Proairshow, LLC

Air Show Narration & Sound Services
307 West Fredericks Street
Anderson, South Carolina 29625
864-226-3489
hugh@proairshow.com

AIRCRAFT DEBRIS TRAJECTORY ANALYSIS

A Report on the Ballistic Trajectory Characteristics and Relative Scatter Patterns of In-flight Airframe Separations Debris Specific to The Airshow Environment.

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prepared by:

Hugh E. Oldham jr.
as of 10/31/1999
307 W. Fredericks Street
Anderson, South Caroling 29625
864-226-3489

PURPOSE

The introduction, approval and use of airshow maneuvers which direct aircraft energy toward the spectator area has intensified the ongoing debate within the airshow industry relating to the safety aspects of these maneuvers.

The Federal Aviation Administration has predicated its approval of certain maneuvers packages, which direct aircraft energy toward the spectator area, upon data and mathematical formulae published in both its Inspector's Handbook and in Advisory Circular AC 91-45C, plus other unpublished information.

The purpose of this report is to present information and data gained during an analytical study of in-flight airframe disintegration debris scatter patterns as they specifically relate to the airshow environment.

SUMMARY CONCLUSION

It is not possible to rely on the FAA Handbook Formula to provide a safe separation distance and prevent possible injury to airshow spectators.

INTRODUCTION

The relative scatter pattern of aircraft parts from an airplane that is involved in an in-flight separation and the ballistic trajectory of individual parts can be predicted using standard mathematical analytical techniques. The trajectory of each part can be predicted by using its weight, assuming its drag characteristics, correcting for the wind, and inputting its initial separation velocity and angle.

This report is based on factual information obtained from various sources (see References) and on certain assumptions that are based on standard aeronautical engineering practices as noted. The results of the trajectory calculations are dependent upon the estimates used for the separation conditions, component drag coefficients, and winds aloft.

For the purpose of this report, it is assumed that an in-flight aircraft component separation will take place due to unknown causes. No allowance is made in the presented data for energy imparted to the separated component due to in-flight collision, explosion, generated lift, or on-board thrust. The scenario leading up to the component separation from controlled flight will not be addressed.

It is recognized that evaluations of this type are not precise. The results presented should only be used as a guide in evaluating and analyzing theoretical possibilities. The author, contributors, nor referenced individuals or organizations assume no responsibility for the accuracy of the formulas and/or the coding provided.

THE FAA FORMULA

"Virtually, all of the "head-on" maneuvers approved, thus far, (by the FAA) have been based on a formula to compute the trajectory of a projectile in space. The formula is considered to be conservative since no consideration is given to the atmosphere." Ed Fell, AFS-20, FAA Memorandum dated August 24, 1988.

A Scatter Distance Formula is present in the FAA's publication AC 91-45C, *INTRODUCING WAIVERS: AVIATION EVENTS*, Chapter 4. "AIR RACE COURSE DESIGN", Section 54., "RACE COURSE SHOWLINE.", page 32, and graphical depicted in Appendix 1, Figure 21 of the same publication. This formula states that the Scatter Distance is equal to the Aircraft's Speed times the Square Root of 2 times the Aircraft's Altitude (AGL) divided by the Acceleration of Gravity (32.2 ft/sec/sec).

Scatter Distance (in feet) equals Aircraft Speed (in MPH) times the Square Root of Two Times the Aircraft Altitude (in feet) divided by 32.2

Although this formula may provide adequate spectator separation distances for an Air Race type of events, where it may be assumed that the aircraft are in level flight, it fails to address all the variables involved in the airshow environment.

The FAA Formula limits its variable inputs to those of Aircraft Speed and Altitude, while neglecting the Projectile's Weight, Frontal Area, Drag Characteristics, and Angle of Separation. Further, no allowance is made for Wind Effects nor Density Altitude. These additional variables will dramatically influence the projectile's down range capabilities.

The relationship between a projectile's Size and Weight (Mass Density) in conjunction with its Drag Characteristics (Coefficient of Drag times Frontal Area = CdS) and the Atmospheric Density will determine the projectile's Terminal Velocity. For a given shape, the smaller the size and higher the weight, the higher the Terminal Velocity. The higher the Terminal Velocity and higher the Weight, the higher the potential destructive capability of the projectile.

An example of this relationship between mass density and terminal velocity would be a comparison of the flight characteristics of a Table Tennis Ball vs. that of a Golf Ball. Both balls are of similar size and shape and exhibit approximately similar CdS. The mass density of the golf ball is many times that of the table tennis ball, therefore the golf ball has a much higher terminal velocity. If both balls are launched at the same initial velocity and angle of departure, the table tennis ball will rapidly slow due to its high drag to weight ratio, a product of its low terminal velocity. Its flight path will be relatively short and its destructive capability low. Conversely, the golf ball will maintain a higher velocity due to its lower drag to weight ratio and resulting higher terminal velocity. It will fly much farther than the table tennis ball and will pack a much higher destructive capability.

It can be assumed that within the airshow environment, aircraft do not maintain straight and level flight patterns. An airshow aircraft is experiencing dynamic acceleration in all three axis. Therefore, one can not expect the angle of departure of a separating item to be on the horizontal plane. Angles of Departure below the horizon will decrease the potential debris scatter distance while angles above the horizon will impart a parabolic flight segment to the item's flight path and increase the debris scatter distance. And finally, the Wind Conditions will affect the lighter, but still dangerous, parts.

The above information indicates that while the FAA Handbook Formula is adequate in predicting pure ballistic flight, the limited variable data neglects to consider important information necessary for an objective, analytical evaluation of potential debris scatter patterns resulting from in-flight airframe disintegration within the airshow environment. The omitted factors will affect the potential debris scatter distances. Specificity, the drag characteristics of low mass density projectiles will tend to decelerate the projectile and reduce the scatter distance. Conversely, a positive angle of departure could increase the scatter distances, and an increased mass density coupled with a positive angle of departure could significantly increase the scatter distance.

Due to the lack of published empirical data, relative to the potential debris scatter patterns relating specifically to the airshow environment, a research project was undertaken to establish a mathematical formula that would encompass all germane variables necessary to realistically predict the impact point of such debris.

THE ESTABLISHMENT OF A MATHEMATICAL MODEL

Very early in this research project, it became apparent that the establishment of a mathematical model that would be capable of accurately predicting the debris scatter distance of an in-flight airframe separation, would require that all germane variables be addressed in nonlinear, second order equations. Such equations do not lend themselves to explicit solution, but are readily solved using interactive procedures. For this reason, computer simulation would be necessary. The first attempts to redefine the FAA Formula were attempted using Lotus 123 spreadsheets. As the formulas evolved and additional research was digested, the 123 spreadsheets became cumbersome.

