardized briefing for the particular maneuver required by the flight. During each flight, engine failure occurred at 500 ft. AGL, and the results were recorded by the computer. The following are the instructions given before each flight.

Flight #1

"The purpose of this experiment is to test procedures used by pilots in emergency situations. You are to begin this flight with a normal takeoff, a straight-out departure, and climb to 3000 ft. After reaching altitude, you will receive further instructions. Sometime during the flight you will experience an emergency – handle the situation using any procedure you wish. If you are ready to begin, bring the airplane to runway heading and begin your takeoff."

Flight #2

"As you now know, the emergency situation we are studying is engine failure in a single engine aircraft during the climb-out phase of the flight. Again, this time your engine will fail – handle the situation any way you wish. If you are ready, bring the aircraft to runway heading and begin your takeoff."

Flight #3

"For test flight #3, we would like for you to try the following procedure: When your engine fails, turn the aircraft 180° and make a simulated landing on your new heading. Your engine may fail at any time continue in a straight-out departure until then. If you are ready, bring the aircraft to runway heading and begin takeoff."

Flight #4

"For test flight #4, we would like for you to try the following procedure: When your engine fails, turn the aircraft 180° using a coordinated 45° banked turn with the airspeed just above stall and make a simulated landing on your new heading. The object is to turn the aircraft with a minimum loss of altitude. Again, continue in a straight-out departure until your engine fails. If you are ready, bring the aircraft to runway heading and begin takeoff."

Flight #5

"For test flight #5, we would like for you to, when your engine fails, turn the aircraft 180° with 45° bank, full rudder, airspeed just above stall, and make a simulated landing on your new heading. The object is still to turn the aircraft with a minimum loss of altitude."

Flight #6

"For test flight #6, when your engine fails, turn the aircraft 180° with 15° bank, full rudder, airspeed just above stall and make a simulated landing on your new heading."

Flight #7

"For test flight #7, when your engine fails, turn the aircraft 180° with 30° bank, coordinated rudder, with the airspeed just above stall and make a simulated landing on your new heading. Remember the object is to turn the aircraft with a minimum loss of altitude."

Results

The automated computer system, which analyzed the flight test data, produced as a final output for each flight (Fig. 11):

- four graphs of airspeed, rate of climb, bank angle, and angle of attack as a function of time;
- four graphs of airspeed, bank angle, rate of climb and angle of attack as a function of time;
- Three orthoginal views and one 3-D isometric view of the simulator's flight path;
- a digital print out of various flight parameters.

A full size display of any particular graph or flight path can also be obtained. All of the

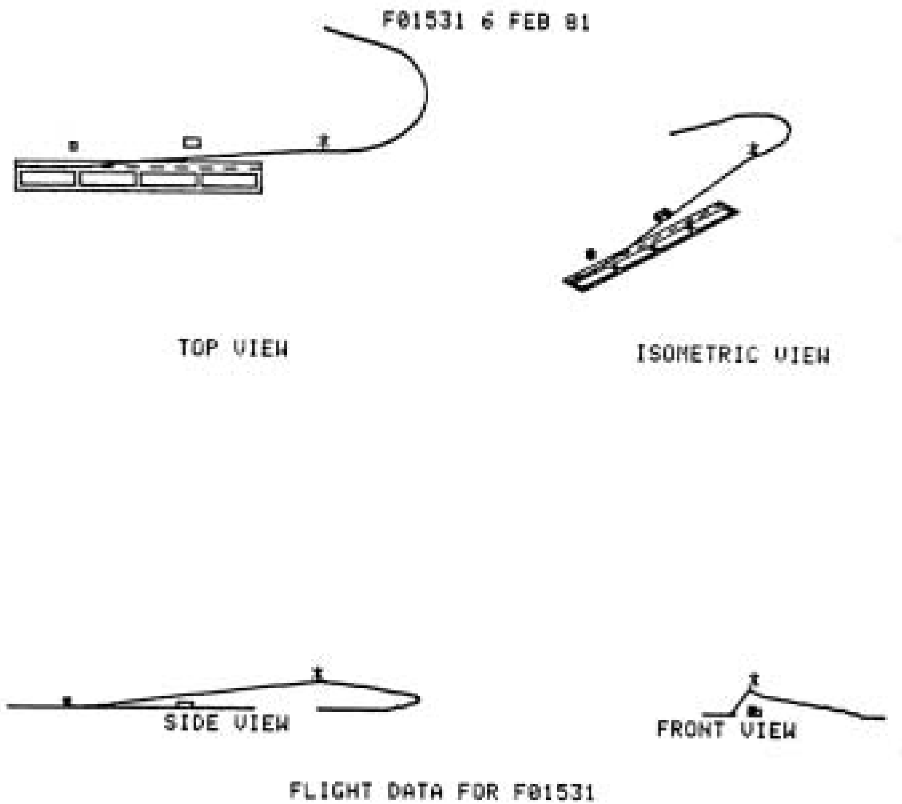

Figure 12a. Flight path drawings and digital output of an unsuccessful test flight.

