January 30, 2004

Mr. Mark Delligatti
Senior Project Manager
Spent Fuel Project Office
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville MD. 20852

**Private Fuel Storage, L.L.C. Revised Report by Burdeshaw Associates, Ltd. on the Evaluation of F-16 Aircraft Crash Impact Speeds and Angles for Skull Valley Type Events**

**DOCKET NO. 72-22 / TAC NO. L22462**
**PRIVATE FUEL STORAGE FACILITY**
**PRIVATE FUEL STORAGE L.L.C.**

References: 1. January 6, 2004 Request for Revised Documents Associated with the Private Fuel Storage Consequences Analysis (TAC L21150)

Per the NRC Staff's January 6, 2004 request (Reference 1), Private Fuel Storage, L.L.C. (PFS) is hereby providing a revised report by Burdeshaw Associates, Ltd. regarding the evaluation of F-16 aircraft crash impact speeds and angles for Skull Valley Type Events. The revised report includes all of the information pertaining to the evaluation of F-16 crash impact speeds and angles that PFS had earlier submitted to the Staff in responses to Staff Requests for Additional Information (RAIs). Because the NRC Staff has determined that PFS's F-16 crash impact speed and angle evaluation does not contain Safeguards Information, we are not submitting the revised report as containing Safeguards Information. PFS is also providing copies of the report directly to counsel for the Staff (Sherwin Turk) and the State of Utah (Denise Chancellor) and to the members of the Licensing Board.

If you have any questions regarding this submittal, please contact me at 608-787-1236 or Mr. J. L. Donnell, Project Director, at 303-741-7009.

Sincerely,

John D. Parkyn, Chairman
Private Fuel Storage L.L.C.

NMSS01

cc: Michael C. Farrar, Esq. (1 copy of report)
Dr. Jerry R. Kline (1 copy of report)
Dr. Peter S. Lam (1 copy of report)
Sherwin E. Turk, Esq. (1 copy of report)
Denise Chancellor, Esq. (2 copies of report)

January 2004

# EVALUATION OF F-16 AIRCRAFT CRASH IMPACT SPEED AND ANGLE FOR SKULL VALLEY-TYPE EVENTS

## Revision 1

Maj. Gen. Wayne O. Jefferson, Jr., USAF (Ret.)
Col. Ronald E. Fly, USAF (Ret.)
Brig. Gen. James L. Cole, Jr., USAF (Ret.)
Burdeshaw Associates, Ltd.

TABLE OF CONTENTS

# EVALUATION OF F-16 AIRCRAFT CRASH IMPACT SPEED AND ANGLE FOR SKULL VALLEY-TYPE EVENTS

## I. INTRODUCTION

### A. Purpose of Evaluation

#### 1. Characterize F-16 Skull Valley-Type Event Crash Impact Speed and Angle for Use in Consequences Proceeding

The possible impact speed and impact angle of a crashing F-16 are of interest in examining the ability of critical areas of the PFS Facility in Skull Valley to maintain structural integrity in the event of a possible F-16 crash into them. The kinetic energy and momentum possessed by the crashing aircraft are dependent on the impact speed. The angle of impact will determine the components of the impact velocity in the horizontal and vertical directions. Those components of impact velocity are necessary in order to understand the physical effects on any storage cask or building structure impacted by the aircraft.

#### 2. Determine Distribution of Skull Valley-Type Event F-16 Crash Impact Speeds and Angles for Use in Consequences Proceeding

In previously assessing the probability of an F-16 crash impacting the PFS Facility, PFS presented the results of its analysis of ten years of F-16 mishap reports (FY 1989 through FY 1998). See Aircraft Crash Impact Hazard at the Private Fuel Storage Facility (August 10, 2000) (Rev. 4) ("Aircraft Report"). PFS was able to obtain F-16 Class A mishap reports from the U.S. Air Force concerning Class A mishaps occurring during that period in which 121 F-16 aircraft were destroyed. PFS previously analyzed the reports to determine the nature of the events that could lead to a crash in Skull Valley. In the course of that analysis, PFS determined that 61 of the 121 destroyed aircraft were destroyed in accidents caused by events that reasonably could have occurred in Skull Valley and classified those accidents as "Skull Valley Type Events". See Aircraft Report Tab H; Private Fuel Storage, L.L.C. (Independent Spent Fuel Storage Installation), LBP-03-04, slip op. at 24-25 (2003). These 61 accidents have now been re-examined for this evaluation in order to determine the distribution of impact velocities and impact angles for possible F-16 crashes into the PFS facility.[1]

[1] In a request for additional information, the NRC Staff asked why we cite only one documented crash impact speed above 400 knots when one additional mishap in the database of 121 destroyed aircraft (13 May 98) had a documented impact speed of 520 knots. The reason we did not include the 13 May 98 mishap is because we had previously determined that it was not a Skull Valley Type Event. This is explained further in Appendix A.

## B. Approach

In preparing this evaluation, Maj. Gen. Wayne O. Jefferson, Jr., USAF (Ret.), and Col. Ronald E. Fly, USAF (Ret.) closely examined the 61 previously categorized Skull Valley Type Event F-16 accidents. Each analyzed the reports individually and then reviewed the other's analysis to jointly determine the impact speed and impact angle for the aircraft in the reports. Brig. Gen. James L. Cole, Jr., USAF (Ret.) provided an independent review of this final evaluation.

There were four F-16 accidents[2] included in the 61 Skull Valley Type Events in which the aircraft was destroyed after running off a runway following landing after an engine failure or malfunction. These were included in the original analysis because they provided information about the original question of whether or not a pilot remains in control of his aircraft after an event leading to a mishap and if so, does he actually control the aircraft. These 4 accidents, while resulting in the relatively low speed destruction of the aircraft, do not provide useful information about the likely impact speed and impact angle of an F-16 crashing in Skull Valley near the PFSF. Thus, they have been discarded from further analysis here, leaving 57 Skull Valley Type Event relevant accidents to analyze.

The results of this evaluation are presented in Tab A to this evaluation. The table in Tab A contains a chronological listing of the 57 Skull Valley Type Event accidents, with the information in the mishap reports pertinent to the aircraft crash impact speed and angle.[3] Based on this information, the impact speeds and angles for the 57 accidents were determined or estimated as described below.

### 1. Speed and Angle Based on Documented Information from the Mishap Reports

The mishap reports listed in Tab A were first examined to extract all documented references to impact speeds and impact angles. Not every mishap report states an actual aircraft impact speed and/or angle. Some reports state either impact speed or angle or both, some describe speed or angle in qualitative terms and some state neither speed nor angle. Of the 57 mishap reports reviewed, 32 of the reports documented or characterized the impact speeds and/or

---

[2] 24 April 1992, 5 May 1992, 27 August 1993, and 30 March 1994.

[3] The four runway accidents which were not used are listed separately at the bottom of Tab A.

angles of the crash impact.[4] The reported speeds and angles for these 32 accidents are presented and analyzed in Tab B. Where the mishap report documents a range of data (e.g. 20 Sep 90 accident, ejection speed of 190-200 knots calibrated airspeed (KCAS)), PFS has selected the mid-range value (195 KCAS) as the best estimate of the actual value and used this for computational purposes.[5]

### 2. Inference of Speed and Angle Based on Other Report Information and Comparison with Other Accidents

For those cases in which a specific documented impact speed was not found in the mishap report, sufficient ancillary information was found in almost every case from which a reasonable estimate could be made of the actual impact speed. This was possible through: a) assessing the impact speed based on the relationship (derived from accidents with documented impact speeds) between impact speed and the speed and/or altitude of the aircraft at the time the pilot ejects; b) comparing the accident in question with similar accidents for which documented impact speeds were available; and c) using other information in the report describing the accident.

Where impact angles were not documented in the mishap reports, approximate angles could be determined in some cases from the qualitative or quantitative descriptions contained in the reports and comparison to similar accidents. However, no useful general mathematical relationships were found between accident impact angles and the other accident parameters (such as speed or altitude at the time of ejection) to generally permit the estimation of impact angles for those accidents in which the impact angle was not documented.

This section describes in more detail the individual approaches used to estimate the impact speeds and angles for those accidents for which specific impact information was not provided in the reports and for placing numerical estimates on the qualitative descriptions of speed and angle found in the reports.

---

[4] These 32 mishap reports include some reports that used descriptive adjectives, such as "low speed" or "shallow," to characterize the impact speed or angle of the crash. Of the 32 mishap reports, 26 provide numerical values for either impact speed, or impact angle or both.

[5] Section I.B.3 below explains the treatment of calibrated, indicated, and true airspeeds in this evaluation.

### a. Impact Speed Assessment Based on Speed at Ejection and/or Altitude at Ejection

Often, even though impact data was not documented in a report, ejection speed and/or altitude data was. This ejection information in the report was based on pilot testimony or recording devices in the aircraft which recorded those parameters. Successful ejection precedes impact and most often occurs relatively close to impact in terms of time and space. Our analysis of the data shows a positive correlation between the speed and/or altitude of the aircraft at the time of ejection and the impact speed. This allows impact speed to be estimated from those ejection parameters.

### b. Comparisons with Similar Accidents

If an accident were similar to ones for which documented impact speed or angle data was found, estimates could be made on that basis. The similarity of the accidents was determined largely by comparing the circumstances at which the pilot ejected from the aircraft to accidents with documented impact data where the pilot ejected under similar circumstances.

### c. Assessment Based on Accident Circumstances and Other Information

In other cases, the description of the crashing aircraft (obtained from the ejecting pilot, pilots in nearby aircraft, or from witnesses on the ground) provided a sound basis from which one can estimate the impact speed and/or impact angle.

A number of crashing aircraft were described as "falling like a leaf" or in a "flat spin" or "crashing with little or no forward speed", etc., indicating that the aircraft was either in a deep stall descent condition or in something very close to it. The sink rate of an F-16 in such a condition is known and the vertical impact speed may be closely estimated by that. Impact angles in those cases are nearly vertical (although the aircraft orientation is flat or horizontal).

Impact angles can also be estimated where the angle is described in qualitative terms, e.g., "shallow" or where sufficient information (e.g., ejection speed and altitude and time or distance to impact) is available to quantitatively estimate the angle.

## 3. Treatment of Airspeeds in Evaluating F-16 Impact Speeds

In evaluating airspeeds, one must note that aircraft mishap reports generally document airspeed as knots "indicated" or "calibrated" airspeed (KIAS, KCAS). Indicated airspeed is simply what the pilot's airspeed indicator reads and is used because it relates directly to the aerodynamics of flight (e.g. stall speed, takeoff speed, etc.). Calibrated airspeed is indicated airspeed corrected for errors that might occur because of the location of the sensors which measure the airflow around the aircraft. In the F-16, the indicated and calibrated airspeeds are the same, or very nearly so, and will be treated as being synonymous in this evaluation and the Tabs.[6] "True" airspeed (in knots, KTAS), on the other hand, measures the speed at which the aircraft moves through space, which is the same as the speed over the surface of the earth presuming there is no wind. It differs from indicated/calibrated airspeed because of the effects of air pressure and temperature and it changes as altitude changes. In general, the higher an aircraft is, the greater the true airspeed is for a given indicated/calibrated airspeed. For understanding the kinetic energy and momentum of an aircraft, true airspeed is the better measure. Consequently, in the work that follows, indicated/calibrated airspeeds (KIAS/KCAS) have been converted to true airspeeds (KTAS).[7] All airspeeds are in terms of knots, or nautical miles per hour, rather than statute miles per hour. A nautical mile is equal to 1.15 statute miles.

## II. ACCIDENT CHARACTERIZATION

### A. Mishap Reports

#### 1. Description

PFS previously acquired F-16 Aircraft Accident Investigation Reports from the Air Force through a Freedom of Information Act (FOIA) process involving several agencies and commands within the Air Force. These reports are the result of investigations conducted under Air Force Instruction 51-503 by the Air Force after each mishap to determine the cause of the accident for purposes of preserving all available evidence and providing a complete factual summary for use in claims, litigation, disciplinary actions, adverse administrative proceedings, and other purposes in accordance with AFI 51-503.

The mishap reports follow a set format which sets forth the details of the circumstances surrounding the accident, including: a summary of the history of the flight, the flight mission, preflight activities and planning, the actual flight activity, impact information, egress (ejection)

---

[6] Accordingly, airspeeds reported either as KCAS or KIAS in the mishap reports will be denominated as KCAS in the Tabs.

[7] Calibrated airspeed (KCAS) is converted to True airspeed (KTAS) by applying corrections for pressure altitude (MSL) and for temperature, using the Standard Day relationship between MSL and temperature for all accidents.

information including the functioning of the emergency escape mechanism, rescue activity, maintenance and mechanical factors, supervisory factors, pilot qualifications, navigation aids and facilities, weather, and pertinent directives and publications. The report may conclude with a statement of opinion by the investigating officer as to the cause of the mishap. The Impact and Egress (emergency escape) System sections in particular give relevant information about impact speed and angle.