The evolved formulae were then programmed in the BASIC language for solution on an IBM compatible computer. The interactive integration was performed with time increments of 0.05 seconds, displayed at one second intervals in order to achieve economy of computation. More refined methods are available. The BASIC language and MS-DOS were chosen due to their universal availability and understanding. (Copies of the program disk (5 1/4" & 3 1/2") are available at cost.)

THE COMPUTER PROGRAM

A program originally developed by the National Transportation Safety Board (NTSB) was used as a starting point. The NTSB program (Clark 1985) lacked the flexibility to incorporate the possible variables encountered in the airshow environment. It was necessary to subject the NTSB program to a process of refinement and expansion, evolving into a new program specifically tailored to the airshow environment. This new program was named "TAP" for Trajectory Analysis Program.

Further input was gained from The International Society of Air Safety Investigators and informal conversations with many aviation safety experts and aerospace engineers.

The initial TAP Input requirements were as follows:

1. Initial altitude of disintegration.
1. Initial density altitude.
2. Altitude of impact at Ground Level.
3. Wind velocity and direction.
4. Horizontal true airspeed at disintegration.
5. Rate of climb or sink at disintegration.
6. Weight of projectile.
7. Projectile Drag Coefficient.
8. Projectile frontal area.

The TAP design goal Output were as follows:

1. Horizontal distance from disintegration at impact.
2. Horizontal, vertical, and total velocities.
3. Terminal velocity.
4. Time to fall.
5. Flight-path angle at impact.
6. Ground speed of projectile at impact and x and z components of that velocity.

These initial requirements were refined as the process of developing the formulae progressed as follows:

INPUTS

Wind and Density Altitude.

The wind conditions and atmospheric variables are limited in the airshow environment by the localized nature of the event and the limited altitude envelope. The possible wind/altitude shift is limited within the airshow altitude envelope, therefore lateral corrections for wind shift are not made. The vertical component is equal to zero. A model of the wind at various altitudes at the show site was taken from "Dynamic and Physical Meteorology," Haltiner and Martin, McGraw-Hill Book Co., NY, NY, 1957. The following equation for the wind at altitude was derived:

$$\text{Wind} = \text{Surface Wind (SW)} + \text{SW} * (\text{altitude}/30)^{.26}$$

The density altitude at disintegration altitude can be inputted as an additional variable or will default to the disintegration altitude. The atmospheric density at sea level is assumed, a standard day; with a density of .002378 lb sec^2/ft^4 (Slugs). The program adjusts the atmospheric density to the actual altitude as the projectile falls (ICAO Standard Atmosphere, NACA 1955).

Horizontal True Airspeed at Disintegration.

At the instant of disintegration, the aircraft is assumed to be in steady, unyawed, and unaccelerated flight and suddenly disintegrates into a number of parts. (Multiple or progressive disintegrations can be synthesized by superimposition of a series of sudden disintegrations using multiple computer runs.)

Rate of Climb or Sink at Disintegration.
(Flight Path Angle)

Although, from an overall statistical viewpoint, disintegrations caused by flutter, fatigue, or explosions, a level or shallow descending flight path angle is likely (Matterson, 1984). These studies limited the climb angle to $+2.9^{\circ}$ to -5.7° and vertical speeds of +15 fps to -30 fps. This was considered to limited for the dynamic nature of an airshow presentation. Due to the high rate of pitch change and g loadings during such a presentation, this parameter was changed to "Flight Path Angle". It is important to remember that during high g loading, the Nose Pitch Angle leads the Flight Path Angle by several degrees.

Projectile Drag Coefficient.

It is assumed the projectiles experience aerodynamic forces as drag in the both the horizontal and vertical. The drag coefficient (Cd) is constant. This assumption of constant Cd may be realistic for stable items, for rapidly spinning or auto-rotating items with Cd varying about a mean value, and for items whose drag does not change with angle (a sphere). For slowly rotating items, the assumption may be less realistic.

Inputting the required drag coefficient (Cd) will require a drag estimate based on the size and shape of the projected object. For most debris, a modified flat plate drag coefficient of 1.0 is acceptable. The accepted flat plate Cd of 1.2 is based on plates with sharp edges. That value was not considered appropriate due to studies which indicate most debris will have rounded edges.
Data from the McDonald Douglas Corporation's Weapons Systems Division, indicates that debris Cd's can range from 0.007, for airfoil shapes with high Reynolds Numbers, to 2.0, for very complex, high drag producing, debris shapes (Souders, 1966).

Generally accepted Drag Coefficients, at Reynolds' Numbers ranging between 10^3 to 3 X 10^5 are:

Sphere 0.44 Cd

Disk (flat side to flow) 1.12 Cd

Flat Plate (flat side to flow) Length/Breadth = 1 1.16 Cd
Length/Breadth = 20 1.50 Cd

Circular Cylinder (flat side to flow) Length/diameter. = 1 0.91 Cd
Length/Diameter. = 2 0.85 Cd
Length/Diameter. = 7 0.99 Cd

Airfoil 0.04 Cd

Circular Cylinder (flat side parallel to flow)
Length/Diameter. = 1 0.63 Cd
Length/Diameter. = 20 0.90 Cd
Length/Diameter. = *infinity* 1.20 Cd

Late Model Automobile as low as 0.34 Cd

Projectile Frontal Area.

The Projectile Frontal Area is the measurement of the area presented to the airflow in square feet. When dealing with a unstable or tumbling object it is assumed best to add the planform and frontal areas together then multiply by a correction factor of 0.632 to establish a mean frontal area (Clark, 1985).

Example: A Circular Cylinder, 14 inches in diameter by 6 inches wide. The frontal area of the flat side is 153.9 square inches; the frontal area of the rounded side is 84.0 square inches. If the cylinder is unstable and tumbling, it would present different frontal areas during its rotation. Integrating the various frontal areas follows:

153.9 Sq. Inch + 84.0 Sq. Inch X .632 = 150.4 Sq. Inch.
150.4 Sq. inch = 1.044 Sq. Ft

1 Square Foot would be the assumed Frontal Area.

OUTPUTS

The Outputs of the program are fairly straightforward:

Horizontal distance from disintegration to impact.