FLIGHT DATA FOR F01531 6 FEB 81

DURATION OF FLIGHT: 114 SEC	AIRCRAFT WEIGHT: 1600 LBS
RUNWAY HEADING: 270 DEG	FINAL POSITION (X): 5048 FT
FIELD ELEVATION: 47 FT	FINAL POSITION (2): 2422 FT
MAX ALTITUDE: 487 FT(AGL)	MAX AIRSPEED: 73 KNTS
MAX R/C: 2964 FT/MIN	MIN R/C: 1946 FT/MIN
MAX RIGHT BANK: 4 DEG	MAX LEFT BANK: 17 DEC
MAX ANGLE OF ATTACK: 14 DEC	

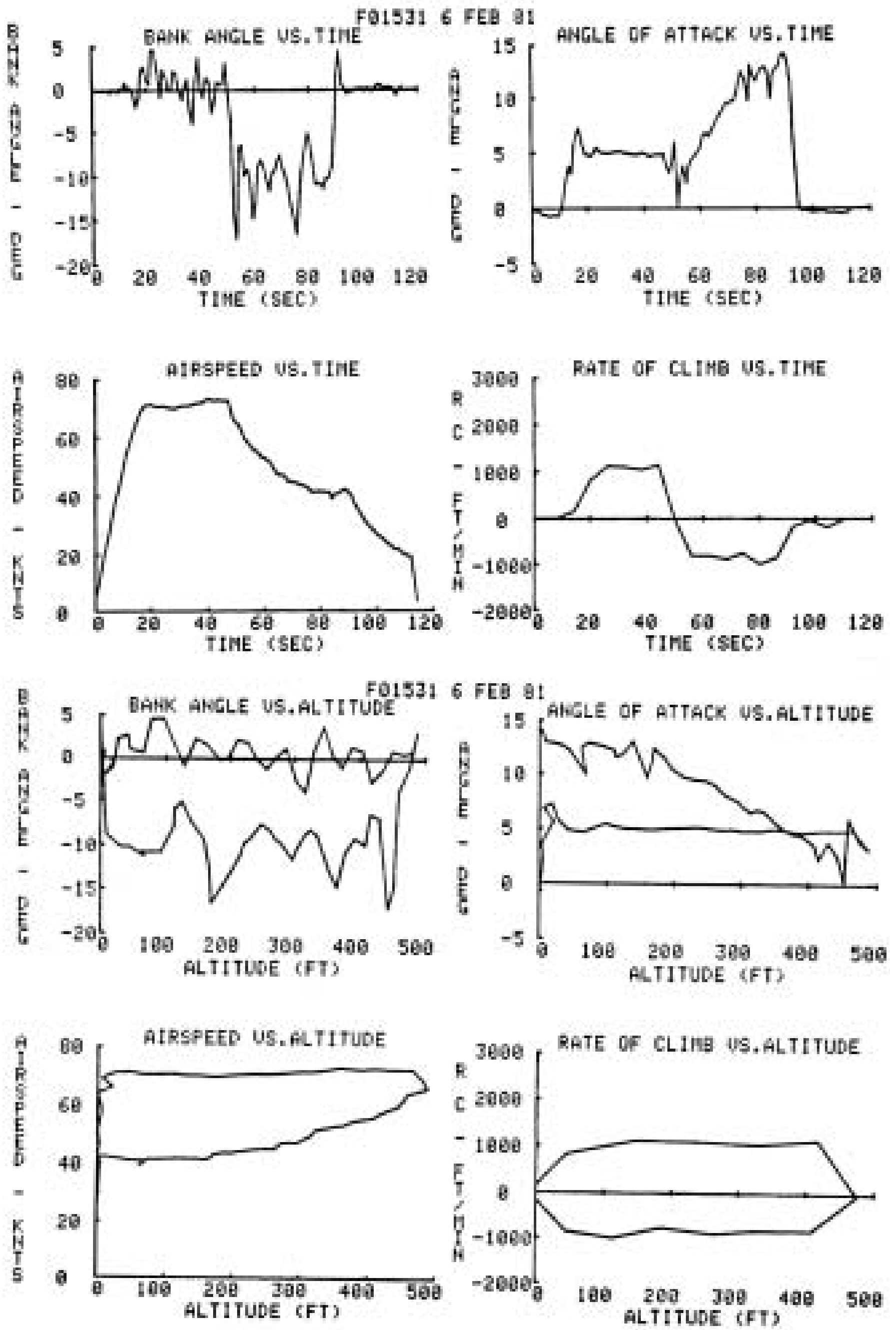

Figure 12b. Graphic output of the flight parameters from of an unsuccessful test flight.

analysis in the subsequent section is based on this information depicted in these displays.

Analysis

The first step in the data analysis was to establish the criteria for successful conventional emergency landings and for successful turnback emergency landings. The following are the criteria used for successful conventional emergency landings:

- the maximum rate of descent during the flight must not exceed 2500 feet per minute (fpm);
- the rate of descent at touchdown must not exceed 500 fpm;
- the wings must be level ($\pm 5°$) at all altitudes below 100 ft. AGL.

The criteria for successful turnback emergency landings are the same as for the conventional emergency landings with the following additions:

- the pilot must complete a turn of at least 175° at an altitude above 100 ft. AGL;
- the maximum bank angle in the turn must be less than 55°.

Figure 12 shows the output of an unsuccessful turnback flight. Compare this output with that in Fig. 11, which is from a successful turnback flight.

