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Mancil W. Milligan, Major Professor

We have read this thesis
and recommend its acceptance:

H. J. Wilkerson, Professor

Frank Speckhart, Professor

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A Prototype Airplane Takeoff Monitor With Learning Features

A Thesis
Presented for
the Master of Science
Degree

The University of Tennessee, Knoxville

Mark M. Zhou

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Finally, I want to emphasis that the original idea for the instrument is from Dr. Milligan and Dr. Wilkerson. They were awarded the U. S. patent of Airplane Takeoff Monitor with Learning Features in December 1990. Without their creative ideas and previous work, this thesis would not have been possible.

ABSTRACT

This thesis resulted in the development of a prototype instrument for airplane take-off performance monitoring with learning feature. The most important feature for this instrument is the learning of the real airplane take-off performance and using the historical data of this particular airplane to predict take-off performance for present conditions instead using a pure theoretical model.

The method and program developed here can be directly use in a commercial type instrument. The system can run independently or be integrated into a Flight Expert System(FLES)(1).

The instrument automatically compares measured acceleration with that predicted using historical data. The flight crew's judgment for go will be objectively reconfirmed if the data agree well from the early stages of ground roll until rotation. This will help to insure no false rejected take-offs. On the other hand, if low acceleration is detected, a yellow or red warning will be issued immediately depending on the seriousness of the condition. The measured data together with flight crew's experiences and quick

judgment will insure a cautious take-off or rejected take-off at lower speed. After the takeoff, this new data may be added to the data base for future use.

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CHAPTER I

INTRODUCTION

Dr. M. W. Milligan and Dr. H. J. Wilkerson patented their invention of an Airplane Take-off Monitor with Learning Feature(2) in December 1990. They have worked in airplane take-off performance monitoring for more than ten years. The early type of take-off monitor they built was an a crude instrument using analog techniques with no "learning" feature.

The purpose of this thesis was to build a working prototype for demonstration. The methodology and software developed can be directly used for a commercial type system. The monitor can be an independent system or part of a Flight Expert System (FLES). The prototype system consists of an accelerometer (please see the detail specifications in appendix A), a control panel, and a laptop IBM PS/2. The data communication between the PS/2 and accelerometer is through a RS-232 serial port. Display information is on the PS/2 LCD display.

Take-off is one of the most important and most dangerous phases of flight. In spite of pre-flight check before every take-off, there may still be undetected problems with the airplane. This instrument will help the pilot identify performance problems during the take-off ground roll.

Before every transport category take-off, the flight crew is required to determine the decision speed, V1[3], for current take-off conditions. Decision speed is the maximum speed to which the airplane can be accelerated and from which the airplane can be stopped within the remaining runway length if normal acceleration is achieved prior to V1. After the decision speed is reached, pilots will continue the take-off even if one of the engines fail. Some military pilots use more accurate methods like time-speed check or time-distance check

On January 13, 1982, an Air Florida Boeing 737 crashed into 14th Street Bridge shortly after take-off from Washington National Airport and killed 78 people. Had this type of instruments been on board the airplane, it may have never happened. The aircraft accelerated at a lower-than-normal rate during takeoff, requiring 45 seconds and nearly 5,400 feet of runway, 15 seconds and nearly 2,000 feet more than normal, to reach liftoff speed[4] because the thrust was set low as inlet engine pressure sensors were blocked by ice. The Safety Board (NTSB) believes that this accident clearly illustrates fallacies in takeoff field length criteria and decision speed concept employed by air carrier operators[4].

The NTSB, in the official accident report, pointed out: " The Board believes that a concerted effort and support by various elements of the aviation community could overcome the technical hurdles involved and would lead to the implementation of a take-off performance monitoring system that could contribute significantly to flight safety. The Board believes that such a concerted effort should be initiated by a joint government-industry task force at the earliest possible date."[4]

It is important that the pilot be warned as early as possible in the take-off roll whether, under the climatic conditions, the airplane will be airborne at the proper take-off point. If the airplane is incapable of proper take-off under these conditions, the pilot should begin his braking as early as possible.[5]

The instrument developed here will provide a quantification of the take-off roll performance. The primary function of this instrument is to provide flight crew with information of airplane performance of the current take-off compared with predicted performance based on recorded historical data. The displayed data will insure that the flight crew will be able to quantitatively monitor the airplane take-off performance during take-off ground roll.

Depending only on pilot experiences and quick judgment sometimes is disastrous. The following flight deck recording during the 45 second take-off roll of the Air Florida Boeing-737 is an example of this. At 1559:58, the first officer remarked, "God, look at that thing, that don't seem right, does it?" Between 1600:05 and 1600:10, the first officer stated, "...that's not right...," to which the captain responded, "Yes, it is, there's eighty." The first officer reiterated, "Naw, I don't think that's right." About 9 seconds later the first officer added, "...maybe it is," but then 2 seconds later, after the captain called, “hundred and twenty,” the first officer said, “I don’t know.” After the captain called “Vee one”(4) continue take-off was decided. The co-pilot definitely felt that something was not normal during the disastrous take-off. But there was no instrument to help him to quantify the problem. The captain failed to recognize abnormal conditions, even with four reminders from the copilot.

This instrument will automatically compare measured acceleration with the predicted by using historical data. The flight crew’s judgment for “go” will be objectively reconfirmed if the data agrees well from the early stage of ground roll until rotation. This will insure no false rejected take-offs. On the other hand, if low acceleration is detected, a yellow or red warning will be issued immediately, depending on the seriousness of the condition. The measured data together with flight crew’s experiences and quick judgment will insure a cautious take-off or a safe rejected take-off at low speed. After the takeoff, this new data may be added to the data base for future uses.

This instrument will reduce the work load of the flight crew during ground roll because it automatically compares the performance with "learned" performance based on historical data and clearly displays the essential data. Its operation is totally independent of the airplane systems, except for the electrical power supply. It will not interference with other airplane systems and will work properly even if other airplane system(s) fail, which often happens preceding an accident.

The historical performance data will provide a good source for airplane performance trend monitoring. If the take-off data shows airplane performance deteriorating during a period, the airplane may need maintenance work.

Some common reasons for inadequate takeoff acceleration, revealed by the NTSB take-off accident investigations, include: engine power loss; erroneous instrumentation indications of engine and airplane performance; improper control surface configurations; parking brake engaged; wheels and tire problems; contaminated runways; improper take-off performance calculations; and wind shear.(1)

CHAPTER II

BACKGROUND

The most accepted concept for take-off performance is the decision speed concept. It is part of FAR Part 25(3) and is used by air carrier operators in spite of NTSB illustrated fallacies of the concept in their official report(4). There are two significant fallacies in the takeoff criteria. One, the aircraft accelerate-stop-performance upon which the decision speed and runway length computations are based is determined during the aircraft type certification tests on a clean dry runway. There are no assurances that the aircraft can be stopped from decision speed within the limits of a minimum length runway on a snow, ice, or even liquid contaminated runway. Second, the decision speed computation are based upon the demonstrated and theoretical acceleration of the aircraft using normal takeoff power. If, for any reason, the aircraft acceleration is less than normal, the runway distance used to achieve decision speed will increase and the length of runway available for stopping will be decreased. Thus, with subnormal acceleration, such as the Air Florida Boeing 737, there is no assurance that the aircraft can stop from decision speed on the remaining runway even if the runway surface is clean and dry[4].

Monitoring take-off performance is always a very important task. With ever increasing airplane weights, engine thrust and take-off speeds, the need for monitoring take-off performance become even more important. There have been many systems and patents proposed to address the problem. There are no systems presently being used in airplanes. The proposed systems can be categorized into different groups. They represented the different approaches to the problem.

From the installation place point of view, there are ground installation, airplane installation and ground and airplane combination installation systems.

Ground systems are remote systems because of their location. Ground Doppler Radar System[6] would measure airplane speed and display processed data to Air Traffic Controller(ATC). The ATC would warn the flight crew if the displayed data indicated a problem. Infrared beam system[7] would measure the time interval and airplane runway location by infrared sensors along the runway and produce warning signals to flight crew if low acceleration is detected.

The weight, volume, power dissipation etc. of ground systems would not be limited by airplane airworthiness consideration. Airplanes would not require any modifications as long as the airport are equipped with the system. The system could also be used for ground movement monitoring for big airports especially in night or low visibility weather. The longer chain of communications and slower response time are disadvantages for these systems. The cost would be high for most of these systems.

Interlock for Aircraft Take-off Safety Monitor(8) is a ground and airplane combination system. The ground computer would calculate theoretical take-off performance for current take-off conditions and input them directly into the on board indicators. The Pilots would compare the predicted data with measured performances.

Ground and airplane combination systems have advantages compared to totally ground based systems. They reduce the communication chain of ground systems and the cost of on board part of systems would be relatively low. The disadvantages are extra work load for flight crew and the on board indicators are too simple to perform more tasks automatically. Sudden take-off condition changes such as wind direction changes would produce large error for predicted performances.

Most of the proposed systems are on board systems because the flight crew can directly interface with the system and it would be easier to measure airplane movement parameters. These systems are restricted by strict airworthiness considerations. This means the weight, volume, power consumption etc. are limited. Possible interferences with other on board systems are another important consideration for these systems.

AQ-100-A Electronic Take-off System[9] is an on board computer system. The main sensor is a wheel rotation sensor for distance, speed and acceleration measurement. A density altitude sensor automatically provides the system with actual density altitude. The system would provide both visual and audible cues/warnings through out the takeoff roll to aid pilot in making rapid "go/no-go" decisions based on actual aircraft performance[9].

From an instrumentation point of view, there are electric-mechanic, electronic-mechanical, servo-mechanic devices, remote sensing systems and computer controlled systems

From the number of sensors point of view there are single sensor, double sensors and multiple sensors. A single sensor will lower the possibility of sensor malfunction which will give wrong data to the system but this is trade-off by require more pilot inputs. Multiple sensor systems are highly automatic systems. They can be made very reliable by using redundant sensors.

Because the task of the system, almost all the systems are time to distance, speed or acceleration devices. The main measurement is position, distance, speed or acceleration. The sensors used for previous examples were light beam(for position), wheel counter(for distance), Doppler radar(for speed) and accelerometer(for acceleration) for the main measurement. Time is another measurement used in the systems. It is generated internally by the system.

Large aeronautical companies are often the assignee for these inventions because of the equipment required, the technical difficulties faced and the high cost involved for the research. The assignee for Take-off Computer(10) is United Aircraft Corporation; for the Aircraft Performance Margin Indicator(11) is The Boeing Company; for Ground Doppler Radar System(6) is the Northrop Corporation.

CHAPTER III

MATHEMATICAL MODEL FOR TAKE-OFF ROLL

Take-off roll can be modeled as a one dimensional acceleration motion. The forces acted on the airplane during a take-off roll are show in Figure 3.1. From Newton's Second Law of Motion in the x-direction the following equations are derived:

$$\sum F_x = ma_x \qquad (3.1)$$

where: $\sum F_x$ - summation of all forces in x-direction

m - mass of the airplane

a_x - x-direction acceleration of the airplane

The forces acting on the airplane are:

$$\sum F_x = T_e - D - F_r - W\sin\theta \qquad (3.2)$$

where: T_e - engine thrust

D - aerodynamic drag

F_r - rolling friction force

W - airplane weight

θ - runway slope, positive when the runway is upward slope and negative when the runway is downward.

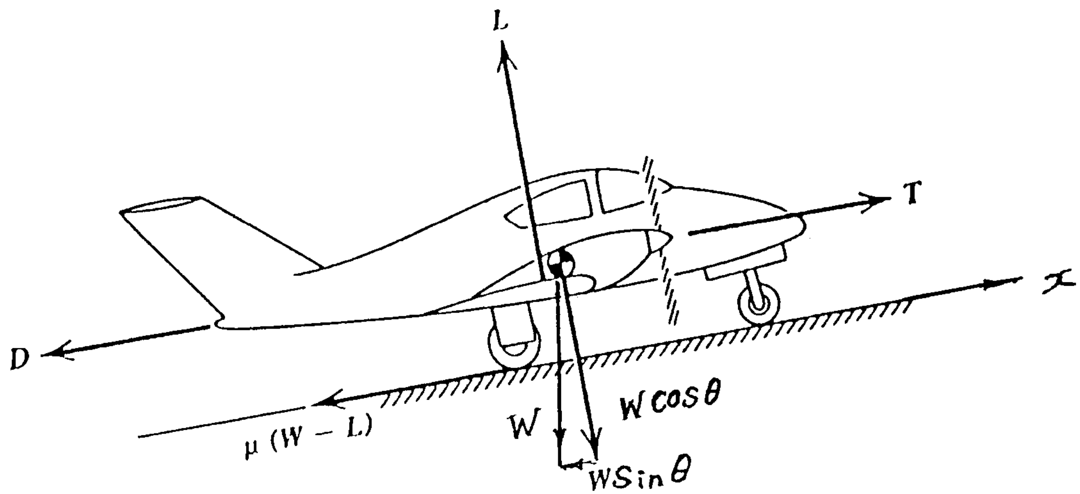


Figure 3.1 Forces Acting on an Airplane during Ground Roll(16)

Combining Equations 3.1 and 3.2:

$$ma_x = T_e - D - F_r - W\sin\theta \qquad (3.3)$$

Normally, thrust is the dominant force for a take-off roll. Modeling thrust accurately is a very complex problem. Air pressure, air temperature, airport elevation, engine conditions and pilot operation preferences are some of the facts influencing the thrust. The objective here is to express the trust with a simple model which has accuracy enough for our purpose. Empirically, the relationship between 100% rated thrust and speed can be expressed as:

$$T_e = C_1 + C_2 v + C_3 v^2 \qquad (3.4)$$

C_1 - constant

C_2 - constant

C_3 - constant

v - airplane airspeed

The drag is separated into two parts: parasitic drag and lift induced drag with ground effect.

$$D = \frac{1}{2}\rho v^2\left(C_{d0} + \frac{C_l^2}{\pi A e}\frac{IGE}{OGE}\right) \qquad (3.5)$$

ρ - air density

C_{d0} - drag coefficient at zero lift

A - aspect ratio

e - Oswald's wing efficiency factor[12]

C_l - lift coefficient

IGE - induced drag in ground effect

OGE - induced drag out-of-ground effect

Before rotation the attitude of the airplane on the ground is constant and hence C_l and C_{d0} are constant. Equation 3.5 can be rewritten as:

$$D = \frac{1}{2}\rho v^2 S C_d \tag{3.6}$$

The friction force associated with rolling resistance can be written as:

$$F_r = \mu(W\cos\theta - L) \tag{3.7}$$

μ - coefficient of rolling resistance

The coefficient of rolling resistance has a general range of 0.02 (for dry, level pavement) to 0.3 (for soft ground) which includes most runways. Fifty percent change of the value will influence less than 2% of the rolling distance(13). The value selected for all the take-offs is 0.02.

where the lift is:

$$L = \frac{1}{2}\rho v^2 S C_l \tag{3.8}$$

Combine equations 3.3, 3.4 3.6, 3.7 and 3.8

$$a_x = \frac{g}{W}\left[C_1 + C_2 v + \left(C_3 + \frac{1}{2}\rho S(\mu C_l - C_d)\right)v^2 - W(\mu\cos\theta + \sin\theta)\right] \tag{3.9}$$

where the air density is:

$$\rho = \frac{1}{R}\frac{p}{T} \tag{3.10}$$

where: p - air pressure

T - air temperature.

R - constant

Combining Equation 3.9 and 3.10, and defining a new constant $C_4 = \frac{S}{2R}(\mu C_l - C_d)$ where C_4 is the combined influence of aerodynamic drag and rolling resistance change caused by lift.

$$a_x = \frac{g}{W}\left[C_1 + C_2 v + \left(C_3 + C_4 \frac{p}{T}\right)v^2 - W(\mu\cos\theta + \sin\theta)\right] \quad (3.11)$$

This is the equation used for acceleration calculations. The constants will be solved for by using least-squares method on measured acceleration during actual take-offs. In order to separate C_3 and C_4, take-offs with $\frac{p}{T}$ (or air density ρ) differences would be required. Unfortunately, we have no control over $\frac{p}{T}$. As a first order approximation, C_3 is neglected. Now after only one take-off the monitor system will solve for the constants and save them in the data base. The C_3 influence is small compared with C_1 and C_2. After neglecting C_3 Equation 3.11 become:

$$a_x = \frac{g}{W}\left[C_1 + C_2 v + C_4 \frac{p}{T} v^2 - W(\mu\cos\theta + \sin\theta)\right] \quad (3.12)$$

Since 100% of rated thrust will not always be used for take-off, we can modify the thrust by the percent of rated thrust p_t[14].

$$a_x = \frac{g}{W}\left[p_t C_1 + p_t C_2 v + C_4 \frac{p}{T} v^2 - W(\mu\cos\theta + \sin\theta)\right] \quad (3.13)$$

p_t - percent of rated thrust or power as appropriate

From the definitions of acceleration and speed:

$$a_x = \frac{dV_g}{dt} \quad (3.14)$$

$$V_g = \frac{ds}{dt} \quad (3.15)$$

where: V_g - ground speed

s - ground roll distance

Air speed is the ground speed with the component of wind speed in the direction of ground speed subtracted.

$$v = V_g - v_w \cos\varphi \quad (3.16)$$

Where: v_w - wind speed as input prior to flight

φ - angle between ground speed and wind speed

Integration of acceleration will give the ground speed and integration of ground speed will give the ground roll distance.

$$V_g = \int_{t_0}^{t} a_x dt \quad (3.17)$$

$$s = \int_{t_0}^{t} V_g dt \quad (3.18)$$

These integration will be evaluated numerically using the following relationships.

$$s_i = s_{i-1} + v_{i-1}\Delta t + \frac{1}{2}(a_{i-1} + a_i)\Delta t^2 \quad (3.19)$$

$$v_i = v_{i-1} + \frac{1}{2}(a_{i-1} + a_i)\Delta t \quad (3.20)$$

The subscript i is for the present time increment and i-1 is for the previous time increment.