Self-explanatory

Horizontal, vertical and total velocities.

The program outputs only the total velocity which is computed from the horizontal and vertical velocities.

Terminal velocity.

The program displays a terminal velocity at both disintegration altitude and ground level. The program continually computes a terminal velocity for the current altitude as the object falls.

Time To Fall.

Self-explanatory.

Flight Path Angle at Impact.
The angle of impact is displayed as a negative number indicating the number of degrees below the horizontal (-90.000 = straight down). Note that under some wind conditions, the angle of impact will indicate that the projectile is moving backwards relative to its original line of flight. The angle of impact has considerable influence on the destructive potential of the projectile.

Ground Speed of Projectile at Impact and the x and z Components of that Velocity.

This information is not displayed. It was considered redundant to the speed at impact information. However the x and z component information is used to compute the flight path and is available within the program.

COMPARISON OF THE FAA FORMULA VS. THE TAP PROGRAM

Repeated computer runs were conducted to establish the validity of the Trajectory Analysis Program (TAP). These runs were compared to the data presented by the FAA Handbook Formula. The results of these comparisons follow.

Due to the FAA Handbook Formula's limited input and pure trajectory output, the TAP inputs were also limited. For purposes of the comparison the TAP inputs associated with drag calculations were locked a levels that would force TAP to compute almost pure trajectory. The TAP inputs locked were:

"INITIAL DENSITY ALTITUDE" Default to Flight Path Altitude.
"INITIAL FLIGHT PATH ANGLE" Locked at Horizontal or 0.0 Degrees
"GROUND LEVEL" Default to 0.00 Feet
"FLIGHT PATH COURSE" Locked at 1 degree.
"FRONTAL AREA" Locked at 0.0001 sq. ft.[*]
"DRAG COEFFICIENT OF DEBRIS" Locked at 0.0001 Cd.[*]
"WEIGHT OF DEBRIS" Locked at 600 Lb.[*]
"SURFACE WIND" Locked at 0 Kts.
"SURFACE WIND DIRECTION" Locked at 1 degree.

[*] Data effecting drag calculations; resultant CdS = 1^{-8}

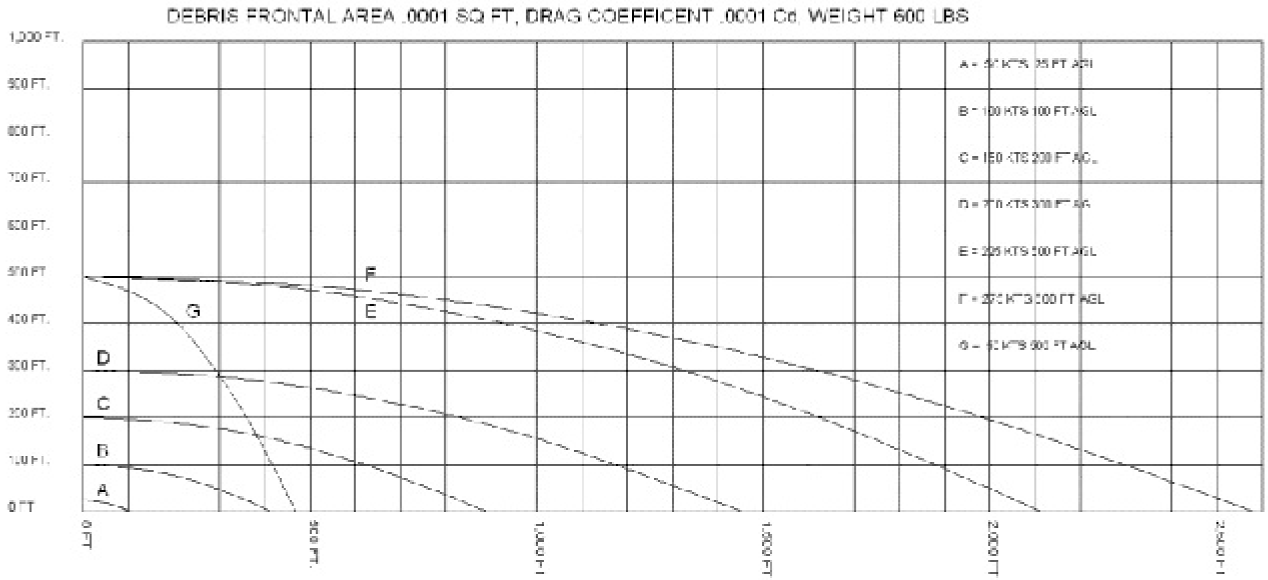
The resulting output comparison:

IAS	Altitude	FAA Distance	TAP Distance
50 Kts	25 Ft AGL	105 Feet	101 Feet
100 Kts	100 Ft AGL	421 Feet	414 Feet
150 Kts	200 Ft AGL	892 Feet	887 Feet
200 Kts	300 Ft AGL	1457 Feet	1453 Feet
225 Kts	500 Ft AGL	2116 Feet	2110 Feet
275 Kts	500 Ft AGL	2587 Feet	2579 Feet
50 Kts	500 Ft AGL	470 Feet	469 Feet

PROJECTED DEBRIS FLIGHT PATH

BALLISTIC FLIGHT

GRAPH 1 PAGE 8



The above data indicates that it can be assumed that the FAA and TAP formulas will yield similar results when compared in the calculation of pure trajectory.

Yet, in the real world, aircraft debris will not travel in a vacuum. The debris will be subject to drag from the atmosphere and it cannot be assumed that the debris will depart on a horizontal plane.

A further comparison varies from the FAA data. The following variables were unlocked and set to simulate a projectile of moderate mass density with different Cd's and Angles of Departure.

Initial Indicated Airspeed 150 Knots.
Initial Flight Path Altitude 200 Feet AGL
Frontal Area 2 Sq. Ft
Weight of Debris 25 Lbs.