### 2. Determination of Impact Speeds and Angles and Ejection Speeds and Altitudes

The Air Force, as part of its accident investigation, may determine and document the aircraft's impact speed and impact angle for analysis of the actions and circumstances of the accident. The aircraft speed and impact angle can be derived from several recorders that normally are on the F-16 such as the Crash Survivable Flight Data Recorder (CSFDR) and the aircraft video tape recorder, if they are recoverable. Ejection parameters, also useful in estimating impact speed and angle, may be recoverable from a FLCS Data Recorder (located in the ejection seat which records aircraft flight parameters up until the pilot ejects from the aircraft) if it is recoverable.

As well, examination of the wreckage itself often reveals these parameters as the instruments on the flight panel will freeze or show impact markings (the needle slams the instrument backing and leaves a mark) of the last airspeed and aircraft orientation readings at impact.

## B. Accidents with Documented Impact Speed and/or Angle Data

Of the 57 Skull Valley Type Event accidents examined for impact speed and angle, the reports for 25 of the accidents document the crash impact speed in some respect. For 21 of these accidents, the mishap reports provide numerical values for the impact speeds and for four of the accidents the reports describe the impact speeds in qualitative terms (e.g., "low speed"). The documented impact velocities for these 21 accidents are shown in Tab B, along with a histogram showing the distribution of impact velocities for the 21 accidents for which specific impact speeds were documented. As can be seen from the histogram, the documented impact speeds are clustered around the 151 to 250 knot range (62%), with only 1 of the documented impact speeds above 400 knots (428 KTAS).

In 26 reports, impact angles or aircraft positions at impact are documented in some respect. For 18 of these accidents, the mishap reports provide numerical values for the impact angles and for 8 of the accidents the reports describe the impact angles in qualitative terms (e.g., "shallow" or "flat"). With respect to the accidents for which numerical values were provided, we used the aircraft's pitch angle at impact as the basis for estimating the impact angle. The rationale for doing so is explained in detail in Appendix B.

Impacts described as "shallow" would be descending or gliding nearly horizontally and can be taken as having an impact angle of less than 10 degrees.[8] Impacts described as "flat" would be descending essentially vertically, and were taken to be descending with impact angles between 80 and 90 degrees. Impacts described as having little or no forward velocity would also be descending essentially vertically, or "flat," and were similarly taken to be descending with impact angles between 80 and 90 degrees.

A histogram of the documented impact angles for these 26 accidents is provided in Tab B. As can be seen from the histogram, the category of impact angles with the most cases are those with shallower angles of less than 10 degrees, followed by the 20.1 to 30 degree impact category and the 80.1 to 90 degree category (representing flat or near vertical impacts).

In 13 reports, numerical values for both impact speed and impact angle were given. A scatter chart of this data is provided in Tab B. The scatter diagram shows only minor correlation between the two variables. A linear regression analysis using the least squares method[7] applied to the documented speeds and angles showed a coefficient of determination, $R^2$, of 0.2347, which confirms this very weak correlation.[9] A further examination of the data was made using nominal values of 5 degrees for shallow impact angles and 85 degrees for flat impacts and an $R^2$ of 0.2009 was obtained, further verifying the weak correlation between impact speed and angle. The scatter diagram for this evaluation is shown at the bottom of Tab B.

---

[8] For purposes of this report, those impact angles described as "shallow" are included in the 0-10 degree category. This is consistent with the engine out glide angles (approximately 5-7 degrees) required to maintain recommended airspeeds. As a point of comparison, a typical approach for a normal landing is flown at 2.5 - 3.0 degree descent angle.

[9] The coefficient of determination $R^2$ is defined as the proportion of the total variation in the dependent variable (here the impact angle) that is explained by the variation in the independent variable (here the impact speed). Therefore, a small coefficient of determination, such as 0.24, shows little or no correlation between the two variables (a coefficient of 1.0 would indicate complete correlation between two variables).

### C. Accidents with Impact Speed Inferred from Other Information

For the 36 accidents for which the impact speeds are not documented directly, other information is presented which nevertheless may be used to reasonably estimate the impact speed. For instance, in many cases the ejection parameters of speed and altitude are documented as a result of information gained from the ejection seat recorder. As discussed below, the impact speed data show a positive correlation with ejection speed and ejection altitude. Therefore, reasonable impact speed estimates by comparison with other accidents are possible as discussed below.

In reviewing the mishap reports in Tab A, it may be seen that there is one accident (20 Sept 90) with only the ejection speed documented and no documented ejection altitude or impact speed. The impact speed of this accident is estimated in sections 1.a. and b. below.

It may also be seen that there were 7 accidents with a documented ejection altitude but no documented ejection speed or impact speed. The impact speeds for these accidents are estimated in sections 2.a and b. below.

There were 18 accidents in which both ejection airspeed and ejection altitude were documented, but in which no impact speed was documented. The impact speeds for these accidents are estimated in sections 3.a. and b. below.

Finally, there were 10 accidents for which a numerical impact speed was not documented but sufficient information was otherwise available from the mishap reports to estimate the impact speed. The impact speeds for these accidents are estimated in section 4 below.

#### 1. Impact Speeds Inferred from Ejection Speeds

##### a. Characterization of Accidents with Known Ejection Speeds and Impact Speeds

An examination of the mishap report for the 20 Sept 90 accident with only the ejection speed documented indicates that the ejection was at a relatively low altitude. The pilots in this 2 seat version of the F-16 were descending from a height of 4,500 ft AGL while attempting an airstart. When the airstart attempt failed, the pilot in command terminated the airstart attempt, and made a turn to the northwest. His wingmen confirmed that the flight path was clear, and the two pilots prepared for ejection and then ejected.

In examining the accidents documenting both ejection airspeed and impact speed, 9 were found with ejection altitudes from 1,380 ft to 5,400 ft AGL. This range of altitudes brackets the likely actual ejection altitude of the 20 Sept 90 accident, thereby providing the best estimate for its impact speed. From these, it is possible to examine the relationship of the speeds and develop a metric for estimating the impact speed from the ejection airspeed where only the latter is known. A plot of Ejection Speed versus Impact Speed using these 9 reports for which both are known reveals a relationship as shown on the chart in Tab C. Fitting a linear regression line to this data results in the relationship of

Impact Speed = 0.7911 x Ejection Speed + 71.193

This equation has a coefficient of determination, $R^2$, of 0.8143 which shows a good correlation between impact speed and ejection speed.

**b. Application of Relationship between Ejection Speed and Impact Speed to an Accident with Ejection Speed Specified**

Applying the relationship derived above between ejection speed and impact speed allows estimation of the impact speed for the 20 Sept 90 accident for which neither ejection altitude nor documented impact speed was available. This is shown in Tab D.

**2. Impact Speeds Inferred from Ejection Altitudes**

**a. Characterization of Accidents with Known Ejection Altitudes and Impact Speeds**

In reviewing the accidents in Tab A again, it may be seen that there are 7 accidents in which the ejection altitude is documented but neither the ejection speed nor impact speeds are documented. It may also be seen that 6 of these occurred with ejection altitudes between 300 and 2,300 ft. and 1 at an altitude estimated to be 6,500 feet[10]. There were 20 accidents with

[10] We estimated an ejection altitude of 6,500 feet AGL for the accident of 4 Apr 91 based on the altitude at which the pilot's maneuvering began and the maneuvers he actually performed while attempting to remain clear of the lead aircraft in his formation. The ejection speed is also not known, but we estimate it to be very low, based on the description of the maneuvering and the aircraft response. This suggests a lower impact speed as does the fact that the aircraft was at idle power and had its speed brakes fully extended, thus increasing the drag on the aircraft. Suggesting a higher impact speed was the fact that the aircraft was in a very nose low attitude at ejection. Because of the lack of further defining information, however, the impact speed for this accident was simply estimated by use of the regression equation.

ejection altitudes below 11,000 ft AGL in which both the ejection altitude and impact speed were documented. A table and a chart showing the relationship between these two variables is shown in Tab E. There is a correlation between these two variables and a linear regression trend line shows the relationship of

Impact Speed = 0.0256 x Ejection Altitude + 170.04

This equation has an $R^2$ of 0.7652, which shows a good correlation between impact speed and ejection altitude.

**b. Application of Relationship Between Ejection Altitude and Impact Speed to Accidents with Ejection Altitude Specified**

Using the equation derived in the above paragraph allows an estimation of the impact speed of the 7 accidents where the ejection altitude is documented but neither the impact speed nor the ejection speed is documented. These are set forth in Tab F. Note that this relationship was not used to estimate impact speed for those accidents in which the ejection altitude was known but the aircraft was also described as falling in a deep stall. In that case, as discussed below, the F-16 deep stall velocity controls the impact speed.

**3. Impact Speeds Inferred from both Ejection Speeds and Altitudes**

**a. Characterization of Accidents with Known Ejection Altitudes and Speeds and Impact Speeds**

There were 18 accidents in which both the ejection speed and ejection altitude were documented but no impact speed was given. The altitudes at which the pilots ejected for these 18 accidents ranged from 209 to 5,700 feet AGL and their ejections speeds ranged from 149 to 263 KTAS. Since ejection altitude and ejection speed each show a correlation with impact speed, both of these ejection variables can be used simultaneously in a multiple regression analysis to obtain a formula to estimate the impact speed for accidents in which both the ejection speed and altitude are known but the impact speed is not.

The ejection speed, ejection altitude, and impact speed are known for 14 accidents which are similar in altitude and airspeed to the 18 accidents with unknown impact speed. These 14 accidents for which all three of these variables are known are set forth in Tab G. From this information, one can derive the following formula, Impact Speed = 71.806 + 0.017 x Ejection Altitude + 0.583 x Ejection Speed,

using a computerized multiple regression algorithm[11] where Ejection Altitude and Ejection Speed are the independent variables and Impact Speed is the dependent variable. This equation has a coefficient of multiple determination,[12] $R^2$ of 0.9384 and an $R^2b$ of 0.9272[13], which shows a strong relationship between impact speed and the altitude and speed at which ejection occurs. The higher value for $R^2$ over those of the two simple regressions above (0.8143 and 0.7652) shows that this equation provides a better correlation than either of the two previous equations based on either the Ejection Speed or the Ejection Altitude alone. However, despite the goodness of fit of the data to the regression line, as with any regression analysis, care must be used when applying the equation derived from the analysis outside the range of the data used in the regression.

#### b. Application of Regression Model to Infer Impact Speeds from Known Ejection Speeds and Altitudes

Using the multiple regression formula derived above allows the estimation of the impact speeds for the 18 accidents which have both documented Ejection Altitude and Ejection Speed. These are set forth in Tab H.

### 4. Impact Speeds Inferred from Other Information

There were 6 accidents in which the aircraft was in a flat spin or deep stall condition at impact and impact speed was not documented. When an aircraft is in this condition it has different flight dynamics and the previous regression formulas would not apply. In 4 other cases, ejection altitude and speed parameters were not documented. However, it is still possible to credibly estimate impact speed in these remaining cases, because of known characteristics of F-16 flight or from comparison with other similar accidents.

---

[11] Windows Excel, Microsoft Office XP Standard.

[12] The coefficient of multiple determination $R^2$ is, for multiple regression analysis, defined as the proportion of the total variation in the dependent variable (impact speed) explained by the multiple regression of the dependent variable on the independent variables (ejection speed and altitude).

[13] $R^2b$ is the adjusted coefficient of multiple determination and accounts for the effect of reducing the degrees of freedom in the analysis as additional independent variables are considered. The effect is small where, as here, the number of observations (14) is much larger that the number of independent variables (2) in the analysis.

a. **Deep Stall Speed**

When an F-16 is in a deep stall mode of (non-)flight, it falls at a predictable vertical velocity of 10,000 to 15,000 feet per minute.[14] This mode of falling would encompass those accidents in which the aircraft was described as "falling like a leaf" or in a flat spin with little or no forward velocity. If an F-16 were descending vertically at the rate of 10,000 feet per minute, the vertical velocity would be 98.7 knots. Descending vertically at 15,000 feet per minute, it would have a vertical velocity of 148 knots. An average of these is 123 knots.

There were 5 accidents in which the aircraft was described by witnesses as falling like a leaf, in a flat spin, or having little or no forward velocity. All 5 were assigned an estimated impact speed of 123 knots. These are presented in TAB I.

There was also one accident in which the aircraft was uncontrollable and fell from 14,000 feet. The 16 Sept 97 aircraft was involved in a midair collision at about 14,000 ft. in which both hydraulic systems were lost; the pilots (2 seater) could not control the aircraft, so they ejected. In two of the other documented accidents[15], the aircraft lost hydraulic pressure and went into uncontrolled, uncoordinated flight with impacts described as flat, inverted and flat plate. Thus, this aircraft can also be characterized as a flat plate impact. In addition, the time from the mid-air collision until ocean impact (70 seconds from 14,000 ft to sea level, or 118.5 knots average) is consistent with the rate of fall associated with a deep stall. See Tab I.

b. **Other Information**

In addition to the deep stall velocity, other information about an accident can also be used to estimate the aircraft's impact velocity. If the aircraft impact speed is described as "slow" or at a "low speed", a reasonable estimate is that it was flying at or below a glide speed of 225 knots.[16] This estimate of the term "slow speed" was applied to the 3 September 90 accident and is also shown in TAB I. This estimate is supported by the accident of 22 Aug 97, whose impact speed was also described as "slow" but which we estimated on the basis of its ejection altitude to be 201 KTAS (see Tab F).