LEAST-SQUARES METHOD USED TO SOLVE FOR CONSTANT C'S

Using measured acceleration, the ground speed and air speed can be calculated by using Equation 3.20, 3.16. Substituting these values into Equation 3.13, the following linear equations for the C's are obtained. The accelerometer samples ten times per second so ten equations will derived per second.

$$B_{n\times 3}C_{3\times 1} = A_{n\times 1} \tag{3.21}$$

$A_{n\times 1}$ - matrix of combined accelerations

$B_{n\times 3}$ - coefficient matrix of constant C's

$C_{3\times 1}$ - undetermined constant C's

n - number of equations(ten per second)

Transforming Equation 3.21 by multiplying both sides with the transposition matrix of the coefficient matrix $B_{n\times 3}$

$$(B^{T}{}_{3\times n}B_{n\times 3})C_{3\times 1} = B^{T}{}_{3\times n}A_{n\times 1} \tag{3.22}$$

$B^{T}{}_{3\times n}$ - transposition of coefficient matrix $B_{n\times 3}$

Equation 3.22 is changed into the following form after defining new matrices $B_{3\times 3} = B^{T}{}_{3\times n}B_{n\times 3}$ and $A_{3\times 1} = B^{T}{}_{3\times n}A_{n\times 1}$

$$B_{3\times 3}C_{3\times 1} = A_{3\times 1} \tag{3.23}$$

This is a simple system of linear equations with three unknown C's. Solving these three linear equations will give the least-squares solutions[15] for the constant C's which will be saved in future use.

PREDICTED DISTANCE

Constant C's are read from disk file. Airplane gross weight, wind speed, wind direction, runway heading, field elevation, altimeter setting, and air temperature are inputted by pilot. The acceleration is computed using Equation 3.13. Numerical integration of acceleration is evaluated using Equation 3.19 and 3.20 to get the predicted distance.

LIVE DISTANCE[14]

Live distance is the predicted distance based on the actual "today" performance. It consists of two parts: (1)measured distance to present speed obtained by numerically integrating the measured acceleration and (2)predicted remaining distance corrected by present acceleration ratio.

$$s_{live} = \int_{0}^{t@v} \left(\int a_m dt \right) dt + \frac{a_{prd@v}}{a_{m@v}} \int_{t@v}^{t@vr} \left(\int a_{prd} dt \right) dt \qquad (3.23)$$

a_m - measured acceleration

a_{prd} - predicted acceleration by using historical constant C's

$a_{m@v}$ - measured acceleration at present speed

$a_{prd@v}$ - predicted acceleration at present speed

t@v - time at present speed v

t@vr - time at reference speed v

s_{live} - live distance

The integrations are evaluated using the same numerical Equations 3.19 and 3.20. The first part of integration is performed one summation each step(one tenth of a second). The second integration need as many as two hundred summation during one step. This is a problem for real time program. To solve this problem, the results of each step of the integration performed to get predicted distance is saved in the memory. Then, a look up table of the integration results from any speed to reference speed is built by using linear interpolation. Equation 3.24 can rewrite:

$$s_{live} = s_{roll@v} + \frac{a_{prd@v}}{a_{m@v}} s_{prd}(v \rightarrow vr) \qquad (3.25)$$

$s_{roll@v}$ - roll distance to present speed

$s_{prd}(v \rightarrow vr)$ - predicted distance look up table from present speed to reference speed

Reference speed is a pilot selected speed for the program to terminate. The rotation speed is recommended for this value though pilot can choose any value less of equal rotation speed.

HISTORICAL DATA

The computer program automatically maintains the files. There are two files for the program output: acceleration data file and constant C database(please see the Appendix C for detail file structures). All the files are designed so that they can input into most spreadsheet programs. A second program can replay any historical take-offs with only a IBM-PC or compatible with the acceleration data files on disk. This provides means of take-off performance study and airplane take-off performance trend monitoring. Constant C database is used as an input file for predicted acceleration. Missing or damage to this file will cause the programs to quit running.

CHAPTER IV

TEST PROCEDURES AND RESULTS

Twelve take-off were performed on three different airplanes. The first four take-offs were data recording for King Air 200 twin-engine turbo-propeller airplane. The last eight take-offs were real system tests on two different Piper airplanes. The tests are summarized in Table 4.1

The test weather conditions are summarized in Table 4.2. The test plan is in the Appendix D.

The take-off monitoring instrument consists of an accelerometer connected to a laptop PS/2 computer through a RS-232 serial communication port. The accelerometer has an resolution(digital output least count to the PS/2) of ±0.01g. Detail specifications of the accelerometer are in the Appendix A. The program developed takes the input data, calibrates the system, builds the communication between the IBM PS/2 and the accelerometer, processes and displays the data, solves for the C's and maintains the files. Figure 4.1 is the flow diagram of the program.

Table 4.1 Summary of the Tests

NUMBER	DATE	AIRPLANE	AIRPORT	% Power
1	Nov. 1,1992	King Air 200	TYS	90
2	Nov. 1,1992	King Air 200	LAN	90
3	Nov. 5,1992	King Air 200	TYS	90
4	Nov. 5,1992	King Air 200	MEM	90
5	Nov. 13,1992	Piper PA-24-250	DKX	100
6	Nov. 13,1992	Piper PA-24-250	TYS	100
7	Nov. 13,1992	Piper PA-24-250	TYS	100
8	Nov. 13,1992	Piper PA-24-250	TYS	100
9	Feb. 9, 1993	Piper PA-44-180	TYS	98
10	Feb. 9, 1993	Piper PA-44-180	TYS	98
11	Feb. 9, 1993	Piper PA-44-180	TYS	98*
12	Feb. 9, 1993	Piper PA-44-180	TYS	98*

* The actual power setting for Number 11 and 12 are 81% and 70%.

Table 4.2 Test Weather Conditions

NO.	TEMP F	WIND SPEED mph	WIND Dir. deg	ALT. Setting inHg	WEATHER	AIRPORT	RWY	GW lb
1	58	0	0	29.98	light rain	TYS	5R	12020
2	36	10	250	29.86	clear	LAN	28	12020
3	45	4	250	29.88	light rain	TYS	23	11850
4	40	6	320	30.14	overcast	MEM	36	11515
5	53	11	230	30.12	clear	DKX	26	2458
6	52	7	210	30.12	clear	TYS	23R	2438
7	52	7	210	30.12	clear	TYS	23R	2434
8	52	7	210	30.12	clear	TYS	23R	2430
9	66	9	270	30.12	clear	TYS	23R	3795
10	66	9	270	30.12	clear	TYS	23R	3780
11	66	9	270	30.12	clear	TYS	23R	3765
12	66	9	270	30.12	clear	TYS	23R	3750

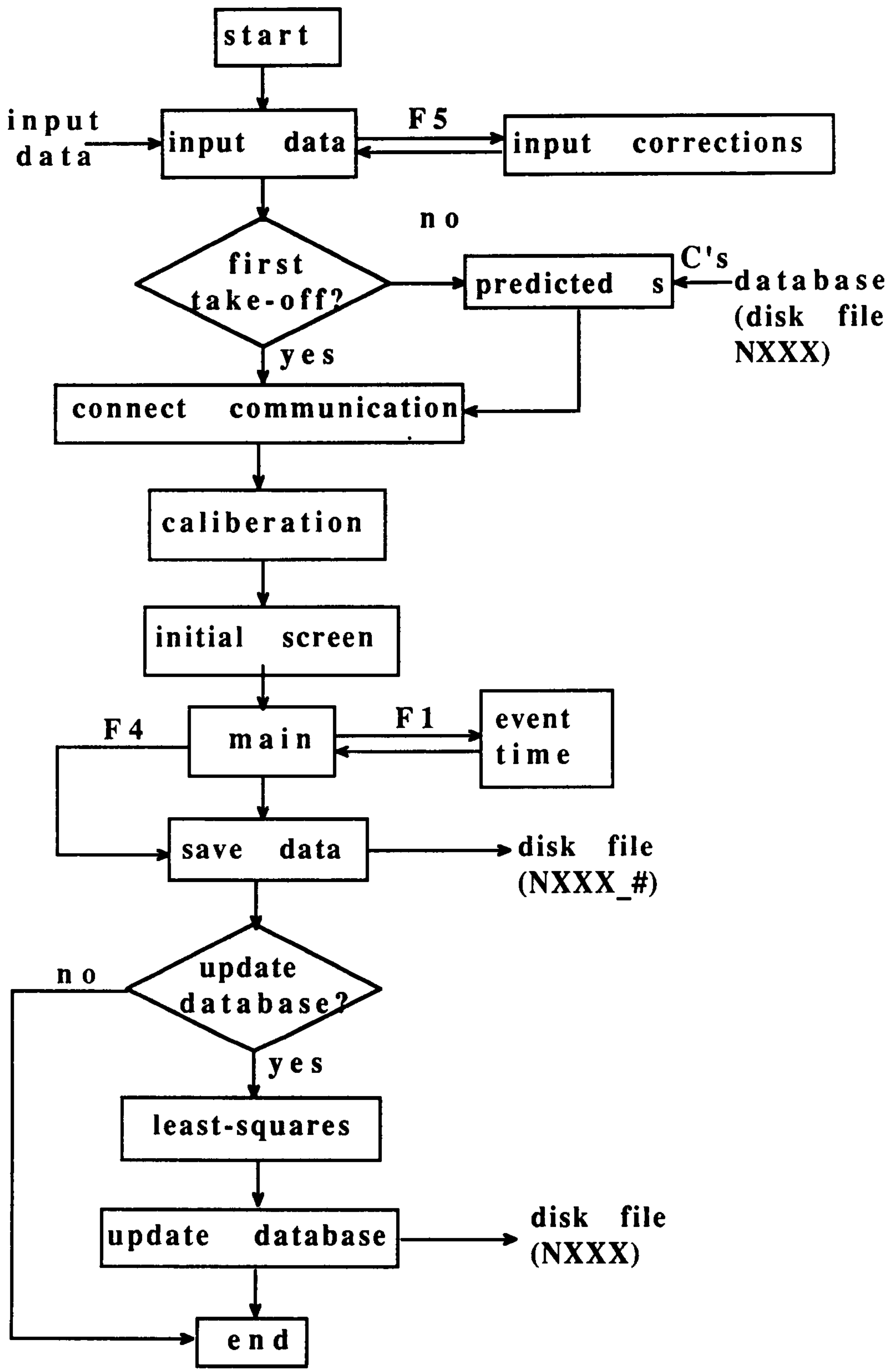


Figure 4.1 Program Flow

Table 4.3 is a summary of constant C's solved for by using least mean square method. The data used to determine the C's is from the maximum acceleration point to reference speed. The definitions of constant C's are in Chapter Three. The average C's are used for calculating predicted acceleration.

Table 4.4 is a summary of distance, speed and time at power setting(at maximum acceleration).

Acceleration data are shown in Figure 4.2 to 4.13. An important result revealed by these data is that the acceleration gradually reaches a maximum instead of starting from a maximum as indicated by some mathematical models(16). The acceleration decreases after the maximum because thrust decreases with the airspeed and the drag increases even though the rolling resistance is decreased. The flat steps in the acceleration plots are caused by the least count of the accelerometer.

The rolling distances are show in Figure 4.14 to 4.17. The points on the plots are test points.

The live distances are show in Figure 4.18 to 4.20. Live distance is the predicted distance for present condition. It consists of two parts: the measured distance obtained by integration of measured acceleration and predicted distance from present speed to

Table 4.3 Summary of Constant C's

No	Airplane	C1	C2	C4 $x10^2$
1	King Air 2000	3086.6	6.02	-1.74
2	King Air 2000	3201.0	9.17	-2.56
3	King Air 2000	2926.7	7.52	-2.05
4	King Air 2000	2664.9	19.38	-3.64
Average	King Air 2000	2969.8	10.52	-2.50
5	Piper PA-24-250	765.17	-2.72	0.20
6	Piper PA-24-250	660.04	-2.59	0.15
7	Piper PA-24-250	437.16	9.00	-2.89
8	Piper PA-24-250	721.78	-0.78	-0.73
Average	Piper PA-24-250	712.60	-2.66	0.18
9	Piper PA-44-180	1456.2	-7.30	0.084
10	Piper PA-44-180	1353.7	-3.44	-0.461
11	Piper PA-44-180	1341.9	-9.63	0.410
12	Piper PA-44-180	972.1	-4.69	-0.490
Average	Piper PA-44-180	1404.9	-5.37	-0.189

Note 1). The average for PA-24-250 does not include Number 7 and 8

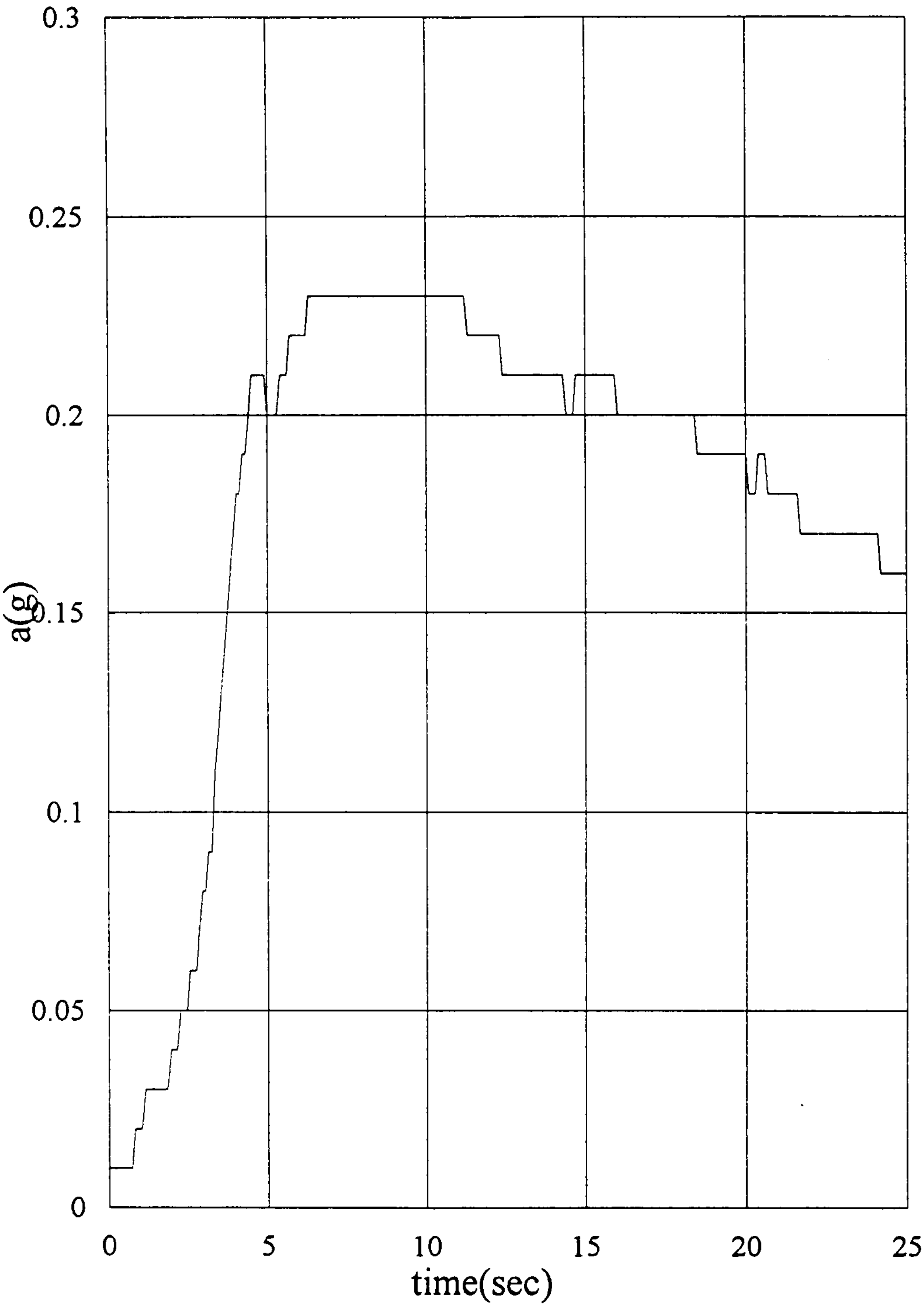
2). Number 11 and 12 were low power tests

3). The average for PA-44-180 does not include Number 11 and 12

Table 4.4. Conditions at Maximum Acceleration

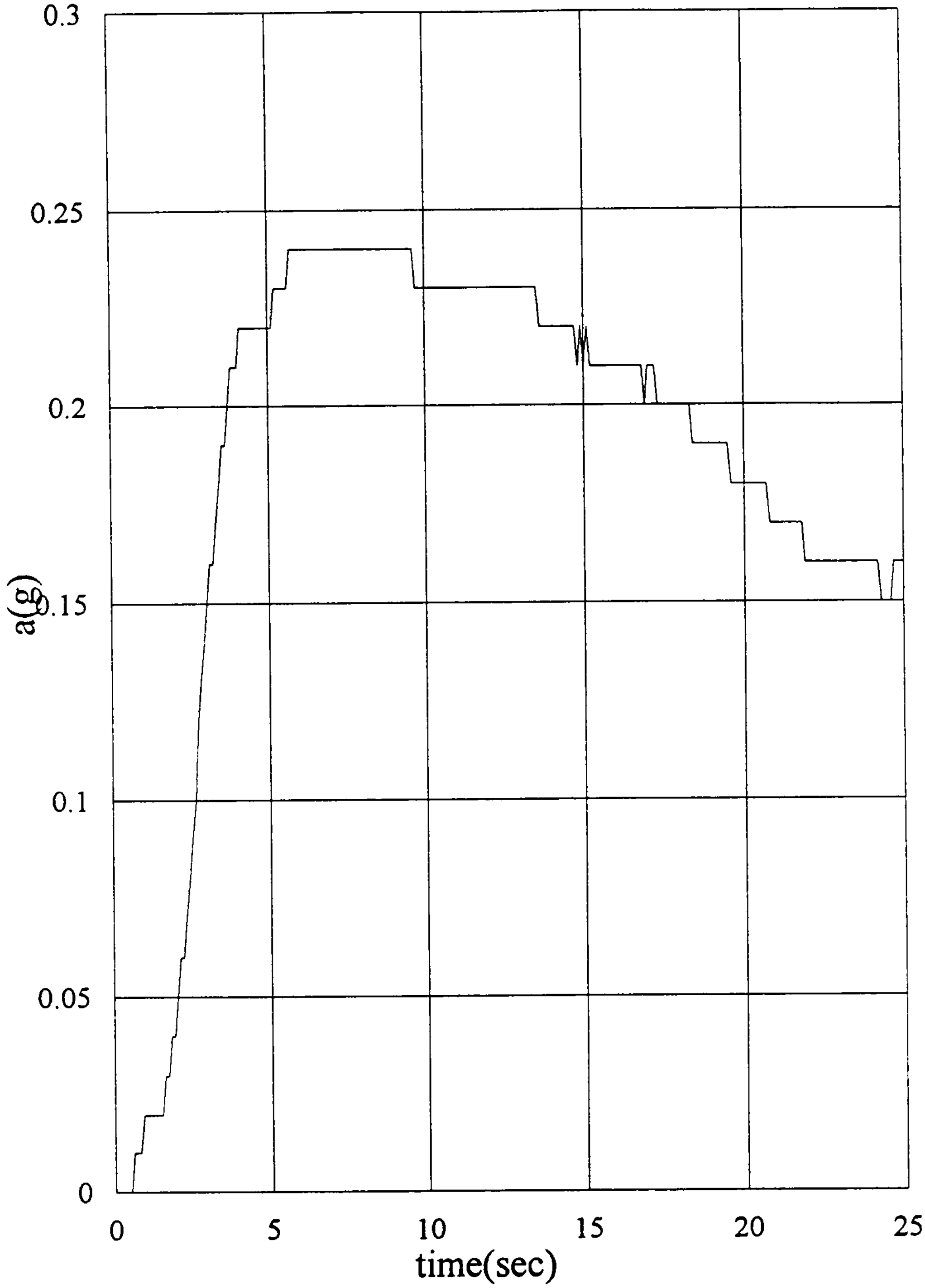
No	Airplane	s(ft)	v(ft/s)	t(s)
1	King Air 2000	243.2	59.07	11.2
2	King Air 2000	183.1	52.45	9.6
3	King Air 2000	259.0	59.60	11
4	King Air 2000	220.4	55.35	11.2
5	Piper PA-24-250	218.0	55.13	9.8
6	Piper PA-24-250	13.7	13.70	3.3
7	Piper PA-24-250	3.1	6.21	1.9
8	Piper PA-24-250	44.5	26.48	4.8
9	Piper PA-44-180	79.2	34.78	5.5
10	Piper PA-44-180	188.7	53.71	11.5
11	Piper PA-44-180	116.1	37.84	8.5
12	Piper PA-44-180	79.3	28.82	6.9

Note: 1). Using brake while set the power in Number 6,7 and 8.