Test Flight 1

Recall that for this flight, the pilot was told to climb to 3000 ft. AGL and await further instructions. Therefore, the engine fai1ure at 500 feet should have been totally unexpected. The data analysis shows that 17 out of the 20 pilots (85%) continued straight ahead to emergency landings. Of those that continued straight ahead, 100% of the landings were successful (assuming there was a suitable place to land the aircraft). Two of the three pilots who attempted to turnback to the airfield crashed as a result of steep bank angles and the subsequent spin/stall. Both of these pilots have private ratings and between 100 and 200 hours of total flight time. The pilot who was successful in turning back to the airfield also has a private rating, but has less than 100 hours total flight time. The angle of bank used by this pilot in the turn was 40°

An interesting observation made during the testing was that less than 50% of the pilots tried to restart the engine. One FAA certified flight instructor did not try to restart the engine; however, every pilot with military flight training did attempt a restart.

Test Flight 2

Recall that the only difference between this flight and test flight 1 is that the pilot knows his engine will fail. The pilot who successfully turned back to the airfield in flight 1 did so again in flight 2. The two pilots who unsuccess- fully tried to turnback in flight 1 decided to continue straight ahead to successful emergency landings in flight 2. Again, 100% of the straight ahead emergency landings were successful. Inter- estingly, one student pilot with 56 hours of flight time attempted to turnback in flight 2 after having made a successful straight ahead landing in flight 1. The attempted turnback was unsuccessful.

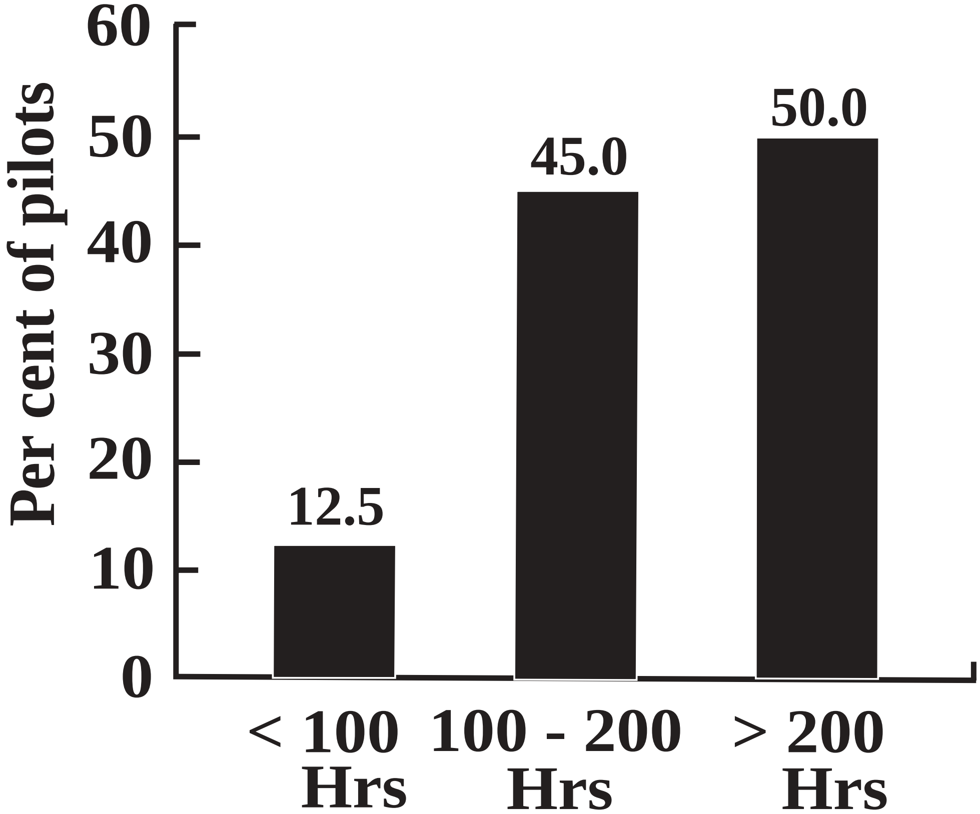

Figure 13. Test flight 3 success rate for pilots grouped according to flight hours.

Test Flight 3

In this flight, the pilot was told to attempt a 180° turn and emergency landing after engine failure. No specific procedure was specified. This type of flight could occur in a real life situation if, after engine failure, the pilot immediately realize that there wasn't a suitable landing area anywhere ahead. If this happens, the pilot will be tempted to try a turnback to the airfield. The overall percentage of successful flights was 42.86%. Figure 13 shows a breakdown of the success rate by the pilots grouped according to flight hours. As expected, the highest percentage of successful flights occured in the group of pilots with more than 200 hours. Figure 14 shows the distribution of the successful flights according to the maximum bank angle used in the turn. Approximately eighty-five percent (84.62%) of the unsuccessful flights were the result of the bank angle exceeding 55° and a subsequent spin/stall.