Cd CdS Flight TAP Terminal Time To Speed at
Angle Distance Velocity Impact Impact

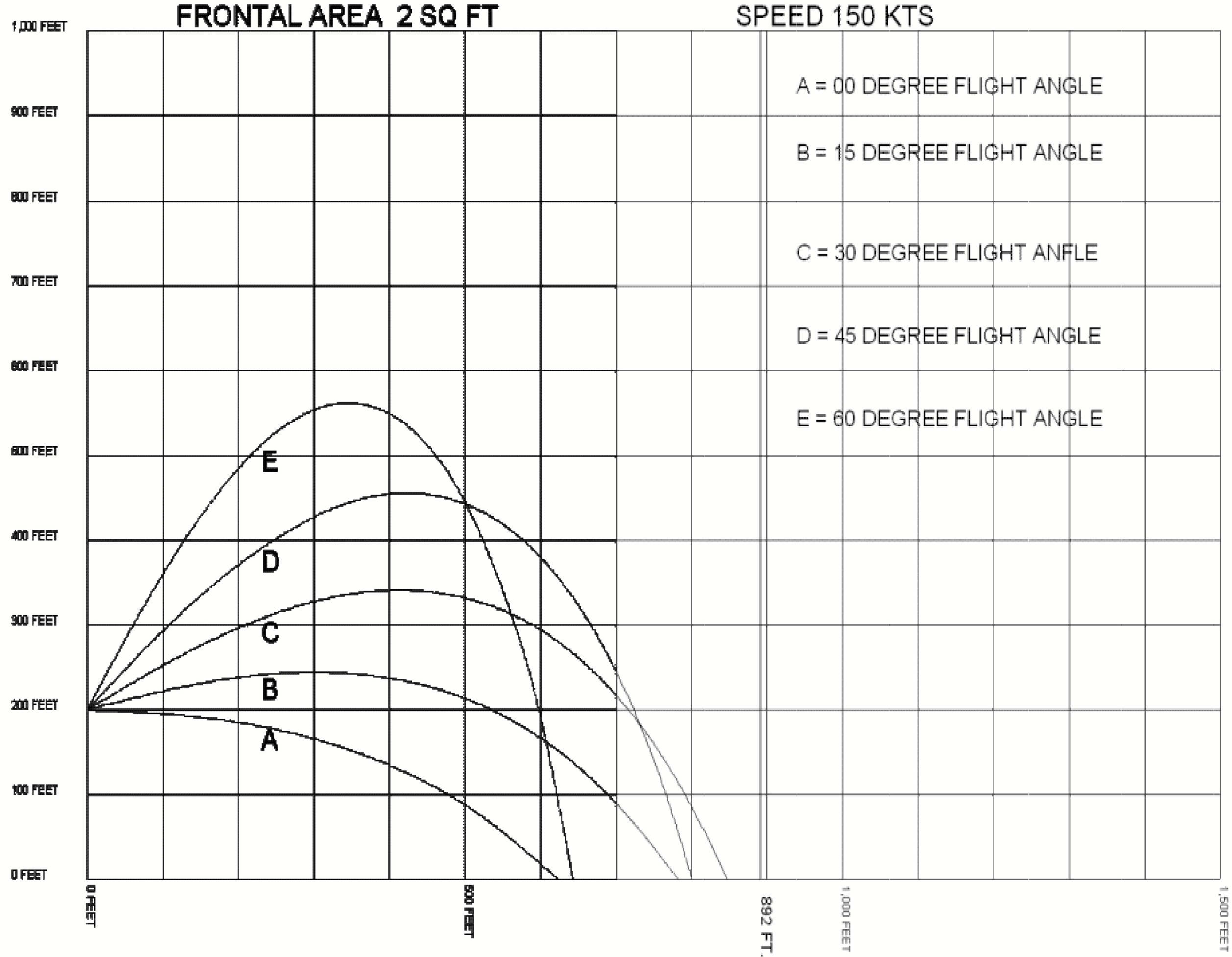
0.44 0.88 00.00 624 Ft 91.5 Kts 3.99 Sec 80 Kts
0.44 0.88 15.00 783 Ft 91.5 Kts 5.95 Sec 74 Kts
0.44 0.88 30.00 848 Ft 91.5 Kts 7.90 Sec 75 Kts
0.44 0.88 45.00 801 Ft 91.5 Kts 9.60 Sec 78 Kts
0.44 0.88 60.00 643 Ft 91.5 Kts 11.00 Sec 81 Kts

PROJECTED DEBRIS FLIGHT PATH

GRAPH 2 PAGE 8

DEBRIS WEIGHT 25 LBS
FRONTAL AREA 2 SQ FT

DRAGE COEFFICENT .044 Cd
SPEED 150 KTS



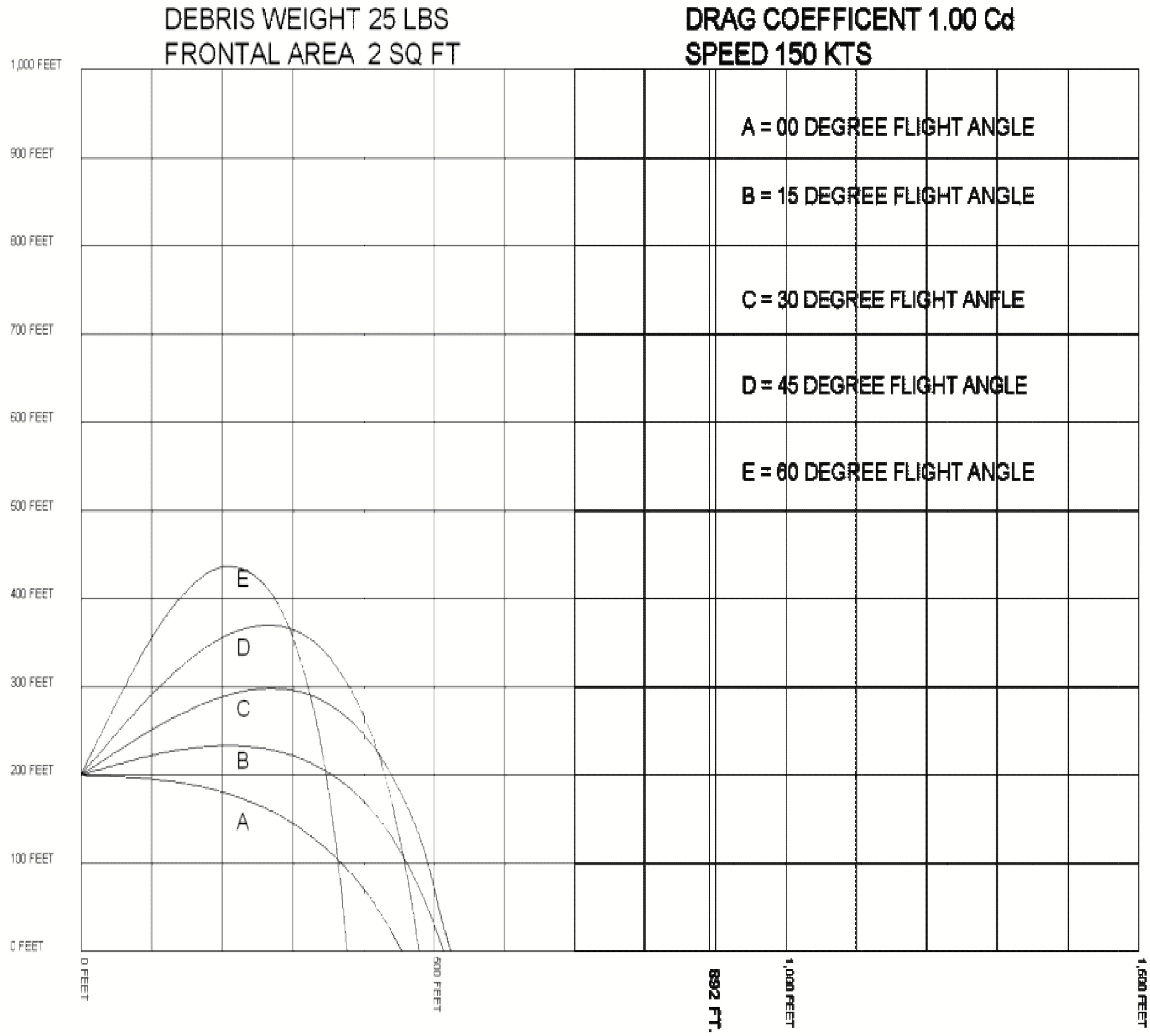
Cd CdS Flight TAP Terminal Time To Speed at
Angle Distance Velocity Impact Impact