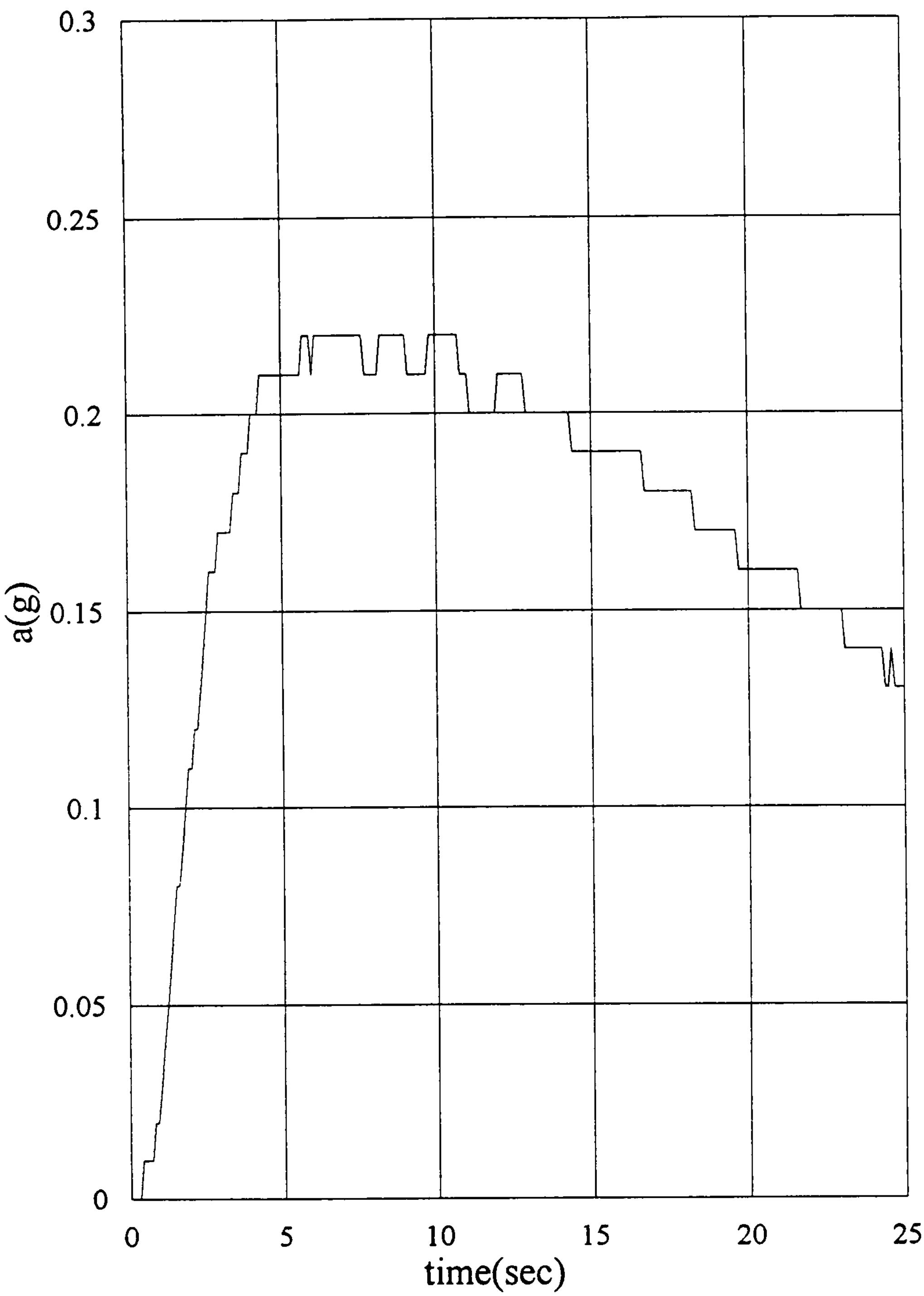
T. O. No. 1   Nov. 1, 1992 King Air 200
12,020 lb. 29.98 inHg,58°F, wind calm, light rain TYS Rwy 5R

Figure 4.2 Acceleration for Take-off Number 1



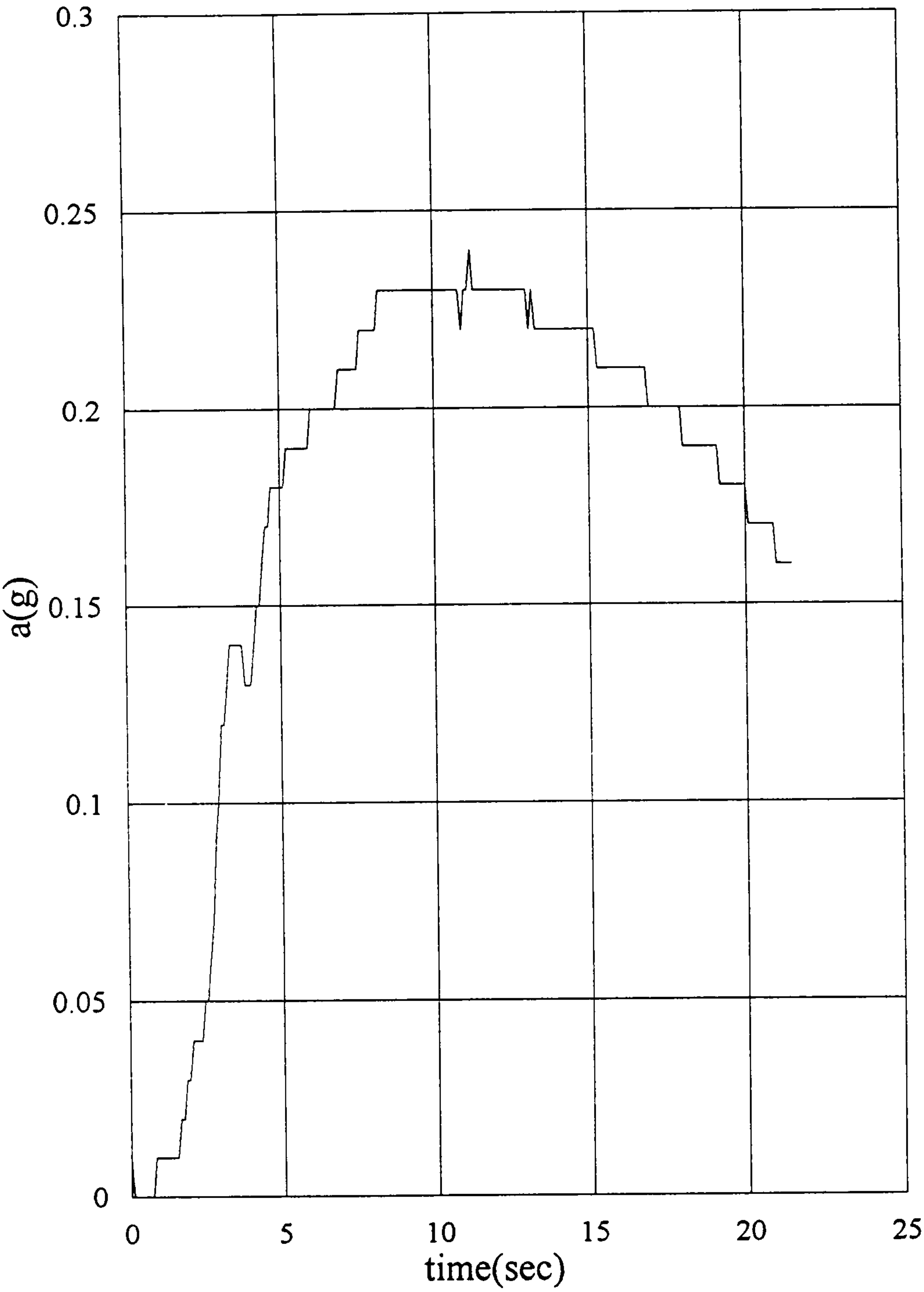
T.O. No. 2 Nov. 1,1992 King Air 200
12,020 lb. 29.86 inHg,36°F, wind 250@10, LAN Rwy 28

Figure 4.3 Acceleration for Take-off Number 2



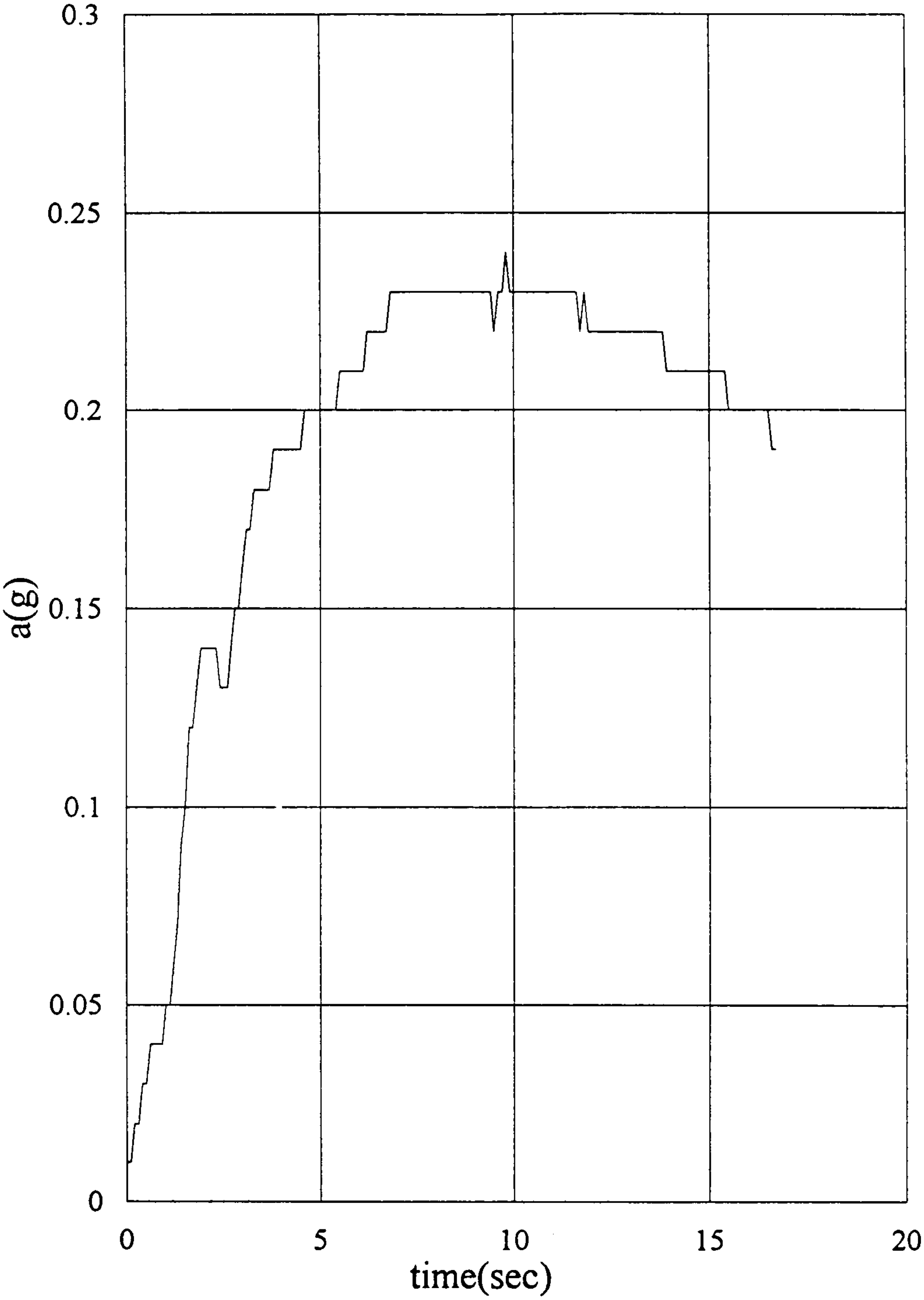
T.O. No. 3 Nov. 5, 1992 King Air 200
11,850 lb. 29.88 inHg,45°F, wind 250@4, TYS Rwy 23

Figure 4.4 Acceleration for Take-off Number 3



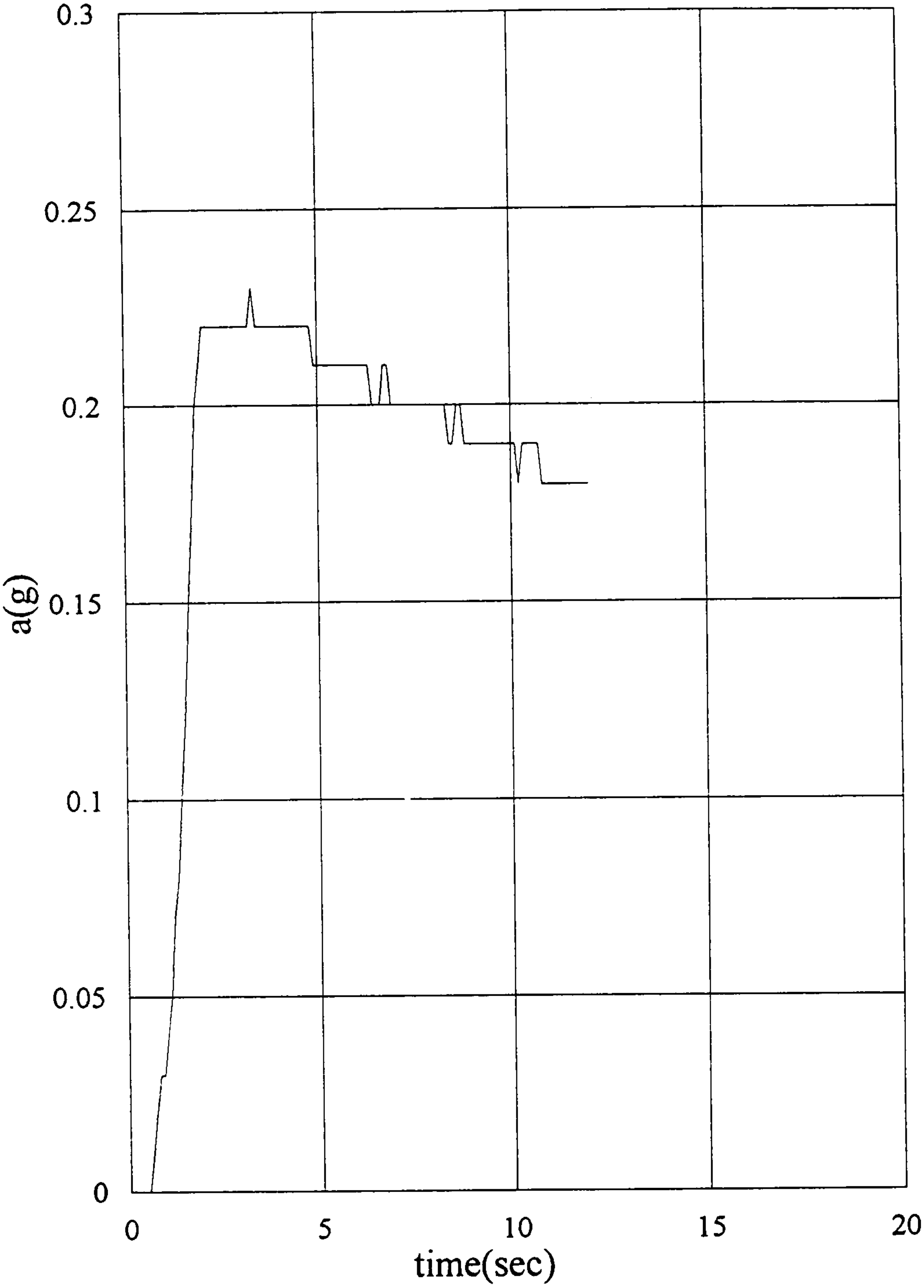
T. O. No. 4 Nov. 5, 1992 King Air 200
11,515 lb. 30.14 inHg,40°F wind 320@6, MEM Rwy 36