Test Flight 4

The procedure for the 180° turn to an emergency landing was specified in this flight as follows:

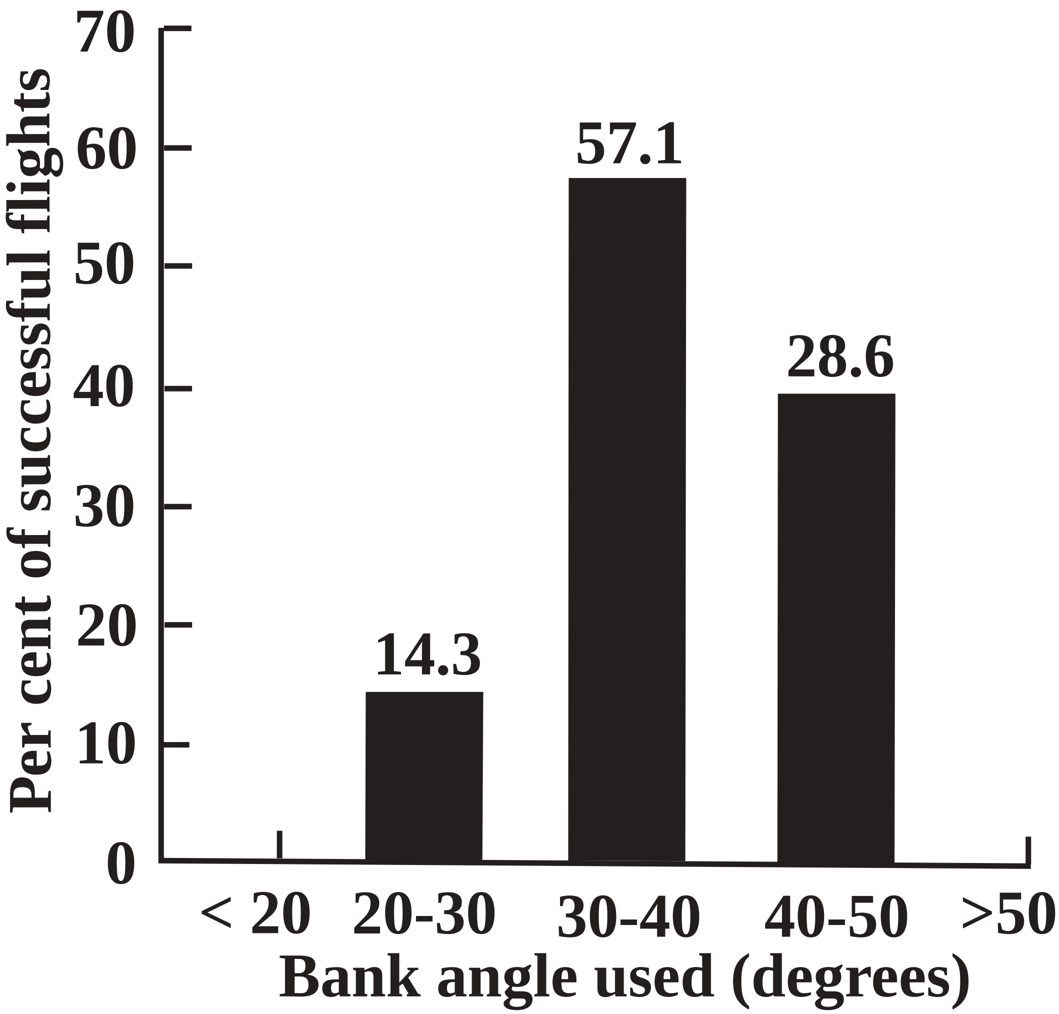

Figure 14. The distribution of successful flights according to the bank angle used.

45° bank with coordinated rudder;

airspeed just above stall.

The overall success rate for this flight was 75%. Figure 15 depicts the success rate for each pilot group. As expected, the lowest success rate occured in the group of pilots with less than 100 hours. Of the successful flights, the average altitude lost in the turn was 339 ft. The average time in the turn was 21.1 seconds and the average rate of descent upon turn completion was 1067 fpm.

One hundred percent of the unsuccessful flights were caused by the pilot allowing the bank angle to become too steep. This resulted in a high rate of descent and in some cases, impact while still in the turn. However, the pilots who were unsuccessful were given the opportunity to repeat the flight. Of the 25% of the pilots that failed on the first attempt, 10% were successful on their second attempt and 5% were successful on the third attempt. Ten percent of the pilots were unable to perform the maneuver successfully after three attempts. The two pilots who were unsuccessful after three attempts had less than 100 hours and one was a student pilot.

Test Flights 5 and 6

Originally, flights 5 and 6 were designed to investigate the effect of excess rudder on the gliding turn. However, because the computer controlled acquisition system was unable to record the rudder deflection and because the pilots did not consistently use 'full rudder' in their turns, the flight data is not useful for complete analysis.

Test flight 5 required the pilot to turn the aircraft 180° using 45° bank, full rudder, with the airspeed just above stall. This maneuver was extremely difficult because it required the airplane to be cross controlled with opposite aileron to prevent the bank angle from exceeding 45° This flight had an overall success rate of 45%. One hundred percent of the failures were the result of steep bank angles and the resulting spin/stall.

Flight 6 required the pilot to turn the aircraft 180° using 15° bank, full rudder, with the airspeed just above stall. The success rate for this flight of 55% was slightly higher than flight 5. Like the maneuver in flight 5, this maneuver required the airplane to be cross controlled. Consequently, the airplane developed a high rate of descent relative to the rate of turn and the failures were the result of the pilots not completing the 180° turn above 100 ft. AGL.