---

[14] T.O. F-16C-1, Section VI, Flight Characteristics, Deep Stall ¶ 2.

[15] The accidents of 13 Jan 91 and 19 Mar 91 also involved loss of all hydraulic pressure and subsequent flat stalls or spins.

[16] Maximum endurance (time aloft) basic glide airspeed is 170 KCAS and maximum range basic glide airspeed is 200 KCAS. Both must be adjusted by +5 KCAS for every 1,000 pounds of fuel and stores over 1,000 pounds. TO 1F-16CG-1CL-1.

The 1 Sep 92 accident had no documented ejection or impact data. However, the mishap report indicates that the pilot prepared for ejection as he approached 2000 feet with a failed engine at which point he zoomed the aircraft and then ejected. Assuming the pilot was at approximately 300 knots[17] when he began his zoom at 2,000 ft AGL and then zoomed for his controlled ejection, at the apex of the zoom the aircraft would have been at approximately 3,500 ft AGL and at a speed of 170 knots (182 KTAS). Using these parameters as the altitude and speed of ejection in the multiple regression analyses above gives an estimated impact speed of 237 KTAS.

If the aircraft impacts the ground in controlled flight, the impact speed can be estimated from the flight speed of the aircraft prior to impact. For example, in the 25 May 90 accident, the aircraft flew into the ground after the pilot made a descending turn on to what was intended to be a low level segment of flight at 300 ft. AGL at a speed of 480 knots (KTAS). Thus, the impact velocity of the aircraft was estimated to be 480 KTAS. <u>See</u> Tab I.

If one accident for which no specific data is provided is very similar to another where data was provided, the impact speed of the first accident can be estimated to be similar to that of the second. For example, in the accident of 15 Jan 91, the aircraft was struck by lightning at an altitude of between 21,000 and 23,000 ft. MSL. The pilot, intending to land, descended for approximately three minutes to a lower, but unknown altitude, at which time he experienced a fuselage fire and then made a controlled ejection. The report documented that the impact angle was approximately 20 degrees nose low, but the speed was unknown. By comparison, in the accident of 16 Dec 91, the aircraft suffered an engine failure and caught fire at approximately 16,000 ft. MSL. The aircraft descended to 11,000 ft. MSL (approximately 11,000 ft. AGL) and the pilot ejected, at 230 knots. That aircraft impacted the ground at an angle of 24 degrees nose low at a speed of 428 knots (KTAS). Therefore, because the two accidents are similar, it can be estimated that the impact speed of the first aircraft was about 430 knots KTAS. <u>See</u> Tab I.[18]

#### 5. Collective Presentation of Accident Impact Speed

Based on the evaluations in Sections II.B and C above, the impact speeds for 57 of the Skull Valley-type event accidents have been evaluated and determined or estimated based on the

[17] A reasonable airspeed for an F-16 with a Pratt and Whitney engine and inoperable Jet Fuel Starter below 10,000 feet MSL.

[18] Subsequent to our initial Report, we received information that the ejection altitude and airspeed for this mishap were 3,500 ft. AGL 273 KTAS respectively. Therefore, employing the regression formula based on ejection speed and altitude from above, we now estimate that the aircraft impact speed was 284 KTAS. While PFS is not re-estimating its distribution of potential F-16 impact velocities for Skull Valley, this new data shows that its estimated distribution is conservative, as this accident had been one of the fastest estimated impact speeds in the Skull Valley Type Event data base. Because PFS is <u>not</u> re-estimating its distribution of potential F-16 impact velocities for Skull Valley, we <u>do not</u> change the statistics or tables in this Report to reflect this new information.

information in the mishap reports.[19] The impact speeds for all 57 accidents are presented in table form in Tab J. A histogram of the resulting speeds is also presented.

An evaluation of whether the impact speed estimation process introduced any bias into the resulting distribution in the histogram in Tab J was done by comparing the shape of the histogram in Tab J with the shape of the histogram in Tab B, which is constructed entirely from accidents with documented impact speeds. If nothing were known about the accidents without documented impact speeds, other than that they involved F-16s in Skull Valley Type Events, the shape of a histogram of documented plus unknown speeds would be expected to be similar to the shape of a histogram of documented speeds alone, since the unknowns come from the same population as the accidents with documented speeds. Here, the accidents without documented speeds were not entirely unknown, in that we were able to estimate speeds for them based on information in the mishap reports. However, since if there were nothing else different about the accidents without documented impact speeds (i.e., the ones with estimated speeds), the shape of a histogram of documented plus estimated speeds—the histogram in Tab J—would be expected to be similar to the shape of a histogram of documented speeds alone—the histogram in Tab B.

A comparison of the shapes of the histograms in Tabs J and B can be done by comparing the fractions of accidents in one histogram in each range of impact speeds (e.g., 200.1-250 KTAS) to the fractions of accidents in the other histogram in the same ranges of speeds. The bar graph in Tab J entitled Comparison of Documented and Estimated Impact Speed Distributions illustrates that comparison. From the graph it may be seen that the two distributions are of similar shapes with a clustering of accident impact speeds in the 150 to 250 KTAS range.[20] The documented plus estimated (Tab J) distribution does contain a substantially higher fraction of accidents in the 100.1-150 KTAS range. That is due to the inclusion of the deep stall accidents, whose impacts were described in the mishap reports in qualitative rather than quantitative terms.

[19] As noted above, impact speeds have not been estimated for four accidents in the database of 61 Skull Valley Type Events (24 Apr 92, 5 May 92, 27 Aug 93, 30 Mar 94). Those accidents occurred on the runway in connection with landings. Therefore, because they do not represent crash impacts as such, they are not relevant to the assessment of crash impact speeds for the PFS analysis.

[20] The differences in fractions of accidents between the histograms in the 150.1-200 and 200.1-250 KTAS ranges appear to be caused by a large number of accidents with impact speeds near the range dividing point of 200 KTAS. The accidents remain clustered in the 150 to 250 KTAS range, as in Tab B. See Tab J.

Thus, no deep stall accidents appeared in the Tab B documented speed histogram. Other than that, the two distributions appear to be similar. Therefore, we can conclude that our impact speed estimation process has not introduced bias into the distribution of impact speeds shown in Tab J.

**D. Accidents with Impact Angles Inferred from Other Information**

Unlike impact speed, estimation of impact angles by regression analysis was not feasible. Such analyses were attempted using ejection speed, ejection altitude, and impact speed as predictors for impact angle, with no useable correlations found. However, in addition to the accidents for which the impact angle was documented in the mishap reports, for certain accidents the impact angle may be quantitatively estimated from other information in the reports (e.g., ejection speed and altitude and time or distance to impact). We have estimated impact angles for eight such accidents below.

The 26 Dec 89 mishap report states that the pilot ejected at 1,400 ft MSL and that the aircraft impacted the ground approximately 20 seconds later, 7,000 feet from the landing point of the pilot. The aircraft was traveling at an estimated 250 KTAS at ejection. Assuming this same speed (the estimated impact speed from Tab H was 241 KTAS) for 20 seconds would give an air distance from ejection to aircraft impact of 8,438 feet. Using 1,400 ft as the vertical leg of a right triangle and 8,438 ft. as the hypotenuse, with $\alpha$ as the impact angle, $\sin \alpha = 1400/8{,}438$ or 0.1658, which gives an impact angle of approximately 10 degrees.[21]

The 18 Apr 91 accident shows an ejection at 2,800 ft AGL (170 kts) and the airplane crashing 1 mile from the pilot. Assuming the pilot came straight down (no wind) the same relationships apply, and the impact angle would be 28 degrees.

The 9 Nov 93 accident, documented in the mishap reports as impacting at a shallow glide angle, shows an ejection at 610 ft AGL and 220 KTAS. The airplane crashed 12 seconds later (after having traveled an estimated 4,456 feet at 220 KTAS). The same relationships as above yield an impact angle of 8 degrees, falling within the zero to 10 degree shallow range in which

[21] Using 1,400 feet as the vertical leg and 7,000 feet as the horizontal leg yields an impact angle of approximately 11 degrees. At 250 KTAS, this latter horizontal distance would indicate a travel time of about 17 seconds.

the accident was originally classified in Tab B based on the mishap report describing the impact angle as a "shallow glide."[22]

With respect to the 13 Jan 95 accident, the pilot zoomed the aircraft in accordance with the appropriate procedures and reached an apex altitude of 7,000 ft. MSL with an airspeed of 230 KCAS. The pilot then established a descent to maintain airstart airspeed and ejected twenty nine (29) seconds later. Assuming that the descent parameters after the zoom were in accordance with the emergency procedures, the plane would have descended at approximately 7 degrees and 230 KCAS. In the 29 seconds prior to the pilot ejecting, the plane would have descended approximately 1,520 ft., to 5,480 ft. MSL (4,280 ft. AGL). The aircraft crashed 39 seconds after ejection at 325 KCAS (326 KTAS). Using this calculated ejection altitude as one side of a right triangle, and the air distance traveled as the hypotenuse,[23] an impact angle of approximately 11 degrees is determined.[24]

The 3 Aug 96 mishap report contains information from which one can reasonably compute an impact angle for this accident. The pilot ejected at approximately 5,400 ft. AGL and 310 KTAS. The airplane impacted 21 seconds later at 352 KTAS. The maximum distance the airplane could have flown from the point of ejection to the impact point is 12,492 ft.[25] Using the ejection point as one corner of a right triangle, the ejection altitude of 5,400 ft. as one side of the triangle, and a hypotenuse of 12,492 ft., yields a descent angle and impact angle of approximately 26 degrees. [26]

The angles calculated for the above five accidents are most likely minimum angles of impact. In each case, the calculation assumed that the plane traveled in a straight line from the

---

[22] In Tab B, a nominal impact angle value of 5 degrees was assigned to accidents which were described by the mishap reports as involving a shallow impact angle. In Tab K, we now replace this nominal value for the 9 Nov 93 accident with the quantitative estimate derived above.

[23] The impact speed is higher than the ejection speed. Using the impact speed as the speed of the aircraft after ejection yields an air distance traveled of 21,487 ft.

[24] Using the average of the ejection and impact speeds as the speed of the aircraft after ejection provides an air distance traveled of 19,114 ft. and an impact angle of approximately 13 degrees.

[25] This is a conservative estimate because it assumes the airplane instantaneously accelerated to impact speed the moment the pilot ejected.

[26] If the average of ejection and impact velocities is used, the air distance traveled by the aircraft would have been 11,747 ft. This provides a descent angle of approximately 27 degrees.

point of ejection to impact on the ground. In fact, the crashing aircraft may have flown at a slower average airspeed and followed a somewhat parabolic descent resulting in a somewhat steeper impact than calculated by trigonometry alone.

In addition, it was possible to estimate the angles for three other accidents based on information in the mishap reports.

The 4 Apr 91 accident is categorized as an 80-90 degree impact. The mishap report indicates that the nose of the aircraft fell to a near vertical position just prior to ejection, and that the airplane continued in a descending vertical spiral until impact. The on-scene accident commander for this accident (with whom Col. Fly spoke) stated that the evidence at the accident site confirmed that a nearly direct vertical impact had occurred.[27]

The 21 April 1997 accident involved an ejection at 50 feet and a subsequent impact in a landing attitude at approximately 170 knots. The impact angle would then be about 3-5 degrees.

As discussed in section II.C.4.a above, the 16 Sep 97 accident was categorized as a vertical deep stall accident. It would therefore have an impact angle of 80 to 90 degrees.

Based on the evaluations in Sections II.B and D, the impact angles for 33 of the 57 Skull Valley-type event accidents have been evaluated and determined or estimated based on the information in the mishap reports. The impact angles for these 33 accidents are presented in table form in Tab K.

After evaluating and estimating the 33 impact angles above, 24 accidents remained without an impact angle assigned. While the information is not available to reasonably assign a specific numeric impact angle to these accidents, there is enough information in the reports to broadly determine whether the impact angle for each accident would fall into one of two broad categories, those at lower impact angles, from 0 to 45 degrees, and those at higher impact angles, from 45 to 90 degrees. As already seen in Tab B above, the impacts seem to cluster in groupings below 40 degrees and above 60 degrees, so this appears to be a natural division of angles. The remaining 24 accident reports were analyzed for descriptions of ejections, impacts, etc. to come to a conclusion for each accident as to the broad category into which it would likely fall. Based

---

[27] Telephone conversation between Col. Ronald E. Fly, USAF (Ret.), and Lt. Col. (now Col. USAF Ret.) Blanco, July 7, 2003.

on this evaluation, the remaining 24 accidents were judged as having impacted at an angle of 45 degrees or less, and this information has been added to the bottom of the table in Tab K.