Figure 4.5 Acceleration for Take-off Number 4



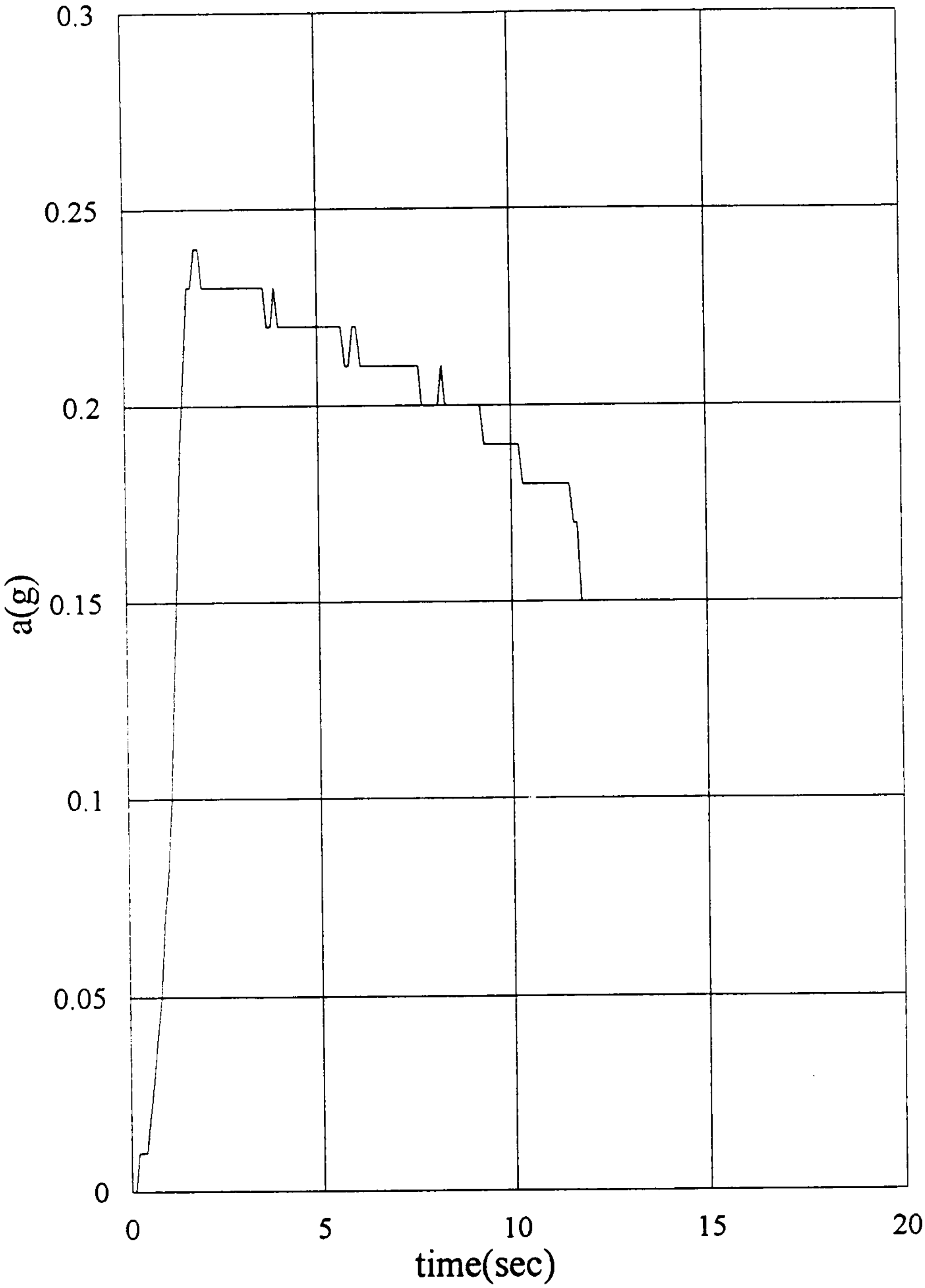
T. O. No. 5 Nov. 13, 1992 Piper PA-24-250
2,458 lb. 30.12 inHg,53°F, wind 230@11, DKX Rwy 26

Figure 4.6 Acceleration for Take-off Number 5



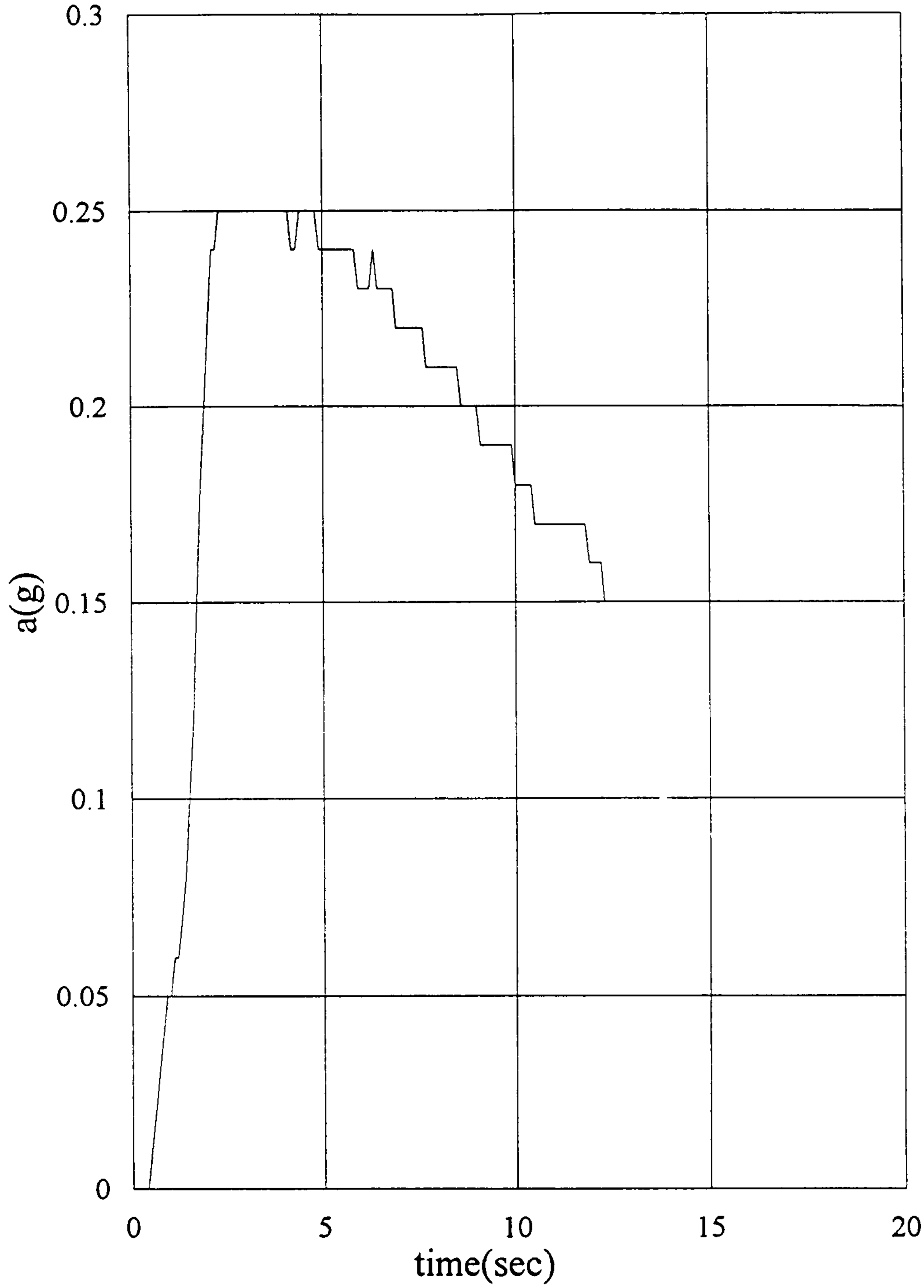
T.O. No. 6 Nov. 13, 1992 Piper PA-24-250
2,438 lb. 30.12 inHg,52°F, wind 210@9, TYS Rwy 23R

Figure 4.7 Acceleration for Take-off Number 6



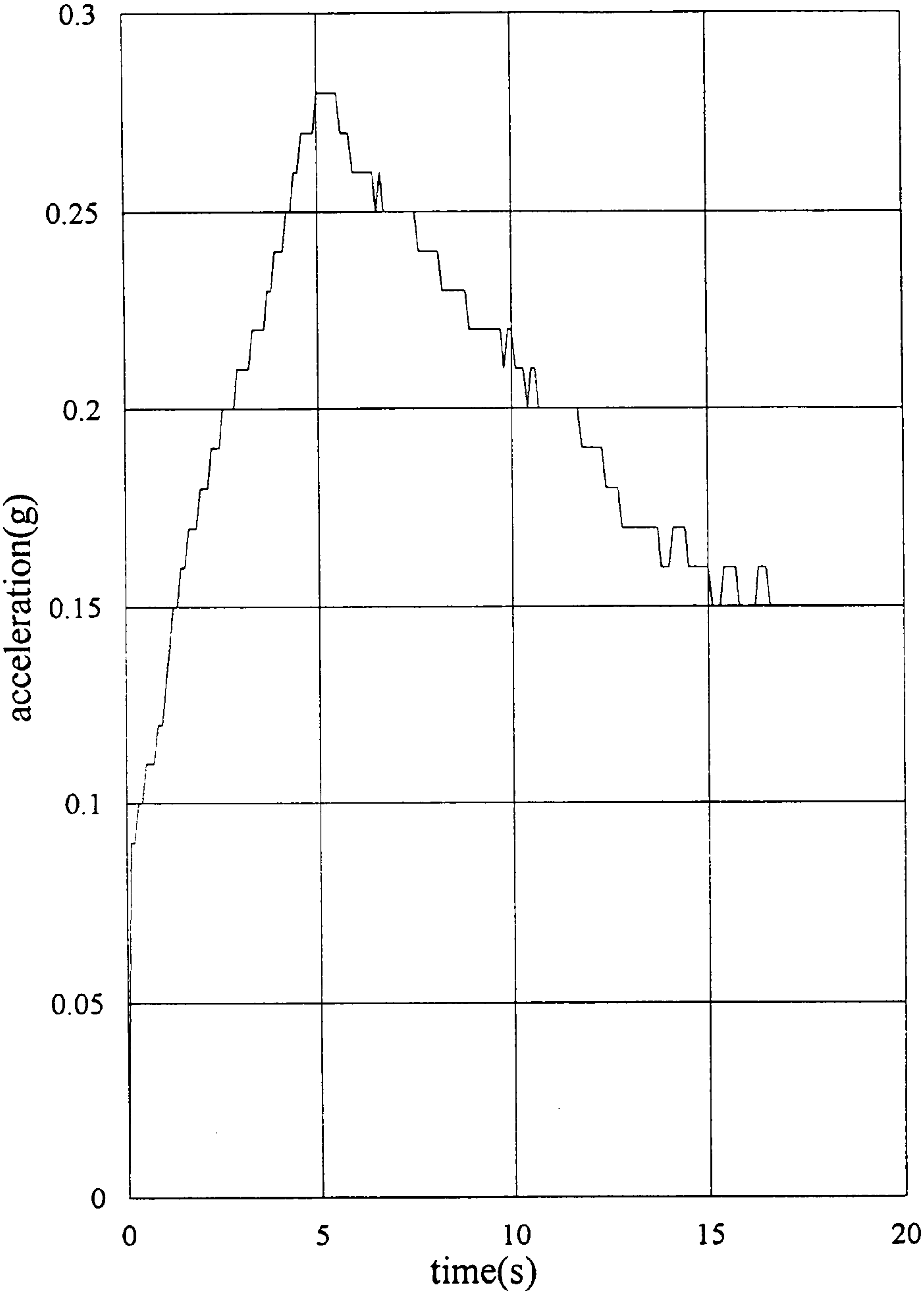
T.O. No. 7 Nov. 13, 1992 Piper PA-24-250
2434 lb. 30.12 inHg, 52°F, wind 210@9, TYS Rwy 23R

Figure 4.8 Acceleration for Take-off Number 7



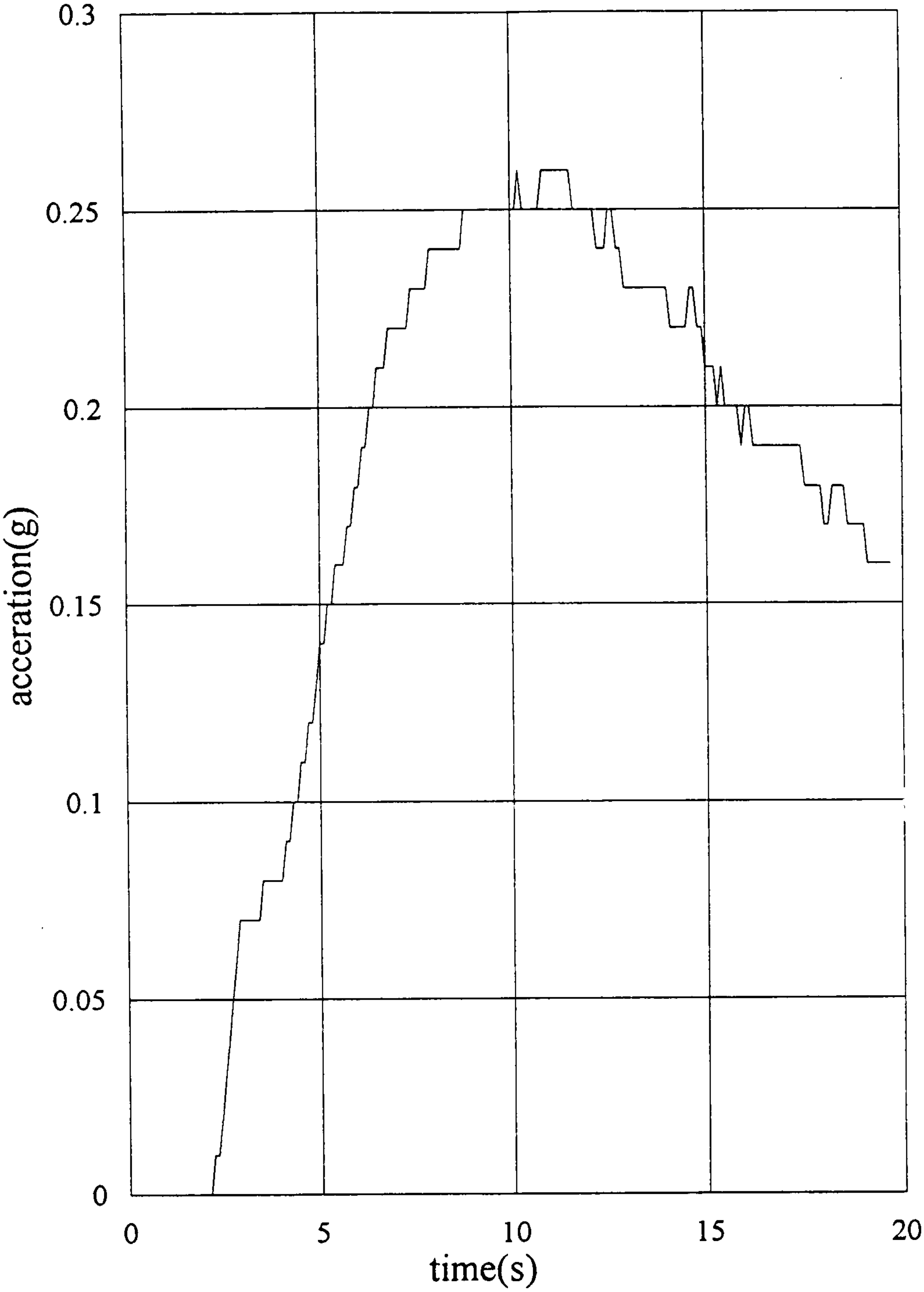
T. O. No. 8 Nov. 13, 1992 Piper PA-24-250
2,430 lb. 30.12 inHg,52°F wind 310@9, TYS Rwy 23R

Figure 4.9 Acceleration for Take-off Number 8



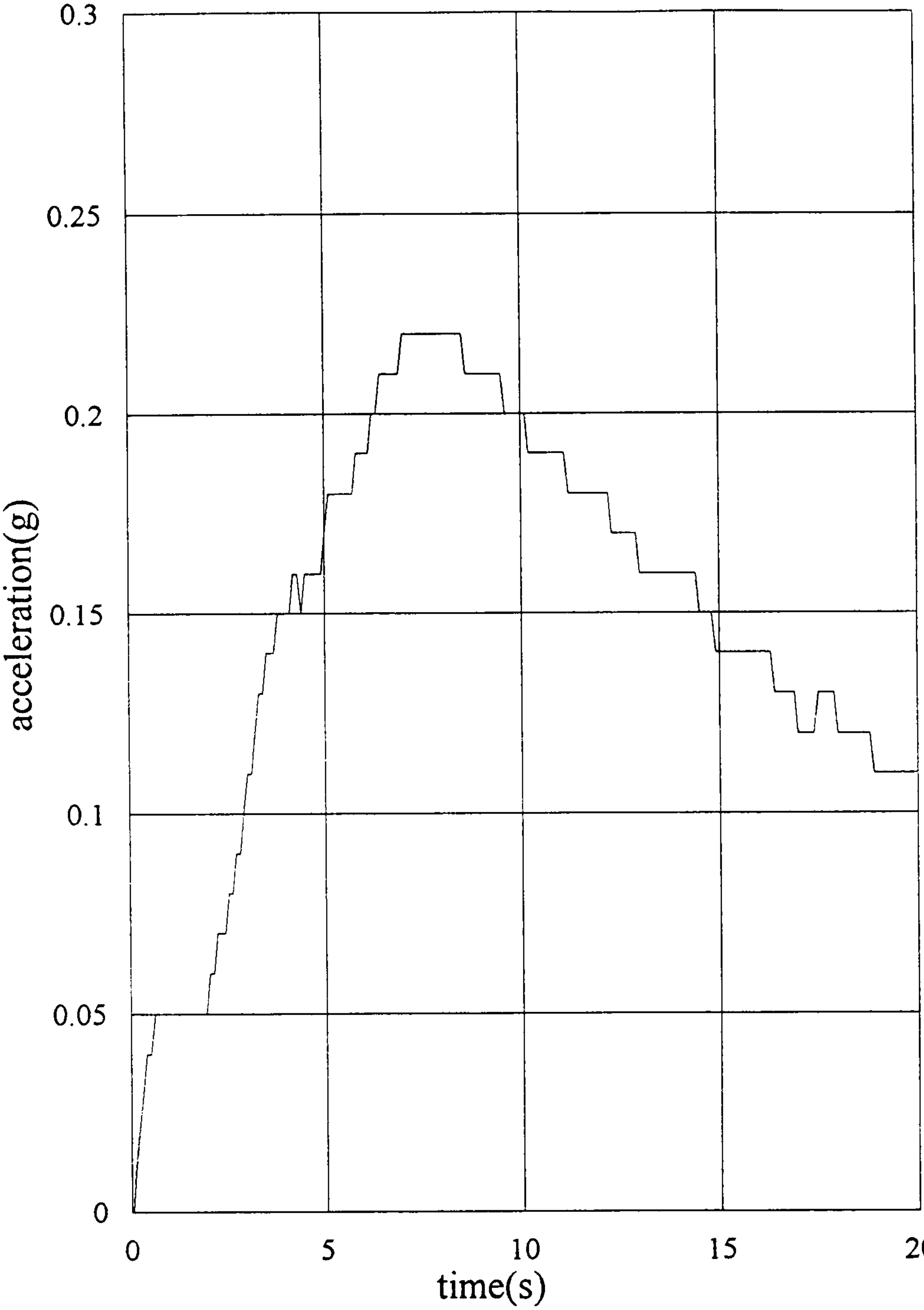
T.O. No. 9 Feb. 9, 1993 Piper PA-44-180
3795 lb. 30.12 inHg,66°F wind 270@9, TYS 23R