Test Flight 7

This flight required the pilot to perform the 180° turn using the following procedure:

- 30° bank with coordinated rudder;
- Airspeed just above stall.

The overall success rate for this flight was 95%. Figure 16 shows the success rate for each pilot group. The one pilot who was unsuccessful on his first attempt at the maneuver was successful on his second attempt. An analysis of the first flight revealed that the reason for the failure was that the pilot used only 20° of bank instead of the 30° specified in the procedure. Of the successful flights, the average altitude lost in the turn was 341 ft. The average time in the turn was 26.1 seconds and the average rate of descent upon turn completion was 994 fpm.

Summary of Results and Analysis

Based on the analysis of the seven flights, the procedures used in test flight 4 and 7 justify further comparison as both appear to be feasible procedures for turnback to the airfield. Comparing the altitude lost in the turn (Fig. 17), the experimental data supports the theory that 45° bank will result in the minimum loss of altitude during the gliding turn. However, the altitude lost in the 30° turn is only slightly greater. A comparison of the descent rate at turn completion (Fig. 18), on the other hand, shows a slight advantage to the 30° banked

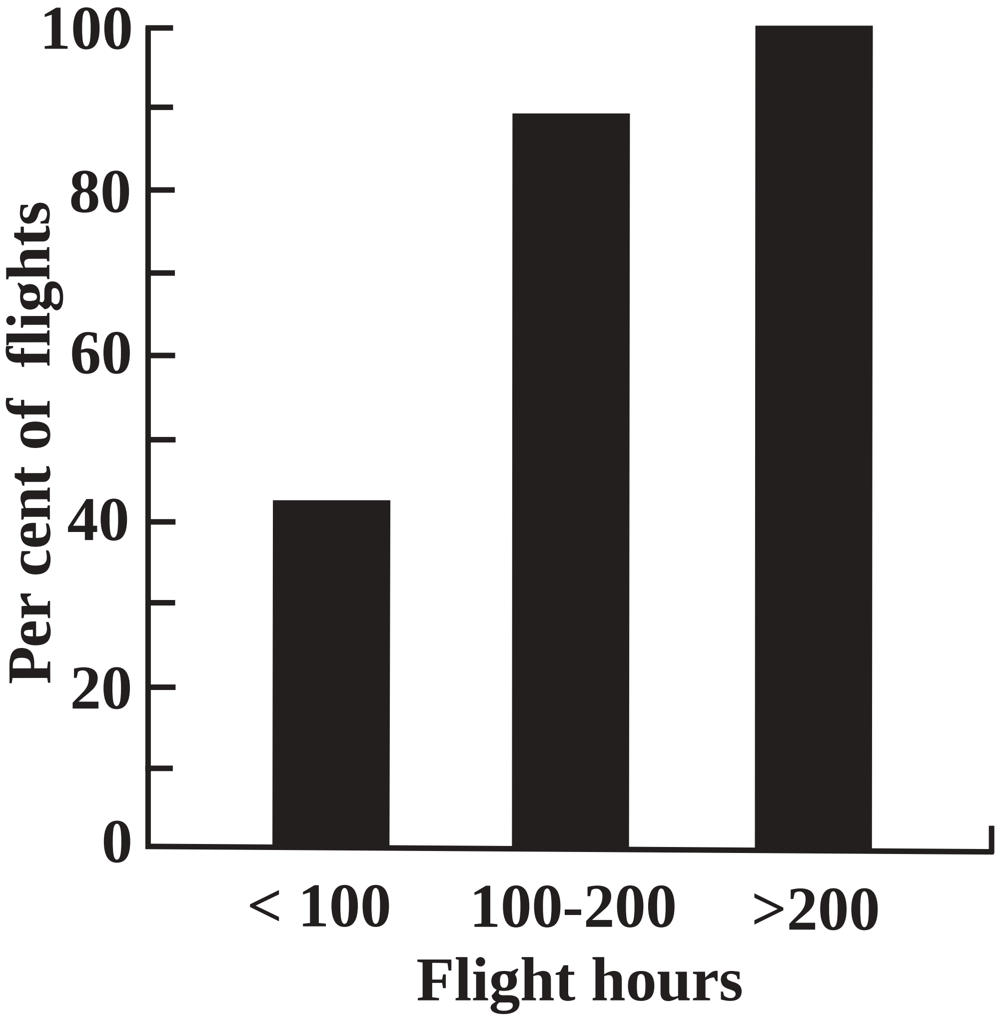

Figure 15. Test flight 4 success rate for pilots grouped according to flight hours.

turn. Finally, a comparison of the success rate gives a distinct advantage to the procedure in test flight 7 (Fig. 19).