1.00 2.00 00.00 455 Ft 60.7 Kts 4.35 Sec 54 Kts
1.00 2.00 15.00 515 Ft 60.7 Kts 5.85 Sec 54 Kts
1.00 2.00 30.00 525 Ft 60.7 Kts 7.35 Sec 56 Kts
1.00 2.00 45.00 479 Ft 60.7 Kts 8.65 Sec 57 Kts
1.00 2.00 60.00 377 Ft 60.7 Kts 9.75 Sec 59 Kts

See Graph 3

PROJECTED DEBRIS FLIGHT PATH

GRAPH 3 PAGE 8



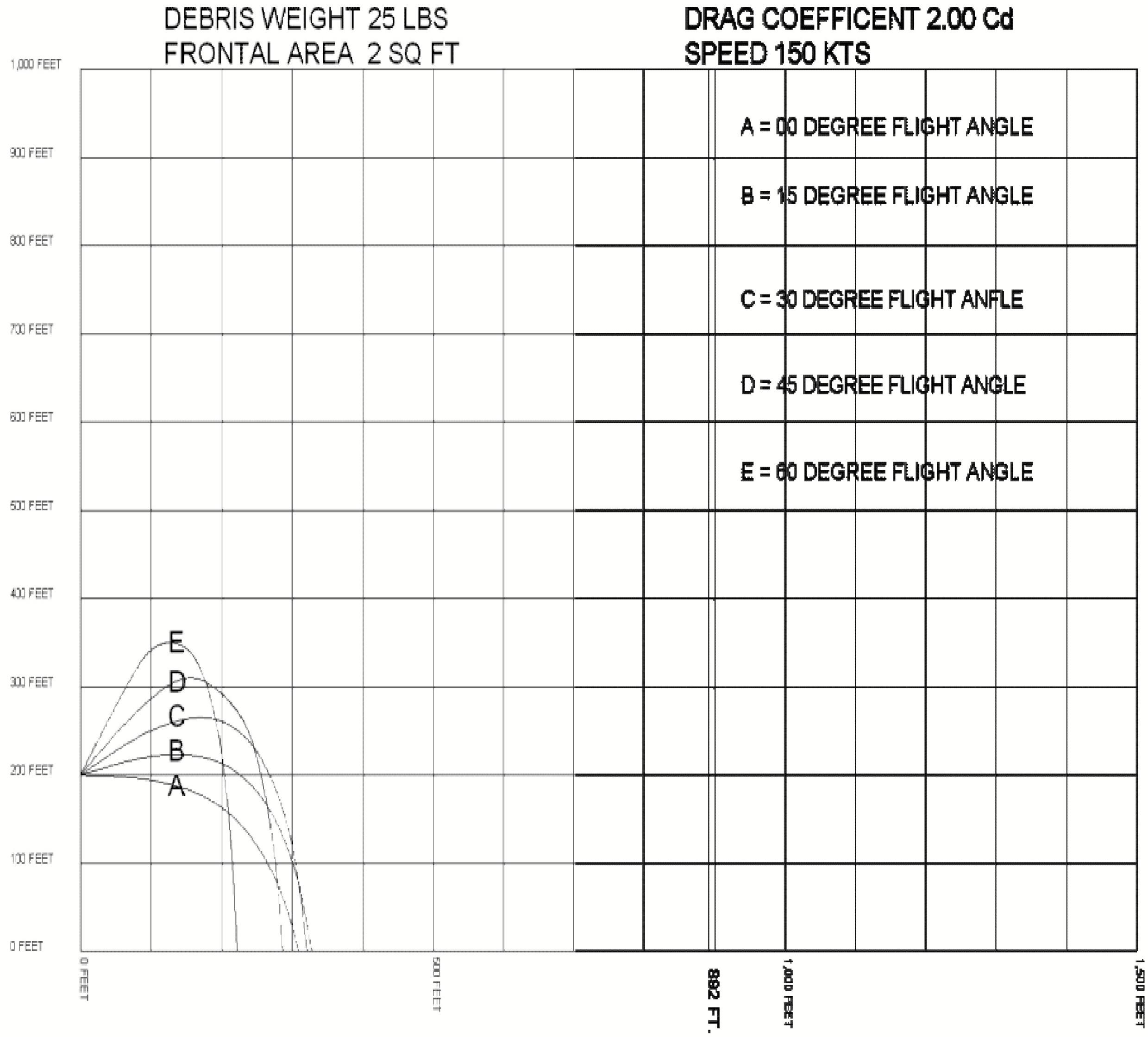
Cd CdS Flight TAP Terminal Time To Speed at
Angle Distance Velocity Impact Impact

2.00 4.00 00.00 309 Ft 42.9 Kts 4.80 Sec 41 Kts
2.00 4.00 15.00 328 Ft 42.9 Kts 5.90 Sec 41 Kts
2.00 4.00 30.00 321 Ft 42.9 Kts 7.05 Sec 42 Kts
2.00 4.00 45.00 287 Ft 42.9 Kts 8.10 Sec 42 Kts
2.00 4.00 60.00 222 Ft 42.9 Kts 8.95 Sec 43 Kts

See Graph 4

PROJECTED DEBRIS FLIGHT PATH

GRAPH 4 PAGE 9



The relationship between weight, frontal area, and Cd results in a relative slow terminal velocity. The scatter range is well below the 892 feet predicted by the FAA formula. In this case, the FAA formula proves more than adequate.