Figure 4.10 Acceleration for Take-off Number 9



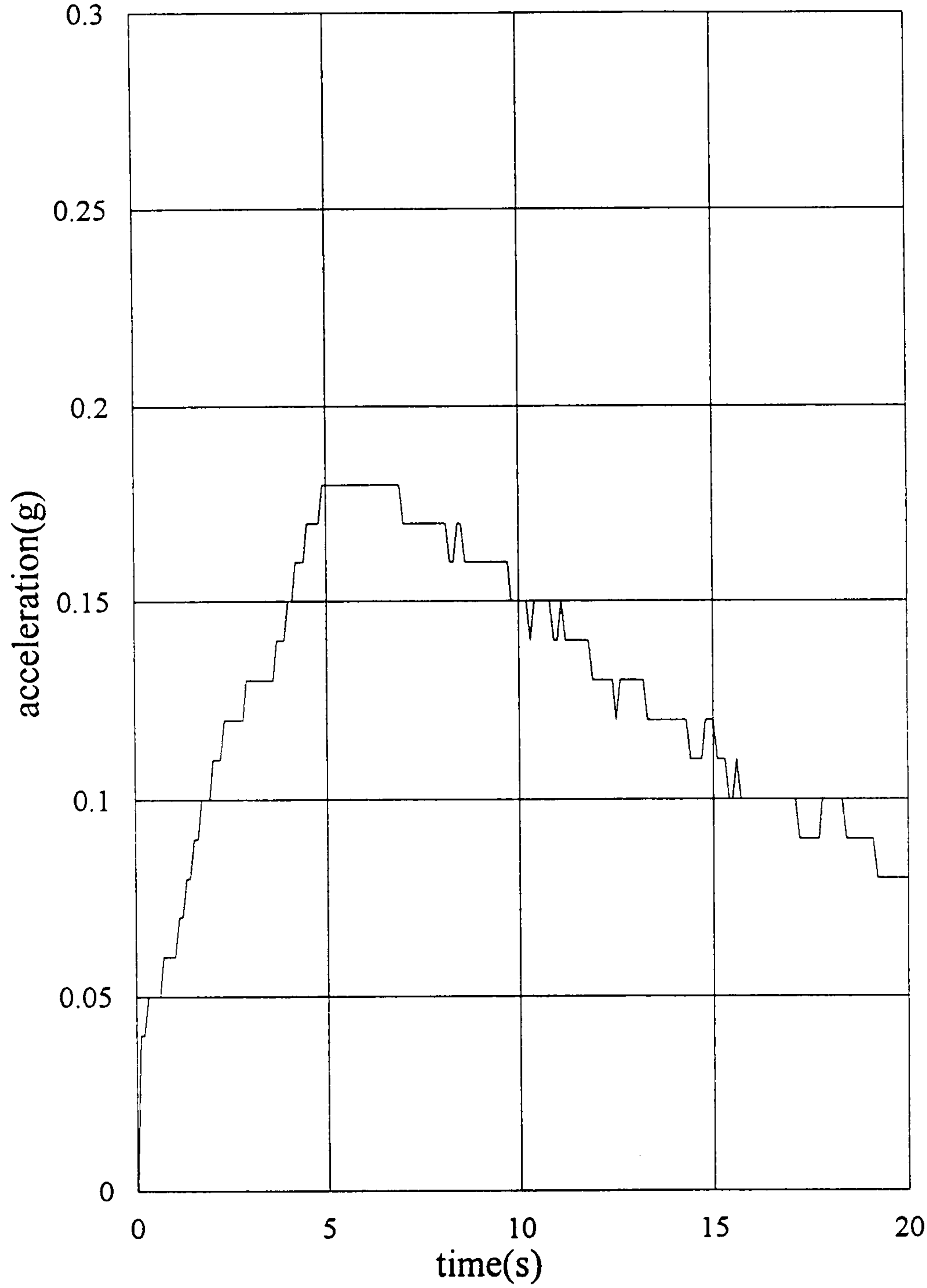
T. O. No. 10 Feb. 9, 1993 Piper PA-44-180
3780 lb. 30.12 inHg,66°F wind 270@9, TYS 23R

Figure 4.11 Acceleration for Take-off Number 10



T. O. No. 11 Feb. 9, 1993, Piper PA-44-180
3765 lb 30.12 inHg,66°F wind 270@9, TYS Rwy 23R

Figure 4.12 Acceleration for Take-off Number 11



T.O. No. 12 Feb. 9, 1993, Piper PA-44-180
3750 lb 30.12 inHg,66°F wind 270@9, TYS 23R

Figure 4.13 Acceleration for Take-off Number 12

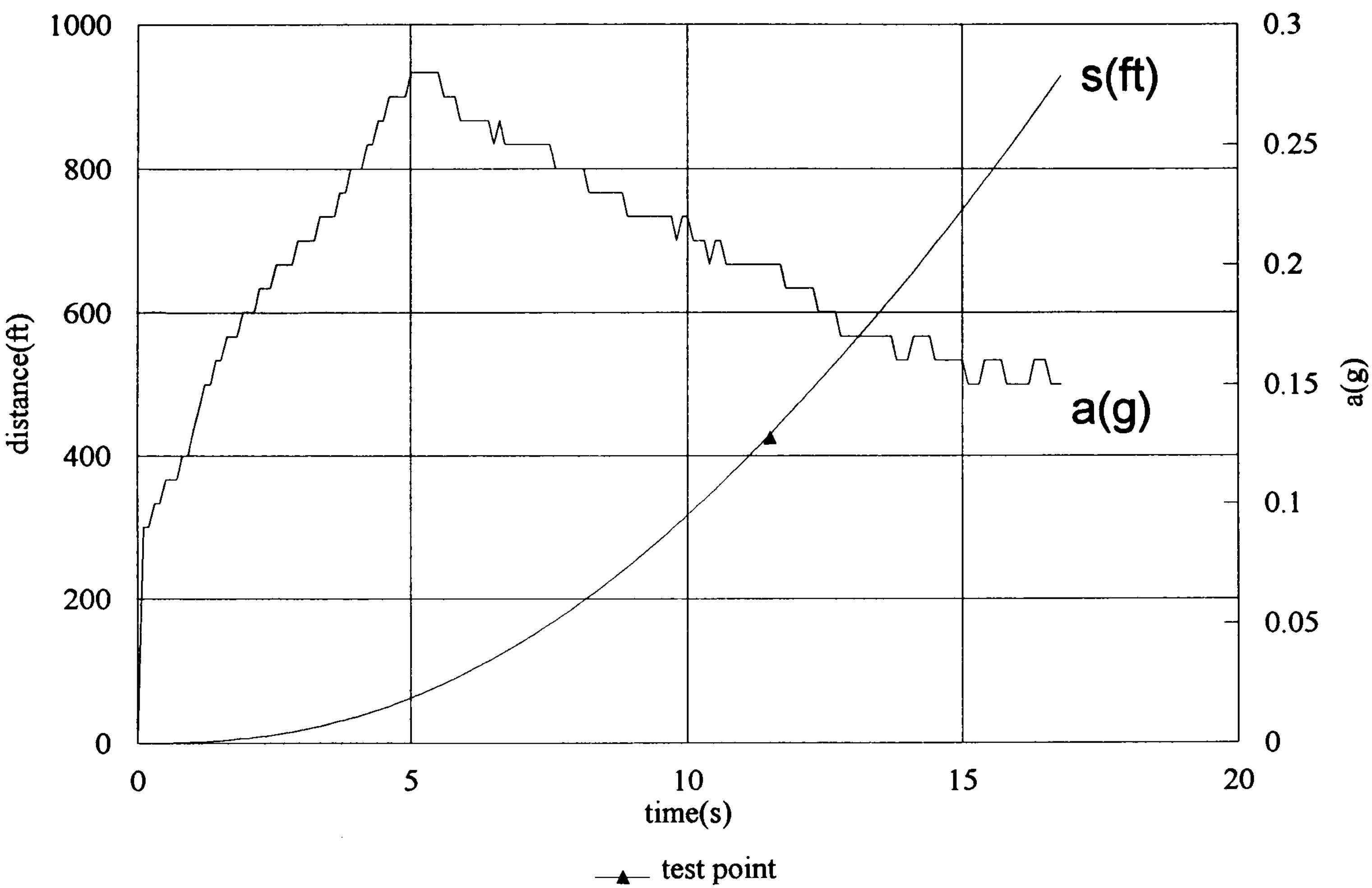


Figure 4.14 Rolling Distance for Take-off 9

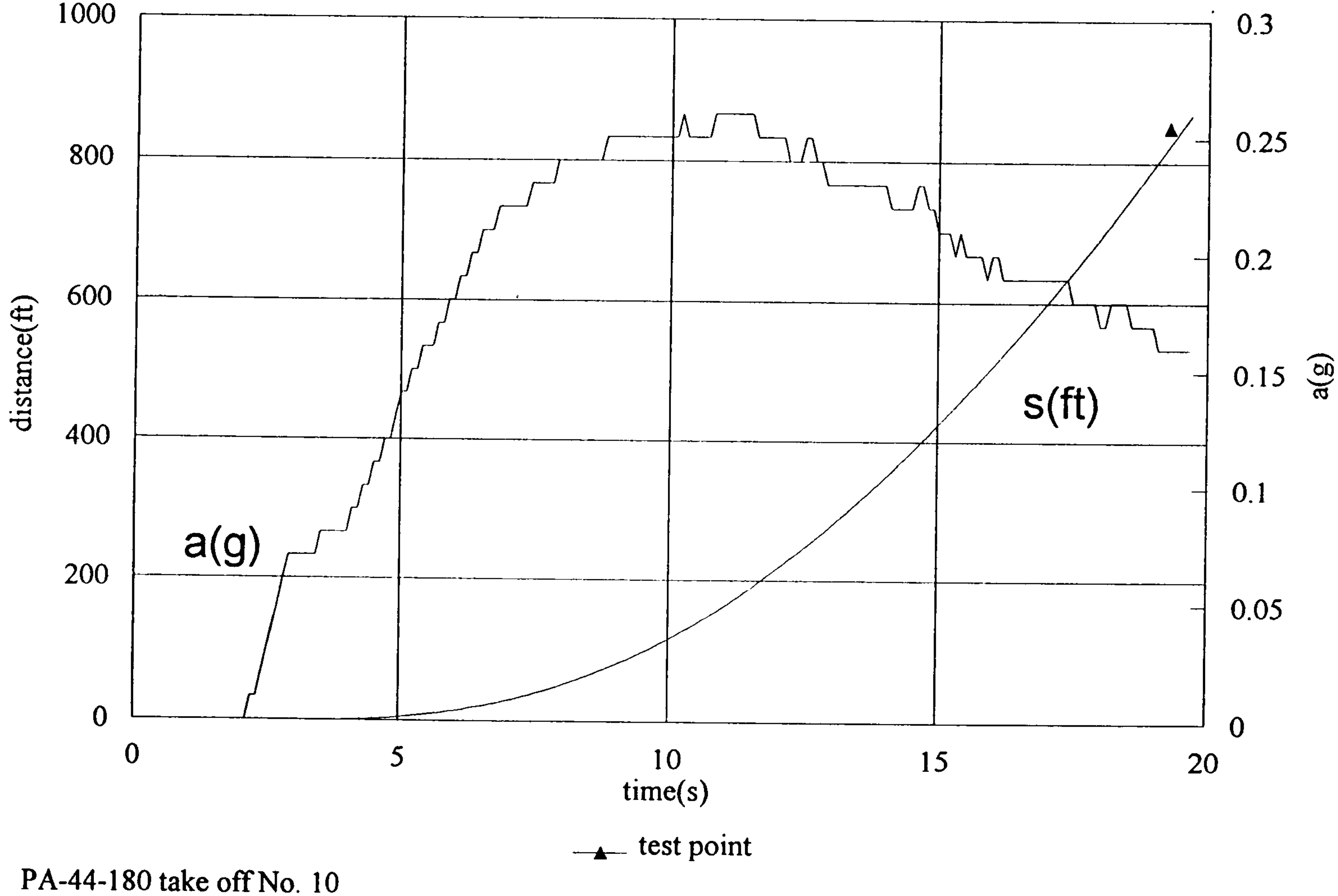
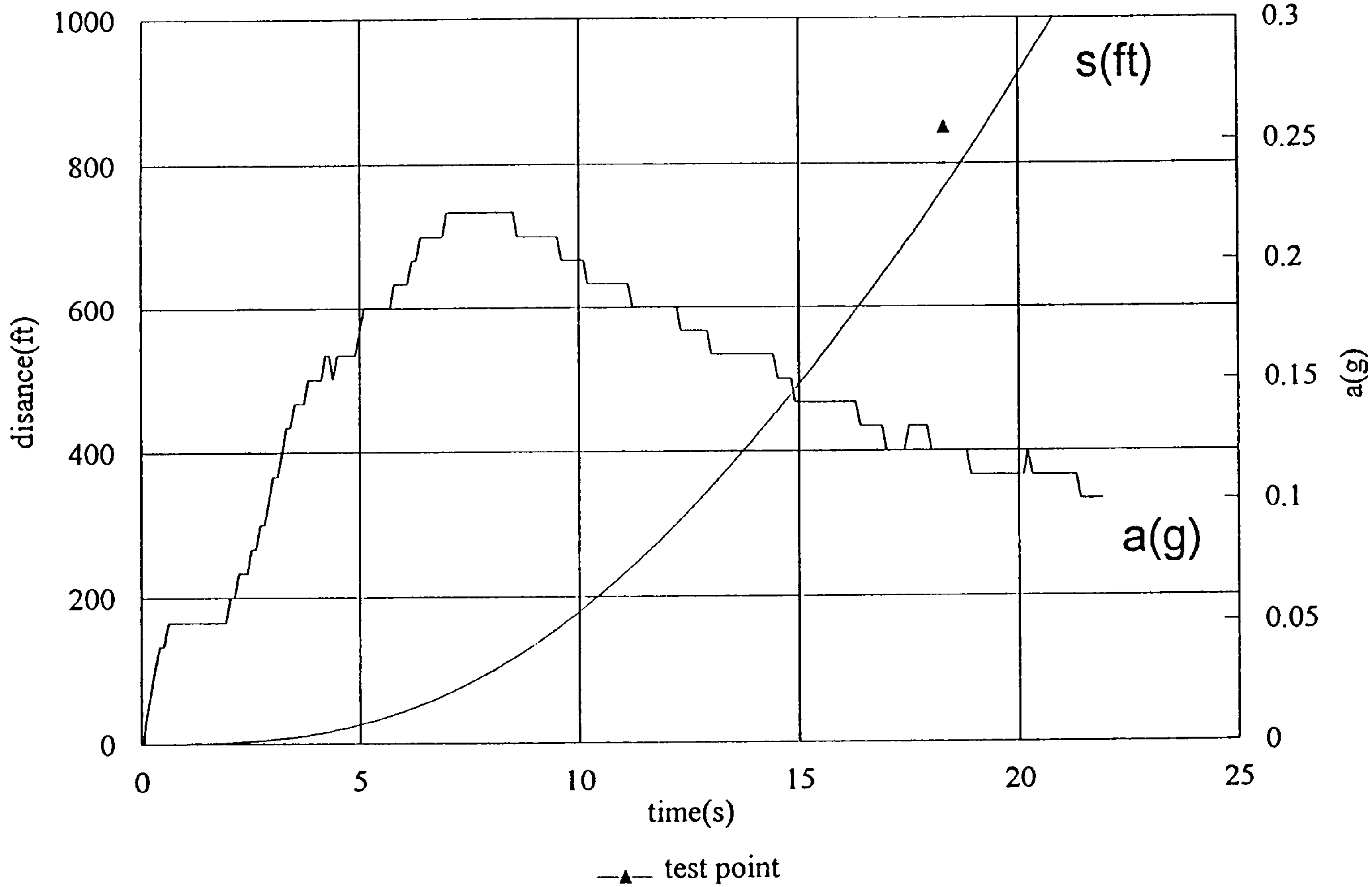
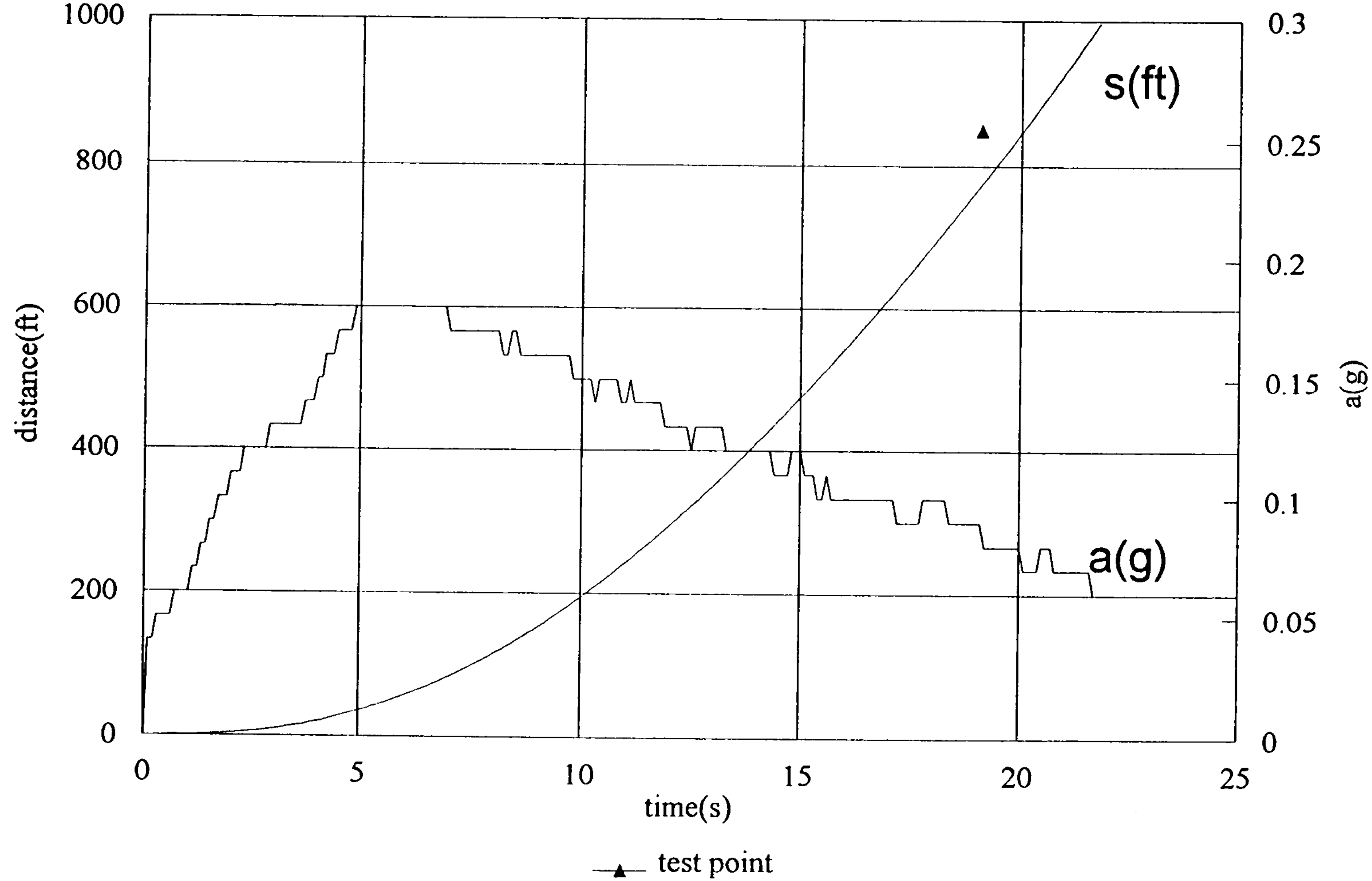