### E. Correlations Between Impact Speed and Impact Angle

The combined estimated speeds and estimated specific angles and the documented speeds and angles are all presented and correlated in Tab L. There were 33 accidents for which both speeds and specific angles were either documented or estimated. Tab L contains a scatter diagram of this speed and angle data. It is evident that there is little or no general correlation between these impact speeds and impact angles (a linear regression line has an $R^2 = 0.1078$).

As noted above, the accidents may be divided into two groups on the basis of impact angle, one group with angles equal to or less than 45 degrees and another group with steeper to near vertical angles. Examining the relationship between impact speed and specific impact angles for accidents with angles below 45 degrees also reveals little or no correlation (linear regression, $R^2 = 0.0871$, Tab L). Regarding the near vertical impacts, because most of them occurred after the aircraft entered a deep stall, the impact velocities of those crashes tend to be in the moderate range. For example, as noted above, the deep stall velocity for the F-16 is 98 to 148 knots, averaging 123 knots. There are six deep stall accidents in the database. There was also one impact at 65 degrees (3 Sep 90) at a documented "low speed" (estimated to be 225 KTAS), and one impact at a near vertical angle (4 Apr 91) at a higher estimated speed.

### F. Accident Distributions

#### 1. Impact Speed Distributions of All Accidents

As described above, documented and estimated crash impact speeds for 57 Skull Valley Type Event accidents (i.e., 61 accidents minus four runway accidents) are presented in Tab J. It is clear that the impact speeds cluster around and below the 200-250 KTAS range, with one in the range of 350 to 400 KTAS, two in the 400-450 range,[28] and one in the 450-500 KTAS range.

#### 2. Angle Distribution of All Accidents

Tab K contains two histograms showing the impact angle distribution for the 33 cases where the angle was provided in the mishap report or where sufficient information was provided to allow estimation of a specific impact angle. The two histograms show two groups of accidents – the first showing those with angles less than 45 degrees, and second showing those

[28] One of these two accidents is the 15 Jan 91 mishap discussed in note 18 for which we received additional information after our initial Report. As explained in note 18, while this new information enables us to now estimate the speed for this accident to be 284 KTAS, PFS is not re-estimating its distribution of F-16 potential impact velocities to account for this new information.

with angles greater than 45 degrees to near vertical. As can be seen from the histograms, the most likely impact angle for an F-16 accident in Skull Valley is 10 degrees or less, with successively steeper impact angles being less likely until one finds no impact angles in the 40 to 60 (actually 35 to 65) degree range. The remaining accidents, shown on the second histogram, are vertical and near vertical impacts. Most of these impacts resulted from the aircraft entering a deep stall such that it fell flat with little or no forward velocity.

### G. Derivation of Vertical and Horizontal Velocities

For the analysis of the effects of an aircraft crash impact on the PFS facility, in addition to the likely distribution of total impact velocities, it is also useful to know the distributions of the horizontal and vertical components of the velocities. The horizontal components of velocity can be used to analyze the effects of horizontal or near horizontal impacts on structures at the facility and the vertical components can be used to analyze the effects of vertical impacts. Therefore, we have used the accidents in which the impact speed is known or estimated and the specific angle is known or estimated to produce distributions of horizontal and vertical components of impact velocities. The horizontal component of velocity is simply calculated by multiplying the total impact velocity by the cosine of the impact angle. The vertical component is calculated by multiplying the total impact velocity by the sine of the impact angle. The calculations and the distribution of horizontal and vertical components of velocities are shown in Tab L. The horizontal distribution shows that the most likely horizontal component of impact velocity will be in the 150 to 250 knot range, with the second most likely grouping at 0 to 50 knots. The vertical distribution shows that the most likely vertical component of impact velocity will be 50 knots or less with a second peak at 100 to 150 KTAS. There were two occurrences of a vertical impact speed above 200 KTAS, including one estimated vertical velocity over 300 knots.

**Appendix A**
**Assessment of 13 May 1998 F-16 Mishap**

Our Report does not include the 13 May 98 mishap (whose report cites a 520 KCAS impact speed) because we did not assess that accident as a Skull Valley Type Event (SVTE), and the statement in our Report concerning documented airspeeds is in reference to SVTE mishaps. See Report Section II.B and Tab A. In our assessment of the set of Skull Valley Type Events for the PFSF aircraft crash probability proceeding, we considered the May 13, 1998 accident and determined that it was not a Skull Valley Type Event for the following reasons:

> <u>Accident Occurring on 13 May 98</u>: This accident occurred at 830 ft. AGL and 520 knots during a low-level flight. The aircraft struck a flock of American White Pelicans near the Missouri River. It hit at least 5 of these large birds, which weigh 12.5 to 15.5 pounds and have a 5-foot long body and 8 to 9 1/2-foot wingspans. On impact, one or more of the birds broke though the canopy and pinned the pilot against the seat, subjecting him to significant windblast. The pilot ejected immediately. Flocks of very large birds are not present in Skull Valley. Moreover, according to Air Force data, the number of bird strikes decreases rapidly as the altitude increases (70% occur at 1,000 feet AGL or below), so aircraft at 3,000 to 4,000 ft AGL, at which the F-16s normally transit Skull Valley, are much less likely to experience a bird strike (less than 3% of bird strikes occur in this altitude range). Additionally, an aircraft flying at the typical airspeed for F-16s in Skull Valley, 350 to 400 KIAS, would experience less of an impact force when hitting a bird and therefore breaking of the canopy would most likely not occur (this accident is the only known case where the canopy was broken on an F-16 by a bird strike). The much more likely event would be for a bird to be ingested into the engine and cause it to fail, which would leave the pilot in control of the aircraft with the ability to avoid structures on the ground, like the PFSF.

Aircraft Crash Impact Hazard at the Private Fuel Storage Facility, Rev. 4 (August 10, 2000) ("Aircraft Report"), Tab H, at 24. The Atomic Safety and Licensing Board concurred with our assessment that this mishap was not a SVTE since it would not be expected to occur during Skull Valley flight. <u>Private Fuel Storage, L.L.C.</u> (Independent Spent Fuel Storage Installation), LBP-03-04, 57 NRC 69, 168 (2003). Therefore, we do not include this accident in our data set for assessing F-16 crash impact speeds and angles for Skull Valley Type Events.[1]

---

[1] The appropriateness of using Skull Valley Type Events for our assessment is discussed in detail in the Addendum to Appendix A of the Cornell Report. C. Allin Cornell, Probability Assessment of the Aircraft Crash Impact Hazard for the Private Fuel Storage Facility Based on Engineering Evaluations of Storage Cask and Canister Transfer Building Structural Integrity, Rev. 1 (January 2004) ("Cornell Report"), Addendum to App. A.

Furthermore, it would not be appropriate to attempt to use this accident as an additional source of information for characterizing the crash impact speed and angle for SVTEs (see Addendum to Appendix A of the Cornell Report) because the resultant pilot actions and flight dynamics of the aircraft after impacting five large pelicans (weighing 12.5 to 15.5 pounds each) were far different from mishaps that would be expected to occur in Skull Valley in which a pilot would generally remain in control of the aircraft with the ability to follow the applicable emergency procedures to trade speed for altitude. Thus, in a typical SVTE, at the time of ejection, the speed of the aircraft would be much less than the approximately 520 kts that occurred in the 13 May 98 mishap.[2] Thus, the flight dynamics at the time of ejection for the 13 May 98 mishap would not be analogous to expected SVTE mishaps. In this respect, generally it is the flight dynamics at the time of ejection, and not those at the time of the initiating event, that are the controlling determinants of impact speed and angle. See Report at Section II.C.

[2] The documented 520 kts impact speed referred to in the mishap report was the speed at which the aircraft impacted the 5 white pelicans. PFS Exh 201 at 3. However, while not specified in the report, the speed at ejection and at impact would probably be very close to this value.

Tab A

Chronological Listing of Data from F-16 Mishap Reports FY89 - FY 98

| | Accident | | Ejection | | | | Impact | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Altitude | Altitude AGL | Speed | KTAS | Speed | KTAS | Elevation | Angle | | | |
| | | *Engine Failure?* | *documented or inferred* | *documented or inferred* | *documented* | *calculated* | *documented* | *calculated* | *documented or inferred* | *documented or inferred* | | | |
| | Date | | MSL | AGL | KCAS | KTAS | KCAS | KTAS | | | Date | Bank | AOA |
| 1 | 26-Dec-89 | Yes | 1400 | *1380* | 240-250 | *250* | | | *20* | | 26-Dec-89 | | |
| 2 | 3-Apr-90 | Yes | about 2300 | *2280* | | | | | *20* | | 3-Apr-90 | | |
| 3 | 25-May-90 | No | none | none | | | | | *198* | 11 dive | 25-May-90 | | |
| 4 | 7-Aug-90 | Yes | approx 1000 | *957* | | | 157 | *157* | *43* | 9 nose down | 7-Aug-90 | | |
| 5 | 3-Sep-90 | Yes | | | | | low speed | *slow* | | 110-120 *(65)* | 3-Sep-90 | | |
| 6 | 20-Sep-90 | Yes | | | 190-200 | *199* | | | 1250 | | 20-Sep-90 | | |
| 7 | 23-Oct-90 | Yes | | *1800* | 250 | *263* | | | 1700 | | 23-Oct-90 | | |
| 8 | 13-Jan-91 | Yes | 23,000 | | | | | | | flat, inverted | 13-Jan-91 | | |
| 9 | 15-Jan-91 | No | | | | | | | *5* | 20, nose down | 15-Jan-91 | 30 left | |
| 10 | 20-Feb-91 | Yes | | 300 | | | | | | | 20-Feb-91 | | |
| 11 | 19-Mar-91 | No | 9,800 | | 310-320 | *~365* | | | unknown | flat plate | 19-Mar-91 | | |
| 12 | 4-Apr-91 | No | 7000-8000 | *6500* | | | | | *155* | | 4-Apr-91 | | |
| 13 | 18-Apr-91 | Yes | | 2800 | 170 | *181* | | | *~1320* | | 18-Apr-91 | . | |
| 14 | 7-May-91 | Yes | | 506 | 145 | *146* | 156 | *156* | ~114 | 8.5 nose down | 7-May-91 | 21 right | |
| 15 | 8-Jun-91 | Yes | | 900 | 200 | *202* | | | *28* | | 8-Jun-91 | | |
| 16 | 17-Jul-91 | Yes | | 2500 | 180 | *187* | | | S/L | | 17-Jul-91 | shallow rt | |
| 17 | 27-Nov-91 | Yes | | 1000 | | | | | S/L | | 27-Nov-91 | | |
| 18 | 16-Dec-91 | Yes | 11,000 | ~11,000 | 230 | *273* | 428 | *428* | *95* | 24 nose low | 16-Dec-91 | 50 right | 1.58 |
| 19 | 13-Jan-92 | Yes | | <500 | 110 | *113* | 145.75 | *149* | 1,366 | 6.6 nose down | 13-Jan-92 | 5.1 left | 11.3 |
| 20 | 31-May-92 | Yes | 6100 | *3114* | 200 | *220* | | | *2,986* | | 31-May-92 | | |
| 21 | 31-Aug-92 | Yes | ~2000 | *1890* | | | | | *110* | | 31-Aug-92 | | |
| 22 | 1-Sep-92 | Yes | | | | | | | | | 1-Sep-92 | | |
| 23 | 18-Sep-92 | Yes | | *600* | | | 255 | *261* | *1,428* | *21 nose down* | 18-Sep-92 | 29 left | |
| 24 | 22-Oct-92 | Yes | | <500 | | | | | | | 22-Oct-92 | | |
| 25 | 17-Dec-92 | Yes | 3534 | *3184* | 142 | *143* | | | *~350* | 25 nose low | 17-Dec-92 | | |
| 26 | 19-Feb-93 | Yes | | | | | very low forward velocity | very low forward velocity | | inverted *(flat)* | 19-Feb-93 | | |
| 27 | 23-Feb-93 | Yes | 1800 | *1460* | 220-250 | *241* | | | *340* | | 23-Feb-93 | | |
| 28 | 21-Apr-93 | Yes | | 50 | | | 170 | *171* | *580* | | 21-Apr-93 | | |
| 29 | 11-Aug-93 | Yes | 1700 | 1700 | ~210 | *215* | ~200 | *200* | S/L | 10 nose down | 11-Aug-93 | 5 left | 8 |
| 30 | 11-Sep-93 | Yes | 29,000 | | | | very little forward velocity | very little forward velocity | *690* | *(flat)* | 11-Sep-93 | | |
| 31 | 9-Nov-93 | Yes | 8210 | 610 | 194 | *220* | 194 | *218* | ~7,600 | shallow glide | 9-Nov-93 | | 7 |
| 32 | 2-Feb-94 | Yes | | ~1800 | 170-180 | *184* | 220 | *226* | *1590* | 6 nose down | 2-Feb-94 | 24 right | |
| 33 | 7-Feb-94 | Yes | | >1500 | ~150 | *155* | ~210 | *212* | 700 | | 7-Feb-94 | | |
| 34 | 1-Jul-94 | Yes | | ~1500 | <250 | *258* | | | *575* | | 1-Jul-94 | | |
| 35 | 20-Sep-94 | Yes | 7500 | 3300 | ~175 | *196* | 192 | *204* | 4,200 | 4.2 nose down | 20-Sep-94 | 4.2 right | 10.547 |
| 36 | 25-Oct-94 | Yes | | 1380 | 123 | *134* | 156 | *166* | 4,200 | 30 dive | 25-Oct-94 | 50 left | 10 |
| 37 | 13-Jan-95 | Yes | | | | | 325 | *332* | 1,200 | | 13-Jan-95 | | 3.5 |
| 38 | 5-Feb-95 | Yes | *~8840* | 3300 | 296 | *338* | *288* | *314* | 5,500 | *7 dive* | 5-Feb-95 | 17 left | 4.7 |
| 39 | 15-May-95 | Yes | | 2000 | 160 | *177* | | | ~4,800 | | 15-May-95 | | |
| 40 | 25-Jun-95 | Yes | | ~2000 | ~200 | *208* | | | *~900* | flat | 25-Jun-95 | Lt wing 1st | |
| 41 | 13-Jul-95 | Yes | ~8000 | *5700* | 230 | *260* | | | 2,300 | | 13-Jul-95 | Lt bank | |
| 42 | 21-Aug-95 | Yes | 6250 | 4500 | 220 | *243* | | | *1,750* | | 21-Aug-95 | | |
| 43 | 21-Dec-95 | Yes | | <1500-2000 | <200 | *223* | 200-300 (250) | *272* | *5,400* | shallow dive | 21-Dec-95 | | |
| 44 | 19-Mar-96 | Yes | ~3,000 | 2000 | 200 | *209* | | | *1,000* | | 19-Mar-96 | | |
| 45 | 7-Jun-96 | Yes | | ~1600 | 160-170 | *173* | | | *~1,400* | | 7-Jun-96 | Lt wing low | |
| 46 | 11-Jul-96 | Yes | | 209 | 165 | *165* | | | S/L | 18 - 25 nose low | 11-Jul-96 | 10 right | |
| 47 | 3-Aug-96 | Yes | ~5487 | ~5400 | 285 | *310* | 352 | *352* | ~87 | | 3-Aug-96 | | 4.2 |
| 48 | 21-Nov-96 | Yes | | 4000-5000 | ~150 | *162* | | | ~650 | | 21-Nov-96 | rt wing low | |
| 49 | 29-Jan-97 | Yes | | ~800-840 | 164 | *169* | 180 | *182* | *1,000* | shallow descent | 29-Jan-97 | rt bank | |
| 50 | 4-Feb-97 | Yes | 10400 | 6200 | | | 320 | *343* | ~4,200 doc | 35 nose low | 4-Feb-97 | 60 right | 10 |
| 51 | 21-Apr-97 | Yes | | 1500 | | | 179 | *179* | *~200* | 10 nose down | 21-Apr-97 | shallow lt | |
| 52 | 12-May-97 | Yes | | 497 | 184 | *203* | | | *~6,000* | | 12-May-97 | | |
| 53 | 22-Aug-97 | Yes | | ~1200 | | | "low speed" | *slow* | S/L | | 22-Aug-97 | | |
| 54 | 16-Sep-97 | No | 13,760 | 13,760 | 436 | *539* | | | S/L | | 16-Sep-97 | | |
| 55 | 8-Jan-98 | Yes | | 1700 | | | 190-200 | *208* | 4,200 | 15 nose low | 8-Jan-98 | | 5.5-5.75 |
| 56 | 22-Jul-98 | Yes | | 3000 | 165 | *173* | ~220 | *220* | S/L | | 22-Jul-98 | | |
| 57 | 24-Aug-98 | Yes | | ~1100 | <200 | *204* | | | S/L | | 24-Aug-98 | | |
| | | | | | | | | | | | | | |
| | Not Applicable, runway related | | | | | | | | | | | | |
| 58 | 24-Apr-92 | | | | | | | | | | | | |
| 59 | 5-May-92 | | | | | | | | | | | | |
| 60 | 27-Aug-93 | | | | | | | | | | | | |
| 61 | 30-Mar-94 | | | | | | | | | | | | |