NOTE: The higher the "CdS", for a given weight, the lower the "Flight Path Angle" for maximum throw distance. This is due to the relationship between "Terminal Velocity" and "Time to Impact".

During an in-flight airframe disintegration, it can be assumed that the debris projectile mass density will vary over a broad range. The average Terminal Velocity of light plane parts has been reported to be approximately 35 fps (Logan, 1968). Parts with Terminal Velocities in this range would not pose a threat to the spectator area when using the FAA Scatter Distance Formula. It can also be assumed that many parts (castings, forgings, landing gear assemblies, wheels and brakes, engines and accessories, propeller blades and hubs, etc.) will have much greater mass densities and associated higher Terminal Velocities. These high mass density parts, like the golf ball used in the example on page 3, will have both a higher scatter distance potential and pack the greatest destructive capability. The trajectory of these parts will more closely follow the pure ballistic flight path used by the FAA Scatter Distance Formula. When a Flight Path Angle of Departure above the horizontal is computed, the Scatter Distance of such debris can exceed the FAA Scatter Distance.

It is recognized that there is a low probability of an airshow aircraft disintegration scenario-taking place while the aircraft is directing energy toward the show's spectators. It must also be recognized that the possibility exists. The results of an disintegration incident which displaces aircraft debris into the designated spectator area would be disastrous. Such a high potential for catastrophic results exists that worst case scenarios must be addressed during an objective, analytical evaluation of any airshow maneuver.

One part of a disintegrating aircraft that has a high mass density and a great chance of intact survivability is the aircraft engine. Reprogramming the variables to simulate worst case scenario involving such an object, will result in a high terminal velocity and a long scatter range.

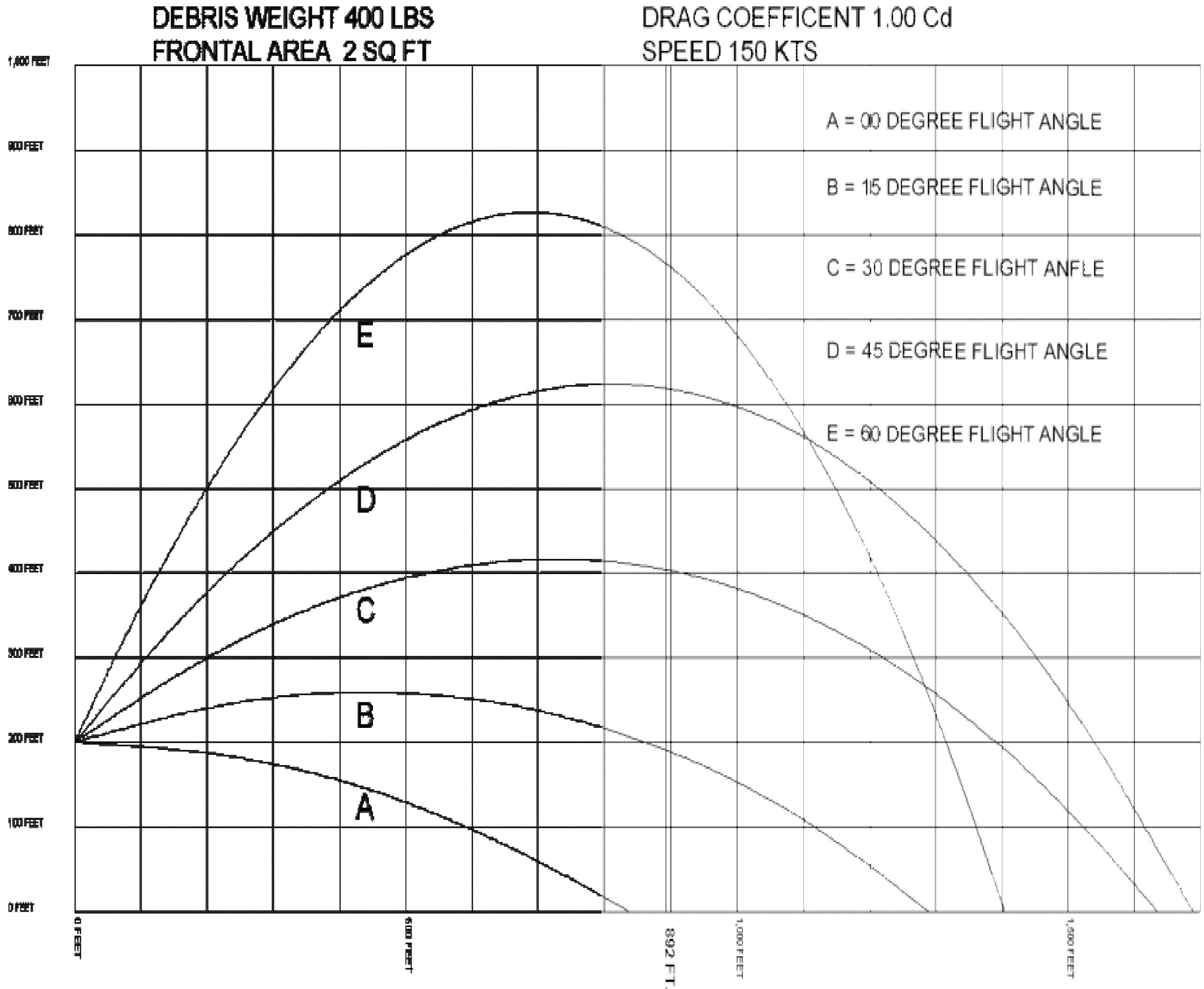
Initial Indicated Airspeed 150 Knots.
Initial Flight Path Altitude 200 Feet AGL
Frontal Area 2 Sq. Ft
Weight of Debris 400 Lbs