Additional Considerations

There are several other factors which must be investigated before turning back to the airfield can be considered feasible. In this experiment, the average time to engine failure after the initiation of takeoff roll was 45.63 seconds. The time required to turn the airplane and land was an additional 45.74 seconds. The question that must be considered is whether or not turning back to the airfield will endanger other airport traffic. At major airports, the pilot will have to expect to deal with landing or departing aircraft on his departure runway and traffic on any crossing runways in use. Crossing runways may be used simultaneously if the conditions outlined in Section 231 of the Airmans Information Manual covering Air

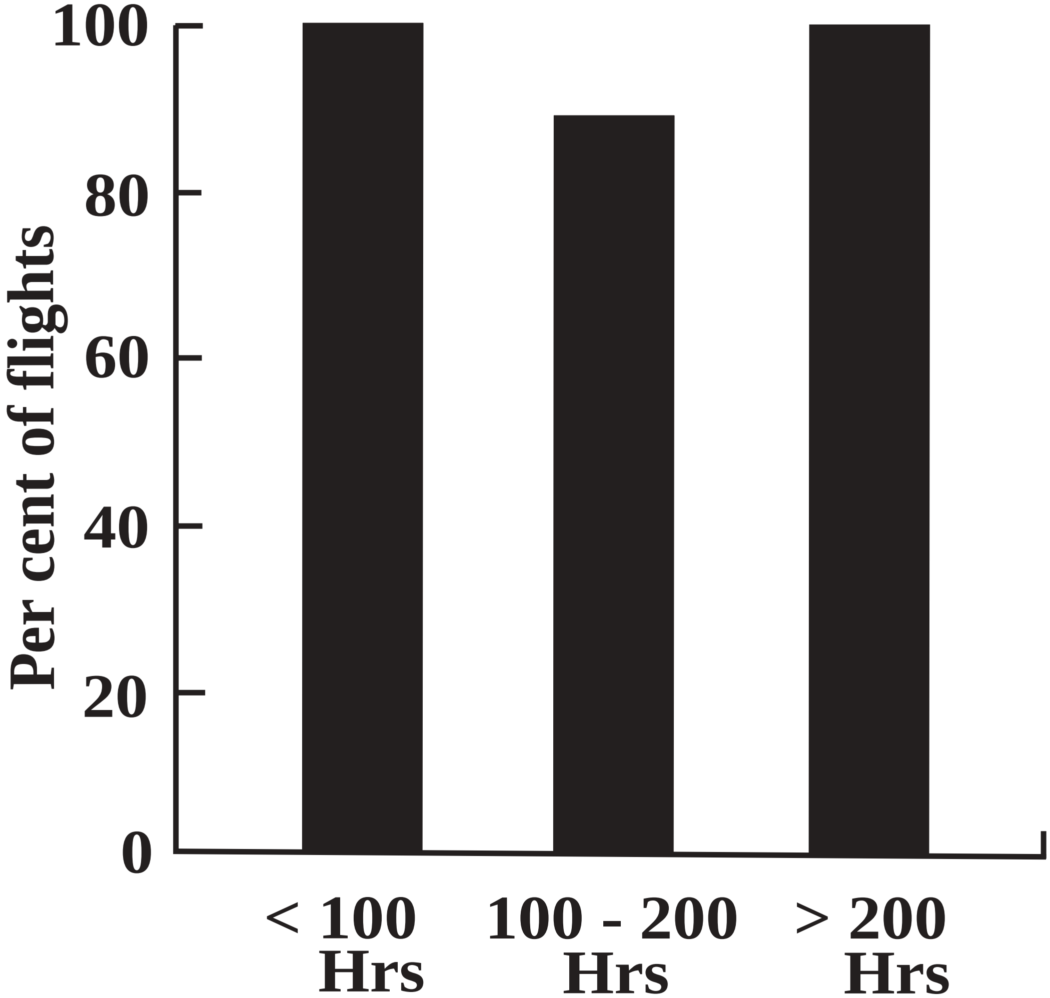

Figure 16. Test flight 7 success rate for pilots grouped according to flight hours.

Traffic Control (ATC) procedures are met. Thus, communication with the controller would be necessary to minimize the chance of an incident with other aircraft in the traffic pattern. Additionally, in a real situation, the pilot will probably elect to turn the aircraft an additional 5 or 10 degrees so that after making the turn, the aircraft will be gliding back toward the departure runway. In the experiment, the average turn diameters for flights 4 and 7 were 1356 ft. and 1519 ft. respectively. Therefore, if the pilot is unable to turn back to the reciprocal of the initial runway heading just before landing, the glide/landing path may cross the active runway and its taxiways. Again, communication with the controller would be required to prevent a possible incident.

Although communication with the controller is necessary, the pilot must first establish his turnback and airspeed before using the radio. Section 224 of the Airmans Information Manual exempts emergencies from those situations requiring the pilot to notify the controller