Note: *Inferred data is in Italics* and is data which is not directly stated in the report, but which is easily inferred from it.
*E.g., If both MSL and AGL are stated for the same event, the ground elevation may be inferred.*
Ground elevations were also obtained from ground coordinates through the use of USGS data available through TopoZone.com.

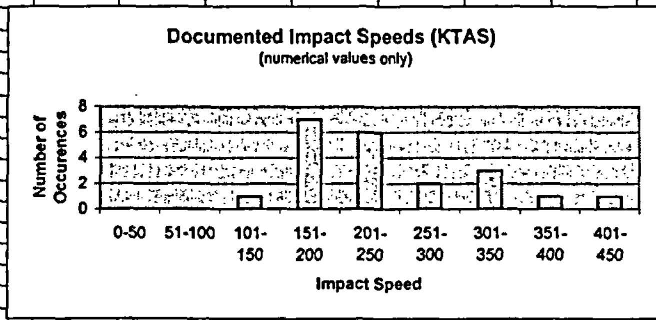
TAB B (1)

## Documented Impact Speeds and Angles

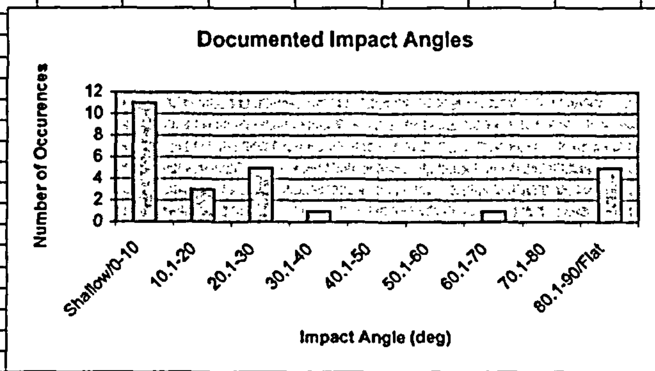
| | Accident Date | Impact Speed KTAS | Impact Angle (degrees) | Impact Angle Documented and Inferred | |
|---|---|---|---|---|---|
| 1 | 25-May-90 | | 11 | 11 | |
| 2 | 7-Aug-90 | 157 | 9 | 9 | |
| 3 | 3-Sep-90 | slow | 65 | 65 | |
| 4 | 13-Jan-91 | | flat | 85 | |
| 5 | 15-Jan-91 | | 20 | 20 | |
| 6 | 19-Mar-91 | | flat plate | 85 | |
| 7 | 7-May-91 | 156 | 8.5 | 8.5 | |
| 8 | 16-Dec-91 | 428 | 24 | 24 | |
| 9 | 13-Jan-92 | 149 | 6.6 | 6.6 | |
| 10 | 18-Sep-92 | 261 | 21 | 21 | |
| 11 | 17-Dec-92 | | 25 | 25 | |
| 12 | 19-Feb-93 | very low forward velocity | flat | 85 | |
| 13 | 21-Apr-93 | 171 | | | |
| 14 | 11-Aug-93 | 200 | 10 | 10 | |
| 15 | 11-Sep-93 | very little forward velocity | flat | 85 | |
| 16 | 9-Nov-93 | 218 | shallow glide | 5 | |
| 17 | 2-Feb-94 | 226 | 6 | 6 | |
| 18 | 7-Feb-94 | 212 | | | |
| 19 | 20-Sep-94 | 204 | 4.2 | 4.2 | |
| 20 | 25-Oct-94 | 166 | 30 | 30 | |
| 21 | 13-Jan-95 | 332 | | | |
| 22 | 5-Feb-95 | 314 | 7 | 7 | |
| 23 | 25-Jun-95 | | flat | 85 | |
| 24 | 21-Dec-95 | 272 | shallow dive | 5 | |
| 25 | 11-Jul-96 | | 21.5 | 21.5 | |
| 26 | 3-Aug-96 | 352 | | | |
| 27 | 29-Jan-97 | 182 | shallow descent | 5 | |
| 28 | 4-Feb-97 | 343 | 35 | 35 | |
| 29 | 21-Apr-97 | 179 | 10 | 10 | |
| 30 | 22-Aug-97 | slow | | | |
| 31 | 8-Jan-98 | 208 | 15 | 15 | |
| 32 | 22-Jul-98 | 220 | | | |

Tab B (2)

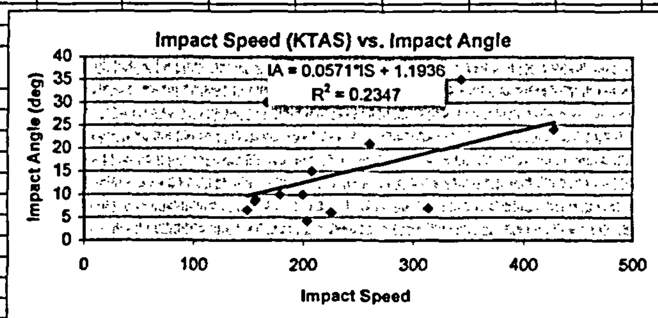
| Documented Airspeed Categories KTAS | |
|---|---|
| 0-50 | 0 |
| 51-100 | 0 |
| 101-150 | 1 |
| 151-200 | 7 |
| 201-250 | 6 |
| 251-300 | 2 |
| 301-350 | 3 |
| 351-400 | 1 |
| 401-450 | 1 |
| Total | 21 |




| Documented Angle Categories | |
|---|---|
| Shallow/0-10 | 11 |
| 10.1-20 | 3 |
| 20.1-30 | 5 |
| 30.1-40 | 1 |
| 40.1-50 | 0 |
| 50.1-60 | 0 |
| 60.1-70 | 1 |
| 70.1-80 | 0 |
| 80.1-90/Flat | 5 |
| Total | 26 |

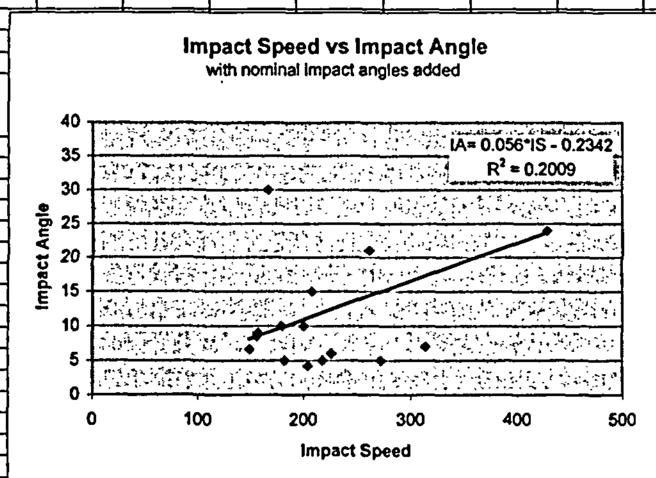



| Number | Impact Speed (KTAS) | Impact Angle (deg) |
|---|---|---|
| 1 | 204 | 4.2 |
| 2 | 226 | 6 |
| 3 | 149 | 6.6 |
| 4 | 314 | 7 |
| 5 | 156 | 8.5 |
| 6 | 157 | 9 |
| 7 | 179 | 10 |
| 8 | 200 | 10 |
| 9 | 208 | 15 |
| 10 | 261 | 21 |
| 11 | 428 | 24 |
| 12 | 166 | 30 |
| 13 | 343 | 35 |




Using documented/inferred angles

| Number | Impact Speed KTAS | Impact Angle (deg) |
|---|---|---|
| 1 | 157 | 9 |
| 2 | 156 | 8.5 |
| 3 | 428 | 24 |
| 4 | 149 | 6.6 |
| 5 | 261 | 21 |
| 6 | 200 | 10 |
| 7 | 218 | 5 |
| 8 | 226 | 6 |
| 9 | 204 | 4.2 |
| 10 | 166 | 30 |
| 11 | 314 | 7 |
| 12 | 272 | 5 |
| 13 | 182 | 5 |
| 14 | 343 | 35 |
| 15 | 179 | 10 |
| 16 | 208 | 15 |