Figure 4.15 Rolling Distance for Take-off 10



PA-44-180 take off No. 11

Figure 4.16 Rolling Distance for Take-off 11



PA-44-180 take off No. 12

Figure 4.17 Rolling Distance for Take-off 12

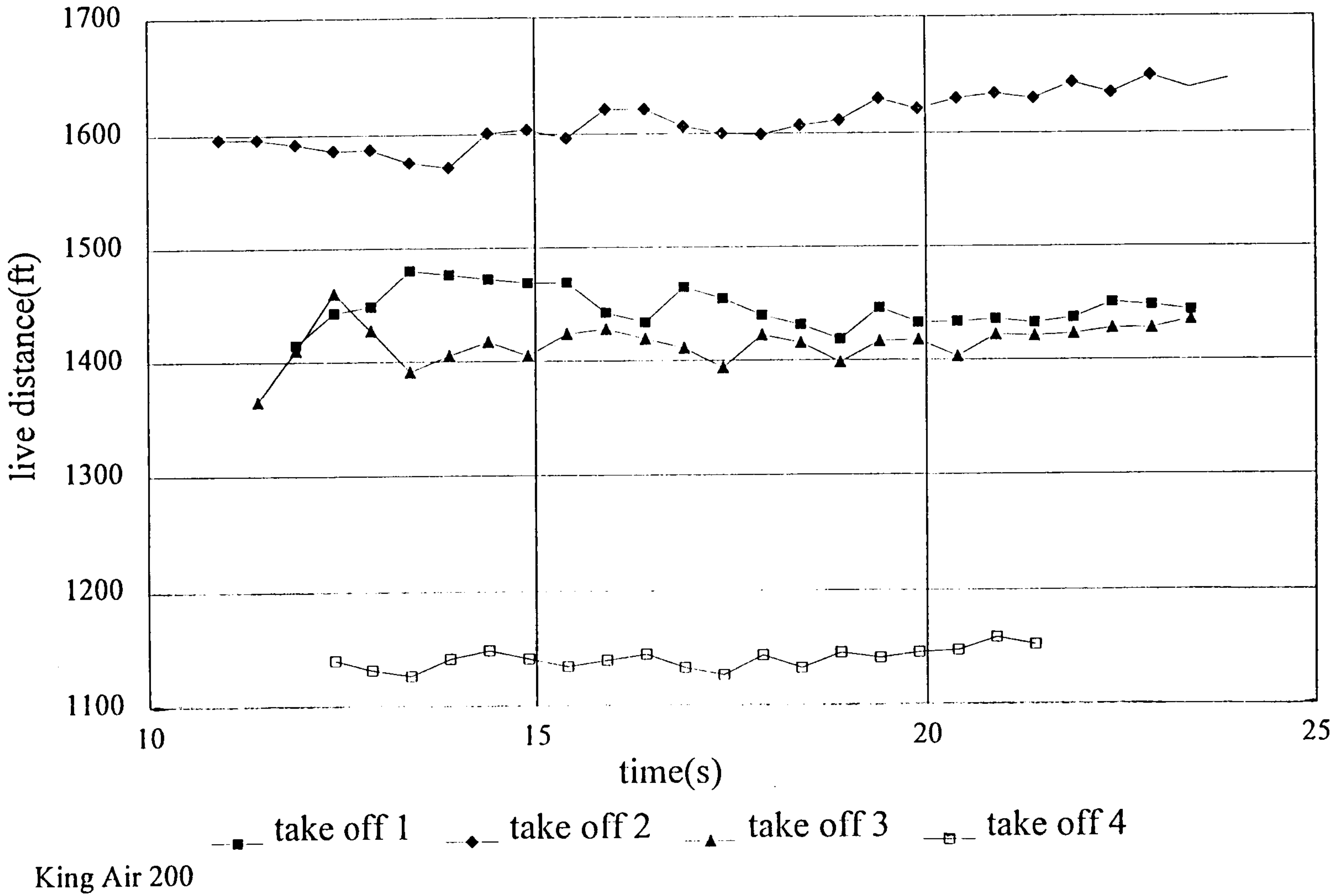


Figure 4.18 Live Distance for King Air 200

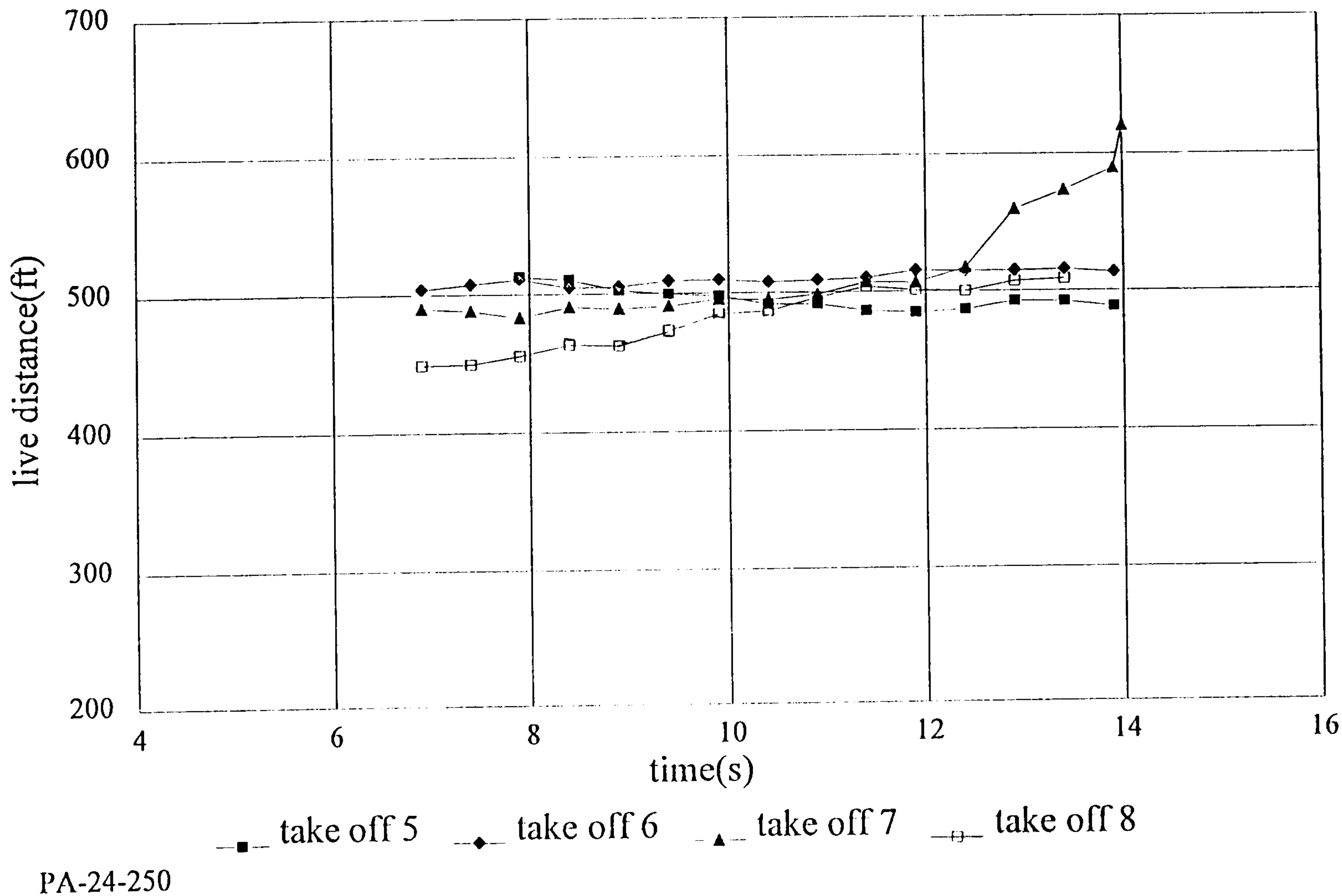


Figure 4.19 Live Distance for PA-24-250

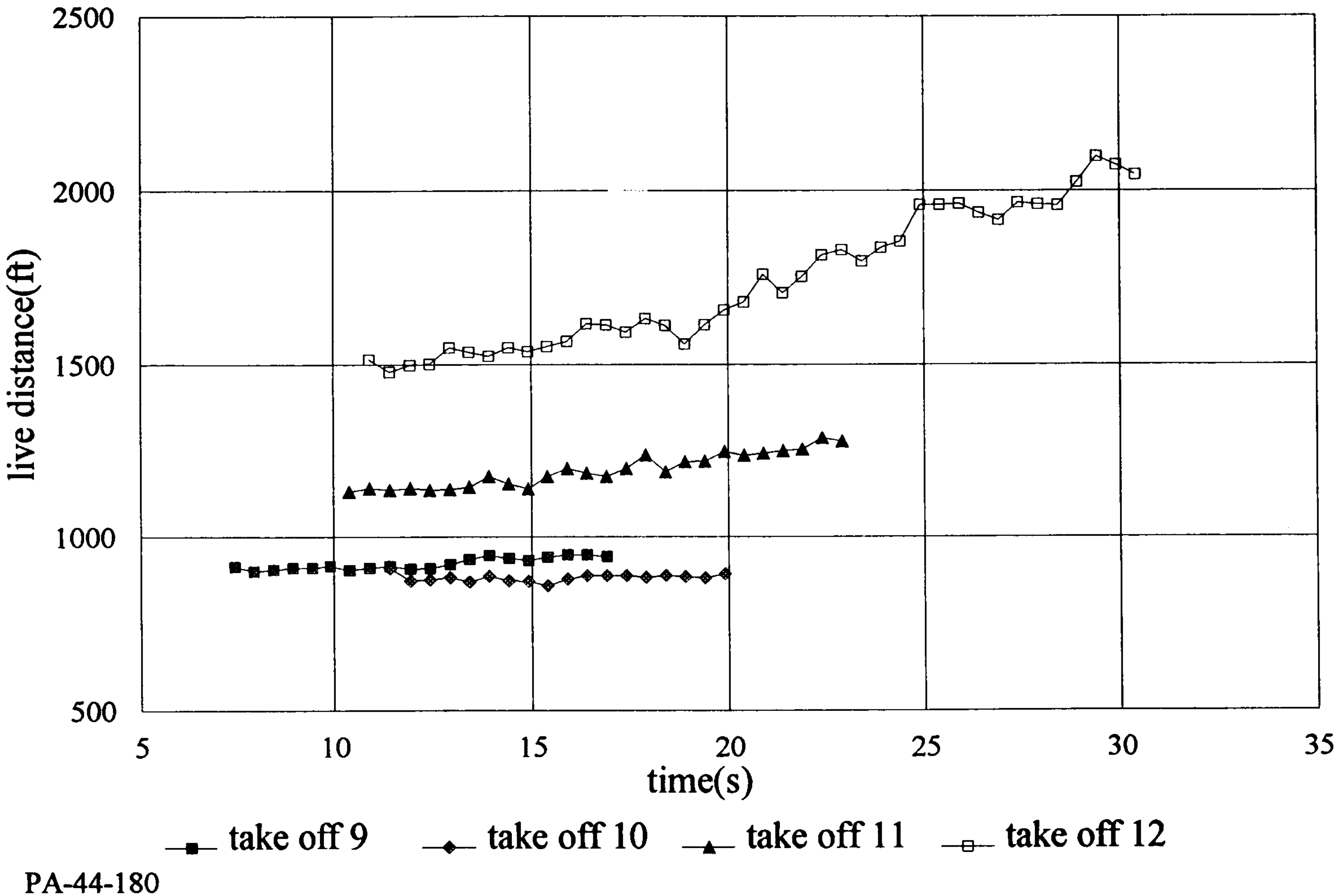


Figure 4.20 Live Distance for PA-44-180

reference speed v_r. The curves do not start at time equal zero because the early part of the take-off roll is very sensitive to the power setting technique. If the acceleration is above 0.15g, the program considers that a take-off is started and begins to output live distance and plot the screen.

The live distance is important information that enables the pilot to know the airplane predicted take-off distance at any moment. For Number 11 and 12 low power tests, the live distances are 56% and 141% higher than the normal predicted distance. Please see Table 4.5 for details.

The predicted distances are shown in Table 4.6

The acceleration ratios are show in Figure 4.21 to Figure 4.23. Acceleration ratio is a good way to present accelerations to pilot. It provides more information to the pilot than a acceleration plot. The acceleration ratio curve becomes a straight line of value one when actual acceleration is equal to the nominal acceleration. The accelerations for number 11 and 12 low power tests are noticeable lower than normal ones(number 9 and 10). This will help the pilot to easily identify subnormal acceleration.

Table 4.5 Distances at Different Power Settings

NUMBER	POWER	PREDICTED S (FT)	S_{live}/S_{pred}	S_{roll}/S_{pred}
9	98%	847.5	111%	111%
10	98%	848.6	105%	104%
11	98% 81%*	838.7 1008.2	156% 129%	155% 128%
12	98% 70%*	839.8 1150.9	241% 177%	217% 158%

* The actual power setting for low power test

Table 4.6 Predicted Distances

NUMBER	Airplane	PREDICTED S(ft)
1	King Air 2000	1347
2	King Air 2000	1550
3	King Air 2000	1260
4	King Air 2000	1077
5	Piper PA-24-250	508.6
6	Piper PA-24-250	467.3
7	Piper PA-24-250	467.5
8	Piper PA-24-250	467.7
9	Piper PA-44-180	847.5
10	Piper PA-44-180	848.6
11	Piper PA-44-180	838.7
12	Piper PA-44-180	839.8