Cd	CdS	Flight Angle	TAP Distance	Terminal Velocity	Time To Impact	Speed at Impact
1.00	2.00	00.00	838 Ft	242.8 Kts	3.59 Sec	142 Kts
1.00	2.00	15.00	1299 Ft	242.8 Kts	6.05 Sec	133 Kts
1.00	2.00	30.00	1636 Ft	242.8 Kts	8.85 Sec	129 Kts
1.00	2.00	45.00	1689 Ft	242.8 Kts	11.45 Sec	131 Kts
1.00	2.00	60.00	1405 Ft	242.8 Kts	13.50 Sec	135 Kts

See Graph 5

PROJECTED DEBRIS FLIGHT PATH

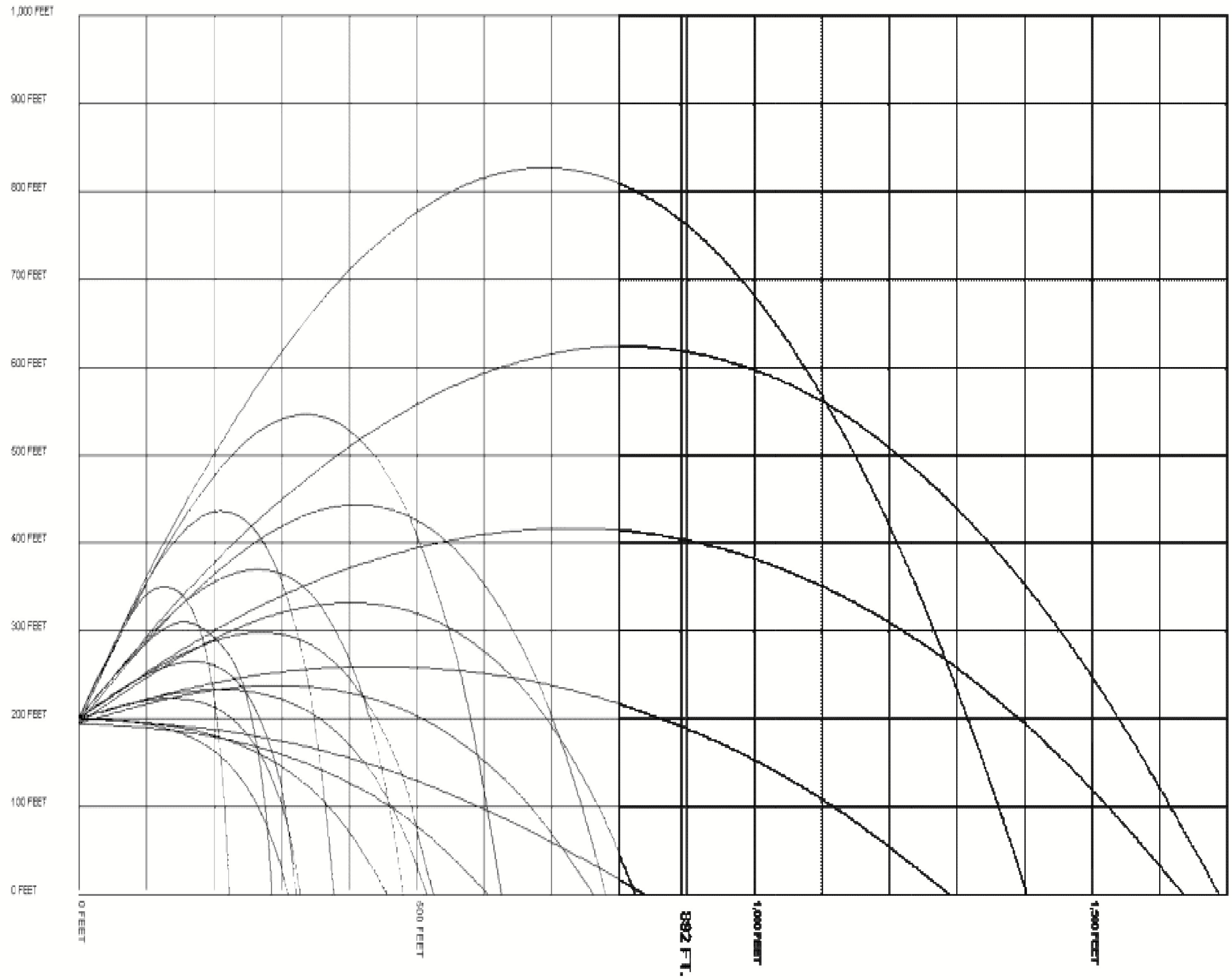
GRAPH 5 PAGE 10



PROJECTED DEBRIS FLIGHT PATH

GRAPH 6

COMBINED DATA FROM GRAPH 2-5



The above data indicates that even with the flight path horizontal, the heavier projectile would fly to within 54 feet of the predicted impact point of the FAA formula. At impact, the projectile would be flying only 26 degrees below the horizon at 142 Knots. This low impact angle and high speed could allow the projectile to bounce, crossing the 892 foot mark.

With the Flight Path Angle only 3° above the horizon, the projectile would cross the 892 foot mark while still airborne.

The maximum throw distance would occur with the projectile at a Flight Path Angle of Departure of +40°. It would cross the FAA Scatter Distance point of 892 feet from the point of disintegration with an airborne altitude of over 500 feet, and impact the ground 1,710 feet from the point of disintegration at -53° flight angle at 130 Knots. Total in-flight time of the projectile, from disintegration to impact would be 10.65 seconds.

CONCLUSIONS

The dynamic nature of airshow maneuvers does not allow for precise, analytical predictions of aircraft debris scatter patterns. The parameters affecting the potential flight paths of objects, which may separate from controlled flight in any attitude, offer multiple variables that interactively affect the trajectory of the separated part. The data presented in this report and supporting documentation, confirms that the referenced FAA Handbook Formula is inadequate for use in an objective, analytical evaluation of airshow maneuvers directed at the spectator area and the establishment of safe spectator separation distances for these maneuvers. It is not possible to relay on the FAA Handbook Formula to provide safe separation distances and prevent possible injury to airshow spectators in the event of an in-flight airframe disintegration.

Therefore, any airshow maneuver that directs aircraft energy toward the spectator area, approved under current FAA policy, is suspect.