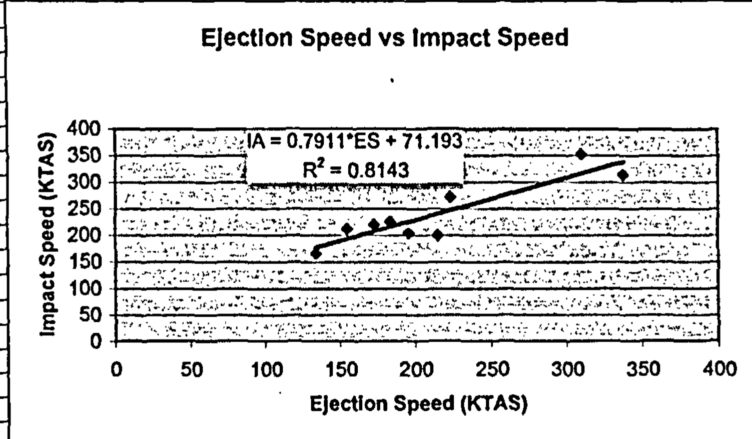


TAB C

**Documented Ejection Speed vs. Documented Impact Speed**

| | Accident Date | Ejection Altitude AGL | Ejection Speed KTAS | Impact Speed KTAS |
|---|---|---|---|---|
| 1 | 11-Aug-93 | 1700 | 215 | 200 |
| 2 | 2-Feb-94 | 1800 | 184 | 226 |
| 3 | 7-Feb-94 | >1500 | 155 | 212 |
| 4 | 20-Sep-94 | 3300 | 196 | 204 |
| 5 | 25-Oct-94 | 1380 | 134 | 166 |
| 6 | 5-Feb-95 | 3300 | 338 | 314 |
| 7 | 21-Dec-95 | 1750 | 223 | 272 |
| 8 | 3-Aug-96 | 5400 | 310 | 352 |
| 9 | 22-Jul-98 | <3000 | 173 | 220 |

| For Chart | |
|---|---|
| Ej. Spd. | Imp. Spd. |
| 134 | 166 |
| 155 | 212 |
| 173 | 220 |
| 184 | 226 |
| 196 | 204 |
| 215 | 200 |
| 223 | 272 |
| 310 | 352 |
| 338 | 314 |



TAB D

Calculating Impact Speed from Ejection Speed
using Linear Regression Model
IS = 0.7911(ES) + 71.193
where Impact Speed is unkown and only Ejection Speed (not Altitude) is available

| | Accident Date | Documented Ejection Speed KTAS | Calculated Impact Speed KTAS |
|---|---|---|---|
| 1 | 20-Sep-90 | 199 | 229 |

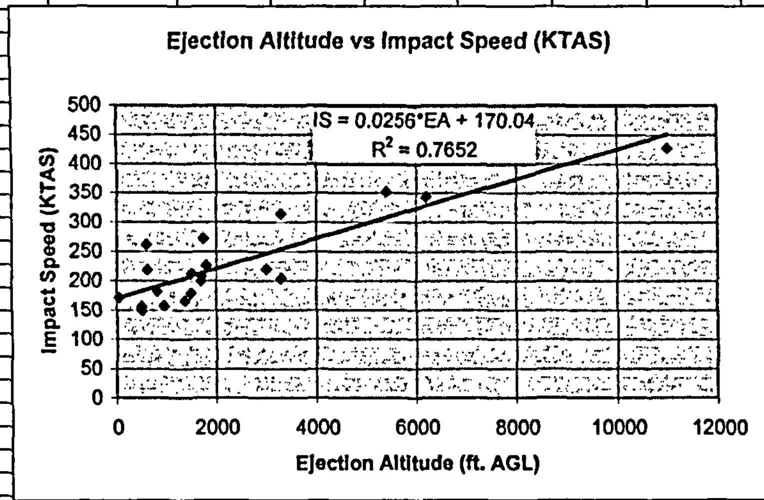
TAB E

## Documented Ejection Altitude vs Documented Impact Speed

| | Accident Date | Ejection Altitude ft. AGL | Impact Speed KTAS |
|---|---|---|---|
| 1 | 7-Aug-90 | 957 | 157 |
| 2 | 7-May-91 | 506 | 156 |
| 3 | 16-Dec-91 | 11,000 | 428 |
| 4 | 13-Jan-92 | 500 | 149 |
| 5 | 18-Sep-92 | 600 | 261 |
| 6 | 21-Apr-93 | 50 | 171 |
| 7 | 11-Aug-93 | 1700 | 200 |
| 8 | 9-Nov-93 | 610 | 218 |
| 9 | 2-Feb-94 | 1800 | 226 |
| 10 | 7-Feb-94 | 1500 | 212 |
| 11 | 20-Sep-94 | 3300 | 204 |
| 12 | 25-Oct-94 | 1380 | 166 |
| 13 | 5-Feb-95 | 3300 | 314 |
| 14 | 21-Dec-95 | 1750 | 272 |
| 15 | 3-Aug-96 | 5400 | 352 |
| 16 | 29-Jan-97 | 820 | 182 |
| 17 | 4-Feb-97 | 6200 | 343 |
| 18 | 21-Apr-97 | 1500 | 179 |
| 19 | 8-Jan-98 | 1700 | 208 |
| 20 | 22-Jul-98 | 3000 | 220 |

For Chart, Use

| Ejec. Alt. | IS (KTAS) |
|---|---|
| 50 | 171 |
| 500 | 149 |
| 506 | 156 |
| 600 | 261 |
| 610 | 218 |
| 820 | 182 |
| 957 | 157 |
| 1380 | 166 |
| 1500 | 179 |
| 1500 | 212 |
| 1700 | 200 |
| 1700 | 208 |
| 1750 | 272 |
| 1800 | 226 |
| 3000 | 220 |
| 3,300 | 204 |
| 3300 | 314 |
| 5400 | 352 |
| 6200 | 343 |
| 11,000 | 428 |



| TAB F | | | |
|---|---|---|---|
| | Calculating Impact Speed from Ejection Altitude | | |
| | using Linear Regression Model | | |
| | IS = 0.0256*(EA) + 170.04 | | |
| | where Impact Speed is unknown and only Ejection Altitude (not Speed) is available | | |
| | | | |
| | Accident Date | Ejection Altitude (ft. AGL) | Calculated Impact Speed (KTAS) |
| 1 | 3-Apr-90 | 2300 | 229 |
| 2 | 20-Feb-91 | 300 | 178 |
| 3 | 4-Apr-91 | 6500 | 336 |
| 4 | 27-Nov-91 | 1000 | 196 |
| 5 | 31-Aug-92 | 2000 | 221 |
| 6 | 22-Oct-92 | 500 | 183 |
| 7 | 22-Aug-97 | 1200 | 201 |

TAB G

## Ejection Altitude, Ejection Speed vs. Impact Speed

## Developing the Multiple Regression Formula

| | Accident Date | Ejection Altitude ft. AGL | Ejection Speed KTAS | Impact Speed KTAS |
|---|---|---|---|---|
| 1 | 7-May-91 | 506 | 146 | 156 |
| 2 | 16-Dec-91 | 11000 | 273 | 428 |
| 3 | 13-Jan-92 | 500 | 113 | 149 |
| 4 | 11-Aug-93 | 1700 | 215 | 200 |
| 5 | 9-Nov-93 | 610 | 220 | 218 |
| 6 | 2-Feb-94 | 1800 | 184 | 226 |
| 7 | 7-Feb-94 | 1500 | 155 | 212 |
| 8 | 20-Sep-94 | 3300 | 196 | 204 |
| 9 | 25-Oct-94 | 1380 | 134 | 166 |
| 10 | 5-Feb-95 | 3300 | 338 | 314 |
| 11 | 21-Dec-95 | 1750 | 223 | 272 |
| 12 | 3-Aug-96 | 5400 | 310 | 352 |
| 13 | 29-Jan-97 | 820 | 169 | 182 |
| 14 | 22-Jul-98 | 3000 | 173 | 220 |

Values for Multiple Regression Calculation

| Imp. Spd. | Ej. Alt. | Ej. Spd. |
|---|---|---|
| 149 | 500 | 113 |
| 156 | 506 | 146 |
| 166 | 1380 | 134 |
| 182 | 820 | 169 |
| 200 | 1700 | 215 |
| 204 | 3300 | 196 |
| 212 | 1500 | 155 |
| 218 | 610 | 220 |
| 220 | 3000 | 173 |
| 226 | 1800 | 184 |
| 272 | 1750 | 223 |
| 314 | 3300 | 338 |
| 352 | 5400 | 310 |
| 428 | 11000 | 273 |

Derived multiple regression: Impact Speed = 71.806 + 0.017 * (Ejection Altitude) + 0.583 * (Ejection Speed)

$R^2 = 0.9384$ $R^2b = 0.9272$

| TAB H | | | | | | |
|---|---|---|---|---|---|---|
| | Calculation of Estimates of Impact Speed based on both | | | | | |
| | Ejection Altitude and Ejection Speed using Multiple Regression Model | | | | | |
| | IS =71.806 + 0.017 * (EA) + 0.583 * (ES) | | | | | |
| | | | | | | |
| | Accident Date | Ejection Altitude ft. AGL | Ejection Speed in KTAS | | Calculated Impact Speed KTAS | |
| | | | | | | |
| 1 | 26-Dec-89 | 1380 | 250 | | 241 | |
| 2 | 23-Oct-90 | 1800 | 263 | | 256 | |
| 3 | 18-Apr-91 | 2800 | 181 | | 225 | |
| 4 | 8-Jun-91 | 900 | 202 | | 205 | |
| 5 | 17-Jul-91 | 2500 | 187 | | 223 | |
| 6 | 31-May-92 | 3114 | 220 | | 253 | |
| 7 | 17-Dec-92 | 3184 | 149 | | 213 | |
| 8 | 23-Feb-93 | 1460 | 241 | | 237 | |
| 9 | 1-Jul-94 | 1500 | 258 | | 248 | |
| 10 | 15-May-95 | 2000 | 177 | | 209 | |
| 11 | 13-Jul-95 | 5700 | 260 | | 320 | |
| 12 | 21-Aug-95 | 4500 | 243 | | 290 | |
| 13 | 19-Mar-96 | 2000 | 209 | | 228 | |
| 14 | 7-Jun-96 | 1600 | 173 | | 200 | |
| 15 | 11-Jul-96 | 209 | 165 | | 172 | |
| 16 | 21-Nov-96 | 4500 | 162 | | 243 | |
| 17 | 12-May-97 | 497 | 203 | | 199 | |
| 18 | 24-Aug-98 | 1100 | 204 | | 209 | |
| | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| TAB I | | | | | | | | |
| | Other Impact Velocities Inferred from other Information | | | | | | | |
| | | | | | | | | |
| Date | | Ejection Altitude | Ejection Speed | Notes | | Documented impact speed | Estimated Impact speed | Notes |
| | | ft. AGL | KTAS | | | KTAS | KTAS | |
| **Those aircraft "falling like a leaf", in a flat spin, etc.** | | | | | | | | |
| | See Text for derivation of speed (123 knots) | | | | | | | |
| 13-Jan-91 | | 23,000 | flat inverted spin | | | | 123 | flat, inverted |
| 19-Mar-91 | | 9,800 | 310-320 | 45 nose low, 45 leftbank | | | 123 | flat plate |
| 19-Feb-93 | | | | mode 2 actuation | | very low forward velocity | 123 | inverted |
| 11-Sep-93 | | FL 290 | | uncommanded pitchup | | very little forward velocity | 123 | |
| 25-Jun-95 | | 2000 | 200 | slightly climbing, wings level | | | 123 | flat |
| | | | | | | | | |
| 16-Sep-97 | | ~14,000 | | | | | 123 | |
| | | | | | | | | |
| **Other Cases** | | (See text) | | | | | | |
| | | | | | | | | |
| 25-May-90 | | | | | | Est 480 KCAS | 480 | 11 deg dive |
| 3-Sep-90 | | | | zoomed | | low speed | 225 | 110-120 nose down, near inverted |
| 1-Sep-92 | | | | | | | 237 | See text |
| 15-Jan-91 | | descending from FL 210-230 for landing | | lightning strike | | | 430 | 20 nose down |
| | | | | | | | | |