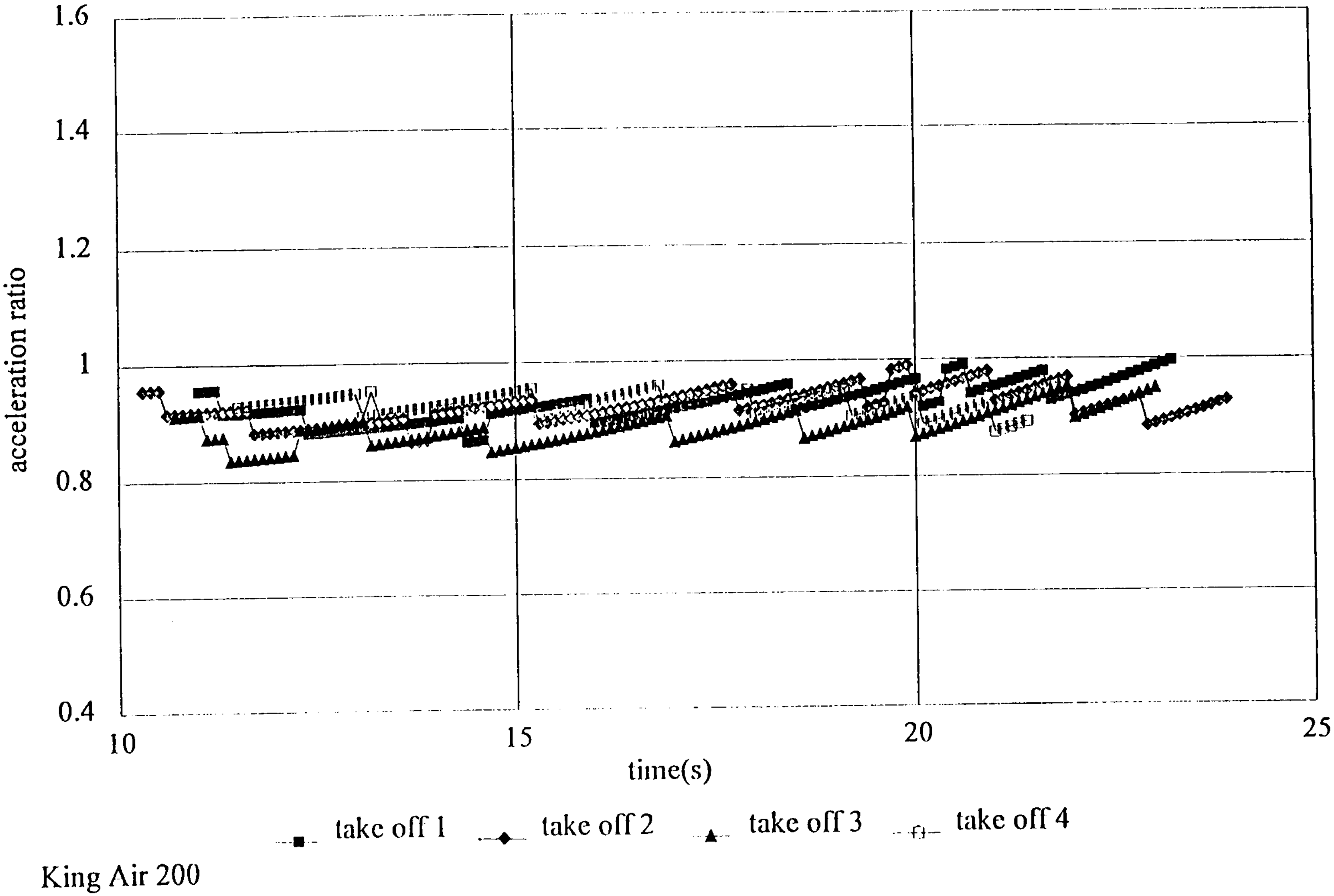


Figure 4.21 Acceleration Ratio for King Air 200

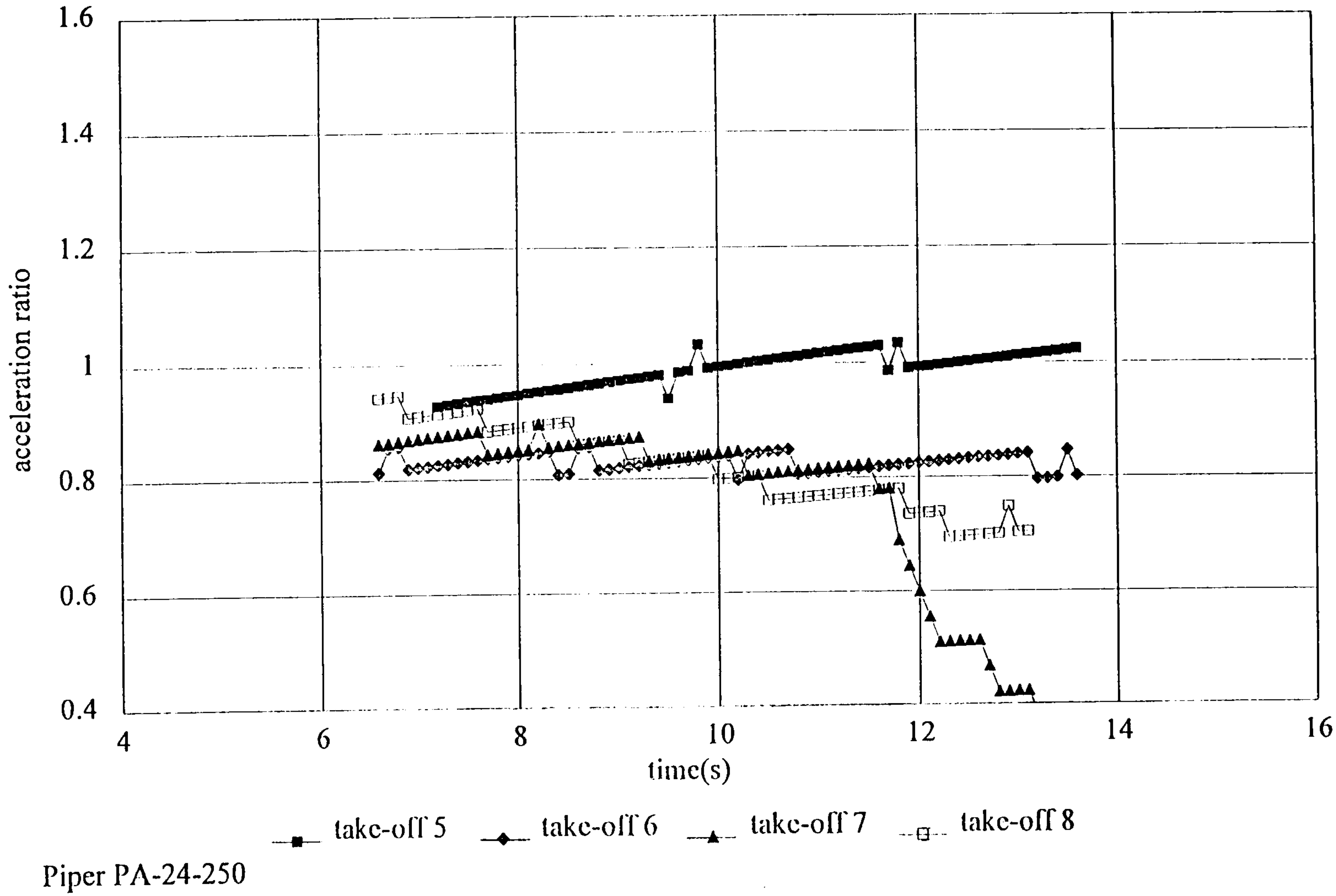


Figure 4.22 Acceleration Ratio for PA-24-250

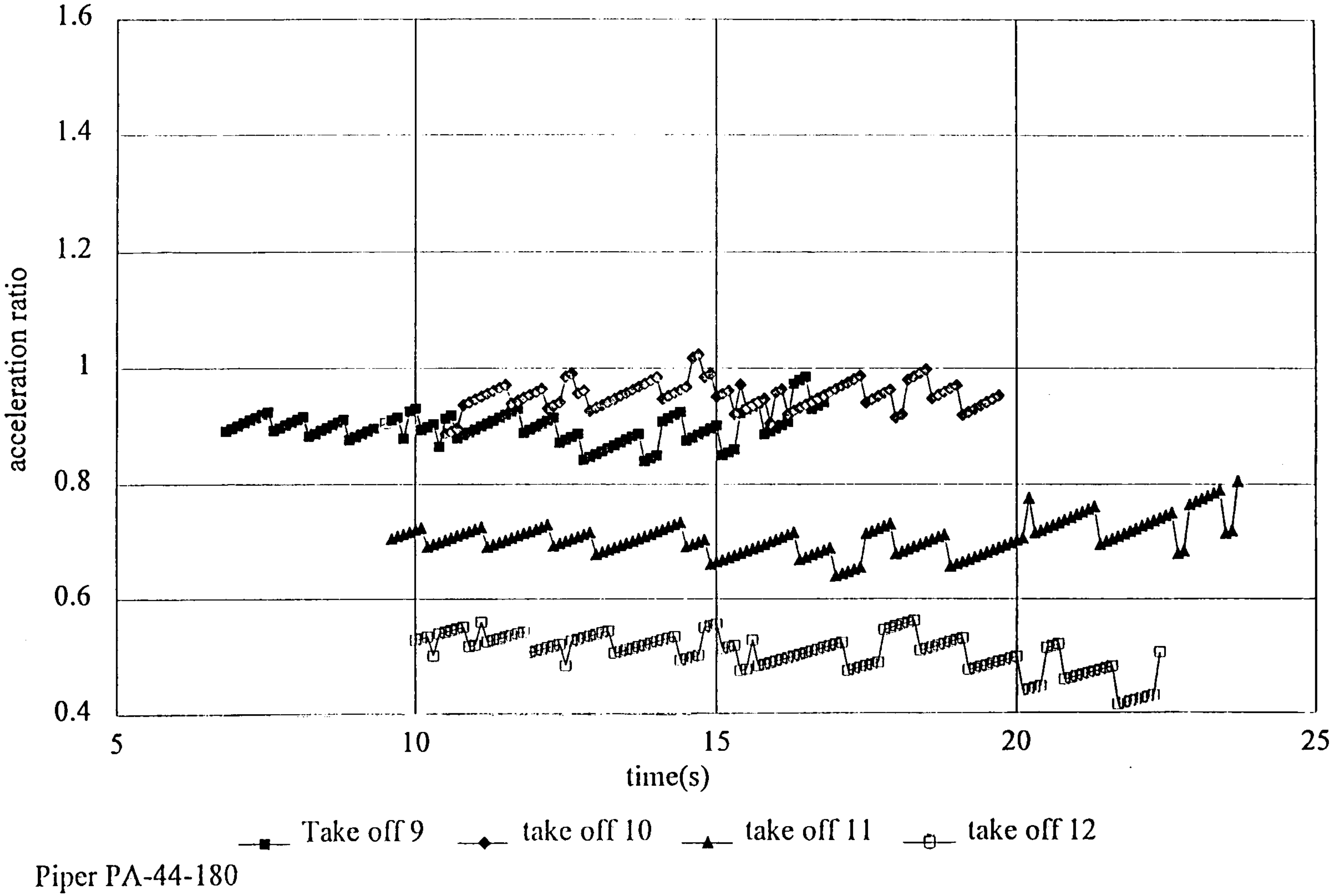


Figure 4.23 Acceleration Ratio for PA-44-180

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The system performed as designed during the demonstration tests. The system can predict take-off distance for present conditions before take-off. It will be a good instrument for both normal take-off operation and take-off safety. Another function of this instrument is to provide a powerful tool for take-off performance study and data collecting. The file system automatically gives file names, assign take-off number, saves historical data, solves the constants and updates the data base. The acceleration ratio plot verses time provide the pilot a clear picture of the airplane's performance for the present take-off compared with historical performance. The live distance informs the pilot of the predicted take-off distance from any moment.

Using constant C's to represent the acceleration is a concise and accurate way to give airplane take-off performance. Constant C's bring detail information about the entire take-off performance although using constant C's needs a computer to calculate the acceleration, speed and distance which are pilot interested.

An important result found from the test data is that the power setting period is long enough not to be neglected. The acceleration data revealed that the engine need a certain time to increase to the maximum power output after the throttle is set. If pilot advance the throttle slowly, the power setting time is even longer(please see Table 4.4 for power setting time). Some take-off calculations(16) use maximum thrust from the beginning and result in shorter ground roll distance when compared with test data because their mathematical model did not consider the acceleration ramp.

Take-off distance is very sensitive to thrust provided by engine. Table 4.5 shows that the roll distance increased about 55% when the power decreased about 20%; the roll distance increased 117% when the power decreased to 30%. The higher the take-off speed, the more sensitive to the thrust.

Pilot can get a clear picture of take-off performance by only a glance of the acceleration ratio time domain plot on the screen. The tests proved that it is the best way to provide information to pilot. Pilots would need to devote a lot of attention to readings if the direct acceleration data were printed on the screen. The normalized acceleration ratio bar graph is a better way. Since the pilot can only look at the screen a few times during a take-off, it can not provide a whole picture of the performance.

RECOMMENDATIONS

SYSTEM

The accelerometer output resolution(least count) needs to be at least ±0.001g. The accelerometer used for this study was ±0.01g. The test data show that it did not provide the response needed to smoothly represent the actual acceleration. This increase of the resolution is necessary to improve system performance.

Use data from different density altitudes to separate C3 and C4. Study the C3 influences on the take-off performance

Rewrite the program in C for portability among computers.

FUTURE TESTS

Tests on jet airplanes are need to verify the mathematical model and the system for applications to jet powered airplanes.

Airplane manufactures provide 'standard' constant C's from their certification tests. Pilot can compare the airplane performance with 'standard' data at any time to see the deviations of the performances.

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APPENDIXES

APPENDIX A

APPENDIX A

The g •analyst Specifications[17]

Manufacturer:	Valentine Research, Inc. 10280 Alliance Road Cincinnati, Ohio 45242 1-800-331-3030
Transducer system:	Three accelerometers in orthogonal alignment.
Transducer element:	Electromagnetic force-balance accelerometer with flexure suspension.
Measurement resolution:	±0.01g
Data sample rate:	Ten samples per second.
Measurement Orientation:	g's measured in the plane of the road.
Anti-alias filter:	Third-order Bessel function(doesn't "ring" in time domain).
Processor type:	16-bit Intel 8097 Microcontroller

A/D:	10-bit resolution, 8 channels
Processor speed:	11.9808 MHz

Operation Limits

Measurement range, g:	On axis: ±2.54g(clipping limit). Off axis: vector sum of lateral and longitudinal g components so long as neither components exceeds clipping limit. If one or both components exceeds limit, the g numeric will show bars
On board Memory:	Memory limit is 8 minutes.
Temperature range:	Operating: -20 $^{\circ}C$ to +85 $^{\circ}C$
Terrain:	No terrain limits.(Remember, g•analyst readings always indicate the plane of the road, regardless of inclination of the road).
Accuracy:	±1% of indicated g at 25 $^{\circ}C$, plus an additional "round-off" error not to exceed half of the display's smallest increment(0.005g).