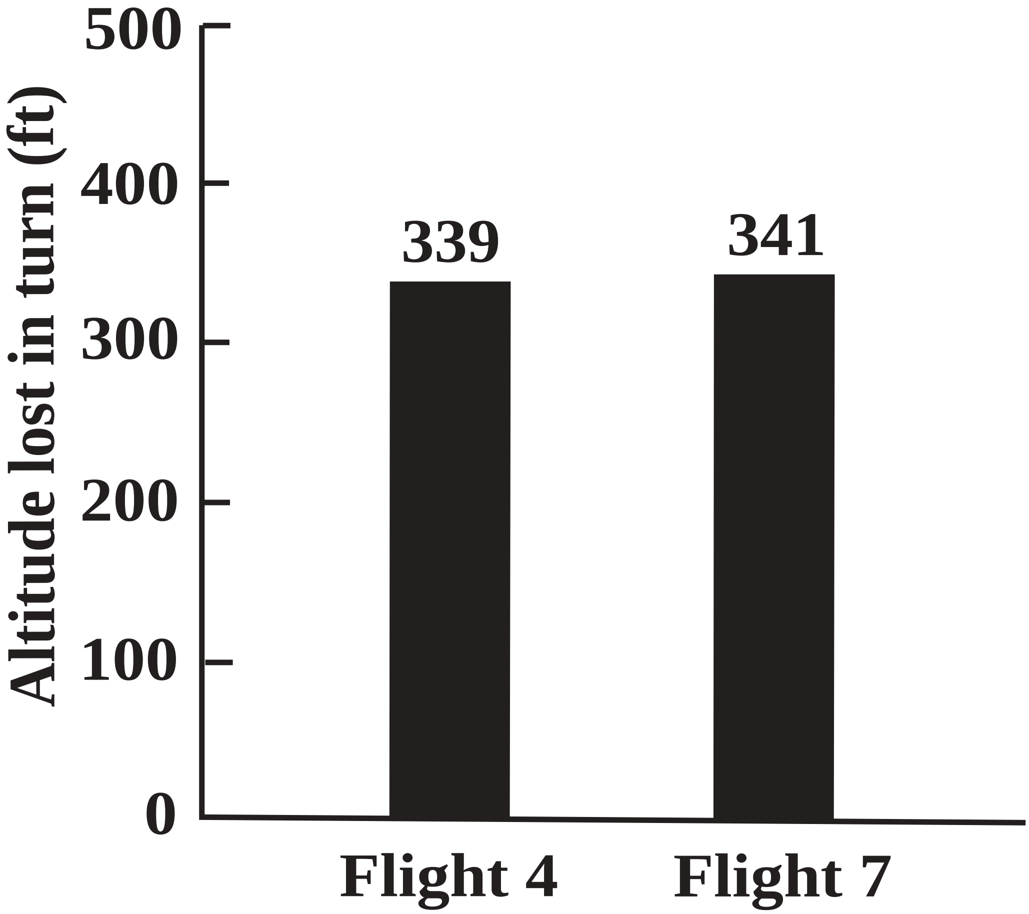

Figure 17. A comparison of the altitude lost in a 180° turn for flights 4 and 7.

before performing a major unexpected maneuver. If the pilot waits until after communication with the tower to initiate the turn, valuable altitude and airspeed are wasted.

Conclusions

The analysis of emergency procedures for low altitude engine failure during the takeoff/climb-out phase has led to several significant conclusions. First, 15% of the pilots tested ignored standard procedure in Flight 1 and attempted to turnback to the airfield when engine failure occured at 500 ft. AGL. The percentage would probably have been significantly higher if the pilots were told that the area outside the airfield was unsuitable for emergency landing. Only 33.3% of the attempted turnbacks in Flight 1 were succesful. However, 100% of the straight ahead emergency landings in the same flight were successful. When told to attempt to turnback in Flight 3, only 42.86% were successful. Thus, the first signifi- cant result of the analysis:

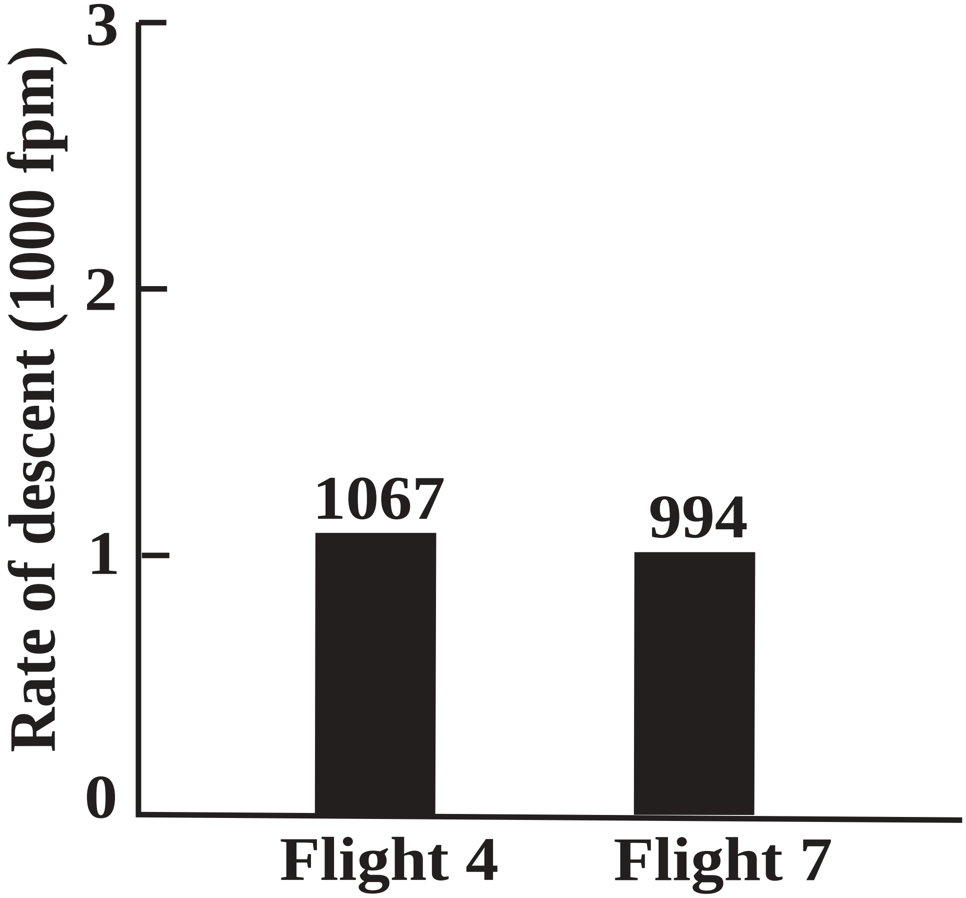

Figure 18. A comparison of the rate of descent upon turn completion for flights 4 and 7.