TAB J Final Tabulation of Documented and Estimated Impact Speeds

| | Accident Date | Documented Impact Speed KCAS | Estimated Impact Speed (TAS) | Combined Doc and Est Impact Speeds (TAS) |
|---|---|---|---|---|
| 1 | 26-Dec-89 | | 241 | 241 |
| 2 | 3-Apr-90 | | 229 | 229 |
| 3 | 25-May-90 | | 480 | 480 |
| 4 | 7-Aug-90 | 157 | | 157 |
| 5 | 3-Sep-90 | slow | 225 | 225 |
| 6 | 20-Sep-90 | | 229 | 229 |
| 7 | 23-Oct-90 | | 256 | 256 |
| 8 | 13-Jan-91 | | 123 | 123 |
| 9 | 15-Jan-91 | | 430 | 430 |
| 10 | 20-Feb-91 | | 178 | 178 |
| 11 | 19-Mar-91 | | 123 | 123 |
| 12 | 4-Apr-91 | | 336 | 336 |
| 13 | 18-Apr-91 | | 225 | 225 |
| 14 | 7-May-91 | 156 | | 156 |
| 15 | 8-Jun-91 | | 205 | 205 |
| 16 | 17-Jul-91 | | 223 | 223 |
| 17 | 27-Nov-91 | | 196 | 196 |
| 18 | 16-Dec-91 | 428 | | 428 |
| 19 | 13-Jan-92 | 149 | | 149 |
| 20 | 31-May-92 | | 258 | 258 |
| 21 | 31-Aug-92 | | 221 | 221 |
| 22 | 1-Sep-92 | | 237 | 237 |
| 23 | 18-Sep-92 | 261 | | 261 |
| 24 | 22-Oct-92 | | 183 | 183 |
| 25 | 17-Dec-92 | | 213 | 213 |
| 26 | 19-Feb-93 | | 123 | 123 |
| 27 | 23-Feb-93 | | 237 | 237 |
| 28 | 21-Apr-93 | 171 | | 171 |
| 29 | 11-Aug-93 | 200 | | 200 |
| 30 | 11-Sep-93 | | 123 | 123 |
| 31 | 9-Nov-93 | 218 | | 218 |
| 32 | 2-Feb-94 | 226 | | 226 |
| 33 | 7-Feb-94 | 212 | | 212 |
| 34 | 1-Jul-94 | | 248 | 248 |
| 35 | 20-Sep-94 | 204 | | 204 |
| 36 | 25-Oct-94 | 166 | | 166 |
| 37 | 13-Jan-95 | 332 | | 332 |
| 38 | 5-Feb-95 | 314 | | 314 |
| 39 | 15-May-95 | | 209 | 209 |
| 40 | 25-Jun-95 | | 123 | 123 |
| 41 | 13-Jul-95 | | 320 | 320 |
| 42 | 21-Aug-95 | | 290 | 290 |
| 43 | 21-Dec-95 | 272 | | 272 |
| 44 | 19-Mar-96 | | 228 | 228 |
| 45 | 7-Jun-96 | | 200 | 200 |
| 46 | 11-Jul-96 | | 172 | 172 |
| 47 | 3-Aug-96 | 352 | | 352 |
| 48 | 21-Nov-96 | | 243 | 243 |
| 49 | 29-Jan-97 | 182 | | 182 |
| 50 | 4-Feb-97 | 343 | | 343 |
| 51 | 21-Apr-97 | 179 | | 179 |
| 52 | 12-May-97 | | 199 | 199 |
| 53 | 22-Aug-97 | "low speed" | 201 | 201 |
| 54 | 16-Sep-97 | | 123 | 123 |
| 55 | 8-Jan-98 | 208 | | 208 |
| 56 | 22-Jul-98 | 220 | | 220 |
| 57 | 24-Aug-98 | | 209 | 209 |

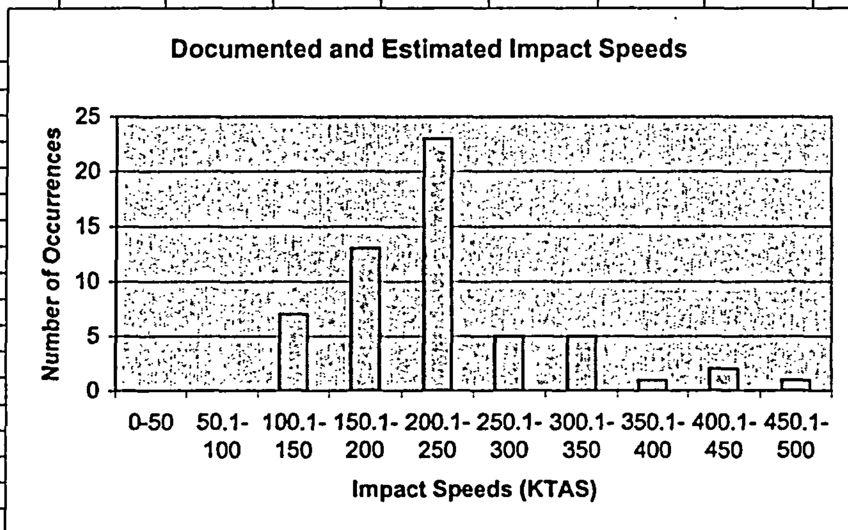
Number of Occurences

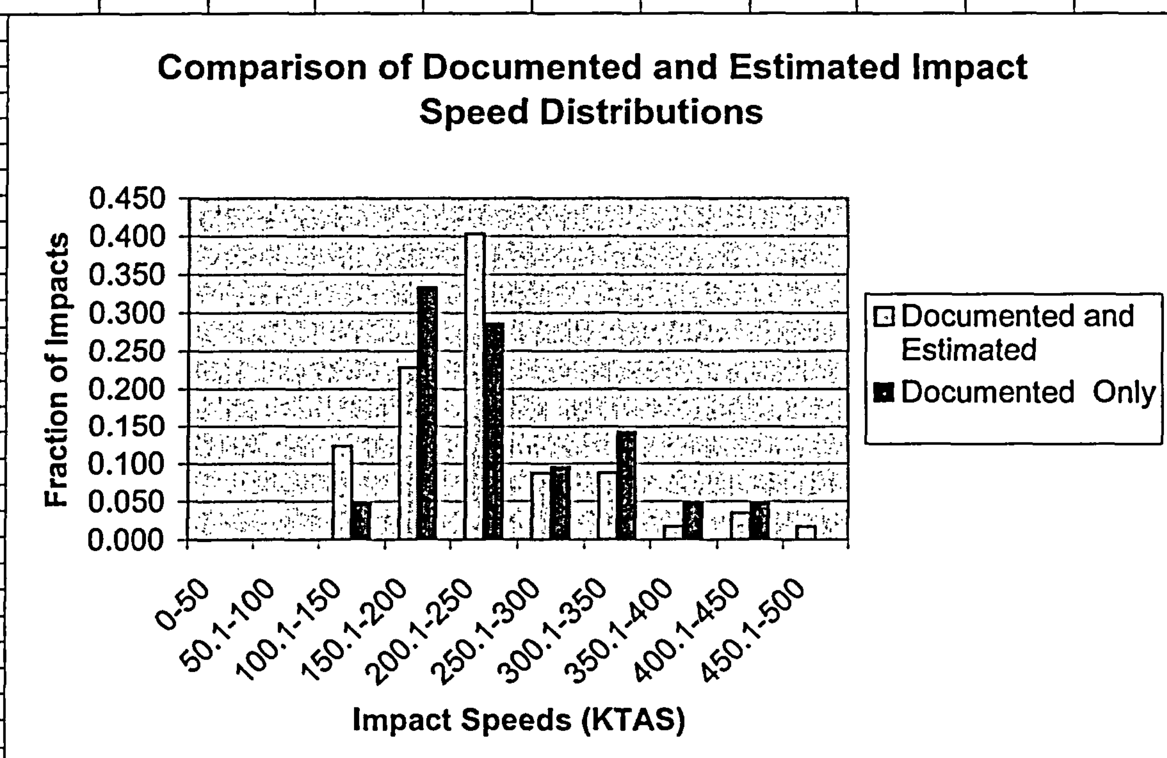
| Speed Categories | |
|---|---|
| 0-50 | 0 |
| 50.1-100 | 0 |
| 100.1-150 | 7 |
| 150.1-200 | 13 |
| 200.1-250 | 23 |
| 250.1-300 | 5 |
| 300.1-350 | 5 |
| 350.1-400 | 1 |
| 400.1-450 | 2 |
| 450.1-500 | 1 |
| Total | 57 |

Fractional Speed Distribution

| Speed Range | Documented and Estimated | Documented Only |
|---|---|---|
| 0-50 | 0.000 | 0.000 |
| 50.1-100 | 0.000 | 0.000 |
| 100.1-150 | 0.123 | 0.048 |
| 150.1-200 | 0.228 | 0.333 |
| 200.1-250 | 0.404 | 0.286 |
| 250.1-300 | 0.088 | 0.095 |
| 300.1-350 | 0.088 | 0.143 |
| 350.1-400 | 0.018 | 0.048 |
| 400.1-450 | 0.035 | 0.048 |
| 450.1-500 | 0.018 | 0.000 |
| Total | 1 | 1 |

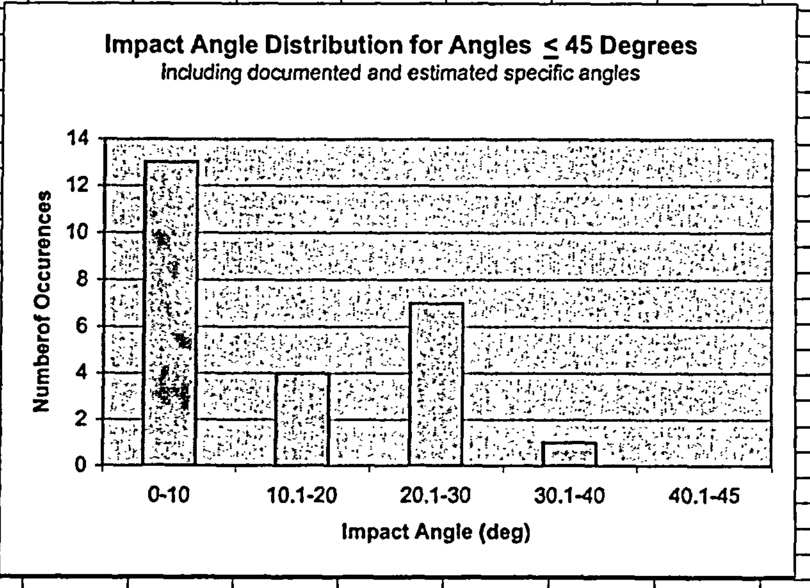
| Documented Airspeed Categories KTAS (see Tab B) | |
|---|---|
| 0-50 | 0 |
| 50.1-100 | 0 |
| 100.1-150 | 1 |
| 150.1-200 | 7 |
| 200.1-250 | 6 |
| 250.1-300 | 2 |
| 300.1-350 | 3 |
| 350.1-400 | 1 |
| 400.1-450 | 1 |
| 450.1-500 | 0 |
| Total | 21 |

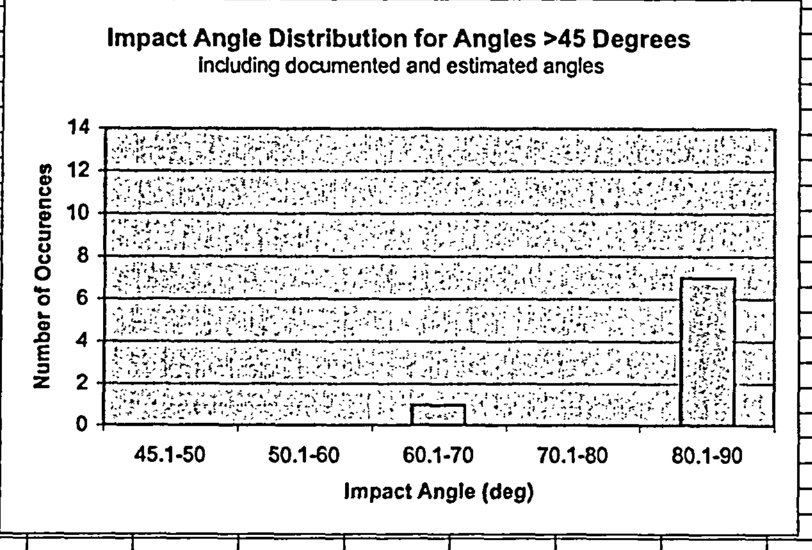

Documented and Estimated Impact Speeds
Number of Occurrences
25
20
15
10
5
0
0-50
50.1-100
100.1-150
150.1-200
200.1-250
250.1-300
300.1-350
350.1-400
400.1-450
450.1-500
Impact Speeds (KTAS)