APPENDIX B

APPENDIX B

PROGRAM LIST

```
'*****************************************************************
'*                                                               *
'* Date:        May 27, 1993                                     *
'* Hardware:    IBM-PC or compatible                             *
'*              g.analyst                                        *
'*              g.link cable connect g.analyst with PC through*
'*                 RS-232                                        *
'* Keys:        F1  event times.  save up to 3 event times       *
'*              F4  quit program execution and save data         *
'*              F5  change input data                            *
'*              F8  fresh screen and start from zero             *
'*                                                               *
'*****************************************************************

      DIM acc(900), accc(900), spretab(900)
      DIM event(9)                    'time events. use only 3
      DIM a5(6, 6), c(6), a1(600, 6), c1(600), x1(6), o(6), s5(6)
      CLS

      KEY(1) ON                       'time events
      KEY(4) ON                       'quit program & save data
      KEY(8) ON                       'refresh screen
      KEY(5) ON                       'correct input data
      ON KEY(1) GOSUB 401                  'time events
      ON KEY(4) GOSUB 301                  'save data
      ON KEY(5) GOSUB 601                  'chang inputed data

      PRINT " ***Press F5 if you need chang inputed data***"
      PRINT
      INPUT "1. Airplane number(last 3 characters?)", airno$
      airno$ = "N" + airno$
'airplane No. and file name of c1,c2,c3
      INPUT "2. Pecent thrust(%)?              ", pp
```

```
        pp = pp / 100!
        INPUT "3.Take-off Gross Weight(lb)?         ", w
        INPUT "4. Runway Number(without R, L, C)    ", rh
        rh = 31.41593 * rh / 180!                      'runway heading
        INPUT "5. Field elevation(ft)?            ", h
        INPUT "6. Wind Speed(mph)?                ", ws
        ws = ws * 1.466667                          'ft/sec
        INPUT "7. Wind Direction(Deg.)?           ", wd
        wd = 3.141593 * wd / 180!                      'degree to radians
        INPUT "8. Outside Air Temperature(F)?      ", oat
        oat = oat + 459.7                          ' F-R
        INPUT "9. Altimeter Setting(inHg)?         ", p
        p = p * 2116.2 / 29.92                      'inHg-lb/ft^2
        p = p * (1! - .0064967 * .3048 * h / 288.16) ^ (9.81 / 287! /
.0064967)
'transformed to local presure
        INPUT "10. Reference speed(knots)          ", vr
'       vr = .4471 * vr / .3048                     'mph-m/s-ft/s
        vr = .5151 * vr / .3048                     'knot-m/s-ft/s

        c6 = 0          ' initial values for first T. O.
        c7 = 0
        c8 = 0
        nto = 0
        INPUT "12. first take-off with this instrument(Y,N)?", an$
        IF an$ = "Y" OR an$ = "y" THEN 1010       'first take-off no data

1070    OPEN airno$ FOR INPUT AS #1
        INPUT #1, nto
        INPUT #1, c6, c7, c8, ssetp1, vsetp1
        CLOSE
        KEY(5) OFF

'predicted distance
        s1 = ssetp1
        v1 = vsetp1
        k = CINT(2 * v1)
        s2 = s1
        FOR i = 1 TO 800
        c9 = v1 + ws * COS(rh - wd)
```

```
      a0 = (pp * c6 + pp * c7 * c9 + c8 * c9 * c9 * p / oat) / w
      j = CINT(2 * v1)
      spretab(j) = s1
      IF j - k < 2 THEN 1400

      FOR ii = 1 TO j - k - 1
      spretab(j - ii) = (j - k - ii) * (s2 + s1) / (j - k)
      NEXT ii

1400  s2 = s1
      k = j
      s1 = s1 + .1 * v1 + .005 * a0 * 32.2
      v1 = v1 + a0 * 3.22
      IF c9 >= vr THEN 1000          'c9 air speed
      NEXT i

      PRINT "********Data error.**********"
      STOP

1000  spred = s1
      FOR j = CINT(2 * vsetp1) TO k
      spretab(j) = spred - spretab(j)
      NEXT j

      PRINT
      PRINT
      PRINT
      PRINT "*********S predicted = "; s1; "ft*************"
      GOTO 1040

1010  INPUT "verify this is FIRST take-off(Y,N)?", an$
      IF an$ <> "Y" AND an$ <> "y" THEN 1070
' avoid erasing data base

      OPEN airno$ FOR APPEND AS #1
'prepare space for average data
      SEEK #1, 1
      PRINT #1, "                                                  "
      PRINT #1, "                                                  "
      CLOSE
```

```
nto = 0

1040   IF pp > .4 THEN 88
       PRINT "NOT ENOUGH POWER FOR TAKE OFF!!!"
       BEEP
       BEEP
       STOP

88     ky = 0                              'event counter
       s1 = 0!
       v1 = 0!
       mu = .02
       th = 0!
       acc2 = 0
       c = mu * w * COS(th) + w * SIN(th)
       CLOSE

'calibaration
1020   PRINT
       PRINT
       PRINT
       PRINT "Ready for Caliberation. g.analyst must on."
       PRINT
       PRINT "Press any key to continue"

       OPEN "COM1:2400,N,8,1,ASC,OP0,CD0" FOR INPUT AS #1
       DO
       LINE INPUT #1, accel$
       LOCATE 20, 1
       PRINT USING "###.###"; VAL(LEFT$(RIGHT$(accel$, 18), 4)) /
100!
       LOOP WHILE INKEY$ = ""
       SCREEN 2
       CLS
       LOCATE 1, 1
       PRINT "Caliberation ...   pleas wait"
       cal = 0!
       FOR i = 1 TO 10
       LINE INPUT #1, accel$
       cal = cal + VAL(LEFT$(RIGHT$(accel$, 18), 4))
```

```
        NEXT i
        cal = cal / 10!
        PRINT cal / 100!              '100 to move point two digits left
        IF cal < 3! THEN 1030
        CLOSE
        PRINT
        PRINT
        PRINT "Initial reading too big!  Re-Install accelerometer."
        PRINT "Caliberate again."
        PRINT
        PRINT
        GOTO 1020

' wait for any key to start
1030    LOCATE 8, 1:  PRINT "READY"
        PRINT
        PRINT "Press any key to continue..."
        DO
        LINE INPUT #1, accel$
        LOCATE 14, 1
        PRINT USING "###.###"; (VAL(LEFT$(RIGHT$(accel$, 18), 4)) -
cal) / 100!
'100 to move point two digits left.  the input from g.analyst is
integer
        LOOP WHILE INKEY$ = ""
        CLOSE #1

'display table
        CLS 2
        LOCATE 3, 4
        PRINT " ROLL"
        LOCATE 6, 4
        PRINT " LIVE"
        LOCATE 9, 4
        PRINT " REFERENCE"
        LOCATE 9, 30
        PRINT USING "##### ft"; spred        'predicted speed

        VIEW
        LINE (20, 0)-STEP(340, 80), , B
```

```
        LINE (26, 3)-STEP(328, 74), , B
        LINE (26, 28)-(354, 28)
        LINE (26, 52)-(354, 52)
        LINE (178, 3)-(178, 77)

'**grids**************
        LINE (0, 199)-(599, 99), , B
        LINE (99, 199)-(99, 99)
        LINE (199, 199)-(199, 99)
        LINE (299, 199)-(299, 99)
        LINE (399, 199)-(399, 99)
        LINE (499, 199)-(499, 99)

'       LINE (0, 179)-(599, 179)
        LINE (0, 174)-(599, 174)
        LINE (0, 149)-(599, 149)
        LINE (0, 124)-(599, 124)
        LOCATE 12, 12
        PRINT "           10sec                    20sec                    30sec"
        LOCATE 19, 76
        PRINT "a/a_n"
        LOCATE 16, 76
        PRINT "1.25"
        LOCATE 22, 76
        PRINT "0.75"

'initial value for loop
        VIEW SCREEN (0, 199)-(639, 20)
        LINE (0, 149)-STEP(0, 0)            'orignal
        amax = 0!
        s = 0!
        v = 0!
        s1 = 0!
        v1 = 0!
        a = 0!
        time = 0!
        control = 0          'if control=0 v1=v s1=s
                             'if control=1 v, s measured. s1,v1 calculated

        ON KEY(8) GOSUB 501                 'refresh screen
```

```
        OPEN "COM1:2400,N,8,1,ASC,OP0,CD0" FOR INPUT AS #1

        FOR i = 0 TO 179
        FOR i9 = 0 TO 4
        LINE INPUT #1, accel$
        T2 = 5 * i + i9
        acc1 = (VAL(LEFT$(RIGHT$(accel$, 18), 4)) - cal) / 100!
' cal is initial reading. readings are integer. /100 transfer to g
        IF acc1 < amax THEN 1050            'find right max a at time t1
        amax = acc1
        t1 = T2
1050    IF acc1 > .15 THEN control = 1          'initial control

        acc(T2) = acc1
        a3 = p / oat * (v + ws * COS(rh - wd)) ^ 2
        LOCATE 3, 28
        PRINT USING "###### ft"; s
        s = s + .1 * v + .005 * (acc1 + acc2) * .5 * 32.2
        v = v + 3.22 * (acc1 + acc2) * .5
        a0 = (pp * c6 + pp * c7 * c9 + c8 * c9 * c9 * p / oat) / w
        IF control > .5 THEN 1060
        a0 = acc1

1060    accc(T2) = a0
        v1 = v1 + a0 * 3.22
        IF control > .5 AND nto > .5 GOTO 87
        ssetp = s                    'distance set power.  save in file
        vsetp = v
        s1 = s
        v1 = v
        PSET STEP(2, 0)
        GOTO 91

87      LINE -(2 * T2, -100! * acc1 / a0 + 249)
' a/a0 graph
91      acc2 = acc1
        IF v + ws * COS(rh - wd) >= vr THEN 77
        aver = acc1 + aver                  'acumulator for average
        IF acc1 <= 0 AND control > .5 THEN 125  'lost power. no accel.
        NEXT i9
```

```
      IF control < .5 THEN 126
'AVOID DIVID BY 0 DURING power adjusting
      s2 = s + 5! * a0 / aver * spretab(CINT(2 * v))
      LOCATE 6, 28
      PRINT USING "###### ft"; s2

126    aver = 0!              ' reset accumlator
      NEXT i
      KEY(8) OFF

77     LOCATE 3, 28
      PRINT USING "###### ft"; s;
      LOCATE 6, 28
      PRINT USING "###### ft"; s2
      CLOSE #1
      GOSUB 301                    'data save subroutine
      LOCATE 22, 10
      PRINT " 1,ENTER --  update datebase"
      LOCATE 23, 10
      PRINT " -1,ENTER -- rerun"
      LOCATE 24, 10
      INPUT ; " 0,ENTER -- end", a
      SCREEN 0                     'reset the screen text 80x25
      IF a < .5 GOTO 89
      GOSUB 65                     'SOLVE 3c & UPDATE C3 FILES
      END

'rerun or end?
89     IF a < -.5 THEN 88   'RE-RUN THE PROGRAM
      END

'lose power or brake
125    LOCATE 12, 10
      PRINT "LOST POWER!!!"
      FOR i = 1 TO 10
      BEEP
      FOR j = 0 TO 100
      NEXT j
      NEXT i
      END
```

```
'data save subroutine
301    CLOSE #1
'      CLS 2
       OPEN airno$ + "-" + LTRIM$(STR$(nto + 1)) FOR APPEND AS #2
       PRINT #2, airno$; ",", DATE$; ",", nto + 1
       PRINT #2, pp; ",", w
       PRINT #2, rh; ",", h
       PRINT #2, ws; ",", wd
       PRINT #2, oat; ",", p
       PRINT #2, vr; ",", spred
       PRINT #2, ssetp; ",", vsetp
       PRINT #2, t1; ",", T2
       PRINT #2, cal / 100
       FOR j = 0 TO T2 - 1                'outloop value t2 = t2+1
       PRINT #2, j, ","; acc(j), ","; accc(j)
'unit g*.01, delta time .1 second
       NEXT j
       PRINT #2, event(0), event(1), event(2), "initial reading:"; cal /
100
       CLOSE #2
       LOCATE 1, 1
       PRINT "data were saved in file "; airno$ + "-" +
LTRIM$(STR$(nto + 1))
       RETURN

'*********envent time serve sub I**********
401    event(ky) = T2
       ky = ky + 1
       RETURN

'rerun the program.  refresh screen
501    CLS
       ky = 0                  'event counter
       s1 = 0!
       v1 = 0!
       SCREEN 2
       LINE INPUT #1, accel$
       acc2 = (VAL(LEFT$(RIGHT$(accel$, 18), 4)) - cal) / 100!
       LOCATE 8, 1:  PRINT "READY"
       PRINT
```

```
        PRINT "Press any key to continue..."
        DO
        LOCATE 14, 1
        PRINT USING "###.###"; (VAL(LEFT$(RIGHT$(accel$, 18), 4)) -
cal) / 100!
'100 to move point two digits left.  the input from g.analyst is
integer
        LOOP WHILE INKEY$ = ""
        CLS 2
        LOCATE 3, 4
        PRINT " ROLL"
        LOCATE 6, 4
        PRINT " LIVE"
        LOCATE 9, 4
        PRINT " REFERENCE"
        VIEW
        LINE (20, 0)-STEP(340, 80), , B
        LINE (26, 3)-STEP(328, 74), , B
        LINE (26, 28)-(354, 28)
        LINE (26, 52)-(354, 52)
        LINE (178, 3)-(178, 77)

'**grids**************
        LINE (0, 199)-(599, 99), , B
        LINE (99, 199)-(99, 99)
        LINE (199, 199)-(199, 99)
        LINE (299, 199)-(299, 99)
        LINE (399, 199)-(399, 99)
        LINE (499, 199)-(499, 99)

'       LINE (0, 179)-(599, 179)
        LINE (0, 174)-(599, 174)
        LINE (0, 149)-(599, 149)
        LINE (0, 124)-(599, 124)

        LOCATE 12, 12
        PRINT "           10sec                    20sec                  30sec"
        LOCATE 19, 76
        PRINT "a/a_n"
        LOCATE 16, 76
```

```
PRINT "1.25"
LOCATE 22, 76
PRINT "0.75"

LOCATE 9, 30
PRINT USING "##### ft"; spred        'predicted speed

VIEW SCREEN (0, 199)-(639, 20)
LINE (0, 149)-STEP(0, 0)            'orignal

amax = 0!
time = 0!
s = 0!
v = 0!
s1 = 0!
v1 = 0!
a = 0!
control = 0
RETURN

'****** input correcting sub.*********
601   INPUT "Which line need change?  ", linno
      ON linno GOTO 610, 620, 630, 640, 650, 660, 670, 680, 690,
691
610   INPUT "1. airplane number(last 3 numbers?)  ", airno$
      airno$ = "N" + airno$
'airplane No. and file name of c1,c2,c3
      RETURN
620   INPUT "2. pecent Power(%)?                ", pp
      pp = pp / 100
      RETURN
630   INPUT "3.Take-off Gross Weight(lb)?        ", w
      RETURN
640   INPUT "4. Runway Number                    ", rh
      rh = 31.41593 * rh / 180!               'runway heading
      RETURN
650   INPUT "5. field elevation?              ", h
      RETURN
660   INPUT "6. Wind Speed(Miles/hr)?            ", ws
      ws = ws * 1.466667                      'ft/sec
```

```
     RETURN
670   INPUT "7. Wind Direction(Deg.)?            ", wd
     wd = 3.141593 * wd / 180!                    'degree to radians
     RETURN
680   INPUT "8. Outside Air Temperature(F)?       ", oat
     oat = oat + 459.7                        ' F-R
     RETURN
690   INPUT "9. Altimeter Setting(inHg)?          ", p
     p = p * 2116.2 / 29.92                     'inHg-lb/ft^2
     p = p * (1! - .0064967 * .3048 * h / 288.16) ^ (9.81 / 287! /
.0064967)
'transformed to local presure
     RETURN
691   INPUT "10. reference speed(mph for PA-250)    ", vr
     vr = .5151 * vr / .3048                    'mph-m/s-ft/s
     RETURN

'*******************************************
'initializatin
     CLS
65    v = vsetp                    'initial speed
     s = ssetp                    'initial distance
     FOR i = 1 TO 3
     FOR j = 1 TO 3
     a5(i, j) = 0!
     NEXT j
     c(i) = 0!
     NEXT i

'coefficiants calculation loop
     FOR i5 = t1 TO T2 - 1
'if change interval, other two places same
     a0 = acc(i5)
     GOSUB 10                     'coefficiants calculation
     s = s + .1 * v + .005 * a0 * 32.2
     v = v + a0 * 3.22
     NEXT i5

     GOSUB 15                     'X'X & X'b for least square method
     GOSUB 20                     'order vector & scale vector
```

```
        GOSUB 30                    'forward elimination
        GOSUB 40                    'backward substitute
        GOSUB 70                    'results print out

'add new data and update database
        OPEN airno$ FOR APPEND AS #2
        PRINT #2, DATE$; ","; x1(1); ","; x1(2); ","; x1(3); ","; ssetp; ",";
vsetp
        c6 = (c6 * nto + x1(1)) / (nto + 1)
        c7 = (c7 * nto + x1(2)) / (nto + 1)
        c8 = (c8 * nto + x1(3)) / (nto + 1)
        ssetp1 = (ssetp1 * nto + ssetp) / (nto + 1)
        vsetp1 = (vsetp1 * nto + vsetp) / (nto + 1)
        SEEK #2, 1
        PRINT #2, nto + 1                   'update the data
        PRINT #2, c6; ","; c7; ","; c8; ","; ssetp1; ","; vsetp1
        CLOSE
        RETURN

'coefficiants calculation
10      a1(i5, 1) = pp
        a1(i5, 2) = pp * (v + ws * COS(rh - wd))
        a1(i5, 3) = p / oat * (v + ws * COS(rh - wd)) ^ 2
        c1(i5) = a0 * w + mu * w * COS(th) + w * SIN(th)
        RETURN

' coefcients for least square methed
15      FOR j = 1 TO 3
        FOR k = 1 TO 3
        FOR i = t1 TO T2 - 1                'range same as i5
        a5(k, j) = a5(k, j) + a1(i, j) * a1(i, k)
        NEXT i
        NEXT k
        NEXT j
        FOR j = 1 TO 3
        FOR i = t1 TO T2 - 1                'range same as i5
        c(j) = c(j) + a1(i, j) * c1(i)
        NEXT i
        NEXT j
        RETURN
```

```
'order vector & scale vector
20      FOR i = 1 TO 3
        o(i) = i
        s5(i) = ABS(a5(i, 1))
        FOR j = 2 TO 3
        IF ABS(a5(i, j)) > s5(i) THEN s5(i) = ABS(a5(i, j))
        NEXT j
        NEXT i
        RETURN

'Newton's methed, forwar elimination
30      FOR k = 1 TO 2
        GOSUB 50                        'row pivot
        FOR i = k + 1 TO 3
        factor = a5(o(i), k) / a5(o(k), k)
        FOR j = k + 1 TO 3
        a5(o(i), j) = a5(o(i), j) - factor * a5(o(k), j)
        NEXT j
        c(o(i)) = c(o(i)) - factor * c(o(k))
        NEXT i
        NEXT k
        RETURN

'backward substitute
40      x1(3) = c(o(3)) / a5(o(3), 3)
        FOR i = 2 TO 1 STEP -1
        sum = 0
        FOR j = i + 1 TO 5
        sum = sum + a5(o(i), j) * x1(j)
        NEXT j
        x1(i) = (c(o(i)) - sum) / a5(o(i), i)
        NEXT i
        RETURN

'row pivot
50      pivot = k
        big = ABS(a5(o(k), k) / s5(o(k)))
        FOR ii = k + 1 TO 3
        dummy = ABS(a5(o(ii), k) / s5(o(ii)))
        IF dummy <= big THEN 60
```

```
        big = dummy
        pivot = ii
60      NEXT ii
        dummy = o(pivot)
        o(pivot) = o(k)
        o(k) = dummy
        RETURN

'results print out
70      PRINT "                    Solutions of the Constant:"
        FOR i = 1 TO 3
        PRINT "                    C"; i; "="; x1(i)
        NEXT i
        RETURN
```

APPENDIX C

APPENDIX C

FILE STRUCTURES

The program automatically maintains the files including file names and take-off numbers. There are two files the program automatically outputs. The database file will be used for future take-offs. Missing or damaging this file will cause the program quit running except for the first take-off. Data files will be good records of the airplane performance. The database file names are the last three characters of airplane number with letter 'N' in front. The data file name is the database file name plus '_#'. where # is take-off number automatically given by the program. # ranges from 1 to 999.

The files are designed so that it can directly input into most spread sheet programs.

DATABASE FILE

The first group of C1, C2 ... V power set is the average. All other correspond to a take-off on the date.

file name: NXXX

where XXX is the last three characters of airplane number

file type: ASCII file. data are separated by comma.

contents:

#

C1, C2, C3, S power set, V power set

date, C1, C2, C3, S power set, V power set

date, C1, C2, C3, S power set, V power set

... ...

date, C1, C2, C3, S power set, V power set

DATA FILE

file name: NXXX_#

file type: ASCII file. data are separated by comma.

contents:

XXX, date, #

percent power, gw

rwy heading, alt. of airport

wind speed, wind direction

oat, pressure

ref. speed, predicted distance

s power set,	v power set	
t power set,	t end	
initial accelerometer reading		
time,	a measured,	a calculated
time,	a measured,	a calculated
...	...	...
time,	a measured,	a calculated
event time 1,	event time 2,	event time 3

APPENDIX D

APPENDIX D

Plan for PA-24 and PA-44 Test

PURPOSES: Learning airplane take-off performance using the new instrument; testing the new instrument and program; recording the airplane take-off acceleration for further study.

TEST DATA:

manual notes

a) preflight:	measuring fuel in each tank
	calculating the GW
	ATIS weather information
b) during conditions:	condition time
	RPM
	Manifold pressure
c) post flight:	measuring fuel in each tank
	calculating the GW
	ATIS weather information
recording	recording acceleration
CONFIGURATION:	GW/CG: optional

flaps:	up
propeller:	set
mixture:	rich
carb. heat:	off
power:	as required by conditions

TEST CONDITIONS(for PA-24) :

001	roll the plane 750 feet before runway mark. full stop. set to normal take-off power, release the brake until runway mark is reached(T. O. power)
002	full stop at first runway mark accelerate engine to 2400 RPM and set manifold pressure to 24.1" Hg. release the brake until next runway mark reached. (add or subtract .17" Hg. for 10 F above or below 55 F) (75% power)
003	same as 003 except manifold pressure: 21.8" Hg.(65% power)

VITA

Mark M. Zhou was born in Xian, Shaanxi province, People's Republic of China on June 24, 1961. In February of 1978, he entered Northwestern Polytechnic University(NPU), Xian, to pursue a degree in Aerospace Engineering. In December of 1981, he received a Bachelor degree of Engineering from NPU, and immediately began work in the Airplane Performance Department at China Flight Test Center as a engineer for more the next 6 years. In August of 1988, he joined Boeing in Flight Test Engineering at Seattle, Washington as a test analysis engineer in Structures and Systems. In August of 1990, he received his senior engineer certification from Boeing for his work in Boeing 747-400, 737-400 and 737-500 certification tests and Boeing 767, 757 production tests. At the same time, he got his private pilot license from Federal Aviation Administrations(FAA). In January of 1991, he entered the Graduate School at the University of Tennessee, Knoxville, to study Aerospace Engineering, and received his Master of Science degree in May, 1993