Hugh E. Oldham
21 August 1990

TRAJECTORY ANALYSIS FOR AIRCRAFT DEBRIS

COMPUTER PROGRAM

The TAP Basic Computer Program (On Screen Version) used to generate the projected debris flight path data used in The Airshow Environment Aircraft Debris Trajectory Analysis Report.

```
10:REM FULL TRAJETORY ANALYSIS PROGRAM FOR SCREEN DISPLAY
20:REM PROGRAM 1.10 8/20/90
30:REM FILE NAME "TRAJSCRN"
40:CLS
50:PRINT "TRAJECTORY ANALYSIS"
60:PRINT "FOR"
70:PRINT "AIRCRAFT DEBRIS"
80:PRINT " "
```

```
90:INPUT "INTIAL INDICATED AIR SPEED (KTS)";VEL
100:INPUT "INTIAL FLIGHT PATH ANGLE (DEG +/-)";ANGA
110:INPUT INTIAL FLIGHT PATH ALTITUDE (FEET AGL)";ALT
120:INPUT "INTIAL FLIGHT PATH DENSITY ALTITUDE IF DIFFERENT
FROM INTIAL ALT ";DALT
130:IF DALT =O THEN DALT=ALT
140:PRINT "INTIAL DENSITY ALTITUDE ";DALT
150:INPUT "GROUND LEVEL (MSL FEET) ";GROUNDLEVEL
160:INPUT FLIGHT PATH COURSE MAG (DEG 001-360)";COURSE
170:IF COURSE <1 GOTO 160
180:IF COURSE >360 GOTO 160
190:INPUT "FRONTAL AREA OF DEBRIS (SQ FEET) ';FAREA
200:INPUT "DRAG COEFFICIENT OF DEBRIS (Cd)';CD
210:CDS=CD*FAREA
220:INPUT "WEIGHT OF DERBIS (LBS)";WT
230:INPUT "SURFACE WIND SPEED (KTS)";SWIND
240:INPUT "SURFACE WIND DIRECTION (DEG mAG 01 - 360)";DWIND
250:IF DWIND < 1 GOTO 240
260:IF DWIND > 360 GOTO 240
270:IF COURSE > DWIND THEN WINDC=COS(COURSE-DWIND)*SWIND
280:IF COURSE > DWIND THE WINDC=COS(DWIND-COURSE)*SWIND
290:IF SWIND >0 THE AWIND=WINDC+(ALT/30)^.26
300:IF SWIND=0 THE AWIND=SWIND
310:PRINT "HEAD WIND FACTOR AT FLIGHT PATH ALTITUDE ",AWIND
320:PRINT "HEAD WIND FACTOR AT SURFACE ",WINDC
330:PRINT "COMPUTE AIR MASS DENSITY AT ";DALT;" FEET MSL"
340:REM COMPUTE AIR MASS DENSITY IN SLUGS PER CUBIC FOOT
350:SLUGS=.002378*(1-(6.875*10^-6*ALT))^4.2561
360:GSLUGS=.002378*(1-(6.875*10^-6*GROUNDLEVEL))^4.2561
370:TVEL=(2*WT/(CDS*SLUGS))^.5
380:GLTEVL=(2*WT/(CDS*GSLUGS))^.5
390:PRINT "INTIAL TERMINAL VELOCITY (FPS) = ";TVEL
400:TVELKTS-TVEL*.5921052
410:GLTVELKTS=GLTVEL*.5921052
420:PRINT "INTIAL TERMINAL VELOCITY ";TVELKTS;" KTS"
430:TVELKTS=TVEL*.5921052
440:PRINT "GROUND LEVEL TERMINIAL VELOCITY ";GLTVELKTS," KTS"
450:PI=3.1416
460:TP=1!
470:DT=.05
480:WIND1=WINDC*6080/3600
490:T=0!
500:X=0!
510:Z=ALT
```

```
520:ANGCOR=PI/180!
530:DT2=DT*DT
540:ANG=ANGA*ANGCOR
550:REM CALCULATE TRUE AIRSPEED (FPS)
560:U=1.69*VEL*COS(ANG)
570:V=1.69*VEL*SIN(ANG)
580:PRINT " "
590:PRINT " "
600:PRINT " "
610:PRINT " TIME Z Y FPANGLE KNOTS"
620:PRINT T,X,Z,ANGA,VEL
630:PRINT " "
640:W=WIND1*(Z1/30!)^.26
650:REM
660:REM CALULATE GROUND SPEED
670:UO=U-W
680:VO=V
690:REM CALCULATE DRAGE AND ACCELERATION
700:VEL2=U*U+V*V
710:IF U=0! THEN U=.01
720:FP=ATN(V/U)
730:FPANG=FP/ANFCOR
740:K=1!
750:IF U<0! AND V<0! THEN K=-1!
760:SLUGS=.002378*(1-(6.875-10^-6))^4.2561
770:DRAG=(SLUGS/2)*VEL2*CDS
780:AX=DRAG*COS(FP)*32.2*K/WT
790:AZ=-DRAG*SIN(FP)*32.2*K/WT-32.2
800:REM
810:REM CALCULATE VELOCITIES AND DISTANCES
820:UO=UO=AX=DT
830:V=V=AZ=DT
840:U-UO=W
850:VO=V
860:FPE=ATN(V0/UO)
870:FPANG=FPE/ANGCOR
880:IF UO<0! AND VO<0! THEN FPEANG=FPEANG-180!
890:X=X=UO*DT+.5*AX*DT2
900:Z=Z=VO*DT+.5AZ*DT2
910:Z1=Z
920:IF Z1<1! THEN Z1=1!
930:W=WIND1*(Z1/30!)^.26
940:T=T=DT
950:IF T<TP-.005 GOTO 980
```

```
960:PRINT CINT (T),X,Z,FPEANG,((UO*UO+VO*VO)^.5)*.592105
970:TP=TP=1
980:IFZ>GROUNDLEVEL GOTO 690
990:PRINT T,X,Z,FPEANG,((UO*UO=VO*VO)^.5)*.592105
1000:PRINT " "
1010:PRINT "DEBRIS TERMINAL VELOCITY ";GLVELKTS;" KTS"
1020:PRINT "TIME TO IMPACT ";T;" SECONDS"
1030:PRINT "DEBRIS THROW DISTANCE ";X;" FEET"
1040:PRINT "ANGLE OF IMPACT ";FPEANG;" DEGREES"
1050:IMPACTA=(((UO*UO+VO*VO)^.5)*.68182)
1060:IMPACTB=(((UO*UO+VO*VO)^.5)*.592105)
1070:PRINT "SPEED AT IMPACT ";IMPACTA;" MPH"
1080:BEEP
1090:INPUT "COMPUTE ANOTHER (Y/N) ";ANS$
1100:IF ANS$="Y" GOTO 10
1110:END
```

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