Turning back to the airfield after engine failure is feasible under proper circumstances. Turning with 30° bank, coordinated rudder, at an airspeed slightly above stall, will yield the best combination of the performance and safety.

The proper circumstances mentioned above incorporate several aspects of each individual flight. First, the minimum altitude at which this maneuver can be successfully performed will vary with the type of aircraft and the pilot's ability. Therefore, a pilot should not attempt to turn back to the airfield unless the procedure has been practiced at a safe altitude and the minimum turnback altitude for the combination of his ability and aircraft is known. This minimum turnback altitude should be the altitude lost in a gliding 180° turn from climb-out configuration plus 100 ft. Also, as previously stated, turnback should not be attempted if there is a suitable landing area ahead.

Finally, consideration of the need to communicate with the controller yields the following sequence of events for the turnback maneuver when the circumstances dictate its performance:

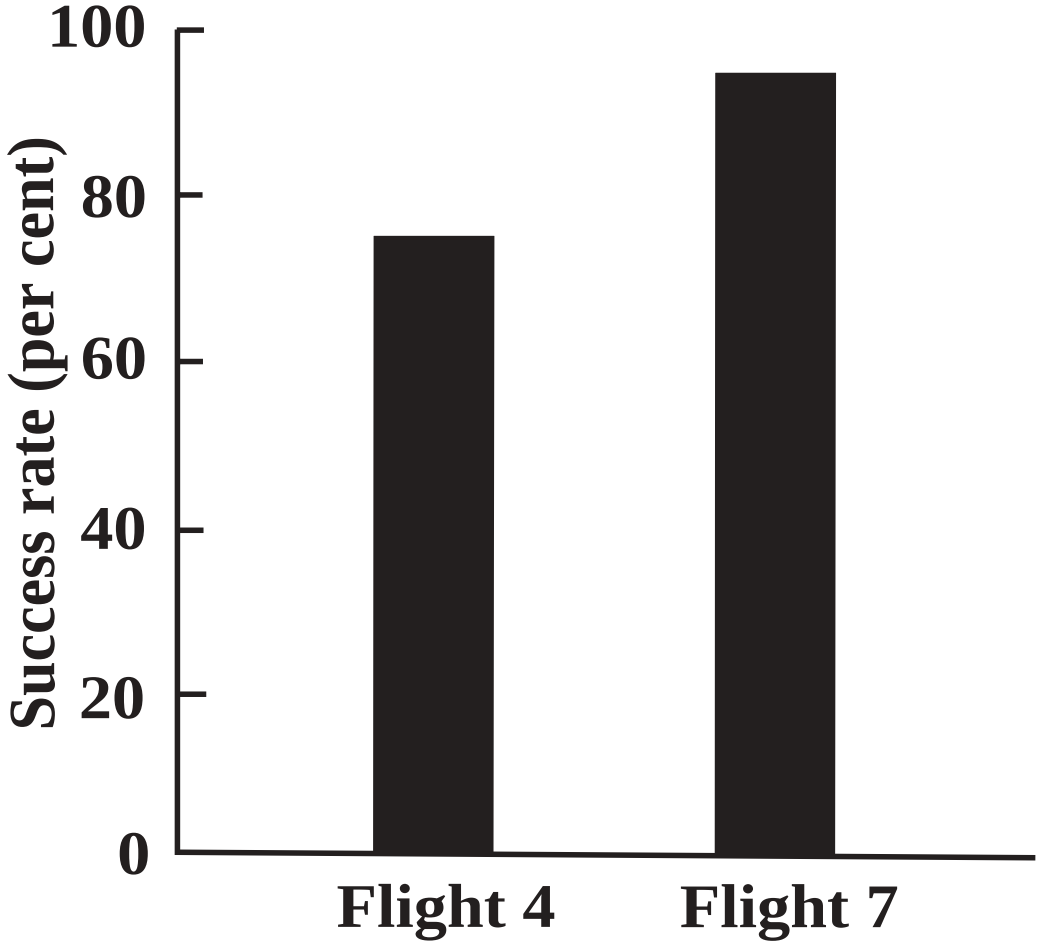

Figure 19. A comparison of the success rate for test flights 4 and 7.

initiate turn - establish bank angle (30°) and airspeed (slightly above stall);

communicate intentions to controller;

Attempt to restart the engine.

Thus, the pilot who experiences engine failure during takeoff/climb-out is no longer limited to proceeding straight ahead to a forced landing. If there is no suitable landing area ahead, the pilot who has practiced and mastered the turnback technique will immediately know whether or not turning back to the airfield is possible (by the minimum turnback altitude) and will be able to perform the maneuver successfully.

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