Comparison of Documented and Estimated Impact Speed Distributions
Fraction of Impacts
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
0-50
50.1-100
100.1-150
150.1-200
200.1-250
250.1-300
300.1-350
350.1-400
400.1-450
450.1-500
Impact Speeds (KTAS)
Documented and Estimated
Documented Only

| Tab K | | | |
|---|---|---|---|
| | Chronological Listing of Documented Impact Angles | | |
| | with Estimated Angles Added | | |
| | Accident | | |
| | Date | Angle (deg) documented | Angle (deg) documented and estimated |
| 1 | 26-Dec-89 | | 10 |
| 2 | 25-May-90 | 11 | 11 |
| 3 | 7-Aug-90 | 9 | 9 |
| 4 | 3-Sep-90 | 110-120* | 65 |
| 5 | 13-Jan-91 | flat, inverted | 85 |
| 6 | 15-Jan-91 | 20 | 20 |
| 7 | 19-Mar-91 | flat plate | 85 |
| 8 | 4-Apr-91 | | 85 |
| 9 | 18-Apr-91 | | 28 |
| 10 | 7-May-91 | 8.5 | 8.5 |
| 11 | 16-Dec-91 | 24 | 24 |
| 12 | 13-Jan-92 | 6.6 | 6.6 |
| 13 | 18-Sep-92 | 21 | 21 |
| 14 | 17-Dec-92 | 25 | 25 |
| 15 | 19-Feb-93 | inverted | 85 |
| 16 | 21-Apr-93 | | 5 |
| 17 | 11-Aug-93 | 10 | 10 |
| 18 | 11-Sep-93 | | 85 |
| 19 | 9-Nov-93 | | 8 |
| 20 | 2-Feb-94 | 6 | 6 |
| 21 | 20-Sep-94 | 4.2 | 4.2 |
| 22 | 25-Oct-94 | 30 | 30 |
| 23 | 13-Jan-95 | | 11 |
| 24 | 5-Feb-95 | 7 | 7 |
| 25 | 25-Jun-95 | flat | 85 |
| 26 | 21-Dec-95 | shallow dive | 5 |
| 27 | 11-Jul-96 | 18 - 25 | 21.5 |
| 28 | 3-Aug-96 | | 26 |
| 29 | 29-Jan-97 | shallow descent | 5 |
| 30 | 4-Feb-97 | 35 | 35 |
| 31 | 21-Apr-97 | | 5 |
| 32 | 16-Sep-97 | | 85 |
| 33 | 8-Jan-98 | 15 | 15 |
| 34 | 3-Apr-90 | | ≤45 |
| 35 | 20-Sep-90 | | ≤45 |
| 36 | 23-Oct-90 | | ≤45 |
| 37 | 20-Feb-91 | | ≤45 |
| 38 | 8-Jun-91 | | ≤45 |
| 39 | 17-Jul-91 | | ≤45 |
| 40 | 27-Nov-91 | | ≤45 |
| 41 | 31-May-92 | | ≤45 |
| 42 | 31-Aug-92 | | ≤45 |
| 43 | 1-Sep-92 | | ≤45 |
| 44 | 22-Oct-92 | | ≤45 |
| 45 | 23-Feb-93 | | ≤45 |
| 46 | 7-Feb-94 | | ≤45 |
| 47 | 1-Jul-94 | | ≤45 |
| 48 | 15-May-95 | | ≤45 |
| 49 | 13-Jul-95 | | ≤45 |
| 50 | 21-Aug-95 | | ≤45 |
| 51 | 19-Mar-96 | | ≤45 |
| 52 | 7-Jun-96 | | ≤45 |
| 53 | 21-Nov-96 | | ≤45 |
| 54 | 12-May-97 | | ≤45 |
| 55 | 22-Aug-97 | | ≤45 |
| 56 | 22-Jul-98 | | ≤45 |
| 57 | 24-Aug-98 | | ≤45 |
| | *note: maximum angle is 90 degrees (vertical), beyond that it's less than 90. | | |

| Impact Angle Categories | |
|---|---|
| 0-10 | 13 |
| 10.1-20 | 4 |
| 20.1-30 | 7 |
| 30.1-40 | 1 |
| 40.1-45 | 0 |
| 45.1-50 | 0 |
| 50.1-60 | 0 |
| 60.1-70 | 1 |
| 70.1-80 | 0 |
| 80.1-90 | 7 |
| total | 33 |



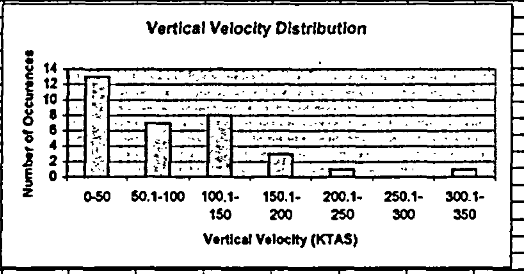
TAB L (1)

Chronological Listing of F-16 Impact Angles and Speeds
with Vertical and Horizontal Velocities calculated

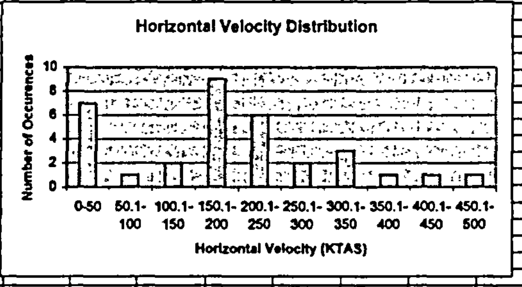
| | Accident Date | Combined Doc and Est Impact Speeds (TAS) | Impact Angle documented or estimated | Vertical Velocity KTAS | Horizontal Velocity KTAS |
|---|---|---|---|---|---|
| 1 | 26-Dec-89 | 241 | 10 | 42 | 237 |
| 2 | 25-May-90 | 480 | 11 | 92 | 471 |
| 3 | 7-Aug-90 | 157 | 9 | 25 | 155 |
| 4 | 3-Sep-90 | 225 | 65 | 204 | 95 |
| 5 | 13-Jan-91 | 123 | 85 | 123 | 11 |
| 6 | 15-Jan-91 | 430 | 20 | 147 | 404 |
| 7 | 19-Mar-91 | 123 | 85 | 123 | 11 |
| 8 | 4-Apr-91 | 336 | 85 | 335 | 29 |
| 9 | 18-Apr-91 | 225 | 28 | 106 | 199 |
| 10 | 7-May-91 | 156 | 8.5 | 23 | 154 |
| 11 | 16-Dec-91 | 428 | 24 | 174 | 391 |
| 12 | 13-Jan-92 | 149 | 6.6 | 17 | 148 |
| 13 | 18-Sep-92 | 261 | 21 | 94 | 244 |
| 14 | 17-Dec-92 | 213 | 25 | 90 | 193 |
| 15 | 19-Feb-93 | 123 | 85 | 123 | 11 |
| 16 | 21-Apr-93 | 171 | 5 | 15 | 170 |
| 17 | 11-Aug-93 | 200 | 10 | 35 | 197 |
| 18 | 11-Sep-93 | 123 | *85* | 123 | 11 |
| 19 | 9-Nov-93 | 218 | 8 | 30 | 216 |
| 20 | 2-Feb-94 | 226 | 6 | 24 | 225 |
| 21 | 20-Sep-94 | 204 | 4.2 | 15 | 203 |
| 22 | 25-Oct-94 | 166 | 30 | 83 | 144 |
| 23 | 13-Jan-95 | 332 | 11 | 63 | 326 |
| 24 | 5-Feb-95 | 314 | 7 | 38 | 312 |
| 25 | 25-Jun-95 | 123 | 85 | 123 | 11 |
| 26 | 21-Dec-95 | 272 | 5 | 24 | 271 |
| 27 | 11-Jul-96 | 172 | 21.5 | 63 | 160 |
| 28 | 3-Aug-96 | 352 | 26 | 154 | 316 |
| 29 | 29-Jan-97 | 182 | 5 | 16 | 181 |
| 30 | 4-Feb-97 | 343 | 35 | 197 | 281 |
| 31 | 21-Apr-97 | 179 | 10 | 31 | 176 |
| 32 | 16-Sep-97 | 123 | 85 | 123 | 11 |
| 33 | 8-Jan-98 | 208 | 15 | 54 | 201 |
| | | | | | |
| | | | | | |
| | Not Applicable, runway related | | | | |
| | 24-Apr-92 | | | | |
| | 5-May-92 | | | | |
| | 27-Aug-93 | | | | |
| | 30-Mar-94 | | | | |

Tab L (2)

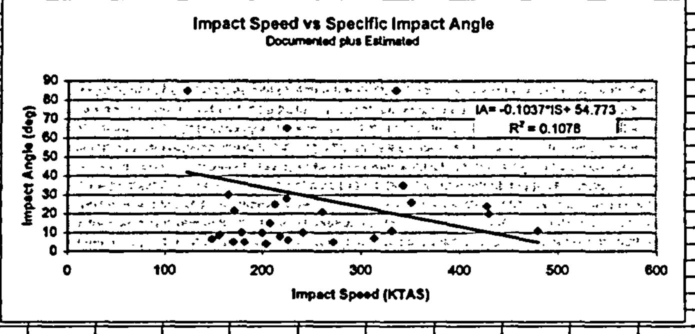
| Vertical Velocity categories | |
|---|---|
| 0-50 | 13 |
| 50.1-100 | 7 |
| 100.1-150 | 8 |
| 150.1-200 | 3 |
| 200.1-250 | 1 |
| 250.1-300 | 0 |
| 300.1-350 | 1 |
| Total | 33 |

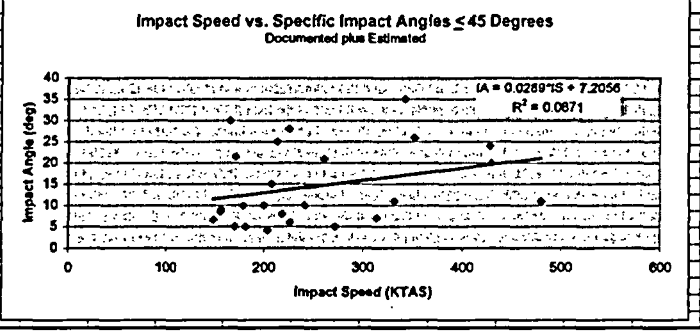



| Horizontal Velocity Categories | |
|---|---|
| 0-50 | 7 |
| 50.1-100 | 1 |
| 100.1-150 | 2 |
| 150.1-200 | 9 |
| 200.1-250 | 6 |
| 250.1-300 | 2 |
| 300.1-350 | 3 |
| 350.1-400 | 1 |
| 400.1-450 | 1 |
| 450.1-500 | 1 |
| Total | 33 |




| Accident<br>Date | Combined Doc and Est Impact Speeds (TAS) | Impact Angle documented or estimated |
|---|---|---|
| 20-Sep-94 | 204 | 4.2 |
| 21-Apr-93 | 171 | 5 |
| 29-Jan-97 | 182 | 5 |
| 21-Dec-95 | 272 | 5 |
| 2-Feb-94 | 226 | 6 |
| 13-Jan-92 | 149 | 6.6 |
| 5-Feb-95 | 314 | 7 |
| 9-Nov-93 | 218 | 8 |
| 7-May-91 | 156 | 8.5 |
| 7-Aug-90 | 157 | 9 |
| 21-Apr-97 | 179 | 10 |
| 11-Aug-93 | 200 | 10 |
| 26-Dec-89 | 241 | 10 |
| 13-Jan-95 | 332 | 11 |
| 25-May-90 | 480 | 11 |
| 6-Jan-98 | 208 | 15 |
| 15-Jan-91 | 430 | 20 |
| 18-Sep-92 | 261 | 21 |
| 11-Jul-96 | 172 | 21.5 |
| 16-Dec-91 | 428 | 24 |
| 17-Dec-92 | 213 | 25 |
| 3-Aug-96 | 352 | 26 |
| 18-Apr-91 | 225 | 28 |
| 25-Oct-94 | 166 | 30 |
| 4-Feb-97 | 343 | 35 |
| 3-Sep-90 | 225 | 65 |
| 13-Jan-91 | 123 | 85 |
| 19-Mar-91 | 123 | 85 |
| 19-Feb-93 | 123 | 85 |
| 11-Sep-93 | 123 | 85 |
| 25-Jun-95 | 123 | 85 |
| 16-Sep-97 | 123 | 85 |
| 4-Apr-91 | 336 | 85 |




| | Date | TAS | Angle |
|---|---|---|---|
| 1 | 20-Sep-94 | 204 | 4.2 |
| 2 | 21-Apr-93 | 171 | 5 |
| 3 | 29-Jan-97 | 182 | 5 |
| 4 | 21-Dec-95 | 272 | 5 |
| 5 | 2-Feb-94 | 226 | 6 |
| 6 | 13-Jan-92 | 149 | 6.6 |
| 7 | 5-Feb-95 | 314 | 7 |
| 8 | 9-Nov-93 | 218 | 8 |
| 9 | 7-May-91 | 156 | 8.5 |
| 10 | 7-Aug-90 | 157 | 9 |
| 11 | 21-Apr-97 | 179 | 10 |
| 12 | 11-Aug-93 | 200 | 10 |
| 13 | 26-Dec-89 | 241 | 10 |
| 14 | 13-Jan-95 | 332 | 11 |
| 15 | 25-May-90 | 480 | 11 |
| 16 | 6-Jan-98 | 208 | 15 |
| 17 | 15-Jan-91 | 430 | 20 |
| 18 | 18-Sep-92 | 261 | 21 |
| 19 | 11-Jul-96 | 172 | 21.5 |
| 20 | 16-Dec-91 | 428 | 24 |
| 21 | 17-Dec-92 | 213 | 25 |
| 22 | 3-Aug-96 | 352 | 26 |
| 23 | 18-Apr-91 | 225 | 28 |
| 24 | 25-Oct-94 | 166 | 30 |
| 25 | 4-Feb-97 | 343 | 35 |
| 26 | 3-Sep-90 | 225 | 65 |
| 27 | 13-Jan-91 | 123 | 85 |
| 28 | 19-Mar-91 | 123 | 85 |
| 29 | 19-Feb-93 | 123 | 85 |
| 30 | 11-Sep-93 | 123 | 85 |
| 31 | 25-Jun-95 | 123 | 85 |
| 32 | 16-Sep-97 | 123 | 85 |
| 33 | 4-Apr-91 | 336 | 85 |